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Do Speed Humps Help Reduce Vehicular Speeds, Volumes, and Motorist Accidents?

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<u>Do Speed Humps Help Reduce Vehicular Speeds, Volumes, and Motorist Accidents?</u>

by

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Table of Contents

List of Figures

List of Tables

Abstract

California has adopted a Complete Streets policy, which requires local municipalities to design roadways that meet the needs of all users (pedestrians, bicyclists, and motorists). This policy, combined with complaints about motorists speeding in residential areas, has been a catalyst for jurisdictions to install traffic calming measures on residential streets. One popular traffic calming measure used in the City of Redwood City is the installation of speed humps. A speed hump is a raised pavement surface that provides a physical reminder for motorists to slow down while traveling over it. Although literature shows that the installation of speed humps can decrease vehicular speeds on residential roads, the impact speed humps have on adjacent streets has not been fully researched.

This project has evaluated the effectiveness of speed humps at reducing vehicular speeds, volumes, and motorist accidents. The term "appropriate area", as used in this research, is defined as the speed hump installation area which is determined by the City Engineer. The research has addressed impacts on two types of streets: streets with speed humps installed and streets adjacent to their installation. The following research questions have been addressed:

- If installed in an appropriate residential area, can speed humps reduce vehicular speeds and volumes? How are vehicular volumes on adjacent streets impacted?
- If installed in an appropriate area, can speed humps reduce the occurrence of motorist collisions? How is the occurrence of motorist collisions impacted on adjacent streets? After the installation, do residents on adjacent streets feel safer in their neighborhood?

Key words: Complete Streets, speed humps, traffic calming

Section 1: Introduction

Problem Statement

This research determined if speed humps were effective at reducing vehicular speeds, volumes, and motorist accidents within a localized community.

Overview

When the automobile was introduced to American society in the late 1800s, most roadways were unpaved and designed for horse, carriage, and foot traffic. Few individuals owned an automobile and the demand for paved roadways was minimal. However, when the automobile's popularity increased in the early 20th century, a demand for widespread automobile facilities was created (Robin et al., 2010). This demand represented society's desire for more positive freedom, which is defined by Hall (2015) as a government action designed to better society.

Throughout the 20th century, the federal government exercised positive freedom by passing legislation and appropriating funds for the enhancement of the roadway network (Mikesell, 2011; Weingroff, 1996). These legislative acts helped the roadway network expand from rudimentary postal roads in the 19th century, to paved city roadways and extensive highway interchange systems of 21st century urban areas.

In broad terms, an urban city's roadway network consists of arterial, collector, and local streets. Arterial streets are where a majority of the city's traffic is concentrated. They are intended to move large volumes of vehicles through the city and onto a freeway. Collector streets carry less traffic than arterials and are designed to provide a connection from local to arterial streets. Moreover, collector and arterial streets are designed for commute traffic to use while navigating through a city. Local streets are typically in residential areas. They carry neighborhood traffic and are intended to have low vehicular volumes (Institute of Transportation Engineers, 2010). Laplante and McCann (2008) claim that many commuters choose to use local streets as a way to bypass congested collector and arterial streets. This has created large volumes of traffic and high vehicular speeds in residential neighborhoods.

Parents, cyclists, and community activists voiced their concerns about the externalities of increased vehicular travel on local streets (Laplante and McCann, 2008). Some of the externalities included traffic congestion, increased accidents, and unsafe travel conditions for individuals choosing to walk, bike, or use public transportation. In general, these groups wanted safer neighborhoods and asked their governing bodies to provide measures that achieved this (Laplante and McCann, 2008; Lynott et al., 2009).

In 2008, the State of California passed Assembly Bill 1358 (AB 1358); this legislation is referred to as California's Complete Streets Act (State of California, 2010). A complete street is a street that is designed to provide for the mobility of motorists, pedestrians, and bicyclists (Sallis and Glanz, 2006; George, 2013). One provision of AB 1358 requires jurisdictions to amend their general plans to include roadway design elements that accommodate the needs of all roadway users (Assembly Bill No. 1358, 2008). One way jurisdictions have met this provision is through the installation of traffic calming measures. The goal of traffic calming is to reduce speeds on local roads and improve safety for all roadway users (McCann, 2005; City of Sunnyvale, 2008).

There are many traffic calming measures that can improve roadway safety; one measure that is used on local streets is the installation of speed humps. A speed hump is a raised pavement surface or large, engineered bump in the road that encourages motorists to reduce their speeds while traveling over it. It should not be confused with a speed bump, a small and abrupt engineered bump in the road that is typically installed in shopping centers. Speed humps are approximately 12-14 feet long and extend the width of the roadway. They are installed in residential areas when warranted (City of Redwood City, 1997). Figure 1.1 graphically shows the difference between a speed hump and a speed bump.

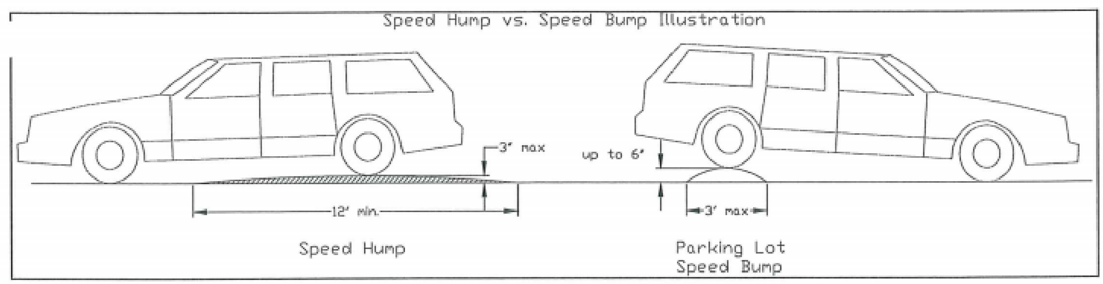


Figure 1.1: Speed Hump vs. Speed Bump (City of Redwood City, 1997)

The City of Redwood City (Redwood City) has adopted a speed hump policy to help control vehicular speeds on select local roadways (City of Redwood City, 1997). One limitation of this policy is that it does not currently address impacts speed humps may have on streets adjacent to their installation and within a localized area.

Section 2: Literature Review

Background

The widespread use of the automobile has impacted society. One positive impact is the ability of motorists to expediently travel from one location to another. However, this impact has consequences. Two associated consequences include increased speeding on local roadways and an increase in unsafe roadway conditions for pedestrians and bicyclists. To combat these consequences, governments around the world have focused efforts on improving local communities (Svara et al., 2013; Project for Public Spaces, n.d.).

Hockenos (2013) and George (2013) identify the Netherlands as the first country to introduce traffic calming measures, measures intended to improve roadway safety and reduce vehicular travel speeds, in residential neighborhoods. In the 1970s, the Netherlands introduced the Woonerf, a Dutch term meaning “livable street”. The goal of the Woonerf was for motorists and pedestrians to share the same space and safely interact with one another (Cottrell et al., 2006).

Woonerfs have no traffic signals, stop signs, or sidewalks. Instead, their design includes street lights, raised pavements, and textured pavements to decrease vehicular congestion and increase neighborhood aesthetics. After Woonerfs were installed, communities in the Netherlands experienced a decrease in traffic collisions and an increase in pedestrian activity. In 1976, the government formally adopted Woonerfs and declared that “the rights of the motorist are expressly subordinate to the rights of other road users” (Wit and Talens, n.d.). With this statement, the government protected the mobility of pedestrians.

After the widespread success of the European Woonerf, American public administrators, transportation engineers, and transportation planners started to view roadway design from the perspective of pedestrians, bicyclists, and persons with disabilities (*Complete the Streets*, 2008). Transportation engineers and planners started recommending traffic calming measures such as speed humps, traffic circles, and raised pavement crosswalks, to provide long term roadway safety solutions (Kotsopoulos, 2000; Metzger, 2008; Tester et al., 2004). In turn, public administrators relied on the analysis performed by transportation engineers and planners to educate themselves on the advantages and disadvantages of each measure before final approval (Rickert, 2008; Institute of Transportation Engineers, 2013; Seskin et al., 2012; Shopes, 2008).

Complete Streets

In the 1990s, American local governments promoted walkable communities (Bristol, 2012). Walkable communities use traffic calming measures to encourage walking and bicycling in the community and near schools. They challenge people to walk one or two blocks to their destination, rather than driving the same distance. The Safe Routes to School program, a program which provides government funding for the installation of sidewalks and safe crossing zones near schools (George, 2013; McCann, 2005), was introduced in “Denmark in the late 1970s as part of a very successful initiative to reduce the number of children killed while walking and bicycling to school” (History of SRTS, 2013). Denmark’s success was repeated in the United States in 1997 and an American Safe Routes to School program was adopted by Congress in 2005. This program has encouraged children to be physically active. It has also reduced school zone congestion, because many parents opt to walk their children to school rather than drive (Robin et al., 2010).

Concurrently, concerned parents, bicycle activists, and community activists communicated their desire for more “sidewalks, bike lanes, and mass transit accommodation in project planning, design, and construction” (Brock, 2008) to their public administrators. In 2003, these groups increased their efforts and lobbied their congresspersons for legislation requiring jurisdictions to address the needs of all roadway users. In other words, they sought legislation for a Complete Streets policy.

Complete Streets measures include curb ramps, wider sidewalks, crosswalk improvements, bike lanes, audible crossing signals for people with visual impairment, speed humps, and landscape improvements. In theory, adding Complete Streets measures to current roadway design can provide health benefits and increase roadway utility for all users (Robin et al., 2010). Complete Streets also create walkable communities and can promote healthy lifestyles (Assembly Bill No. 1358, 2008).

As a result of this lobbying, the California state legislature adopted state law AB 1358, a Complete Streets Act that requires jurisdictions "to accommodate the safe and convenient travel of [all] users of streets, roads, and highways" (Assembly Bill 1358, 2008). This law also states that when "any substantive revision of the circulation element of the general plan" occurs, cities and counties must "modify the circulation element to plan for a balanced, multimodal transportation network that meets the needs of all users of streets, roads, and highways, defined to include motorists, pedestrians, bicyclists, children, persons with disabilities, seniors, movers of commercial goods, and users of public transportation" (Assembly Bill No. 1358, 2008).

Speed Humps

Speed humps satisfy provisions of AB 1358. In the 1990s speed humps were referred to as "sleeping policemen" (Moran, 2006), because they are self-enforcing and the consequences of not reducing your speed when traveling over them can be severe (Dixon and Jacko, 1998; Thompson, 2002). A speed hump is a raised pavement surface that is 12-14 feet wide, 3-4 inches high, and encourages motorists to reduce their speed to 15 MPH when traveling over it (City of

Redwood City, 1997). If a vehicle travels over a speed hump at a higher speed, the driver risks jolting or damaging the vehicle (Dixon and Jacko, 1998; Cottrell et al., 2006). Speed humps evolved from the speed bump, which is typically installed in shopping center parking lots. A speed bump is approximately 1-3 feet wide, 3-4 inches high, and encourages vehicles to reduce their speeds to 10 MPH when traveling over it. If a speed bump is placed in the public right of way, a driver traveling over it at speeds greater than 10 MPH may risk serious damage to his car and passengers; cities also risk liability claims (Chadda and Steward, 1985). The larger width of the speed hump is more forgiving of higher speeds than the speed bump and can be installed in residential areas when warranted.

Possible Advantages of Traffic Calming Measures and Speed Humps

Bristol (2012) and Burden et al. (2011) claim that traffic calming measures reduce the occurrence of automobile collisions, improve pedestrian safety, create a better connected community, and provide better air quality. Moreover, Tester (2004) and Knapp (2000) claim that speed humps are long term safety solutions, because they are a physical reminder for motorists to drive with caution. This is especially important in residential neighborhoods where young children play in the street.

Before the installation of speed humps, residents claimed that cars traveled down their streets “like they [were] on a racetrack” (Shopes, 2008) and created safety hazards for children. After the installation of the speed humps, residents stated that vehicular speeds were reduced and believed that child safety had increased (Kotsopoulos, 2000; Rickert, 2008; Shopes, 2008; Knapp, 2000; George, 2013).

Figure 2.1 shows the probability of a pedestrian fatality if struck by a motorist traveling at various speeds. A pedestrian hit by a car traveling at 40 MPH has an 85 percent chance of serious injury and a 5 percent chance of serious injury if hit by a car traveling at 20 MPH. Based on figure 2.1, it can be concluded that a pedestrian hit by a car traveling at low speeds (20 MPH) has a greater chance of surviving an accident than a pedestrian that is hit by a car traveling at high speeds (40 MPH).

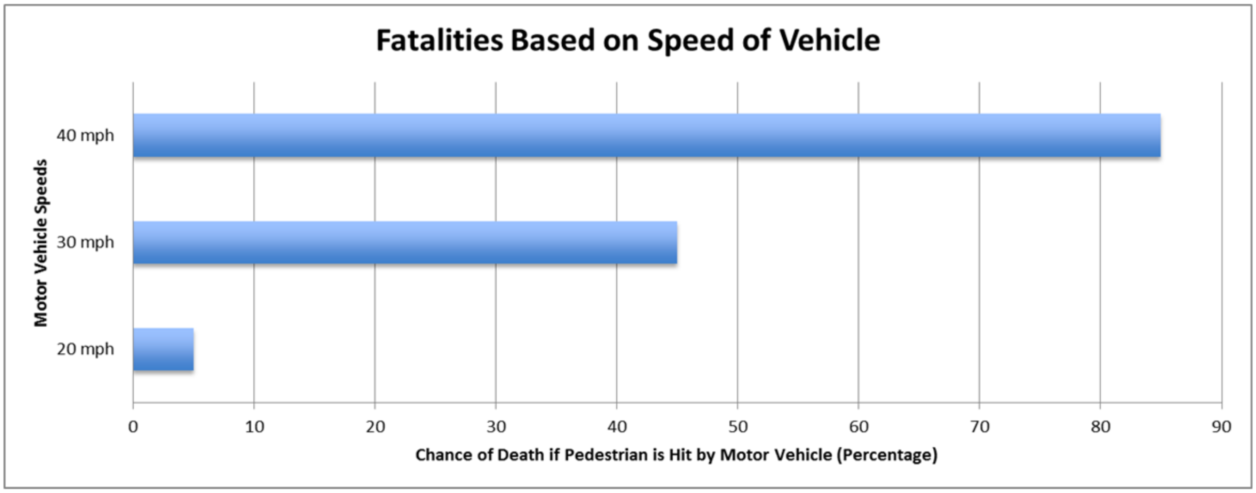


Figure 2.1: Fatalities Based on Speed of Vehicle (reproduced from U.K. Department of Transportation, 1987)

Possible Disadvantages of Traffic Calming Measures and Speed Humps

When a speed hump is installed on a residential street, motorists may choose to bypass that street and travel on an adjacent street without the speed deterrent. This can increase the occurrence of speeding on adjacent streets (Kotsopoulos, 2000; Chadda and Steward, 1985). Anticipating motorist behavior and determining where to install speed deterrents is difficult. It is essential for public administrators to balance the needs of their constituency when making these decisions (Rosenbloom et al., 2009). Pedestrians and bicyclists may advocate for wider sidewalks, more bicycle lanes, and fewer vehicle lanes. Motorists may advocate for more travel lanes and fewer travel delays caused by slowing to navigate around speed deterrents (*Be the Advocate for Complete Street*, 2013).

Emergency responders have also voiced their concerns about the hazards speed humps pose for them. They must reduce their travel speeds to navigate over a speed hump and consequently emergency response times can be reduced by up to 10 seconds, as reported by the Institute of Transportation Engineers. In the case of an emergency, Rickert (2008) and Thompson (2002) state that 10 seconds can be the difference between life and death. Additionally, residents share these concerns. Shopes (2008) described an instance where a resident was concerned that should he have a heart attack, he could die waiting for the ambulance to navigate over all of the traffic calming measures in his neighborhood.

Stakeholders

Pedestrians, property owners, and bicyclists share a mutual interest in reducing vehicular speeds and increasing roadway safety. Motorists have an interest in driving on roadways that allow them to navigate to their destination as quickly and safely as possible. Law enforcement officers are tasked with maintaining a safe environment (Redwood City Police Department Welcome Message, 2010). Moreover, when motorists follow the speed laws, law enforcement officers are able to divert their attention to other tasks, which allows them to better protect the community.

Methods Used to Evaluate Speed Humps

Cottrell et al. (2006) used before and after studies to identify speed profiles, interviews with residents to identify the perceived impact of the speed humps, and case studies to conclude that complete streets promote walkable communities. The first case study was in Sacramento, California; it concluded that bike counts on identified roadways increased after the Complete

Street improvements. The second case study was in Fresno, California; it concluded that Fresno became more bike friendly after the Complete Streets improvements. The third case study was in Lancaster, California; it concluded that speeds and collisions were reduced after the Complete Street improvements. Moreover, economic activity increased in downtown areas, which yielded higher sales tax revenues for the municipality and attracted new businesses.

Tables 2.1 and 2.2 are representations of a quantitative before and after analysis of speeds, volumes, and traffic accidents on six roadway segments with speed humps performed by Cottrell et al. (2006). Table 2.1 data shows varied results. Four of the street segments experienced an increase in vehicular mean speed and volume. Fourteen segments experienced a decrease. Table 2.2 shows that traffic accident data is relatively unchanged. From these tables, it can be deduced that speed humps are effective at reducing vehicular speeds and volumes on calmed streets.

Table 2.1: Before-After Speeds Along Calmed Streets (Cottrell et al., 2006).

Before-after speeds along calmed streets

Neighborhood	Street	Route	Sample size		Mean speed		85^{th} % speed		% <25 mph	
			Before	After	Before	After	Before	After	Before	After
Bonneville Golf	Wasatch Dr	North	1,319	1,510	32.0	25.2	37.9	30.2	12.7	52.4
			1,185	1,238	32.0	29.4	37.7	35.4	12.0	25.3
		South	1,576	1,423	31.4	30.5	36.9	36.8	13.7	21.0
East Bench	Skyline Dr	East	589	489	29.0	23.2	35.6	29.0	28.8	66.0
			881	807	22.7	23.4	27.1	28.2	74.7	67.7
		West	828	820	27.0	27.6	32.3	32.2	38.3	32.1
			356	335	28.3	23.2	35.6	29.4	34.5	65.0
	Wasatch Dr	North	1,039	1,191	29.7	23.5	35.4	28.2	22.6	67.1
		South	1,019	941	28.7	23.4	34.1	28.9	26.6	65.2
Glendale	Glendale Dr	North	590	441	26.6	22.9	35.0	27.8	44.5	71.0
	Montgomery St	South	484	109	25.1	23.0	32.1	29.3	52.1	65.8
Harvard-Yale	1500 East	North	2,363	2,097	30.6	22.9	36.3	27.7	17.8	71.2
		South	1,997	1,179	25.2	22.9	29.3	27.0	52.9	74.5
St. Mary's	Kennedy Dr	East	1,014	981	28.3	29.6	34.5	35.7	32.2	24.0
		West	1,213	1,141	30.0	31.8	36.6	38.7	23.9	17.0
	Vista View Dr	North	607	512	24.1	22.8	28.8	27.3	61.9	73.2
Upper Avenues	Northmont Dr	East	254	296	27.6	21.6	33.7	27.2	36.2	76.5
		West	206	218	28.4	26.5	35.3	34.5	33.0	45.2

NOTE: Speeds are in mph. Divide mph by 0.6214 to obtain km/h.

Table 2.2: Motor Vehicle Crashes on Calmed Streets (Cottrell et al., 2006)

Motor vehicle crashes on calmed streets

Street	Installation date	Study period	Study period length (months)	Crashes	
				Before	After
Glendale Dr	March 2000	5/97–12/02	68	1	5
Kennedy Dr	July 2001	1/00–12/02	36	2	0
Montgomery St	September 2000	5/98–12/02	56	1	0
North Hills Dr	February 1999	3/95–12/02	94	0	0
Northmont Dr	February 1999	3/95–12/02	94	1	0
Oakhills Dr	August 2002	3/02–12/02	10	0	0
St. Mary's Dr	March 2002	5/01–12/02	20	0	0
Skyline Dr	February 2001	3/99–12/02	46	0	0
Vista View Dr	September 2002	5/02–12/02	8	0	0
Wasatch Dr (golf)	August 1999	3/96–12/02	82	0	0
Wasatch Dr (East Bench)	November 1999	9/96–12/02	76	2	0
1500 East	May 2000	9/97–12/02	64	3	4
Total				10	9

Kotsopoulos (2000) used a before and after analysis to evaluate vehicular speeds and volumes on roadways with speed humps. This analysis showed that there was a 48 percent decrease in vehicle volumes and a 29 percent decrease in speeds on streets with speed humps. However, on the adjacent streets there was a 23 percent increase in vehicle volumes and a 3.3 percent increase in speeds. This analysis concluded that although adding speed humps to one street can positively impact that neighborhood, one of the externalities of the installation is that traffic may shift to the adjacent street.

Dixon and Jacko (1998) conducted a before and after study focusing on speeds to assess whether speed humps had a significant effect on driver behavior in the Netherlands. They used an experimental design with a control group to further their conclusions. The experimental street had a speed hump and the control street did not. Both streets had similar width, length, and vehicle usage roadway characteristics. The study showed that there was a 40 percent decrease in speeds on the street with the speed hump and the authors concluded that the presence of the speed hump changed motorist behavior.

Both Thompson (2002) and Rickert (2008) used a before and after analysis and concluded that there was a decrease in cut through traffic and vehicular speeds on streets with speed humps. Rickert (2008) studied four locations and made general conclusions and Thompson

(2002) studied one location but identified that the before speeds were 36-37 MPH and the after speeds reduced to 26-27 MPH.

Tester (2004) used a case study to show that children living on a block with speed humps were less likely to be hit by a car than children living on a street more than one block away from speed humps. The study concluded that there is a “53-60% reduction in the odds of injury or death among children struck by an automobile in the neighborhood” (Tester et al., 2004) when a speed hump is present. Tester warns that an increase in traffic volume or speeds is correlated to an increase in child/motorist accidents.

Literature Review Conclusion

Successful lobbying efforts for pedestrian and bicycle facilities was the impetus for California’s Complete Streets Act, which required municipalities to provide safe, convenient facilities for pedestrians, bicyclists, motorists, and transit users (Bleier et al., 2011). This literature review concludes that, when implemented in an appropriate area, a Complete Street can encourage walking and bicycling, provide safer travel for pedestrians, and reduce traffic collisions (Knapp, 2000; Seskin et al., 2012). Additionally, traffic calming measures can reduce vehicular speeds, reduce the likelihood of motorist accidents, and encourage walkable communities.

This literature review has outlined the history of Complete Streets, focusing on the application of speed humps as a traffic calming measure. As described in the case analyses, before and after speed and volume studies can show the impact speed humps have on an area before and after their installation. This literature review also revealed that although speed humps can be effective speed deterrents for streets, there is a potential for speeding problems to shift elsewhere.

Section 3: Methodology

Introduction

This research study used a quasi-experimental analysis, focusing on time-series measurements, to evaluate the effectiveness of speed humps. Data was provided from Redwood City's traffic accident database and speed and volume studies for selected roadways. Informal interviews and site visits were also performed to identify the impacts speed humps have from a variety of perspectives: that of the community, engineers, and public administrators. The literature review identified that traffic calming devices, such as speed humps, can be effective at reducing speeds and volumes on the street with the installation. The purpose of this research design was to verify the impact speed humps had on the streets with the installation and identify their impact on adjacent streets.

Research Questions

The following research questions have helped focus the paper's analysis and research.

Question 1: If installed in an appropriate residential area, can speed humps reduce vehicular speeds and volumes?

One goal of traffic calming is to create safer communities and reducing vehicular speeds in residential areas is one way to accomplish this. This paper has provided a quasi-experimental analysis which analyzed speed and volume data on the selected roadways.

Question 1a: How are vehicular volumes on adjacent streets impacted?

A speed hump impacts a localized community, not just the street it is installed on. This paper's qualitative tools have analyzed speed and volume data on streets adjacent to the speed hump installation.

Question 2: If installed in an appropriate area, can speed humps reduce the occurrence of motorist collisions?

The literature review suggested that streets with excessive motorist speeds have an increased probability of motorist accidents. To test this statement, this paper's research design analyzed accident records on streets before and after a speed hump installation.

Question 2a: How is the occurrence of motorist collisions impacted on adjacent streets?

The research design analyzed traffic accident reports.

Question 2b: After the installation, do residents on adjacent streets feel safer in their neighborhood?

One way to measure the effectiveness of a traffic calming measure is to poll community perception. The research design has used qualitative measures such as community correspondence to address this question.

Outline of Methods Used for each Research Question

Both quantitative and qualitative data have been analyzed to address the research questions. Using data collected, this paper provides recommendations on how to improve Redwood City's speed hump policy.

Speed and Volume Surveys (addresses research questions 1, 1a)

Traffic Engineers collect speed and volume data through the use of surveys. Streets identified in this study were surveyed before and after the speed hump installation to determine if the presence of speed humps had an impact on motorist behavior. Speed and volume surveys were requested and provided by the Redwood City traffic engineering department. Data analyzed includes the 85^{th} percentile speed, mean speed, and traffic volumes.

Traffic Accident Database (addresses research questions 2, 2a)

Data from Redwood City's traffic accident database was used to analyze reported accident records on streets identified for this study. This data was requested from and provided by Redwood City.

Focus Interviews (addresses research questions 1, 1a, 2, 2a, 2b)

Focus interviews with traffic engineering staff were conducted to determine their perception of speed humps. These interviews provided insight for the research design which were not gleaned from other quantitative or qualitative research methods. The interviews were informal and unstructured. This format was chosen due to its success at yielding an active dialog on the subject.

Methods Overview

Speed and Volume Surveys

A quasi-experimental analysis, focusing on time series measurements (Haas and Springer, 2006), was conducted to assess vehicular speeds and volumes before and after the installation of speed humps. This approach is similar to the before and after analysis approach, which analyzes one sample of before and one sample of after measurements; more data is collected for the quasi-experimental analysis. While the before and after analysis is cost effective, it can lead to questionable results because threats to internal validity may be present in the data sample.

One threat to internal validity that the time series measurement can reduce is a history event. An example of a history event is construction. When a street undergoes construction activity, traffic may need to be detoured around it. This can change motorist behavior on the impacted street. Another threat to internal validity can be regression to the mean. This occurs when some data points are significantly higher or lower than the other data; these data points are referred to as outliers (Haas and Springer, 2006).

With the quasi-experimental analysis, three sets of speed and volume measurements were collected before and after the installation of speed humps. The measurements for each set were collected during the same week and at approximately the same time. These results are tabulated in table 4.4.

Two Redwood City residential areas were chosen for analysis. The first street was McGarvey Avenue between Farm Hill Boulevard and Alameda de las Pulgas. In 2008, neighbors on McGarvey Avenue expressed their concerns about excessive speeding on their street to Redwood City's traffic engineering staff. Traffic engineering staff worked with the community to identify an appropriate traffic calming solution, and the installation of speed humps was the consensus. In 2009, permanent speed humps were installed.

The second street was Fernside Street between Massachusetts Avenue and Goodwin Avenue. In 2013, this area was identified as a trial area for speed humps due to complaints from neighbors about excessive speeds on Fernside Street. After meeting with the community, Redwood City installed temporary rubber speed humps.

24-hour speed and volume measurement data was collected. The data contains the mean speed and volume of vehicles traveling on the roadway segment within the 24 hour period.

Traffic Accident Database

Redwood City's traffic accident database contains reported traffic accident records. The database search focused on motorist accidents before and after the speed hump installations. Data was collected for years 2003 through 2015 for McGarvey Avenue. This range provided a six year period before and after the speed hump installation, which occurred in 2009. Data was collected for years 2012 through 2015 for the Fernside Street neighborhood. This range provided a four year range before and a one year range after the speed hump installation, which occurred in 2014.

Site Visits

Site visits were conducted to determine roadway characteristics. The site visits provided an opportunity to collect an unobtrusive source of data (Patton et al., 2013). The site visits were performed after the permanent speed humps were installed.

Focus Interviews

Focus interviews were conducted with the traffic engineering staff from the cities of Redwood City, Sunnyvale, and Modesto. The purpose of these focus interviews was to assess the perception of speed humps from professional engineers. The interviews were open format and collected information on their experience with traffic calming devices, thoughts on the application of speed humps, and overall impression of speed humps. Participants were informed that their identity would remain anonymous.

Section 4: Findings

<u>Focus Interviews</u>

Redwood City's traffic engineering staff (2015) stated that traffic calming involves designing measures to improve traffic flow and safety on local, collector, and arterial streets. These streets comprise the roadway network and in general, function in the following ways:

- Local streets transport neighborhood traffic onto collector streets
- Collector streets collect neighborhood traffic and connect it to arterial streets
- Arterial streets are the main thoroughfares within the city that connect to the highway interchange system

Traffic calming improvements in one area can impact a localized community. For example, when improvements to increase traffic flow are applied to collector and arterial streets, the benefit of reduced volumes or less cut through traffic in adjacent residential neighborhoods can be achieved (Sunnyvale Traffic Engineering Staff, personal communication, May 13, 2015).

In general, traffic calming can be accomplished through the 3 E's: education, engineering, and enforcement (Redwood City Traffic Engineering Staff, personal communication, August 19, 2015). Education teaches people about proper driving behavior. It can be dispersed in pamphlets, brochures, and community meetings. Unfortunately, education alone may or may not have a permanent impact on driver behavior.

Engineering solutions such as speed humps can have a dramatic reduction in speeds and overall motorist behavior in the area of the installation. Speed humps create a permanent physical reminder for motorists to pay attention to their surroundings. Enforcement, from the Police Department, can serve as an effective deterrent for speeding. However, enforcement is very expensive and is not always achievable due to the availability of police officers. The 3 E's work best in conjunction with one another. Education and engineering solutions are common parings. Enforcement, while a temporary solution, works well in conjunction with Education/continuous communication with the community (Sunnyvale Traffic Engineering Staff, personal communication, May 13, 2015).

Prior to the construction of speed humps, Redwood City traffic engineering staff use education/neighborhood outreach to gage the community's desire for speed humps, discuss their positive and negative externalities, and explain the implementation process (Redwood City Traffic Engineering Staff, personal communication, August 19, 2015). In Redwood City and Modesto, speed humps must first be requested from the community. In their request, the residents should identify which block they would like the speed humps installed on. Once the request is made, traffic engineering staff can evaluate the site. The final location is made through a collaborative process with the community, but ultimately the traffic engineers make the final placement decision. (Modesto Traffic Engineering Staff, personal communication, September 25, 2015).

For a roadway to qualify for Redwood City's speed hump program, it must pass a variety of thresholds as shown in Appendix A of this paper and summarized here:

- Residential street with a posted speed limit of 30 MPH or less
- Satisfactory pavement condition
- Documented, persistent speed problem, where the 85^{th} percentile speed exceeds 33 MPH
- The roadway must not be a primary or secondary emergency response route or regularly scheduled public transit route
- At least 60% of the properties impacted by the proposed speed hump location must support its installation, via a signed petition

Table 4.1 outlines some of the negative and positive impacts speed humps have on the community. Elements in table 4.1 were communicated from Redwood City, Sunnyvale, and Modesto traffic engineering staff.

Table 4.1: Negative and Positive Externalities

Negative Externality	Positive Externality
Aesthetics: speed humps are permanent roadway features which do not blend into the surrounding area	Speed reduction
Impact on property value: the presence of speed humps may indicate a perceived speeding problem on a roadway, which can sway prospective home buyers	Reduction in the occurrence of accidents on the street
Delays: motorists must reduce their speeds while navigating over speed hump, which can cause a few seconds delay to their overall travel time	Community satisfaction: residents have acknowledged that speed humps address persistent speeding problems on their streets
Comfort: some drivers and passengers may experience a decreased level of comfort while the vehicle is traversing the speed hump	
Increased vehicle noise: some individuals may notice a high ambient noise level as vehicles travel over the speed hump	

Requests for traffic calming measures have increased in cities with high densities. In these areas, there are high volumes of vehicles on the roadway, increased neighborhood reports of unsafe roadway conditions, and active community activists' intent on solving speeding problems (Redwood City Traffic Engineering Staff, personal communication, August 19, 2015). One common request to address the increased roadway demand is to widen arterial roadways. However, traffic engineers believe that increasing the roadway capacity is a poor solution to improving traffic flow, because existing roadways were not designed for unlimited capacity shifts (Redwood City Traffic Engineering Staff, personal communication, August 19, 2015).

Community support prior to the implementation of a traffic calming measure is very important. When the community is engaged early in the design process, engineers and neighbors can work together to find the best traffic calming solution for a particular street (Redwood City Traffic Engineering Staff, personal communication, August 19, 2015). More importantly, community engagement can reduce the likelihood that a permanent traffic calming measure, once installed, will need to be removed due to lack of community support.

The community should be viewed as a resource. In their letter dated February 11, 2013, the neighbors along the 1200 block of Fernside Street thanked Redwood City for the speed hump installation along the 1500 block of Fernside Street. They acknowledged that speeds in the area surrounding the speed humps were reduced. However, their letter expressed concerns that once motorists navigated over the speed hump, they sped down the remainder of the street and increased the neighbors' concerns that accidents would increase if the problem was not addressed. This precipitated the addition of two more speed humps along Fernside Street.

Modesto traffic engineering staff (2015) furthered this assertion by saying that while speed humps are effective at reducing speeds on the block they are installed on, they only slow traffic in the immediate vicinity of their installation. This is one reason why multiple speed humps may be installed on a long roadway.

Perception is a powerful tool. When neighbors perceive a speeding problem in their area they have a few options: do nothing, contact their traffic engineer and request an evaluation, or contact their councilmember for resolution. Traffic engineers recognize that perception is not reality. For this reason, speed surveys are conducted when reports of excessive speeding problems are submitted (Redwood City Traffic Engineering Staff, personal communication, August 19, 2015).

Site Visits

Fernside Street is a City owned residential roadway. It is located in the south eastern portion of Redwood City. It has one travel lane and one parking lane in each direction. The western edge of pavement delineates the jurisdictional boundary between Redwood City to the east and the Town of Woodside to the west.

Fernside Street has a straight roadway alignment with gentle curves. There is a general elevation difference of 14 feet over 0.15 miles from Massachusetts Avenue to Roosevelt Avenue and 25 feet over 0.65 miles from Roosevelt Avenue to McGarvey Avenue (Google Earth Pro, 2015). It is surrounded by large residential homes and according to Redwood City's 2010 census, has an average median household income between $100,001 and $125,000 per year (Redwood City GIS, 2015). Redwood City's 2010 General Plan classified this area as low density residential. There is an elementary school three blocks south of the 1500 block of Fernside Street.

The existing striping improvements on Fernside Street between Massachusetts Avenue and Harcross Road include a centerline and edge of travel lane striping on the south side of the street. In this section, there is a sidewalk on the north side of the street and gravel improvements on the south side of the street. Parked cars were not witnessed during the site visit. The existing striping improvements between Harcross Road and McGarvey Avenue include a centerline and speed hump pavement legends; cars were parked on both sides of the street during the site visit. In this section, sidewalk improvements and a landscape planter strip were observed on both sides of the street.

Speed humps were located near 1538 Fernside Street and 1433 Fernside Street. Each speed hump terminated at the edge of the paved roadway, near the gutter. The posted speed limit was 25 MPH, with a recommended speed of 15 MPH while traveling over each speed hump. During the site visit the speed humps and associated signage were visible.

McGarvey Avenue is a City owned residential street. It has one travel lane and one parking lane in each direction. It is surrounded by residential homes and according to Redwood City's 2010 census, has an average median household income between $100,001 and $125,000 per year (Redwood City GIS, 2015). Redwood City's 2010 General Plan classified this area as low density residential.

The existing striping improvements on McGarvey Avenue between Farm Hill Boulevard and Alameda de las Pulgas included a centerline, edge of travel lane striping, and sharrows. Sharrows are "share the road" pavement markers that are installed to remind motorists to share the road with bicyclists. Sidewalk improvements existed on both sides of the street. Parked cars were noted on both sides of the street during the site visit.

The posted speed limit was 25 MPH, with a recommended speed of 15 MPH while traveling over each speed hump. McGarvey Avenue between Alameda de las Pulgas and Farm Hill Boulevard has a steep alignment (vertical curve), with a general elevation difference of 57 feet over 0.30 miles from Farm Hill Boulevard to Alameda de las Pulgas (Google Earth Pro, 2015). Speed humps were installed near 3025, 3003, and 2797 McGarvey Avenue. Each speed hump terminated at the edge of the paved roadway, near the gutter. During the site visit the speed humps and associated signage were clearly visible.

Speed, Volume, and Reported Accident Findings

A time series analysis using multiple speed and volume measurements before and after the speed hump installation was conducted. Two sets of speed and volume measurements were collected for Fernside Street before the installation of speed humps at 1245 Fernside Street on May 13, 2009 and May 14, 2009. Three sets of data were collected after the installation at 1649, 1545, and 1245 Fernside Street on July 14, 2015 through July 16, 2015. Three additional sets of data were collected during the trial period at 1649, 1545, and 1245 Fernside Street on October 22, 2013 through October 24, 2013. Table 4.2 averages the data collected at the three locations along Fernside Street. Table 4.3 summarizes the data collected at 1245 Fernside Street. Figure 4.1 is a map which shows the change in volume on Fernside Street before and after the speed hump installation and the approximate location of the speed humps.

Table 4.2 Fernside Street (Massachusetts Avenue to McGarvey Avenue)

	Before speed humps	During trial period	After speed humps	% Reduction (before to after)
85th percentile speed (MPH)	33.78	29.44	28.41	16%
% < 25 MPH	10%	42%	53%	
Average Speed (MPH)	29.8	25.86	24.7	17%
Average daily volume (vehicles per day)	2,730	2,713	1,902	30%

Table 4.3 Data Collection at 1245 Fernside Street

	Before speed humps	During trial period	After speed humps	% Reduction (before to after)
85th percentile speed (MPH)	33.78	30.98	26.93	20%
% < 25 MPH	10%	27%	68%	
Average Speed (MPH)	29.8	27.17	22.54	24%
Average daily volume (vehicles per day)	2,730	2,511	1,705	38%

Alameda de las Pulgas is a collector street which runs adjacent to Fernside Street. Vehicular volume data for Alameda de las Pulgas between Woodside Road and McGarvey Avenue was collected in 2008, before the speed hump installation on Fernside Street; data was not collected on Alameda de las Pulgas after the speed hump installation. Table 4.6 summarizes the data collected for Alameda de las Pulgas.

Two sets of speed and volume measurements were collected for McGarvey Avenue before the installation of speed humps at 2833 and 3008 McGarvey Avenue on January 14, 2009 and January 15, 2009. Three sets of data were collected after the speed hump installation on June 10, 2009 and June 11, 2009 at the same locations. The data for McGarvey Avenue is summarized in table 4.4. Figure 4.2 illustrates the change in volume on McGarvey Avenue before and after the installation of speed humps and the approximate location of the speed humps.

Roosevelt Avenue is a collector street which runs adjacent to McGarvey Avenue. Vehicular volume data for Roosevelt Avenue between Fernside Street and McGarvey Avenue was collected in 2008, before the speed hump installation on McGarvey Avenue; data was not collected on Roosevelt after the speed hump installation. Table 4.6 identifies the data collected for Roosevelt Avenue. Table 4.5 shows the speed and volume data collected for Fernside Street and McGarvey Avenue.

Table 4.4 McGarvey Avenue (Farm Hill Boulevard to Alameda de las Pulgas)

	Before speed humps	After permanent installation	% reduction (before to after)
85th percentile speed (MPH)	32.75	20.75	37%
% < 25 MPH	19%	95%	
Average Speed (MPH)	29	18.5	36%
Average daily volume (vehicles per day)	10,379	9,587	8%

Table 4.5 Fernside Street and McGarvey Avenue

Street	Volume (vehicles per day)		Mean Speed		85th % Speed		% < 25 MPH	
	before	after	before	after	before	after	before	after
Fernside Street	2,730	1,902	29.8	24.7	33.78	28.41	10%	53%
McGarvey Avenue	10,379	9,587	29	18.5	32.75	20.75	19%	95%

Table 4.6 Volume on Streets Adjacent to the Speed Hump Installation

	Before speed humps	After permanent installation	% Change (before to after)
Roosevelt Avenue	9,086	Not Collected	N/A
Alameda de las Pulgas	8,634	Not Collected	N/A
Volumes in vehicles per day			

Table 4.7 Traffic Accident Summary (Redwood City Traffic Accident Database, 2015)

Street	Accident study period	Permanent speed hump installation date	Accidents		
			Before	After	% Change
			Total	Total	Total
Fernside Street	2012 - 2015	2014	4	0	100%
McGarvey Avenue	2003 - 2015	2009	23	6	74%

FIGURE 4.1 CHANGE IN VOLUMES IN FERNSIDE NEIGHBORHOOD

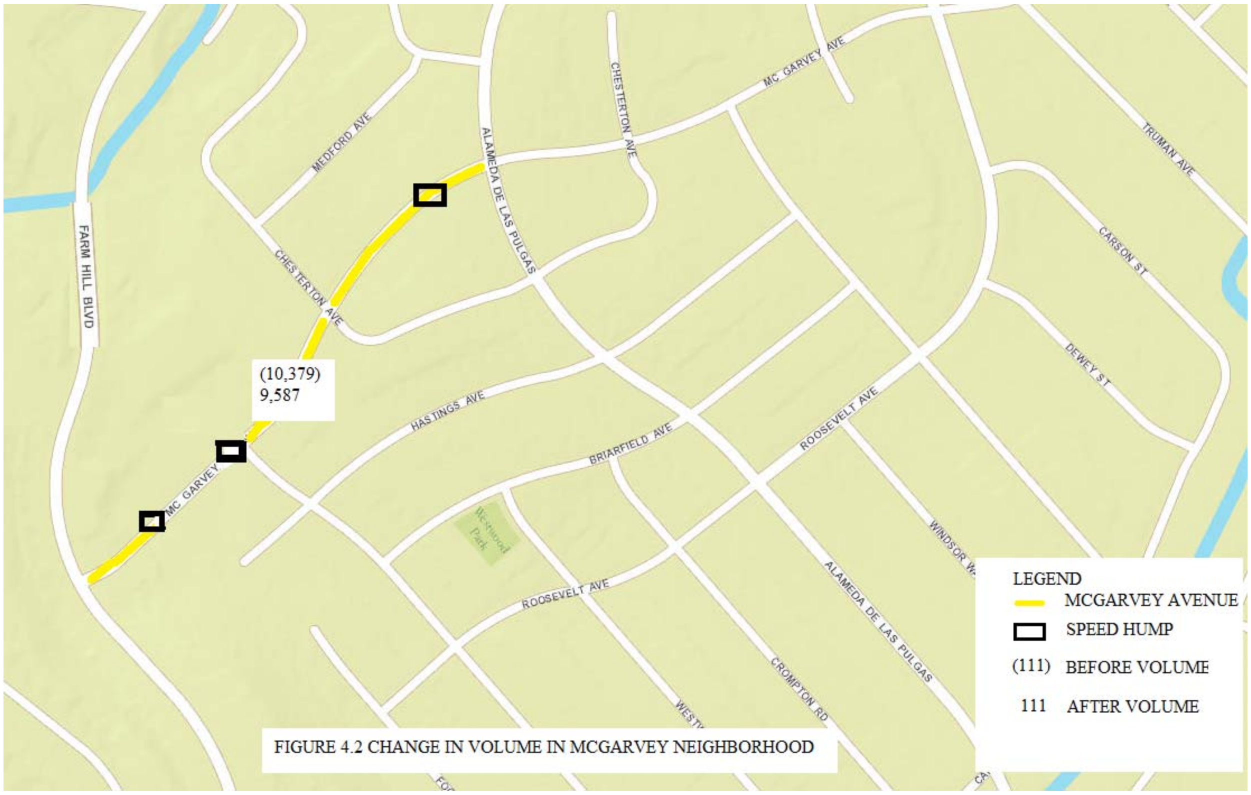


FIGURE 4.2 CHANGE IN VOLUME IN MCGARVEY NEIGHBORHOOD

A search of Redwood City's traffic accident database yielded the number of reported accidents which occurred on Fernside Street and McGarvey Avenue before and after the speed hump installations. Table 4.7 shows the traffic accident summary. Three years prior to the installation of speed humps, there were 4 reported accidents on Fernside Street between Massachusetts Avenue to McGarvey Avenue; two years after the installation, there were 0 reported accidents. Six years prior to the installation of speed humps, there were 23 reported accidents on McGarvey Avenue between Alameda de las Pulgas and Farm Hill Boulevard; six years after the installation there were 6 reported accidents.

Section 5: Analysis and Conclusion

Analysis

According to table 4.5, vehicular volumes on Fernside Street decreased by 828 vehicles or 30% during the analysis period. While the decreased volumes on Fernside Street indicates that vehicular congestion has reduced on this residential road, it does not address where the traffic shifted to. Traffic calming measures are designed to encourage safe driving behavior. They are not designed to permanently eliminate vehicles from the entire roadway network. Therefore, this research analyzed motorist activity on Alameda de las Pulgas, a collector street adjacent to Fernside Street. The hypothesis was that vehicles traveling on Fernside Street shifted to Alameda de las Pulgas to avoid travel delays associated with the Fernside speed humps.

Vehicular volume data was available on Alameda de las Pulgas before the speed hump installation on Fernside Street. However, data was not available for comparison after the speed hump installation. Although a quantitative analysis could not be completed given the available data, this available data suggest that a portion of the vehicles no longer traveling on Fernside Street may have shifted to Alameda de las Pulgas.

After the installation of the speed humps on Fernside Street, residents reported a noticeable reduction in speeding. They also reported that they were satisfied with the outcome of the speed humps (Redwood City Traffic Engineering Staff, personal communication, August 19, 2015). The response from residents is consistent with the findings as outlined in Table 4.5. Community feedback after the speed hump installation is just as important as it was prior to the installation. Traffic engineers rely on community feedback to finalize their evaluation of traffic calming measures in residential areas and draw conclusions about the measures' effectiveness.

The Fernside Street analysis contained three sets of speed and volume measurements at one location for the before speed humps analysis and three sets of measurements at three locations for the after speed humps analysis. The variation in the number of locations measured during the analysis period yielded slightly different results. Table 4.2 aggregated the data for all locations and shows a 30% vehicular volume reduction. Table 4.3 only included data for one location and shows a 38% vehicular volume reduction. An 8% variation in vehicular volumes was noted. This variation exists because the community submitted complaints of excessive speeding on the 1500 block of Fernside Street after temporary speed humps were installed in the 1200 block of Fernside Street. The community also requested additional speed humps to be installed along the 1500 block of Fernside Street. Although the variation can be explained, it indicates that when traffic calming measures are analyzed block by block, results may differ from those obtained by analyzing an entire street.

The Fernside Street mean vehicular speed decreased by 17% to 24.70 MPH and the number of cars driving under the posted speed limit increased from 10% to 53%. This 43% increase in speed limit compliance indicates that speed humps are indeed “sleeping policemen” (Moran, 2006). Their presence appears to have contributed to the level of speed limit compliance.

According to table 4.5, vehicular volumes on McGarvey Avenue decreased by 792 vehicles or 7.6%. This reduction in vehicular volumes is not significant enough to suggest that motorist behavior has changed or that motorists are bypassing McGarvey Avenue. In fact, vehicular volume fluctuations less than 10% do not suggest a long term change in motorist activity, instead they may suggest a daily shift in volumes (Redwood City Traffic Engineering Staff, personal communication, August 19, 2015).

Table 4.5 also shows that the McGarvey Avenue mean vehicular speeds decreased by 36% to 18.50 MPH and the number of cars driving under the posted speed limit increased from

19% to 93%. This data shows that almost all of the cars traveling along this roadway section were in compliance with the posted speed limit after the speed hump installation. This is a significant finding that reinforces the belief that speed humps are effective speed deterrents (Kotsopoulos, 2000; Chadda and Steward, 1985).

As shown in figure 4.2, the residential streets immediately adjacent to McGarvey Avenue do not directly connect to collector streets. Roosevelt Avenue is the closest collector street which runs adjacent to McGarvey Avenue. Although vehicular volume data was not available for Roosevelt Avenue after the McGarvey Avenue speed hump installation, the small change in volumes on McGarvey Avenue do not indicate that the speed humps would be an underlying cause for changes in vehicular volumes on Roosevelt Avenue.

After the speed hump installation, the number of reported accidents decreased by 100% and 74% on Fernside Street and McGarvey Avenue, respectively, as shown in table 4.7. This data furthers the hypothesis that traffic calming measures improve motorist behavior and increase the safety of roadways.

Future speed hump evaluation studies should focus on speed hump impacts within localized communities. Speed and volume studies using a time series analysis should be performed on the calmed and adjacent streets. Although this recommendation will increase the amount of time and tax dollars spent during the evaluation phase, it is one way to ensure that a thorough evaluation of the measure has been conducted.

Redwood City’s traffic calming program is funded by the City’s Special Gas Tax Street Improvement Fund. “This fund accounts for revenue received from the State of California derived from gasoline taxes” (City of Redwood City CAFR, 2014) and can only be used to improve roadways. This fund is a stable revenue source and allows Redwood City to improve their roadways each year. Throughout the state, consumers contribute $0.42 from each gallon of gas purchased to California's gas tax fund (Walter, 2015). This fund is shared between state and local agencies. Because taxpayer dollars are the funding source, it is essential that they are spent prudently.

The data collected in this study shows that speed humps reduce speeds, volumes, and the occurrence of traffic accidents on calmed streets. The community should note the evaluation engineers conduct when determining if a street qualifies for speed humps, the amount of community involvement with the speed hump implementation process, and the net positive benefit that speed humps have on the community. Although there may be other factors improving motorist behavior, this research suggests that the presence of the speed humps improve motorist alertness to their surroundings.

As with most resources, traffic calming has its proponents and critics. Proponents may enthusiastically promote traffic calming, while critics may not. Critics may argue that streets selected for traffic calming improvements are predetermined, do not undergo evaluation, and are not consistent with community requests. After review of Redwood City's speed hump policy and performing this research design, this research suggests that this assertion is untrue. Engineering judgment and community support are key factors in determining which streets receive speed humps. More importantly, there are specific criteria which must be met before a street will be considered for a traffic calming measure.

Each street is unique and receives an individualized evaluation when a request for traffic calming is received. These evaluations are conducted by professional engineers who understand the benefits and constraints behind various traffic calming measures. They work closely with the community to assess the nature of the complaint and identify the best solution for the area. At times, the political environment may guide the choice of the traffic calming measure. However, the selected treatment must receive support from a majority of the residents on the street it is installed on. Traffic calming is a growing field. It has its proponents and critics. Although these groups may have differing interests, traffic engineers work with all involved to provide the best solution for a given area.

Research Questions

Question 1: If installed in an appropriate residential area, can speed humps reduce vehicular speeds and volumes?

Table 4.1 shows that vehicular speeds and volumes decreased by 17% and 30%, respectively, on Fernside Street; table 4.3 shows that vehicular speeds and volumes decreased by 29% and 8%, respectively, on McGarvey Avenue. The literature review also showed that vehicular speeds were reduced after the speed hump installation in residential areas (Kotsopoulos, 2000; Rickert, 2008; Shopes, 2008; Knapp, 2000; George, 2013). This research concludes that when installed in an appropriate area, speed humps can reduce vehicular speeds and volumes.

Question 1a: How are vehicular volumes on adjacent streets impacted?

The literature review showed that speeding increased on adjacent streets; vehicular volumes increased by 23% on adjacent streets (Kotsopoulos, 2000). The data collection methods for a future quantitative speed hump analysis should include speed and volume counts on streets adjacent to the speed hump installation to further address this question.

Question 2: If installed in an appropriate area, can speed humps reduce the occurrence of motorist collisions?

Table 4.7 shows a 100% decrease in accidents on Fernside Street and a 74% decrease on McGarvey Avenue. This research concludes that when installed in an appropriate area, speed humps can reduce the occurrence of motorist accidents.

Question 2a: How is the occurrence of motorist collisions impacted on adjacent streets?

There was no increase in complaints regarding accidents on streets adjacent to the speed hump installation (Redwood City Traffic Engineering Staff, personal communication, August 19, 2015).

Question 2b: After the installation, do residents on adjacent streets feel safer in their neighborhood?

Cottrell et al. (2006) and Kotsopoulos (2000) state that residents feel safer in their neighborhoods after the speed hump installation. However, Shopes (2008) states that the reduced emergency response time experienced by responders navigating over the speed humps alarms some residents. This research is inconclusive on this element.

Future Study Evaluation Recommendations

Redwood City's speed hump policy does not analyze or reference impacts that speed humps may have on streets adjacent to their installation. When traffic counts are collected before and after the speed hump installation on the selected street, traffic counts should also be collected on the adjacent streets. The analysis should also include traffic accident data collection for the adjacent street. If these recommendations are followed, engineers can thoroughly analyze the impact speed humps will have on the localized community. Regarding the data collection, the after study should be conducted one year after the data collection for the before study; it should be conducted in the same month as the before study. this may reduce threats to the internal validity of the data.

Policy Update Recommendations

Redwood City's current speed hump policy describes speed humps, when/where they can be implemented, and the process to request them. However, one more element can be added to increase the policy's thoroughness. A section outlining the negative and positive externalities of speed humps, as introduced in this paper's table 4.1, should be added to the design and construction considerations section of the policy. This addition will help residents understand the externalities of speed humps prior to their communication with the City's traffic engineering staff.

Conclusion

The conclusions this paper draws are similar to those identified by Cottrell et al. (2006), though variations exist in this paper's data collection methodology. Both studies show that speed humps are effective at reducing vehicular speeds and volumes on calmed streets. This research has also shown that speed humps are effective at reducing the occurrence of motorist accidents on calmed streets and that they have an impact on localized communities.

It is important to note that when installed in an appropriate area, speed humps can encourage motorists to travel on adjacent collector streets. Consequently, the speed humps appear to reduce volumes in residential areas and allow the roadway network to function as designed, where most of the commute traffic travels on arterial and collector streets.

Appendix A:
Redwood City Policy and Guidelines on Speed Hump Use

CITY OF REDWOOD CITY
POLICY AND GUIDELINES FOR
SPEED HUMP USE

INTRODUCTION

Speed humps have been increasingly recognized by engineers as a suitable geometric design technique for controlling traffic speeds under appropriate roadway circumstances. This policy and guideline describes those appropriate roadway circumstances and details of geometric design requirements for speed humps as applicable in the City of Redwood City. They are based on *Guidelines for the Design and Application of Speed Humps* (Institute of Transportation Engineers, March 1993); research and experimentation by the City of Portland, Oregon; the City of Portland's *Traffic Manual, Chapter 7 - Speed Bumps;* experience in the City of Redwood City's own tests and prior applications of speed humps; and interpretations and amplification of details specific to Redwood City.

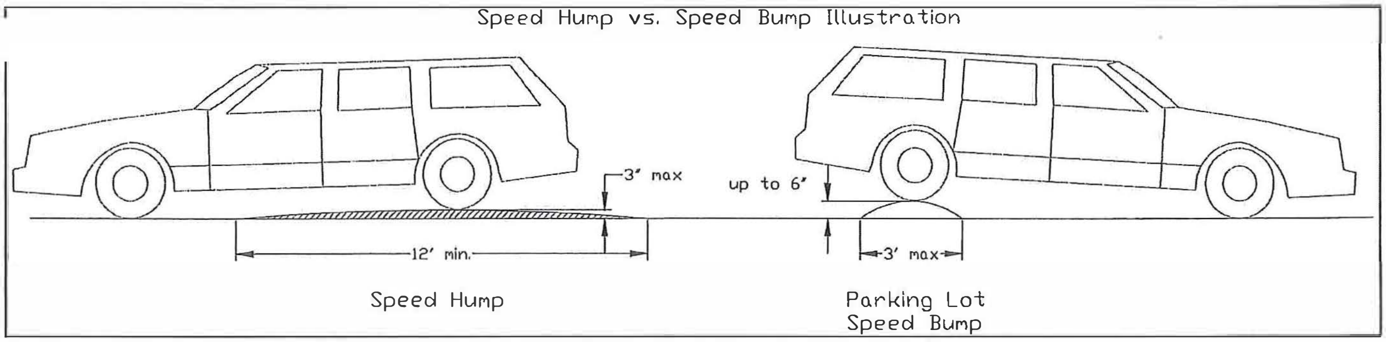
USE OF THIS POLICY AND GUIDELINES

This document is to be used in conjunction with good professional engineering judgment and practice. The guidelines herein do not constitute either final or complete design and evaluation criteria for speed humps and speed hump systems. Local site conditions must be evaluated for all speed hump installations. In addition, specific terrain, roadway, traffic or land use characteristics or other unusual conditions may require case-specific modification of or exception to these guidelines.

DEFINITIONS

A speed hump is a roadway geometric design feature consisting of raised pavement extending transversely across (or partly across) a roadway for the primary purpose of reducing the speed of vehicles traveling thereon. In a speed hump, the raised pavement area normally rises and returns to the prevailing grade of the surrounding pavement over a distance of at least 12 feet in the direction of travel, with a maximum rise of 2.5 to 4 inches. Most speed humps are parabolic in cross-section. Flat-topped sections and elongated forms to 22 feet in the direction of travel are also recognized.

The considerable length in the direction of travel and limited maximum height is what physically distinguishes speed humps from the abrupt speed "bumps" commonly found in private drives and parking lots. Although there are no explicit standards for speed bumps, they generally have heights of 3 to 6 inches or more and lengths in the direction of travel of less than 3 feet. Figure I illustrates the difference between the cross section of a speed hump and an abrupt parking lot speed bump.



From an operational performance perspective, speed humps and abrupt speed bumps have crucially different effects on vehicles and their occupants. Within the range of typical residential street speeds, speed humps cause a gentle vehicle rocking motion that causes mild discomfort to drivers and passengers, with the level of discomfort tending to increase the faster the vehicle passes over the speed humps, which is an effect consistent with the objective of inducing drivers to travel at speeds reasonable for neighborhood streets. Drivers typically choose to cross speed humps at speeds between 15 and 25 miles per hour. Abrupt speed bumps, by contrast, cause significant driver discomfort at typical desirable residential street speeds. In a performance effect, which is completely contrary to the intended purpose of the bumps, driver/passenger discomfort tends to *decrease* the faster a vehicle is driven over an abrupt speed bump, because vehicle suspensions are expressly designed to absorb the jolts of quick passage over abrupt bumps rather than transmitting them to the passenger compartment. As a result, when confronted with an abrupt speed bump, most drivers either cross at extremely low speeds (5 mph or less) or continue at relatively high speeds (30 mph or more).

GUIDELINES FOR SPEED HUMP USE

Engineering Study

Speed humps should only be installed where the engineering study concludes that:

- Speed conditions to which speed humps respond appropriately exist;
- Judicious use of other guide, warning or regulatory control devices has been considered;
- A reasonable level of enforcement has not solved or appears unlikely to solve the problem, or that a necessary level of enforcement is unlikely to be made available; and
- Key design guidelines, as outlined herein for location, placement, configuration details and related street and traffic conditions, can be reasonably conformed-to at the site under consideration.

Street Classification And Use

Speed humps can only be installed on those roadway facilities functionally classified as "local" streets in the Redwood City General Plan.. Table 1 lists the street segments streets classified as "collector" streets or higher classes of streets in the General Plan's functional classification hierarchy. Street segments on Table I are **not eligible** to be considered as candidates for speed hump application.

TABLE 1: STREETS INELIGIBLE FOR SPEED HUMPS

Primary Arterial Streets

Roadway	From	To
El Camino Real (SR 82)	N. City Limit	S. City Limit
Middlefield Road	Main Street	S. City Limit
Broadway	El Camino Real	Woodside Road
Veterans Boulevard	U.S. 101	Woodside Road
Industrial Way	N. City Limit	Whipple Avenue
Edgewood Road	I-280	Alameda de las Pulgas
Whipple Avenue	El Camino Real	U.S. 101
Farm Hill Boulevard	I-280	Jefferson Avenue
Jefferson Avenue	Farm Hill Boulevard	Veterans Boulevard
Woodside Road	Alameda de las Pulgas	U.S. 101
Marine Parkway	U.S. 101	Bridge
Redwood Shores Parkway	U.S. 101	Bridge
Seaport Boulevard	U.S. 101	East Terminus
Main Street	El Camino Real	Veterans Boulevard
Winslow Street	Whipple Avenue	Brewster Avemie

Major Collector Streets

Roadway	From	To
Alameda de las Pulgas	N. City Limit	Woodside Road
Hudson Street	Jefferson Avenue	Woodside Road
Florence	Bay Road	Marsh Road
Bay Road	Fifth Avenue	Florence
Broadway	Woodside Road	Fifth Avenue
Blomquist	Whipple Avenue	Seaport Boulevard
Twin Dolphin Drive	Marine Parkway	Redwood Shores Parkway
Whipple Avenue	El Camino Real	Alameda de las Pulgas
Marine Parkway	Bridge	Shearwater
Middlefield Road	Marshal Street	Winslow Street
Marshall	Broadway E.	Broadway W.

Minor Collector Streets

Roadway	From	To
Jefferson Avenue	Farm Hill Blvd.	West Terminus
Massachusetts	Woodside Road	Alameda de las Pulgas
Oak	El Camino Real	Valota Road
Roosevelt	El Camino Real	Alameda de las Pulgas
Brewster Avenue	El Camino Real	Alameda de las Pulgas
Hopkins Avenue	Broadway	Alameda de las Pulgas
Broadway	El Camino Real	Hopkins Avenue
Fifth Avenue	Middlefield Road	Broadway
Maple	Veterans Blvd.	East Terminus
Canyon	Edgewood	Jefferson Avenue
Valota Road	Jefferson Avenue	Woodside Road
Hudson Street	Whipple Avenue	Jefferson Street
Broadway	Hopkins	Main Street
Bay Road	Woodside Road	Fifth Avenue
Bridge	Marine Parkway	Redwood Shores Parkway
Shell	Marine Parkway	Redwood Shores Parkway
Shearwater	Marine Parkway	Redwood Shores Parkway
Marshall	Middlefield	Main Street

Street Width And Number Of Lanes

Speed humps should be used only on streets with no more than two travel lanes and only on streets where pavement width is no greater than 40 feet.

Pavement Characteristics

Overall pavement on streets considered for speed humps should have good surface and drainage qualities. Where major resurfacing/reconstruction of a street is planned for the near future, speed hump installation should be deferred and incorporated in the resurfacing process.

Street Grades

Speed humps should not be employed on streets with grades exceeding 5 percent approaching the speed hump site. When installed on streets with sustained downgrades, special care should be taken to ensure that vehicles will not approach a speed hump at excessive speeds.

Horizontal And Vertical Alignment

Speed humps should not be placed within severe horizontal or vertical curves that might result in substantial lateral or vertical forces on a vehicle traversing the speed hump. Speed humps should be avoided within horizontal curves of less than 300 feet centerline radius and on vertical curves with less than the minimum safe stopping sight distance. At mid-block locations on typical residential streets, the stopping sight distance requirement is usually at least 200 feet, the nominal stopping sight distance for vehicles traveling at 30 mph. If possible, speed humps should be located on tangent sections rather than curve sections.

Sight Distance

Speed humps should generally be installed only where the minimum safe stopping sight distance (as defined in AASHTO's *A Policy On Geometric Design Of Streets*) can be provided. For mid-block locations on typical residential streets, a minimum safe stopping sight distance allowance would normally be at least 200 feet, nominal stopping sight distance for vehicles traveling at 30 mph. Depending on the character of the intersection and the control devices employed, sight distance requirements might be less for speed humps located within the influence area of intersections. Speed humps could be placed as close as 60 feet from the intersection where the primary approach is STOP controlled, and where there are clear sight triangles from the cross street, and speeds of traffic approaching the speed hump from the cross street are necessarily slow. Where the approach from the humped street is uncontrolled, or there is substantial prevalence of high speed turns from the cross street, or there is significant obstruction of the sight triangles from the cross street, then minimum separation of the speed hump from the intersection should tend toward the 200 foot limit.

Traffic Speeds

Speed humps should only be used on streets where traffic speeds are intended to be low. Speed humps should not be installed on streets where the posted speed limit is considerably greater than speeds at which most motorists feel comfortable in traversing the speed humps. Speed humps should generally be installed only on streets where the posted or prima facia speed limit is 30 mph or less. Where speed problems occur on streets with higher speed limits (such as streets posted for 35 mph experiencing 45-50 mph traffic), employment of focused enforcement and combinations of other types of control measures should be considered instead of speed humps.

When speed humps are installed to address speeding concerns, studies should be performed to confirm the magnitude of the speeding problem to ensure that the installation of speed humps can be expected to appreciably address that problem. As justification for speed humps on streets intended for low speed, numbers of vehicles exceeding speed limits, percentage of all vehicles exceeding speed limits, 85th percentile speed and speed of fastest vehicles may all be considered in evaluating whether there is a speed problem which speed humps should be used to counter and in allocating available community resources among sites experiencing problems. In Redwood City, specific criteria are as follows: Eighty-fifth percentile speed exceeds 33 mph or 66 percent the traffic exceeds the posted speed limit (normally 25 mph) or the average speed of vehicles in the top 15 percentile is 40 mph or greater.

Traffic Volumes

Speed humps should be installed only on streets classified as "local" streets. Such streets typically serve an average daily traffic volume of 3000 vehicles or less. Requests are occasionally received to install speed humps on streets classified as "local" but serving traffic volume indicative of a higher functional classification of street (nominally, above 3000 ADT). When considering such situations, the City must make a conscious policy decision. Is the street *really* a "local" street that is simply impacted by too much and too fast traffic? Then speed humps may be an appropriate response. Or is the street really fulfilling a necessary and appropriate collector function in the City's circulation network - in essence, is its designation as "local" a misclassification? In this latter case, the level of control speed humps exert is probably too restrictive and speed humps should not be used; the City might even consider upgrading the functional classification of the street in its next general plan review.

In allocation of community resources to implement speed humps, subject to the above consideration of nominal ceiling volume indicating service of more than "local" street function, streets with the highest volume and largest numbers of vehicles exceeding speed limits would tend to receive priority over streets with lower volumes and number of vehicles exceeding speed limits. However, no minimum volume threshold shall preclude speed humps being used in cases where low volume streets experience very high proportions of high speed incursions.

Traffic Safety

When installed for the purpose of addressing documented or anticipated vehicle or pedestrian accidents, the causes of those accidents should be susceptible to correction by speed control.

Proposed speed hump locations must be evaluated in the field to determine that such installations will not introduce increased accident potential for the subject street.

Vehicle Mix

Speed humps should not normally be installed on streets that carry significant volumes of long wheel-base vehicles unless there is a reasonable alternative route for those vehicles. (Typically, heavy or long-wheelbase vehicles constituting up to 5 percent of all traffic is considered normal; the heavy vehicle component would have to be well above five (5) percent of all traffic to be considered "significant" enough to refuse hump installation in a situation where speed humps would otherwise seem desirable or necessary). Special consideration of reasonableness of effects on heavy vehicles is also indicated in the anomalous situation where a significant generator of long wheel-base vehicle traffic is located with access and egress only from streets classified "local".

Bicyclists, motorcyclists, low-riders and operators of other types of special vehicles often consider speed humps annoying. However, nothing in the experience with speed humps to date indicates the speed humps constitute any type of unusual hazard or obstruction for these types of vehicles. Hence, possible presence of the vehicle types is **not** reason to deny approval of speed humps in circumstances where they would otherwise appear desirable or needed.

Emergency Vehicle Access

Speed humps should not be installed on streets that are defined or used as primary emergency vehicle access routes. Primary emergency vehicle routes are comprised of two types of streets:

1. Routes used by emergency vehicles to cross large parts of the community or on paths logically used to service large numbers of potential destinations. Routes of this type are generally on the City's designated circulation system of streets of collector level and higher. Hence, they are normally already ineligible for speed humps based on their functional classification.

2. Streets of generally local service character which happen to serve as the immediate egress route from an emergency vehicle dispatch point or immediate access route to a regular destination for emergency vehicles (such as where a fire station or a hospital emergency room access is located on a street classified "local"). Such circumstances will negate the eligibility of streets which would otherwise be eligible for speed humps.

The City has a duty to maintain a street system which reasonably allows for timely emergency service response. However, on local streets the City also has other compelling duties which may to some degree conflict with maintaining the streets in a manner to optimize emergency service response. Those duties include attempting to maintain local residential streets in a manner which will induce traffic behavior consistent with areas where child pedestrians in the street may be expected or to maintain the streets in a manner which induces traffic behavior assuring residents the quiet enjoyment of their homes secure from traffic impacts. On local residential streets which are **not** on primary emergency response routes, what is reasonable accommodation for timely emergency service response may be quite different from what is reasonable on the primary routes. In those circumstances, hump placement which causes minor potential increases to emergency service response time affecting small numbers of properties would be acceptable. In fact, Portland's experimentation shows that all types of emergency vehicles including 85-foot aerial ladder trucks can safely cross 3 inch by 14 foot speed humps at speeds of at least 20 miles per hour, that rescue vehicles could tolerate speeds to 30 mph and that normal automobiles (such as police cars and battalion chief cars) could tolerate considerably faster speeds. The ability of fire vehicles to tolerate hump-crossing speeds of 20 mph is crucial since it implies a zero impact on response time; fire vehicles rarely if ever achieve speeds of 20 mph on the types of local access streets where speed humps would normally be employed.

The City will normally seek to identify and implement measures which offset the effects of neighborhood traffic management on emergency response and to avoid implementations where the cumulative effect of neighborhood traffic controls dramatically alters the actual delivery of emergency response.

Transit Routes

Speed humps generally should not be installed along streets with established conventional bus transit routes with normal service frequency. School transit, shuttle vans, para-transit vehicles and similar services and "tripper" routes of conventional transit are not included in this consideration because they can reasonably be expected to operate in the neighborhood environment at speeds where speed humps would not pose problems. In addition, many of these vehicles are not exceptionally long wheelbase vehicles. If speed humps are installed on conventional bus transit routes, or streets which serve a confluence of school transit routes, they should not have a height greater than 3 inches.

Citizen Support

Where speed humps are considered at citizen request, and the other factors described in these guidelines are complied with, a petition requesting humps signed by representatives of 60 percent of the properties in the primary impact zone of the speed humps shall be considered sufficient indication of community support for the City to act on the request (impact zone to be defined by the City staff on a case by case basis)

DESIGN AND CONSTRUCTION CONSIDERATIONS

Dimensions And Cross Sections

Figure II shows the profile of the parabolic speed hump to be employed in Redwood City. The 3 inch maximum height by 14 foot length profile is the desired profile with an acceptable construction variation tolerance of .25 inch (giving a hump range from 2.75 to 3.25 inch in maximum height). Speed humps in this height range are expected to cause crossing speeds of 20 to 25 mph.

Figure III shows details of hump taper at gutter lines. The gutter taper is specifically intended to maintain gutter drainage flows and not affect the downstroke of bicycle pedals on the tapered section.

Traffic Control

Speed humps will be accompanied by standard W 37 warning signs facing each direction of traffic placed generally adjacent to each hump (or slightly in advance if dictated by roadside features) and by standard W 37 advance warning signs placed in each approach direction at least 200 feet in advance of the first hump in a series (or a solo hump). The advance warning signs may be accompanied by a supplementary plate, either W 71 indicating length of section for a series of speed humps or W 34A indicating distance to a solo hump. A supplementary advisory speed plate (W 6) may be provided on the adjacent warning signs. Sign locations and supplementary plates will be as directed by the Transportation Manager. Figure III also illustrates details of hump warning and advance warning signs and supplementary plates.

The speed humps shall be marked with 12 inch reflective white stripes set parallel to the centerline tangent on 6-foot centers with the center-most stripes offset by 3 feet on centers from the centerline. The word message BUMP in eight (8) foot white reflective letters shall be placed fifty (50) feet in advance on each approach to each hump. Figure III provides further specification to these marking details.

Spacing And Location

Location and spacing of speed humps will be determined on a case by case basis by the City's Transportation Manager. In all except very unusual cases, speed humps intended to operate in series would be located no closer than 200 feet apart and no farther than 750 feet apart. Where unaffected by compounding locational factors, they would normally be located at least 275 feet apart and no farther than 550 feet apart within a single block. On short blocks (less than 500 feet in length), a single hump per block would be typical. Spacing and number of speed humps will vary substantially depending on absence or presence and type of control at intersections at the limits of and within the segment where speed humps are to be employed.

The first hump from either direction in a series should, if practical, be located in a position where it is least likely to be approached at very high speed. Possible placements to achieve this objective include putting the first hump in a system close to (but not less than) minimum safe stopping sight distance from an intersection, preferably a controlled one, close to minimum safe stopping sight distance of a small radius curve or at the top of a hill (rather than the middle or the bottom) where a lengthy downgrade is involved. Where solo speed humps are employed, a placement objective is to minimize the likelihood of a very high speed approach from either direction, usually leading to placement roughly at mid-block.

Maximum and minimum spacing criteria may be relaxed somewhat to conform to particular site conditions.

Installation Angle

Speed humps should be installed at a right angle to the centerline tangent of the roadway.

Utilities

Speed humps will not be located over utility manholes, gate valves, pull-boxes, access vaults or ventilation gratings or located immediately adjacent to fire hydrants.

Drainage And Roadway Edge Treatment

The specific hump cross-sections presented above provide edge treatment designed to maintain existing gutter flows. In ideal circumstances, speed humps would be located close downgrade from existing drainage inlets and locations immediately upgrade from inlets would be avoided. However, because the edge tapers are designed to maintain gutter flows, this consideration is subordinated to other locational criterion.

Speed humps should not be installed in the immediate vicinity of features designed for surface cross-drainage (dips) or where surface cross run-off flow is a known problem.

If speed humps are installed on roadways without vertical curb defining the edge of the traveled way, it may be necessary to consider measures to discourage drivers from attempting radical hump avoidance maneuvers outside the traveled way. Countermeasures include placement of the speed humps at points where existing roadside features like trees or utility poles are adjacent to the hump or placing bollards or delineators adjacent to the traveled way at the hump.

Coordination With Street Geometry And Adjacent Features

Speed humps will not be installed where on-site assessment of roadway geometrics finds that the proposed location constitutes a critical point in the roadway system, e.g., a severe combination of horizontal, vertical curvature and/or street cross-slope and/or complicating abutting use conditions or street features.

Intersections And Driveways

Speed humps should not be installed within an intersection or driveway. On approaches to intersections controlled by traffic signals, safe stopping distance separation should be maintained so that motorists preoccupied with hump crossing will still have time to perceive and react to changes in the signal indication.

Parking

Each hump installation will be evaluated individually for site specific considerations involving on-street parking. While speed humps should not normally be cause for on-street parking restrictions, such measures could be contemplated where parked vehicles seriously diminish the effectiveness of warning signing and markings or seriously compromise drainage flows at the speed humps.

Street Lighting

There is no requirement to provide special nighttime illumination of speed humps. However, where street lighting exists on streets being considered for speed humps, the speed humps will be placed to take advantage of the available lighting unless other compelling location and spacing criteria make placement in the best illuminated areas unfeasible or impractical.

Construction Methods and Materials

Prior to hump construction, construct a wooden template/screed to the dimensions shown on the plans. Prior to placing AC, a tack coat, asphaltic emulsion SS-1 per Section 94 of the Caltrans Specifications shall be applied to all horizontal and vertical surfaces. Sweep clean the pavement of all soil and debris immediately prior to application of the tack coat. Apply the tack coat to existing pavement at a rate of 0.05 to 0.10 gallons per square yard of surface covered or as directed by the Engineer. Spread and compact asphalt concrete in accordance with Section 39 of the California Standard Specifications (1995) and the following requirements. Hand lay the asphalt concrete using the template/screed allowing for compaction (typically about 1/2 inch maximum). Asphalt concrete shall conform to section 39 of the California Standard Specifications and shall be 3/8 inch maximum fine graded. Construct the hump to the dimensions specified on Figures III and IV with a dimensional tolerance of =/- 0.25 inch. Compaction of AC shall be equivalent to an 8 ton static roller. Apply the asphaltic emulsion SS-1 to all newly placed AC surfaces as a seal coat. Some communities require that the AC be placed in two lifts. Experience indicates that adequate conformance to design tolerance can be achieved in a single lift through use of the template/screed and reasonable diligence of workmanship and inspection. If the two lift method is used, separate templates should be constructed and used for each lift.

This policy and guideline was prepared by and for the City of Redwood City Community Development Services – Engineering and Construction in 1997.

ATTACHMENT N

REDWOOD CITY SPEED HUMP
POLICY SUMMARY

Definitions

Speed hump: A raised pavement area for speed control purposes conforming to explicit engineering specifications for maximum height, profile and minimum length (in direction of vehicle travel). *Speed bump:* A raised pavement area for speed control purposes *not* conforming to recognized engineering specifications for *speed humps*; generally, more abrupt (higher and/or shorter) than *speed humps.*

Eligibility Conditions

Eligible For Humps	Ineligible/Questionable For Humps
Persistent speed problem: 85'th %ile speed 33 mph or greater or 66% of all vehicles exceed 25 mph or average of top 15 %ile speeds observed is 40 mph or greater.	Speeds unremarkable: Criteria opposite not met.
Local access street.	Arterial or collector street.
Two-lane street.	Street with more than two lanes.
Street less than 40 feet wide.	Street wider than 40 feet.
Pavement quality satisfactory.	Pavement needs resurfacing/reconstruction.
Grades less than 5 percent in area of hump.	Grades greater than 5 percent or sustained downgrade present.
Straight and level or mild horizontal and/or vertical curves.	Horizontal curves of less than 300 foot centerline radius or vertical curves with less than safe stopping sight distance.
Streets posted 30 mph or less.	Streets posted 35 mph or more.
Low volume streets (generally below 3000 ADT).	Moderate to high volume streets (generally more than 3000 ADT).
Streets used by a relatively normal percentage of long wheelbased vehicles (trucks).	Streets used by an abnormally high percentage of long wheelbased vehicles.
Streets used occasionally by emergency vehicles operating at low to moderate speeds.	Streets used as primary emergency vehicle circulation routes.
Streets not used for frequent, regularly-scheduled public transit routes. Use by school transit, paratransit and infrequent conventional transit tripper service is acceptable..	Regular frequently served conventional transit routes.

Design And Construction Considerations

*Maximum height:*3 inches, *Minimum length;* 14 feet. See profile detail on Figure III.
Signs and markings: See details per Figure IV.
Spacing: 200 feet to 750 feet; 275 to 550 feet desirable.
Location: 60 feet minimum from intersections; 200 foot sight distance desirable for isolated mid-block locations.
Drainage: Maintain gutter flows.
Illumination: Locate to take advantage of existing street lighting where feasible.
Appearance: Locate to minimize visibility of signs and markings from closest homes.
Avoid the following:

- Locations within intersections
- Locations at driveways
- Locations over utility manholes, gate valves, pull boxes, access vaults or ventilation gratings
- Locations at fire hydrants
- Locations immediately upgrade from drainage inlets.
- Locations at or adjacent to surface cross drains.

Appendix B:
Redwood City Neighborhood Petition for Speed Humps

City of Redwood City

Neighborhood Petition for Speed Hump Installation

THE UNDERSIGNED BELOW AGREE TO THE FOLLOWING:

1. All persons signing this petition this petition do hereby certify that they reside within the impacted area, which is hereby defined as the street segments of:
   ____
   ____
   ____

2. All persons signing this petition request that the City of Redwood City investigate the plausibility of installing speed humps on my street in this neighborhood:
   ____
   ____

3. All persons signing this petition do hereby agree that the following contact person(s) represent the neighborhood as facilitator(s) between the neighborhood residents and City of Redwood City staff in matters pertaining to items 1 and 2 above:

Name: ______________ Address: ______________ Phone #: ______________
Name: ______________ Address: ______________ Phone #: ______________
Name: ______________ Address: ______________ Phone #: ______________

ONLY ONE SIGNATURE PER ADDRESS

	Name (Please Print)	Address	Phone Number	Signature
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				
13.				
14.				
15.				
16.				
17.				
18.				
19.				
20.				

Appendix C:
Redwood City Emergency Response Routes


CITY OF REDWOOD CITY
LEGEND
PRIMARY EMERGENCY RESPONSE ROUTE
SECONDARY EMERGENCY RESPONSE ROUTE
0
1000
2000
4000
1 inch = 2000 ft.

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