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16. ABSTRACT There is a need to develop new policies and practices for roadside features that support the California Department of Transportation's (Caltrans') safety and asset management goals. The goal is to assist highway designers in including maintenance planning strategies to improve worker safety and working conditions. Such policies and practices should be defensible and based on data and scientific methodologies and techniques. The recent research project "Performance Measures for Roadside Features" (Task 2761) identified a number of items, such as including more hardscape, that would enhance worker safety if fully implemented. Caltrans needs research to prioritize these items and to create draft guidance (such as the memos in the appendices) that would provide templates for the Divisions of Maintenance and Design to use to update the Maintenance Manual and the Highway Design Manual and thus realize these safety benefits. Researchers from the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center at UC Davis revisited previous findings to develop a prioritized list of items that could enhance worker safety. Using this prioritization, the researchers drafted guidance that could be used by Caltrans Maintenance or Design as templates (draft engineering memos) for updating the appropriate manuals. This report documents the research effort and findings. The memos generated through this research are provided in the appendices.		13. TYPE OF REPORT AND PERIOD COVERED Final Report June 2022 – December 2023
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Roadside Safety Performance Measures for Specific Countermeasures to Protect Workers

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California Department of Transportation

Division of Research, Innovation and System Information

Executive Summary

This report documents research and development of new policies and practices for roadside features that support the California Department of Transportation's (Caltrans') safety and asset management goals.

Problem, Need, and Purpose of Research

There is a need to develop new policies and practices for roadside features that support Caltrans' safety and asset management goals. The goal of these policies and practices is to assist highway designers in including maintenance planning strategies to improve worker safety and working conditions. Such policies and practices should be defensible and based on data and scientific methodologies and techniques.

The recent research project "Performance Measures for Roadside Features" (Task 2761) identified a number of items, such as including more hardscape, which would enhance worker safety if fully implemented [1]. Caltrans needed research to prioritize these items and to create draft guidance (such as memorandums in the appendices) that would provide templates for the Divisions of Maintenance and Design to use to update the Maintenance Manual and the Highway Design Manual, and thus realize these safety benefits. The purpose of this research was to execute this prioritization and develop the corresponding guidance documents.

Overview of the Work and Methodology

Researchers from the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center reviewed the findings of Tasks 2761 and 3289 and worked with the project panel to develop prioritized lists of items that could enhance worker safety. The researchers followed this prioritization and drafted guidance documents (memorandums and proposed manual updates) that could be used by Caltrans Maintenance or Design as templates for memos or for updating the appropriate manuals. The research included the following tasks:

Task 1: Manage project

Task 2: Develop updated list of safety enhancements

Task 3: Finalize and prioritize list in accordance with Caltrans panel input

Task 4: Develop draft guidance documents useful for updating manuals

Task 5: Develop final report

Major Results and Recommendations

The key deliverables are the draft guidance documents, which can be used by Caltrans Maintenance or Design to develop formal memos and manual updates that can improve the safety for roadside maintenance workers. As a side benefit, AHMCT developed decision support tools to assist Caltrans managers in making decisions related to these guidance documents. These tools—not part of the proposed deliverables—include flood, sea level rise, and fire danger maps. The process for developing the guidance documents is discussed in the final report body. The guidance documents are provided in the appendices.

The research also confirmed the critical importance of a collaborative relationship with the project pane to yield successful results. This is a known success criteria but was particularly important in the current research.

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Acronyms and Abbreviations

Acronym	Definition
AHMCT	Advanced Highway Maintenance and Construction Technology Research Center
BCP	Budget Change Proposal
BP	Burn Probability
Caltrans	California Department of Transportation
CFL	Conditional Flame Length
CHP	California Highway Patrol
DOT	Department of Transportation
DRISI	Caltrans Division of Research, Innovation and System Information
DTSC	Department of Toxic Substances Control
DUI	Driving Under the Influence
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
GIS	Geographic Information System
HERE	Homeland Emergency Response Exchange
MASH	Manual for Assessing Safety Hardware
NDDOT	North Dakota Department of Transportation
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
ODOT	Oregon Department of Transportation

Acronym	Definition
PeMS	Performance Measurement System
PennDOT	Pennsylvania Department of Transportation
PM	Project Manager
QR	Quick-Response
RPS	Risk to Potential Structures
SLR	Sea Level Rise
SR	State Route
SWITRS	Statewide Integrated Traffic Records System
TWW	Treated Wood Waste
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
VHT	Vehicle Hours Traveled
VMT	Vehicle Miles Traveled
WFAS	Wildland Fire Assessment System
WHP	Wildfire Hazard Potential

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Chapter 1: Introduction

Problem

There is a need to develop new policies and practices for roadside features that support the California Department of Transportation's (Caltrans') safety and asset management goals. The goal is to assist highway designers in including maintenance planning strategies to improve worker safety and working conditions. Such policies and practices should be defensible and based on data and scientific methodologies and techniques.

The recent research project "Performance Measures for Roadside Features" (Task 2761) identified several items, such as including more hardscape, that would enhance worker safety if fully implemented [1]. Caltrans needs research to prioritize these items and to create draft guidance (such as the memorandums in the appendices) that could provide templates for the Divisions of Maintenance and Design to use to update the Maintenance Manual and the Highway Design Manual and thus realize these safety benefits.

Objectives and Scope

Researchers from the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center at UC Davis revisited the findings of Tasks 2761 and 3289 to develop prioritized lists of items that could enhance worker safety. Using this prioritization, the researchers drafted guidance that could be used by Caltrans Maintenance or Design as templates for memos or for updating the appropriate manuals.

Research Methodology

This research included the following tasks:

Task 1: Manage project

Task 2: Develop updated list of safety enhancements

Task 3: Finalize and prioritize list in accordance with Caltrans panel input

Task 4: Develop draft guidance documents useful for updating manuals

Task 5: Develop final report

Overview of Research Results and Benefits

The key deliverables of this project include:

- Draft combined list of potential safety enhancements
- Final prioritized list of potential safety enhancements documented herein
- Draft guidance documents which can be used by Caltrans Maintenance or Design as templates for updating the appropriate manuals and are documented herein. The guidance documents developed in this research have been provided individually to the project manager (PM) and the panel. These documents are also provided in individual Appendix A to Appendix G in this final report.
- Final Report

The key deliverables are the draft guidance documents, which can be used by Caltrans Maintenance or Design to develop formal memos and manual updates and can improve the safety for roadside maintenance workers. As a side benefit, AHMCT developed decision support tools that can assist Caltrans managers in making decisions related to these guidance documents. These tools—not part of the proposed deliverables—include flood, sea level rise, and fire danger maps.

Chapter 2: Prioritized List of Potential Safety Enhancements

The recent research project “Performance Measures for Roadside Features” (Task 2761) identified a number of items, such as including more hardscape, that could enhance worker safety if fully implemented [1]. At the outset of the current project, the panel was asked to update the list of items and to provide them in priority order. Three prioritized lists were provided by separate panel members, two of which had significant overlap. AHMCT and the panel decided to cycle through these three lists and develop guidance documents for approximately the top three priority items from each. This process guided the subsequent development of guidance documents and the needed supporting tools. The three prioritized lists are provided in Tables 2.1 to 2.3. Here, priority 1 is highest priority. For some items, multiple guidance documents were developed, as will be clarified in Chapter 3. Some items were merged and addressed by a single guidance document or guidance documents, such as priority 2 and 3 items of Table 2.3. Priority 1 items of Table 2.2 and Table 2.3 were addressed by the same guidance document.

Table 2.1: Panel member A prioritized list of safety enhancements

Priority	Item
1	Develop landscape maintenance practices based on weather, conservation, and climate change
2	Develop additional training to keep up with existing policies (e.g., drought guidance is changing landscaping)
3	Obtain a memo from the Deputy Division Chief of Maintenance to identified locations of guardrails with aesthetic treatment, then outline expectations for replacement and installation

Table 2.2: Panel member B prioritized list of safety enhancements

Priority	Item
1	Convert metal beam guardrail locations into concrete barriers to reduce maintenance effort and staff exposure (while ensuring this approach is safe for end users)
2	Utilize “quick change” from Districts 4 and 5, including support sleeves and posts
3	Consider pole maintenance issues in non-fire areas (e.g., gore areas). Wooden poles must be completely dug out from the ground to replace, while steel poles can be replaced by removing and replacing a couple of rivets.

Table 2.3: Panel member C prioritized list of safety enhancements

Priority	Item
1	Convert metal beam guardrail locations into concrete barriers to reduce maintenance effort and staff exposure (while ensuring this approach is safe for end users)
2	Install metal guardrail posts based on fire danger rating map (while ensuring this approach is safe for end users)
3	Install steel sign poles based on fire danger rating map (while ensuring this approach is safe for end users)

Chapter 3: Guidance Documents

Memorandum Topics

For the prioritized lists provided in Chapter 2, AHMCT developed guidance documents and in some cases, related decision support tools. The safety enhancements were addressed in priority order as follows: A.1, B.1, C.1, A.2, etc. In other words, the three priority lists were cycled through, starting with highest priority for each list. AHMCT discussed each topic with the panel to develop a clearer understanding of the issue and then drafted a guidance document. Each draft was reviewed by the panel members, who provided valuable feedback. The document was then updated, and the cycle continued until a final draft guidance document was produced. In several cases, a supplemental decision support tool was developed by AHMCT to support the guidance document or provide a useful tool to aid implementation. These tools, which have also been provided to Caltrans, are discussed in detail in Chapter 4. Table 3.1 lists the memos developed in this research and provides the cross-reference to the appendix where each specific memo is provided. The topic in Appendix A led to several memos and a proposed update to the Maintenance Manual.

Table 3.1: Guidance documents and memorandums generated in this research

Memorandum title	Appendix
Develop Landscape Maintenance Practices Based on Weather, Conservation, and Climate Change <ol style="list-style-type: none">1. Higher wages and incentives to attract and retain experienced landscape maintenance workers2. Encampment removal in landscape maintenance practices3. Hardscape roundabouts and splitter islands4. Maintenance manual update proposal	A
Develop Additional Training to Keep Up with Existing Policies (e.g., Drought Guidance Is Changing Landscaping) <ol style="list-style-type: none">1. Suggested training practices	B

Memorandum title	Appendix
Identify Locations of Guardrails with Aesthetic Treatment, then Outline Expectations for Replacement and Installation	C
Convert Metal Beam Guardrail Locations into Concrete Barriers to Reduce Maintenance Effort and Staff Exposure (While Ensuring this Approach Is Safe for End Users) (combined Priority 1 from Table 2.2 and 2.3) <ol style="list-style-type: none"> 1. Equipment availability 2. Maps to aid with the decision-making process 	D
Utilize "Quick Change" from Districts 4 and 5, Including Support Sleeves and Posts	E
Consider Pole Maintenance Issues in Non-Fire Areas (e.g., Gore Areas). Wooden Poles Must Be Completely Dug Out from the Ground to Replace, while Steel Pole Can Be Replaced by Removing and Replacing a Couple of Rivets	F
Install Metal Guardrail and Sign Posts Based on Fire Danger Rating Map (While Ensuring this Approach Is Safe for End Users; combined Priorities 2 and 3 from Table 2.3) <ol style="list-style-type: none"> 1. Guardrails 2. Sign posts 	G

Main Summary from Each Memorandum Topic

Appendix A Summary

- **Wages**

There should be higher wages and incentives to attract quality candidates as well as retain experienced workers. According to California Department of Housing and Community Development 2022 data [2], Caltrans' suggested income for maintenance worker in Districts 1, 2, 3, 6, 8, 9, and 10 is classified as low to median income for a household of one person. Caltrans' suggested income for maintenance worker in Districts 4, 5, 7, 11, and 12 is classified as **very low income** for a household of one person. In addition, Caltrans employees pay for health care premiums out of their paycheck. According to 2023 Health Plan premium data from San Luis Obispo County provided by Caltrans, an employee pays \$72 to \$428 for self per month, \$135 to \$847 for self and one dependent per month, and \$194 to \$1,119 for self and two or more dependents per month [3].

Taking into consideration that the workers have family members, current wages and benefits are not sufficiently competitive to incentivize people to take on landscape maintenance duties, which also carry the most risk of exposure to traffic.

According to the National Work Zone Safety Information Clearinghouse, 45.3% of worker fatalities are due to workers on foot being struck by vehicles, as shown in Figure 3.1 [4]. The percentage of highway worker fatalities involving workers on foot being struck by a vehicle has an increasing trend from 2015 to 2020, with the exception of 2019, as shown in Figure 3.2 [4].

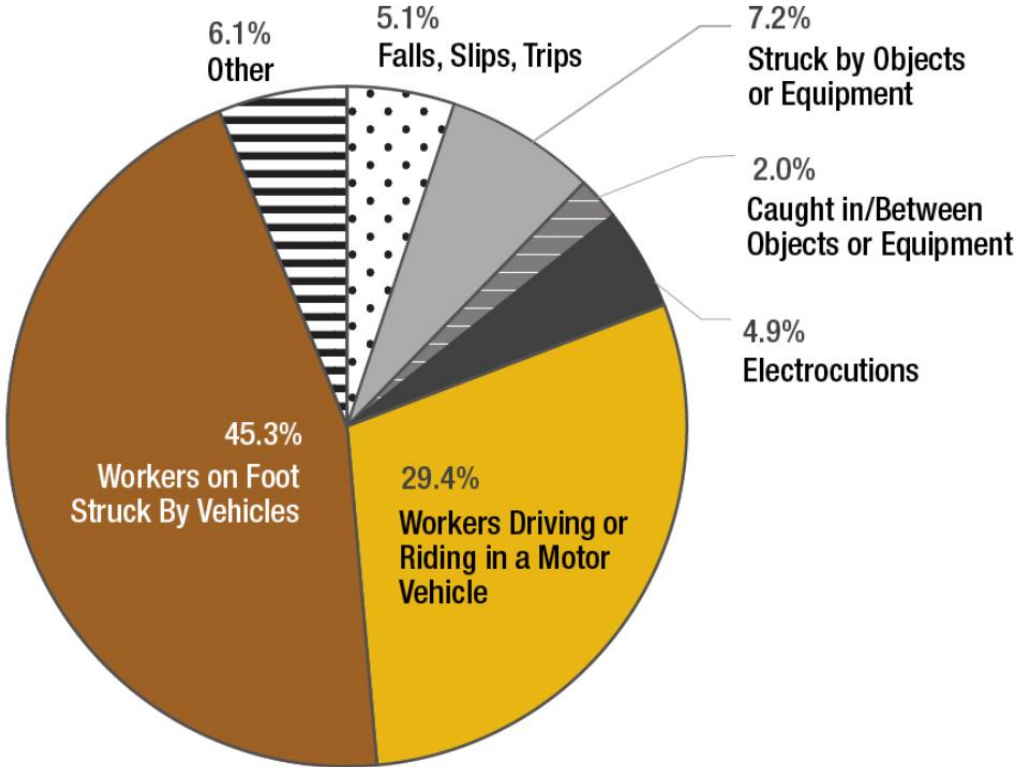


Figure 3.1: Types of events resulting in highway worker fatalities at road construction sites, 2017-2019 average. Image courtesy of the National Work Zone Safety (extracted from [4]).

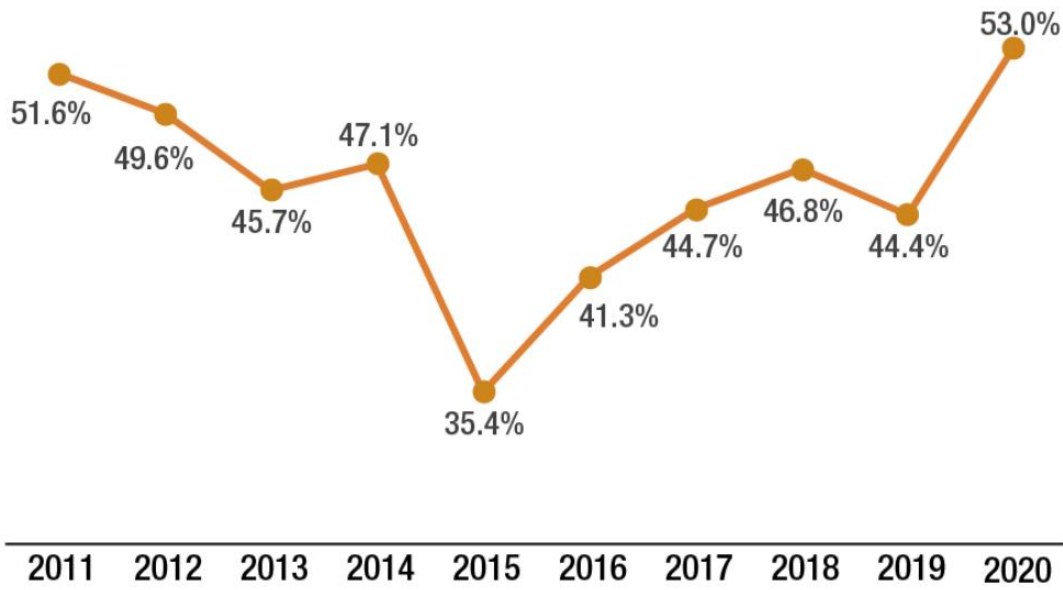


Figure 3.2: Percent of highway worker fatalities involving workers on foot being struck by a vehicle. Image courtesy of the National Work Zone Safety (extracted from [4]).

To enhance worker safety and performance, higher wages and incentives should be considered to attract and retain experienced employees. In general, having more staff is crucial to speed up work duration, which decreases worker exposure to traffic.

- **Encampment removal**

The increase in encampments poses challenges for landscape maintenance. As a result, the Caltrans Division of Maintenance issued its encampment removal policy on October 10, 2022 [5]. This internal policy detailed a step-by-step approach for dealing with encampment removal according to the level of urgency. **All workers involved in the encampment removal process must be aware of the policy to ensure worker safety.**

- **Hardscape**

From 2011 to 2017, there were 39,373 work zone related traffic collisions in California. The total cost associated with these collisions was \$5.743 billion dollars, with **\$3.253 billion dollars being related to 288 fatal incidents.** The primary collision factors were unsafe speed, improper turning, and driving under the influence (DUI). Collisions occurred primarily during daylight hours [6].

Of the 24 impaired driving crashes, 21 crashes were associated with alcohol impairment, with the remainder due to medical or drug impairment. Of the 26 speed-involved crashes, at least two involved vehicles exceeding 100 mph. Many of the motorcycle crashes at roundabouts involved loss of control and

motorcycles striking curbs. **Many of the fixed object crashes involved vehicles striking the splitter and central islands of roundabouts, striking curbs,** and sometimes other fixed objects, such as sign posts, light poles, landscaping walls, boulders, and trees. **At least 35 of the 39 fixed object crashes involved vehicles striking a curb (page 12 of [7]).** The curb is where workers most likely park to have landscape maintenance access. Based on the data, it is dangerous to have workers maintain landscape at roundabouts and splitter islands due to the high probability of a vehicle striking those areas. For example, Figures 3.3 to 3.5 demonstrate an accident associated with roundabout and splitter island provided by Caltrans maintenance personnel. Speeding can cause vehicles to run onto a roundabout and break a splitter island. In addition, Table 3.2 summarizes the characteristics of fatal crashes at roundabouts and compares them to the statistics of characteristics at all fatal crashes at intersections.

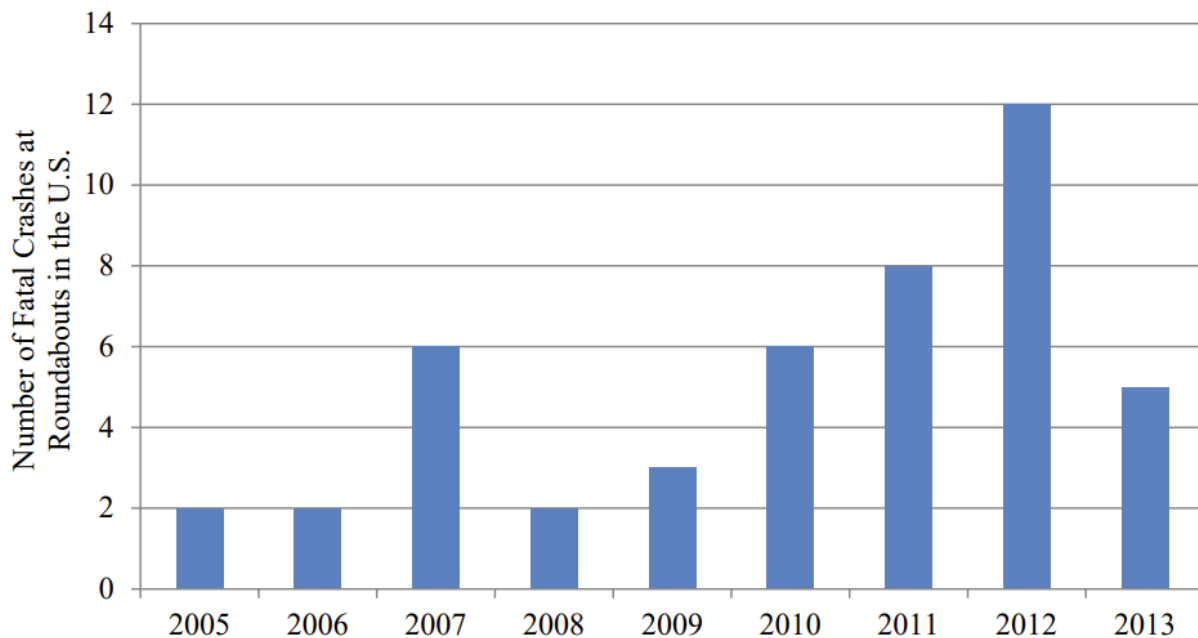


Figure 3.3: Number of fatal crashes at roundabouts in the U.S. by year. Image courtesy of US Department of Transportation (DOT) – Federal Highway Administration (extracted from page 10 of [7]).

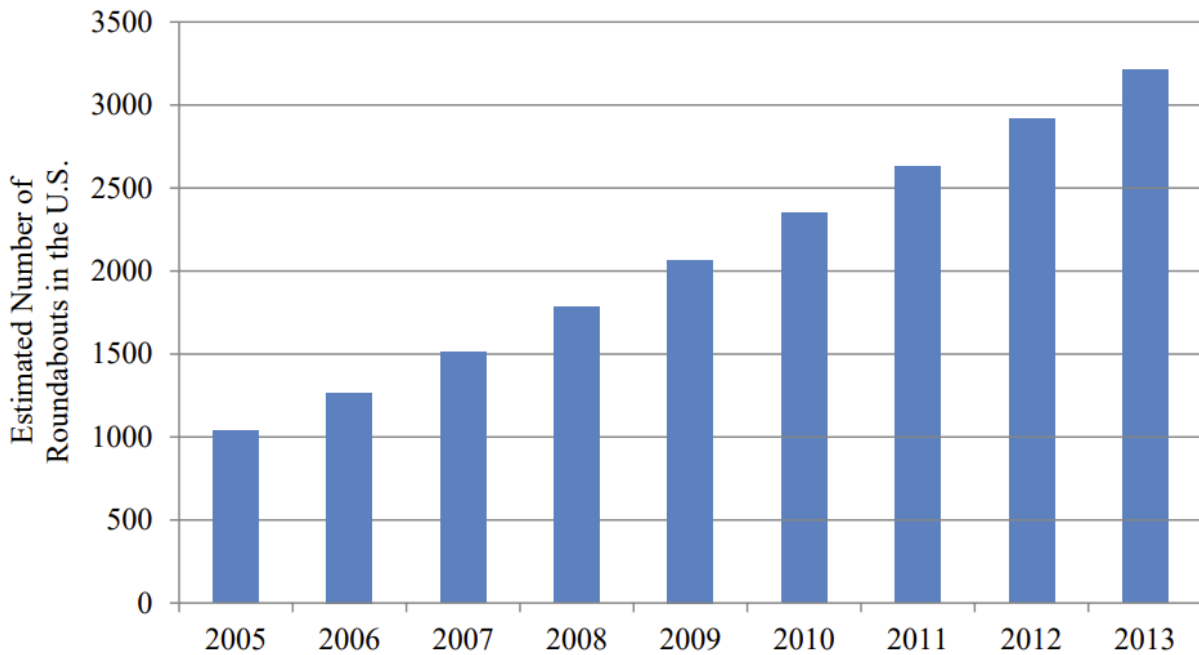


Figure 3.4: Estimated number of roundabouts in the U.S. per year. Image courtesy of US DOT – Federal Highway Administration (extracted from page 11 of [7]).

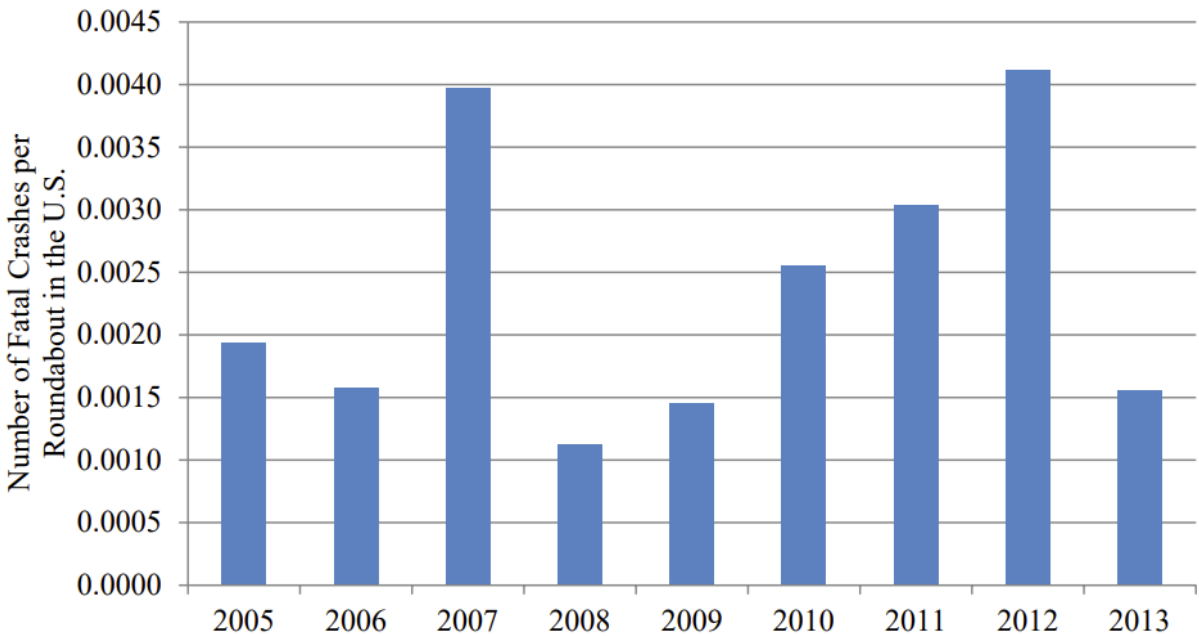


Figure 3.5: Estimate number of fatal crashes per roundabout in the U.S. by year. Image courtesy of US DOT – Federal Highway Administration (extracted from page 11 of [7]).

Table 3.2: Summary of characteristics of fatal crashes at roundabouts compared to fatal crashes at all intersections in the U.S. (page 12 of [7]).

Characteristics cited in Crash Reports	Number of Crashes with Characteristic (Percent of all fatal roundabout crashes)	Number of Crashes without Characteristic or where Information Not Reported (Percent of all fatal roundabout crashes)	Percent of Fatal Crashes at All Intersections in the U.S. with Characteristic
Multiple Vehicles Involved	8 (17%)	38 (83%)	67%
Vehicle Struck Fixed Object(s)	39 (85%)	7 (15%)	11%
Motorcycle Involved	21 (46%)	25 (54%)	23%
Speed Cited	26 (57%)	20 (43%)	20%
Impaired Driving Cited	24 (52%)	22 (48%)	21%
Bicyclist Involved	1 (2%)	45 (98%)	4%
Pedestrian Involved	0 (0%)	46 (100%)	16%
Light Conditions (Daylight)	20 (43%)	26 (57%)	57%
Multilane Roundabout	13 (28%)	33 (72%)	N/A

- **Maintenance Manual update proposal**

A new section regarding landscape control at roundabouts and splitter islands should be added to the Maintenance Manual using this suggested approach:

- Update should be made for: Maintenance Manual Chapter E – Landscaping.
- Suggested addition: Section E.13: Roundabouts and Splitter Islands Safety Recommendation.
- Suggested content: A roundabout is a place where three or more roads join, and traffic must go around a circular area rather than straight across. A splitter island is a raised or painted traffic island that separates traffic in opposing directions of travel, typically used at

roundabouts. Roundabouts and splitter islands shall be hardscaped when there are high safety concerns. Roundabouts shall have either a vertical element or landscaping utilized to prevent motorists from looking across the roundabout to see the traffic status.



Figure 3.6: Example of a roundabout and splitter island incident. Image courtesy of Caltrans.

The particular roundabout in Figure 3.6 does not reflect the design concept of slowing down traffic. Drivers misuse the roundabout since they can look across and assess upcoming traffic. Roundabouts and splitter islands should serve their purpose with the consideration of maintenance personnel safety.

Appendix B Summary

- **Suggested training practices**

According to survey responses, most participants prefer re-training every six months to a year. In addition, trainings that include demonstrations, such as repair and troubleshooting, should be in-person.

There were suggestions that a complete rundown training should take place before crew assignment, training frequency should be based on years of service, and training frequency should be based on each district's needs. The reasons for each suggested training structure are as follows:

Table 3.3: List of trainings and frequency recommendation

Training name	Frequency
Caltrans policy on safety	Annually
Desirable landscape plants vs. non-native invasive weed classes	6 months
Drought-tolerant planting trainings	Annually
Equipment training	6 months
Irrigation repairs (hands-on)	Annually
Irrigation programming and troubleshooting (hands-on)	Annually
Proper tree trimming training (hands-on)	Annually
Proper pruning practices training	Annually
Pesticide usage training	Annually
Pesticide safety training	Annually
Weed identification training	6 months

Training before crew assignment

Instead of assigning a person to a crew immediately upon hiring, that person should go through two to three weeks of training (before crew assignment) so that they know what duties they are expected to perform. Then, individuals can evaluate what duties they perform well and vice versa. The individuals can rank the duties from most to least familiar. Individuals will be assigned to duties they are familiar with first, and as they gain more experience, they can be trained on other duties. In addition to the comprehensive training, a questionnaire form can be sent out to the candidates to assess their level of experience in the field. Then, Caltrans can select individuals they think will be a good fit for the jobs.

Benefits: people will learn about the expected duties and what duties will be the most compatible to them. In addition, Caltrans can separate qualified candidates from unqualified ones. For example, during the training, individuals might come to find out that the position is not a right fit for them. At the end of the training, the individuals can determine whether they want to commit to the job. People who do not like the job can be ruled out during/after the training instead of quitting during their first days in a field crew.

Training frequency based on years of service

The training frequency should be based on years of service. For instance, first-year employees should have monthly training; second-year employees should have training every three months; and employees with three or more years of service should have training every six months to a year.

Benefits: Re-instating trainings will ensure duties are being performed correctly and safely, especially for employees in their first years of service.

Training based on Caltrans district and region

Landscaping maintenance approaches may vary by district and region. Landscape work orders should be counted and categorized in Excel so that the frequency of each duty can be determined. Then, training should be re-instated for the duties that are expected the most within that district/region.

Benefits: Prioritize trainings that are the most applicable for a specific district/region.

Summary for this section: Training should be re-instated based on the recommended frequency. Demonstrative training should be done in-person to better convey hands-on tasks. In addition, there should be a structural reform for training. The first training structure is to train before crew assignment. This approach rules out candidates who might not be the right fit for the job at an early stage, which creates more qualified crews. The second training structure is to train based on the number of years of service. This approach builds a strong foundation for new employees as they progress in the position. The third training structure is to train based on Caltrans district and region. This approach prioritizes the most common landscape practices in a specific district/region.

In addition, quick response (QR) codes should be utilized so that employees can quickly access the policy guidelines when necessary.

Recommendations

- The majority of maintenance personnel agree that they do not fully follow the landscape policies due to uncertainties in the field. The actions that the crews have taken when they cannot fully follow the policies include but are not limited to:
 - Some plants need to be removed and not-replanted due to an increase in unsheltered population.
 - Water conservation can be mandatory during drought conditions, which affects groundcover plants and shrubs. One team decided to deep water once a week instead of shallow watering three times a week.
 - Vehicles sometimes cannot be fully parked on the shoulder due to flooding. A shoulder closure request must be submitted by the Maintenance Supervisor so that landscape crews can carry out their duties.

There should be an advisory section in the policy where different scenarios are listed and how other people have approached their tasks when unexpected circumstances arise. The adaptive actions the crews have come up with should be recorded. When an action is repetitive, it should be added to the policies.

Appendix C Summary

According to a survey conducted by the AHMCT team, treating guardrails in the field can take from 1 to 3 hours. In addition, there are environmental concerns from agencies when applying the guardrail treatment in the field.

Treating guardrails in-house should be implemented across all Districts because the process **reduces worker exposure to traffic** as well as addresses the concerns from environmental agencies.

Scenic areas, like forests, national parks, and coastlines, are common locations for treated guardrails. To pinpoint treated guardrail locations, the AHMCT team looked into scenic areas in each Caltrans district and considered the survey responses. The known treated guardrail locations are as follows:

- Forestry route of State Route (SR) 299 – Trinity County
- Forestry route of SR 3 – Trinity County
- Forestry route of SR 36 – Trinity County
- Forestry route of SR 96 – Siskiyou County
- Forestry route of US Highway 97 – Siskiyou County
- SR 1, post mile 20.61 through 37.45 - Santa Cruz County
- SR 9, post mile 0.05 through 6.46 – Santa Cruz County
- SR 190 – Inyo County
- SR 1, post mile 64.35 to 70.42 - Monterey County
- SR 1, post mile 32 through 74 - San Luis Obispo County
- US Highway 101, post mile 1.5 to 10.55 – Monterey and San Luis Obispo Counties
- SR 168, the route to Sierra National Forest, Fresno County
- Forestry and scenic route of US State 395 – Mono and Inyo Counties
- Forestry route of SR 2 – Los Angeles and San Bernardino Counties
- Forestry route of SR 138 – San Bernardino County
- Sutter Sierra Region – but the crew does not treat the guardrails. The treated guardrails are installed during construction. If a treated guardrail gets damaged, it is replaced with a plain, galvanized guardrail. Sierra County opposed Natina-treated guardrails because it does not match with existing rail already installed on the corridor, which is not aesthetically pleasing. Since there is uncertainty about this location, the location is not outlined on the map (Figure 3.7).



California State Parks, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA

Figure 3.7: Known locations of Natina-treated guardrails marked on the California map. Data credited to the U.S. Department of Agriculture (USDA), US Forest Service, and Caltrans. Link to the map: [Treated Guardrails Map \(https://ucdavis.maps.arcgis.com/apps/mapviewer/index.html?webmap=36322e9796bf4e57a3efc82ee4331f7d\)](https://ucdavis.maps.arcgis.com/apps/mapviewer/index.html?webmap=36322e9796bf4e57a3efc82ee4331f7d)

The AHMCT team met with a Natina representative to outline the expectations of applying the Natina treatment in-house. The Natina representative recommended to contact him directly for any needs as he has worked with Caltrans.

Natina Treatment Application Expectations [8]

- Material requirement: Only apply treatment on **galvanized metal**, particularly steel
- Treatment cure time: **4 to 6 weeks**
- Ideal ambient conditions to apply the treatment: Hot, sunny conditions with temperatures **above 50°F** and **above freezing** at night. There should be no rain or snow within one week of application. There should be minimal to low wind.
- Materials needed to apply the treatment: Hudson-style pump sprayer, TP8001-VS Teejet VisiFlo Flat Spray Tip or similar, with the spray nozzle adjusted to fine mist, and safety goggles
- Treatment application precautions when applying in-house:
 - Apply to the **non-road side first** (back of guardrail)
 - Only spray areas that you want to color
 - Move, cover, and mask off any materials and surfaces near spraying area
 - Using a pump sprayer, apply a light coat during the hottest part of the day to the entire target surface. Ensure that all angles of the target surface are covered.
 - Minimize Natina running or pooling on the surface
 - Applying too much Natina may result in improper curing and a mismatched final color
 - Allow Natina to **dry for 2 to 3 days after the first coat**. Sweep guardrail lightly with a broom to remove dusty residue, and then apply a second coat over the top of the first coat.
 - **Wait 5 to 7 days**, and then flip and repeat the same process on the road side (front) of the guardrail. For ideal color development, the surface should be dry for at least 5 to 7 days before second application.
 - Color development and transition will occur after application and will vary in colors while curing. Natina is **fully cured within 4 to 6 weeks**.
- Touch-ups and maintenance:
 - Natina can be applied using a clean rag or sponge to contain coverage area and help to avoid any accidental staining
 - Use a dabbing motion. **Do not wipe when applying**.
 - Follow the prior application instructions, replacing spraying application with dabbing application
- Storage:
 - Allow Natina to fully cure prior to storage, 4 weeks at a minimum after second application

- Natina-treated guardrail is best stored indoors or under a covered facility, with **as much ventilation as possible**
- Plain galvanized, and Natina-applied material should **never be stacked with metal touching metal**. If you need to stack, place small strips of wood or dunnage between every piece of metal to ensure they are not touching and getting proper ventilation.

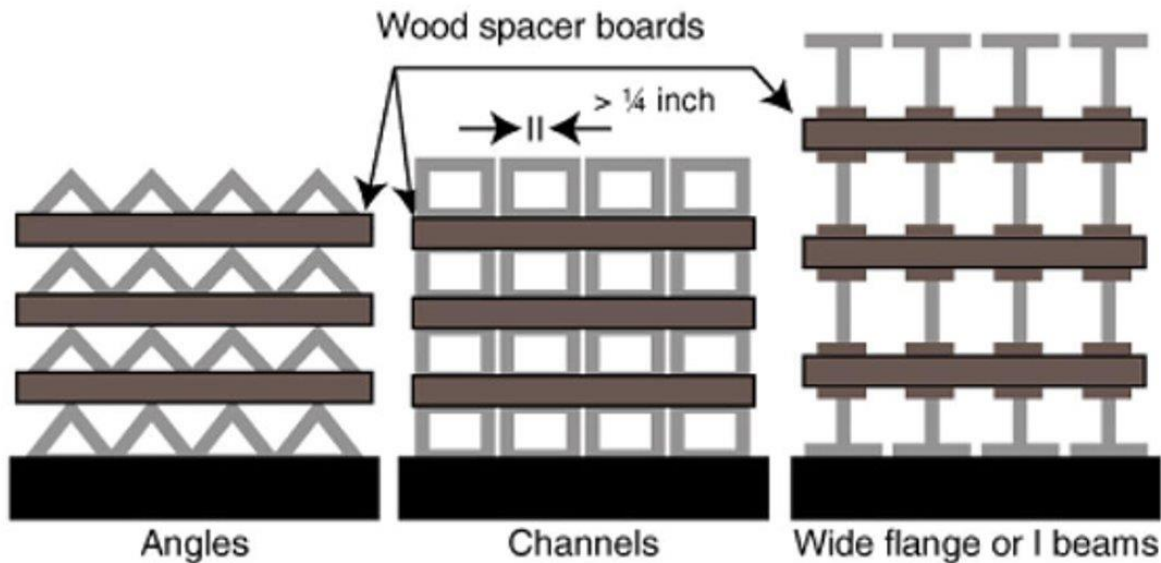


Figure 3.8: Storage method recommended by Natina [8]

Additional resources about Natina

- Natina Steel solution is sold in 2.5-gal increments. When applied correctly, Natina Steel should yield approximately 100 linear feet per gallon.
- **Caltrans can choose to have Natina treat the guardrails in the Natina facility (in Arizona)** and have the guardrails shipped back when ready. For inquiry, please contact Kris Knights.

Appendix D Summary

• Equipment availability

The procurement process demands significant information from staff who often cannot execute the equipment orders in a timely manner due to limited funds.

Based upon discussions with the Division of Equipment, the recommendations are as follows:

- Refer to and understand the resources for writing an effective Budget Change Proposal (BCP). The Division of Equipment personnel mentioned

that including environmental reasons where appropriate should increase the success rate of BCP approval.

- Existing resource on how to write a compelling BCP: [How to Write an Effective Budget Change Proposal \(BCP\) | Department of Finance \(https://dof.ca.gov/budget/how-to-write-an-effective-budget-change-proposal-bcprev-03-00/\)](https://dof.ca.gov/budget/how-to-write-an-effective-budget-change-proposal-bcprev-03-00/)
- Environmental impacts should be included as they will be a part of “Buy Clean Initiative”, a [Bipartisan Infrastructure Law \(https://www.transportation.gov/sites/dot.gov/files/2022-09/Signed_Buy_Clean_Policy_Statement.pdf\)](https://www.transportation.gov/sites/dot.gov/files/2022-09/Signed_Buy_Clean_Policy_Statement.pdf) initiated by President Biden. Specifically, the plan [9] is as follows:
 - A. There will be reports used to communicate the environmental impacts of construction materials. These reports will help in investing in the production of clean and reliable materials.
 - B. Based on the reports, a Buy Clean policy will be developed. Materials purchased with taxpayer dollars are serving the best interests of the American people while also supporting job creation in sustainable industry.
 - C. Research will continue to drive down the emissions that come from the materials and processes used in transportation infrastructure.

Moving toward the Buy Clean Initiative policy will require significant resources. Therefore, **Caltrans should incorporate this policy (and other environmental policies) into BCPs to justify the budget.**

- Utilize federal resources.
 - Link to federal resources: [DOT Climate Change Center | US Department of Transportation \(https://www.transportation.gov/priorities/climate-and-sustainability/dot-climate-change-center\)](https://www.transportation.gov/priorities/climate-and-sustainability/dot-climate-change-center) and Sources of Greenhouse Gas Emissions | [US Environmental Protection Agency \(EPA\) \(https://www.epa.gov/\)](https://www.epa.gov/)
- Utilize Outlook Calendar. A calendar that keeps track of equipment status and potential equipment sharing should be created and shared among the employees.
- Utilize existing data to justify the need of an equipment item or vehicle.
 - It is recommended that staff use accident data from the [Statewide Integrated Traffic Records System \(SWITRS\) https://iswitr.chp.ca.gov/Reports/jsp/userLogin.do](https://iswitr.chp.ca.gov/Reports/jsp/userLogin.do) to justify equipment and hardware parts usage. An account is required to

request reports, but the resources are free and clearly categorized for user needs.

- **Maps to aid with the decision-making process**

Based on literature review and national data, the following approaches can potentially aid Caltrans in choosing the most compatible barrier option:

- An interactive map that highlights fire threat level, flood depth, terrain, sea level rise (SLR), and accident volume in California.
- Existing resources from Caltrans and other DOTs and government agencies.

Table 3.4: Preferred barriers for each factor

Factor:	Accident	Terrain	SLR	Floodplains	Fire threat	End-user safety	Worker safety
Preferred Barrier:	Concrete barriers	Depends on elevation (ex. ground conditions)	Metal guardrails	Metal guardrails	Metal guardrails	Metal guardrails	Concrete barriers

To interpret Table 3.4 visually, an interactive map combining all the factors was created. Data information for each factor include:

1. **Accident volume:** The data were from the period of 01/01/2022 to 12/31/2022. The data were requested and then provided by the California Highway Patrol (CHP). The link to the data request form is [CHP-SWITRS \(https://iswitr.chp.ca.gov/Reports/jsp/index.jsp\)](https://iswitr.chp.ca.gov/Reports/jsp/index.jsp).
2. **Terrain:** The map was provided by ArcGIS Online. The link to the layer is [Imagery Hybrid – Overview \(https://www.arcgis.com/home/item.html?id=28f49811a6974659988fd279de5ce39f\)](https://www.arcgis.com/home/item.html?id=28f49811a6974659988fd279de5ce39f).
3. **SLR:** The data were provided by Coastal Storm Modeling System. At the time of this memorandum, the data were last revised on 03/10/2021. The link to the data is [OCOF - Flood Map \(https://data.pointblue.org/apps/ocof2_flood_map/download_data#!?z=6&lat=37.2695121765137&lon=-119.3063926696775&grp=23&asc=1&abl=42&slr=0&sto=0&hol&nou=false&csl=0&cst=0&cho&cno=false&opc=\)](https://data.pointblue.org/apps/ocof2_flood_map/download_data#!?z=6&lat=37.2695121765137&lon=-119.3063926696775&grp=23&asc=1&abl=42&slr=0&sto=0&hol&nou=false&csl=0&cst=0&cho&cno=false&opc=)).
4. **Floodplains:** The data were provided by the California Department of Water Resources. The link to the data is [Boundaries/bam viewer](#)

Table 3.5: Barrier characteristics (from page 1 of [10])

Barrier system	Deflection	Initial Cost	Maintenance Cost	Passed Crash Tests with the following
Steel Beam Guardrails	4 feet	Low	Medium	Cars, pickups
Permanent Concrete Barriers	0 feet	High	Low	Cars, pickups, single unit trucks, semi-trucks

To interpret Table 3.5, each factor can be analyzed using existing resources. Information for each factor is as follows:

1. **Deflection:** If the space between the lane and the median is limited, a barrier with minimal deflection is preferable. This factor is based on engineering judgement.
2. **Initial cost and maintenance cost:** There is on-going research on this topic being conducted by another AHMCT project team. This research will yield in-depth information about the costs and benefits in choosing metal guardrails versus concrete barriers. Thus, this topic will not be discussed in this report.
3. **Type of vehicles:** For passenger vehicles, such as sedans and vans, metal guardrails are preferable; however, for commercial vehicles, such as trucks and semi-trucks, concrete barriers are preferable. On the Caltrans website, the [California truck network maps](https://dot.ca.gov/programs/traffic-operations/legal-truck-access/truck-network-map) (<https://dot.ca.gov/programs/traffic-operations/legal-truck-access/truck-network-map>) determine the freeway routes that trucks mainly take. Caltrans also developed a [Performance Measurement System \(PeMS\) website](https://pems.dot.ca.gov/?report_form=1&dnode=State&content=loops&tab=def_summary&export=&s_time_id=1672531200&s_time_id_f=01%2F01%2F2023&e_time_id=1677715140&e_time_id_f=03%2F01%2F2023&tod=all&tod_from=0&tod_to=0&dow_0=on&dow_1=on&dow_2=on&dow_3=on&dow_4=on&dow_5=on&dow_6=on&holidays=on&gb=district&q=vmt&q2=&chart.x=73&chart.y=7) (https://pems.dot.ca.gov/?report_form=1&dnode=State&content=loops&tab=def_summary&export=&s_time_id=1672531200&s_time_id_f=01%2F01%2F2023&e_time_id=1677715140&e_time_id_f=03%2F01%2F2023&tod=all&tod_from=0&tod_to=0&dow_0=on&dow_1=on&dow_2=on&dow_3=on&dow_4=on&dow_5=on&dow_6=on&holidays=on&gb=district&q=vmt&q2=&chart.x=73&chart.y=7) that provides vehicle miles traveled (VMT), vehicle hours traveled (VHT), truck VMT, and truck VHT across the districts. With this information, the VMT and the truck VMT can be compared on the main freeway routes, as shown in Figure 3.10.

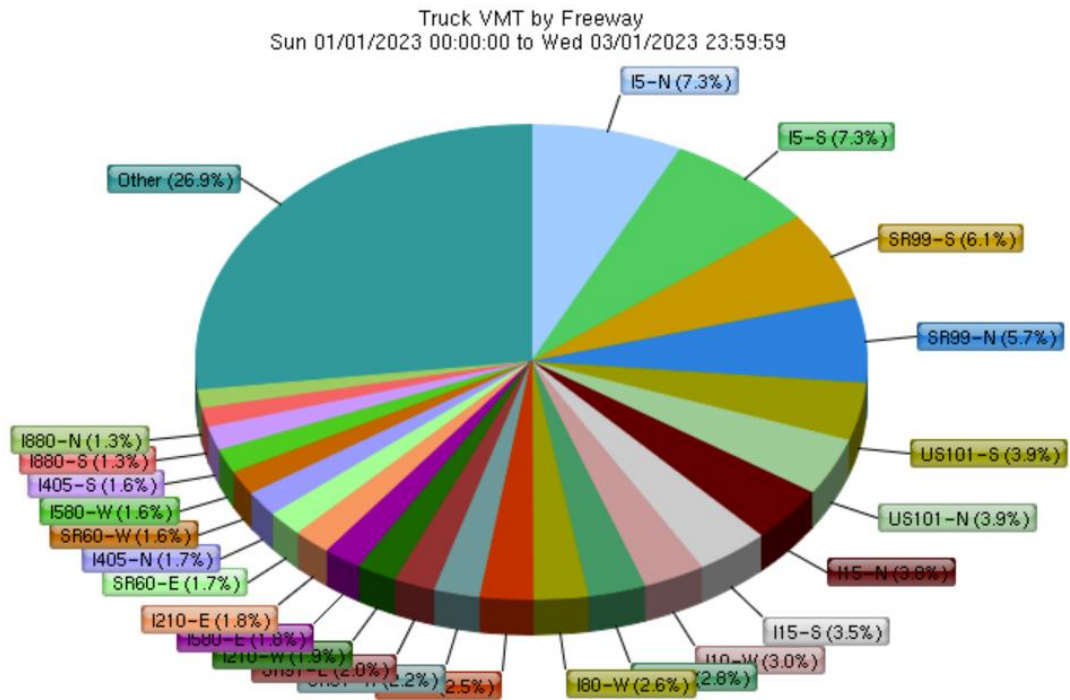
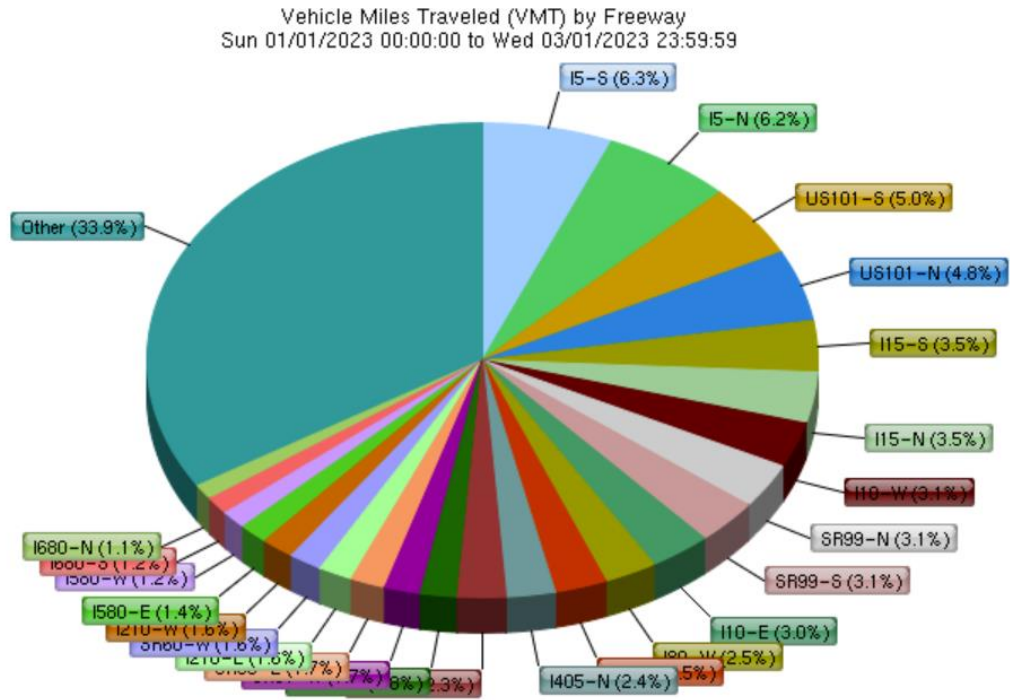


Figure 3.10: VMT and truck VMT classified by freeway. On I-5, the amount of VMT and truck VMT is the highest. The classification can be also done by counties and cities. Image courtesy of Caltrans – PeMS website.

In summary, there is no definitive way to determine whether it is best to install concrete barriers or metal guardrails. The decision is based on many factors, including some judgment. The first tool to aid with the decision-making process is the interactive map, which combines terrain, SLR, floodplains, fire threats, and accident volume. The second tool is the PeMS website. By knowing the volume of trucks and vehicles passing through a certain freeway, the compatible Manual for Assessing Safety Hardware (MASH) test levels can be considered. For example, freeways with high truck VMT should have a high MASH test level. In addition, the tools can be utilized together. For instance, in an accident hotspot with high VMT, the barrier should be concrete with a MASH test level which accommodates passenger cars.

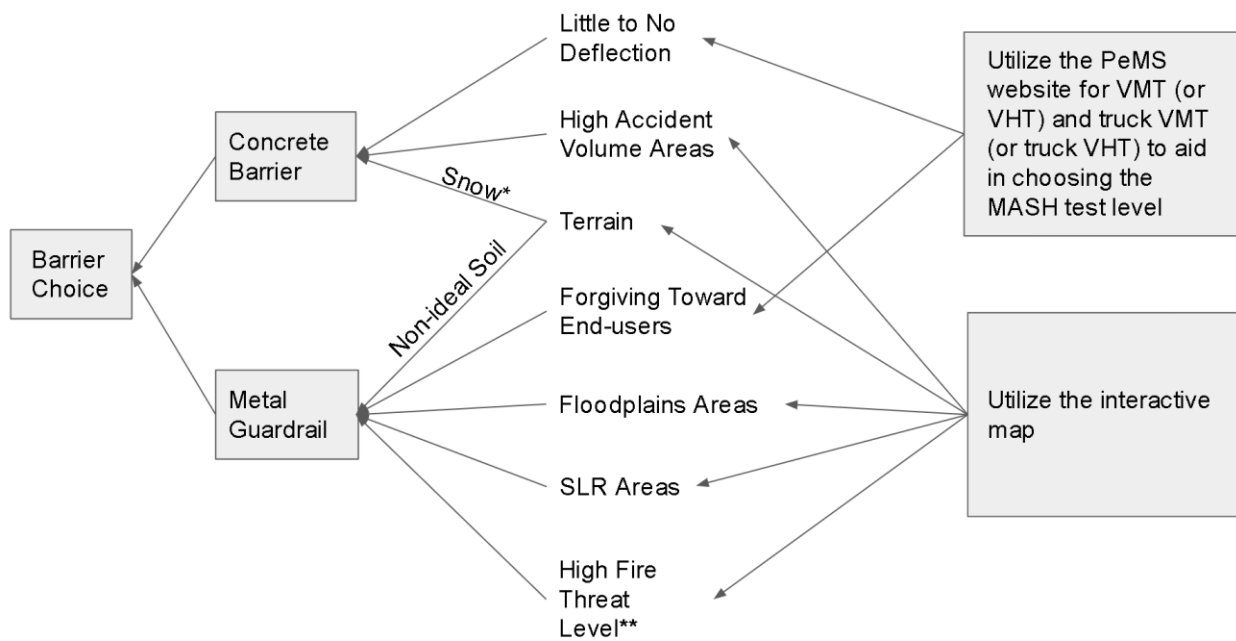


Figure 3.11: Decision tree for choosing a barrier (created by AHMCT). When choosing a barrier, the questions is: what are the dominant factors (ex. fire region)? This diagram was created by the AHMCT team.

*** Regarding snow, if an area uses snow blowers, concrete barriers are preferred as metal guardrails can get damaged according to interviews with Caltrans maintenance personnel. However, per Iowa DOT recommendation, the open design of metal guardrails reduce snow drifting (page 2 of [10]).**

**** In fire prone areas, wooden posts are not recommended.**

Appendix E Summary

The “quick change” process consists of establishing a concrete-reinforced base, then the posts get inserted into or removed from the base when they need to be changed out. The advantages and disadvantage of the “quick change” process are:

- **Advantages:**

- Reduce the amount of treated wood waste (TWW).
According to Department of Toxic Substances Control (DTSC), TWW has the potential to be hazardous waste if it contains elevated levels of one or more of the following constituents: arsenic, chromium, copper, pentachlorophenol, and creosote. If TWW is not properly disposed of, the chemicals it contains can contaminate soil, surface water, and ground water, which poses a risk to human health and the environment. **Analysis of representative samples of TWW has shown that it has the potential to exhibit a hazardous waste characteristic of toxicity under California state standards [11].**
- Reduce the installation time once the setup is established.
According to a SWITRS report, there were **1,450 collisions** related to traffic signals and signs in 2022 for Sacramento County alone (data can be found in Appendix E). Out of the 1,450 collisions, 10 were fatal and 1,014 were injury collisions. **Reducing traffic exposure time is one of the main factors to enhance worker safety. Therefore, reducing installation time is crucial.**
- Enhance safety for the travelling public.
The “quick change” design consists of the post being fastened slightly above ground. The “quick change” design is similar to the breakaway design, which is **recommended and implemented by other DOTs as it is forgiving to end users.**

- **Disadvantage:**

- The initial setup takes time.
Setting up the initial base for “quick change” takes approximately 2 to 5 hours. Although the initial setup takes a long time, it is a one-time setup. Caltrans personnel stated that the time reduction for the following installments is worth the initial trade-off.

Caltrans should implement the “quick change” approach across all districts. **The benefits of the implementation are reducing TWW, reducing installation time for future installments, and enhancing forgiveness toward end-users. Implementing “quick change” enhances the safety of workers and the travelling public, which is a win-win solution.**

It is recommended that Caltrans should:

- Perform crash testing of single and double-post quick change signs
- Upon successful crash testing, adopt the designs into standard plans
- Encourage other Caltrans districts to adopt the “quick change” practice

Appendix F Summary

After considering the issues of pole maintenance in gore areas, the active and reactive solutions suggested are:

Active solutions

- Implementing “quick change” base for time-efficient pole replacement
 - Refer to Appendix E

Reactive solutions

- Relocating the signs
- Considering overhead sign structures
- Consider improving the conspicuity of the gore area with object markers, delineation and/or striping for gore areas that do not already have a contrasting surface treatment
- Considering “escape” lane
- Considering retro-reflective sheeting on sign posts
- Considering maintaining the poles at the gore area on a case-by-case basis
 - Hire contractors (South Carolina DOT)
 - Delay until lane closure when there is a near-miss or an accident at the reported location (Texas DOT)

Appendix G Summary

- **Guardrails**

It is recommended that Caltrans utilize USDA – Forest Service map applications and the comprehensive fire rating map where the data are centralized. Historical fire data, simulated fire data, and current fire data will aid Caltrans in the decision of installing metal posts.

Recommendations for using the comprehensive map

- Watch the instructional video provided by the AHMCT team.
- The fire exposure type, conditional flame length, building exposure, burn probability, risk to potential structures, and wildfire hazard potential layers should be viewed **one at a time**.

Resources

Data for wildfire risk for populated areas: [Forest Service Research Data Archive \(usda.gov\) \(https://www.fs.usda.gov/rds/archive/catalog/RDS-2020-0060\)](https://www.fs.usda.gov/rds/archive/catalog/RDS-2020-0060)

Data for landscape-wide wildfire risk components: [Forest Service Research Data Archive \(https://www.fs.usda.gov/rds/archive/Catalog/RDS-2020-0016\)](https://www.fs.usda.gov/rds/archive/Catalog/RDS-2020-0016). (Note: This link is different from wildfire risk for populated area.)

Map applications:

[USFS maps](#)

<https://usfs.maps.arcgis.com/apps/MinimalGallery/index.html?appid=46e069c721bb49c6abe5a9d57e3a365f>

AHMCT comprehensive fire rating map (more details in Chapter 4): [Fire Rating Map](#)

<https://ucdavis.maps.arcgis.com/apps/mapviewer/index.html?webmap=1066d38d8b2a497e9e3d82eaf5b6c160>

- **Sign posts**

While guardrail sections can be identified by route and highway names, sign posts require the location to be more specific. Thus, the AHMCT team recommended using Google Earth Map Data developed by the Wildland Fire Assessment System (WFAS) [12]. The data display current weather, fire danger, fuel moisture observation, and forecast weather conditions when available. In addition, the data are updated daily and automatically. Using the Google Earth application, the user can pinpoint the location of interest using latitude and longitude. The link to this site is: [Google Earth Map Data \(https://www.wfas.net/index.php?option=com_content&view=article&id=80&Itemid=483\)](https://www.wfas.net/index.php?option=com_content&view=article&id=80&Itemid=483)

The WFAS has fire potential and fire danger maps that are updated daily and automatically. A fire danger rating level takes into account current and antecedent weather, fuel types, and both live and dead fuel moisture. The link to this site is: [Fire Danger Rating \(https://www.wfas.net/index.php?option=com_content&view=article&id=75&Itemid=478\)](https://www.wfas.net/index.php?option=com_content&view=article&id=75&Itemid=478)

The WFAS has an interactive map. The user can interact and display the data to their reference. The map is updated daily and automatically. The link to this site is: [Wildland Fire Assessment System - Severe Fire Danger Mapping System \(https://m.wfas.net/\)](https://m.wfas.net/)

Chapter 4:

Support Tools Developed in this Research

To support the guidance documents, and to ease implementation of their recommendations within Caltrans, AHMCT developed two Geographic Information System (GIS) tools. These maps provide support for visualization of fire danger, flood risk, and impacts of future predicted SLR.

Fire Danger Rating Map Tool

AHMCT developed a fire danger map based on ESRI's ArcGIS tool. This tool is important in guiding tradeoff decisions between using concrete barriers or guardrails with wooden posts. The tool also guides the choice of metal sign and guardrail posts instead of wood posts. The fire danger map tool includes the following info:

- **[US population density](https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_PopulationDensity/ImageServer/info/iteminfo)**
(https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_PopulationDensity/ImageServer/info/iteminfo)

These data reflect 2018 estimates of population counts from the U.S. Census Bureau

- **[Fire exposure type](https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_ExposureType/ImageServer/info/iteminfo)**
(https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_ExposureType/ImageServer/info/iteminfo)

Wildfire exposure is the spatial coincidence of wildfire likelihood and intensity with communities. This data layer delineates where structures are directly exposed to wildfire from adjacent wildland vegetation, indirectly exposed to wildfire from indirect sources such as embers and home-to-home ignition, or not exposed to wildfire due to distance from direct and indirect ignition sources (> 1 mile).

- **[Conditional flame length \(CFL\)](https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_ConditionalFlameLength/ImageServer)**
(https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_ConditionalFlameLength/ImageServer)

The values of CFL represent the most likely flame length at a given location if a fire occurs based on wildfire simulation modeling. This is an average measure of wildfire intensity.

- **[Building exposure](https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_Building_Exposure/ImageServer/info/iteminfo)**
(https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_Building_Exposure/ImageServer/info/iteminfo)

Exposure is the spatial coincidence of wildfire likelihood and intensity with communities. The building exposure layer delineates whether buildings at each pixel are directly exposed to wildfire from adjacent wildland vegetation (pixel value 1), indirectly exposed to wildfire from indirect sources such as embers and home-to-home ignition (pixel values between 0 and 1), or not exposed to wildfire due to distance from direct and indirect ignition sources (pixel value 0).

- **[Burn probability \(BP\)](https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_BurnProbability/ImageServer)**
(https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_BurnProbability/ImageServer)

BP represents the annual probability of wildfire burning in a specific location.

- **[Risk to potential structures \(RPS\)](https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_RiskToPotentialStructures/ImageServer/info/iteminfo)**
(https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_RiskToPotentialStructures/ImageServer/info/iteminfo)

RPS is a measure that integrates wildfire likelihood and intensity with generalized consequences to a structure on every pixel. For every location, it answers the hypothetical question, "What would be the relative risk to a structure if one existed here?" RPS allows for comparing wildfire risk in places where homes already exist to places where new construction may be proposed.

- **[Wildfire hazard potential \(WHP\)](https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_WildfireHazardPotential/ImageServer)**
(https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_WildfireHazardPotential/ImageServer)

WHP is an index that quantifies the relative potential for wildfire that may be difficult to control and is used as a measure to help prioritize where fuel treatments may be needed. The final WHP map is presented in five WHP classes of very low, low, moderate, high, and very high. On its own, WHP is not an explicit map of wildfire threat or risk, but when paired with spatial data depicting highly valued resources and assets such as structures or power lines, it can approximate relative wildfire risk to those specific resources and assets. WHP is also not a forecast or wildfire outlook for any particular season as it does not include any information on current or forecasted weather or fuel moisture conditions. It is instead intended for long-term strategic fuels management.

AHMCT also developed an instructional video for this tool and provided the video to Caltrans. An example of the comprehensive map is shown in Figure 4.1. AHMCT recommends the fire exposure type, CFL, building exposure, BP, RPS, and WHP layers be viewed **one at a time**.

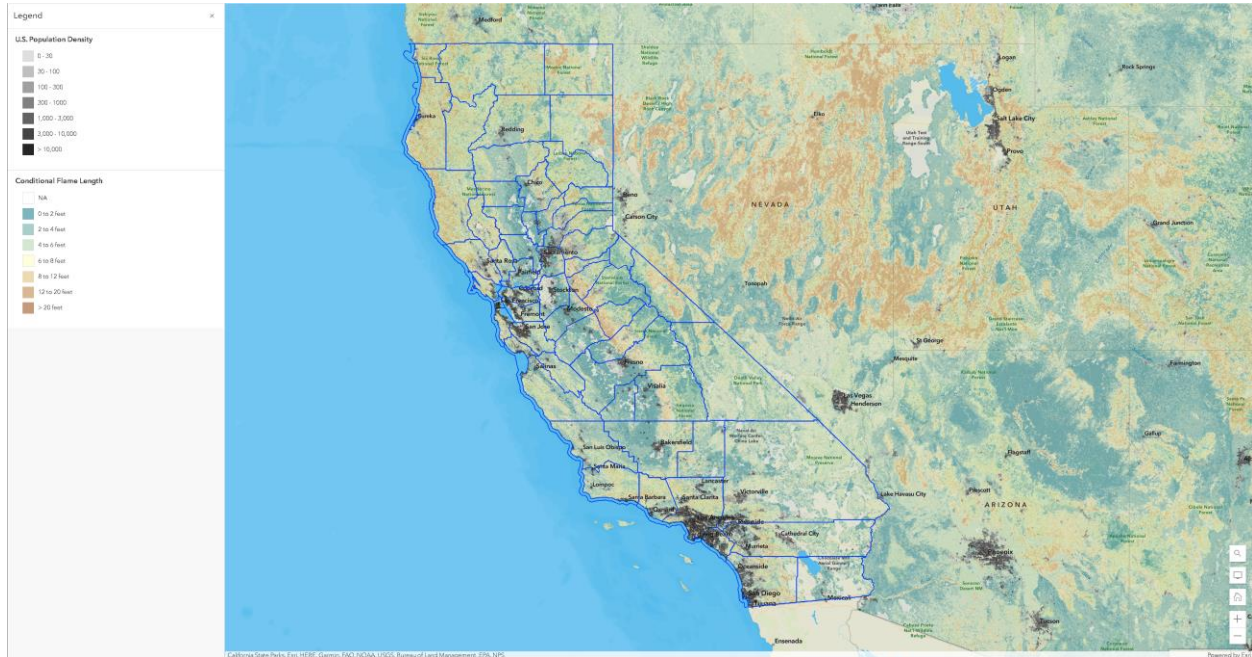


Figure 4.1: Example of the comprehensive map. Data set credited to California State Parks, Esri, Homeland Emergency Response Exchange (HERE), Garmin, Food and Agriculture Organization (FAO), National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS), Bureau of Land Management, EPA, and National Park Service (NPS).

Comprehensive fire rating map link: [Fire Rating Map](https://ucdavis.maps.arcgis.com/apps/mapviewer/index.html?webmap=1066d38d8b2a497e9e3d82eaf5b6c160)
(<https://ucdavis.maps.arcgis.com/apps/mapviewer/index.html?webmap=1066d38d8b2a497e9e3d82eaf5b6c160>)

Flood and SLR Map Tool

To decide between use of guardrails and concrete barriers, AHMCT developed an interactive map combining all the distinguishing factors, specifically accident frequency, terrain, SLR, flood plains, and fire threat, most relevant to this decision-making process. The flood and SLR map tool includes the following info:

1. [Accident volume \(https://iswiirs.chp.ca.gov/Reports/jsp/index.jsp\)](https://iswiirs.chp.ca.gov/Reports/jsp/index.jsp)

The data were obtained for the period of 01/01/2022 to 12/31/2022. The data were requested and then provided by the CHP.

2. **Terrain**
<https://www.arcgis.com/home/item.html?id=28f49811a6974659988fd279de5ce39f>
The map was provided by ArcGIS Online.
3. **SLR**
[https://data.pointblue.org/apps/ocof2_flood_map/download_data#!?z=6&lat=37.2695121765137&lon=-119.3063926696775&grp=23&asc=1&abl=42&slr=0&sto=0&hol&nou=false&csl=0&cst=0&cho&cno=false&opc=\)](https://data.pointblue.org/apps/ocof2_flood_map/download_data#!?z=6&lat=37.2695121765137&lon=-119.3063926696775&grp=23&asc=1&abl=42&slr=0&sto=0&hol&nou=false&csl=0&cst=0&cho&cno=false&opc=))
The data were provided by Coastal Storm Modeling System. At the time of this memorandum, the data were last revised on 03/10/2021.
4. **Floodplains**
https://gis.water.ca.gov/arcgis/rest/services/Boundaries/bam_viewer/MapServer
The data were provided by the California Department of Water Resources.
5. **Fire threat (https://frap.fire.ca.gov/mapping/gis-data/)**
The data were provided by CAL FIRE.
6. **End-user safety**
Prefer metal guardrails. The end-user safety depends on the decision-making panel.
7. **Worker safety**
Prefer concrete barriers. The worker safety depends on the decision-making panel.

AHMCT also developed an instructional video for this tool and provided the video to Caltrans. A sample image from this tool for District 4 is shown in Figure 4.2.

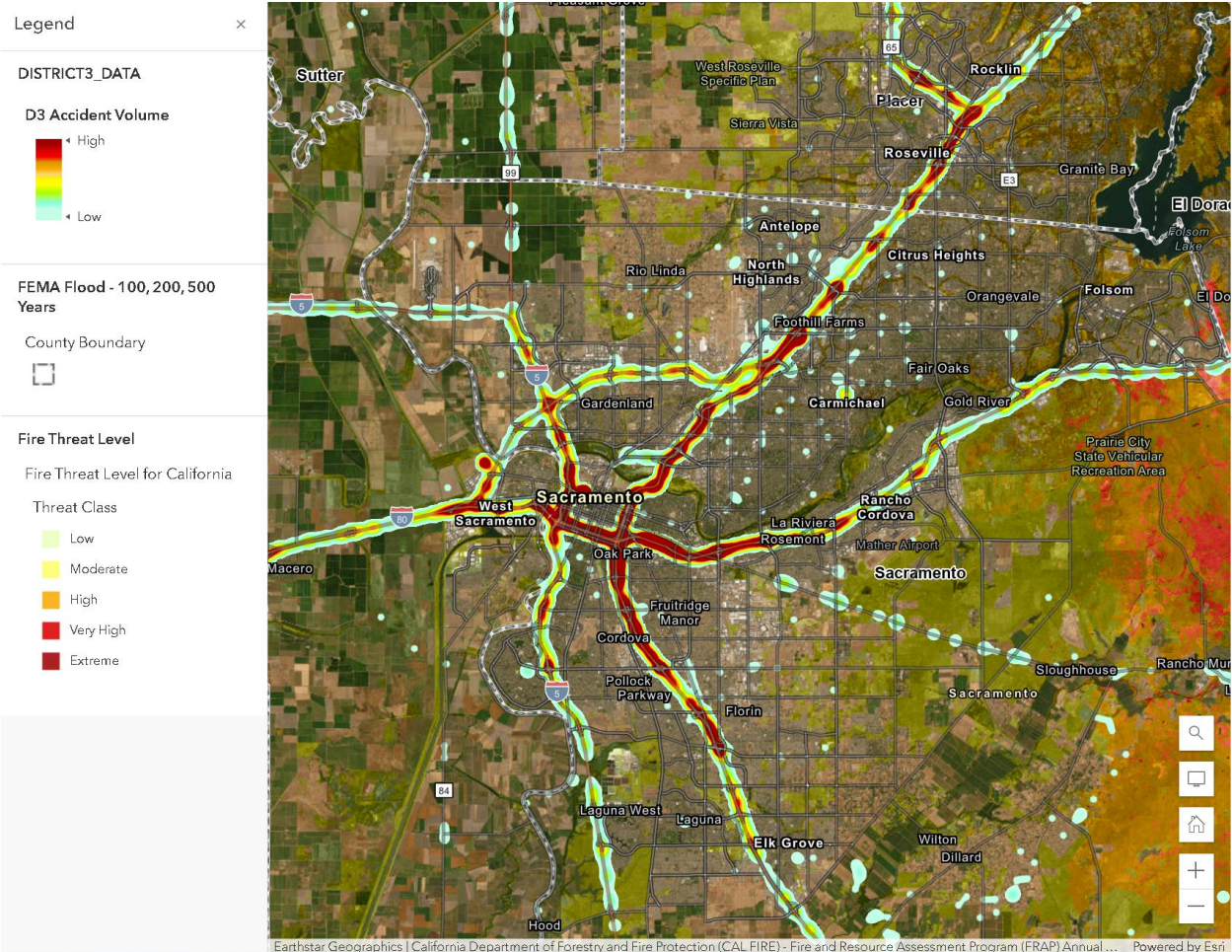


Figure 4.2: Interactive map showing the terrain, accident volume, and fire-prone areas in the Sacramento area. Data set credited to CHP-SWITRS, ArcGIS Online, OCOF, CDWR, and CAL FIRE.

The interactive map link, which combines factors 1 to 5, is available at [Interactive Map ConcreteBarriers MetalGuardrails Complete \(https://ucdavis.maps.arcgis.com/apps/mapviewer/index.html?webmap=6b32c588162f426a9966bff49e6c4cea\)](https://ucdavis.maps.arcgis.com/apps/mapviewer/index.html?webmap=6b32c588162f426a9966bff49e6c4cea)

Chapter 5:

Conclusions and Future Research

Key contributions of this research project included:

- Guidance documents for roadside maintenance, which will improve worker and traveler safety
- GIS-based decision support tools, which will aid the implementation of some of the guidance provided

The development of guidance documents and supporting tools will have a significant impact on improvements for roadside maintenance safety as the documents will promulgate best practices and support supervisors and workers in making improved decisions. The approach used in this project for development of guidance documents and supporting tools would be useful in future projects concerning necessary safety updates to other Caltrans responsibilities, including roadway maintenance, winter maintenance, highway operations, and construction. We recommend that a similar project be established to develop guidance documents and tools for one of these critical areas.

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**Appendix A:
Memos:
Develop Landscape Maintenance
Practices Based on Weather,
Conservation, and Climate Change**

Memo A.1: Higher wages and incentives to attract and retain experienced landscape maintenance workers

Memorandum 1

To: Caltrans Panel

From: AHMCT Research Center

Date: March 15th, 2023

Subject: UPDATED RECOMMENDATIONS FOR LANDSCAPE MAINTENANCE PRACTICES – HIGHER WAGES AND INCENTIVES TO ATTRACT AND RETAIN EXPERIENCED LANDSCAPE MAINTENANCE WORKERS

This memorandum outlines guidance regarding higher wages and incentives for Caltrans landscape maintenance workers. Based on Caltrans maintenance personnel and appropriate support materials, **higher wages and incentives** are necessary to enhance Caltrans performance as well as promote worker safety and working conditions in landscape practices. The following details elaborate statistical evidence and DOT-related documentation, with sources cited under Attachments.

Caltrans highway/landscape maintenance worker makes a monthly salary of \$3,830 to \$4,366, which is equivalent to \$45,960 to \$52,392 annually based on a Caltrans hiring post. According to [California Department of Housing and Community Development \(https://www.hcd.ca.gov/docs/grants-and-funding/inc2k22.pdf\)](https://www.hcd.ca.gov/docs/grants-and-funding/inc2k22.pdf) data [2], Caltrans' suggested income for maintenance worker in Districts 1, 2, 3, 6, 8, 9, and 10 is classified as low to median income for a household of one person; Caltrans' suggested income for maintenance worker in Districts 4, 5, 7, 11, and 12 is classified as **very low income** for a household of one person. In addition, Caltrans employees pay for health care premiums out of their paycheck. According to 2023 Health Plan premium data from San Luis Obispo County provided by Caltrans, an employee pays per month from \$72 to \$428 for self, from \$135 to \$847 for self and one dependent, and from \$194 to \$1,119 for self and two or more dependents [3]. Taking into consideration that the workers have family members, current wages and benefits are not sufficiently competitive to incentivize people to take on landscape maintenance duties which have the most exposure to traffic.

According to interviews conducted with Caltrans maintenance personnel on November and December of 2022, worker safety is at risk due to understaffing. For example, In District 4, a team of six crew members would have less than one year of experience. More specifically, two employees who have six months of experience would train the other four who only have two weeks of experience. As a result, there would be little to no guidance from senior/experienced employees in the field to double-check whether the knowledge that new employees taught one another is correct. **Lack of senior/experienced employees causes longer work duration which increases worker exposure to traffic.** In addition, at the time of the interview, there were only three landscape crews taking care of four to five counties in District 4. Two of those crews went an entire year with one employee and six months with 0 employees. One of those crews, the tree crew, had three employees for over two years, and one of

the employees is 70 years old. **Lack of staff causes longer work duration which again increases worker exposure to traffic.** According to the [National Work Zone Safety Information Clearinghouse \(https://workzonesafety.org/work-zone-data/worker-fatalities-and-injuries-at-road-construction-sites/\)](https://workzonesafety.org/work-zone-data/worker-fatalities-and-injuries-at-road-construction-sites/), 45.3% of worker fatalities are due to workers on foot being struck by vehicles, as shown in Figure A.1 [4]. The percentage of highway worker fatalities involving workers on foot being struck by a vehicle has an increasing trend from 2015 to 2020, with the exception of 2019, as shown in Figure A.2 [4]. **Maintenance duties should be carried out quickly and effectively to lower the probability of workers on foot being struck by vehicles.**

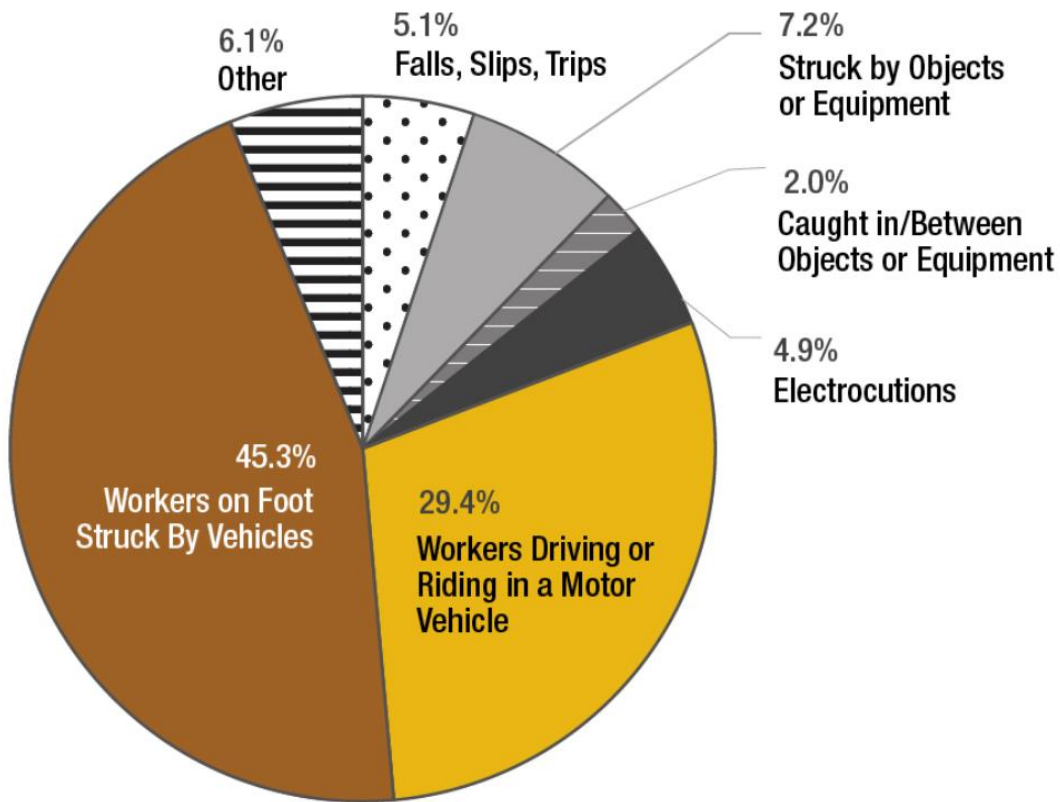


Figure A.1: Types of events resulting in highway worker fatalities at road construction sites, 2017-2019 average. Image courtesy of the National Work Zone Safety (extracted from [4]).

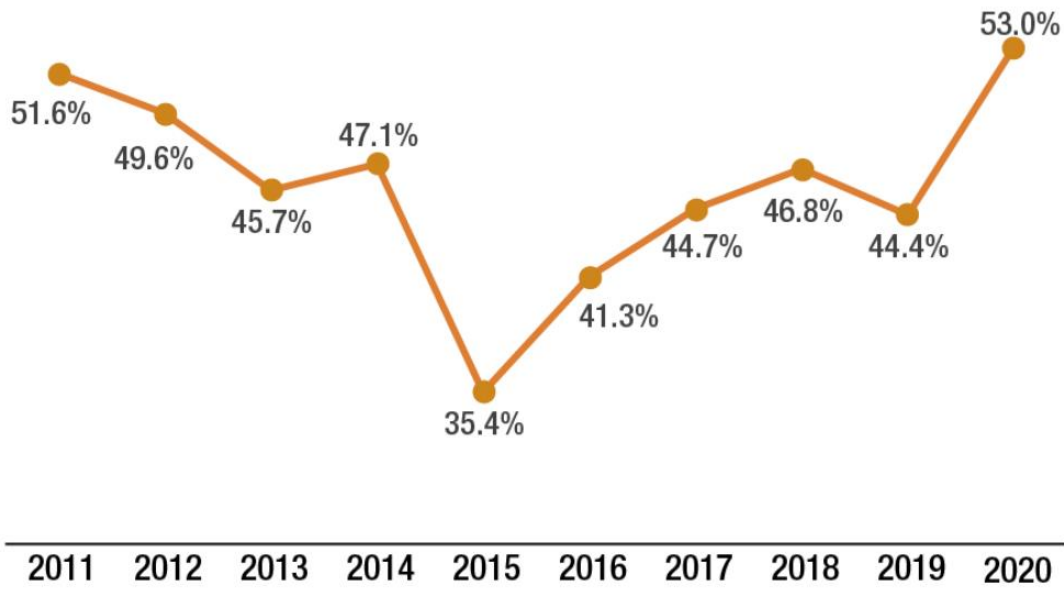


Figure A.2: Percent of highway worker fatalities involving workers on foot being struck by a vehicle. Image courtesy of the National Work Zone Safety (extracted from [4]).

To enhance worker safety and performance, **higher wages and incentives should be considered to attract and retain experienced employees.** In general, **having more staff is crucial to speed up work duration which decreases worker exposure to traffic.**

To ensure the safety of all Caltrans employees, please consider implementing this memorandum as appropriate. "Safety is Caltrans number one priority."

Memo A.2: Encampment removal in landscape maintenance practices

Memorandum 2

To: Caltrans Panel

From: AHMCT Research Center

Date: March 15th, 2023

Subject: UPDATED RECOMMENDATIONS FOR LANDSCAPE MAINTENANCE PRACTICES – ENCAMPMENT REMOVAL IN LANDSCAPE MAINTENANCE PRACTICES

This memorandum outlines guidance regarding encampment removal. It is essential to follow all existing guidance and policies when addressing encampments during landscape maintenance. The following reiterates the existing guidance and policies, and the importance of strictly following these. Sources cited appear under Attachments.

According to the U.S. Department of Housing and Urban Development, there has been an increasing trend regarding persons experiencing homelessness in California as shown in Figure A.3 [13]. The increase in encampments poses challenges for landscape maintenance. As a result, the Caltrans Division of Maintenance issued its encampment removal policy on October 10, 2022 [5]. This internal policy detailed a step-by-step approach for dealing with encampment removal according to the level of urgency. **All workers involved in the encampment removal process must be aware of the policy to ensure worker safety.**

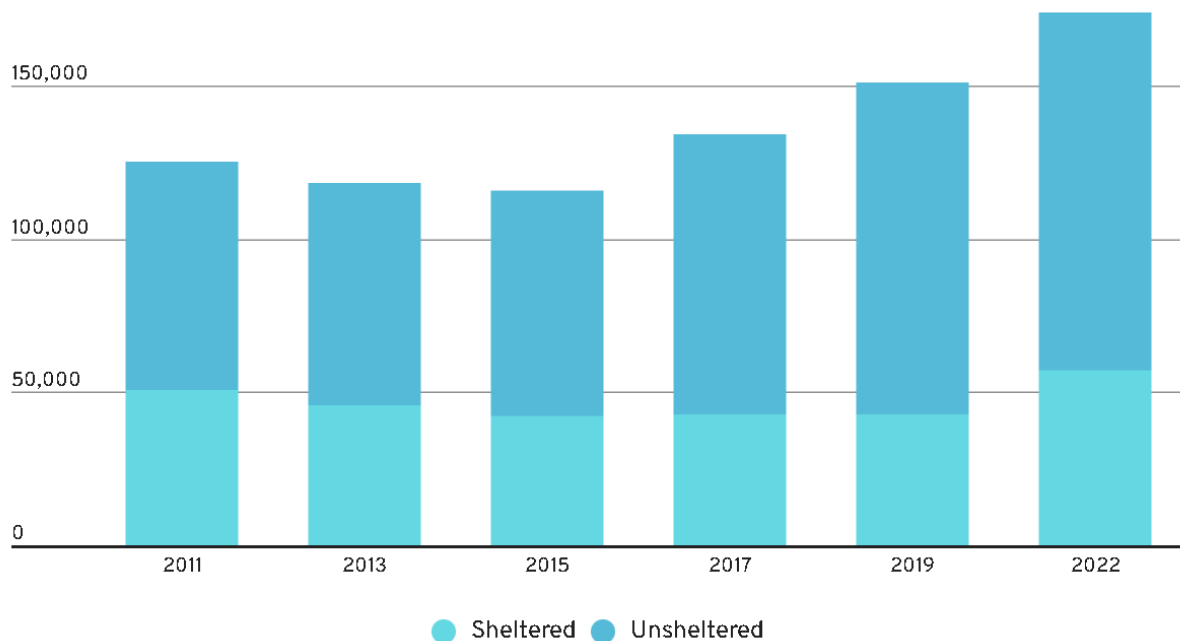


Figure A.3: Number of sheltered and unsheltered individuals experiencing homelessness in California. There has been an increasing trend for homelessness from 2015 to 2022. Image courtesy of U.S. Department of Housing and Urban Development, California Continuums of Care (extracted from [13]).

Memo A.3: Hardscape roundabouts and splitter islands

Memorandum 3

To: Caltrans Panel

From: AHMCT Research Center

Date: March 15th, 2023

Subject: UPDATED RECOMMENDATIONS FOR LANDSCAPE MAINTENANCE PRACTICES – HARDSCAPE ROUNDABOUTS AND SPLITTER ISLANDS

This memorandum is part of the updated recommendations for landscape maintenance practices. Based on Caltrans maintenance personnel and appropriate support materials, **considering hardscape at roundabouts and splitter islands** is necessary to promote worker safety and working conditions in landscape practices. The following details elaborate statistical evidences and DOT-related documentations to illustrate why this is necessary. Sources are cited under Attachments.

From 2011 to 2017, there were 39,373 work zone related traffic collisions in California. The total cost associated with these collisions was \$5.743 billion dollars, with **\$3.253 billion dollars being related to 288 fatal incidents**. The primary collision factors were unsafe speed, improper turning, and DUI. Collisions occurred primarily during daylight hours [6]. **The goal is to eliminate fatalities and serious injuries to the extent possible.**

At the time of this memorandum, the following information regarding the review of fatal and severe injury crashes at roundabouts is the most recent uploaded information on the US Department of Transportation – Federal Highway Administration website¹. Figure A.4, obtained from the Federal Highway Administration roundabouts research, shows that there has been an increasing trend in the number of fatal crashes at roundabouts per year starting in 2009, with the exception of 2013. Although the number of roundabouts in the United States has been increasing each year as shown in Figure A.5, there has been a general increasing trend in the rate of fatal crashes per number of roundabouts over the past five years as shown in Figure A.6 [7].

The Federal Highway Administration roundabouts research also stated **fatal crashes at roundabouts had higher percentages of crashes that occurred during dark light conditions and crashes that involved motorcycles, speeding, impaired driving, and fixed objects compared to fatal crashes at all intersections**. The percentage of fatal roundabout crashes for single-vehicle crashes is 83% (page 11-12, and 18 of [7]).

Of the 24 impaired driving crashes, 21 crashes were associated with alcohol impairment, with the remainder due to medical or drug impairment. Of the 26 speed-involved crashes, at least two involved vehicles exceeding 100 mph. Many of the motorcycle crashes at roundabouts involved loss of control and motorcycles striking curbs. **Many of the fixed object crashes involved vehicles**

¹ Website last updated on August 24, 2022.

striking the splitter and central islands of roundabouts, striking curbs, and sometimes other fixed objects such as sign posts, light poles, landscaping walls, boulders, and trees. **At least 35 of the 39 fixed object crashes involved vehicles striking a curb (page 12 of [7]).** The curb is where workers most likely parked to have landscape maintenance access. Based on the data, it is dangerous to have workers maintain landscape at roundabouts and splitter islands due to the high probability of a vehicle striking those areas. For example, Figures A.7 to A.9 demonstrates an accident associated with roundabout and splitter island provided by Caltrans maintenance personnel. Speeding caused this vehicle to run on the roundabout and break the splitter island. In addition, Table A.1 summarizes the characteristics of fatal crashes at roundabouts and compares them to the statistics of characteristics at all fatal crashes at intersections.

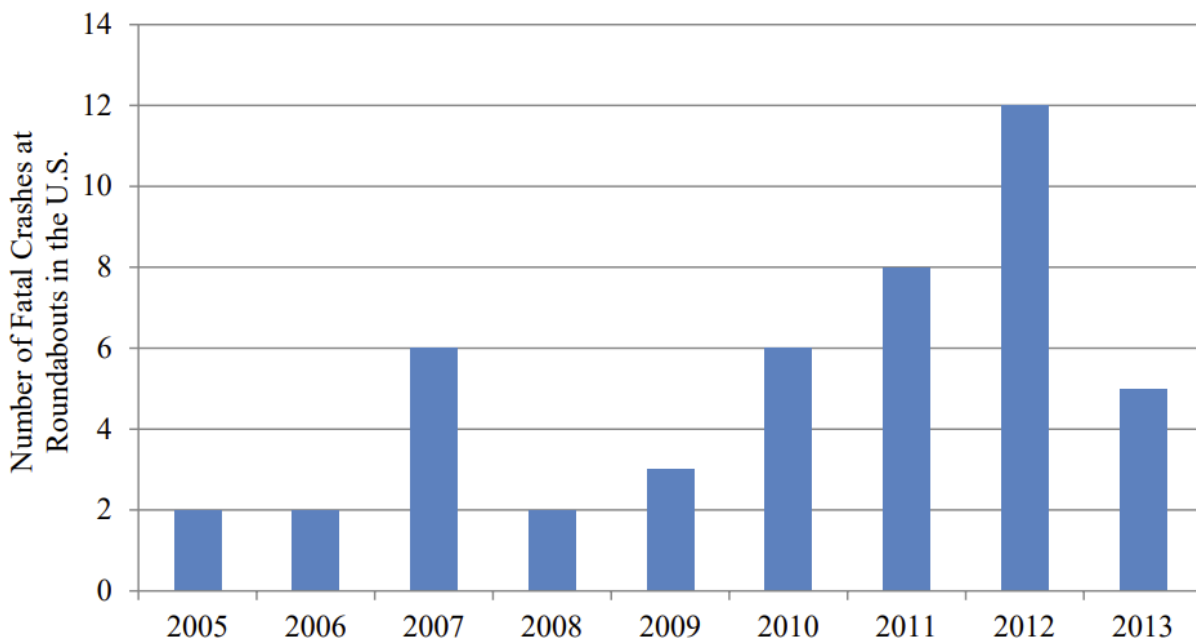


Figure A.4: Number of fatal crashes at roundabouts in the U.S. by year. Image courtesy of US DOT – Federal Highway Administration (extracted from page 10 of [7]).

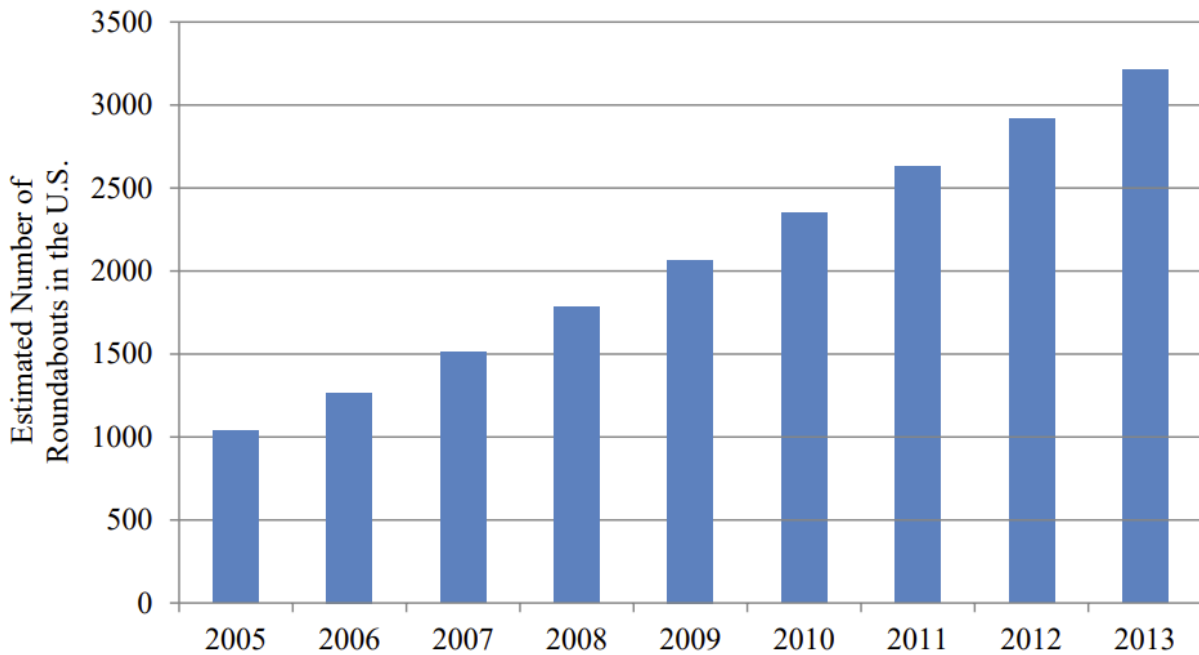


Figure A.5: Estimated number of roundabouts in the U.S. per year. Image courtesy of US DOT – Federal Highway Administration (extracted from page 11 of [7]).

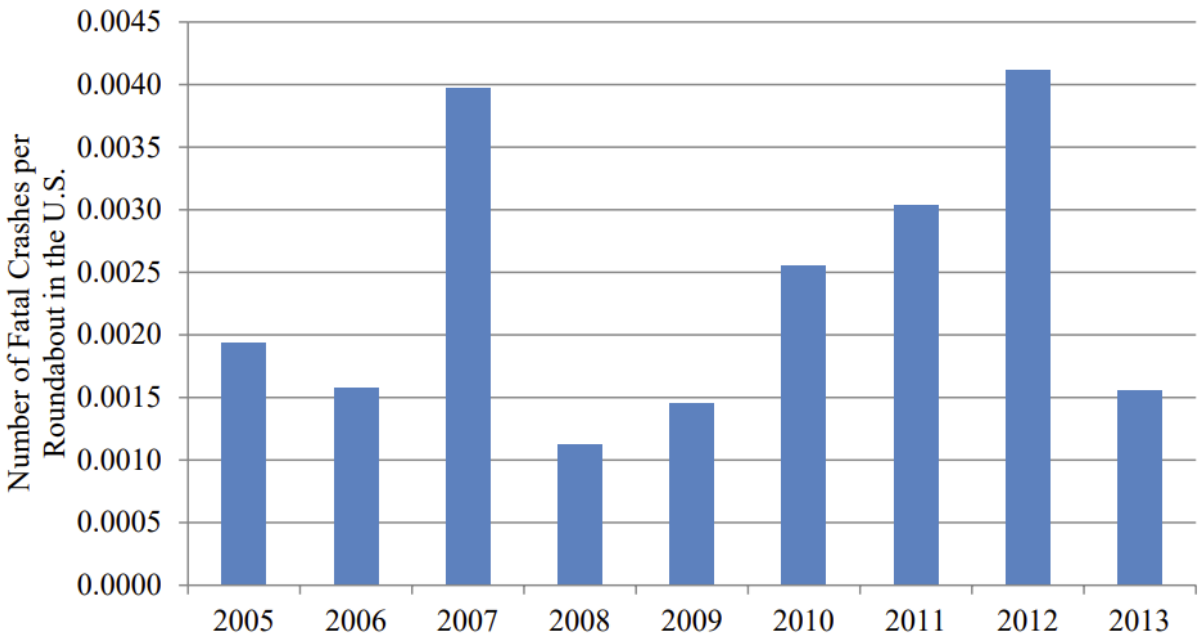


Figure A.6: Estimate number of fatal crashes per roundabout in the U.S. by year. Image courtesy of US DOT – Federal Highway Administration (extracted from page 11 of [7]).

Table A.1: Summary of characteristics of fatal crashes at roundabouts compared to fatal crashes at all intersections in the U.S. (page 12 of [7]).

Characteristics cited in Crash Reports	Number of Crashes with Characteristic (Percent of all fatal roundabout crashes)	Number of Crashes without Characteristic or where Information Not Reported (Percent of all fatal roundabout crashes)	Percent of Fatal Crashes at All Intersections in the U.S. with Characteristic
Multiple Vehicles Involved	8 (17)	38 (83)	67
Vehicle Struck Fixed Object(s)	39 (85)	7 (15)	11
Motorcycle Involved	21 (46)	25 (54)	23
Speed Cited	26 (57)	20 (43)	20
Impaired Driving Cited	24 (52)	22 (48)	21
Bicyclist Involved	1 (2)	45 (98)	4
Pedestrian Involved	0 (0)	46 (100)	16
Light Conditions (Daylight)	20 (43)	26 (57)	57
Multilane Roundabout	13 (28)	33 (72)	N/A



Figure A.7: Roundabout exposes maintenance workers to 360 degrees of upcoming traffic. Red arrows are tracks of vehicles that ended up in the center.

Black arrows indicate signs that have been hit by vehicles that ended up in the center. Image courtesy of Caltrans.



Figure A.8: A vehicle headed toward the roundabout, caused an accident despite the speed limitation. The splitter island was broken as the result. Image courtesy of Caltrans.

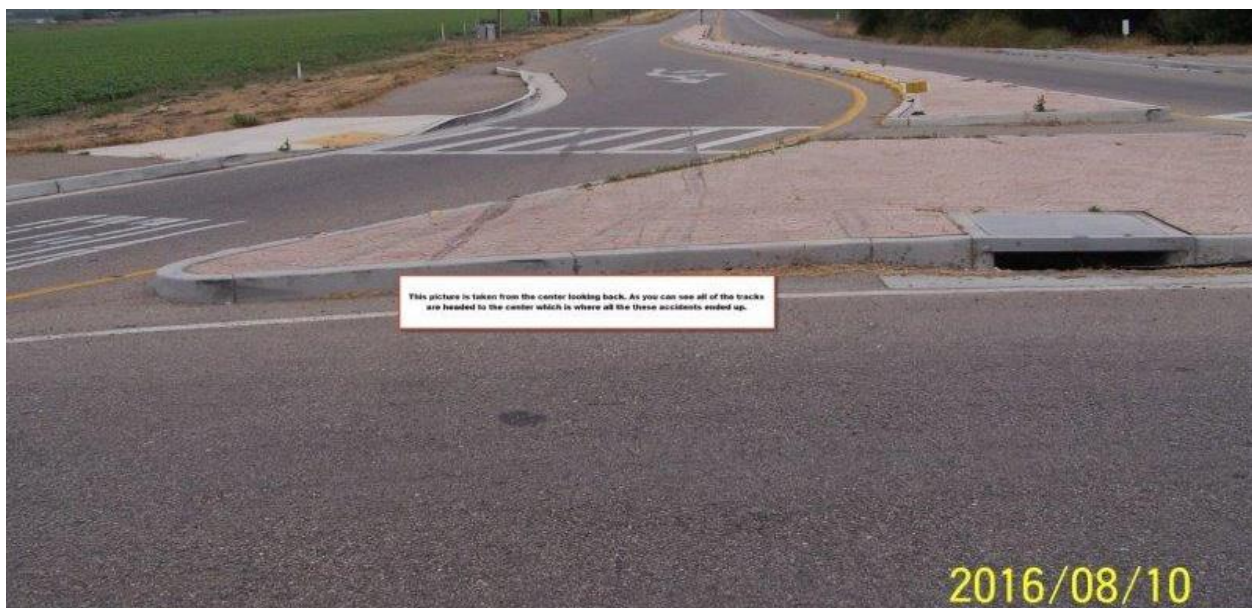


Figure A.9: This picture is taken from the roundabout center looking back. Tracks are headed to the center which is where all these accidents ended up. Skid marks indicate people speeding. If there was landscape in the splitter island, workers could have been hit during maintenance. Image courtesy of Caltrans.

To ensure the safety of all Caltrans employees, please consider implementing this memorandum as appropriate. "Safety is Caltrans number one priority".

Memo A.4: Maintenance manual update proposal

Memorandum 4

To: Caltrans Panel

From: AHMCT Research Center

Date: March 15th, 2023

Subject: UPDATED RECOMMENDATIONS FOR LANDSCAPE MAINTENANCE PRACTICES – MAINTENANCE MANUAL UPDATE PROPOSAL

This is a follow-up to the hardscape roundabouts and splitter islands memorandum. **The focus is to suggest a corresponding maintenance manual update.** Specifically, a new section regarding landscape control at roundabouts and splitter islands should be added. The suggested approach is as follows:

- Update should be made for: Maintenance Manual Chapter E – Landscaping.
- Suggested addition: Section E.13: Roundabouts and Splitter Islands Safety Recommendation.
- Suggested content: Roundabout is a place where three or more roads join and traffic must go around a circular area rather than straight across. Splitter island is a raised or painted traffic island that separates traffic in opposing directions of travel, typically used at roundabouts. Roundabouts and splitter islands shall be hardscaped when there are high safety concerns. Roundabouts shall have either a vertical element or landscaping utilized to prevent motorists from looking across the roundabout to see the traffic status.



Figure A.10: Example of a roundabout and splitter island incident. Image courtesy of Caltrans.

In Figure A.10, this particular roundabout does not reflect the design concept of slowing down traffic. Drivers misuse the roundabout since they can look across and assess upcoming traffic. Roundabouts and splitter islands should serve their purpose with the consideration of maintenance safety.

Appendix B:

Memo:

Develop Additional Training to Keep Up with Existing Policies (e.g. Drought Guidance Is Changing Landscaping)

Memo B.1: Develop Additional Training for Landscape Practices To Keep Up With Existing Policies

Memorandum 1

To: Caltrans Panel

From: AHMCT Research Center

Date: July 6th, 2023

Subject: UPDATED RECOMMENDATIONS – DEVELOP ADDITIONAL TRAINING FOR LANDSCAPE PRACTICES TO KEEP UP WITH EXISTING POLICIES

The focus of this memorandum is ensuring an adequate amount of training for landscaping practices. To further understand the efficiency of the Caltrans training system, a survey was distributed to maintenance personnel across Caltrans districts. The breakdown of responses was as follows:

1) Ensuring an adequate amount of landscaping trainings

Figure B.1 breaks down how maintenance personnel think about Caltrans current training frequency.

There is an adequate amount of landscaping trainings, and everyone knows their expected duties in the field

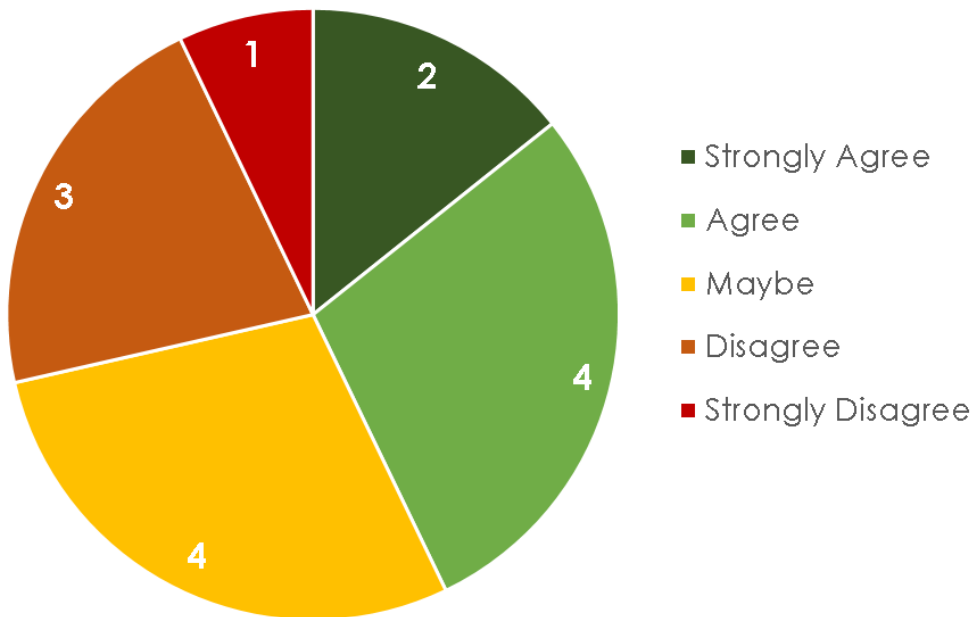


Figure B.1: Survey result on how maintenance personnel feel about the current landscape training frequency

From the survey responses, most participants prefer reinstating trainings every six months to a year. In addition, trainings that include demonstrations such as repair and troubleshooting should be in-person.

Table B.1: List of trainings and frequency recommendation

Training name	Frequency
Caltrans Policy on Safety	Annually
Desirable landscape plants vs. non-native invasive weed classes	6 months
Drought-tolerant planting trainings	Annually
Equipment training	6 months
Irrigation repairs (hands-on)	Annually
Irrigation programming and troubleshooting (hands-on)	Annually
Proper tree trimming training (hands-on)	Annually
Proper pruning practices training	Annually
Pesticide usage training	Annually
Pesticide safety training	Annually
Weed identification training	6 months

In addition, there were suggestions that a complete rundown training should take place before crew assignment, training frequency should be based on years of service, and training frequency should be based on each district's needs. The reasons for each suggested training structure are as follows:

Training before crew assignment

Instead of assigning a person to a crew immediately upon hiring, that person should go through two to three weeks of training (before crew assignment) so they know what duties are expected of them. Then, individuals can evaluate what duties they perform well and vice versa. The individuals can rank the duties from most to least familiar. The individuals will be assigned to duties they are familiar with first, and as they gain more experience, they can be trained on other duties. In addition to the comprehensive training, a questionnaire form can be sent out to the candidates to assess their level of experience in the field. Then, Caltrans can select individuals they think will be the best fit for the job.

Benefits: people will learn about expected duties and what duties will be the most compatible to them. In addition, Caltrans can separate qualified candidates from unqualified ones. For example, during the trainings, individuals might find out that the position is not a right fit for them. At the end of the trainings, the individuals can determine whether they want to commit to the job. People who do not like the job can be ruled out during/after the trainings instead of quitting during their first days on a field crew.

Training frequency based on years of service

The training frequency should be based on years of service. For instance, first-year employees should have monthly trainings; second-year employees

should have trainings every three months; employees with three or more years of service should have trainings every six months to a year.

Benefits: re-instating trainings will ensure duties are being performed correctly and safely, especially for employees in their first years of service.

Training based on Caltrans district and region

Landscaping maintenance approaches may vary in different districts and regions. Landscape work orders should be counted and categorized in Excel so the frequency of each duty can be determined. Then, training should be re-instated for the duties that are expected the most within that district/region.

Benefits: prioritize trainings that are the most applicable for a specific district/region.

Summary for this section: training should be re-instated based on the recommended frequency. Demonstrative training should be done in person to better convey hands-on tasks. In addition, there should be a structural reform for training. The first training structure is to train before crew assignment. This approach rules out candidates that might not be the right fit for the job at an early stage, which creates more qualified crews. The second training structure is to train based on the number of years of service. This approach builds a strong foundation for new employees as they progress in the position. The third training structure is to train based on Caltrans district and region. This approach prioritizes the most common landscape practices in a specific district/region.

2) Existing policies

Some participants mentioned that they do not know where to find existing landscape policies. Therefore, a list of landscape policies and resources are provided below. The list should be distributed among maintenance personnel.

- Link to planting and irrigation policies: [Sec 4-20 Landscape \(https://dot.ca.gov/-/media/dot-media/programs/construction/documents/policies-procedures-publications/construction-manual/sec4-20.pdf\)](https://dot.ca.gov/-/media/dot-media/programs/construction/documents/policies-procedures-publications/construction-manual/sec4-20.pdf) (July 2019)
- Link to landscape architecture policy: [Project Development Procedures Manual \(https://dot.ca.gov/-/media/dot-media/programs/design/documents/pdpm-chapter29-a11y.pdf\)](https://dot.ca.gov/-/media/dot-media/programs/design/documents/pdpm-chapter29-a11y.pdf) (May 2018)
 - Link to updated planting policy: [Highway Planting Policy 21-06-01 \(https://dot.ca.gov/-/media/dot-media/programs/design/documents/final-highway-planting-policy-21-06-01-v2_a11y.pdf\)](https://dot.ca.gov/-/media/dot-media/programs/design/documents/final-highway-planting-policy-21-06-01-v2_a11y.pdf) (June 2021)

- Link to [landscape architecture – roadsides \(https://dot.ca.gov/-/media/dot-media/programs/design/documents/chp0900-032020.pdf\)](https://dot.ca.gov/-/media/dot-media/programs/design/documents/chp0900-032020.pdf) (March 2020)
- Link to irrigation systems, plantings, tree and shrub maintenance, controlling pests and diseases, groundcover maintenance, lawn maintenance, lawn disease, washing plantings, pruning, weed control, and rodent control policies: [Landscape Chapter E \(https://dot.ca.gov/-/media/dot-media/programs/maintenance/documents/21-chpt-e-july-2014-a11y.pdf\)](https://dot.ca.gov/-/media/dot-media/programs/maintenance/documents/21-chpt-e-july-2014-a11y.pdf) (July 2014)
- Link to [water conservation resources \(https://dot.ca.gov/programs/design/lap-plan-or-design-a-state-hwy-project/lap-h-highway-planting/sus-d-water-conservation\)](https://dot.ca.gov/programs/design/lap-plan-or-design-a-state-hwy-project/lap-h-highway-planting/sus-d-water-conservation)
- Link to [irrigation, planting, and quantity checklists \(https://dot.ca.gov/-/media/dot-media/programs/design/documents/cadd/ppm-text-ch2-sect2-22-a11y.pdf\)](https://dot.ca.gov/-/media/dot-media/programs/design/documents/cadd/ppm-text-ch2-sect2-22-a11y.pdf) (May 2020)
- Link to [control of native \(non-landscaped\) vegetation and use of pesticides policies \(https://dot.ca.gov/-/media/dot-media/programs/maintenance/documents/17-chpt-c2-july-2014-rev-1-02-a11y.pdf\)](https://dot.ca.gov/-/media/dot-media/programs/maintenance/documents/17-chpt-c2-july-2014-rev-1-02-a11y.pdf) (July 2014)
- Link to [equipment policy \(https://dot.ca.gov/-/media/dot-media/programs/maintenance/documents/06-chpt-4-july-2014-a11y.pdf\)](https://dot.ca.gov/-/media/dot-media/programs/maintenance/documents/06-chpt-4-july-2014-a11y.pdf) (July 2014)
- Internal link to [water management \(https://maintenance.onramp.dot.ca.gov/ovwm/natural-resource-management-branch-0\)](https://maintenance.onramp.dot.ca.gov/ovwm/natural-resource-management-branch-0)
- Internal link to [vegetation management \(https://maintenance.onramp.dot.ca.gov/ovwm/natural-resource-management-branch-0\)](https://maintenance.onramp.dot.ca.gov/ovwm/natural-resource-management-branch-0)

In addition, QR codes should be utilized so that employees can quickly access the policy guidelines when necessary. The process of creating a QR code is straightforward and quick. The AHMCT team has sent QR code samples to the panel, and the decision of implementing QR code can be further discussed.

Maintenance workers also responded to whether the existing policies outline all the expectations for their duties.

Landscaping policies outline all the expectations I need to confidently perform my duty in the field

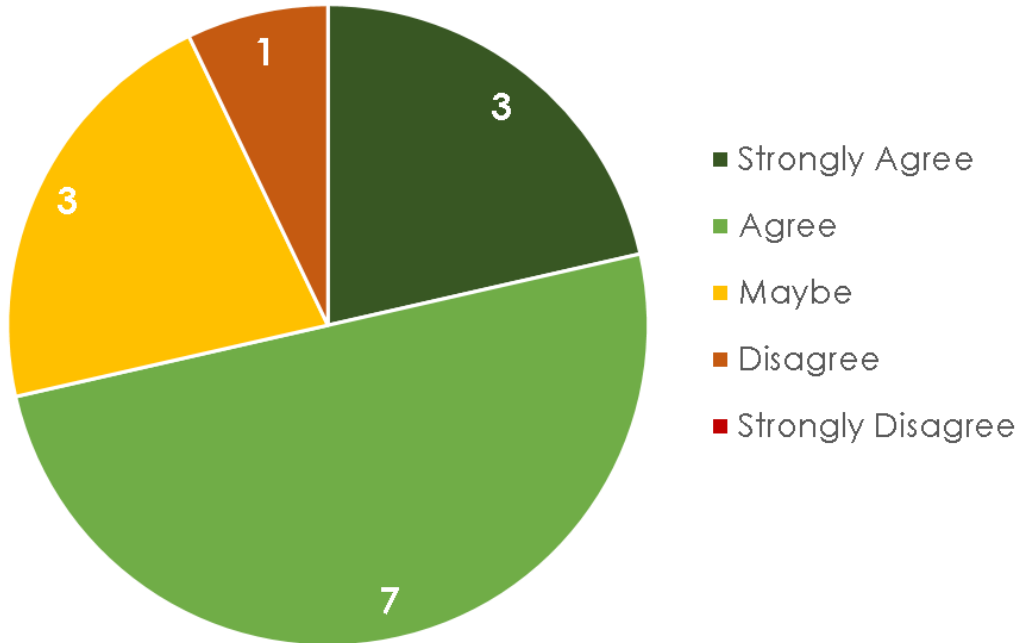


Figure B.2: Survey result on whether landscape policies are clear to the maintenance crews

From the survey responses, Caltrans landscaping policies are clear, yet outdated. The policies that need to be reviewed and updated are:

- Policies that associate with technologies.
- Policies that have not been updated for the past five years.
- Policies that have been affected by the current situations such as drought, water conservation, flooding, and an increase in unsheltered population.

Summary for this section: The list of policies and resources should be distributed among maintenance workers as some individuals are not aware of the policies in place. Policies that associate with technologies like equipment, policies that have not been updated for the last five years, and policies that are affected by current situations should be reviewed and updated. Moreover, implementing QR codes is highly recommended as workers can gain immediate access to policy guidelines through phones or tablets.

3) Maintenance crew adaptation in the field

The majority of maintenance personnel agree that they do not fully follow the landscape policies due to uncertainties in the field, as shown in Figure B.3

Landscaping policies, in some cases, cannot be fully followed. I sometimes have to use my best judgement to carry out my duty in the field.

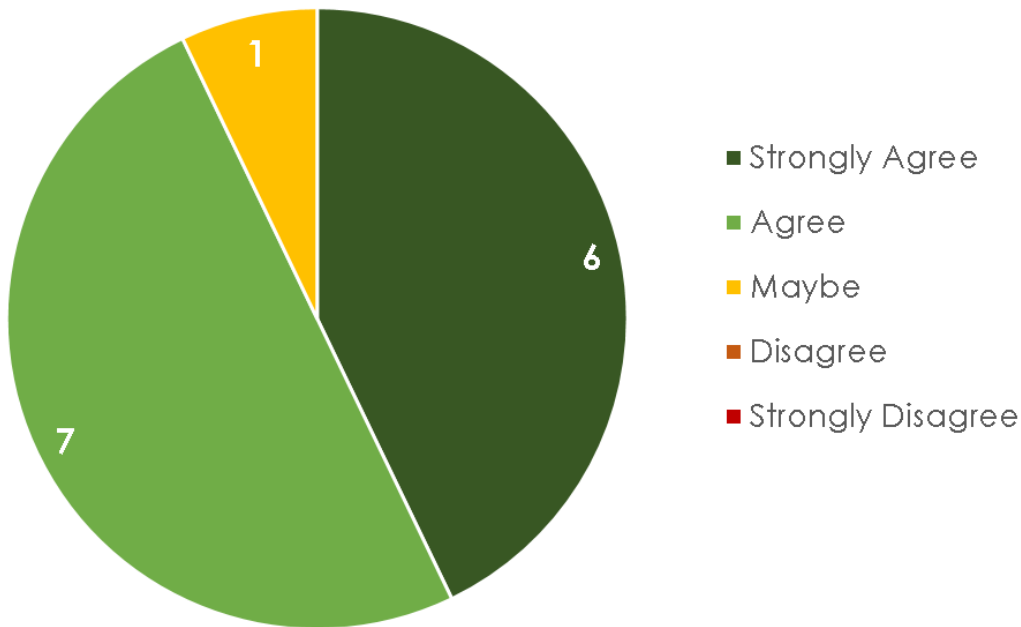


Figure B.3: Survey result on how closely people follow the landscape policies

The actions that the crews have taken when they cannot fully follow the policies include but not limited to:

- Some plants need to be removed and not-replanted due to an increase in unsheltered population.
- Water conservation can be mandatory during drought conditions which affects groundcover plants and shrubs. One team decided to deep water once a week instead of shallow watering three times a week.
- Vehicles sometimes cannot be fully parked on the shoulder due to flooding. A shoulder closure request has to be submitted by the Maintenance Supervisor so that landscape crews can carry out their duties.

There should be an advisory section in the policy where different scenarios are listed, and how other people have approached their tasks when unexpected circumstances arise.

For example, from [Section E.02.6 – Irrigating Plants in Chapter E](https://dot.ca.gov/-/media/dot-)
(<https://dot.ca.gov/-/media/dot->

[media/programs/maintenance/documents/21-chpt-e-july-2014-all.pdf](#)), the original content and the suggested additional content in **bold** is as follows:

“Young plants with fewer, shallower roots require more frequent watering than older, established plants.

As a rule, shallow-rooted plants, such as lawns and certain shrubs, require frequent watering for short periods of time. Deep-rooted plants, such as many trees and shrubs, require less frequent but deeper watering.

In case of drought, deep watering once a week is preferred

Areas watered by an automatic irrigation system should be programmed to minimize water runoff. Familiarization with the automatic irrigation system equipment is important to maximize the benefits of the system. Special attention should be given to watering areas under highway structures, which do not get naturally watered by seasonal rainfall.

Generally, drought tolerant native trees and shrubs require less water once they become established. Rainfall is all that some native plants require after the first few years of establishment. During the establishment period, native plants should be watered only as often as recommended.

Weak wood, excessive top growth, and/or destructive fungi may result from over-watering. Weak, succulent growth on plants also cannot withstand winter frosts.”

Summary for this section: landscape crews often adapt in the field. The adaptive actions the crews have come up with should be recorded. When an action is repetitive, it should be added to the policies. For example, in case of drought, deep watering once a week is preferred over shallow watering 3 times a week.

Overall recommendations:

- ❖ The majority of the maintenance personnel believes that it is necessary for training to be re-instated more frequently. Caltrans should consider a new training structure based on maintenance personnel suggestions. The suggested training structures are:
 - Training before crew assignment. This approach ensures the trainees are suitable for the tasks in the field before being assigned to a crew.
 - Training frequency based on years of service. This approach focuses on building a strong foundation for new employees. In the first year of service, employees should be trained monthly, then the training frequency can be decreased as the length of service increases.

- Training frequency based on region and district needs. This approach prioritizes trainings for frequently performed tasks in a region/district.
- ❖ Policies that have not been updated for 5+ years, policies that associate with technologies, and policies that have been affected by current situations should be reviewed and updated.
- ❖ QR codes should be considered to enhance policy accessibility.
- ❖ Maintenance crews often adapt in the field. The adaptive actions should be recorded and added to the policies when the actions are repetitive.

**Appendix C:
Memo:
Identify Locations of Guardrails with
Aesthetic Treatment, then Outline
Expectations for Replacement and
Installation**

Memorandum

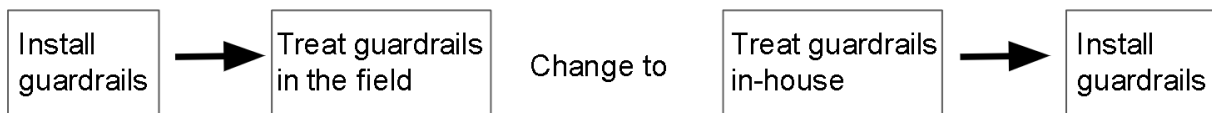
To: Caltrans Panel

From: AHMCT Research Center

Date: October 2nd, 2023

Subject: UPDATED RECOMMENDATIONS – EXPECTATIONS FOR TREATED GUARDRAILS REPLACEMENT AND INSTALLATION

The focus of this memorandum is to outline the locations that need treated guardrails and identify the expectations when applying the treatment in-house. To enhance worker safety, the operational process when applying treatment to guardrails should be changed as follows:



According to a survey conducted by the AHMCT team, treating guardrails in the field can take from 1 to 3 hours. In addition, there are environmental concerns from agencies when applying the guardrail treatment in the field. Treating guardrails in-house should be implemented across all Districts because the process **reduces worker exposure to traffic** as well as addresses the concerns from environmental agencies.

To enhance the effort of treating guardrails in-house, the AHMCT team mapped out the locations that need treated guardrails and the treatment application recommendations from the manufacturer in the following sections.

Treated Guardrail Locations

A survey was conducted among Caltrans maintenance personnel to determine the locations and the conditions of treated guardrails. Scenic areas like forests, national parks, and along the coast are common locations for treated guardrails. To pinpoint treated guardrail locations, the AHMCT team looked into scenic areas in each Caltrans district and considered the survey responses. The common treated guardrail locations are as follows:

- National and State forestry areas
- National and State parks
- Along the Coast of District 5

From the survey responses, [Natina \(https://www.natina.com/\)](https://www.natina.com/) is the treatment that the districts use. The locations for Natina-treated guardrails can be outlined, as shown in Figure C.1. **The data is incomplete** as the survey was not able to capture all locations. The known locations are:

- Forestry route of State Route (SR) 299 – Trinity County
- Forestry route of SR 3 – Trinity County
- Forestry route of SR 36 – Trinity County
- Forestry route of SR 96 – Siskiyou County

- Forestry route of US Highway 97 – Siskiyou County
- SR 1, post mile 20.61 through 37.45 - Santa Cruz County
- SR 9, post mile 0.05 through 6.46 – Santa Cruz County
- SR 190 – Inyo County
- SR 1, post mile 64.35 to 70.42 - Monterey County
- SR 1, post mile 32 through 74 - San Luis Obispo County
- US Highway 101, post mile 1.5 to 10.55 – Monterey and San Luis Obispo Counties
- SR 168, the route to Sierra National Forest, Fresno County
- Forestry and scenic route of US State 395 – Mono and Inyo Counties
- Forestry route of SR 2 – Los Angeles and San Bernardino Counties
- Forestry route of SR 138 – San Bernardino County
- Sutter Sierra Region – but the crew does not treat the guardrails. The treated guardrails are installed during construction. If the treated guardrails get damaged, it gets replaced with plain galvanized guardrails. Sierra County opposed to Natina treated guardrails because it does not match with exiting rail already installed on the corridor, which is not aesthetically pleasing. Since there is uncertainty about this location, the location is not outlined on the map (Figure C.1).



Figure C.1: Known locations of Natina-treated guardrails marked on the California map. Data credits to the USDA, US Forest Service, and Caltrans. Link to the map: [Treated Guardrails Map \(https://ucdavis.maps.arcgis.com/apps/mapviewer/index.html?webmap=36322e9796bf4e57a3efc82ee4331f7d\)](https://ucdavis.maps.arcgis.com/apps/mapviewer/index.html?webmap=36322e9796bf4e57a3efc82ee4331f7d)

The AHMCT team met with a Natina representative to outline the expectations of applying the Natina treatment in-house. In addition, the Natina representative recommended to contact him directly for any needs as he has already worked with Caltrans.

Natina main contact:

Kris Knights

kris@natina.com

(520) 483-0333

Natina Treatment Application Expectations [8]

- Material requirement: only apply treatment on **galvanized metal**, particularly steel
- Treatment cure time: **4 to 6 weeks**
- Ideal ambient conditions to apply the treatment: hot, sunny conditions with temperature **above 50°F** and **above freezing** at night. There should be no rain or snow within one week of application. There should be minimal to low wind.
- Materials needed to apply the treatment: Hudson-style pump sprayer, TP8001-VS Teejet VisiFlo Flat Spray Tip, or similar, with the spray nozzle adjusted to fine mist, and safety goggles
- Treatment application precautions when applying in-house:
 - Apply to the **non-road side first** (back of guardrail)
 - Only spray areas that you want to color
 - Move, cover, and mask off any materials and surfaces near spraying area
 - Using a pump sprayer, apply a light coat during the hottest part of the day to the entire target surface. Ensure that all angles of the target surface are covered
 - Minimize Natina running or pooling on the surface
 - Too much Natina applied may result in improper curing and mismatched final color
 - Allow Natina to **dry for 2 to 3 days after first coat**. Sweep guardrail lightly with a broom to remove dusty residue, and then apply a second coat over the top of the first coat
 - **Wait 5 to 7 days**, and then flip and repeat the same process on the road side (front) of the guardrail. For ideal color development, the surface should be dry for at least 5 to 7 days before second application.
 - Color development and transition will occur after application and will vary in colors while curing. Natina is **fully cured within 4 to 6 weeks**.
- Touch-ups and maintenance:
 - Natina can be applied using a clean rag or sponge to contain coverage area and help to avoid any accidental staining
 - Use a dabbing motion. **Do not wipe when applying**.

- Follow the prior application instructions, replacing spraying application with dabbing application
- Storage:
 - Allow Natina to fully cure prior to storage, 4 weeks at a minimum after second application
 - Natina-treated guardrail is best stored indoors or under a covered facility, with **as much ventilation as possible**
 - Plain galvanized, and Natina-applied material should **never be stacked with metal touching metal**. If you need to stack, place small strips of wood or dunnage between every piece of metal to ensure they are not touching and getting proper ventilation.

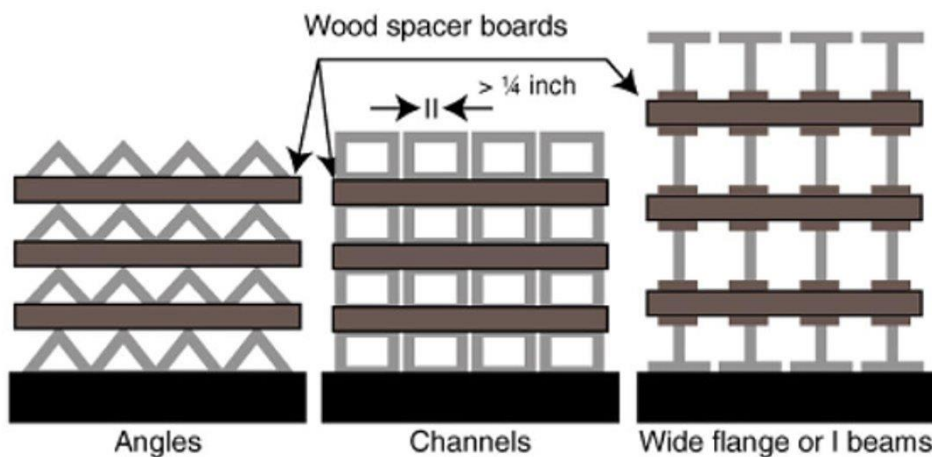


Image Source: Natina

Additional resources about Natina

- Natina Steel solution is sold in 2.5 gallon increments. When applied correctly, Natina Steel should yield approximately 100 linear feet per gallon.
- **Caltrans can choose to have Natina treat the guardrails in the Natina facility (in Arizona), and have the guardrails shipped back when ready.** For inquiry, please contact Kris Knights.

Appendix D:

Memo:

Convert Metal Beam Guardrail Locations into Concrete Barriers to Reduce Maintenance Effort and Staff Exposure (While Ensuring This Approach Is Safe for End Users)

Memo D.1: Converting Metal Beam Guardrail Into Concrete Barrier – Equipment Availability

Memorandum 1

To: Caltrans Panel

From: AHMCT Research Center

Date: July 6th, 2023

Subject: UPDATED RECOMMENDATIONS FOR CONVERTING METAL BEAM GUARDRAIL INTO CONCRETE BARRIER – EQUIPMENT AVAILABILITY

This memorandum outlines guidance regarding equipment availability to maintain concrete barriers and metal guardrails effectively. To further understand what maintenance workers need to perform their duties effectively, a survey was sent out to maintenance personnel across Caltrans districts.

Substantial equipment is not required to maintain concrete barriers because concrete barriers do not need regular maintenance. However, workers indicated that having metal forms, concrete mixers, loaders, and equipment to manage non-proprietary MASH²-rated barriers can improve maintenance effectiveness.

In contrast to concrete barriers, metal guardrails require regular maintenance. Workers indicated that having newer trucks and equipment can improve maintenance effectiveness. Specifically, hydraulic cutters, motorized augers, pounder trucks, and guardrail trucks are in high demand across districts.

Although staff know what equipment they need to enhance the effectiveness of their duties, they have trouble obtaining the equipment due to insufficient funds and existing policies. For instance, staff must exchange existing equipment to obtain new equipment, which creates a challenge as they have to familiarize themselves with the new equipment without having the previous equipment as a backup. In addition, there is a limit on the amount of vehicles and equipment that maintenance crews can possess. If staff want to request or retain a piece of equipment, they must show high utilization, which may not be sensible for specialized equipment that is used infrequently. The process to obtain equipment also takes a long time. **The procurement process demands significant information from staff who often cannot execute the equipment orders in a timely manner due to limited funds.**

This memo, which is based in part upon discussions with the Division of Equipment, recommends the following:

- *Refer to and understand the resources for writing an effective Budget Change Proposal (BCP).* The Division of Equipment personnel mentioned that including environmental impacts or concerns, where appropriate, should increase the success rate of BCP approval. Section 1 lists resources that can help with drafting a BCP.
- *Utilize federal resources.* In 2023, the Biden administration opened an application to grants that are worth millions of dollars. The goal is to

improve infrastructure to address climate change and more. The grant(s) can potentially help with the equipment funding as investing in equipment is crucial to keeping up with project demands. Information regarding grants and other federal resources is provided in Section 2.

- *Utilize Outlook Calendar.* A calendar that keeps track of equipment status and potential equipment sharing should be created and shared among the employees. The steps to do so are listed in Section 3.
- *Utilize existing data to justify the need of an equipment/vehicle.* An example is shown in Section 4. The AHMCT research team can assist with this process as needed.
- *Demonstrate consistency with and the potential to further goals contained in the [Caltrans 2020-2024 Strategic Plan \(https://dot.ca.gov/-/media/dot-media/programs/risk-strategic-management/documents/sp-2020-16p-web-a11y.pdf\)](https://dot.ca.gov/-/media/dot-media/programs/risk-strategic-management/documents/sp-2020-16p-web-a11y.pdf) (Safety First, Cultivate Excellence, Enhance and Connect the Multimodal Transportation Network, Strengthen Stewardship and Drive Efficiency, Lead Climate Action, Advance Equity and Livability in all Communities)*

1. Make Budget Change Proposal (BCP) more compelling by incorporating environmental reasons

Existing resource on how to write a compelling BCP: [How to Write an Effective Budget Change Proposal \(BCP\) | Department of Finance \(https://dof.ca.gov/budget/how-to-write-an-effective-budget-change-proposal-bcprev-03-00/\)](https://dof.ca.gov/budget/how-to-write-an-effective-budget-change-proposal-bcprev-03-00/)

When appropriate, environmental impacts are good considerations in BCPs. One of the justification criteria is “What statements/information from authorities and clients support the request?” Some examples are listed below.

According to the United States Environmental Protection Agency (EPA), the majority of U.S. greenhouse gas emissions come from the transportation sector, as shown in Figure D.1.

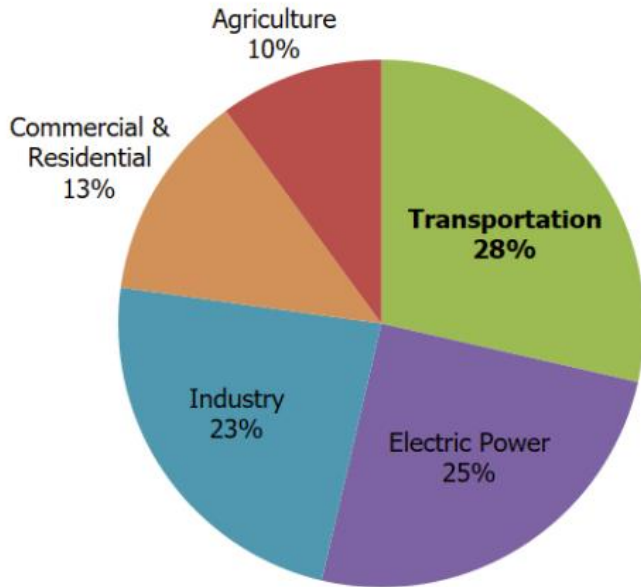


Figure D.1: Total U.S. greenhouse gas emissions by economic sector in 2021. The total emissions in 2021 was 6,340 million metric tons of CO₂ equivalent. Percentages may not add up to 100% due to independent rounding. Land use, land-use change, and forestry in the U.S. is a net sink and offsets 12% of these greenhouse gas emissions, and this net sink is not shown in the diagram. Content courtesy of the EPA [14].

The EPA recommendations to reduce greenhouse emissions in the transportation sector are provided in Table D.1.

Alternative fuel sources and advanced technologies will require significant resources. **Caltrans should incorporate the EPA's recommendation into BCPs to justify the budget.**

In addition to the EPA's recommendation, environmental impacts should be included as they will be a part of "Buy Clean Initiative", a [Bipartisan Infrastructure Law](https://www.transportation.gov/sites/dot.gov/files/2022-09/Signed_Buy_Clean_Policy_Statement.pdf) (https://www.transportation.gov/sites/dot.gov/files/2022-09/Signed_Buy_Clean_Policy_Statement.pdf) initiated by President Biden. Specifically, the plan [9] is as follows:

- A. There will be reports used to communicate the environmental impacts of construction materials. These reports will help in investing in the production of clean and reliable materials.
- B. Based on the reports, a Buy Clean policy will be developed. Materials purchased with taxpayer dollars are serving the best interests of the American people while also supporting job creation in sustainable industry.
- C. Research will continue to drive down the emissions that come from the materials and processes used in transportation infrastructure.

Table D.1: Examples of greenhouse emission reduction opportunities. Content courtesy of the EPA [14].

Type	How Emissions Are Reduced	Examples
Fuel Switching	Alternative sources can include biofuels; hydrogen; electricity from renewable sources, such as wind and solar; or fossil fuels that are less CO ₂ -intensive than the fuels that they replace. Learn more about Green Vehicles and Alternative and Renewable Fuels (https://www.epa.gov/renewable-fuel-standard-program/alternative-fuels) .	<ul style="list-style-type: none"> Using electric, plug-in hybrid electric, or hydrogen fuel cell vehicles. Using renewable fuels such as low-carbon biofuels.
Improving Fuel Efficiency with Advanced Design, Materials, and Technologies	Using advanced technologies, design, and materials to develop more fuel-efficient vehicles. Learn about the EPA's vehicle greenhouse gas rules (https://www.epa.gov/regulations-emissions-vehicles-and-engines/regulations-greenhouse-gas-ghg-emissions) .	<ul style="list-style-type: none"> Developing advanced vehicle technologies such as hybrid and electric vehicles that can capture energy via regenerative braking and return it to the battery. Reducing the weight of materials used to build vehicles. Reducing the aerodynamic drag of vehicles through improved shape design.

Moving toward the Buy Clean Initiative policy will require significant resources. Therefore, **Caltrans should incorporate this policy (and other environmental policies) into BCPs to justify the budget.**

2. Utilize Federal resources

- Applying for Biden-Harris Grant Funding:
It is highly recommended that Caltrans apply for a share of the \$848 million in competitive grant funding offered by the Biden-Harris administration. The projects should demonstrate protection for community transportation systems from natural hazards and climate change impacts.

Grant details (application due August 18, 2023) can be found at: [Biden-Harris Administration Opens Applications for \\$848 Million in Competitive Grant Funding to Make Roads, Bridges, Transit, Rail, and Ports More](#)

[Resilient to Climate Change | US Department of Transportation \(https://www.transportation.gov/briefing-room/biden-harris-administration-opens-applications-848-million-competitive-grant-funding\)](https://www.transportation.gov/briefing-room/biden-harris-administration-opens-applications-848-million-competitive-grant-funding)

Grant application: [View Opportunity | GRANTS.GOV](https://www.grants.gov/web/grants/view-opportunity.html?oppld=347585)

(<https://www.grants.gov/web/grants/view-opportunity.html?oppld=347585>)

Link to other grants (see the announcement section): [DOT Climate Change Center | US Department of Transportation \(https://www.transportation.gov/priorities/climate-and-sustainability/dot-climate-change-center\)](https://www.transportation.gov/priorities/climate-and-sustainability/dot-climate-change-center)

- Considering the Transportation Resilience 2023 Conference: It is highly recommended that Caltrans participate in the conference to further study how other DOTs and agencies tackle similar challenges.

Conference details: [Transportation Research Board - Transportation Resilience 2023: International Conference on Extreme Weather and Climate Change Challenges \(https://trb.secure-platform.com/a/page/TransportationResilience\)](https://trb.secure-platform.com/a/page/TransportationResilience)

These resources can potentially help to obtain funding for new and updated equipment. To achieve/maintain sustainable projects, the equipment used should be up to standard. **In other words, investing in equipment is crucial to keep up with the demands of a sustainable project.**

According to the [Federal Transit Administration \(FTA\)](https://www.transit.dot.gov/regulations-and-programs/environmental-programs/transit-and-sustainability)

(<https://www.transit.dot.gov/regulations-and-programs/environmental-programs/transit-and-sustainability>) [15], examples to achieve a sustainable project, quoted directly from FTA, are:

- Helping metropolitan areas meet national ambient air quality standards (NAAQS) by reducing overall vehicle emissions and the pollutants that create smog
- Facilitating compact development, conserving land and decreasing travel demand
- Reducing the need for constructing more roads, meaning less runoff from impervious surfaces that may degrade water resources
- Reducing fuel use and greenhouse gas emissions
- Providing critical services that connect all members of the community with jobs, healthcare, school, and other opportunities

The U.S currently has many goals regarding working toward sustainability. **Adding sustainable goals aligns with BCPs justification criteria.** Additional resources include:

U.S. Department of Transportation Climate Change Center: [DOT Climate Change Center \(https://www.transportation.gov/priorities/climate-and-sustainability/dot-climate-change-center\)](https://www.transportation.gov/priorities/climate-and-sustainability/dot-climate-change-center)

U.S. Environmental Protection Agency: [Sources of Greenhouse Gas Emissions \(https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions\)](https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions)
Caltrans 2020-2024 Strategic Plan (<https://dot.ca.gov/-/media/dot-media/programs/risk-strategic-management/documents/sp-2020-16p-web-a11y.pdf>)

3. Calendar system

It is recommended that Caltrans implement and use a shared Outlook Calendar to keep track of equipment status and sharing. The steps to set up the calendar system are:

- One email is created. The sole purpose of this email is to keep track with the equipment status.
- This calendar is then shared to employees via their Outlook emails. The employees can view (or edit if permitted) the calendar.
- The calendar can be accessed through phones and tablets.
- Figures D.2, D.3, and D.4 demonstrate the setup process.

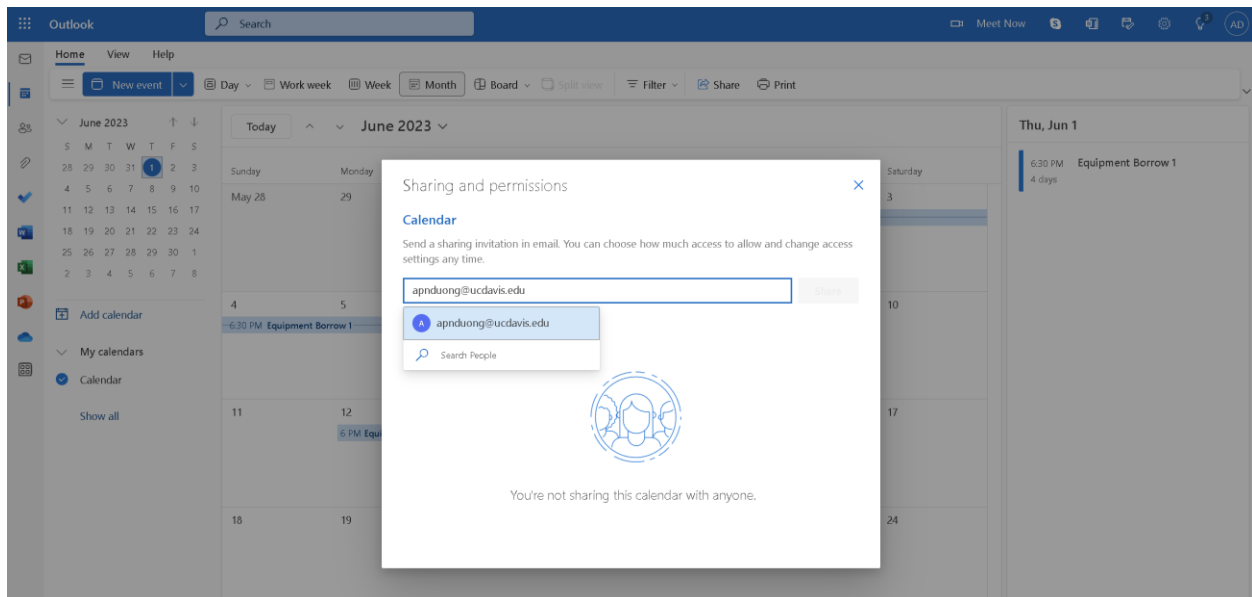


Figure D.2: Sharing the “Equipment Status” to Caltrans staff via emails

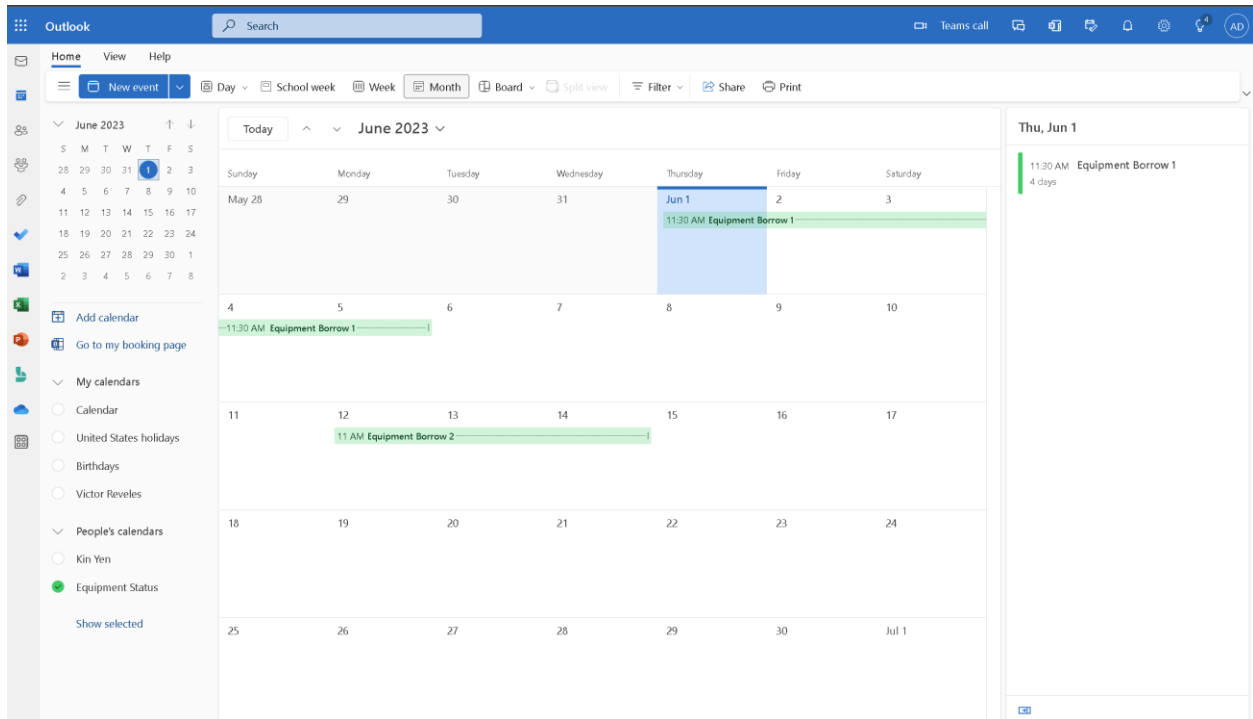


Figure D.3: The “Equipment Status” can be viewed (or hidden) on one’s calendar. This figure shows the website interface.

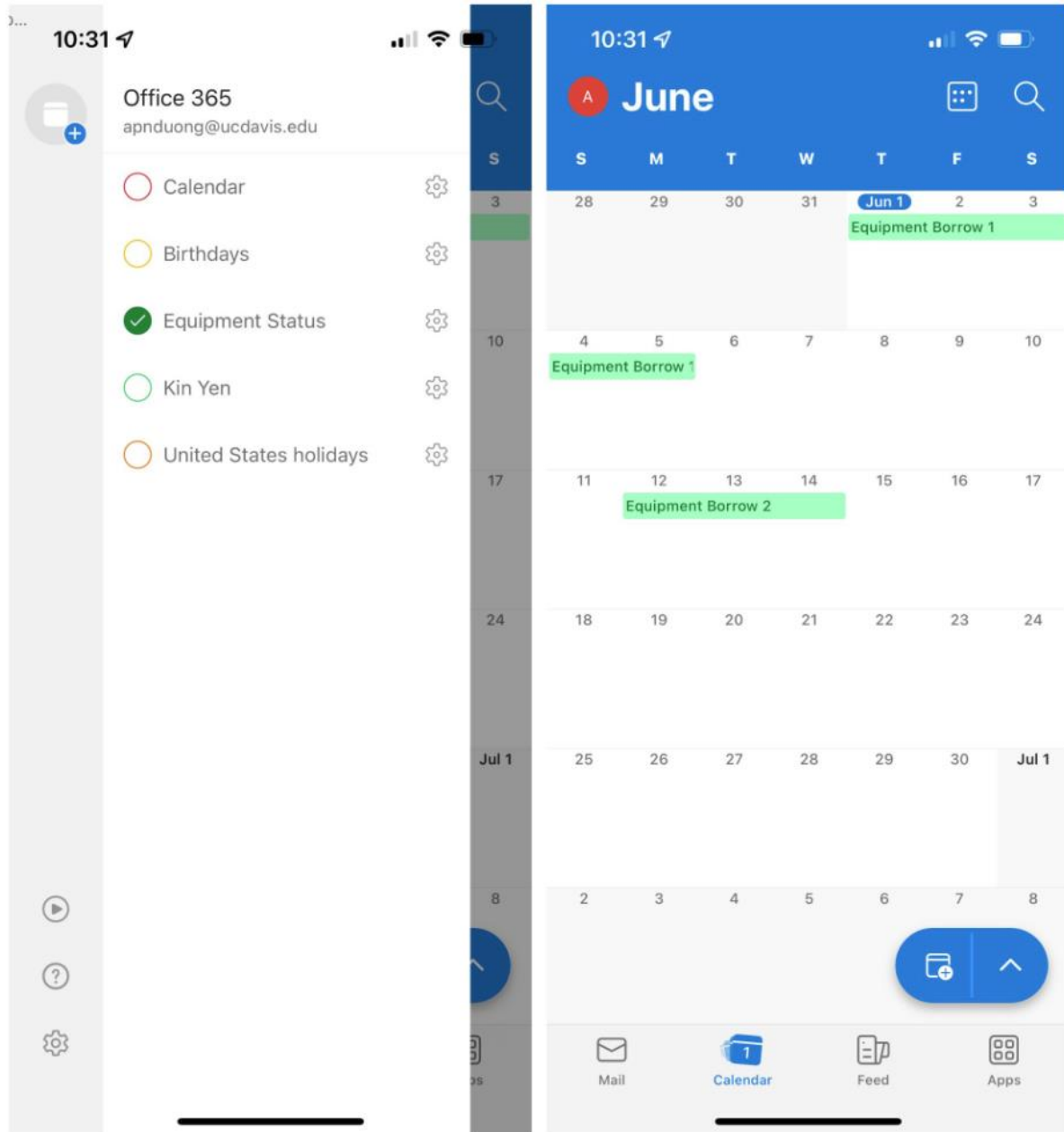


Figure D.4: The “Equipment Status” can be viewed (or hidden) on one’s calendar. This figure shows the phone interface.

Advantages of the calendar system:

- Employees know who possesses the equipment and where, thus arrangements can be made.
- Caltrans already uses Microsoft Outlook service; therefore, the calendar system is free of additional charge or license. The process may be familiar for most Caltrans staff.
- The equipment usage frequency can be tracked as the calendar saves past activities. This can help with documenting utilization.

4. Utilize existing data to justify the need of an equipment/vehicle

To show high equipment utilization, it is recommended that staff use accident data from the [Statewide Integrated Traffic Records System \(SWITRS\)](https://iswitr.chp.ca.gov/Reports/jsp/userLogin.do) (<https://iswitr.chp.ca.gov/Reports/jsp/userLogin.do>) to justify equipment and hardware parts usage. An account is required to request reports, but the resources are free and clearly categorized for user needs.

The screenshot displays the SWITRS portal interface. At the top left, there is a logo for the California Highway Patrol with the text "WELCOME TO THE CALIFORNIA HIGHWAY PATROL". A navigation menu on the left includes "Home", "I-SWITRS", "California Highway Patrol Home Page", "SWITRS Reports", "OTS Reports", "Raw Data", "Request History", "User Profile", "Report Samples", and "Logout". The main content area is titled "SWITRS Reports - Criteria Selection" and contains a form with the following sections:

- FILTER RECORDS BY:** Includes radio buttons for "JURISDICTION" (selected), "LOCATION", and "COUNTY". Each has a dropdown menu with "ALL" selected.
- REPORTING PERIOD START (MM/DD/YYYY):** An empty text input field.
- REPORTING PERIOD END (MM/DD/YYYY):** An empty text input field.
- Reports will include all reported collisions on private property and on/associated with State Highways.**
- INCLUDE COLLISIONS THAT OCCURRED ON:** Includes checkboxes for "PRIVATE PROPERTY (Use for Univ/State Park Dist/Airport/Harbor)" and "STATE HIGHWAY (interstate, U.S., state route)", both of which are checked.
- REPORT TYPE:** A dropdown menu set to "Collisions By Hour of Day by Day of Week".
- Buttons:** "GENERATE REPORT" and "CLEAR FORM".

At the bottom of the page, there is a footer with links for "Back to Top", "About", "Contact Us", "FAQ", and "Get Adobe Reader", along with "Conditions of Use" and "Privacy Policy" links, and a copyright notice for 2019 State of California.

Figure D.5: SWITRS portal to request accident data

Memo D.2: Converting Metal Beam Guardrail Into Concrete Barrier – Based On Flood Maps, Fire Map, Terrain Map, Traffic Volume, And Literature Review.

Memorandum 2

To: Caltrans Panel

From: AHMCT Research Center

Date: July 5th, 2023

Subject: UPDATED RECOMMENDATIONS FOR CONVERTING METAL BEAM GUARDRAIL INTO CONCRETE BARRIER – BASED ON FLOOD MAPS, FIRE MAP, TERRAIN MAP, TRAFFIC VOLUME, and LITERATURE REVIEW.

This memorandum provides guidance in choosing between concrete barriers and metal guardrails while ensuring the approach is more forgiving toward end users. To determine whether concrete barriers or metal guardrails are preferable in a specific location, the key factors to be considered are: fire threat level, floodplains, sea level rise (SLR), terrain, and accident volume. For instance, a high-accident-volume segment indicates concrete barriers to minimize maintenance. These determining factors are summarized in Table 1, wherein the first row presents individual factors, and the second row illustrates the preferred barrier for that factor. The challenge is balancing between worker safety and end-user safety. Although metal guardrails require more maintenance, they are much more forgiving towards end users compared to concrete barriers.

Based on literature review and national data, the following approaches can potentially aid Caltrans in choosing the most compatible barrier option:

- An interactive map that highlights fire threat level, flood depth, terrain, SLR, and accident volume in California.
- Utilizing existing resources from Caltrans and other DOTs and government agencies.

Table 1: Preferred barriers for each factor

Factor:	Accident	Terrain	SLR	Floodplains	Fire threat	End-user safety	Worker safety
Preferred Barrier:	Concrete barriers	Depends on elevation (ex. ground conditions)	Metal guardrails	Metal guardrails	Metal guardrails	Metal guardrails	Concrete barriers

To interpret Table 1 visually, an interactive map combining all the factors was created. Data information for each factor is as follows:

8. **Accident volume:** the data was from the period of 01/01/2022 to 12/31/2022. The data was requested and then provided by the California Highway Patrol. The link to the data request form is [CHP-SWITRS \(https://iswitr.chp.ca.gov/Reports/jsp/index.jsp\)](https://iswitr.chp.ca.gov/Reports/jsp/index.jsp).

9. **Terrain:** the map was provided by ArcGIS Online. The link to the layer is [Imagery Hybrid – Overview \(https://www.arcgis.com/home/item.html?id=28f49811a6974659988fd279de5ce39f\)](https://www.arcgis.com/home/item.html?id=28f49811a6974659988fd279de5ce39f).
10. **Sea level rise (SLR):** the data was provided by Coastal Storm Modeling System. At the time of this memorandum, the data was last revised on 03/10/2021. The link to the data is [OCOF - Flood Map \(https://data.pointblue.org/apps/ocof2_flood_map/download_data#!?z=6&lat=37.2695121765137&lon=-119.3063926696775&grp=23&asc=1&abl=42&slr=0&sto=0&hol&nou=false&csl=0&cst=0&cho&cno=false&opc=\)](https://data.pointblue.org/apps/ocof2_flood_map/download_data#!?z=6&lat=37.2695121765137&lon=-119.3063926696775&grp=23&asc=1&abl=42&slr=0&sto=0&hol&nou=false&csl=0&cst=0&cho&cno=false&opc=)).
11. **Floodplains:** the data was provided by the California Department of Water Resources. The link to the data is [Boundaries/bam_viewer \(MapServer\) \(https://gis.water.ca.gov/arcgis/rest/services/Boundaries/bam_viewer/MapServer\)](https://gis.water.ca.gov/arcgis/rest/services/Boundaries/bam_viewer/MapServer).
12. **Fire threat:** the data was provided by CAL FIRE. The link to the data is [GIS Data \(https://frap.fire.ca.gov/mapping/gis-data/\)](https://frap.fire.ca.gov/mapping/gis-data/).
13. **End-user safety:** prefer metal guardrails. The end-user safety depends on the decision-making panel.
14. **Worker safety:** prefer concrete barriers. The worker safety depends on the decision-making panel.

The interactive map is illustrated in Figure 1. The interactive map link which combines factors 1 to 5 is available at [Interactive Map ConcreteBarriers MetalGuardrails Complete \(https://ucdavis.maps.arcgis.com/apps/mapviewer/index.html?webmap=6b32c588162f426a9966bff49e6c4cea\)](https://ucdavis.maps.arcgis.com/apps/mapviewer/index.html?webmap=6b32c588162f426a9966bff49e6c4cea)

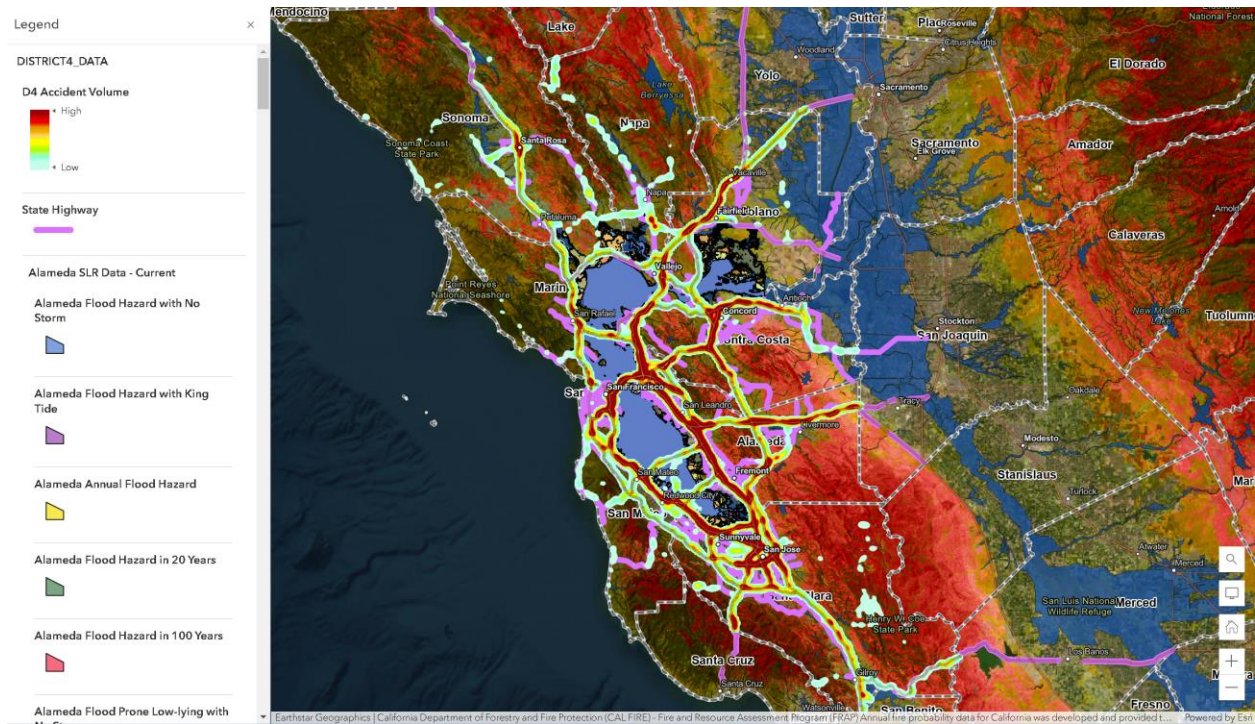


Figure 1: Interactive map showing the terrain, accident volume, flood prone areas, areas that will be affected by SLR, and fire prone areas in District 4.

Other factors to consider when choosing an appropriate barrier include: deflection of the system when impacted, the system's cost, and the types of vehicles the system can be expected to contain and redirect. These factors are summarized in Table 2, source Iowa DOT [10].

Table 2: Barrier characteristics (from page 1 of [10])

Barrier system	Deflection	Initial Cost	Maintenance Cost	Passed Crash Tests with the following
Steel Beam Guardrails	4 feet	Low	Medium	Cars, pickups
Permanent Concrete Barriers	0 feet	High	Low	Cars, pickups, single unit trucks, semi-trucks

To interpret Table 2, each factor can be analyzed using existing resources. Information for each factor is as follows:

4. **Deflection:** if the space between the lane and the median is limited, a barrier with minimal deflection is preferable. This factor is based on engineering judgement.
5. **Initial cost and maintenance cost:** there is on-going research conducted by another AHMCT group. This research will yield in-depth information

about the cost-benefits in choosing metal guardrails versus concrete barriers. Thus, this topic will not be discussed in this memorandum.

6. **Type of vehicles:** for passenger vehicles such as sedan and van, metal guardrail is preferable; however, for commercial vehicles such as truck and semi-truck, concrete barrier is preferable. On the Caltrans website, the [California truck network maps \(https://dot.ca.gov/programs/traffic-operations/legal-truck-access/truck-network-map\)](https://dot.ca.gov/programs/traffic-operations/legal-truck-access/truck-network-map) determine the freeway routes that trucks mainly take. Caltrans also developed a [Performance Measurement System \(PeMS\) website \(https://pems.dot.ca.gov/?report_form=1&dnode=State&content=loops&tab=det_summary&export=&s_time_id=1672531200&s_time_id_f=01%2F01%2F2023&e_time_id=1677715140&e_time_id_f=03%2F01%2F2023&tod=all&tod_from=0&tod_to=0&dow_0=on&dow_1=on&dow_2=on&dow_3=on&dow_4=on&dow_5=on&dow_6=on&holidays=on&gb=district&q=vmt&q2=&chart.x=73&chart.y=7\)](https://pems.dot.ca.gov/?report_form=1&dnode=State&content=loops&tab=det_summary&export=&s_time_id=1672531200&s_time_id_f=01%2F01%2F2023&e_time_id=1677715140&e_time_id_f=03%2F01%2F2023&tod=all&tod_from=0&tod_to=0&dow_0=on&dow_1=on&dow_2=on&dow_3=on&dow_4=on&dow_5=on&dow_6=on&holidays=on&gb=district&q=vmt&q2=&chart.x=73&chart.y=7) which provides vehicle miles traveled (VMT), vehicle hours traveled (VHT), truck VMT, and truck VHT across the districts. With this information, the VMT and the truck VMT can be compared on the main freeway routes, as shown in Figure 2.

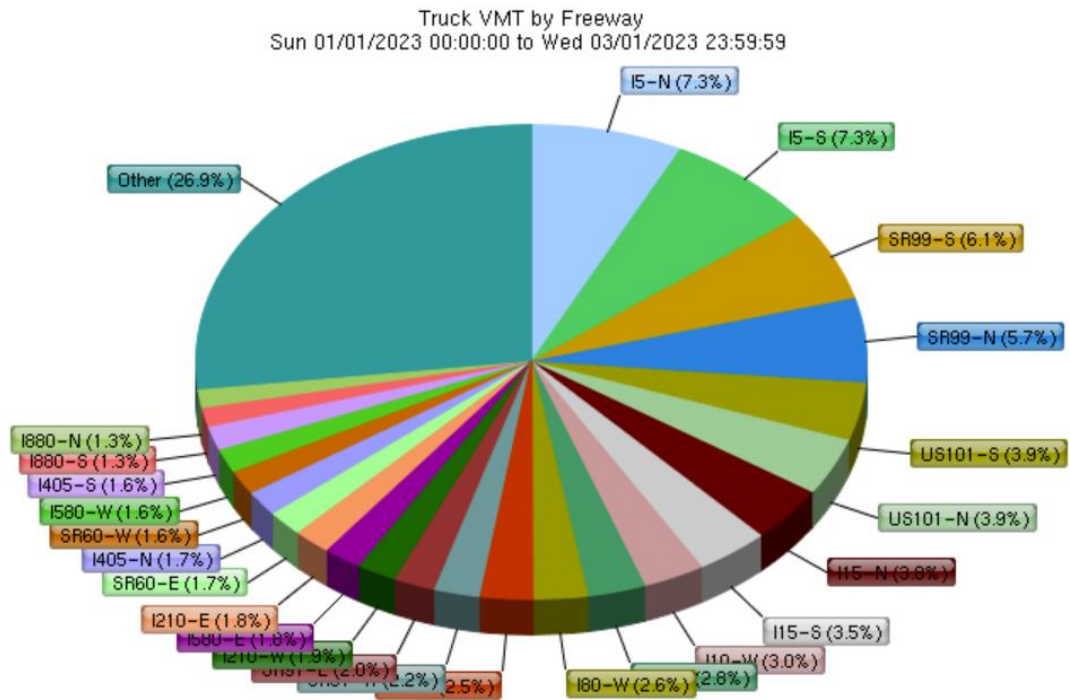
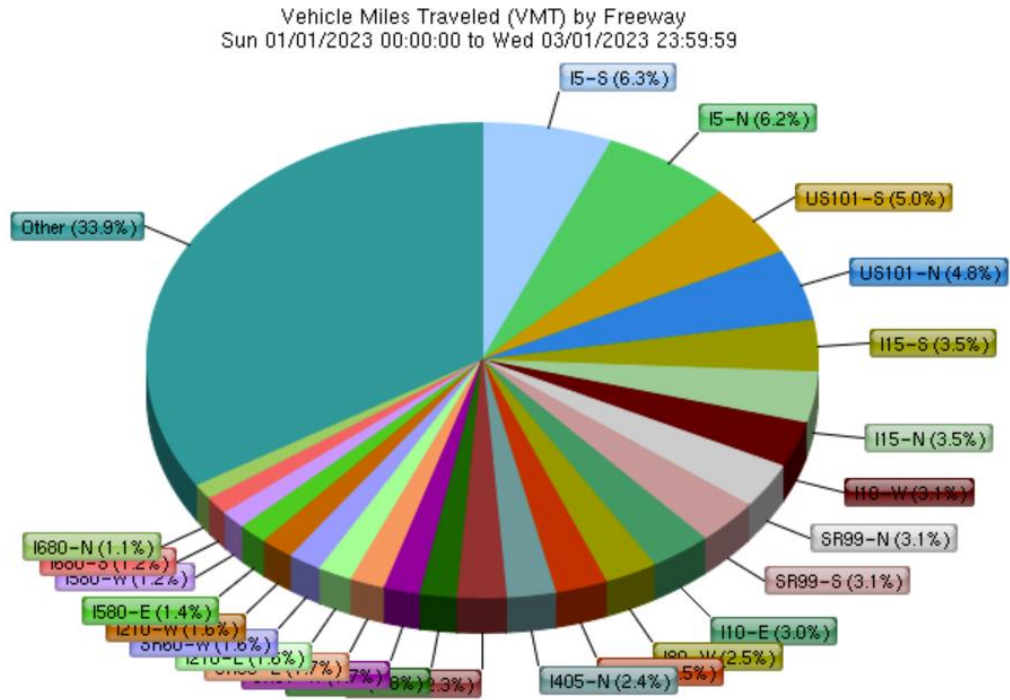


Figure 2: VMT and truck VMT classified by freeway. On I-5, the amount of VMT and truck VMT is the highest. The classification can be also done by counties and cities. Image courtesy of Caltrans – PeMS website.

After comparing the VMT and the truck VMT volume on each freeway, the implementation of the Manual for Assessing Safety Hardware (MASH) can be considered. The MASH test levels provide guidelines for North Dakota DOT (NDDOT) in installation, inspection, and maintenance of commonly used safety barrier systems [16].

MASH test levels in NDDOT guidelines (from American Association of State Highway and Transportation Officials (AASHTO) Roadway Design Guide, Chapter 5, Roadside Barriers) (from page 9 of [16])

- **TL-1:** 25-degree impact angle at 31 mph, with small car (2,420 lb) and pickup truck (5,000 lb).
- **TL-2:** 25-degree impact angle at 44 mph, with small car (2,420 lb) and pickup truck (5,000 lb).
- **TL-3:** 25-degree impact angle at 62 mph, with small car (2,420 lb) and pickup truck (5,000 lb).
- **TL-4:** TL-3 +15-degree impact angle, 56 mph single-unit truck (22,000 lb)
- **TL-5:** TL-3 +15-degree impact angle, 50 mph tractor-van trailer (80,000 lb)
- **TL-6:** TL-3 +15-degree impact angle, 50 mph tractor-tank trailer

Table 3: Caltrans crash test levels (from page 9 of [17])

Test Level	Test Vehicle Designation and Type		Test Conditions	
	MASH	NCHRP Report 350 ³	Speed (mph)	Angle (degrees)
2	1100C (Passenger Car)	820C (Passenger Car)	44	25
	2270P (Pickup Truck)	700C (Passenger Car)	44	25
		2000P (Passenger Car)	44	25
3	1100C (Passenger Car)	820C (Passenger Car)	62	25
	2270P (Pickup Truck)	700C (Passenger Car)	62	25
		2000P (Passenger Car)	62	25
4	1100C (Passenger Car)	820C (Passenger Car)	62	25
	2270P (Pickup Truck)	700C (Passenger Car)	62	25
	10000S (Single Unit Truck)	2000P (Passenger Car)	56	15
		8000S (Single Unit Truck)	56	15

In Table 3, Caltrans crash test levels guidelines are also based on American Association of State Highway and Transportation Officials guidelines for designing barriers. Knowing the volume of trucks and vehicles travel on a certain freeway, the appropriate barrier with compatible MASH test level can

³ NCHRP: National Cooperative Highway Research Program

be considered accordingly. For example, the NDDOT utilizes average daily traffic (ADT) as guidance in designing clear distances for foreslope and backslope, as shown in Figure 3. Caltrans also utilizes ADT to determine the appropriate median type and width when installing barriers on the freeway, as shown in Figure 4.

NDDOT Design Clear Distances (for foreslope)

Design Speed (mph)	Design ADT***	Foreslope				
		FLAT	1V:6H	1V:5H	1V:4H	1V:3H
≤40	UNDER 750	7-10	7-10	7-10	7-10	**
	750–1500	10	12	12	14	**
	1500–6000	12	14	14	16	**
	OVER 6000	14	16	16	18	**
45-50	UNDER 750	10	12	12	14	**
	750–1500	14	16	16	20	**
	1500–6000	16	18	20	26	**
	OVER 6000	20	22	24	28	**
55	UNDER 750	12	14	14	18	**
	750–1500	16	18	20	24	**
	1500–6000	20	22	24	30	**
	OVER 6000	22	24	26	32*	**
60	UNDER 750	16	18	20	24	**
	750–1500	20	24	26	32*	**
	1500–6000	26	30	32*	40*	**
	OVER 6000	30	32*	36*	44*	**
65-75	UNDER 750	18	20	20	26	**
	750–1500	24	26	28	36*	**
	1500–6000	28	32*	34*	42*	**
	OVER 6000	30	34*	38*	46*	**

Figure 3: An NDDOT example utilizes ADT when designing clear distances (from page 4 of [16]).

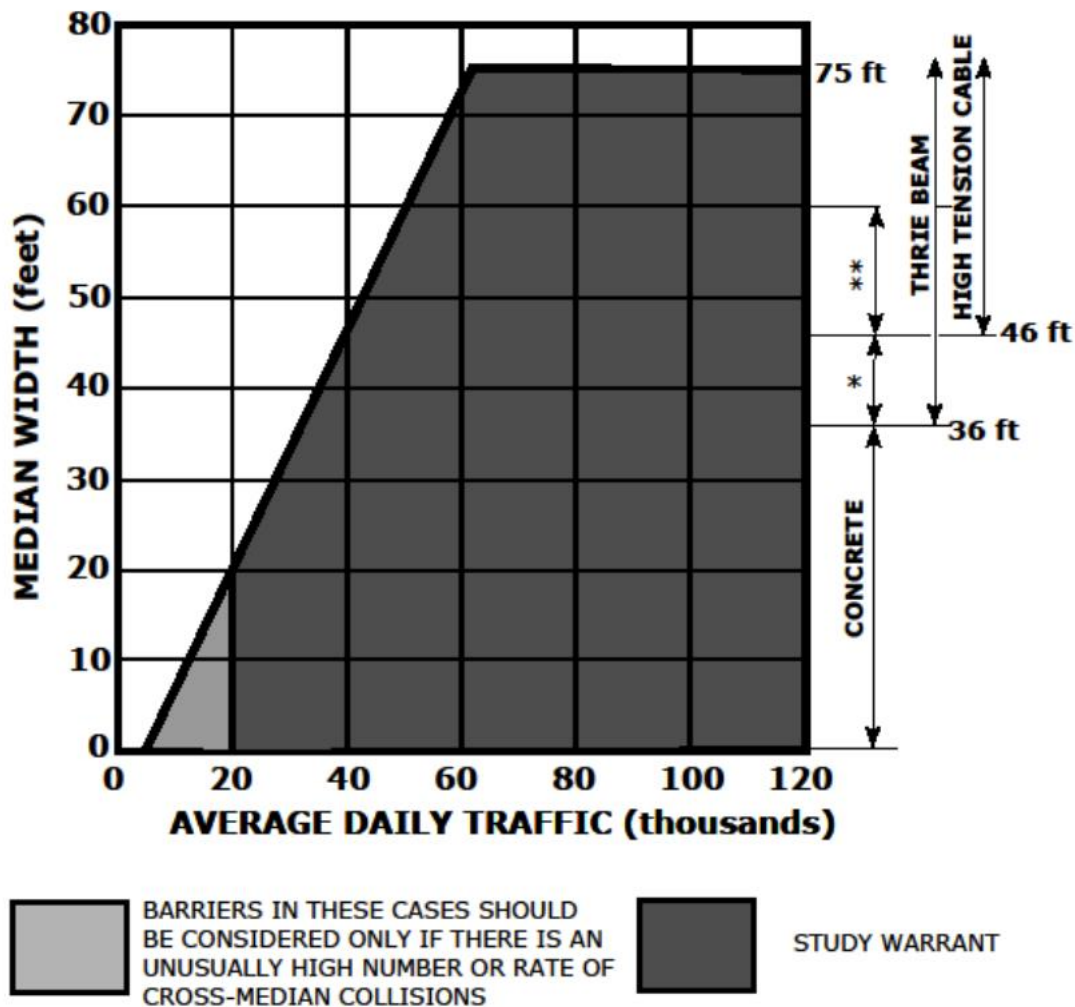


Figure 4: Freeway median barrier study from Caltrans (from page 49 of [17]).

In summary, there is no definitive way to determine whether it is best to install concrete barriers or metal guardrails. The decision is based on many factors, including some judgment. The first tool to aid with the decision-making process is the interactive map which combines terrain, SLR, floodplains, fire threats, and accident volume. The second tool is the PeMS website. By knowing the volume of trucks and vehicles passing through a certain freeway, the compatible MASH test levels can be considered. For example, freeways with high truck VMT should have high MASH test level. In addition, the tools can be utilized together. For instance, in an accident hotspot with high VMT, the barrier should be concrete with MASH test level accommodating passenger cars.

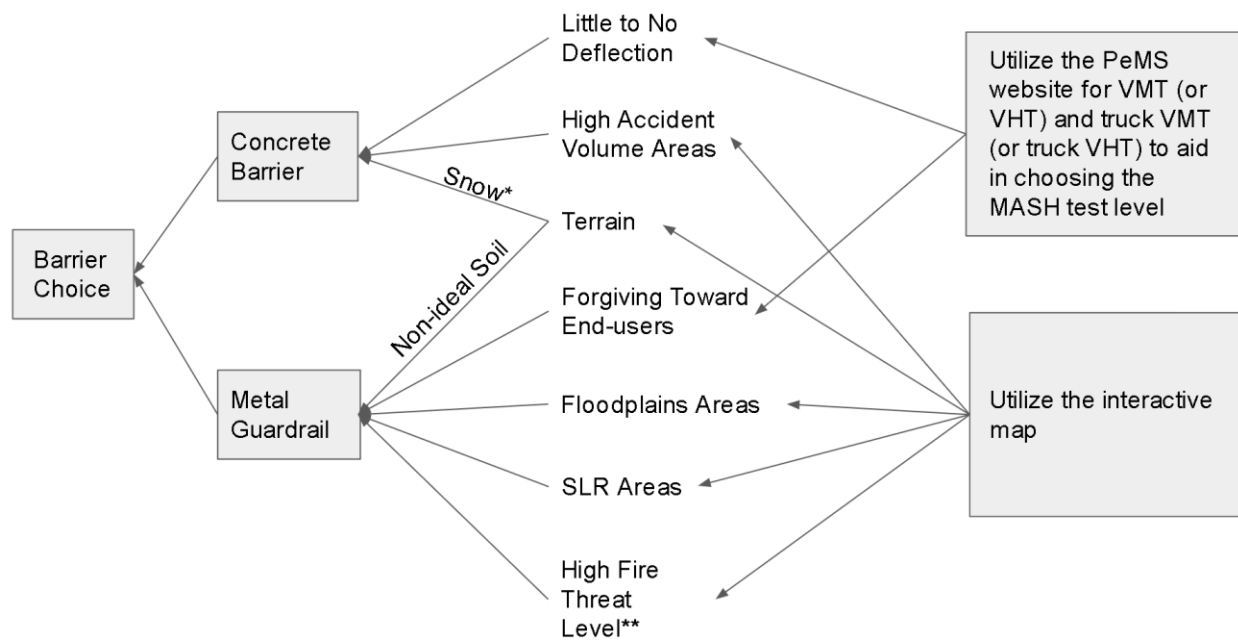


Figure 5: Decision tree for choosing a barrier (created by AHMCT). When choosing a barrier, the questions is: what are the dominant factors (ex. fire region)?

Note: *Regarding snow, if an area uses snow blowers, concrete barriers are preferred as metal guardrails can get damaged, according to interviews with Caltrans maintenance personnel. However, per Iowa DOT recommendation, the open design of metal guardrails reduce snow drifting (page 2 of [10]).

****In fire prone areas, wooden posts are not recommended.**

To enhance worker safety in maintaining barriers, the following options can be considered:

- Using the [interactive map](https://ucdavis.maps.arcgis.com/apps/mapviewer/index.html?webmap=6b32c588162f426a9966bff49e6c4cea) (<https://ucdavis.maps.arcgis.com/apps/mapviewer/index.html?webmap=6b32c588162f426a9966bff49e6c4cea>) to identify accident hotspots, then enhance safety protocols at those hotspots. For example, workers should be alerted that they are in an elevated risk zone.
- Using the [PeMS website](https://pems.dot.ca.gov/?report_form=1&dnod=State&content=loops&tab=det_tod&export=&s_time_id=1672531200&s_time_id_f=01%2F01%2F2023&e_time_id=1680307140&e_time_id_f=03%2F31%2F2023&dow_0=on&dow_1=on&dow_2=on&dow_3=on&dow_4=on&dow_5=on&dow_6=on&holidays=on&q=vmt&fn=1&pct1=25&pct2=75&chart.x=61&chart.y=17) (https://pems.dot.ca.gov/?report_form=1&dnod=State&content=loops&tab=det_tod&export=&s_time_id=1672531200&s_time_id_f=01%2F01%2F2023&e_time_id=1680307140&e_time_id_f=03%2F31%2F2023&dow_0=on&dow_1=on&dow_2=on&dow_3=on&dow_4=on&dow_5=on&dow_6=on&holidays=on&q=vmt&fn=1&pct1=25&pct2=75&chart.x=61&chart.y=17) to identify traffic volume throughout hours of the day, and/or days of the week (Figure 6). Mitigate maintenance at peak hours. This method is

already implemented within Caltrans, yet the information should be relayed and emphasized.

Performance > Aggregates > Time of Day ▾ ABOUT THIS REPORT

From: 01/01/2023 To: 03/31/2023
 Min Range: 2 days Max Range: 5 years

Include Days: Su Mo Tu We Th Fr Sa Holidays

Quantity: Vehicle Miles Traveled (VMT) ▾

Statistics: Mean, Min, Max
 Mean, Mean+σ, Mean-σ
 Median, 25 %, 75 %
 Discrete Days

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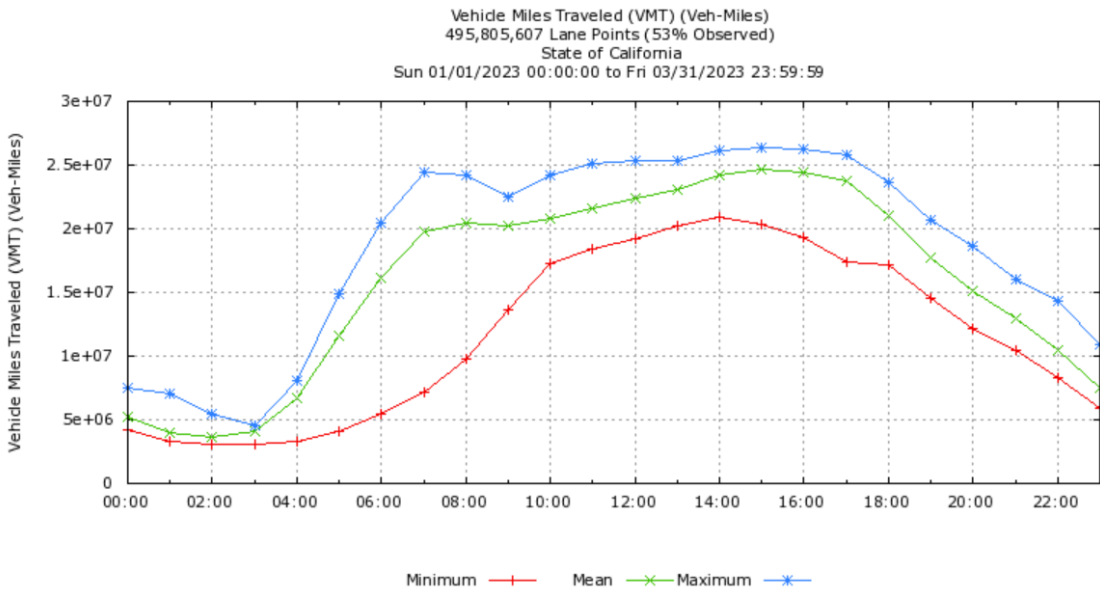


Figure 6: VMT observed in the State of California from January 1st, 2023 to March 31st, 2023. Image courtesy of Caltrans – PeMS website.

Appendix E:
Memo:
**Utilize “Quick Change” from Districts 4
and 5, Including Support Sleeves and
Posts**

Memorandum

To: Caltrans Panel

From: AHMCT Research Center

Date: August 30th, 2023

Subject: UPDATED RECOMMENDATIONS – UTILIZE “QUICK CHANGE” FROM DISTRICTS 4 AND 5, INCLUDING SUPPORT SLEEVES AND POSTS

The focus of this memorandum is to document the “quick change” process. Although Caltrans has utilized the process for over a decade, not all Caltrans districts are familiar with it. The “quick change” process consists of establishing a concrete-reinforced base, then the posts get inserted into or removed from the base when they need to be changed out. The advantages and disadvantage of the “quick change” process are:

- **Advantages:**
 - Reduce the amount of treated wood waste (TWW).
According to [Department of Toxic Substances Control \(DTSC\)](https://dtsc.ca.gov/) (<https://dtsc.ca.gov/>), TWW has the potential to be hazardous waste if it contains elevated levels of one or more of the following constituents: arsenic, chromium, copper, pentachlorophenol, and creosote. If TWW is not properly disposed of, the chemicals it contains can contaminate soil, surface water, and ground water. This poses a risk to human health and the environment. **Analysis of representative samples of TWW has shown that it has the potential to exhibit a hazardous waste characteristic of toxicity under California state standards [11].**
 - Reduce the installation time once the setup is established.
According to a Statewide Integrated Traffic Records System (SWITRS) report, there were **1,450 collisions** related to traffic signals and signs in 2022 for Sacramento County alone (data attached in appendix E.E.1). Out of the 1,450 collisions, 10 were fatal and 1,014 were injury collisions. **Reducing traffic exposure time is one of the main factors to enhance worker safety. Therefore, reducing the installation time is crucial.**
 - Enhance safety for the travelling public
The “quick change” design consists of the post being fastened slightly above ground. The “quick change” design is similar to the breakaway design, which is **recommended and implemented by other DOTs as it is forgiving to end users.**
- **Disadvantage:**
 - The initial setup takes time
Setting up the initial base for “quick change” takes approximately 2 to 5 hours to establish. Although the initial setup takes a long time, it

is a one-time setup. Caltrans personnel stated that the time reduction for the following installments is worth the initial trade-off.

The “quick change” process and similar implementation from other Departments of Transportation (DOTs) are detailed in the following sections.

1. The “quick change” concept in detail

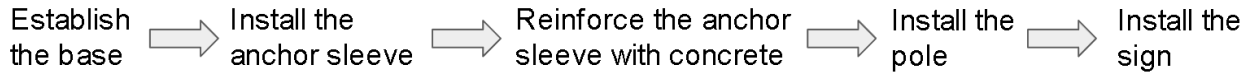


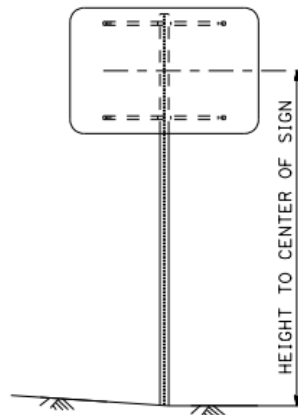
Figure E.1: The steps of “Quick Change” process. Diagram created by the AHMCT team.

- **Establish the base**

Dig out the debris. The dig out should be able to accommodate the anchor sleeve and the reinforced material.

- **Install the anchor sleeve**

Insert the anchor sleeve into the established base. The anchor sleeve size varies with the post size.



SINGLE POST INSTALLATION

POST SIZE	Max AREA (SQUARE FEET) OF SIGN							SLEEVE SIZE
2" x 2" x 12 Ga	10.8	8.9	7.6	6.6	5.9	5.3	4.8	2 1/4" x 2 1/4" x 10 Ga
2 1/2" x 2 1/2" x 10 Ga	20	18	16	14	12	11	10	2 3/4" x 2 3/4" x 10 Ga
HEIGHT TO CENTER OF SIGN SINGLE POST GROUND SIGNS 100 MPH WIND SPEED	5'-0"	6'-0"	7'-0"	8'-0"	9'-0"	10'-0"	11'-0"	-

Figure E.2: Size of the sleeve according to the post size. Drawing courtesy of Caltrans.

- **Reinforce the anchor sleeve with concrete or insert the anchor sleeve with stabilizing wing directly into the soil**

For concrete installation, it is recommended that the footing size is a minimum of 12 inches in diameter and 30 inches deep. The top of lower slip plate must be 2½ inches above the concrete surface.

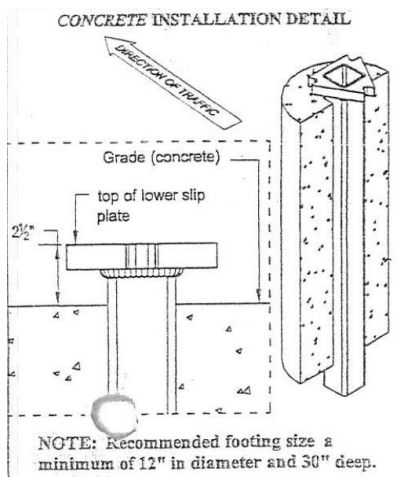


Figure E.3: Concrete installation detail. Drawing courtesy of Caltrans.

For direct drive soil installation, it is recommended to install with the widest bearing surface of the stabilizing wing parallel with the face of the sign.

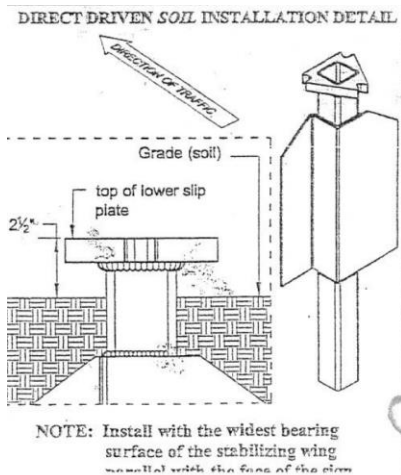


Figure E.4: Direct driven soil installation detail. Drawing courtesy of Caltrans.

- **Install the post**
Insert the post into the anchor sleeve. Use fastener to secure the post to the anchor sleeve at the desired height.

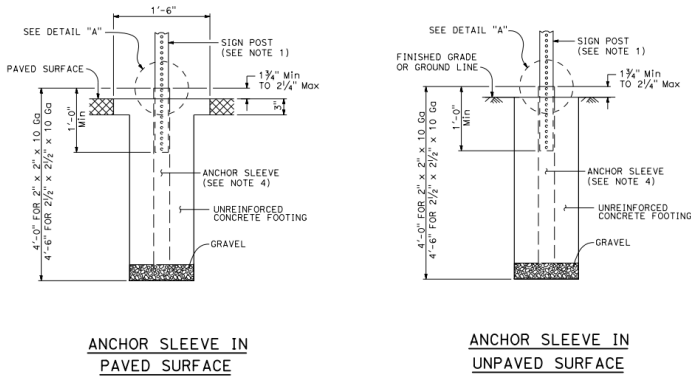


Figure E.5: Post being inserted into the anchor sleeve in paved and unpaved surface. Drawing courtesy of Caltrans.

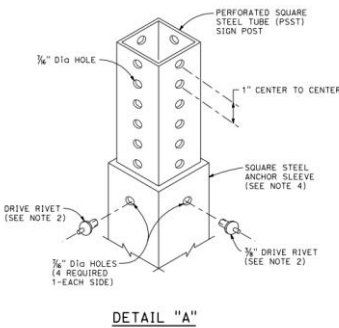


Figure E.6: Detail of the post being inserted and fastened into the anchor sleeve. Drawing courtesy of Caltrans.

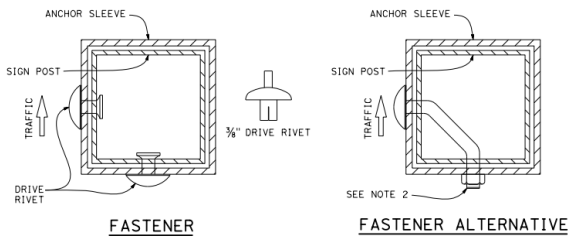


Figure E.7: Fastener details. Drawing courtesy of Caltrans.

- **Install the sign**

Single-post installation and two-post installation details are as follow:

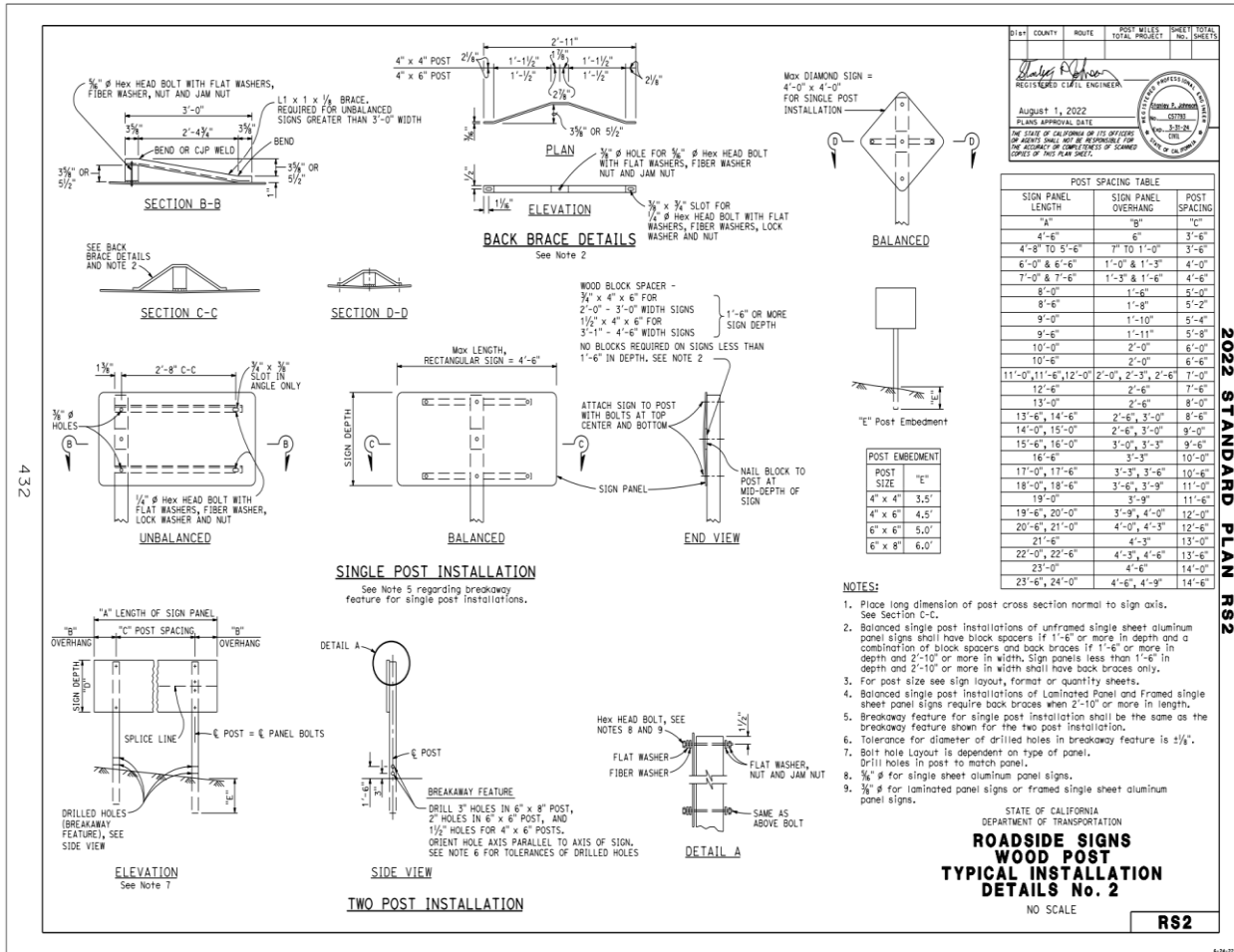


Figure E.8: Details for installing sign on a single post or two posts. Drawing courtesy of Caltrans.

According to the standard plan, the size of single and double-post should be up to 50 square feet.

The detailed drawings of the “quick change” standard plan are attached in the appendix. The summarized information in this section is intended to be an overview to the “quick change” process.

2. Other DOT implementations similar to “quick change” and MASH testing

• U-channel sign support

Fourteen (14) states (Midwest Pooled Fund Program member states) currently use U-channel sign supports for small delineators with sign panels, and thirteen (13) states plan to use them. While many different sign panel sizes are used, the mounting height to the bottom of the sign panel for small delineators was typically 4 feet. Every state mounted these supports in soil, and six states mounted them in both soil and concrete (pg. 8 of [18]).

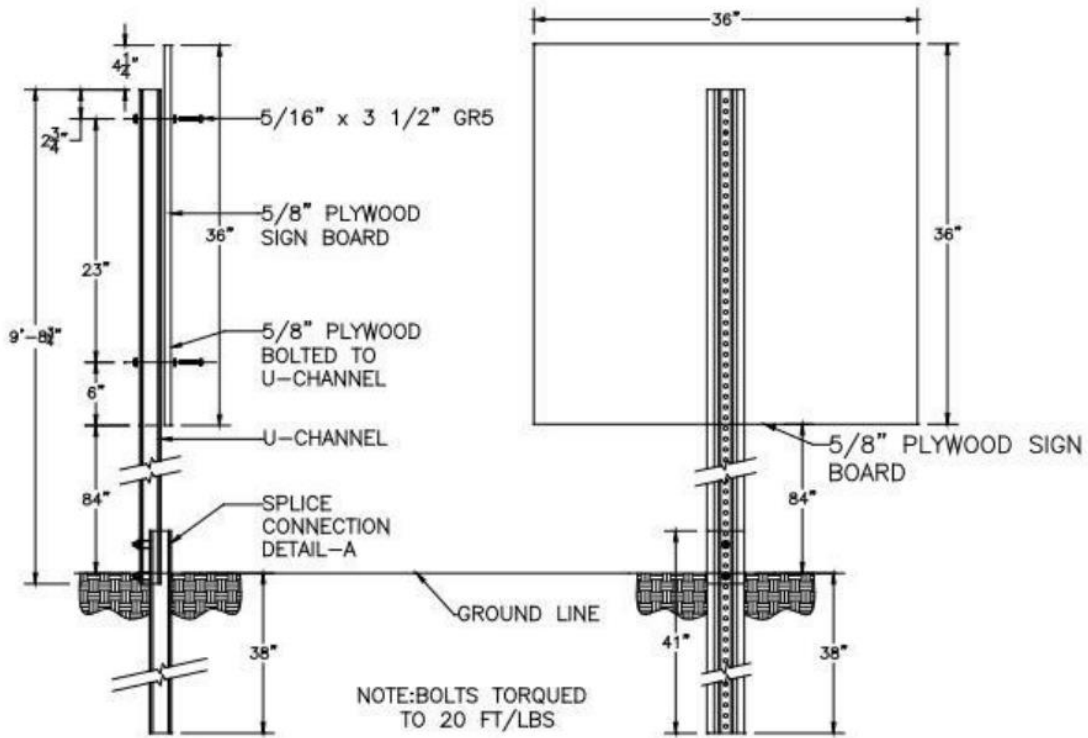


Figure E.9: U-channel schematic, test number RF476460-1-2. Image courtesy of University of Nebraska-Lincoln (page 7 of [18]).



Figure E.10: U-channel post installation (page 25 of [18])

Table E.1: Summary of U-Channel sign support test for National Cooperative Highway Research Program (NCHRP) Project 22-14(03), 2010 (page 7 of [18])

Test No. (Designation)	Post Weight, lb/ft	Test Inertial Weight, lb	Impact Speed, mph	Impact Location	Max. Compartment Deformation and Location, in	Pass/Fail
RF476460-1-2 (3-62)	4	4,958	63.3	Left quarter point	2.1* (Roof)	Pass

*Note: it is believed most of the vehicle damage was due to the secondary impact with the perforated square steel tube support.

- **Breakaway posts**

The [Pennsylvania Department of Transportation \(PennDOT\)](https://gis.penndot.gov/BPR_PDF_FILES/Documents/LTAP/TechSheets/TS_212_Breakway_Sign_Posts.pdf) (https://gis.penndot.gov/BPR_PDF_FILES/Documents/LTAP/TechSheets/TS_212_Breakway_Sign_Posts.pdf) has two different types of breakaway posts. The first type is the square tube which is similar to the Caltrans “quick change” concept, as shown in Figure 11. The second type is the channel bar, as shown in Figure 12.



Figure E.11: Square tube breakaway post. Image courtesy of PennDOT [19].



Figure E.12: Channel bar breakaway post. Image courtesy of PennDOT [19].

According to PennDOT, the square tube post offers the ability to mount signs on all four sides, great loading capacity, and great torsional strength; however, the square tube post costs about 5 to 10% more than the channel bar. The channel bar post has the lowest cost and is easy to install, making it the most common post on local roads; however, the channel bar post has lower loading capacity and cannot mount signs at right angles on the same post [19].

Only Federal Highway Administration (FHWA) and PennDOT-approved sign posts can be used in Pennsylvania. PennDOT follows the American Association of State Highway and Transportation Officials (AASHTO) Manual for Assessing Safety Hardware (MASH) recommendations to assess crash test results. **To be considered crashworthy, a sign post must be forgiving (as opposed to a rigid fixed object) and should not become a flying projectile when hit.** The design of square tube breakaway post is shown in Figure E.13. The square tube breakaway post being damaged upon impact is shown in Figure E.14 [19].

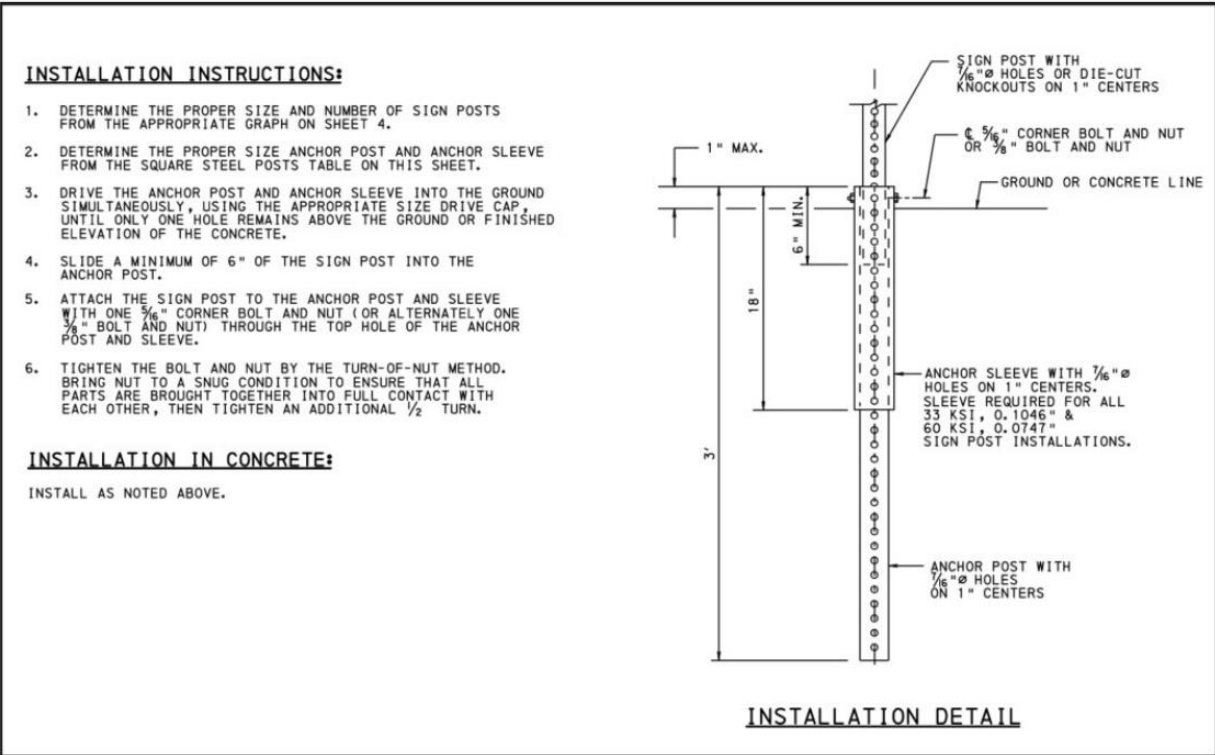


Figure E.13: Square tube breakaway post specifications. Image courtesy of PennDOT [19].



Figure E.14: The square tube breakaway post being damaged upon impact. Image courtesy of PennDOT [19].

Similar to PennDOT, Oregon Department of Transportation (ODOT) has their version of breakaway sign post designs. One of the ODOT drawings is attached below, all the drawings are in the appendix.

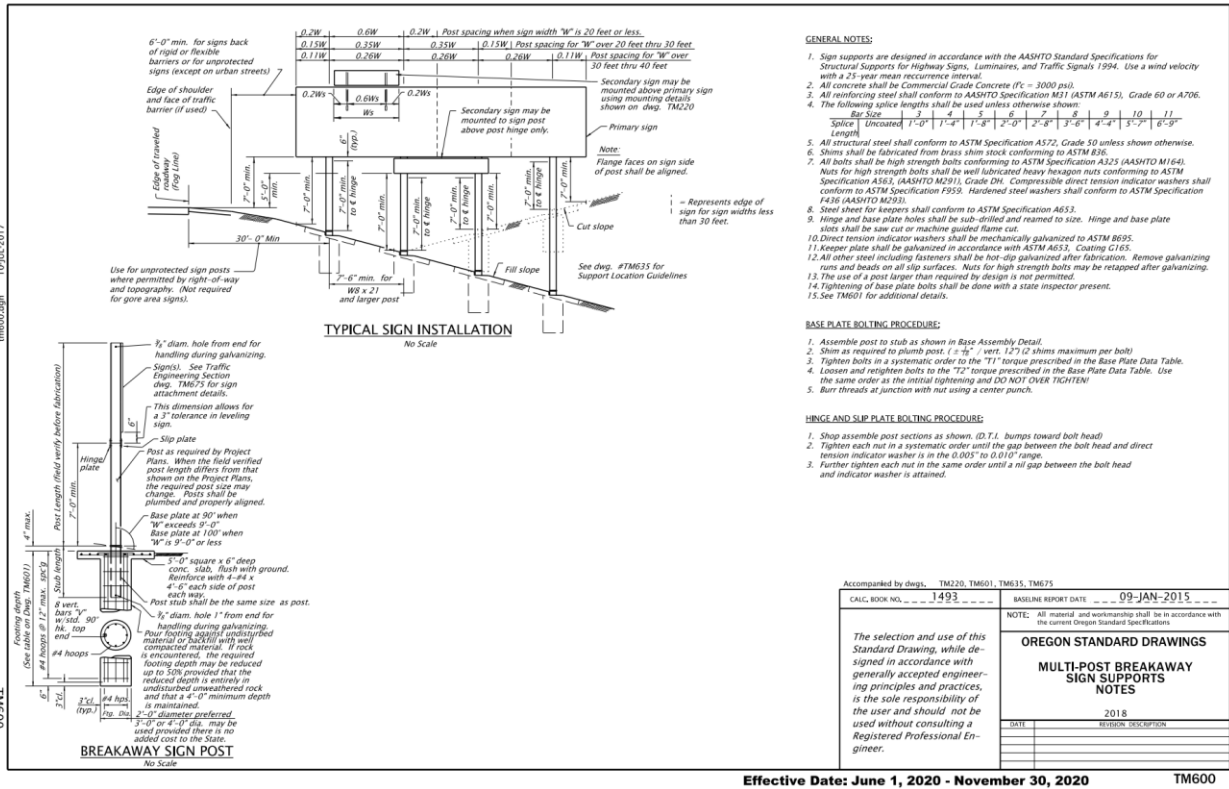


Figure E.15: ODOT breakaway sign post design. Image courtesy of ODOT [20].

3. Federal Highway Administration (FHWA) recommendations [21]

The breakaway sign post has similar concept as Caltrans "quick change." For instance, PennDOT defines the typical breakaway post assembly consists of a sign support post, an anchoring post, and a breakaway component [19]. FHWA recommendations for breakaway sign should be applicable for Caltrans "quick change" post.

The FHWA addresses the frequently asked questions for the breakaway signs and luminaire supports. The following answers are summarized. To read the answers in details, visit [FAQs: Breakaway Sign and Luminaire Supports | FHWA \(https://highways.dot.gov/safety/rwd/reduce-crash-severity/faqs-breakaway-sign-and-luminaire-supports\)](https://highways.dot.gov/safety/rwd/reduce-crash-severity/faqs-breakaway-sign-and-luminaire-supports)

Q: Should we use breakaway bases for sign and light poles mounted on concrete median barriers?

A: No, breakaway bases should not be used. Mounting any pole on top of a median barrier should be avoided because trucks will lean over the barrier upon impact and hit whatever is on top. Work zone signs may be

mounted on barriers if using roll-up signs on fiberglass supports as they have less potential for causing serious damage.

Q: Can we still use pendulum tests to assess breakaway performance of sign and lighting poles?

A: The status of pendulum testing under MASH is undetermined – if the bases can be considered modifications of bases tested under Report 350 then we will agree to review pendulum testing done under 350 criteria (until 1/1/11). If they are totally new designs, then they need to be tested under MASH. Whatever test methods you use must evaluate the roof crush and windshield damage as required in MASH.

Q: Should we use omnidirectional breakaway base everywhere?

A: Crashworthy omnidirectional bases are designed to meet NCHRP Report 350 criteria regardless of which direction they are struck. They are required when installing signs and other breakaway hardware near intersections (including expressway ramps ending on local roads and in roundabouts) and preferred on other undivided facilities. Unidirectional bases (i.e. 4-bolt slip bases) should only be used along divided highways where impacts are limited to the direction of travel of the roadway they are next to.

Q: What is the January 1st, 2013 deadline for breakaway supports?

A: All sign supports within the clear zone of highways signed at speeds of 50 mph or greater must be mounted on breakaway supports or be shielded with a barrier by January 1st, 2013, per the Manual on Uniform Traffic Control Devices (MUTCD)

Q: We want to add lights, a battery, and a solar panel to our school zone sign. Does the combination have to be crash tested?

A: Four factors determine the acceptability of breakaway supports: stub height, vehicle velocity change/ occupant impact forces, windshield penetration, and roof crush. Safe placement of these types of devices on the sign also depends on the structure of the sign, the sign height, the type of vehicle impacting the sign, and the breakaway nature of the sign support when it is impacted. The conditions outlined above assume the sign pole is rigid and that the pole itself will not deform upon impact. The breakaway feature must be a slip base, frangible coupling system, or a cast aluminum transformer base – “base bending or yielding” systems such as u-channel posts, perforated square steel tube posts, or composite posts require full-scale crash testing.

Q: Is it OK to add a decorative shell or casting to a breakaway light pole to make it more aesthetics?

A: Adding decorative hardware to a breakaway luminaire support might affect proper performance. Thus, aesthetic or decorative modifications should be crash tested.

Overall Conclusion

Caltrans should implement the “quick change” approach across all districts. **The benefits of the implementation are reducing treated wood waste, reducing installation time for future installments, and enhancing forgiveness toward the end-users. Implementing “quick change” enhances the safety of workers and the travelling public, which is a win-win solution.**

It is recommended that Caltrans should:

- Perform crash testing of single and double-post quick change signs
- Upon successful crash testing, adopt the designs into standard plans
- Encourage other Caltrans districts to adopt the “quick change” practice

Appendix

STATE OF CALIFORNIA
DEPARTMENT OF CALIFORNIA HIGHWAY PATROL



REPORT 3 - COLLISIONS AND VICTIMS BY PRIMARY COLLISION FACTOR

01/01/2022 thru 12/31/2022

Report Run Date: 06/29/2023

Includes State Highway cases

County: Sacramento

This report is accepted subject to the Terms of Use. Due to collision records processing backlogs, SWITRS data is typically seven months behind. Data requested for dates seven months prior to the current date will be incomplete.

PRIMARY COLLISION FACTOR	TOTAL COLLISIONS	FATAL COLLISIONS	INJURY COLLISIONS	PDO COLLISIONS	KILLED VICTIMS	INJURED VICTIMS	SEVERE INJURIES	OTHER VISIBLE INJURIES	COMPLAINT OF PAIN INJURIES
Driving Or Bicycling Under Influence Of Alcohol Or Drug	1,692	43	692	957	49	1,006	164	441	401
Impeding Traffic	8		3	5		4			4
Unsafe Speed	5,278	18	2,234	3,026	18	3,220	128	753	2,339
Following Too Closely	56		25	31		36	2	9	25
Wrong Side Of Road	317	7	226	84	10	278	32	114	132
Improper Passing	145		41	104		56	7	16	33
Unsafe Lane Change	1,525	4	373	1,148	4	488	34	160	294
Improper Turning	3,505	25	1,174	2,306	27	1,543	155	547	841
Automobile Right-Of-Way	1,971	9	1,201	761	9	1,895	99	478	1,318
Pedestrian Right-Of-Way	124	3	115	6	3	118	13	50	55
Pedestrian Violation	267	64	190	13	64	203	73	76	54
Traffic Signals And Signs	1,450	10	1,014	426	10	1,651	58	404	1,189
Unsafe Starting Or Backing	374	2	72	300	2	88		14	74
Hazardous Parking	16		2	14		2		1	1
Brakes	2		2			2		1	1
Other Equipment	14		3	11		4		2	2
Other Hazardous Violation	132	3	66	63	3	78	5	17	56
Other Improper Driving	139		43	96		47	1	12	34
Other Than Driver	278	4	89	185	4	112	12	52	48
Unknown	384	2	140	242	2	201	13	55	133
NOT STATED	92		49	43		76	7	16	53
Total:	17,769	194	7,754	9,821	205	11,108	803	3,218	7,087

Figure E.E.1: SWITRS report for Sacramento County in 2022



INSTALLATION GUIDE REDI-TORQUE MODEL 280 OMNI DIRECTIONAL SLIP BASE (COMBINATION ANCHOR WITH LOWER SLIP PLATE). RECEIVES SQUARE SIGN SUPPORT

RT280U-SQ1 MEETS OR EXCEEDS NCHRP 350 CRITERIA FHWA ACCEPTANCE LETTERS SS-134 & SS-134A AUGUST 10, 2007 ACCESSORIES SQUARED DEV. & MFG. CO., INC. AUBURN, IL 62615 TEL: (800) 621-7948 FAX: (217) 436-3917 WWW.X-SQRD.COM

PARTS LIST

A: Unibase - Lower Slip Plate

ITEM	QTY	DESCRIPTION
A	1	Combination Anchor/Lower Slip Plate

B: Redi-Torque Match Plate Hardware

ITEM	QTY	DESCRIPTION
B1	3	3/4" -13 x 2-3/4" Gr. 8 Redi-Torque Bolt
B2	6	3/4" U.S.S. Flat Washer
B3	3	3/8" Thick, Teflon Coated Slip Washer
B4	3	3/8" -13 Gr. 8 large diameter Flange Nut
B5*	4	3/16" Thick Leveling Shim

* may not be necessary for every installation

C: Upper Slip Plate Sub-Assembly

ITEM	QTY	DESCRIPTION
C	1	Top Receiver for Square Sign Support
C1	1	Square Sign Support Locking Wedge

STEP A

1. Install appropriate Unibase (A) plumb & squared up with road, with point of triangular slip plate facing oncoming traffic.
2. Depth of embedment to leave 2-1/2" (+/-1/4") from grade to top of Lower Slip Plate of Unibase (A).
NOTE: For soil or concrete installation options, see details at lower left.
NOTE: If installing in concrete, angle the footing hole shallow enough to be able to drive 3-4 inches of Unibase (A) into the bottom of the hole. This will help stabilize the unit as concrete is being poured and cured while also allowing for proper drainage.
NOTE: On multi-leg installations, be sure that all Unibases are squared & lined up with each other.

STEP B

1. Place one each teflon coated Slip Washer (B3) on top of Lower Slip Plate of Unibase (A) at each notched point with open end of slot facing center of triangular slip plate. Leave enough room between the closed ends of the slits to allow 3/8" Redi-Torque Bolt (B1) to pass through.
2. Place Upper Slip Plate (C) onto the three Slip Washers (B3) properly indexed so that square post receiver portion is squared up with road.
3. Slide 1 each 3/8" Flat Washer (B2) on to each Redi-Torque Bolt (B1) then insert Bolt (B1) with Washer (B2) down through notched points of Upper Slip Plate (C), slot of Slip Washer (B3) and notched point of Lower Slip Plate of Unibase (A).
4. Slide 1 each 3/8" Flat Washer (B2) up an exposed thread of each Bolt (B1), followed by threading 1 each 3/8" Flange Nut (B4) on to each Bolt (B1) one half turn, past finger tight.

NOTE: When tightening bolts during this step use the 3/4" (larger) hex and NOT the 3/8" (smaller) hex.

STEP C

1. Insert Square Sign Support into Upper Slip Plate (C) receiver until support bottoms out.
2. With a hand held hammer, drive the square sign support Locking Wedge (C1) into the Upper Slip Plate (C) receiver at the pre-determined corner, marked by a 1/2" notch. (The Locking Wedge does not need to be driven flush with top of Upper Slip Plate receiver).

WARNING: Before moving on to step 3, check the plumb of the sign support(s). If necessary, 3/16" thick Leveling Shim(s) (B5) may be used at this appropriate point(s) between slip plates. To re-plumb, loosen Bolt (B1) at desired point enough to lean the Upper Slip Plate (C) back and slide Leveling Shim (B5) into place. Shim(s) should be placed under Teflon Coated Slip Washers. Maximum of 2 each Leveling Shim per notched point.

3. After Locking wedge (C1) is securely in place, loosen each Bolt (B1) and Nut (B4), one at a time, then re-tighten each Bolt (B1), using the 3/8" (smaller) hex, until the 3/8" hex head twists off from the 3/4" hex head. This will set the proper torque level.

UP TO A MAXIMUM OF THREE OMNI DIRECTIONAL SLIP BASES WITH RED-TORQUE MODEL 280 MATCHPLATE HARDWARE MAY BE INSTALLED WITHIN A SEVEN FOOT SPAN.

CONCRETE INSTALLATION DETAIL

Grade (concrete)

top of lower slip plate

NOTE: Recommended footing size a minimum of 12" in diameter and 30" deep.

DIRECT DRIVEN SOIL INSTALLATION DETAIL

Grade (soil)

top of lower slip plate

NOTE: Install with the widest bearing surface of the stabilizing wing parallel with the face of the stone.

INSTALLED VIEW (FRONT)

REINSTALLATION PROCEDURE:

NOTE: All match plate hardware components are generally reusable except the Redi-Torque Bolts (B1)

1. Remove sign support Locking Wedge (C1) from Upper Slip Plate (C) receiver with a hand held hammer.
2. Place Upper Slip Plate (C) on Lower Slip Plate of Unibase (A) to check for warpage and level of slip.
3. Visually check all welds and castings for fractures or other damage.
4. When assured both Lower Slip Plate (A) and Upper Slip Plate (C) are reusable employ new or reusable hardware (B) with NEW Redi-Torque Bolts (B1) then follow installation procedures, starting with STEP B.

Figure E.E.2: Caltrans drawing (1)

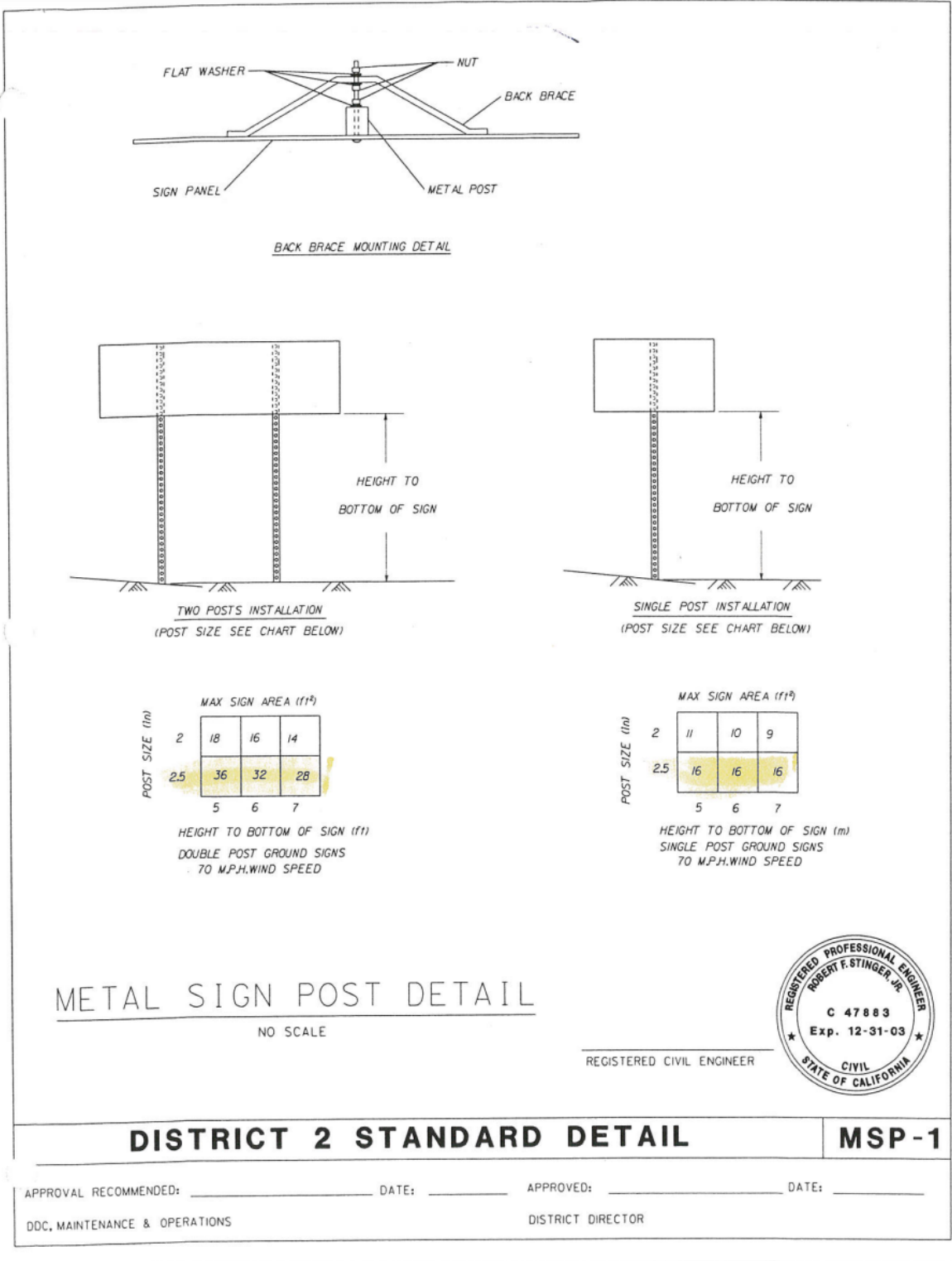


Figure E.E.3: Caltrans drawing (2)

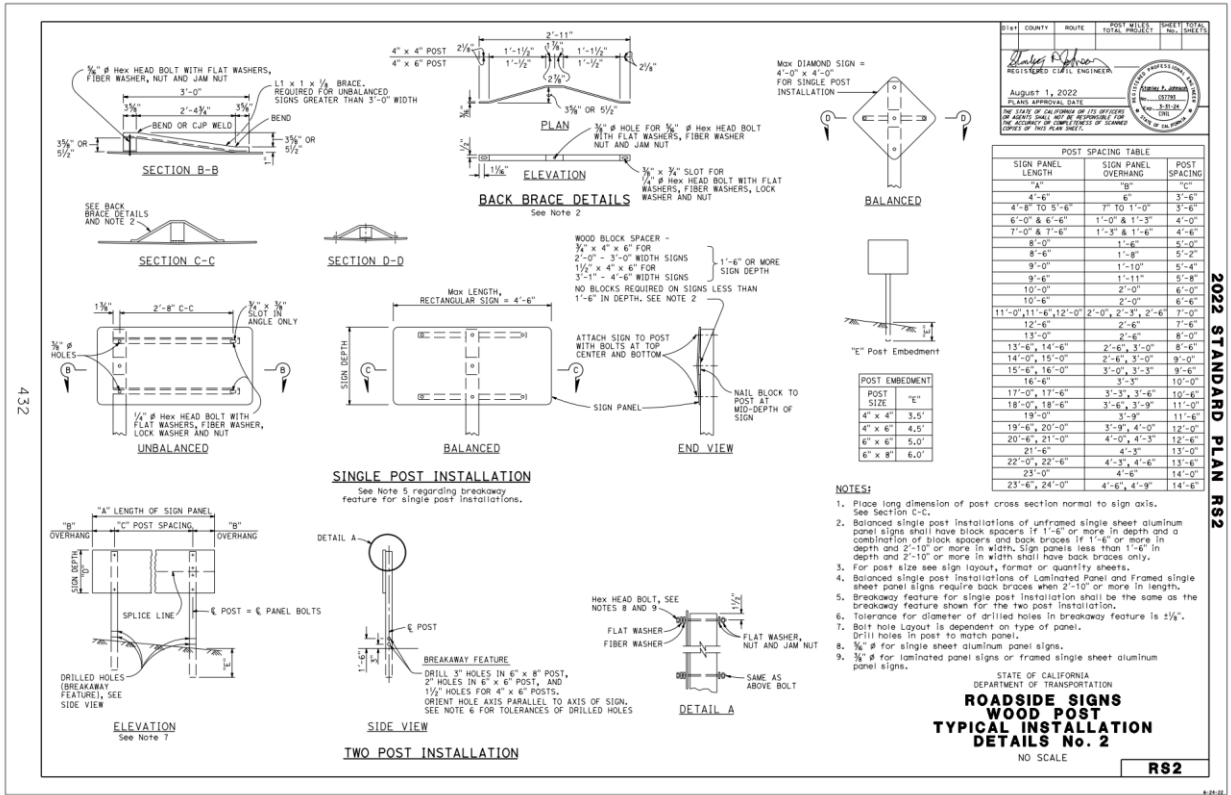


Figure E.E.4: Caltrans drawing (3)

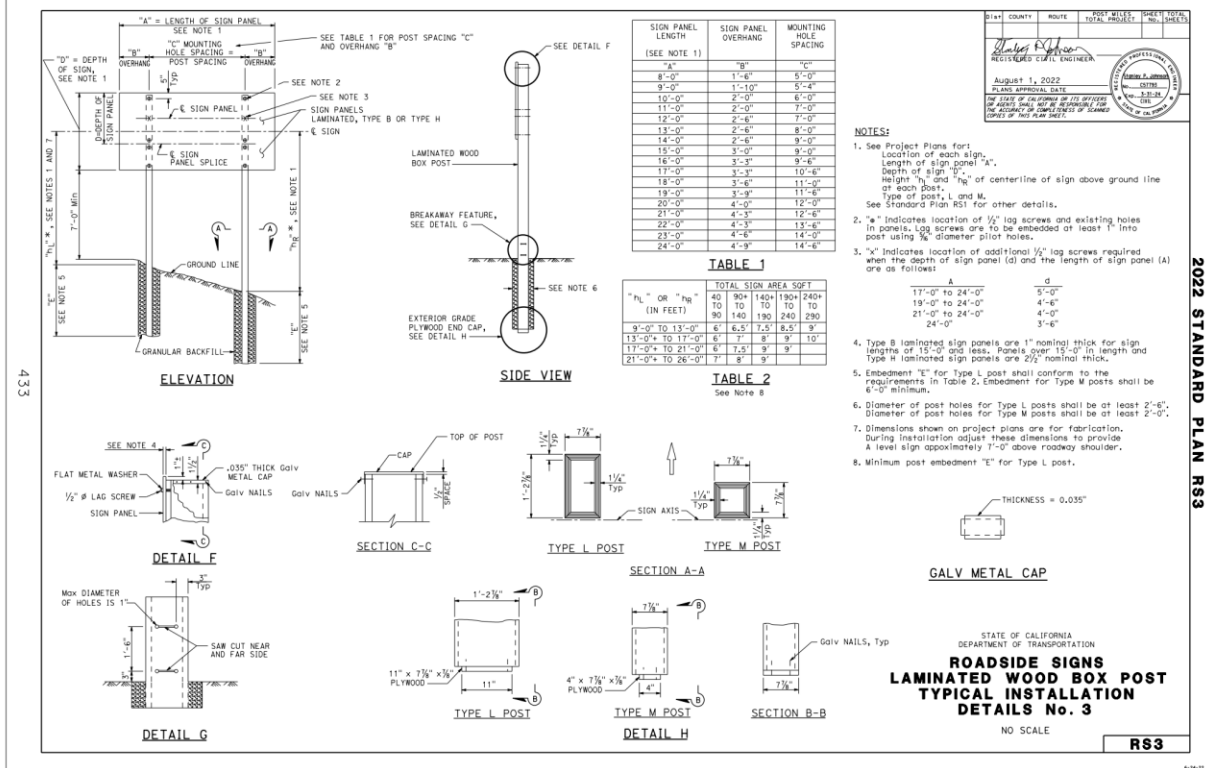


Figure E.E.5: Caltrans drawing (4)

435

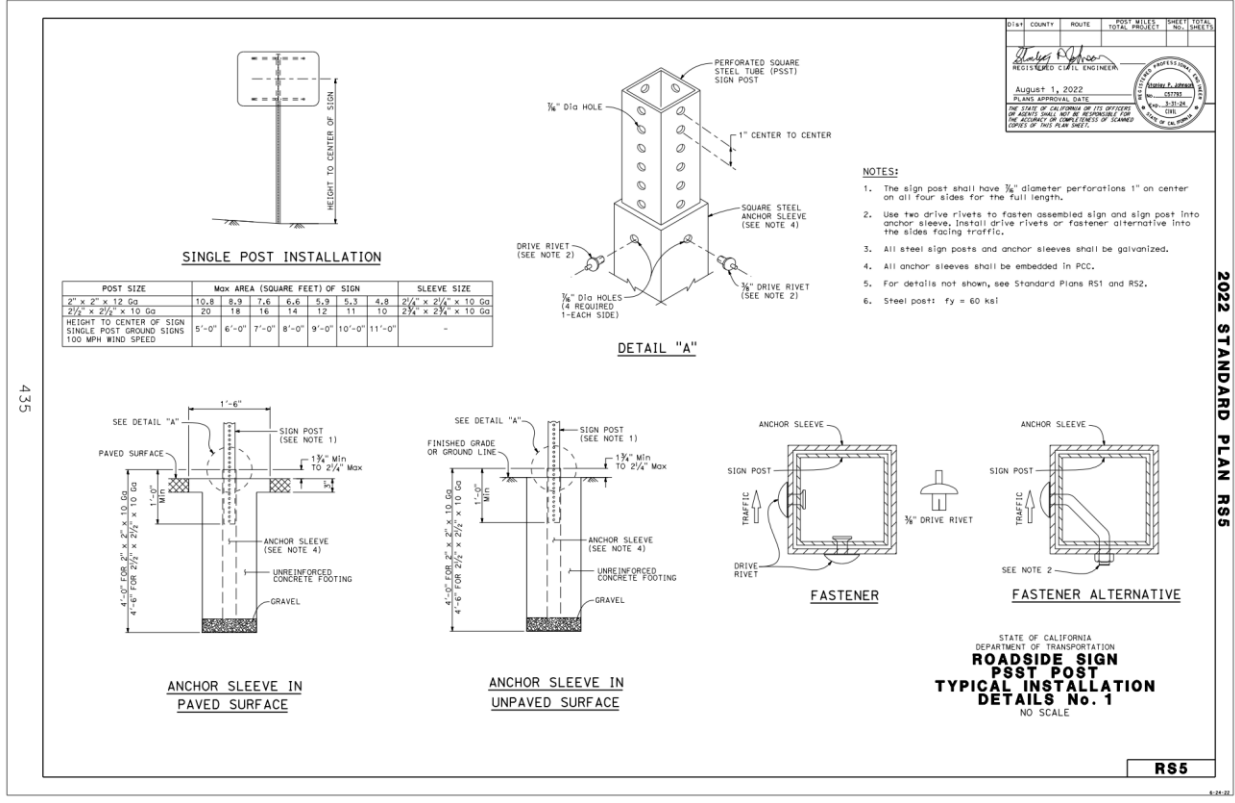


Figure E.E.6: Caltrans drawing (5)

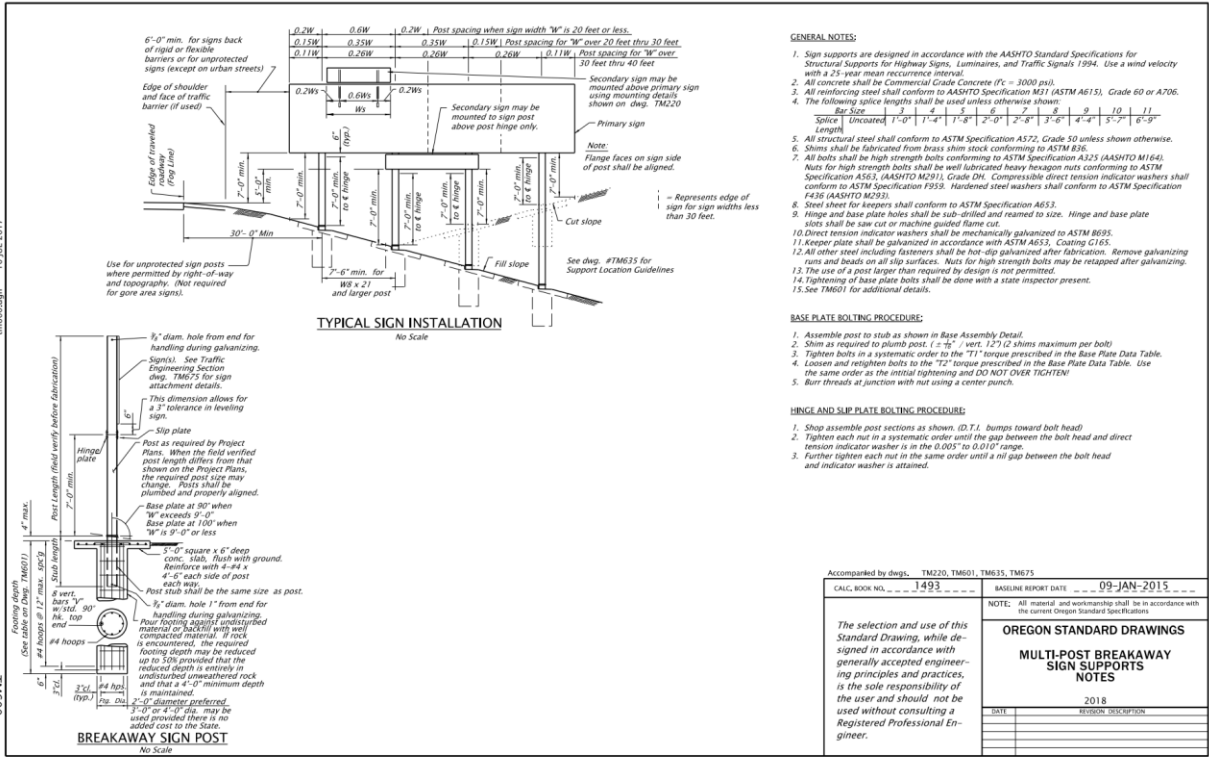


Figure E.E.7: ODOT drawing (1)

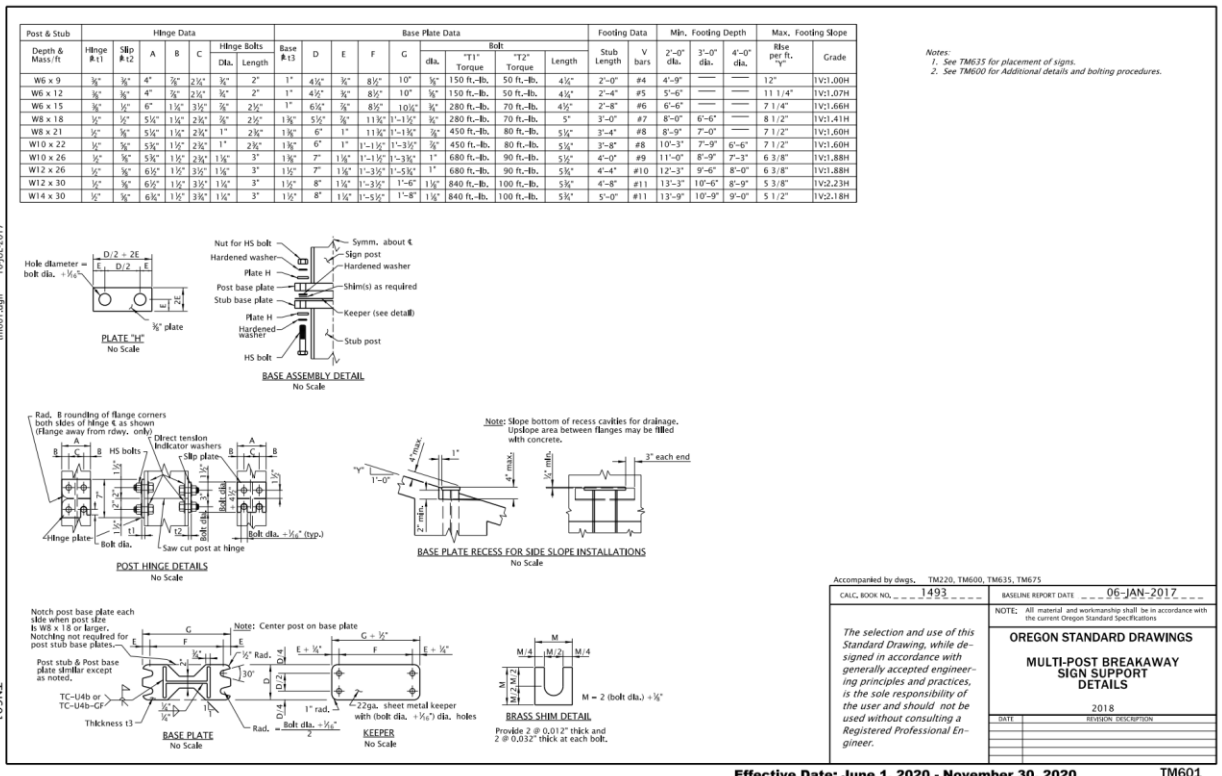


Figure E.E.8: ODOT drawing (2)

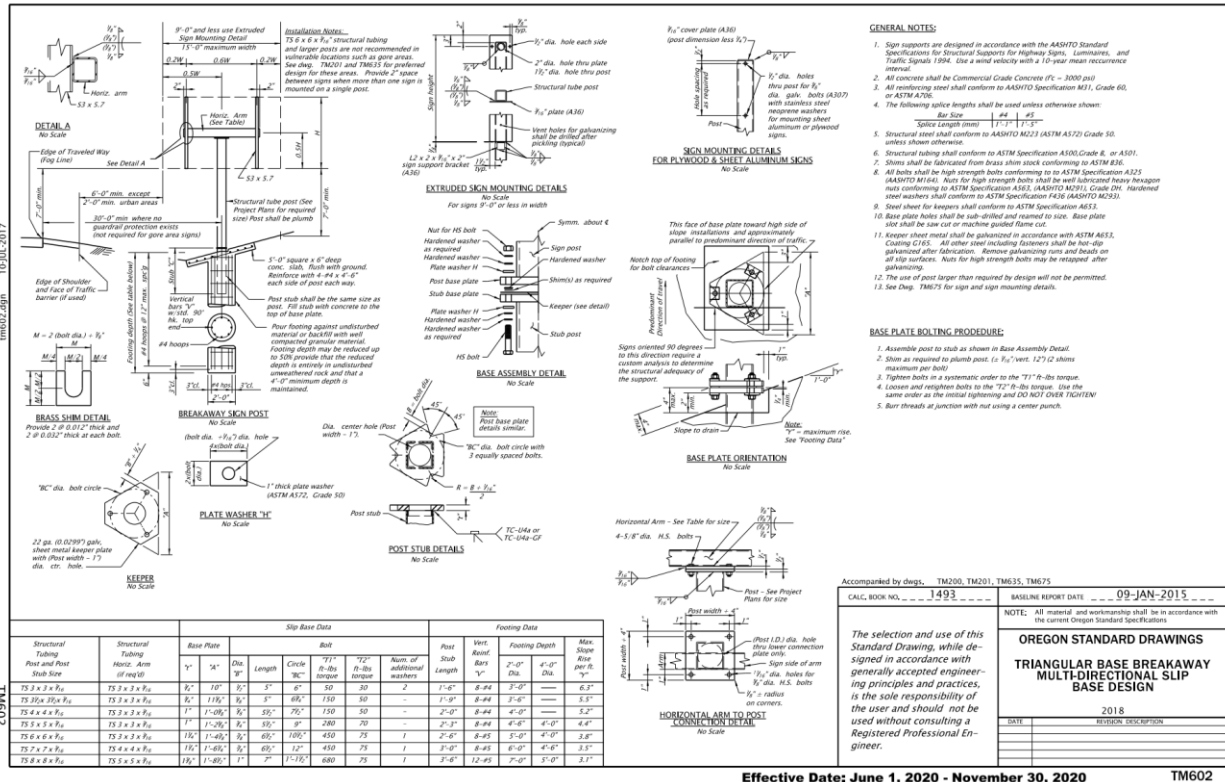


Figure E.E.9: ODOT drawing (3)

Appendix F:

Memo:

Consider Pole Maintenance Issues in Non-Fire Areas (e.g. Gore Areas).

Wooden Poles Must Be Completely Dug Out from the Ground To Replace, While Steel Pole Can Be Replaced By Removing and Replacing a Couple of Rivets

Memorandum

To: Caltrans Panel

From: AHMCT Research Center

Date: October 2nd, 2023

Subject: UPDATED RECOMMENDATIONS – CONSIDER POLE MAINTENANCE ISSUES IN NON-FIRE GORE AREAS

This memorandum highlights the issues of maintaining poles in the gore areas and potentially preventative solutions. Maintaining poles at gore areas is not ideal due to those areas having high probability of vehicle intrusion. The rate of crashes in gore areas is typically higher than the rate of run-off-the-road crashes at other locations [22]. The following sections suggest active and reactive solutions from what Caltrans had already done and what other DOTs had done to mitigate the problems with pole maintenance in gore areas.

- Active solution: install the pole in a time-efficient way if the pole was to get hit
- Reactive solution: prevent the pole from getting hit

Section 1: Caltrans Issued Memorandum

Caltrans had issued a memorandum that addressed the issues of maintaining signs at gore areas [23]. The highlights of that memorandum are as follows: Consideration when repairing existing or installing new exit gore signs:

- Replace the G84-2(CA) or G84-3(CA) signs with larger E5-1a signs and move the signs downstream 150 to 200 feet. The larger signs should be mounted on two wooden posts or two steel posts with approved slip bases (such as the Redi-Torque Model 280 or others) as preferred alternatives
- Replace wooden G84-2(CA) or G84-3(CA) posts with steel posts with quick change base mounts
- Replace standard wooden post installation with wooden posts with wedge type quick change post mounts
- Improve the conspicuity of the gore area with object markers, delineation and/or stripping, especially for gore areas that do not already have a contrasting surface treatment

Section 2: Caltrans Preliminary Investigation

Caltrans had looked into other State DOTs that addressed the issues of maintaining signs at gore areas [24]. The highlights of the investigation are as follows:

- Relocating the signs, using overhead sign structures, and installing pavement markings
 - Four states – Indiana, North Dakota, Ohio, and Rhode Island – reported relocating signs farther back into the exit gore

- Texas – reported placement of exit gore signage on the far right-hand edge of the freeway or shoulder. Texas DOT has considered these locations and others to remove the exit sign from the gore area to limit risk to maintenance personnel when replacing these signs
- Overhead sign structures are used in place of ground-mounted signs in urban areas within Illinois, and have been used in Colorado to sign an urban off-ramp with a challenging layout
- Pavement markings to identify exit lanes are used in six states – Colorado, Indiana, Kentucky, New Hampshire, Rhode Island, and Washington. Applications include the use of route marker shield logos, arrows, wide dotted lines, and diagonals or chevrons
- South Carolina DOT is experimenting with a lightweight, easy-to-replace system for exit gore signs that is composed of two square tube posts and a two-piece sign blank constructed of ALPOLIC⁴ material supplemented with SignFix channels and clamps for mounting
- Texas DOT has delayed exit gore sign replacement until a lane closure could be made at an exit where an employee was recently killed and where other near misses of maintenance personnel have been reported
- Two states are attempting to increase the conspicuity of exit gore signs
 - North Dakota and Rhode Island DOTs use Type 1 object markers (diamond-shaped retroreflective markers used to mark obstructions within or adjacent to the roadway) on or in conjunction with exit gore signs
 - Washington State DOT applies retroreflective sheeting on exit gore sign posts for I-5 exits near Seattle
- South Carolina DOT is in its third year of an on-call vendor contract to repair signs. While major guide and directional signs are replaced fairly quickly after damage or removal under this contract, it can take up to 90 days for exit signs to be replaced because these sign replacements are typically completed in groups within a given area
- South Carolina and Texas DOTs noted that exit gore signs may not be needed when other signage (for example, an overhead sign) is used to provide adequate indication of the exit gore

Section 3: Texas Department of Transportation – Texas A&M University Research

The research “Treatments to Reduce the Frequency of Freeway Exit Sign Hits” conducted by Texas A&M University outlines the major factors of gore area signs being hit and suggests reactive solutions [22].

⁴ A brand of composite metal

The major factors that typically contribute to these sign crashes belong to at least one of the following categories:

- Geometric design characteristics
 - Limited sight distance due to vertical and/or horizontal curve upstream of the exit ramp
 - Significant weaving between closely spaced ramps
 - Shift in horizontal alignment of main lanes
 - Constrained right-of-way
 - Significantly lower advisory speed for ramp and/or frontage road
 - Drop-lane design coupled with limited sight distance
- Driver behavior
 - Inattentive driving
 - Late decision making
 - Excessive speed
- Sign location and placement
 - Visual clutter with other signs
 - Location of exit gore sign too close to pavement
- Pavement marking conditions
 - Faded/worn-out
 - Lane delineators broken or uprooted
- Poor night-time visibility

Table F.1 summarizes the countermeasures. The first four countermeasures address issues related to excessive speeds of vehicles approaching the exit, and potentially large speed differentials between freeway and exit ramp traffic.

Table F.1: Potential countermeasures at the gore area (the pictures are coming from [22] unless stated otherwise)

Countermeasures

Pavement marking as passive speed control devices

- Converging chevrons

Converging chevrons



Source: Report on Passive Speed Control Devices, 2004

- Transverse bars

Transverse bars



Source: Report on Passive Speed Control Devices, 2004

- Peripheral lines

Related Problems

- High operating speeds on approach to exit
- Relatively large speed difference between main line and exit ramp speed

Countermeasures

Related Problems

Peripheral lines



Source: Report on Passive Speed Control Devices, 2004

Rumble strips on the approach lane to the exit



Image source: [Guidelines for Installing Rumble Strips on California State Highways \(https://dot.ca.gov/-/media/dot-media/programs/safety-programs/documents/policy/20-07-rumble-strips-guidelines-and-memo-011421-a11y.pdf\)](https://dot.ca.gov/-/media/dot-media/programs/safety-programs/documents/policy/20-07-rumble-strips-guidelines-and-memo-011421-a11y.pdf)

Ramp speed painted on the pavement in the approach lane to the exit

- High operating speeds on approach to exit
- Relatively large speed difference between main line and exit ramp speed

- High operating speeds on approach to exit
- Relatively large speed difference between main line and exit ramp speed

Countermeasures

Related Problems

Ramp speed painted on the pavement



Advance ramp advisory speed warning sign with flashes



Relocation of exit gore sign farther into gore area

Flexible pylons

- Delineating gore area
- Delineating and extending beyond gore area

- High operating speeds on approach to exit
- Relatively large speed difference between main line and exit ramp speed

Vehicle crashes with exit gore sign

- Late exiting or merging maneuvers
- Vehicles crossing gore area

Countermeasures

Related Problems



“Escape” lane

- On freeway



- On exit ramp

- Late exiting or merging maneuvers
- Vehicles crossing gore area
- Vehicle queue on exit ramp
- Heavy weaving upstream on exit

Countermeasures

Related Problems



Retro-reflective sheeting on sign posts



Image source: [Sign Post Reflectors & Reflective Strips | PEXCO](https://www.pexco.com/traffic/products/pedestrian-safety-products/sign-post-reflectors/)
(<https://www.pexco.com/traffic/products/pedestrian-safety-products/sign-post-reflectors/>)

Reflective object markers on sign posts

Poor night-time visibility

Poor night-time visibility

Countermeasures

Related Problems



Impact attenuator with large retro-reflective bi-directional arrows



Poor delineation and visibility of gore area

Summary

After considering the issues of pole maintenance in gore areas, the active and reactive solutions suggested are:

Active solutions

- Implementing “quick change” base for time-efficient pole replacement
 - Refer to the memorandum “UTILIZE ‘QUICK CHANGE’ FROM DISTRICTS 4 AND 5, INCLUDING SUPPORT SLEEVES AND POSTS” by the AHMCT team

Reactive solutions

- Relocating the signs
- Considering overhead sign structures
- Considering additional pavement markings, especially for gore areas that do not already have a contrasting surface treatment
- Considering “escape” lane
- Considering retro-reflective sheeting on sign posts
- Considering maintaining the poles at the gore area on a case by case basis
 - Hire contractors (South Carolina DOT)
 - Delay until lane closure when there is a near-miss or an accident at the reported location (Texas DOT)

Appendix G:

Memo:

Convert Metal Beam Guardrail Locations into Concrete Barriers to Reduce Maintenance Effort and Staff Exposure (While Ensuring This Approach Is Safe for End Users)

Memo G.1: Install Metal Guardrails Based On Fire Danger Rating Map (While Ensuring This Approach Is Safe For End Users)

Memorandum 1

To: Caltrans Panel

From: AHMCT Research Center

Date: July 7th, 2023

Subject: UPDATED RECOMMENDATIONS – INSTALL METAL POSTS BASED ON FIRE DANGER RATING MAP (WHILE ENSURING THIS APPROACH IS SAFE FOR END USERS)

This memorandum focuses on utilizing resources identifying fire zones in California to help with the decision of installing metal guardrails. These resources are from the U.S. Department of Agriculture (USDA), specifically the U.S. Forest Service (USFS). Work that USDA has done over the years includes:

- Management of 193 million acres of public lands in 43 states and Puerto Rico for multiple uses.
- Sustainable stewardship of more than 600 million acres of forestland across the U.S., including more than 400 million acres of private land.
- The largest forestry research organization in the world.
- Sustainable stewardship of forests in more than 80 countries.
- The USDA, with the collaboration of other government agencies, has developed multiple map applications that do not require an account or fee. These materials can be utilized to support Caltrans in designing, drafting proposals, and planning. The link to this resource is [USFS Data and Tools](https://usfs.maps.arcgis.com/apps/MinimalGallery/index.html?appid=46e069c721bb49c6abe5a9d57e3a365f)
(<https://usfs.maps.arcgis.com/apps/MinimalGallery/index.html?appid=46e069c721bb49c6abe5a9d57e3a365f>)

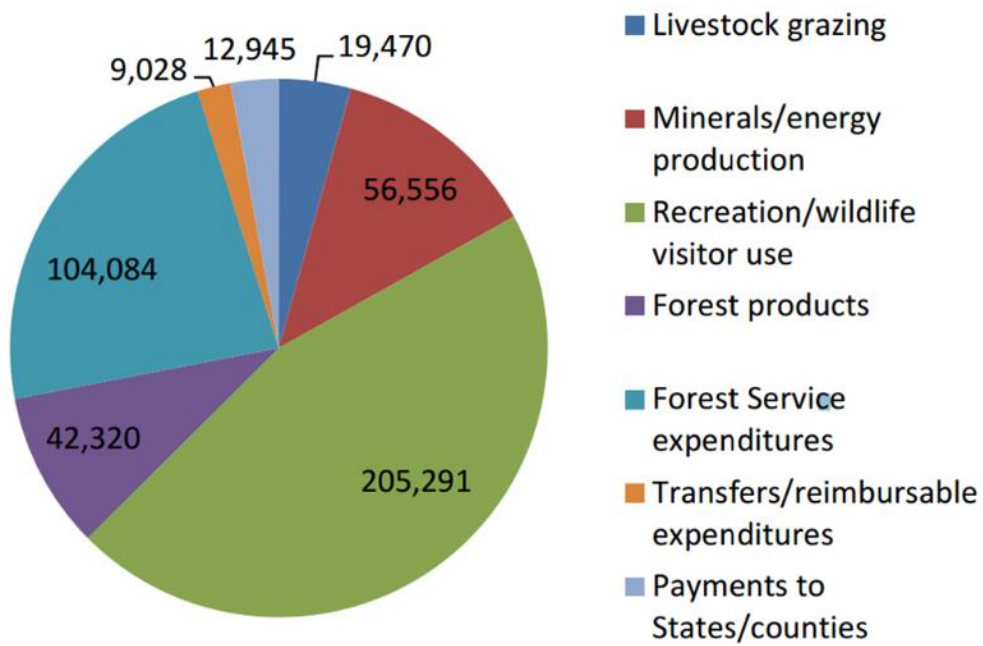


Figure G.1.1: The diagram shows jobs supported in various industries across the U.S. Diagram courtesy of the USDA – USFS.

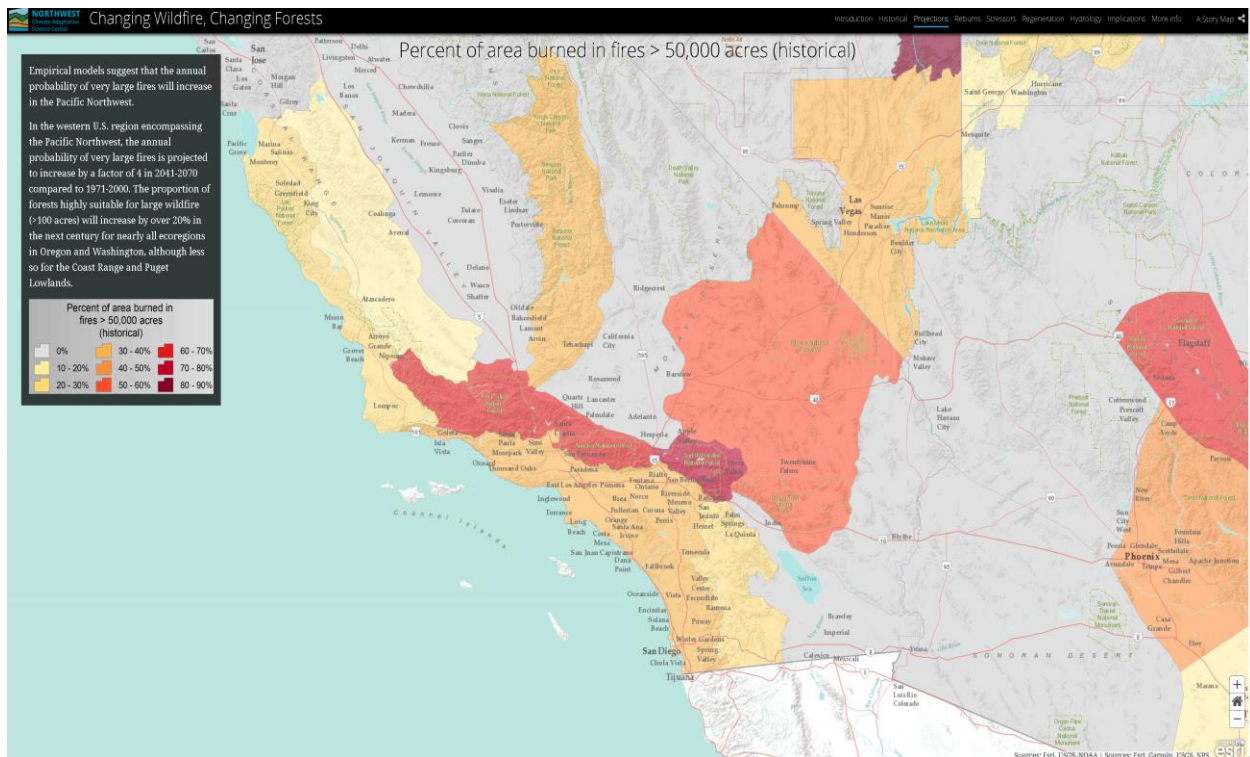


Figure G.1.2: One of the map applications that displays historical data. The map might not display the zone of interest, thus users have to adjust the map using the mouse. Image courtesy of Esri, Garmin, U.S. Geological Survey (USGS), National Park Service (NPS), and National Oceanic and Atmospheric Administration (NOAA).

In addition, the AHMCT team created a comprehensive map where data is centralized. Click on the hyperlink to view the data information in details. The data sets included in the map are:

- [U.S. population density](https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_PopulationDensity/ImageServer/info/iteminfo)
(https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_PopulationDensity/ImageServer/info/iteminfo)

This data reflects 2018 estimates of population counts from the U.S. Census Bureau

- [Wildfire risk to communities – fire exposure type](https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_ExposureType/ImageServer/info/iteminfo)
(https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_ExposureType/ImageServer/info/iteminfo)

Wildfire exposure is the spatial coincidence of wildfire likelihood and intensity with communities. This data layer delineates where structures are directly exposed to wildfire from adjacent wildland vegetation, indirectly exposed to wildfire from indirect sources such as embers and home-to-home ignition, or not exposed to wildfire due to distance from direct and indirect ignition sources (> 1 mile).

- **[Wildfire risk to communities – conditional flame length \(CFL\)](https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_ConditionalFlameLength/ImageServer)**
(https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_ConditionalFlameLength/ImageServer)

The values of CFL represent the most likely flame length at a given location if a fire occurs, based on wildfire simulation modeling. This is an average measure of wildfire intensity.

- **[Wildfire risk to communities – building exposure](https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_Building_Exposure/ImageServer/info/iteminfo)**
(https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_Building_Exposure/ImageServer/info/iteminfo)

Exposure is the spatial coincidence of wildfire likelihood and intensity with communities. The Building Exposure layer delineates whether buildings at each pixel are directly exposed to wildfire from adjacent wildland vegetation (pixel value 1), indirectly exposed to wildfire from indirect sources such as embers and home-to-home ignition (pixel values between 0 and 1), or not exposed to wildfire due to distance from direct and indirect ignition sources (pixel value 0). It is similar to Exposure Type in the companion data publication (Scott et al. 2020, datasets of landscape-wide wildfire risk components), but just in places where housing units or other buildings are present.

- **[Wildfire risk to communities – burn probability \(BP\)](https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_Building_Exposure/ImageServer/info/iteminfo)**
(https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_Building_Exposure/ImageServer/info/iteminfo)

BP represents the annual probability of wildfire burning in a specific location.

- **[Wildfire risk to communities – risk to potential structures \(RPS\)](https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_RiskToPotentialStructures/ImageServer/info/iteminfo)**
(https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WRC_RiskToPotentialStructures/ImageServer/info/iteminfo)

RPS is a measure that integrates wildfire likelihood and intensity with generalized consequences to a structure on every pixel. For every location, it answers the hypothetical question, "What would be the relative risk to a house if one existed here?" This allows comparison of wildfire risk in places where homes already exist to places where new construction may be proposed.

- **[Wildfire risk to communities – wildfire hazard potential \(WHP\)](https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WildfireHazardPotential_classified_2020/ImageServer/info/iteminfo)**
(https://apps.fs.usda.gov/fsgisx01/rest/services/RDW_Wildfire/RMRS_WildfireHazardPotential_classified_2020/ImageServer/info/iteminfo)

WHP is an index that quantifies the relative potential for wildfire that may be difficult to control, used as a measure to help prioritize where fuel treatments may be needed. The final WHP map is presented in five WHP classes of very low, low, moderate, high, and very high. On its own, WHP is not an explicit map of wildfire threat or risk, but when paired with spatial data depicting

highly valued resources and assets such as structures or power lines, it can approximate relative wildfire risk to those specific resources and assets. WHP is also not a forecast or wildfire outlook for any particular season, as it does not include any information on current or forecasted weather or fuel moisture conditions. It is instead intended for long-term strategic fuels management.

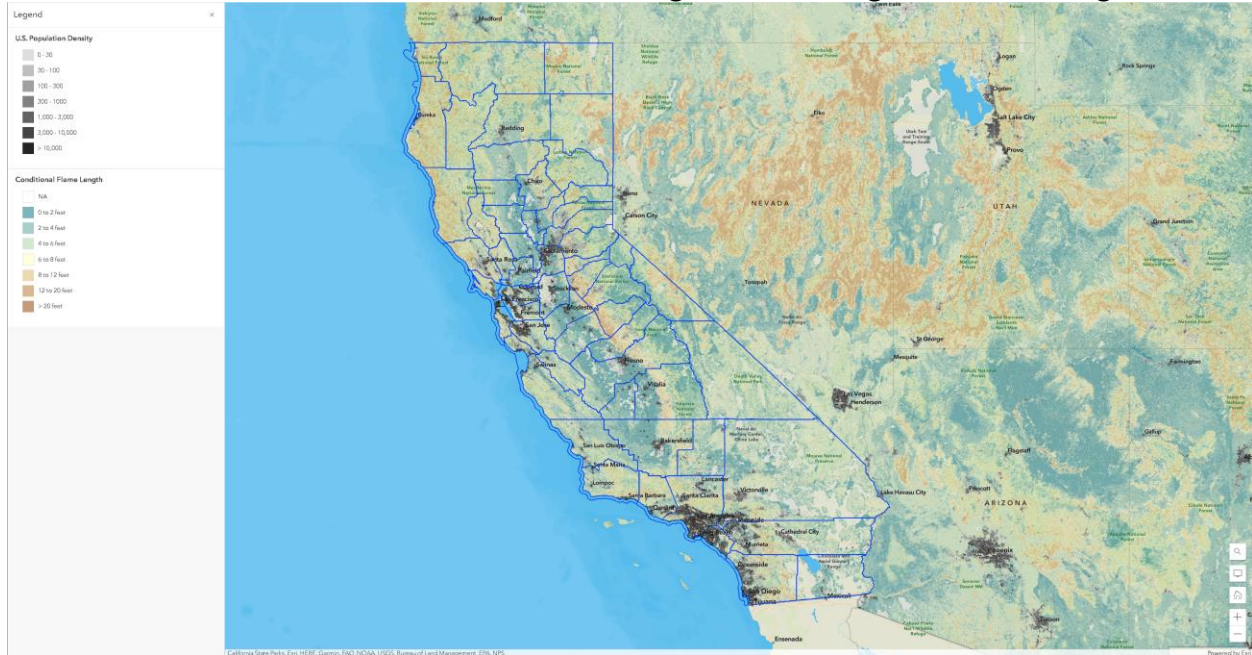


Figure G.1.3: An example of the comprehensive map. This particular data set is credited to California State Parks, Esri, Homeland Emergency Response Exchange (HERE), Garmin, Food and Agriculture Organization (FAO), NOAA, USGS, Bureau of Land Management, Environmental Protection Agency (EPA), and NPS.

Overall recommendation

Along with the comprehensive mapping, the AHMCT team provided an instructional video on how to navigate the map and understand the data. The AHMCT team centralized the data and adjusted its cosmetic settings to enhance user experience. The data is credited to the USDA and other respective government agencies.

It is recommended that Caltrans utilize USDA – Forest Service map applications and the comprehensive map. Historical fire data, simulated fire data, and current fire data will aid Caltrans in the decision of installing metal posts.

Recommendations for using the comprehensive map

- Watch the instructional video provided by the AHMCT team.
- The fire exposure type, conditional flame length, building exposure, burn probability, risk to potential structures, and wildfire hazard potential layers should be viewed **one at a time**.

Resources

Data for wildfire risk for populated areas: [Forest Service Research Data Archive \(https://www.fs.usda.gov/rds/archive/catalog/RDS-2020-0060\)](https://www.fs.usda.gov/rds/archive/catalog/RDS-2020-0060)

Data for landscape-wide wildfire risk components: [Forest Service Research Data Archive \(https://www.fs.usda.gov/rds/archive/Catalog/RDS-2020-0016\)](https://www.fs.usda.gov/rds/archive/Catalog/RDS-2020-0016) (note: this link is different from wildfire risk for populated area)

Map applications: [U.S. Forest Service Climate Gallery \(https://usfs.maps.arcgis.com/apps/MinimalGallery/index.html?appid=46e069c721bb49c6abe5a9d57e3a365f\)](https://usfs.maps.arcgis.com/apps/MinimalGallery/index.html?appid=46e069c721bb49c6abe5a9d57e3a365f)

AHMCT comprehensive map: [Fire Rating Map \(https://ucdavis.maps.arcgis.com/apps/mapviewer/index.html?webmap=1066d38d8b2a497e9e3d82eaf5b6c160\)](https://ucdavis.maps.arcgis.com/apps/mapviewer/index.html?webmap=1066d38d8b2a497e9e3d82eaf5b6c160)

Acknowledgement

Scott, Joe H.; Gilbertson-Day, Julie W.; Moran, Christopher; Dillon, Gregory K.; Short, Karen C.; Vogler, Kevin C. 2020. Wildfire Risk to Communities: Spatial datasets of landscape-wide wildfire risk components for the United States. Fort Collins, CO: Forest Service Research Data Archive. Updated 25 November 2020. DOI (<https://doi.org/10.2737/RDS-2020-0016>)

Scott, Joe H.; Brough, April M.; Gilbertson-Day, Julie W.; Dillon, Gregory K.; Moran, Christopher. 2020. Wildfire Risk to Communities: Spatial datasets of wildfire risk for populated areas in the United States. Fort Collins, CO: Forest Service Research Data Archive. DOI (<https://doi.org/10.2737/RDS-2020-0060>)

Memo G.2: Install Sign Posts Based On Fire Danger Rating Map (While Ensuring This Approach Is Safe For End Users)

Memorandum 2

To: Caltrans Panel

From: AHMCT Research Center

Date: October 2nd, 2023

Subject: UPDATED RECOMMENDATIONS – INSTALL SIGN POSTS BASED ON FIRE DANGER RATING MAP (WHILE ENSURING THIS APPROACH IS SAFE FOR END USERS)

This memorandum focuses on utilizing resources identifying fire zones in California to help with the decision of installing steel sign posts. This memorandum is an extension to the memorandum “UPDATED RECOMMENDATIONS – INSTALL METAL GUARDRAILS BASED ON FIRE DANGER RATING MAP (WHILE ENSURING THIS APPROACH IS SAFE FOR END USERS)” researched by the AHMCT team. Although the content of the two memorandums is interchangeable, this memorandum focuses more on steel sign posts as opposed to metal guardrails.

While guardrail sections can be identified by route and highway names, sign posts require the location to be more specific. Thus, the AHMCT team recommended using Google Earth Map Data developed by the Wildland Fire Assessment System (WFAS). The data displays current weather, fire danger, fuel moisture observation, and forecast weather conditions when available. In addition, the data is updated daily and automatically. Using the Google Earth application, the user can pinpoint the location of interest using latitude and longitude. The link to this is: [Google Earth Map Data \(https://www.wfas.net/index.php?option=com_content&view=article&id=80&Itemid=483\)](https://www.wfas.net/index.php?option=com_content&view=article&id=80&Itemid=483).

The WFAS has fire potential and fire danger maps that are updated daily and automatically. A fire danger rating level takes into account current and antecedent weather, fuel types, and both live and dead fuel moisture. The link to this is: [Fire Danger Rating \(https://www.wfas.net/index.php?option=com_content&view=article&id=75&Itemid=478\)](https://www.wfas.net/index.php?option=com_content&view=article&id=75&Itemid=478).

The WFAS has an interactive map. The user can interact and display the data to their reference. The map is updated daily and automatically. The link to this is: [Wildland Fire Assessment System - Severe Fire Danger Mapping System \(https://m.wfas.net/\)](https://m.wfas.net/).

Additional information: Wildland Fire Assessment System (WFAS) credentials [12]

The system is an integrated, web-based resource to support fire management decisions. It has an extensive nationwide user base of federal, state, and local land managers. The system provides multi-temporal and multi-spatial views of fire weather and fire potential, including fuel moistures and fire danger classes from the US National Fire Danger Rating System (NFDRS), Keetch-Byram and Palmer drought indices, lower atmospheric stability, and satellite-derived vegetation conditions. It provides fire potential forecasts from 24 hours to 30 days.