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FINDING AND CHARACTERIZING HIDDEN DIPS IN ROADS

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Abstract. Sometimes when connecting a crest vertical curve, followed by a sag and another crest, a road disappears from the view of a driver to reappear later. Then, there is a loss of path or a hidden dip in a road. It is essential to avoid losses when they hide dangerous points, such as intersections or unexpected changes in direction. In addition, this loss disrupts drivers and its effect depends on quantitative relationships between the variables involved in the problem. This paper presents a quantitative procedure for studying hidden dips in roads. The method is based on calculating the sections visible and hidden by a driver using a Geographic Information System. An application to a Spanish road is presented. Procedure results were compared with in situ carried out studies and with a video of the highway recorded using a Global Positioning System equipped video camera embarked in a vehicle. The main quantitative issues related to hidden dips are discussed.

Keywords: design, Digital Surface Model (DSM), Digital Terrain Model (DTM), Geographic Information System (GIS), hidden dip, highways and roads, sight distances.

1. Introduction

Some combinations of horizontal and vertical alignments produce shortcomings in three-dimensional (3D) perspective. There are two major types of shortcomings: those that are safety-related and those that are merely aesthetic. Among the safety-related, the partial disappearance of a road from the driver's view with reappearance in the extension of the just-passed roadway section (called "hidden dip") stand out. Sometimes when connecting a crest vertical curve, followed by a sag, the road disappears from driver's view to reappear later. Then, there is a loss of path or a sight hidden dip in the road. It is essential to avoid losses when they hide dangerous points, such as intersections or unexpected changes in direction (Fig. 1). This loss produces driver disorientation if visible sections are nearby and visual indicators suggest that hidden section alignment is similar to visible sections alignment. Sometimes, this disorientation causes erroneous decisions, which possibly cause an accident. A typical case is an overtaking. If a driver believes that he sees all possible vehicles circulating towards him, this is not the case because there are some unnoticed vehicles in the hidden section.

A "hidden dip" is the partial disappearance of the road from the driver's view with reappearance in the extension of the just-passed roadway section (Fig. 1). A particular case of hidden dip appears if there is a curve in the horizontal layout. In this latter case, road reappearance has a displacement from the just-passed roadway section (Janikula, Garrick 2002; Smith, Lamm 1994) (Fig. 2).

The aim of this research was to develop a procedure to detect hidden dips in existing roads. As mentioned, the effect of hidden dips on drivers depends on quantitative relationships between the variables involved in the problem. Secondary task was to characterize these hidden dips by evaluating their impact and calculating the length of the involved highway sections.

This paper presents a quantitative procedure for studying hidden dips in existing roads. The method is based on calculating the available sight distance using a Geographic Information System (GIS). An application to a Spanish road is presented. Procedure results were compared with sight distance studies carried out in situ. In addition, a video was recorded by a Global Positioning System

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(GPS) equipped video camera mounted on a vehicle. This video was used also for comparison.

2. Literature review

Most researches show the importance of 3D shortcomings, specifically hidden dips, but they consider the problem usually from a qualitative point of view (Janikula, Garrick 2002; Smith, Lamm 1994). To aid designers, highway design standards include recommendations (rules applicable in the design phase of a highway) about horizontal and vertical layout coordination in order to avoid 3D alignment shortcomings. For example, *AASHTO 2011: A Policy on Geometric Design of Highways and Streets* and *Ministerio de Fomento 3.1-IC 2000: Norma de Trazado* [Spanish Highway Design Standard] (in Spanish) provide this kind of recommendations. Most of these recommendations are qualitative. However, even for experienced design engineers and despite these recommendations (rules), these shortcomings in the 3D alignment still occur. When this happens, they are not recognized until the road has been built.

On the other hand, more recently, highway design software that generates virtual images of the designed highway is available. In order to check these images, designers see them sequentially. These procedures are aimed to be applied in the design phase of the highway, and they require knowledge about project data (horizontal and vertical layout and cross section) (Altamira *et al.* 2010; Castro 2012; Figueira *et al.* 2014; Larocca *et al.* 2011). In this way, if shortcomings are detected, it is possible modify the design. These procedures do not take into account quantitative aspects of the phenomenon and applying them to already built highways is difficult because the project data is usually not fully known (length of tangents, curves radii, spirals, geometric characteristics of vertical curves).

Recently, several researches centred in quantitative analysis of these shortcomings have been made (Kuhn, Jha 2010; Moreno *et al.* 2014; Zimmermann 2001). In the case of hidden dips, Zimmermann (2001) and Kunh and Jha (2010) have proposed a methodology for checking shortcomings in the 3D alignment in order to help design engineers. The results of the quantitative checking factors are shown in a characteristic graph (the blind section graph). Critical blind spots are recognizable along the graph if drivers are able to see the road again no more than 600 m away, the blind spot depth is more than 0.75 m and the length of hidden section is more than 60 m (Zimmermann suggests 75 m). The 600 m value is taken from studies about drivers' visual field as function of speed (Leutner 1974). This method (Kunh, Jha 2010; Zimmermann 2001) has been designed to be applied during highway design. They have used several software applications (mathematical software and highway design software), but they have not developed specific software. This procedure needs project data (length of tangents, curves radii, spirals, geometric characteristics of vertical curves etc.). Therefore, applying this procedure to already built highways is difficult (because needed data are usually unknown). This method has not been tested on any real-world projects (Jha *et al.* 2011).

In addition, following the Swiss standard *SNV-640140 (VSS 1991: Tracé; Critères Optiques (SNV–640140))* [Geometric Design; Optical Criteria] (in French) it is important that the reappeared section is at a large enough

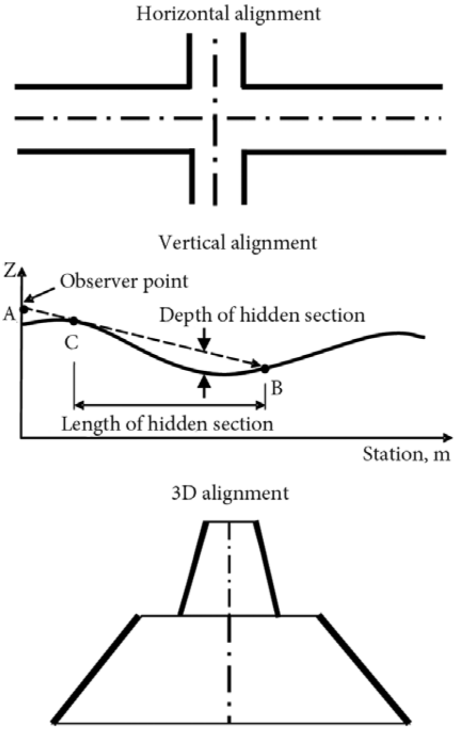

Fig. 1. Hidden dip in an intersection

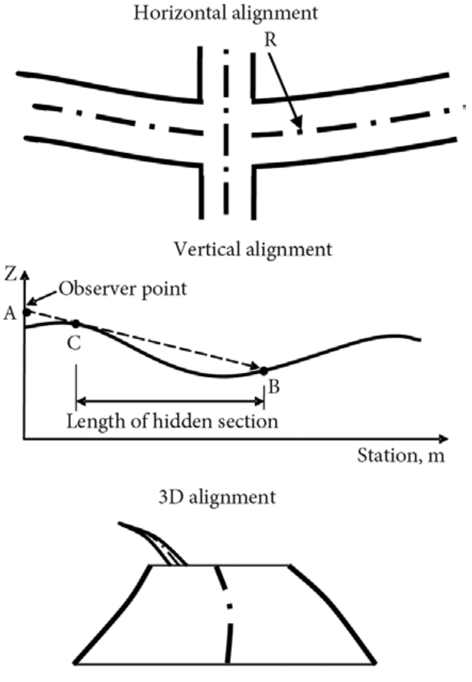

Fig. 2. Hidden dip in a horizontal curve

distance from the observer. Fig. 3 shows critical distances as a function of vehicle's operating speed (V_{85}, km/h). These distances vary between 180 m for a V_{85} = 40 km/h and 865 m for 140 km/h. The standard requires that AB distance from observer to reappeared section (Figs 1 and 2) is larger than this critical distance. Italian standard *Ministero delle Infrastrutture e dei Trasporti 2002: Norme Funzionali e Geometriche per la Costruzione delle Strade* [Italian Design Standard for Highway Building] *(in Italian)* provides similar values.

In case of already built highways, visualization of video inventories are used to detect these shortcomings. It is a slow and costly process (with regard to resources and specialized personnel).

On the other hand, using a GIS to estimate sight distances in existing highways through procedures based on several standard tools (such as view shed calculation tools) has been proposed (Castro *et al.* 2011; Khattak, Shamayleh 2005). These methods have the advantage that knowing highway design data (length of tangents, curves radii, spirals, etc.) is not needed. However, these procedures do not allow finding hidden dips directly.

3. Procedure

The procedure to find hidden dips is based on determining for each highway station what sections ahead are visible and what are hidden. To this aim, a sight diagram is used. The sight diagram (Fig. 4) is a graphic where stations are in *X* axis and shows in the *Y* axis sight distance (measured along vehicle trajectory) for each point. Also, visible sections are shown in a colour different than sections that are not visible. Therefore, from point A there are a first highway section that is visible (AC section in Figs 1 and 4), a second highway section that is not visible (CB section in Figs 1 and 4) and a third highway section that is visible again (BD section in Figs 1 and 4).

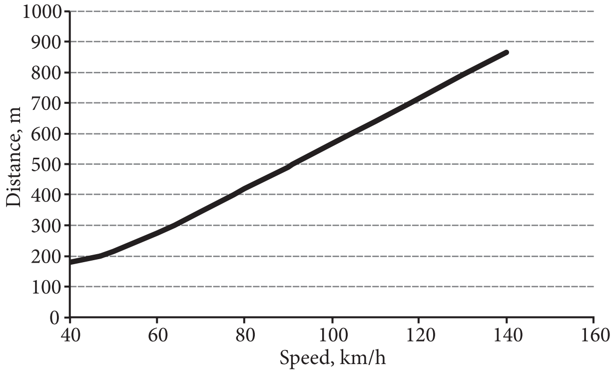

Fig. 3. Critical distances AB between driver and reappeared section according to *SNV–640140:1991*

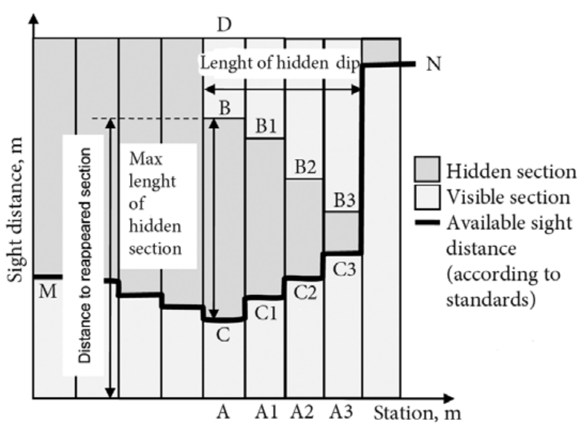

Fig. 4. Sight diagram

Although it is not needed to detect hidden dips, it is useful to plot also the available sight distance (line M, C, C1, C2 …N in Fig. 4) due to where a hidden dip ends the sight distance increases suddenly. In addition, knowing available sight distance is always useful because it is required that this distance be larger than the distance needed to stop a vehicle. Hidden dip starts at station A and ends at station A3.

Between A and A3 stations there are highway sections hidden to a driver and highway sections that reappear. At A3 station the available sight distance value will increase abruptly. Length of hidden dip is the difference between A and A3 stations. Maximum length of hidden section is CB. Maximum distance between driver and reappeared section is AB.

Length of hidden dip is a variable not considered by previous researchers Zimmermann (2001) and Kuhn and Jha (2010). However, it is important to characterize a hidden dip because if the length of hidden dip is very small the drivers are not aware of the existence of a hidden dip.

This sight diagram (Fig. 4) is generated by a software that has been developed for the calculation and analysis of sight distances, based on a GIS (Castro *et al.* 2014). For the study a digital terrain model and a file containing the points that define vehicle trajectory are needed. There are several sources to obtain these points from such as cartographic data, or driving along the studied highway with a Global Navigation Satellite System (GNSS) receiver mounted on a car. The software has tools that simplify getting and managing these points. They are in files of the "shape-file" type or in a "FeatureClass" from geo-databases. Points are required to have an attribute (named "station") that indicates their distance to the trajectory origin measured along this trajectory. Knowledge about highway design (length of tangents, curves radii, spirals etc.) is not needed.

The software has an algorithm that searches which trajectory points are visible from any other. The software stores not only the available sight distance information but also what highway sections are or are not visible from each point. This is an important difference with highway design software and with other works (Castro *et al.* 2011). In them, only sight distance (distance measured along the highway up to the first not visible point) is stored.

As mentioned, results are shown in the sight diagram (Fig. 4). In addition, the software shows longitudinal profile between observation and observed points, horizontal maps and reports. Thanks to these aids for results analysis, a deeper understanding of the hidden dips is achievable. Their relevance is evaluated through the analysis of the maximum length of hidden sections (CB in Fig. 4), length of hidden dip (AA3 in Fig. 4), depth of hidden dip (Fig. 4), distance between driver and highway reappearance (AB, A1B1 etc. in Fig. 4) and available sight distance (AC, A1C1 etc. in Fig. 4).

4. Case study

The software was applied to the M-325 highway located in Madrid (Spain). It is a two-lane rural highway of 15 km and around 3 m lane width. The terrain is rolling. A field study was carried out driving along the highway twice. Also, the highway was filmed with a high resolution video camera installed in a vehicle. The video camera used has an embedded GPS receiver. Therefore, the video recorded also time, vehicle speed and coordinates of trajectory points. Later, these geo-referenced video recordings were analysed. Through the field study, eight hidden dips were detected that were confirmed by the video recording. Using the video recordings, approximate geographical localization of hidden dips, time duration of perceived hidden dips and approximate distance travelled while hidden dips are perceived were determined.

As happens in many already built highways, project information (characteristics of tangents, spirals, circular and vertical curves) was not available. Although it is possible to suppose a vehicle trajectory from cartographic data of the highway, in order to be close to reality, a trajectory was defined from data taken by a GNSS installed in the vehicle travelling along the studied highway. The GNSS receiver is not the video camera embedded GPS. The GNSS receiver was a multi-frequency receiver that receives and processes multiple signal types including GPS L2C, GPS L5, GLONASS C/A L2 and GALILEO and gives access to 72 channels tracking. The receiver antenna was settled on the top of the vehicle, threaded in a robust magnetic base. Data were collected in Real Time Kinematic (RTK) mode. For this study, data were registered with a minimum interval of 0.1 s. From these points a polyline representing vehicle trajectory was defined.

In order to calculate sight distances from the GNSS-determined points, they were placed on the digital terrain model (using only the horizontal information provided by the GNSS). A high resolution Digital Terrain Model (DTM) was used. The DTM had 1 m of grid spacing and was obtained by the Spanish Geographic Institute (IGN) from Light Detection and Ranging (LIDAR) data.

Although Kuhn and Jha (2012) and Zimmermann (2001) analysed the problem using a 20 m point spacing, in this work this spacing was reduced to 5 m (Castro *et al.* 2015). In this way, the precision of the results increases. These points belong to the previously defined vehicle trajectory.

The software needs to know how much highway length will be analysed from each point. As already mentioned, according to the Swiss standard, it is required that highway section reappearance shall not happen at a distance lower than some values that are function of vehicles speed (up to 850 m for V_{85} = 140 km/h). Zimmermann (2001) and Kunh and Jha (2010) established a 600 m critical distance. Based on both values, a highway section 1000 m apart from each studied point has been analysed.

According to *Spanish Highway Design Standard 3.1-IC:2000* the height of eyes above road surface was taken as 1.1 m. Other highway design standards, eg American Association of State Highway and Transportation Officials (*AASHTO*), propose similar values.

5. Results and discussion

In a first study, aimed at detecting hidden dips, a minimum hidden dip depth was considered. As DTM vertical resolution was 0.2 m, this value has been chosen as a minimum hidden dip depth. Also, a hidden dip length larger than 25 m (that corresponds to 1 s reaction time at a 90 km/h speed) or a length of hidden section larger than 75 m, criterion established by Zimmermann (2001), were required. With these hypotheses the eight hidden dips were analysed and the following was detected. Length of hidden dips (difference between the first and the last stations in which a driver sees highway reappearing) varied between 10 m and 230 m. The maximum length of hidden section varied between 75 m and 860 m. Distance at reappearing section (distance from observer and end of hidden section) varied between 265 m and 970 m. Four of those eight hidden dips (cases 2, 3, 7 and 8) are considered as minor hidden dips because of their low hidden dip length (35 m, 30 m, 10 m and 30 m, respectively). Case 5 is difficult to perceive because the reappeared section is too far (970 m) from driver. However, the hidden section starts near to driver (110 m), although with a large enough available sight distance to vehicle stopping. As a consequence, the remaining three cases (1, 4 and 6) are more perceptible for drivers. In cases 1 and 6 the hidden dip distance is much lower than the length of hidden section, while in case 4 the opposite happens.

Table 1 shows the length of hidden dip estimated from the video recordings and calculated with a 0.2 m hidden dip depth. Mean square error is 12.1 m. It must be taken into account that procedure resolution is 5 m (corresponds to the distance between calculation points).

Later, in order to analyse hidden dip depth effect, several depth values were considered. Calculations were made for hidden dip depths of 0.5 m, 0.75 m and 1.1 m (obstacle height for overpassing manoeuvres according to the *Spanish*

Table 1. Length of hidden dip

Number	Video, m	Software, m
1	75	75
2	48	35
3	35	30
4	248	230
5	29	50
6	56	70
7	11	10
8	34	30

Standard 3.1-IC). Length of hidden section decreases linearly with the increasing hidden dip depth (Fig. 5).

If the study is made considering 0.75 m as hidden dip depth (critical hidden dip depth according to Zimmermann (2001) and Kunh and Jha (2010)) seven hidden dips were detected. The case 4, detected in the study with 0.2 m hidden dip depth, disappears. This case had a length of hidden section much lower than its length of hidden dip. In the study considering 0.75 m as hidden dip depth, length of hidden dip varies between 10 m and 65 m. Four cases (2, 3, 7 and 8) have a small length of hidden dip (between 10 m and 30 m). Length of hidden section varies between 90 m and 810 m. Reappeared section is at a distance between 245 m and 960 m. Therefore, from those seven cases five are considered as minor. Four of them (cases 2, 3, 7 and 8) are minor because of their small length of hidden dip, and the other one (case 5) is minor because the reappeared section is too far from driver (960 m). As a consequence, cases 1 and 6 are potentially critical.

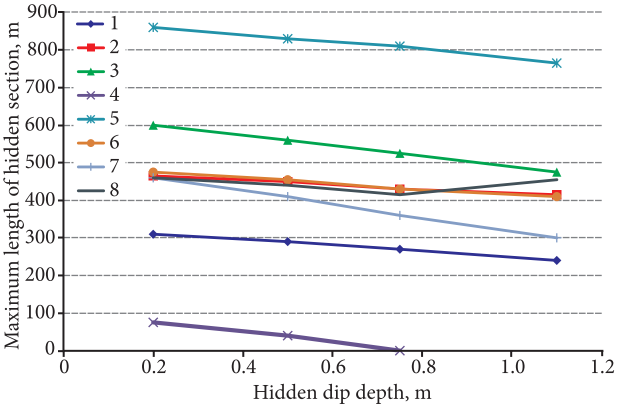

Fig. 5. Max length of hidden section versus hidden dip depth

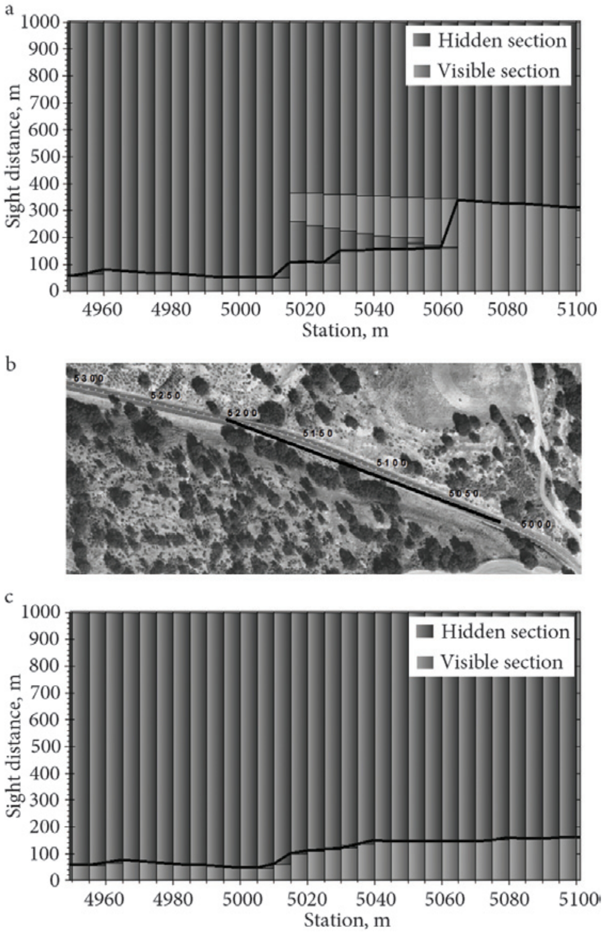

Fig. 6. Hiding of a hidden dip in a horizontal curve through vegetation

As already mentioned, from overpassing manoeuvers point of view, a hidden dip depth larger or equal to 1.1 m is potentially dangerous. If this hidden dip depth were analysed, the same seven hidden dips detected with 0.75 hidden dip depth remain. Four of them (cases 2, 3, 7 and 8) have a length of hidden dip lower or equal to 25 m. Case 5 continues being the case that presents a farther from the driver reappeared section (940 m). The most dangerous hidden dips continue being cases 1 and 6.

On the other hand, these hidden dips are caused by a wrong highway design. They should have been detected and corrected during the design phase of the highway. Once highways are built and there are design shortcomings, there are two mitigating strategies: shortcoming consequences are reduced using signals (reducing posted speed, forbidding overpassing etc.) or reappeared section is hided using visual barriers (eg planting vegetation in roadside borders).

Hiding of reappeared section using vegetation in roadside borders is not an option if horizontal layout is straight (Fig. 1). If there is a curve in the horizontal layout, reappeared section is displaced from the visible section (Fig. 2). In order to hide reappeared section using vegetation in roadside borders, a curve in the horizontal layout is needed. This strategy has been checked in the case study. The sight diagram of this highway showed a hidden dip not detected in the field nor in the video recordings. In Fig. 6a a hidden dip that has 50 m length, 155 m length of hidden section and a reappeared section at 265 m is shown. These calculations were made using, as previously explained, the DTM (taking no account of vegetation nor other obstacles). However, if the horizontal layout is analysed in the GIS (Fig. 6b) driver visuals penetrate the vegetation, visible in the orthophoto, in order to see the reappeared section.

In order to confirm vegetation effect on visibility calculations were repeated using a Digital Surface Model (DSM) that considers vegetation. Both models (DTM and DSM) come from the same institution and have the same resolution. Fig. 6c shows the sight diagram corresponding to using this DSM. As seen in this diagram there is no hidden dip in this section.

6. Conclusions

1. A procedure to detect sight hidden dips based on a Geographical Information System has been developed. This procedure analyses driving considering different hidden dip depths. The considered hidden dip depths had

a lower limit due to the vertical resolution of the Digital Terrain Model used.

2. Using this procedure a hidden dip is characterized through its main parameters: length of hidden dip, maximum length of hidden section and distance from driver to beginning of reappeared section.

3. The procedure allows using it based on a Digital Terrain Model as well as on a Digital Surface Model. This flexibility helps doing a more complete analysis of hidden dips.

4. In the case study eight hidden dips of several characteristics have been detected. Two of them were identified as potentially dangerous.

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