



SURFACE VEHICLE RECOMMENDED PRACTICE

J3234™/3

JUL2025

Issued

2025-07

Active Safety Roadside Concrete Curb Surrogate Recommendation

RATIONALE

Reducing road departure crashes is key for active safety systems since road departure crashes contribute to many road fatalities in the U.S. As more active safety systems, especially road departure mitigation systems (RDMS), are introduced to the market, standard roadside object surrogates are needed for the automotive industry to test and evaluate RDMS. Curb is an important roadside feature that should be considered for the road departure mitigation systems. There are currently no standard testing protocols and testing surrogates for curb detection. SAE International created an Active Safety Roadside Object Surrogate Target Task Force under the Active Safety Systems Standards Committee to study this topic and recommend curb surrogate design guidelines.

INTRODUCTION

Reducing road departure crashes is one of the primary goals of active safety systems. As more active safety systems - especially road departure mitigation systems (RDMS) - are introduced, standard roadside object surrogates are needed for the automotive industry to test and evaluate RDMS and automatic parking systems. The Roadside Object Surrogate Task Force aims to develop design specifications/recommendations for curb surrogates. The surrogates should represent real curbs to the sensors used in RDMS. They can be used for the performance assessment of such in-vehicle sensing systems in simulating real-world test scenarios/conditions. All task force members are from industry, academia, or government agencies. Many members had experience using, testing, and/or developing roadside object surrogates. In addition, the task force gathered information about concrete curb surrogates known to the members and the state-of-the-art features of these surrogates. This document summarizes the findings and recommendations from the Roadside Object Surrogate Task Force.

Since the radar characteristics of concrete curbs depend on their shapes, which may vary in different countries, this task force adopts the concrete curb in the United States to develop the design recommendations of the surrogate concrete curb. These SAE concrete curb surrogate design recommendations are representative of 180-degree approach angles. Concrete curb surrogates for other countries may be developed similarly.

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1. SCOPE

The scope of this document is to provide the design specifications/requirements/guidelines for concrete curb surrogates that represent actual concrete curbs to the in-vehicle sensors and can be used for performance assessment of such in-vehicle sensing systems in real-world test scenarios/conditions. Therefore, this document only includes the recommended concrete curb surrogate characteristics for automotive cameras, LiDARs, and/or radars.

This document is focused only on the concrete curb and not on the asphalt curb, which is not common.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J3063 Active Safety Systems Terms and Definitions

SAE J3157 Active Safety Bicyclist Test Targets Recommendation

SAE J3234/1 Active Safety Roadside Metal Guardrail Surrogate Recommendation

SAE J3234/2 Active Safety Roadside Concrete Divider Surrogate Recommendation

2.1.2 Other Publications

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3. DEFINITIONS

ACTIVE SAFETY SYSTEM: Active safety systems are vehicle systems that sense and monitor conditions inside and outside the vehicle for the purpose of identifying perceived present and potential dangers to the vehicle, occupants, and/or other road users. Active safety systems automatically intervene to help avoid or mitigate potential collisions via various methods, including alerts to the driver, vehicle system adjustments, and/or active control of the vehicle subsystems (brakes, throttle, suspension, etc.) (refer to SAE J3063).

AUTOMATIC EMERGENCY BRAKING (AEB): Detects potential collisions with a vehicle ahead, provides forward collision warning, and automatically brakes to avoid a collision or lessen the severity of impact. Some systems also detect pedestrians or other objects (refer to SAE J3063).

INFRARED: Have a wavelength higher than the red end of the visible light spectrum but less than that of microwaves. In this document, infrared refers to near-infrared radiation with a wavelength from about 800 nm to 1 mm (refer to SAE J3157).

LiDAR: An active sensing technology that can measure the distance to, or other properties of, targets by illuminating the target with light and analyzing the backscattered light (refer to SAE J3157).

4. ABBREVIATIONS

AEB Automatic Emergency Braking

LiDAR Light Detection and Ranging

Radar Radio Detection and Ranging

RCS Radar Cross Section

5. CONCRETE CURB SURROGATE RECOMMENDED SPECIFICATIONS

The concrete curb surrogates should provide sufficient details of the concrete curb characteristics to satisfy the need for all state-of-the-art detection sensors. Table 1 shows the concrete curb characteristics that potentially affect the sensing outcome. Therefore, they should be considered in the design specifications of concrete curb surrogates.

Table 1 - Concrete curb characteristics versus detection sensors

Sensor Type	Concrete Curb Characteristics			Infrared Reflectivity
	Size and Shape	Viewing Angle	Radar Reflectivity	
Camera	X	X		
76-78 GHz Radar	X	X	X	
Lidar/Active Infrared	X	X		X

The size and shape of concrete curb surrogates affect all automotive sensors currently used for road departure mitigation. Concrete curbs have many shapes and sizes, as specified by various standards in different countries. The concrete curb has a fixed height and is continuous in length in the U.S. Some concrete curbs are coated with various surface treatment materials to improve their lifespan and appearance. All variations affect the concrete divider's camera (visual), LiDAR, or radar signatures.

During naturalistic driving, the detection sensors are frequently exposed to concrete curbs from different horizontal and vertical angles. Assuming that the vehicle is always on the road and the roadside object is always on the roadside, the standard concrete curb surrogate must represent the characteristics of the concrete curb from all 180-degree horizontal viewing angles and 0- to 90-degree vertical viewing angles.

5.1 Size and Shape

This document uses the most commonly seen concrete curbs in the U.S. as an example for specifying the design specifications of the surrogate concrete curb. There are many different curb shapes, according to the curb construction requirements from various states in the U.S. [1 to 3]. The most commonly seen street curbs are 6 inches tall and 6 inches wide with round corners of various radii (1 to 3 inches) on the top (see Figure 1). Portland cement is mainly specified in construction specifications for the road concrete curb. The Portland cement to sand/gravel ratio in concrete is from 1:1.25 to 1:3.25. The Portland cement is a combination of calcium, silicon, aluminum, and iron [4]. This information may be helpful and meaningful for Lidar and radar simulations. Concrete curbs in other countries may be specified similarly.

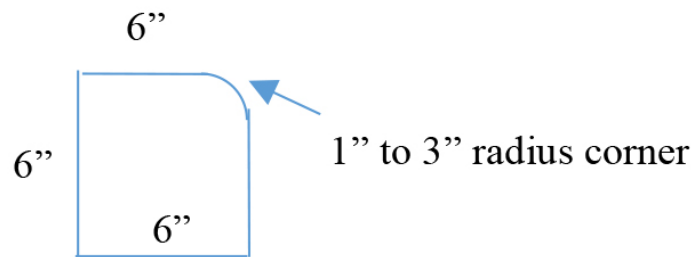


Figure 1 - Example of cross dimensions of a concrete curb

5.2 Color Patterns

The goal of specifying the color of the concrete curb surrogate is to test the performance of the automotive cameras commonly used in active safety systems. 24,735 Google Street View images of road edges in all U.S. states were studied [5, 6]. Of these 24,735 images, 641 show the distinct and clear road curb edges. Figure 2 shows the distribution of the specimens all across the U.S. on a Google map. These 641 curb road edge images are used to find the representative curb color and color patterns. It should be noted that the image used may not exactly represent the true colors due to camera variations. However, the variations in camera color capturing are small and do not affect the specification of the surrogate colors.



Figure 2 - The distribution of curb samples across the U.S. on a Google map
(Reprinted with permission from [23], Figure 5. Map Data: Google Maps)

The surface of the concrete curb can be bare concrete or painted. As the curb ages, its color becomes less uniform due to dust, dirt, tire marks, etc. Some curbs are also painted with various colors, indicating fire hydrant, no parking, handicapped parking, etc. In North America, most concrete curbs are bare concrete. According to the color analysis of 641 concrete curb images over the U.S. from Google Street View [5], the colors of curbs are concentrated in four clustered colors. The representative colors of these color clusters are shown in Table 2. Example curbs are shown in Figure 3. Here, a curb type is defined as all curbs within the same color cluster. So, there are four types of curbs corresponding to four color clusters. Since the curb samples with type 2 color are only 3% of all 641 samples, this type is not considered further and is grayed out in Table 4 to indicate that it is not considered in the surrogate specifications. If the surrogate curb made by these color types is a single color and does not have color variations, they will not look natural. The next step is to divide 641 samples into equal-sized small areas (blocks) to understand the color variations (refer to [6]). The representatives of ten clustered color components are shown in Table 3. The distribution of these ten cluster colors in the four color types is described in Table 4. Type 2 color is the painted curb, while types 1, 3, and 4 are unpainted curbs. Depending on the paint material, not only the color but also the infrared reflectivity is significantly affected. Radar reflectivity can also be affected depending on the thickness and the type of paint. Type 2 color-painted curbs are only 3% of the concrete curb population (see Type 2 in Table 2). Other paint colors represent even a smaller percentage of the curb population nationwide. While the painted curbs were considered, they were not included in the surrogate specification since they represent a small percentage of curbs nationwide. The details of the color composition of each curb color type and examples are described in Appendix B.