

# ASSESSING VERTICAL CURVE DESIGN FOR SAFETY

## Case Study on the N1/R300 Stellenberg Interchange, Western Cape

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### ABSTRACT

This project assessed the safety of a crest vertical curve on a four-lane freeway by examining the required stopping sight distance at operating speeds. The basis of the safety concerns were identified as the geometric properties of the road, such as grade and K-values, where the latter is an indication of the stopping sight distance (SSD). The vertical alignments in both the inbound and outbound directions were determined from GPS surveys. It was found that the available SSD (170 m) along the curve, using 150 mm object height, was significantly less than the required SSD (320) needed on the curve in order to achieve a safe stop, when including the gradient of the road. The analysis was based on the measured 85th percentile speed of 125 km/h. The K-value of the vertical curve at the Stellenberg Interchange does not conform to standards of the Geometric Design Guidelines of South African National Roads Agency Limited (SANRAL, 2002). Collision data was examined to confirm the safety concerns. Collision data was compared with that of a control site, which met all geometric standards for vertical curves. It was found that significantly more collisions, totalling 42 collisions, occurred at the Stellenberg Interchange site compared with the control site that totalled 4 collisions over the 17 month analysis period. The majority of collisions at the test site were head/rear end collisions which typically occurred as a result of inadequate SSD. It is recommended that a 100 km/h speed limit be imposed on the N1 road section through the Stellenberg Interchange as interim measure until reconstruction can be commenced.

## 1. INTRODUCTION

### 1.1 Background

This project examined the safety of a crest vertical curve on a section of four lane freeway, with reference to the required stopping sight distance (SSD) at operating speeds and with consideration of the road gradients. This section of road is affected by queuing in the peak periods and the lack of SSD on approaching the back of queue results in collisions.

The geometric design of this section of freeway was investigated to determine the K-values of the crest curve and compare this with specifications. Recent collision data was obtained from the Cape Town Traffic Management Centre (collected by newly installed highway surveillance cameras) and compared with a control site, where the K-value of the curve is acceptable. The selection of the "control" site was not done in a statistically random manner, but was selected to be observed by the TMC cameras, on the same route and as close as possible, with the same order of magnitude traffic flow and of adequate standard. The road section is not subject to queues forming in the peak periods. As such, it serves to contrast the two situations.

## 1.2 Scope of Work

The study started by determining the K-value of the vertical curve at the Stellenberg site as well as the K-value for the control site. The traffic volumes and operating speeds were obtained. The required SSD was calculated, taking into account the actual gradients of the road and the operating speed. Collision footage from the Traffic Management Centre was used to identify collisions along these sections in order to understand the role of road geometry in collisions. This collision data was analysed according to collision type, collision severity, as well as the location of the incident. This data was compared with the control site that meets the current standards set by the Geometric Design Guideline (SANRAL, 2002). The control site used in this investigation was a section of the N1 near the Koelenhof Interchange.

## 2. SPEED DATA

The current speed limit of this section of freeway is 120 km/h. However, speed limits do not always give indications of the operating speeds along roads. The 85<sup>th</sup> percentile speeds were obtained from the Western Cape Province Department of Transport and SANRAL's Comprehensive Traffic Observation stations. The results are shown in Table 1.

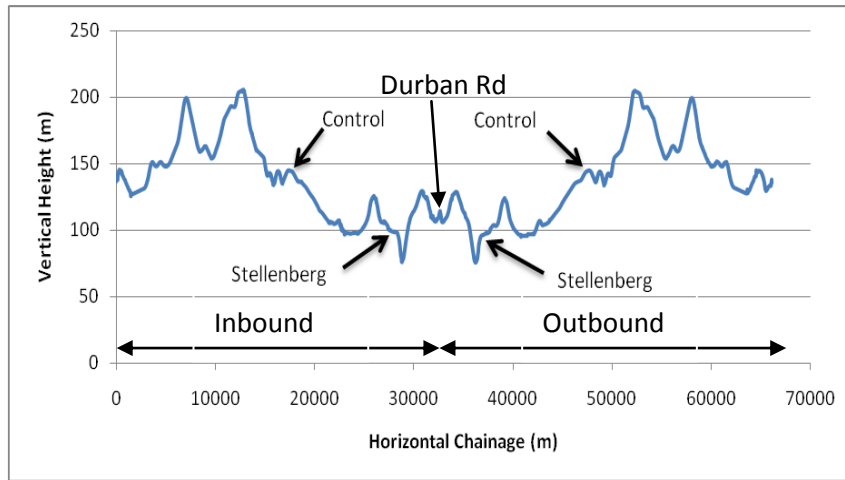
**Table 1:** Summary of 85<sup>th</sup> Percentile speeds (km/h) from different sources

	<b>Stellenberg</b>	<b>Control</b>
<b>Department of Transport</b>	125.2	127.8
<b>SANRAL</b>	123.9	121.9

The rounded value of 125 km/h was used in the study.

## 3. THE CURRENT GEOMETRIC PROPERTIES OF THE ROAD

The exact geometric properties of the road could not be found for the curve of interest or the control site, as the "As built" plans could not be sourced. The road geometry was then determined by the use of a GPS. The horizontal and vertical coordinates were tracked and stored in the memory of the GPS. This route investigation was carried out from the Paarl Interchange on the N1 to the Durban Road Interchange and then back along the same course of road to obtain the data for the inbound and outbound directions of both sites. This data was assimilated to generate a two dimensional plot using the horizontal distances and vertical elevations. The accuracy of GPS systems in the vertical dimension (elevation) is accepted to be poor in general, but the high frequency of readings (1 per second) results in lines and curves that can be smoothed out to give good relative elevations, from which the alignment can be interpreted.



**Figure 1:** Long Section Plan of route taken by GPS

The inbound direction was used to establish the K-values at both sites.

In order to evaluate the geometric properties of the curve at the Stellenberg and control site, the relevant data (chainage and vertical height) were isolated from the dataset. The following graphs (Figure 2a and 2b) show the long sections of curves at both sites and also show a second order polynomial trend line used to calculate the K-value. This method is an approximation and is not proposed as accurate.

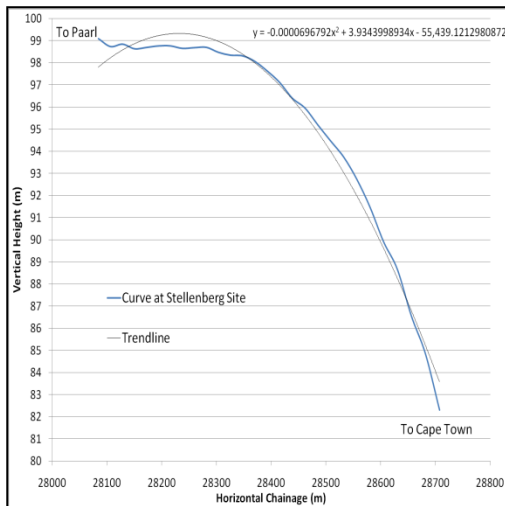
A second order polynomial regression line was fitted to the data and the equation of the line was determined in the form of a basic formula for a parabola, indicated below.

$$y = ax^2 + bx + c \quad (1)$$

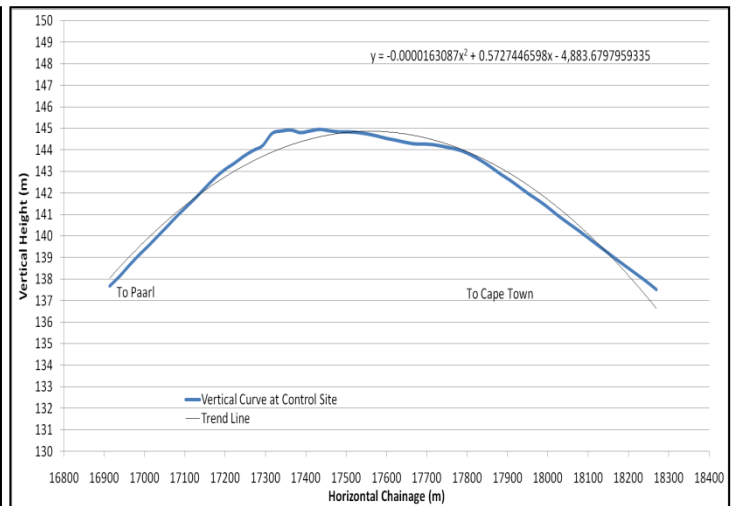
The K-value of a curve can be calculated from the constant value, [a], before the exponential term in the regression equation where,

$$a = \frac{1}{200K} \quad (2)$$

The K-value of both curves at the site of interest and the control site were determined via this method.



**Figure 2a:**



**Figure 2b**

**Figure 2:** Longitudinal Section of Vertical Curve at (a) Stellenberg Site (b) Control Site from GPS Data

#### K-value at Stellenberg Site

The value preceding the  $x^2$  term is equal to 0.0000696792. Therefore,  
 $1/(200K) = 0.0000696792$   
 $K = 71.8 \text{ m/\%}$

#### K-value at Control Site

The value preceding the  $x^2$  term is equal to 0.0000163087. Therefore,  
 $1/(200K) = 0.0000163087$   
 $K = 306.6 \text{ m/\%}$

The K-value of the curve at the Stellenberg site was found to be 72 m/%. Alternative reconstruction the vertical curve with assumptions of gradient difference and interpreted curve length gave a K-value as low as 50 m/%. The larger value was used in the analysis, but it is stressed that the actual curvature should be surveyed to design specifications if it is to be used in redesign of the road.

The K-value of 72 m/%, which is well below the 120 km/h design standard, provides evidence for the safety concerns of the crest vertical curve. The K-value is below the minimum recommended K-value of 180 m/% for crest vertical curves using an object height of 0.15 m and a design speed of 120 km/h, as well as the minimum K-value of 110 m/% required if the object height is 0,6 m. (SANRAL, 2002, p 4-27).

The control site has a K-value of 307 m/% which exceeds the minimum standard and can therefore be regarded as a safe vertical alignment for SSD at operating speed.

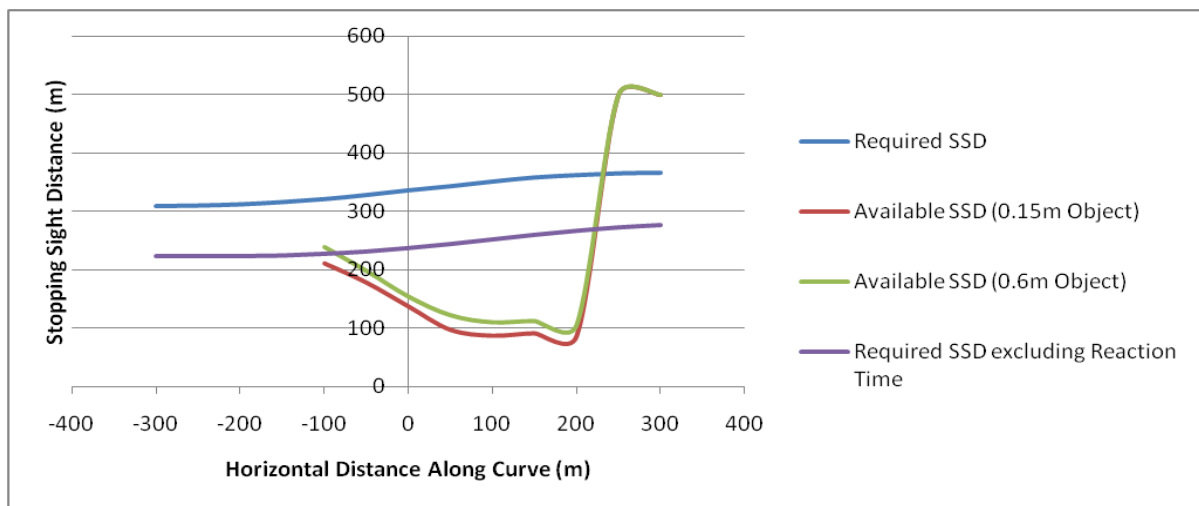
## **4. SIGHT DISTANCE**

The K-values used in design manuals are based on an assumption of Stopping Sight Distance (SSD) calculated for braking distance on a level road. This is not the worst case, as the braking can occur on a section where the average gradient of the braking distance is downhill. This is true in this case (which is referred to as a Type II crest vertical curve): the road has an incoming gradient which is practically level, but increases to an outgoing gradient of -8 %. By taking the average value of 4 % and the operating speed of

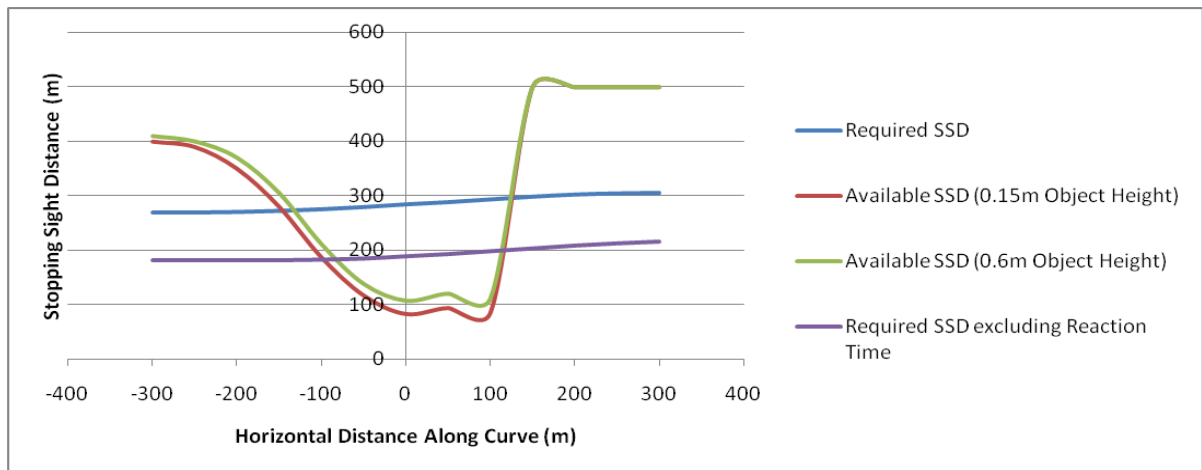
125 km/h, the required SSD increases to 320 m, 50 m more than the 270 m recommended for 120 km/h in Table 3.5 of the SANRAL Geometric Design Guidelines, 2002, p 3-16.

Required SSD was compared against available SSD to evaluate whether sufficient SSD was available for the entire length of the curve. The SSD checks were performed at 50m intervals along the curve in both the inbound and outbound direction. The required SSD checks were performed with the use of a Java computer where the user defines certain required information relating to braking distance and vertical curve theory. The method followed was according Taignidis, I., & Kanellaidis, G. (2001) in the article "Required stopping sight distance on crest vertical curves".

The following graphs (Figure 3 and Figure 4) show the Stopping Sight Distance at different intervals along the curve for the inbound and outbound directions respectively. A sight distance of 500m is taken as unlimited sight distance in order to plot the graph. From the graphical representation, it is clear exactly where sight distance problems are evident as well the extent of the problem. The 0 reference point was taken at the start of the vertical curve as interpreted from the graphs of vertical alignment.



**Figure 3:** Comparison of SSD's along the curve in Inbound Direction



**Figure 4:** Comparison of SSD's along the curve in Outbound Direction

The results obtained from the investigation show that a Stopping Sight Distance problem is evident along certain positions on the curve. Both the available SSDs, with an object height of 0.15 m and 0.6 m respectively, failed to meet the safe distances specified by the required SSD's at certain intervals along the curve. The K-value of the curve is therefore confirmed as unsatisfactory as insufficient SSDs are evident for both object heights in both directions of travel. The figures above also show the required SSD with the exclusion of reaction time. The results reiterate and emphasize the theoretical safety concerns with this section of freeway which could be seen graphically in the previous figures. This illustrates the fact that no matter how quick a driver's reaction time, there are still sections of the curve where the driver would be unable to stop if an object was sighted, resulting in a collision or a near miss event.

## 5. COLLISION DATA

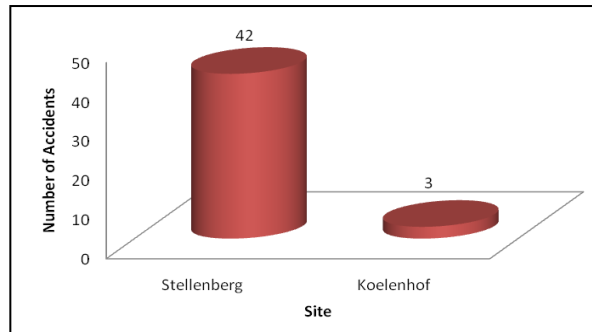
Collision data for the Stellenberg site was compared to the control site to illustrate the nature of the problem. The comparison is an oversimplification, as the queuing in peak periods, that is critical at the Stellenberg site, does not occur at the control site.

Two sources of collision data, namely, the Cape Town Freeway Management System (CT FMS) as well as the Provincial Government of the Western Cape (PGWC) were available. However, after a comparison of the results from both sources, the data provided by the PGWC indicated significant levels of missing data and therefore all data received from the PGWC was excluded from the investigation. Therefore only collision data obtained from the TMC was analysed for this project. Both locations are covered by the TMC and have the same duration of data (17 months). Although this timeframe is short, the conclusion of an unsafe situation at the study site is appropriate in view of the large difference in collisions recorded between the Stellenberg and control sites.

The traffic flows at the two sites were considered to allow for different exposures. As the two sites are defined by the range of observation of the respective traffic cameras, the collisions cannot be converted to a rate per 100 million vehicle-km travelled but could be converted to a rate per 100 000 vehicles. The respective average daily traffic flows were 50 405 (4 546) (2011 figures at CTO station 970) and 42 400 (3 800) (proportional: based on the 2004 counts, which was the last count at CTO station 618) vehicles per day and in the 30<sup>th</sup> highest hour (in brackets). These numbers were considered as of the same order

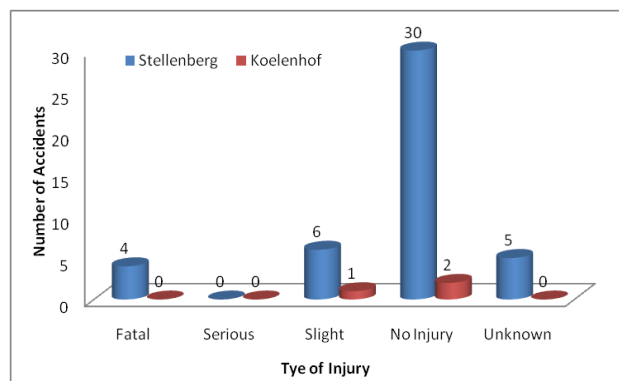
of magnitude and the subsequent analysis used the number of collisions in the 17 month period as such.

The total numbers of collisions that have occurred at the site of interest is significantly greater than that of the control site. For the Stellenberg site, the TMC recorded a total of 42 collisions from the 01 April 2010 until the 31 August 2011, whereas only 3 collisions were recorded at the control site at Koelenhof in the same time period. (This latter number would rise to 4 collisions as adjusted for exposure based on traffic flow).



**Figure 5:** Number of collisions occurring at Stellenberg and control site In 17 month period

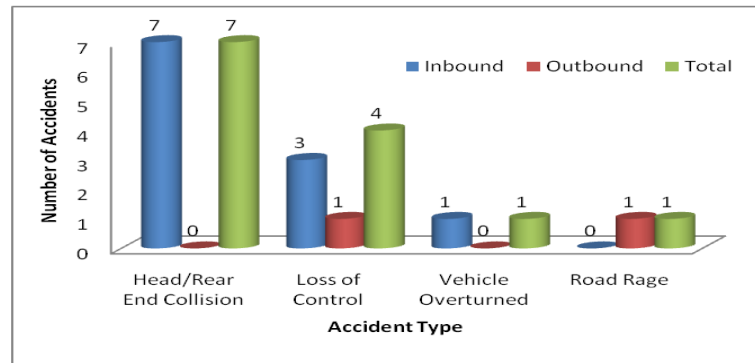
It is clear from the graph that there are significantly more collisions recorded at the Stellenberg site. The number of collisions at the Stellenberg site is more than 10 times greater than the number of collisions occurring at the Koelenhof site. This statistic clearly illustrates the safety concerns of this section of freeway. The injury severity of collisions was examined and compared between the two sites. The following graph shows a breakdown of all types of injuries occurring at both sites.



**Figure 6:** Types of injuries resulting from collisions

Four of the collisions occurring at the Stellenberg site resulted in a fatality. By comparison, there were no fatal collisions at the control site which suggests safer driving conditions. Records also show significantly more slight injuries as well as no-injury collisions that have occurred at the Stellenberg site compared to that of the control site. This further highlights the safety concerns of this section of road.

The data regarding collision type indicated that more than half the collisions that occurred at this site were head/rear end collisions. This is the dominant type of collision occurring at sections of road with insufficient stopping sight distance (Mullins and Keese, 1961).



**Figure 7:** Types of collisions occurring at the Stellenberg site for 17 month period

## 6. INTERPRETATION OF RESULTS

The analysis of the section of freeway at the N1 / R300 Stellenberg Interchange indicated that the existing K-value to be 72 m/% or less. This was compared to the minimum recommended K-value of 180 m/% in the Geometric Design Guidelines (SANRAL, 2002) for a design speed of 120km/h. The available SSD along the curve was significantly lower than the SSD required at the operating speed of 125 km/h.

Collision data was analysed for the section of road with the curve and compared with data from the Koelenhof site where the K-value of the curve was satisfactory. The Koelenhof Interchange represents safer conditions than the site at the Stellenberg Interchange. The Stellenberg Interchange showed a greater number of collisions (42) compared to the site of the Koelenhof Interchange (4) in the 17 month period under consideration. When looking at the severity of all collisions occurring at the two sites, it is clear that more collisions result in injury at the Stellenberg site and the severity of collisions at this site is greater than the severity of collisions occurring at the control site. Therefore a safety concern is evident at the section of the N1 at the Stellenberg Interchange.

The difference between the two sites is that the Stellenberg section is substandard, *inter alia* as the Type II vertical curve with braking on a down grade requires more SSD.

## 7. CONCLUSION

This investigation highlights a safety concern of Type II crest vertical curves in general. The SSD should be checked and the K-value adjusted if the braking distance would be on a significant downward incline.

The study investigated a vertical curve situated on the N1 at the Stellenberg Interchange. It was found that the K-value (72 m/%) is significantly lower than the recommended minimum K-values, according to the Geometric Design Guidelines (SANRAL, 2002). The minimum recommended K-value for a design speed of 120km/h and an object height of 0.15 m is 180 (110 m/% for object 0,6 m). (Geometric Design Guidelines, 2002, p4-27).

Stopping Sight Distance along the curve (170 to 100 m) is lower than what is actually required (320 m) in order for the driver to sight an object and implement a safe stop.



Collision data for a 17 month period at Stellenberg (42 collisions) compared to the control site at Koelenhof (4 collisions) verify the safety concerns. The curve at the Koelenhof site meets vertical curve standards. The types of collisions occurring at the Stellenberg site show a majority of head/rear end collisions which confirms the inadequate Stopping Sight Distance along the curve.

It is concluded that the substandard vertical curve at the Stellenberg site is a major contributory factor to the number of collisions occurring at this location. The redesign and reconstruction of this vertical curve is therefore required in order to achieve a K-value that corresponds to the standards set by the Geometric Design Guidelines.

## **8. RECOMMENDATIONS**

It is recommended that the speed limit of this section of freeway be reduced to 100km/h in order to decrease the required Stopping Sight Distance along the curve. The speeds along this section of freeway should also be managed by erecting a visible speed camera on the section of the curve to ensure that drivers do not exceed the speed limit. This is seen as an interim measure.

The existing K-value of the curve at the Stellenberg site is less than 72 and therefore a reconstruction of the curve is required in order to increase the K-value and achieve safe SSD at the desired operating speed.

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