Raised crosswalks and their design features in traffic calming

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Abstract

A road hump, or speed hump, is a traffic calming device used to reduce vehicle speed and volume on residential streets. Road humps are placed across the road to slow traffic and are often installed in a series of several humps in order to prevent cars from speeding before and after the hump. Speed humps are used in locations where very low speeds are desired and reasonable. Speed humps are typically placed on residential roads and are not used on major roads, bus routes, or primary emergency response routes. In Italy, the road humps are often built in the shape of raised crosswalks (RCWs) and they are generally placed both close and between intersections.

This paper deals with the analysis of observed data on a sample of RCWs located in Tuscany, central Italy. Such data were referred both to geometry characteristics of the single raised crosswalk and recorded differences in vehicle speeds before and after it. Speed data were gathered using two automatic radar-recorders for each one of the sampled raised crosswalks.

All the collected data were analysed firstly through statistical tests in order to assess their homogeneity or not between different locations and various types of roads; secondly, through modelling software to obtain a generally valid formulation to evaluate the functionality of the device. Finally, we were able to make some conclusions and highlight design aspects. On the one side, RCWs with similar geometries have similar effects on the lowering of vehicle speeds, regardless of local conditions (location, road geometry, driver behaviour, etc.). Moreover, recent developments of the research show that raised crosswalks installed in a series have an influence on the speed reduction in function of their number and their distance. On the opposite side, the effects of raised crosswalks with smaller heights (less than 6 cm) show clearly a very low influence on vehicle speed variations.

Keywords: road humps, raised crosswalks series, speed lowering, traffic calming devices.
1 Introduction

Since the 60s, various European cities have been advised the need to restore to the citizens those portions of the town who had been gradually invaded by vehicular traffic using various techniques of traffic calming. In Italy the interest in traffic calming techniques has experienced a notable increase since 90s.

If we wanted to give a definition of traffic calming, we could say that this is a combination of interventions, mainly physical, aimed to reducing the negative effects arising from the use of motor vehicles in those areas where such effects are a source of a security’s reduction for non-motorized users of the road.

One of the purposes of traffic calming priority is therefore to provide benefits for the typically residential environmental hitting directly the grounds of hardship caused by vehicular traffic: traffic volumes and vehicle speeds [1].

The reduced security of urban roads is, in fact, attributable mainly to two reasons:

- The first, of a psychological nature, related to the fact that every road is itself a place intended for the use of vehicles. In consequence, vehicle drivers consider it their right to pursue superiority over other road users (such as pedestrians and cyclists). In addition, each type of user has, in practice, the freedom to take the behaviour they want.
- The second, of a physical nature, linked to wrong urban planning and forecasts of growth in demand for mobility: as a result of this, high traffic volumes are in transit, often at high speeds in residential areas that do not have sufficient capacity to bear.

In those circumstances, the objectives that arise from traffic calming are:

- Improving the safety of some types of road users and improve the quality of life of residents.
- Ensuring good accessibility to these residential areas.
- Improving the conditions of local roads, which will continue to support heavy traffic.

One of the ways to achieve these goals is to use physical constraints, or “elements of traffic calming”, or else the adoption of infrastructure devices able to give significant reductions in speed for drivers of motor vehicles and therefore able to improve the road safety for all users [2]. Overall, these devices include both types here considered, raised crosswalks (or RCWs) and road humps.

2 Devices

2.1 Raised crosswalks (RCWs)

The raised crosswalk devices, created by the combination of a road hump with a pedestrian crosswalk, consisting of a raising of the roadway with a ramp, is made for the dual purpose of giving continuity to the sidewalks on both sides of the
road, and then facilitate the crossing of pedestrians, and to interrupt the continuity of long straights and therefore reduce the speed of vehicles.

They can be put in place both individually and in series. In this second case, RCWs are installed properly spaced so as to moderate the speed of vehicles over a certain extent of a road, resulting in a further reduction of pollutant emissions as a result of their loss of speed. These devices are particularly effective if carried out in series and spaced each other of 80–120 m.

2.2 Road humps

These devices are elements with a convex profile placed on the roadway, whose purpose is to force drivers to reduce speed of their vehicles in the road section in which they are installed.

Like the RCWs, these devices are in fact a discontinuity both visual (break the linearity of the distance) and physical (vehicles must pass a slight height difference).

2.3 The Australian case

Some researchers of the Department of Transport Engineering of the University of Sydney wrote in 1997 a paper dealing with the effects of mid-block speed control devices [3]. This quoted work contains some interesting information on use of such traffic calming devices:

- when flows are greater than 600 veh/h, the increase in travel time over the road on which they are installed is substantial, and increases with increasing traffic volumes;
- the road capacity decreases, and such decrease is more pronounced with the increasing of traffic volumes;
- the opportunity of road crossing for pedestrians, as measured by the parameter of Crossing Opportunities Index (or COI), is reduced and this reduction is more pronounced for the higher volumes of traffic;
- effects of these devices are maximum within 30-50 m from the device and vehicle flows higher than 900 veh/h;
- these devices should be installed at least at 50 m from the intersections.

3 Raised crosswalks (RCWs)

3.1 Italian and international standards

Italian guidelines are quite lacking for any recommendation regarding the RCWs geometry and general features.

Therefore one can find poor references to these devices in various documents, but none of them provides to any detailed technical specification or design guideline.

The Italian Urban Road Safety Planning guide provides the following definition for RCWs: “Raised road areas or raised crosswalks, speed tables:
rising of the roadway by a ramp (with a slope of approximately 10%) to indicate areas of pedestrian crossing or, however, areas to be protected from high speeds. The length affected by the rising generally exceeds that of normal vehicles (10–12 m), otherwise it will be classified as a road hump” [4].

Given the scarcity of information (also about sizing and location of the road humps), it is preferable to treat these special devices as a separate category, because of two reasons as follows:

a) the road humps built in concrete trapezoidal profile (i.e. the only ones suitable for use as pedestrian crossings) can be placed only on roads with speed limits below 30 km/h. As a result, raised crosswalks could not be placed on roads with a higher speed limit.

b) the road humps may have a maximum height of 7 cm. This height means that in most cases the continuity of the pavement can be achieved only by lowering significantly the level of the sidewalk at the same crossing. Moreover, experimental measurements have shown that a height of 7 cm could be not sufficient to induce a vehicle’s speed reduction under the achieved speed at pedestrian crossings.

In other countries there is a bit more interest in these devices. Guidelines and standards on their building, sizing and positioning are often provided.

Particular attention is given to the configuration of the ramps connecting the level of the roadway and the platform. These ramps can take different forms: straight (the most commonly used for manufacturing simplicity, functionality and building costs), a parabolic profile, a sinusoidal profile (useful to facilitate the transit of cyclists), height H and slope S (the latter characterized by a particular layout, well-suited for promoting the passage of heavy vehicles and public transport).

With regard to the geometric dimensions, there is much uniformity among the various standards. Virtually all agree to retain the slope of the ramps below the 10%, to limit the height of the ramp below 10 cm (or for the extension of the platform) and the width below 5 m (local roads), and on road marking to be taken for these devices.

3.2 Measurements on RCWs

The devices used for speed detection was a portable Radar Recorder, produced by CA Traffic Ltd. The measurements have been carried out in seven different sites [5], chosen through the following criteria:

a) differences in geometry;

b) adequate distance from any perturbation cause, such as congestion points, intersections, parking lots, and so on;

c) possibility of Radar Recorder positioning (presence of poles close to).

When facing an isolated RCW, we used a couple of radar recorders, one of which was installed at the RCW and the other at a distance where vehicles do not suffer the calming effect. In case of a RCWs’ series, one radar recorder was always positioned in correspondence with the RCW to be measured (in the case of a series of 3 or more we have always positioned the first radar at a RCW
located in the middle) and the other one was in an intermediate position between RCWs.

The main characteristics of the seven stations are shown in Table 1, while Table 2 summarizes the field data collected for each site, and where:

- \( V_{med} \): average of the observed speeds by the radar close to the RCW;
- \( V_{85} \): 85th percentile of the speed distribution close to the RCW;
- \( V_{85m} \): 85th percentile of the observed speed distribution at the intermediate position, in case of a series of RCWs;
- \( V_{max} \): maximum of the observed speed value by anyone radar;

### Table 1: Observed main characteristics of RCWs [5].

<table>
<thead>
<tr>
<th>Location (city)</th>
<th>Site ref.</th>
<th>Elements in RCWs’ series</th>
<th>Distance between RCWs’ [m]</th>
<th>( H ) [cm]</th>
<th>( L_{platform} ) [m]</th>
<th>( L_{ramp} ) [m]</th>
<th>Avg. flow [veh/h]</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Via Urbiciani (Lucca)</td>
<td>A</td>
<td>2</td>
<td>180</td>
<td>15</td>
<td>3.0</td>
<td>2.0</td>
<td>320</td>
<td>-</td>
</tr>
<tr>
<td>Via dei Cavalletti (Lucca)</td>
<td>B</td>
<td>3</td>
<td>135</td>
<td>15</td>
<td>3.0</td>
<td>2.7</td>
<td>580</td>
<td>-</td>
</tr>
<tr>
<td>Via Strettoia (Pietrasanta)</td>
<td>C</td>
<td>3</td>
<td>100</td>
<td>15</td>
<td>3.3</td>
<td>2.5</td>
<td>180</td>
<td>-</td>
</tr>
<tr>
<td>Via Bernini (Pietrasanta)</td>
<td>D</td>
<td>3</td>
<td>85 (Avg.)</td>
<td>15</td>
<td>3.3</td>
<td>2.5</td>
<td>200</td>
<td>Cycle path</td>
</tr>
<tr>
<td>Via Bonanno (Pisa)</td>
<td>E</td>
<td>2</td>
<td>150</td>
<td>3</td>
<td>4.5</td>
<td>0.8</td>
<td>1150</td>
<td>-</td>
</tr>
<tr>
<td>Viale Michelangelo (Pisa)</td>
<td>F</td>
<td>2</td>
<td>150</td>
<td>10</td>
<td>3.5</td>
<td>1.3</td>
<td>700</td>
<td>Traffic island</td>
</tr>
<tr>
<td>Via Vittorio Veneto (Pontedera)</td>
<td>G</td>
<td>2</td>
<td>150</td>
<td>5</td>
<td>4.0</td>
<td>1.1</td>
<td>930</td>
<td>-</td>
</tr>
</tbody>
</table>

### Table 2: Field measured speeds [km/h] in each of the seven sites [5].

<table>
<thead>
<tr>
<th>Site ref.</th>
<th>( V_{med} ) [km/h]</th>
<th>( V_{85} ) [km/h]</th>
<th>( V_{85m} ) [km/h]</th>
<th>( V_{max} ) [km/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>29</td>
<td>33</td>
<td>48</td>
<td>87</td>
</tr>
<tr>
<td>B</td>
<td>36</td>
<td>43</td>
<td>45</td>
<td>68</td>
</tr>
<tr>
<td>C</td>
<td>35</td>
<td>42</td>
<td>49</td>
<td>58</td>
</tr>
<tr>
<td>D</td>
<td>29</td>
<td>39</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>E</td>
<td>42</td>
<td>49</td>
<td>51</td>
<td>90</td>
</tr>
<tr>
<td>F</td>
<td>36</td>
<td>43</td>
<td>-</td>
<td>79</td>
</tr>
<tr>
<td>G</td>
<td>37</td>
<td>45</td>
<td>46</td>
<td>69</td>
</tr>
</tbody>
</table>
3.3 Models development

It was important to evaluate the efficacy of each type of RCW used in the different sites. Efficacy was assessed using a correlation between the height of RCW and average speed of vehicles measured at the RCW itself, whose results are shown in the chart below (Figure 1).

Figure 1: RCWs’ efficacy on average speed observed at different sites and in respect to different heights.

In the previous study (2011) a comparison between the different samples collected in different sites was conducted using the $F$-test (also known as Fischer test), or test about the homogeneity of variances [6].

During 2013 we carried out a new analysis of data collected for previous study. This analysis was oriented to develop a model to evaluate the efficacy of design features of this type of devices in speed reduction.

We stated the following hypothesis for this analysis:
- the 85th percentile of the speed of vehicles detected was used for analysis;
- heavy vehicles were excluded: a vehicle is classified as heavy when its detected length is greater than 7.5m;
- not all light vehicles registered were included in the calculation of 85th percentile, but only those that could be considered traveling in free flow conditions: we considered those for which the measured gap from the preceding vehicle is greater than 5s.

The first step was to select the structure of the model. The choice fell on a model with 3 independent variables (two geometric variables and one kinematic variable), which are considered sufficiently binding and representative of the speed held by users on the device.

\[
\begin{align*}
\text{height of device (m)} & = h \\
\text{length of the ramp of the device (m)} & = L_{ramp} \\
\text{85th percentile of speed in the outer position, approaching the device (km/h)} & = V_{85,i}
\end{align*}
\]

For the selection and calibration of the model, the open-source software Gretl 1.9.12 was used. This software allows you to write and analyze linear and non-linear regression models. In this first phase of the research, several models of both categories have been tested and compared.
The comparison between the different models tested was carried out on the basis of two methods: the analysis of the adjusted coefficient of determination $R^2$ and the Akaike Information Criterion.

In the field of regression analysis, simple $R^2$ is used as the main index of the goodness of the regression curve. For the analysis of simple linear regression, it is used to measure the fraction of deviance explained, i.e. the proportion of the variability of $Y$ explained by the explanatory variable $X$. In the context of multiple linear regression is used instead the adjusted $R^2$ coefficient: in fact, as the number of explanatory variables (or predictors) increases, it also increases the value of simple $R^2$. In this case the adjusted $R^2$ correctly measure the fraction of the variance explained. It can be negative and it is always lower than the simple $R^2$. When the value of the adjusted $R^2$ approaches unity, greater is the fraction of variance explained by the model, greater is the ability of the latter to describe real data: the rule to follow is therefore to prefer models with higher values of adjusted $R^2$.

Unlike in the case of linear regression, a general method in determining the values of the parameters that provide the best data fitting in the case of non-linear regression does not exist. In this case, we can use classes of numerical iterative algorithms for optimization, which starting from initial values, set by random procedure or by a preliminary analysis (e.g. linear regression model), to come to points considered optimal. We could have a local maximum of the goodness of fitting, in contrast with the case of linear regression, where the maximum is always a global maximum. The software used allows the automatic calculation of several evaluation criteria, among which the one known as the Akaike Information Criterion was used. In this case, the rule to follow is to prefer models with the lowest AIC value.

As above, we carried out a comparison between different models: among all, the more representative result was the one obtained with the following non-linear model:

$$\Delta V_{85} = a + b \cdot e^{-h} + c \cdot \frac{L_{ramp}}{V_{85,i}}$$

where: $\Delta V_{85}$ speed reduction between $V_{85}$ detected on the device and $V_{85}$ detected in an outer position (km/h)

For each parameter, the software also evaluates the p-value, which allows an assessment of significance. We can retain the value of a parameter as significant when its p-value was lower than 5%, or when it is significant to 95% of cases.

The value of the three parameters, obtained using non-linear regression techniques, are the following:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Evaluated value</th>
<th>Std. Error.</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>259.047</td>
<td>38.5950</td>
<td>0.00675</td>
</tr>
<tr>
<td>b</td>
<td>-257.029</td>
<td>38.5142</td>
<td>0.00686</td>
</tr>
<tr>
<td>c</td>
<td>-592.850</td>
<td>105.756</td>
<td>0.01122</td>
</tr>
</tbody>
</table>
This calibrated model pointed out an AIC value of 25.069: it is a very low AIC value, so we can retain the fitting between model and real data as very good. Then, our model can be written in this way:

\[ \Delta V_{85} = 259.047 - 257.029 \cdot e^{-h} - 592.850 \cdot \frac{L_{\text{ramp}}}{V_{85,i}} \]

The good fitting with real data can be observed from the following picture too:

![Model fitting](image)

Figure 2: Model fitting.

4 Conclusions and further developments

Close examination of the collected data and above performed analysis lead us to the following conclusions:

a) The two geometric parameters chosen for the model seem to have a big influence on the speed reduction, evaluated via \( \Delta V_{85} \). The combination of these two parameters gives the slope of the ramp: for a generic driver who is driving along a road, the slope of the ramp makes possible the perception of these devices as obstacles, and therefore this induces the user to reduce the speed;
b) The developed model could give also negative results: in this case, the geometry designed for the device have no efficacy on speed reduction (the device was designed with an insufficient ramp slope or an insufficient height);

c) RCWs with similar geometry (combination of height and length of the ramp) have the same effect on speed reduction, for the same values of $V_{85,i}$, even if they are placed on roads having different geometry (both in layout and elevation);

d) the best designed RCW, in terms of speed lowering effect, has been the one observed in Via Urbiciani, with 15 cm as height and 7.5% as slope;

![Figure 3: Geometric characteristics of the best designed RCW in terms of its observed efficacy in lowering vehicle speeds.](image)

A series of raised crosswalks seem to have better performances than an isolated one. Further research efforts should be made in order to better evaluate the efficacy both of distance between RCWs and of number when built in series. The same research will be also extended to road humps. A more fine-tuned comparison among these traffic calming devices might be also carried out to taking into account some of their produced impacts on the environment, such as noise and energy consumption.
References