

# California Demonstration Project: Safety Improvements on Mountain Ranch Road in Calaveras County

**Final Report  
June 2013**

***HIGHWAYS FOR LIFE***

*Accelerating Innovation for the American Driving Experience.*



U.S. Department of Transportation  
**Federal Highway Administration**

## FOREWORD

The purpose of the Highways for LIFE (HfL) pilot program is to accelerate the use of innovations that improve highway safety and quality while reducing congestion caused by construction. **LIFE** is an acronym for **L**onger-lasting highway infrastructure using **I**nnovations to accomplish the **F**ast construction of **E**fficient and safe highways and bridges.

Specifically, HfL focuses on speeding up the widespread adoption of proven innovations in the highway community. Such “innovations” encompass technologies, materials, tools, equipment, procedures, specifications, methodologies, processes, and practices used to finance, design, or construct highways. HfL is based on the recognition that innovations are available that, if widely and rapidly implemented, would result in significant benefits to road users and highway agencies.

Although innovations themselves are important, HfL is as much about changing the highway community’s culture from one that considers innovation something that only adds to the workload, delays projects, raises costs, or increases risk to one that sees it as an opportunity to provide better highway transportation service. HfL is also an effort to change the way highway community decisionmakers and participants perceive their jobs and the service they provide.

The HfL pilot program, described in Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) Section 1502, includes funding for demonstration construction projects. By providing incentives for projects, HfL promotes improvements in safety, construction-related congestion, and quality that can be achieved through the use of performance goals and innovations. This report documents one such HfL demonstration project.

Additional information on the HfL program is at [www.fhwa.dot.gov/hfl](http://www.fhwa.dot.gov/hfl).

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1. Report No.	2. Government Accession No	3. Recipient's Catalog No	
3. Title and Subtitle California Demonstration Project: Safety Improvements on Mountain Ranch Road in Calaveras County		5. Report Date June 2013	6. Performing Organization Code
7. Authors Shreenath Rao, Ph.D., P.E., Suri Sadasivam, Ph.D., Jagannath Mallela		8. Performing Organization Report No.	
9. Performing Organization Name and Address Applied Research Associates, Inc. 100 Trade Centre Drive, Suite 200 Champaign, IL 61820		10. Work Unit No. (TRAIS) C6B	11. Contract or Grant No.
12. Sponsoring Agency Name and Address Office of Infrastructure Federal Highway Administration 1200 New Jersey Avenue, SE Washington, DC 20590		12. Type of Report and Period Covered Draft Final Report	14. Sponsoring Agency Code
15. Supplementary Notes Contracting Officers Technical Representatives: Byron Lord, Mary Huie, Ewa Flom			
16. Abstract As part of a national initiative sponsored by the Federal Highway Administration under the Highways for LIFE program, Calaveras County, CA, was awarded a \$300,000 grant to conduct a road safety audit (RSA), develop plans and specifications, and perform safety improvements on Mountain Ranch Road east of San Andreas.  The key innovation was the addition of a 2-inch hot-mix asphalt overlay with a Safety Edge <sup>SM</sup> to an approximately 2.1-mile (mi) segment of Mountain Ranch Road (Boo Street to Upper Michel Road) that needed it. The county had identified it as area with enough right-of-way and/or shoulder room to properly construct the Safety Edge (easterly segment). The second safety component was the installation of highly retroreflective striping on top of centerline rumble strips to help keep drivers from drifting into the adjacent lane and oncoming traffic (easterly, center, and westerly segments). The third safety component was backing and/or extending the aggregate base shoulders along segments of the overlaid section that required it for the addition of the Safety Edge and segments that did not get the Safety Edge treatment but would benefit from an improved or widened shoulder (easterly and westerly segments). The fourth safety component was the installation of new metal beam guardrail (MBGR) along a 1.60-mi segment of Mountain Ranch Road. The improvements include new MBGR beginning at the intersection of Rocky Road and terminating at the western intersection of Michel Road (westerly segment). In addition to the construction components, planning and evaluation procedures, including an RSA, and a project information campaign were implemented to maximize the effectiveness of this project.  The project was a great success, and the safety improvements are expected to substantially reduce the crash and fatality rates on Mountain Ranch Road. A detailed economic analysis considering all costs associated with building the as-constructed section versus the baseline section and the economic benefits from improved safety over a 10-year period showed substantial cost benefits for the as-constructed project. The life cycle cost analysis showed a total savings of \$7,889,157.73 for the as-constructed case compared to the baseline case.			
17. Key Words Safety, crash, road safety audit, Safety Edge, guardrails		18. Distribution Statement No restriction. This document is available to the public through the Highways for Life website: <a href="http://www.fhwa.dot.gov/hfl/">http://www.fhwa.dot.gov/hfl/</a>	
Security Classif.(of this report) Unclassified	19. Security Classif. (of this page) Unclassified	20. No. of Pages 48	21. Price

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol
<b>LENGTH</b>				
(none)	mil	25.4	micrometers	µm
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
<b>AREA</b>				
in <sup>2</sup>	square inches	645.2	square millimeters	mm <sup>2</sup>
ft <sup>2</sup>	square feet	0.093	square meters	m <sup>2</sup>
yd <sup>2</sup>	square yards	0.836	square meters	m <sup>2</sup>
ac	acres	0.405	hectares	ha
mi <sup>2</sup>	square miles	2.59	square kilometers	km <sup>2</sup>
<b>VOLUME</b>				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft <sup>3</sup>	cubic feet	0.028	cubic meters	m <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.765	cubic meters	m <sup>3</sup>
NOTE: volumes greater than 1000 L shall be shown in m <sup>3</sup>				
<b>MASS</b>				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
<b>TEMPERATURE (exact degrees)</b>				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
<b>ILLUMINATION</b>				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela per square meter	cd/m <sup>2</sup>
<b>FORCE and PRESSURE or STRESS</b>				
lbf	poundforce	4.45	Newtons	N
lbf/in <sup>2</sup> (psi)	poundforce per square inch	6.89	kiloPascals	kPa
k/in <sup>2</sup> (ksi)	kips per square inch	6.89	megaPascals	MPa
<b>DENSITY</b>				
lb/ft <sup>3</sup> (pcf)	pounds per cubic foot	16.02	kilograms per cubic meter	kg/m <sup>3</sup>
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol
<b>LENGTH</b>				
µm	micrometers	0.039	mil	(none)
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
<b>AREA</b>				
mm <sup>2</sup>	square millimeters	0.0016	square inches	in <sup>2</sup>
m <sup>2</sup>	square meters	10.764	square feet	ft <sup>2</sup>
m <sup>2</sup>	square meters	1.195	square yards	yd <sup>2</sup>
ha	hectares	2.47	acres	ac
km <sup>2</sup>	square kilometers	0.386	square miles	mi <sup>2</sup>
<b>VOLUME</b>				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m <sup>3</sup>	cubic meters	35.314	cubic feet	ft <sup>3</sup>
m <sup>3</sup>	cubic meters	1.307	cubic yards	yd <sup>3</sup>
<b>MASS</b>				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
<b>TEMPERATURE</b>				
°C	Celsius	1.8C+32	Fahrenheit	°F
<b>ILLUMINATION</b>				
lx	lux	0.0929	foot-candles	fc
cd/m <sup>2</sup>	candela per square meter	0.2919	foot-Lamberts	fl
<b>FORCE and PRESSURE or STRESS</b>				
N	Newtons	0.225	poundforce	lbf
kPa	kiloPascals	0.145	poundforce per square inch	lbf/in <sup>2</sup> (psi)
MPa	megaPascals	0.145	kips per square inch	k/in <sup>2</sup> (ksi)

## **ACKNOWLEDGMENTS**

The project team would like to acknowledge the invaluable insights and guidance of Federal Highway Administration (FHWA) Highways for LIFE Team Leader Byron Lord and Program Coordinators Mary Huie, Ewa Flom, and Kathleen Bergeron, who served as the technical panel on this demonstration project. Their vast knowledge and experience with the various aspects of construction, technology deployment, and technology transfer helped immensely in developing both the approach and the technical matter for this document.

The team is also indebted to Project Resident Engineer Ivy Lane, Calaveras County Engineers Jonathan Mitchell and Steven Hollenbeak, and FHWA Engineers Ken Kochevar and Steve Healow for their assistance during this project.

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## ABBREVIATIONS AND SYMBOLS

AADT	annual average daily traffic
dB(A)	A-weighted decibel
Caltrans	California Department of Transportation
CMF	crash modification factors
FHWA	Federal Highway Administration
HfL	Highways for LIFE
HMA	hot-mix asphalt
IRI	International Roughness Index
JMF	job mix formula
LCCA	life cycle cost analysis
MBGR	metal beam guardrail
NPV	net present value
OBSI	onboard sound intensity
OSHA	Occupational Safety and Health Administration
pcf	pounds per cubic foot
RSA	road safety audit
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SWITRS	Statewide Integrated Traffic Records System
VMT	vehicle miles traveled

# INTRODUCTION

## HIGHWAYS FOR LIFE DEMONSTRATION PROJECTS

The Highways for LIFE (HfL) pilot program, the Federal Highway Administration (FHWA) initiative to accelerate innovation in the highway community, provides incentive funding for demonstration construction projects. Through these projects, the HfL program promotes and documents improvements in safety, construction-related congestion, and quality that can be achieved by setting performance goals and adopting innovations.

The HfL program—described in the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU)—may provide incentives to a maximum of 15 demonstration projects a year. The funding amount may total up to 20 percent of the project cost, but not more than \$5 million. Also, the Federal share for an HfL project may be up to 100 percent, thus waiving the typical State-match portion. At the State's request, a combination of funding and waived match may be applied to a project.

To be considered for HfL funding, a project must involve constructing, reconstructing, or rehabilitating a route or connection on an eligible Federal-aid highway. It must use innovative technologies, manufacturing processes, financing, or contracting methods that improve safety, reduce construction congestion, and enhance quality and user satisfaction. To provide a target for each of these areas, HfL has established demonstration project performance goals.

The performance goals emphasize the needs of highway users and reinforce the importance of addressing safety, congestion, user satisfaction, and quality in every project. The goals define the desired result while encouraging innovative solutions, raising the bar in highway transportation service and safety. User-based performance goals also serve as a new business model for how highway agencies can manage the project delivery process.

HfL project promotion involves showing the highway community and the public how demonstration projects are designed and built and how they perform. Broadly promoting successes encourages more widespread application of performance goals and innovations in the future.

### **Project Solicitation, Evaluation, and Selection**

FHWA issued open solicitations for HfL project applications in fiscal years 2006 through 2012. State highway agencies submitted applications through FHWA Divisions. The HfL team reviewed each application for completeness and clarity, then contacted applicants to discuss technical issues and obtain commitments on project issues. Documentation of these questions and comments was sent to applicants, who responded in writing.

The project selection panel consisted of representatives of the FHWA offices of Infrastructure, Safety, and Operations; the Resource Center Construction and Project Management team; the Division offices; and the HfL team. After evaluating and rating the applications and

supplemental information, panel members convened to reach a consensus on the projects to recommend for approval. The panel gave priority to projects that accomplish the following:

- Address the HfL performance goals for safety, construction congestion, quality, and user satisfaction.
- Use innovative technologies, manufacturing processes, financing, contracting practices, and performance measures that demonstrate substantial improvements in safety, congestion, quality, and cost-effectiveness. An innovation must be one the applicant State has never or rarely used, even if it is standard practice in other States.
- Include innovations that will change administration of the State's highway program to more quickly build long-lasting, high-quality, cost-effective projects that improve safety and reduce congestion.
- Will be ready for construction within 1 year of approval of the project application. For the HfL program, FHWA considers a project ready for construction when the FHWA Division authorizes it.
- Demonstrate the willingness of the applicant department of transportation (DOT) to participate in technology transfer and information dissemination activities associated with the project.

### **HfL Project Performance Goals**

The HfL performance goals focus on the expressed needs and wants of highway users. They are set at a level that represents the best of what the highway community can do, not just the average of what has been done. States are encouraged to use all applicable goals on a project:

- **Safety**
  - Work zone safety during construction—Work zone crash rate equal to or less than the preconstruction rate at the project location.
  - Worker safety during construction—Incident rate for worker injuries of less than 4.0, based on incidents reported on Occupational Safety and Health Administration (OSHA) Form 300.
  - Facility safety after construction—Twenty percent reduction in fatalities and injuries in 3-year average crash rates, using preconstruction rates as the baseline.
- **Construction Congestion**
  - Faster construction—Fifty percent reduction in the time highway users are impacted, compared to traditional methods.
  - Trip time during construction—Less than 10 percent increase in trip time compared to the average preconstruction speed, using 100 percent sampling.
  - Queue length during construction—A moving queue length of less than 0.5 miles (mi) in a rural area or less than 1.5 mi in an urban area (in both cases at a travel speed 20 percent less than the posted speed).
- **Quality**
  - Smoothness—International Roughness Index (IRI) measurement of less than 48 inches per mile (in/mi).

- Noise—Tire-pavement noise measurement of less than 96.0 A-weighted decibels (dB(A)), using the onboard sound intensity (OBSI) test method.
- **User satisfaction**—An assessment of how satisfied users are with the new facility compared to its previous condition and with the approach used to minimize disruption during construction. The goal is a measurement of 4 or more on a 7-point Likert scale.

## **REPORT SCOPE AND ORGANIZATION**

This report documents the Calaveras County, CA, HfL demonstration project featuring innovative safety improvements to Mountain Ranch Road. The report presents project information relevant to the innovations, including a road safety audit (RSA) conducted before construction; use of the Safety Edge<sup>SM</sup>; and installation of guardrails, fog lines, highly retroreflective striping, and rumble strips. The report includes an economic analysis and summarizes the technology transfer activities conducted as part of this project.

## **PROJECT OVERVIEW AND LESSONS LEARNED**

### **PROJECT OVERVIEW**

Mountain Ranch Road is a two-lane undivided mountainous road that connects the Calaveras County seat of San Andreas to the communities in the northeastern portion of the county. The traffic volume on this roadway is low, ranging from 1,900 at the eastern end of the roadway to 4,960 near its western terminus at State Route 49. The 2009 two-way weighted average annual daily traffic (AADT) for the portion relevant to the HfL project was 2,272.

The key innovations on this project were safety improvements on three segments of the roadway. Safety components included a hot-mix asphalt (HMA) overlay with a Safety Edge on an approximately 2.1-mi segment (Boo Street to Upper Michel Road (easterly segment)), installation of highly retroreflective striping on top of ground-in centerline rumble strips (Rocky Road to Upper Michel Road (all three segments)), backing and/or extending the aggregate base shoulders along portions of the roadway, installation of new metal beam guardrail (MBGR) along a 1.60 mi segment (Rocky Road to Lower Michel Road (westerly segment)). An RSA was conducted during the preengineering phase of this project. The audit was location-specific and focused on the three most common crash sites on the road, according to the California Statewide Integrated Traffic Records System (SWITRS) database. The RSA identified specific locations for installation of the guardrails and strategic relocation and installation of signage and delineators to discourage maximum speeds on approaches to sharp curves.

The construction activities were done between August 16 and December 14, 2012. Portions of one traffic lane were closed for 129.75 hours over 16 days during this period. The adjacent lane was open to one-lane traffic, and vehicles were escorted through the closure zone by a pilot car, one direction at a time.

### **DATA COLLECTION**

Safety, construction congestion, quality, and user satisfaction data were collected before, during, and after construction to demonstrate that the project innovations can be used to achieve the HfL performance goals in these areas.

The HfL performance goals for safety include meeting both worker and motorist safety goals during construction. During the construction of this project, no workers were injured, so the contractor exceeded the HfL goal for worker safety (incident rate of less than 4.0 based on the OSHA 300 rate). Calaveras County did not set a goal for crash rates during construction, and no work zone crashes were reported.

Calaveras County did not set a performance goal for motorist delay because of the rural location and low traffic volume on this roadway. During the 129.75 hours of partial closure affecting one traffic lane, an estimated 14,740 vehicles were delayed because they had to wait at the end of the closure zones for the return of the pilot car to escort them through the closure zone. The average delay per vehicle was 14 minutes, based on data collected during construction. The maximum

queue length at the flagger was observed to range from five to 20 vehicles and was typically 10 vehicles before the pilot car led the vehicle platoon through the closure zone.

The typical HfL measures of quality—tire-pavement noise and pavement smoothness—were not collected for this project. This is because the innovative aspects of the project relating to safety improvements (such as the Safety Edge, guardrails, rumble strips, fog lines, and highly retroreflective striping) have no direct effect on these measures. However, other measures of quality (Safety Edge slope and HMA mat density) were documented for this project. The slope of the Safety Edge was consistently between 25 and 35 degrees, with an average value of 28.7 degrees. An average compaction of 92.2 percent was measured close to the edge (1 ft from the edge) and 94.0 percent away from the edge (3 ft from the edge), suggesting that good compaction was obtained at both the edge and interior locations.

Highway user satisfaction surveys were conducted after construction was complete. The survey results showed high levels of satisfaction with this construction. Overall, the response to the questions exceeded the HfL goal of 4 out of 7 (or the majority of the respondents) showing favorable response.

## **ECONOMIC ANALYSIS**

A detailed economic analysis considering all costs associated with building the as-constructed section versus the baseline section and the economic benefits of the improved safety over a 10-year period showed substantial cost benefits for the as-constructed project. The life cycle cost differential analysis showed that the baseline case would have saved Calaveras County and the roadway users an estimated \$8,549,462.26 in terms of 2012 net present value (NPV) because of the associated safety improvements. By comparison, the as-constructed project saved an estimated \$16,438,619.99 in NPV, for a total additional savings of \$7,889,157.73. The driver of the cost savings compared to the baseline case was the additional reduction in future crash rates from installation of centerline rumble strips and highly retroreflective striping.

## **CONCLUSIONS**

From the standpoint of speed of construction, motorist and user safety and delay, and quality, this project was an unqualified success and embodied the ideals of the HfL program. The safety improvements on this project are expected to reduce future crash rates substantially, saving lives, reducing the number and severity of injuries, and lowering corresponding crash-related costs.

## PROJECT DETAILS

### BACKGROUND

This project is located in and near the Calaveras County seat of San Andreas on various portions of Mountain Ranch Road (figure 1). Mountain Ranch Road is a rural, two-lane, winding mountainous road that descends over 1,000 vertical feet (ft) in 10.75 mi from about 1mi east of the rural town of Mountain Ranch down to San Andreas. It is a rural major collector with a speed limit of 55 miles per hour and AADT ranging from 1,900 at the eastern end of the roadway to 4,960 near its western terminus at State Route 49. Many people living in the communities of the northeastern part of the county use this road to access various services and businesses in San Andreas and travel to many points south and west in the county and beyond.

This road has a crash rate similar to that of other roads of its type in California, but a much higher-than-average fatality rate (more than 10 times the State average). The above-average fatality rate was determined to be due to a combination of factors. Anecdotal evidence suggested that many motorists allow their vehicles' right tires to drift off the paved edge onto the unpaved shoulder, especially on inside turns, leaving telltale shackle bolt gouges in the asphalt (figure 2). This drift can cause motorists to lose control and run off of the road or lose control when trying to return to their lane and cross the centerline into oncoming traffic. The road is almost exclusively bordered by a deep creek on the south side and a cliff or steep acclivity on the north side, which provide undesirable venues for cars leaving the roadway (figure 3). The road is also bordered on both sides by numerous mature oak and pine trees, most large enough to cause great personal injury and vehicular damage if a vehicle runs off the road.

Various portions of the travel lanes are less than 12 ft wide, reducing allowable error for drivers during normal driving and when trying to regain control of their vehicle in their travel lane after leaving the roadway. Many sections of this road have inadequate shoulders or no shoulders, and many portions of this road have medium- to high-severity edge-shoulder drop-off (figure 4), potentially causing loss of vehicular control for motorists whose tires drop off the asphalt edge. During winter months, a portion of the road can develop frost or ice, making driving even more hazardous and increasing the potential for motorists to drop one or more tires off the paved edge.

Motorists on Mountain Ranch Road faced many challenges, but solutions, such as right-of way acquisition, for widening the road to add proper shoulders were beyond the financial capacity of the county. This demonstration project had the potential to impact a numerically small but important aspect of highway safety: rural, two-lane roads and highways in communities across the country.

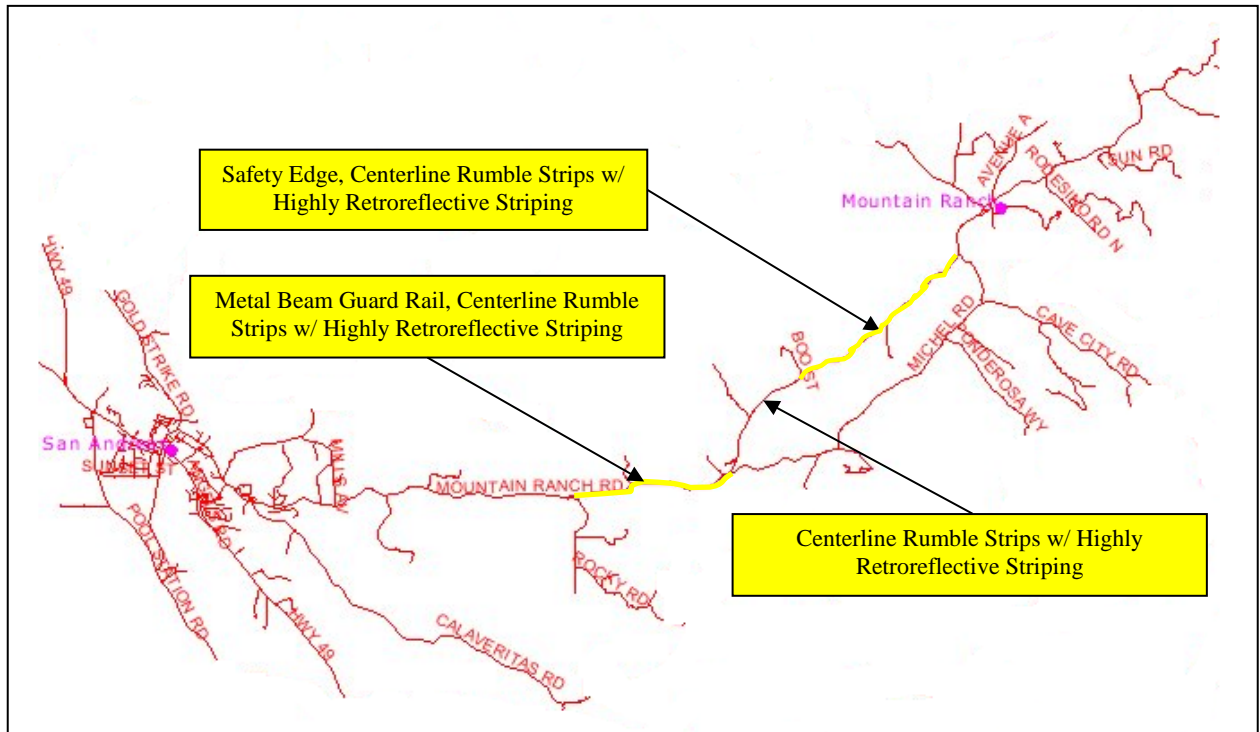


Figure 2. Project location on Mountain Ranch Road east of San Andreas.



Figure 3. Typical car shackle bolt damage to Mountain Ranch Road edge on inside of turn.





Figure 4. Typical narrow shoulders, acclivity on north (left) side of road, and declivity on south (right) side of Mountain Ranch Road.



Figure 5. Typical edge-shoulder dropoff on Mountain Ranch Road.

## **PROJECT DESCRIPTION**

The purpose of this project was to reduce Mountain Ranch Road's fatality rate of 14 per hundred million vehicle miles (hmvm) by 50 percent, to 7/hmvm, for the 5-year period immediately following construction of this project. Shoulder and roadside conditions vary widely on this road, with some segments suitable for HMA overlay, others requiring modification, and others not suitable for any widening because of right-of-way acquisition or steep uphill and downhill slopes immediately next to the road (figure 3). Therefore, it was proposed that the reduction in future crash rates be accomplished through the deployment of four separate construction components designed to help drivers prevent their car tires from drifting off the roadway and minimize drivers' risk of losing control of their vehicles when attempting to reenter the roadway after dropping one or more tires onto the shoulder.

This project included four components incorporating two construction innovations to address the HfL performance goals of safety, reduction of construction congestion, quality, and user satisfaction.

1. The primary safety component included the addition of a 2-in HMA overlay with a Safety Edge to an approximately 2.1-mi segment of Mountain Ranch Road (Boo Street to Upper Michel Road) that needed it and had been identified as an area where the county had enough right-of-way and/or shoulder room to properly construct the Safety Edge (easterly segment).
2. The second safety component was the installation of highly retroreflective striping on top of centerline rumble strips to help keep drivers from drifting into the adjacent lane and oncoming traffic (easterly, center, and westerly segments).
3. The third safety component was backing and/or extending the aggregate base shoulders along segments of the overlaid section that required this for the addition of the Safety Edge and segments that did not receive the Safety Edge treatment but would benefit from an improved or widened shoulder (easterly and westerly segments).
4. The fourth safety component was the installation of new MBGR along a 1.60 mi segment of Mountain Ranch Road. The improvements include new MBGR beginning at the intersection of Rocky Road and terminating at the western intersection of Michel Road (westerly segment).

In addition to the construction components, planning and evaluation procedures, including an RSA, and a project information campaign were implemented to maximize the effectiveness of this project. An RSA was conducted during the preengineering phase of this project. The audit was location-specific and focused on the three most common crash sites on the road, according to Crossroads database. The project also included the construction of four cross-culvert and encroachment-culvert connections to accommodate the correction of shoulder widths and depths (figure 5).



Figure 6. Typical culvert extension required for shoulder widening on Mountain Ranch Road.

## Design Plans

The final plans for the project were completed on December 16, 2011. The project was awarded to George Reed, Inc. on July 10, 2012. The plans for milling the existing pavement surface and placing the new HMA surface with the Safety Edge are shown in figure 6. The plans called for milling 1 in of the existing HMA pavement, placing an SS-1h tack coat, and overlaying the pavement with 2-in Type A PG 64-16 HMA overlay. The plan details for installation of the Safety Edge are shown in figure 7. The figure shows a Safety Edge slope of 30 degrees to be covered with shoulder backing material consisting of a dense-graded aggregate base material. The shoulder backing material could be filled only at locations with sufficient clearance of the Safety Edge from adjacent acclivity and declivity (see figure 3). The figure also shows details for transitioning of the Safety Edge at existing driveways and streets. Figure 8 and 9 show the plans for the installation of the guardrails and rumble strips, respectively.

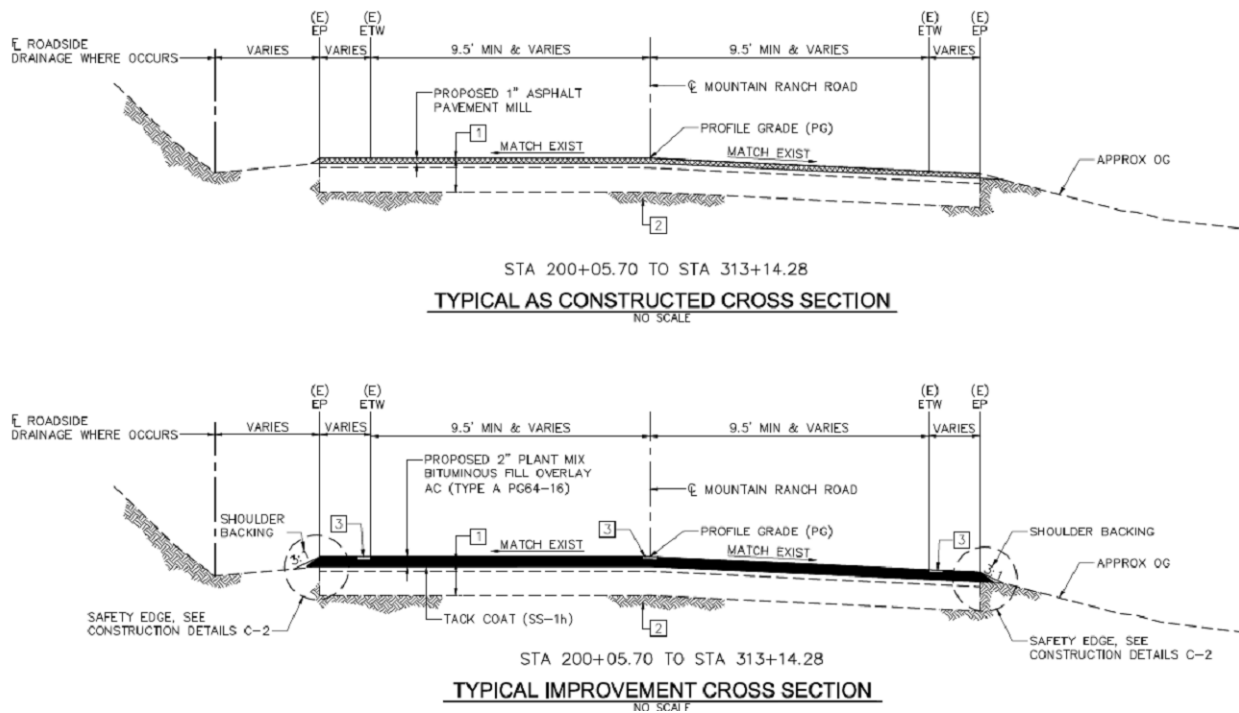


Figure 7. Plans for milling and HMA overlay with a Safety Edge on Mountain Ranch Road.

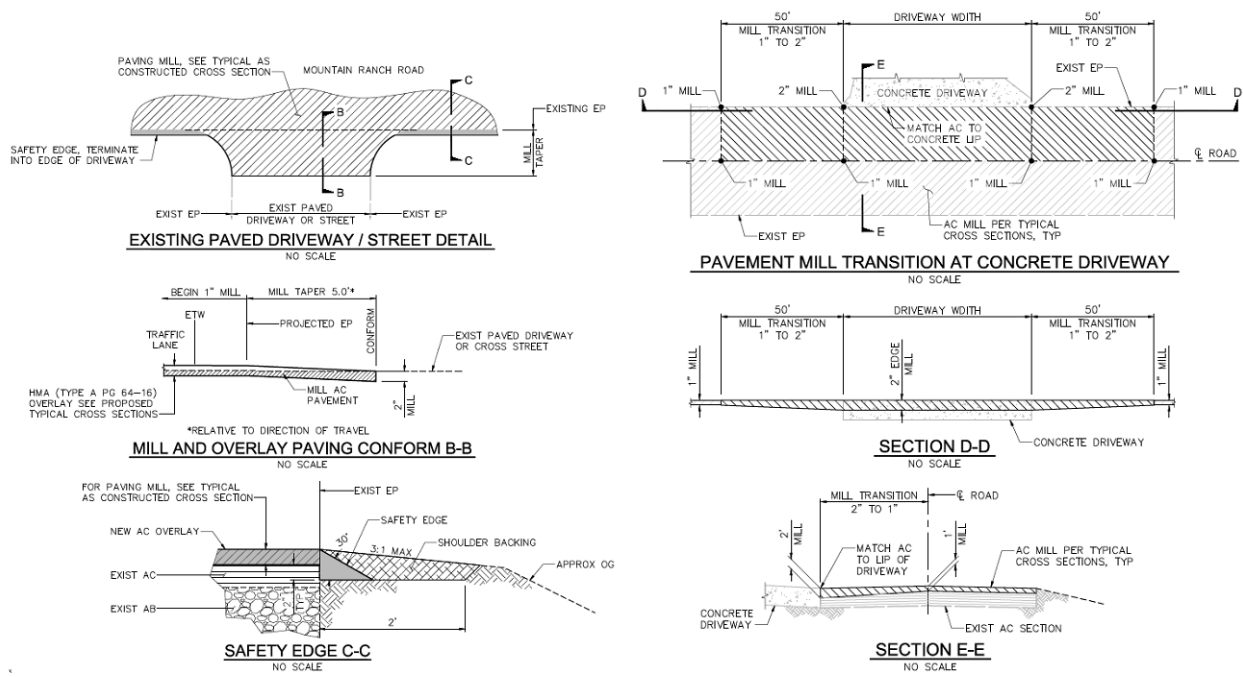


Figure 8. Safety Edge plan details for Mountain Ranch Road.

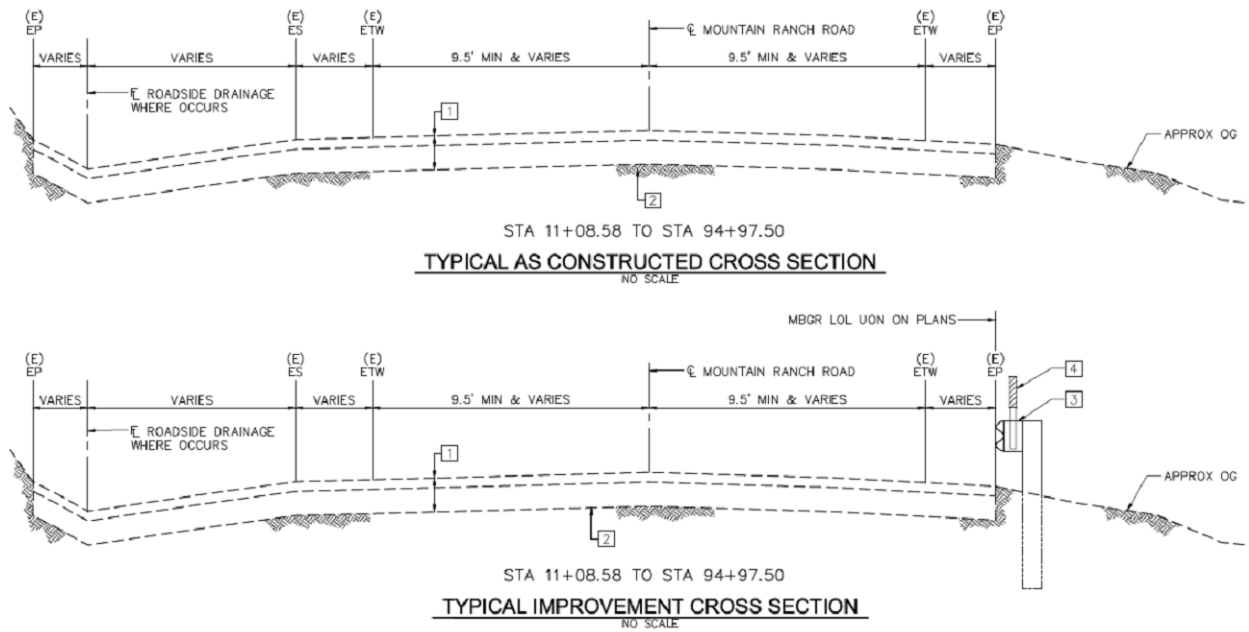


Figure 9. Plans for installation of guardrails on Mountain Ranch Road.

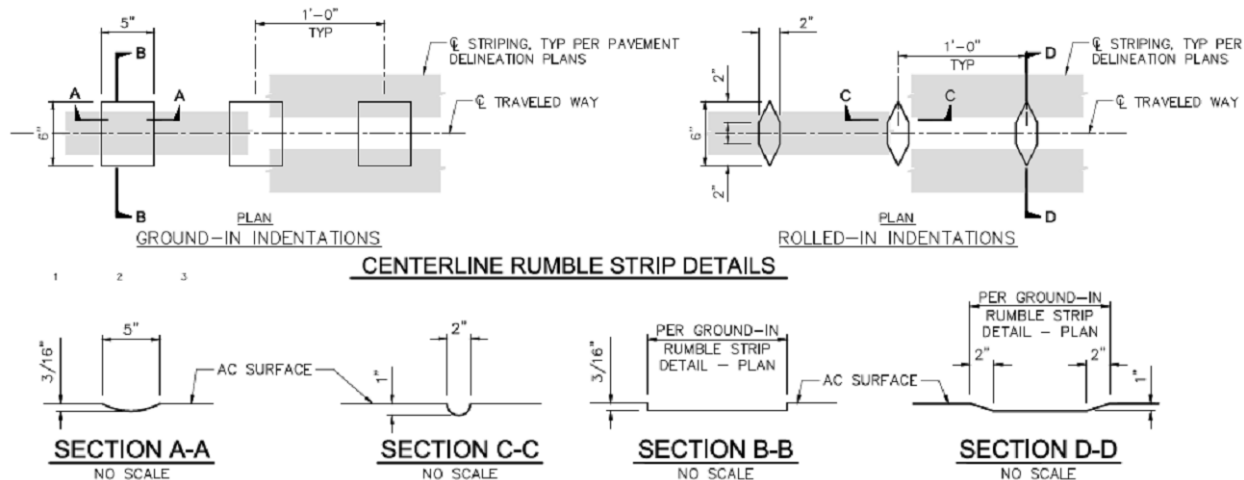


Figure 10. Plans for centerline rumble strip installation on Mountain Ranch Road.

## Construction

Table 1 shows the construction schedule for the project. As shown in table 1, the project began with milling the existing HMA surface on August 16 and 17, 2012. Figure 10 shows the condition and surface texture of the existing pavement surface before milling. Figure 11 shows the milled surface before placement of the overlay and Safety Edge. The HMA overlay with the Safety Edge portion of the project was paved on August 22 and 23, 2012. The HMA mix consisted of  $\frac{3}{4}$ -in Type A HMA with dual grade PG 64-10/PG 64-16 asphalt binder produced at the Clements plant of the contractor, George Reed Inc. Kleinfelder Inc. of Hayward, CA, performed the mix design using aggregates from the Jackson Valley quarry. The aggregate gradation is shown in table 2. The  $\frac{3}{4}$ -in nominal maximum aggregate size was used (rather than  $\frac{1}{2}$ -in or  $\frac{3}{8}$ -in) to increase pavement surface texture and skid resistance. The results of the aggregate quality and binder tests are shown in table 3. The design data at the job mix formula (JMF) for the  $\frac{3}{4}$ -in Type A HMA mix used are shown in table 4.

Figures 12 and 13 show the paving of Mountain Ranch Road and the limited clearances from the pavement edge due to the acclivities and declivities as a result of the mountainous terrain at the project site. One lane was paved at a time and a pilot car was used to lead traffic through the construction zone on the adjacent lane. Figure 14 shows a closeup of the HMA surface and the coarseness of the mix. Figures 15 through 18 show the construction of the Safety Edge using the Advantedge® device installed on the paver screed.

Table 1. Construction schedule for Mountain Ranch Road.

<b>Date</b>	<b>Time Elapsed Under Traffic Control (hour)*</b>	<b>Work Completed</b>
8/16/2012	9.50	1-in HMA milling, sweeping, clean up, and placement of centerline tabs
8/17/2012	9.50	1-in HMA milling, sweeping, clean up, and placement of centerline tabs
8/22/2012	9.50	2-in HMA paving
8/23/2012	10.50	2-in HMA paving, paving ditch and hand work
8/24/2012	9.50	Place shoulder aggregate
8/30/2012	7.00	Rumble strip installation within limits of overlay
8/31/2012	6.50	Fog seal overlay
9/25/2012	8.00	Guardrail installation
9/26/2012	3.00	Guardrail installation
9/27/2012	8.50	Guardrail removal
9/28/2012	8.75	Shoulder repair
11/19/2012	8.75	Guardrail installation
11/20/2012	7.50	Guardrail installation
11/21/2012	7.75	Guardrail installation
12/13/2012	8.00	Rumble strip installation
12/14/2012	7.00	Rumble strip installation
<b>16 days</b>	<b>129.25</b>	<b>TOTAL</b>

\*Does not include traffic impedance caused by mobile traffic control for painting.



Figure 11. Condition and surface texture of existing pavement surface before milling on Mountain Ranch Road.



Figure 12. The existing pavement surface was milled (1 in) before HMA overlay and Safety Edge paving on Mountain Ranch Road.

Table 2. Aggregate gradation for 3/4-in HMA mix used on Mountain Ranch Road.

Bin	1	2	3	4		Reclaimed Asphalt Pavement	Lime	Combined Gradation (JMF TV)
Material Size	Fines	3/8"	1/2"	3/4"			—	—
Bin %	42	28	10	20		____ (JMF TV)		100%
Sieve Size	% Passing							
2"								
1 1/2"								
1"	100	100	100	100				100
3/4"	100	100	100	73.5				95
1/2"	100	100	75.2	1.9				78
3/8"	100	97.1	15.3	0.9				71
No. 4	90	44.6	2.5	0.7				51
No. 8	75	2.7	1.7	0.5				33
No. 16	53	2.2	1.5	0.4				23
No. 30	38	1.8	1.3	0.4				17
No. 50	20	1.4	1.0	0.4				9
No. 100	12	1.0	0.7	0.3				5
No. 200	8.5	0.7	0.4	0.2				3.8
Aggregate Sources and California Mine and SMARA Identification Numbers for each bin: BIN 1 -- Jackson Valley Quarry, SMARA #91-03-0020 & Bellino Pit, SMARA #91-39-0038 BIN 2 -- Jackson Valley Quarry, SMARA #91-03-0020 BIN 3 -- Jackson Valley Quarry, SMARA #91-03-0020 BIN 4 -- Jackson Valley Quarry, SMARA #91-03-0020								

Table 3. Aggregate quality and asphalt binder test results for ¾-in HMA mix used on Mountain Ranch Road.

Aggregate Quality <sup>1</sup>			
Quality Characteristic/Property	Test Method	Test Result	
Crushed particles, coarse aggregate One fractured face (%)	CT 205	100	
Crushed particles, coarse aggregate Two fractured faces (%)	CT 205	100	
Crushed particles, fine aggregate (Passing No. 4 sieve and retained on No. 8 sieve) One fractured face (%)	CT 205	99	
Los Angeles Rattler, Loss at 100 Rev. (%)	CT 211	2.5	
Los Angeles Rattler, Loss at 500 Rev. (%)	CT 211	10.1	
Sand equivalent	CT 217		Avg 66
Fine aggregate angularity (%)	AASHTO T 304 (Method A)	46	
Flat and elongated particles (% by mass at 3:1)	ASTM D 4791		
Flat and elongated particles (% by mass at 5:1)	ASTM D 4791	0.1	
Plasticity Index	CT 204	NP	
Sodium sulfate soundness	CT 214		
Cleanness Value	CT 227		
Fine aggregate Durability Index	CT 229		
Coarse aggregate Durability Index	CT 229		
K <sub>c</sub> factor (Not mandatory until further notice)	CT 303		
K <sub>f</sub> factor (Not mandatory until further notice)	CT 303		
Bulk specific gravity (oven dry) of coarse aggregate	CT 206	2.863	
Absorption of coarse aggregate	CT 206		
Bulk specific gravity (SSD) of fine aggregate	CT 207		
Bulk specific gravity (oven dry) of fine aggregate	LP-2	2.713	
Apparent specific gravity of supplemental fines	CT 208/LP-2		
Absorption of fine aggregate	CT 207		
Bulk specific gravity of the aggregate blend	LP-2	2.785	
Asphalt Binder <sup>1, 2</sup>			
Asphalt binder supplier: <b>VSS Emultech</b>			
Asphalt binder grade: <b>Dual Grade PG 64-10 &amp; PG 64-16</b>			
Supplier recommended mixing temperature: <b>152°-156° C</b>			
Quality Characteristic	Test Method	Test Result	
Specific gravity	AASHTO T 228	1.0341	
Dynamic Shear (RTFO residue), Test Temp. at 10 rad/s, 60°C	AASHTO T 315 <sup>3</sup>	3.714	
Note:			
<sup>1</sup> Including base asphalt in asphalt rubber binder			
<sup>2</sup> Asphalt Binder treated with liquid antistripping must comply with Section 92, "Asphalt," of the Standard Specifications for the grade specified.			
<sup>3</sup> For use in CT 303			



Table 4. HMA design data at JMF for ¾-in HMA mix used on Mountain Ranch Road.

Quality Characteristic	Test Method	Test Result			
Asphalt binder content (%) at design air voids (JMF TV)	CT 367	<b>5.26</b>			
Briquette bulk specific gravity <sup>1</sup>	CT 308 (Method A)	<b>2.525</b>	<b>2.520</b>	<b>2.529</b>	<i>Average</i> <b>2.525</b>
Maximum specific gravity	CT 309	<b>2.629</b>			
Air voids content (design value ± 0.5%) <sup>1</sup>	CT 367	<b>4.0</b>	<b>4.1</b>	<b>3.8</b>	<i>Average</i> <b>4.0</b>
Voids in mineral aggregate (%) <sup>1</sup>	LP-2	<b>13.8</b>	<b>14.0</b>	<b>13.7</b>	<i>Average</i> <b>13.8</b>
Effective specific gravity of RAP aggregate	LP-2	<b>NA</b>			
Voids filled with asphalt (%) <sup>1</sup>	LP-3	<b>72.7</b>	<b>73.5</b>	<b>72.4</b>	<i>Average</i> <b>72.9</b>
Dust proportion	LP-4	<b>0.9</b>			
Effective specific gravity of aggregate	LP-4				
Stabilometer value <sup>1</sup>	CT 366	<b>52</b>	<b>53</b>	<b>46</b>	<i>Average</i> <b>50</b>



Figure 13. Paving Mountain Ranch Road.



Figure 14. Paving Mountain Ranch Road.



Figure 15. HMA material showing the relatively large (3/4-in nominal maximum aggregate size) aggregates for a surface mix.



Figure 16. Advantedge® Safety Edge device installed on the paver screed.



Figure 17. The Safety Edge shoe of the Advantedge® can be raised and lowered by turning the bolt at the top of the device.



Figure 18. Safety Edge shoe of the Advantedge® device engaged onto the HMA to form the Safety Edge.



Figure 19. Contractor welded a piece of metal to the Safety Edge shoe and an angled piece to the end gate to prevent HMA from getting between the shoe and the end gate.

Compaction was performed using three rollers—a vibratory breakdown roller (Caterpillar CB54XW, 26,422 pounds (lbs)) with three passes, an intermediate roller (Caterpillar PS-150C) with five passes, and a finish roller (Caterpillar CB54, 24,000 lbs) with three passes (figures 19 through 22).

As shown in figures 23 through 25, the terrain and small clearances between the roadway edge and the adjacent activities and declivities made it difficult to pave the Safety Edge consistently. However, this issue was estimated to comprise less than 5 percent of the total paving project. A typically formed Safety Edge with uniform break point and Safety Edge slope is shown in figure 26. Figures 27 and 28 show a couple of minor issues encountered while paving the Safety Edge pertaining to the positioning of the Safety Edge shoe. The compaction of the edge may not have been optimum because the shoe was not fully engaged. Because of the inconsistent terrain and shoulders, it was difficult for the screed operator to consistently watch the floating of the cotter pin and ensure appropriate positioning of the Safety Edge shoe.

The Safety Edge shoe was raised when encountering driveways and cross streets, as shown in figure 29, and lowered to the original position past the driveways and cross streets, as shown in figure 30. The typical final paved surface with the Safety Edge is shown in figure 31. The installation of MBGR was done between September 25 and November 21, 2012 (figures 32 through 35), and centerline rumble strips were ground on August 30, December 13, and December 14, 2012 (figure 36). One coat of temporary paint for the centerline striping was applied on December 14. Installation of the permanent retroreflective striping is scheduled for summer 2013 when temperatures are warmer for better adhesion of the striping to the pavement surface.



Figure 20. Three rollers used on the project to densify the 2-in HMA mat.



Figure 21. Breakdown steel drum vibratory roller compacting the HMA mat (edge pass with the drum typically about 2 in over the edge of the mat, although in some cases the drum was almost 12 in over the edge).



Figure 22. Intermediate pneumatic rubber tire roller was typically confined to the interior of the HMA mat (tires no closer than 6 to 9 in from the edge of the mat).



Figure 23. Finish steel-drum static roller leveling the HMA mat to the final finished surface.



Figure 24. Small clearances between roadway edge and appurtenances such as culverts resulted in difficulty paving the Safety Edge consistently.



Figure 25. Small clearances between roadway edge and adjacent hillside. Even when the end gate was pulled all the way in, it was not enough to prevent loose material being pulled into the discharge area and mixing with the HMA.



Figure 26. Worst case where hillside is very close to roadway edge and loose material is mixed with the HMA.





Figure 27. Typically formed Safety Edge on Mountain Ranch Road showing uniform break point and Safety Edge slope.



Figure 28. In a few locations, the Safety Edge shoe was too low and it pushed into the shoulder material.



Figure 29. In some locations, the Safety Edge angle was not uniform because of the HMA thickness between the shoulder material and top of the mat compared to the vertical thickness of the Safety Edge shoe.



Figure 30. The Safety Edge shoe was raised when encountering driveways and cross streets.



Figure 31. The Safety Edge shoe was lowered to the original position at the end of driveways and cross streets.



Figure 32. Finished roadway with Safety Edge.



Figure 33. Preparation for installation of the MBGR.



Figure 34. Driving the posts for the MBGR into the embankment material.



Figure 35. Driving the posts for the MBGR into the embankment material.



Figure 36. Installation of the MBGR.



Figure 37. Ground centerline rumble strips.

## DATA ACQUISITION AND ANALYSIS

Data collection on the Calaveras County HfL project consisted of acquiring and comparing data on safety, construction congestion, quality, and user satisfaction before, during, and after construction. The primary objective of acquiring these types of data was to provide HfL with sufficient information to support the feasibility of the proposed innovations. This section discusses how well the Calaveras County project met the specific HfL goals in these areas.

### SAFETY

The HfL performance goals for safety include meeting both worker and motorist safety goals during construction. The project did not have established performance goals for work zone crash rate or incident rate for worker injuries. No workers were injured during the construction of the Mountain Ranch Road project, so the contractor exceeded the HfL goal for worker safety (an incident rate of less than 4.0 based on the OSHA 300 rate).

As for the safety of the traveling public, Calaveras County's and the contractor's solution was to minimize traffic disruption and interaction with construction activities and workers. This was done by closing the construction lane to traffic during construction, using flaggers to halt traffic on both the east and west ends of the construction zone (figure 37). A pilot car led the one-lane traffic in a single file through the open traffic lane from one end of the closure to the other end (figure 38). This was repeated alternately from west to east and east to west throughout the closure period. No work zone crashes were reported at the project location during construction.



Figure 38. Flaggers halting traffic at the west end of the construction zone.



Figure 39. Pilot car leading traffic in a single file through the open traffic lane from one end of the closure to the other end.

The primary purpose of the construction on Mountain Ranch Road was to improve future safety, specifically the fatality rate, based on the RSA. The cost benefits of these improvements are discussed in the economic analysis section of this report.

### Road Safety Audit

The RSA was performed by Stantec, Inc. and submitted to Calaveras County on June 19, 2012. The study evaluated the existing safety conditions in the area, including roadway curvature, signage, pavement, collision reports, traffic composition, and other roadside safety features. The RSA noted that although crash data from SWITRS records was used dating back to 2001, Calaveras County had undertaken warning sign improvements on portions of the roadway which likely have reduced the potential for speed- and curve-related incidents.

The RSA noted that, based on California Department of Transportation (Caltrans) guidelines, although guardrail was appropriate for much of the westerly segment, physical conditions and collision records, in combination with Caltrans guidelines, did not suggest that installation of guardrail was necessary for much of the length. The RSA recommended specific locations where justification for guardrail was clear, additional locations where it was a reasonable consideration, and other locations where the expense of guardrail may be better used for other safety purposes or activities within the project limits.

The RSA suggested signage treatments and delineation that may be considered in both the guardrail segment and the Safety Edge segment in the vicinity of curves that have experienced collisions or require lower speeds for comfortable passage. The RSA noted that the signage, in



addition to other improvements, could be expected to reduce the frequency and severity of traffic collisions on Mountain Ranch Road. Although Calaveras County had posted delineators along some curves for Mountain Ranch Road, the RSA noted that they may be appropriate for additional locations and the spacing and placement of the existing delineators were not fully consistent with Caltrans guidelines.

The RSA analyzed the guardrail segment and concluded that guardrail was most appropriate and strongly recommended for some sites based on collision frequency or high potential for severity. These were denoted as “A” segments. Guardrail was appropriate but not urgently needed for other locations where collisions were not indicated in the records and where shoulder conditions did not present a strong risk of future collisions (“B” segments). There were also locations along the roadway where guardrail was not recommended as a safety treatment (“C” segments). Table 5 from the RSA shows the recommended milepost limits for guardrail installation.

Table 5. RSA guardrail location evaluation (Stantec RSA report).

Station	Priority	Notes
11+00 to 14+80	C	Wide improved shoulder, no collision history
14+80 to 17+50	A	Significant drop, minimal shoulder
17+50 to 24+50	B	No collision history, but dropoff present
24+50 to 33+00	A	Significant collision history, dropoff, residential structure
37+50 to 41+30	A	Dropoff, collision history
41+30 to 45+00	B	Milder condition
45+00 to 50+50	A	Large trees next to shoulder
50+50 to 60+40	B	No collision history, slight graded shoulder present
60+40 to 65+50	A	Dropoff
65+50 to 71+50	B	No collision history
71+50 to 74+50	A	Sharp curve
74+50 to 78+00	C	Level shoulder, no collision history
78+00 to 79+50	A	Rock wall causes vertical dropoff
79+50 to 86+00	C	Level shoulder
86+00 to 89+50	A	Dropoff, minimum shoulder
89+50 to 95+00	C	Level shoulder

The RSA identified two specific curves (stations 32 to 34 and stations 43 to 45) along the guardrail segment appropriate for additional signage based on the *Manual of Uniform Traffic Control Devices* (MUTCD). The RSA also suggested that roadway locations within the guardrail segment may be appropriate for Safety Edge treatment and the county may wish to consider it in the future.

The RSA noted that the Safety Edge treatment was appropriate for the Safety Edge segment, although that segment was not the site of a large number of collisions compared to the guardrail segment. The RSA noted that various curves should be considered for upgrade of curve warning signage and that delineators should comply with the new edition of the MUTCD. The RSA recommended relocating and installing signage strategically near curves to discourage maximum speeds on approaches to sharp curves as follows:

- Relocate W1-5/W13-1(35) FEBT at 211+50 to 216
- Relocate W1-5/W13-1 (35) FWBT at 243 to 232
- Install W1-4 Rt/W13 (45) FEBT at 273
- Install W1-4 Rt/W13 (45) FWBT at 283
- Relocate W1-4 Rt/ W13 (35) FEBT from 286+5 to 292
- Relocate R2-55 FWBT at 295 to 293 beyond end of curve
- Relocate R2-45 FEBT to 290
- Relocate W1-4 RT/W16 (35) FEBT at 286 to 292
- Relocate R2-35 at 310 FEBT to 304
- Relocate R2-45 at 310 FWBT to 301
- Post W1-4 RT/W16 (35) at 312 FWBT

The RSA also recommended delineators on the outside of curves at the following stations:

- 216 to 220
- 221 to 225
- 226 to 230
- 233 to 236
- 294 to 297
- 301 to 304
- 306 to 308

### **CONSTRUCTION CONGESTION**

As shown in table 1, portions of the roadway were closed (one lane at a time) for 16 days, a total of 129.75 hours. Traffic was halted at either end of the closure (figure 37) and a pilot car led the traffic through the single open lane through the closure zone (figure 38). The low traffic volume (AADT ranging from 1,900 at the eastern end of the roadway to 4,960 near its western terminus at State Route 49; 2,272 used in analysis for the project location based on HfL application information) without any significant morning or evening peaks allowed for this closure without any major traffic impact.

Travel time data were collected during two closure days (August 22 and 23, 2012) by traversing back and forth through the closure zone (table 6). All delays were primarily from waiting while stopped by the flaggers for the pilot car to return from the opposing direction (leading the traffic in the opposing direction). On one occasion, the delay was high (38 minutes) because the paver was being backed through the construction zone. Based on the data collected, the average delay time was 14 minutes per vehicle during the closure. Over the 129.75-hour closure, an estimated 14,740 vehicles were delayed (assuming an average of 5 percent of AADT used the road per daytime hour and an AADT of 2,272). The maximum queue length at the flagger was observed to range from five to 20 vehicles and was typically 10 vehicles before the pilot car led the vehicle platoon through the closure zone.

Table 6. Travel time data collected during HMA paving.

<b>Direction: West to East, West Flagger at Woods Way, East Flagger at Coachman Way</b>							
<b>Construction</b>	<b>Michel Road (Lower)</b>	<b>Woods Way Arrive</b>	<b>Woods Way Leave</b>	<b>Wait Time at Flagger, minutes</b>	<b>Michel Road (Upper)</b>	<b>Total Travel Time, minutes</b>	<b>Delay Time, minutes</b>
Yes	11:27 a.m.	11:28 a.m.	12:03 p.m.	35	12:10 p.m.	43	38
Yes	1:38 p.m.	1:39 p.m.	1:40 p.m.	1	1:47 p.m.	9	4
Yes	2:35 p.m.	2:36 p.m.	2:48 p.m.	12	2:54 p.m.	19	14
<b>No</b>	<b>4:42 p.m.</b>	<b>4:44 p.m.</b>	<b>4:44 p.m.</b>	<b>0</b>	<b>4:47 p.m.</b>	<b>5</b>	<b>n/a</b>
Yes	7:20 a.m.	7:21 a.m.	7:36 a.m.	15	7:41 a.m.	21	16
Yes	8:02 a.m.	8:03 a.m.	8:03 a.m.	0	8:17 a.m.	15	10
<b>West to East Average:</b>							<b>16</b>
<b>Direction: East to West, West Flagger at Woods Way, East Flagger at Coachman Way</b>							
<b>Construction</b>	<b>Michel Road (Upper)</b>	<b>Coachman Way Arrive</b>	<b>Coachman Way Leave</b>	<b>Wait Time at Flagger, minutes</b>	<b>Michel Road (Lower)</b>	<b>Total Travel Time, minutes</b>	<b>Delay Time, minutes</b>
Yes	12:11 p.m.	12:13 p.m.	12:13 p.m.	0	12:19 p.m.	8	4
Yes	2:05 p.m.	2:06 p.m.	2:14 p.m.	8	2:22 p.m.	17	13
Yes	3:00 p.m.	3:01 p.m.	3:05 p.m.	4	3:14 p.m.	14	10
<b>No</b>	<b>4:47 p.m.</b>	<b>4:48 p.m.</b>	<b>4:48 p.m.</b>	<b>0</b>	<b>4:51 p.m.</b>	<b>4</b>	<b>n/a</b>
<b>Flagger moved from Coachman Way to Michel Road (Upper)</b>							
<b>Direction: East to West, West Flagger at Woods Way, East Flagger at Michel Road (Upper)</b>							
<b>Construction</b>	<b>Michel Road (Upper) Arrive</b>	<b>Michel Road (Upper) Leave</b>	<b>Wait Time at Flagger, minutes</b>	<b>Coachman Way</b>	<b>Michel Road (Lower)</b>	<b>Total Travel Time, minutes</b>	<b>Delay Time, minutes</b>
Yes	7:44 a.m.	7:54 a.m.	10	7:57 a.m.	8:02 a.m.	18	14
Yes	8:42 a.m.	8:42 a.m.	0	8:55 a.m.	9:03 a.m.	21	17
<b>East to West Average:</b>							<b>12</b>
<b>Overall Average:</b>							<b>14</b>

## QUALITY

The typical HfL measures of quality—tire-pavement noise and pavement smoothness—were not collected for this project. This is because the innovative aspect of the project relating to the improvement in safety (such as the Safety Edge, guardrails, rumble strips, fog lines, and highly retroreflective striping) have no direct effect on these measures. However, other measures of quality (Safety Edge slope and HMA mat density) were documented for this project, as summarized in tables 7 through 9.

Four sections were identified for collecting Safety Edge slope measurements (section 1A—day 1 eastbound, section 1B—day 1 westbound, section 2A—day 2 eastbound, and section 2B—day 2 westbound). Table 7 shows that the slope of the Safety Edge was consistently between 25 and 35 degrees, with an average value of 28.7 degrees. Note that the measured height was typically greater than the overlay thickness of 2 in because in many locations the shoulder material was

clipped to a level below that of the existing surface (figure 39). Figure 40 shows the typical slope of the Safety Edge on Mountain Ranch Road.

HMA mat density data were collected for the four sections using a nuclear density gauge (Troloxler 3450 RoadReader™ Plus, shown in figure 41). For each section, the density data were collected at 10 stations and two transverse locations per station—1 ft from the edge and 3 ft from the edge. Two readings were taken at each location, and the average of the two readings was used to represent the density at that location. Four cores were also taken, which were used to adjust the nuclear density data. The results, summarized in tables 8 and 9, show an average compaction of 92.2 percent close to the edge (1 ft from the edge) and 94.0 percent away from the edge (3 ft from the edge). The densities suggest that good compaction was obtained both at the edge and interior locations. Note that the 92.2 percent compaction close to the edge is higher than what is typically seen at this location when no Safety Edge is used.

Table 7. Safety Edge slope measurements.

	Height, in	Width, in	Slope, degrees		Height, in	Width, in	Slope, degrees
Section 1A, Day 1 EB	3.50	6.50	28.30	Section 1B, Day 1 WB	2.50	4.63	28.39
	3.50	6.75	27.41		2.50	5.25	25.46
	4.25	7.50	29.54		2.88	6.00	25.60
	4.50	7.63	30.55		2.63	5.63	25.02
	4.25	7.25	30.38		2.63	5.25	26.57
	4.75	7.25	33.23		2.75	5.50	26.57
	3.75	7.00	28.18		2.75	5.75	25.56
	4.13	7.25	29.64		3.25	6.25	27.47
	3.88	7.25	28.12		2.75	5.50	26.57
	4.00	7.00	29.74		2.75	5.75	25.56
	4.50	8.25	28.61		2.25	4.00	29.36
<b>Average: 29.43</b>			<b>Average: 26.56</b>				
Section 2A, Day 2 EB	2.13	5.00	23.03	Section 2B, Day 2 WB	5.50	9.13	31.08
	4.00	7.00	29.74		2.75	5.50	26.57
	3.25	7.50	23.43		3.50	5.88	30.78
	4.25	6.75	32.20		3.75	5.75	33.11
	4.75	8.25	29.93		3.75	6.25	30.96
	4.75	8.75	28.50		3.50	6.25	29.25
	5.00	8.25	31.22		3.75	6.00	32.01
	5.00	8.50	30.47		3.50	6.00	30.26
	4.25	7.88	28.35		2.50	4.25	30.47
	4.25	8.00	27.98		4.25	8.13	27.61
	5.00	8.25	31.22		2.00	3.63	28.89
<b>Average: 28.73</b>			<b>Average: 30.09</b>				
<b>Overall Average, degrees: 28.70</b>							



Figure 40. In many locations the shoulder material was clipped below the level of the existing pavement surface, resulting in Safety Edge heights greater than the overlay thickness.

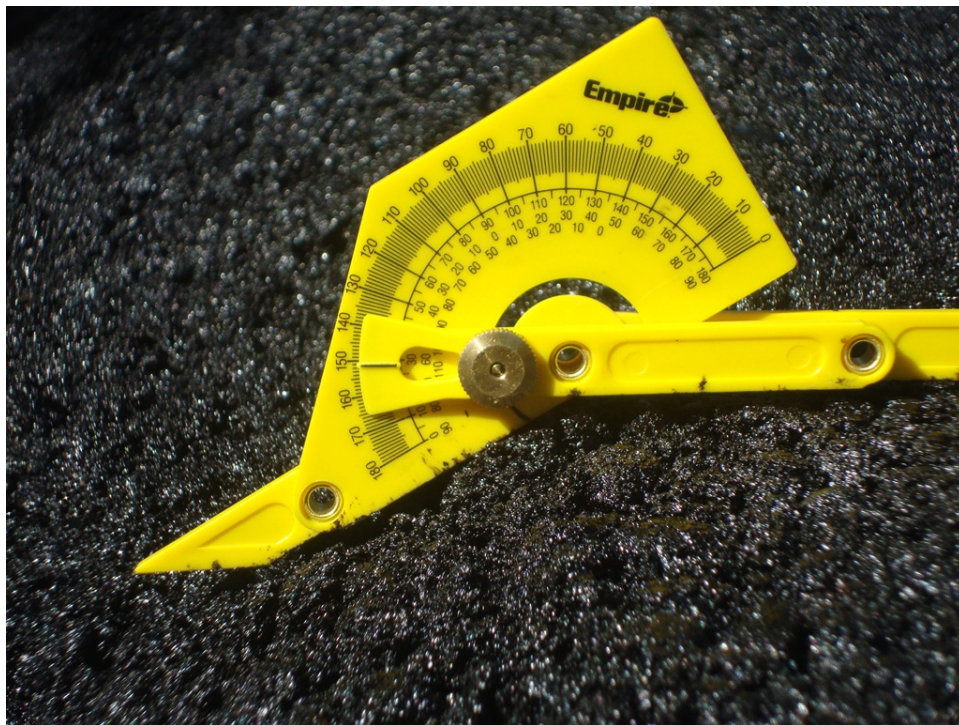


Figure 41. Typical Safety Edge slope on Mountain Ranch Road.



Figure 42. Measuring HMA mat density with a nuclear density gauge on Mountain Ranch Road.

#### **USER SATISFACTION**

The HfL requirement for user satisfaction includes a performance goal of 4-plus on a Likert scale of 1 to 7 (in other words, 57 percent or more participants showing favorable response) for the following two questions:

- How satisfied is the user with the roadway compared with its previous condition?
- How satisfied is the user with the approach used to construct the new facility in terms of minimizing disruption?

Overall, the response to the questions exceeded the HfL goal of 4 out of 7 (or the majority of the respondents) showing favorable response.

Table 8. HMA mat density measured using nuclear density gauge 1 ft from pavement edge.

	Theoretical Maximum Density, pcf	Reading 1, pcf	Reading 2, pcf	Average, pcf	Adjusted, pcf	Percent Compaction	Average
Section 1B, Day 1 WB	164.4	151.5	151.8	151.7	153.3	93%	91.6%
	164.4	148.7	148.6	148.7	150.3	91%	
	164.4	148.1	149.8	149.0	150.6	92%	
	164.4	152.6	152.6	152.6	154.2	94%	
	164.4	149.3	148.7	149.0	150.6	92%	
	164.4	146.2	144.9	145.6	147.2	90%	
	164.4	147.7	146.5	147.1	148.7	90%	
	164.4	149.1	147.7	148.4	150.0	91%	
	164.4	149.6	149.6	149.6	151.2	92%	
	164.4	149.8	148.0	148.9	150.5	92%	
Section 1A, Day 1 EB	164.4	145.9	144.9	145.4	147.0	89%	92.9%
	164.4	148.0	147.7	147.9	149.5	91%	
	164.4	153.6	151.7	152.7	154.3	94%	
	164.4	154.0	153.7	153.9	155.5	95%	
	164.4	151.9	153.0	152.5	154.1	94%	
	164.4	154.7	154.9	154.8	156.4	95%	
	164.4	151.7	151.1	151.4	153.0	93%	
	164.4	151.2	151.7	151.5	153.1	93%	
	164.4	153.8	152.5	153.2	154.8	94%	
	164.4	147.7	147.2	147.5	149.1	91%	
Section 2A, Day 2 EB	164.4	151.5	151.8	151.7	153.3	93%	91.6%
	164.4	148.7	148.6	148.7	150.3	91%	
	164.4	148.1	149.8	149.0	150.6	92%	
	164.4	152.6	152.6	152.6	154.2	94%	
	164.4	149.3	148.7	149.0	150.6	92%	
	164.4	146.2	144.9	145.6	147.2	90%	
	164.4	147.7	146.5	147.1	148.7	90%	
	164.4	149.1	147.7	148.4	150.0	91%	
	164.4	148.6	149.6	149.1	150.7	92%	
	164.4	149.8	148.0	148.9	150.5	92%	
Section 2B, Day 2 WB	164.4	145.9	144.9	145.4	147.0	89%	92.7%
	164.7	148.0	147.7	147.9	149.5	91%	
	164.7	153.6	151.7	152.7	154.3	94%	
	164.7	154.0	153.7	153.9	155.5	94%	
	164.7	152.9	153.0	153.0	154.6	94%	
	164.7	154.7	154.9	154.8	156.4	95%	
	164.7	151.7	151.1	151.4	153.0	93%	
	164.7	151.2	151.7	151.5	153.1	93%	
	164.7	153.8	152.5	153.2	154.8	94%	
	164.7	147.7	147.2	147.5	149.1	91%	
<b>Overall Average:</b>							<b>92.2%</b>

Table 9. HMA mat density measured using nuclear density gauge 3 ft from pavement edge.

	Theoretical Maximum Density, pcf	Reading 1, pcf	Reading 2, pcf	Average, pcf	Adjusted, pcf	Percent Compaction	Average
Section 1B, Day 1 WB	164.4	153.4	153.8	153.6	155.2	94%	94.5%
	164.4	156.3	154.8	155.6	154.4	94%	
	164.4	155.1	152.3	153.7	155.3	94%	
	164.4	153.0	152.7	152.9	154.5	94%	
	164.4	149.3	148.7	149.0	150.6	92%	
	164.4	157.7	154.9	156.3	157.9	96%	
	164.4	156.1	154.9	155.5	157.1	96%	
	164.4	157.1	156.3	156.7	158.3	96%	
	164.4	155.4	153.9	154.7	156.3	95%	
	164.4	153.9	152.4	153.2	154.8	94%	
Section 1A, Day 1 EB	164.4	152.9	151.8	152.4	154.4	94%	94.4%
	164.4	151.6	148.3	150.0	151.6	92%	
	164.4	154.2	154.9	154.6	156.2	95%	
	164.4	152.4	154.7	153.6	155.2	94%	
	164.4	153.4	154.8	154.1	155.7	95%	
	164.4	150.8	153.2	152.0	153.6	93%	
	164.4	152.5	153.5	153.0	154.6	94%	
	164.4	156.6	156.1	156.4	158.0	96%	
	164.4	155.5	154.4	154.9	156.5	95%	
	164.4	155.2	155.6	155.4	157.0	96%	
Section 2A, Day 2 EB	164.7	152.3	152.0	152.2	153.8	93%	93.5%
	164.7	150.8	149.8	150.3	151.9	92%	
	164.7	153.9	153.4	153.7	155.3	94%	
	164.7	152.1	152.6	152.4	154.0	93%	
	164.7	147.9	150.1	149.0	155.5	94%	
	164.7	152.1	152.3	152.2	153.8	93%	
	164.7	151.7	152.5	152.1	153.7	93%	
	164.7	149.6	149.7	149.7	151.3	92%	
	164.7	155.2	153.7	154.5	156.1	95%	
	164.7	157.0	157.0	157.0	158.6	96%	
Section 2B, Day 2 WB	164.4	149.5	148.5	149.0	150.6	92%	93.7%
	164.7	149.4	147.7	148.6	150.2	91%	
	164.7	153.4	154.4	153.9	155.5	94%	
	164.7	154.2	154.9	154.6	156.2	95%	
	164.7	153.4	153.9	153.7	152.7	93%	
	164.7	154.4	154.6	154.5	156.1	95%	
	164.7	153.6	154.3	154.0	155.6	94%	
	164.7	152.8	155.4	154.1	155.7	95%	
	164.7	152.3	152.3	152.3	153.9	93%	
	164.7	153.4	155.6	154.5	156.1	95%	
<b>Overall Average:</b>							<b>94.0%</b>



## ECONOMIC ANALYSIS

A key aspect of HfL demonstration projects is quantifying, as much as possible, the value of the innovations deployed. This generally entails comparing the benefits and costs associated with the innovative safety measures adopted on an HfL project with those from a more traditional approach on a project of similar size and scope. The latter type of project is referred to as a baseline case and is an important component of the economic analysis. Table 10 shows a comparison of the as-constructed project versus the baseline case for the various project segments. For this economic analysis, Calaveras County supplied the cost figures for the project.

Table 10. Comparison of as-constructed project versus baseline case based on information provided by Calaveras County.

Segment	As-Constructed	Baseline
Westerly—Rocky Road to Lower Michel Road	Metal beam guardrails, centerline rumble strips with highly retroreflective striping	Metal beam guardrails
Between—Lower Michel Road to Boo Road	Centerline rumble strips with highly retroreflective striping	Do nothing
Easterly—Boo Road to Upper Michel Road	2-in overlay with Safety Edge, centerline rumble strips with highly retroreflective striping	2-in overlay

### CONSTRUCTION COSTS

Calaveras County received two bids for the construction of this project. They included \$858,997.50 from George Reed Inc. and \$1,057,577.06 from Sierra Mountain Construction, Inc. The contract was awarded to George Reed Inc. In addition to the construction contract, a contract for \$249,896.86 was awarded to Stantec, Inc. for project management, planning, data collection, survey, design, quality assurance, and bid and construction support.

Because of change orders that resulted in the removal of some items and the addition of others, primarily relating to the guardrail installation, the contractor has invoiced Calaveras County \$862,435.87 to date. Additional costs relating to the thermoplastic striping to be done in 2013 is expected to be \$28,600.00, corresponding to an additional 22,000 ft of centerline yellow striping. Including the additional striping, the total construction cost for this project is \$891,035.87.

Both the as-constructed and baseline cases have 2-in HMA overlays and MBGR. The key differences are the centerline rumble strips with highly retroreflective striping and the Safety Edge for the as-constructed case. Excluding the costs for the centerline rumble strips and highly retroreflective striping, the total cost for the baseline case is computed at \$814,566.22 based on invoice information provided by Calaveras County. The 2-in HMA overlay with the Safety Edge (as-constructed case) is assumed to cost the same as a 2-in HMA overlay without the Safety Edge (baseline case), because data from various projects across the United States have shown the difference in HMA materials with the addition of the Safety Edge at less than 1 percent. For this

project, the Safety Edge shoe, which typically costs \$3,000 and can be reused, was loaned to the contractor by FHWA.

Assuming the engineering cost is proportional to the total project cost (28.05 percent for the as-constructed case), the engineering cost is estimated at \$228,450.44 for the baseline case.

## **CONSTRUCTION TIME**

Although the project lasted several months, as shown in table 1, the total actual lane closure time was 129.25 hours over a period of 16 days. There were no detours on this project. Only the portion of a lane affected by construction activities was closed to traffic. The adjacent lane was open to one-lane traffic, and vehicles were escorted through the closure zone by a pilot car, one direction at a time. Thus, the only delays on this project were when vehicles waited at the ends of the closure for the return of the pilot car to escort them through the closure zone.

Table 1 shows that the total as-constructed lane closure time for rumble strip installation was 22 hours. Since the baseline case does not include rumble strip installation, the total lane closure time for the baseline case is estimated at 107.25 hrs.

## **DETOUR**

There were no detours on this project.

## **USER COSTS**

Generally, three categories of user costs are used in an economic life-cycle cost analysis: vehicle operating costs (VOC), delay costs, and crash- and safety-related costs. The cost differential in delay costs was included in this analysis to identify the differences in costs between the baseline and as-built alternatives. Since no detours resulting in increased mileage were included in this project, VOC is not applicable for this analysis.

Based on the data collected, the average delay time was 14 minutes per vehicle during the closure. Over the 129.75 hour closure, an estimated 14,740 vehicles were delayed, as discussed in “Data Acquisition and Analysis.” Thus, the total delay corresponds to 3,439.3 vehicle-hours. Using the 2012 auto/truck composite value of time provided by Caltrans ([www.dot.ca.gov/hq/tpp/offices/eab/benefit\\_cost/LCBCA-economic\\_parameters.html](http://www.dot.ca.gov/hq/tpp/offices/eab/benefit_cost/LCBCA-economic_parameters.html)) of \$17.35, the user costs related to traffic delay for the as-constructed case is calculated as \$59,671.86.

For the baseline case, over the 107.75 hour estimated closure, an estimated 12,241 vehicles were delayed. This delay corresponds to 2,856.1 vehicle-hours and user costs related to traffic delay of \$49,553.34.

No crashes were reported during the construction of this project, so worker and work zone crash-related safety costs are zero for both the as-constructed and baseline cases.

## INITIAL COST SUMMARY

The total initial costs for the as-constructed case include construction costs of \$891,035.87, consulting and planning costs of \$249,896.86, and user costs of \$59,671.86. The total initial costs for this project are \$1,200,604.59.

The total initial costs for the baseline case include construction costs of \$814,566.22, consulting and planning costs of \$228,450.44, and user costs of \$49,553.34. The total initial costs for this project are \$1,092,570.00.

## CRASH ANALYSIS

Table 11 shows the preconstruction crash statistics between February 25, 2003, and September 13, 2011 (3,122 days) for the three project segments (source: SWITRS). The corresponding crash rate per million vehicle miles traveled (VMT) is shown in table 12.

Table 11. Project historical crash data.

Segment	2009 ADT	Fatalities	Severe Injuries	Moderate Injuries	Minor Injuries	Property Damage Only
Westerly	4,960	5	1	9	9	n/a
Between	1,900	0	0	3	2	n/a
Easterly	1,900	1	2	11	6	n/a

Table 12. Project historical crash rate per million vehicle miles traveled.

Segment	2009 ADT	Million VMT	Fatalities	Severe Injuries	Moderate Injuries	Minor Injuries	Property Damage Only
Westerly	4,960	24.70	0.2024	0.0405	0.3644	0.3644	n/a
Between	1,900	4.73	0	0	0.6342	0.4228	n/a
Easterly	1,900	12.42	0.0805	0.1610	0.8857	0.4831	n/a

The benefit-cost analysis economic parameters for 2012 was obtained from Caltrans' website ([www.dot.ca.gov/hq/tpp/offices/eab/benefit\\_cost/LCBCA-economic\\_parameters.html](http://www.dot.ca.gov/hq/tpp/offices/eab/benefit_cost/LCBCA-economic_parameters.html)) and includes unit cost for crashes as follows:

- Fatality—\$4,400,000
- Severe injury—\$221,400
- Moderate injury—\$56,500
- Minor injury—\$26,900
- Property damage—\$2,500

Using these costs for crashes, the preconstruction crash costs for the Mountain Ranch Road project are shown in table 13. Crash modification factors (CMFs) due to safety improvements based on national studies are shown in table 14 for the three roadway segments. Although the Safety Edge was a key safety feature on this project, there are no reliable CMF estimates for the Safety Edge, so it was not included in the analysis.

Table 13. Project preconstruction crash costs (\$/million vehicle miles traveled).

Segment	Fatalities	Severe Injuries	Moderate Injuries	Minor Injuries	Property Damage Only	Total
Westerly	\$890,688	\$8,964	\$20,587	\$9,802	\$0	\$930,040
Between	\$0	\$0	\$35,835	\$11,374	\$0	\$47,209
Easterly	\$354,267	\$35,652	\$50,040	\$12,995	\$0	\$452,955

Table 14. Crash modification factors (CMFs) for project segments.

Segment	Countermeasure	Crash Type	Crash Severity	CMF	Composite CMF
Westerly (as-constructed)	New guardrail	Run off road	Serious and minor injury	0.53	0.2915
	Centerline rumble strips	Head-on, sideswipe	Fatal, serious and minor injury	0.55	
	New guardrail	Run off road	Fatal	0.56	0.308
	Centerline rumble strips	Head-on, sideswipe	Fatal, serious and minor injury	0.55	
Westerly (baseline)	New guardrail	Run off road	Serious and minor injury	0.53	0.53
	New guardrail	Run off road	Fatal	0.56	0.56
Between (as-constructed)	Centerline rumble strips	Head-on, sideswipe	Fatal, serious and minor injury	0.55	0.55
Between (baseline)	None	n/a	n/a	1.0	1.0
Easterly (as-constructed)	Centerline rumble strips	Head-on, sideswipe	Fatal, serious and minor injury	0.55	0.55
	HMA overlay with Safety Edge	Run off road	Fatal, serious and minor injury	1.0	
Easterly (baseline)	HMA overlay without Safety Edge	n/a	n/a	1.0	1.0

Based on the CMFs shown in table 14, the economical benefits due to the various safety features on the project segments for both the as-constructed and baseline cases are shown in table 15.

Table 15. Crash costs (\$/million vehicle miles traveled).

Segment	Scenario	Fatalities	Severe Injuries	Moderate Injuries	Minor Injuries	Property Damage Only	Total
Westerly	Preconstruction	\$890,688	\$8,964	\$20,587	\$9,802	\$0	\$930,040
	Baseline	\$498,785	\$4,751	\$10,911	\$5,195	\$0	\$519,642
	As-constructed	\$274,332	\$2,613	\$6,001	\$2,857	\$0	\$285,803
Between	Preconstruction	\$0	\$0	\$35,835	\$11,374	\$0	\$47,209
	Baseline	\$0	\$0	\$35,835	\$11,374	\$0	\$47,209
	As-constructed	\$0	\$0	\$19,709	\$6,256	\$0	\$25,965
Easterly	Preconstruction	\$354,267	\$35,652	\$50,040	\$12,995	\$0	\$452,955
	Baseline	\$354,267	\$35,652	\$50,040	\$12,995	\$0	\$452,955
	As-constructed	\$194,847	\$19,609	\$27,522	\$7,147	\$0	\$249,125

### LIFE CYCLE COST ANALYSIS

To quantify the benefits of the as-constructed project versus the baseline case, a life cycle cost analysis (LCCA) was performed using a deterministic approach (i.e., no variability in costs, ages, etc., was considered). Life cycle costs differentials were computed in the form of NPV, which is defined as follows:

where:

$$NPV = Initial\ Cost + \sum Future\ Cost * \left[ \frac{1}{(1+i)^n} \right]$$

- NPV = net present value, \$.
- i = discount rate, percent.
- n = time of future cost, years.

A summary of the various costs and the applicable timeline is shown in table 16. A discount rate of 4.0 percent was used based on information provided by Caltrans ([www.dot.ca.gov/hq/tpp/offices/eab/benefit\\_cost/LCBCA-economic\\_parameters.html](http://www.dot.ca.gov/hq/tpp/offices/eab/benefit_cost/LCBCA-economic_parameters.html)).

The life cycle cost differential analysis, summarized in table 16, shows that the baseline case is estimated to save Calaveras County and roadway users \$8,549,462.26 in terms of 2012 NPV based on a 10-year analysis period. This savings is a result of the reduced fatality and injury rates due to the MBGR installation on the westerly segment. By comparison, the as-constructed case is estimated to save \$16,438,619.99 in terms of NPV, for a total additional benefit of \$7,889,157.73. The driver of the cost savings compared to the baseline case is the additional

reduction in future crash rates due to installation of centerline rumble strips and highly retroreflective striping. The safety benefits of the Safety Edge are not considered in the analysis because there are no reliable CMF estimates for Safety Edge.

Table 16. Summary of life cycle cost differentials in 2012 dollars (10-year analysis period).

<b>Cost Category</b>	<b>Age (yrs)</b>	<b>Baseline Roadway</b>	<b>As-Constructed Roadway</b>
Preliminary design and engineering, Construction engineering	0	\$228,450.44	\$249,896.86
Construction costs		\$ 814,566.22	\$ 891,035.87
Delay-related user costs		\$ 49,553.34	\$ 59,671.86
10-year crash-related savings NPV Westerly segment 1.6 mi, average annual daily traffic = 4,960 2.897 million VMT/yr Assume no traffic growth	Years 1-10	-\$9,642,032.26	-\$15,135,926.44
10-year crash-related savings NPV Between segment 0.8 mi, average annual daily traffic = 1,900 0.555million VMT/yr Assume no traffic growth	Years 1-10	-\$0.00	-\$95,596.41
10-year crash-related savings NPV Easterly segment 2.1 mi, average annual daily traffic = 1,900 1.456 million VMT/yr Assume no traffic growth	Years 1-10	-\$0.00	-\$2,407,701.73
<b>Net Present Value of All Cost Differentials</b>		<b>-\$8,549,462.26</b>	<b>-16,438,619.99</b>

## TECHNOLOGY TRANSFER

The second day of HMA Safety Edge paving (August 23, 2012) coincided with a project open house. The open house was held at the Calaveras County Library in San Andreas to disseminate knowledge and experiences gained through the Safety Edge construction process to others in the highway community. The open house was attended by 33 participants representing Calaveras County, Caltrans, FHWA, local consultants and paving contractors, and representatives from nearby governments such as Amador County, Tulare County, and the city of Stockton.

The open house began with introductions followed by a presentation by Ken Kochevar of FHWA (figure 42). Kochevar covered various aspects of the Safety Edge, including how it works, equipment used to pave the Safety Edge, benefits, costs, construction issues, project examples, plans, and specifications. A presentation by paving contractor George Reed Inc. representative Mike Gourley reviewed various aspects of paving the Safety Edge at the Mountain Ranch Road location, including equipment and specific issues relating to the terrain and shoulder clearances.

The presentations were followed by a field trip to the project site, where participants observed paving of the Safety Edge and posed questions to Kochevar and Gourley (figures 43 through 45). After the field trip, participants returned to the Calaveras County Library in San Andreas for follow-up questions and discussion.



Figure 43. Ken Kochevar presenting details of Safety Edge technology at the open house.



Figure 44. Mike Gourley of George Reed Inc. answering participant questions during the field trip portion of the open house.



Figure 45. Ken Kochevar of FHWA explaining details of the Safety Edge during the field trip.





Figure 46. Participants observing the Safety Edge paving during the field trip.