

STUDENT UNDERSTANDING OF SIGHT DISTANCE IN GEOMETRIC DESIGN:

A BEGINNING LINE OF INQUIRY TO CHARACTERIZE

STUDENT UNDERSTANDING OF TRANSPORTATION ENGINEERING

BY

BROCK TAYLOR ANDREWS

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of  
BROCK TAYLOR ANDREWS find it satisfactory and recommend that it be accepted.

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Shane Brown, Ph.D., Chair

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Libby Knott, Ph.D.

---

Shihui Shen, Ph.D.

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Abstract

By Brock Taylor Andrews, M.S.  
Washington State University  
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Chair: Shane A. Brown

While many students demonstrate considerable aptitude in manipulating equations and variables within academic environments, research consistently shows that they lack a construct called conceptual understanding, which accounts for their difficulties in choosing appropriate equations, or understanding basic phenomena that undergird such equations.

This study investigates undergraduate understanding of sight distance and stopping sight distance in introductory transportation courses. Although sight distance and stopping sight distance are fundamental concepts in transportation engineering, students demonstrated considerable difficulty in their understanding of these concepts, often relying on previous experience or preferred equations without relating them to specific phenomena of interest. This paper concludes with suggested approaches to improve student conceptual understanding for transportation engineering educators.

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## **Dedication**

This dissertation/thesis is dedicated to my mother and father  
who provided both emotional and financial support

# CHAPTER ONE

## INTRODUCTION

Student understanding of engineering and the underlying physical sciences is a topic of increasing interest to engineering educators. Recent research indicates that despite high passing rates in most universities, many students do not comprehend science-course content in a deep or meaningful way [1-7]. A report from the National Research Council has identified this lack of deep understanding (also called conceptual understanding) as a high-priority problem facing Science, Technology, Engineering, and Mathematics (STEM) industries, educators, and researchers. Although conceptual understanding is vital for applying science or math to real-world problems, research on student understanding of engineering subjects is nascent. To address this problem, this study investigated students' conceptual understanding of fundamental geometric design concepts.

Although geometric design is typically only a small subset of material present in most introductory transportation engineering courses, it plays a significant role in comprehension of transportation engineering fundamentals. Concepts of geometric design that transportation engineering students need to fully understand include sight distance, stopping sight distance, and design of horizontal and vertical curves, elements common to all streets, roads, and highways [8]. Sight distance is defined as the length of the roadway ahead that is visible to the driver [8]. AASHTO classifies stopping sight distance as, "The sum of two distances: the distance travelled by the vehicle from the instant the driver sights an object necessitating a stop to the instant that the brakes are applied, and the distance needed to stop the vehicle from the instant brake application begins" [8]. Highway curve design should focus on ample sight distance as well as appropriate relationships between curvature and design speed. The focus of this research was to



evaluate conceptual understanding of these fundamental geometric design concepts via demonstration interviews with eighteen students from two public universities.

## CONCEPTUAL UNDERSTANDING

While there is no universal definition for the phrase “conceptual understanding,” Margolis and Laurence [9] describe it as an understanding of the phenomena underlying a calculation, including the context, purpose, necessary assumptions, and range of reasonable values expected. Therefore, conceptual understanding of a topic can generally be described as ‘useful knowledge’ of that subject, where ‘usefulness’ of knowledge aims at characterizing how able a person is to apply that knowledge to a context outside of which it was learned [10]. While students’ computational abilities have been shown to develop with quantitative problem-based homework, lectures, and exams; conceptual understanding is more difficult to develop and assess. Research shows that many students who do well in their courses and on standardized exams are not able to explain fundamental phenomena or answer qualitative questions about them [2-3, 7, 9, 11].

The constructivist stance, on which most contemporary educational research is founded, assumes that individuals use the interpretation of their life experiences to construct their own understanding of the world. Previous research has shown that the application of life experiences to conceptual understanding is not always easy. In their study of physics students’ conceptual difficulties, for example, Lising and Elby (2005) described students who were unable to apply “real life” knowledge based on experiences to problems encountered in the classroom or lab. They attributed this to an epistemological belief in a division between “real world” knowledge and academic knowledge [12]. Hammer (1994) similarly argues that students may have different beliefs about where valid knowledge comes from, and may naturally discount life experiences

[13]. Little research examines how engineering students' life experiences affect their conceptual understanding, despite the applied nature of math and science in engineering disciplines.

### **PREVIOUS RESEARCH ON CONCEPTUAL UNDERSTANDING**

Systematic investigations by Evans et al., (2003), Hake, (1998), and Halloun & Hestenes, (1985), relied on multiple-choice concept inventories to assess conceptual understanding [2-3, 14]. The primary goal of employing concept inventories is to evaluate whether a person has a succinct and accurate working knowledge of a particular set of concepts [15]. These concept inventories present students with conceptual questions containing the correct answer as well as common distractors; incorrect answers based on common student views. Halloun and Hestenes (1985) developed the first of these instruments, called the Force Concept Inventory (FCI). Here, the FCI was used to investigate freshman knowledge of the most basic introductory physics concepts [3]. Because most students were able to successfully perform Newtonian-based calculations on their homework, Halloun and Hestenes expected near-perfect results on the FCI. Surprisingly, FCI results showed that most students did not truly understand fundamental concepts covered in their STEM courses. In addition, students consistently preferred non-Newtonian based explanations for common physical phenomena, as “students’ initial qualitative, common-sense beliefs about motion and causes have a large effect on performance in physics, but conventional instruction induces only a small change in those beliefs [3].” Instructors often encounter this distinction when students who are successful at performing complex calculations in their homework cannot answer ostensibly simple questions about the nature of the topic studied [3].

In the field of engineering education, the FCI methodology and findings inspired the Foundation Coalition (2008) to develop concept inventories in 13 different areas, including

strength of materials, statics, fluid mechanics, chemistry, and heat transfer [16]. Preliminary results from the engineering-specific fields of statics and thermodynamics imply that student conceptual understanding of engineering topics is as low as observed in other STEM areas [6, 17].

Dr. Lillian McDermott and David Trowbridge created the Physics Education and Research Group (PERG) to explore how introductory physics students think about kinetics and kinematics [15]. Kinematic and kinetic concepts, like motion, speed, acceleration, and forces that cause motion, are major concepts taught in high school and introductory college level physics courses. Using the individual demonstration interview as the primary data source, PERG researchers identified specific problems that students had with these concepts. PERG researchers conducted one-on-one demonstration interviews with students using motion tasks developed by Piaget to explore how introductory college physics students think about kinematics [18]. Interviews were centered on eliciting verbal responses from students to characterize and describe their thought process while problem-solving.

While the demonstration interview-based research conducted by McDermott and PERG was originally motivated by a strong desire to increase student comprehension in introductory physics, this approach also works well in other more advanced science-based courses [19]. A primary goal of our research is to investigate the level of student conceptual understanding of two primary geometric design criteria: sight distance (SD) and stopping sight distance (SSD) through the use of demonstration interviews.

## **PURPOSE OF STUDY**

This study is the first investigation of students' conceptual understanding of fundamental concepts in transportation engineering, and aims to ultimately improve engineering education.

This study builds upon extensively validated research methodologies identified as critical by the National Research Council, and is funded extensively by the National Science Foundation. Because of the lack of research on how to improve engineering student's conceptual understanding of transportation engineering, their existing understanding must first be evaluated. As exemplified by previous work [15, 19-21], the in-depth demonstration interviews required for this type of investigation are most effective when focused on only a few concepts. Since sight distance (SD) and stopping sight distance (SSD) are central to many aspects of transportation engineering, those these related concepts were chosen as the focus of the interviews.

## **CHAPTER TWO**

### **RESEARCH METHODS**

In order to discover and thoroughly characterize student's conceptual understanding of these concepts, qualitative interview and analysis methodologies were employed. Qualitative methods allow us to explore and describe in detail students' understandings and mental frameworks in transportation engineering. Qualitative research is often defined as being concerned with the meaning and the processes underlying phenomena, as opposed to a quantitative means of counting or measuring their existence [22-23].

#### **SAMPLE SELECTION**

Participants in this investigation were enrolled in the spring 2009 semester of Introduction to Transportation Engineering at Washington State University or the University of Idaho. When combined, both courses enrolled roughly 100 students. Both classes are introductory undergraduate courses that include 2 to 3 weeks of coverage per semester on

geometric design topics. Instructors of both courses covered geometric design content roughly three weeks before student interviewing began.

Similar to quantitative studies' use of random sampling to avoid bias in their analyses, qualitative studies use purposeful sampling to ensure that the data collected will be meaningful [22]. The term "critical case" refers to an individual or group that, when studied, can shed light on the status of the context or system they are in. It is important to note that critical cases are not meant to be representative of the population they are taken from. Instead, they are groups or individuals positioned in such a way that a description of them also describes some aspect of the larger population. In our case, the purposeful sample, or critical case, was students across academic achievement levels in an introductory transportation course.

Eighteen students participated in this study, all on a voluntary basis. Instructors of both courses provided a list, including only students with a course grade of C or better, that ranked students by, but did not include, course grade. Course grade was fairly well distributed in the sample, with six students in the upper third, seven in the middle, and five in the lower third. Participants were purposefully chosen to represent a range of academic achievement, which allowed for direct inferences to be made about the larger population. Sample selection was done by the research advisor (Shane Brown) and student information not shared with the primary researcher (Brock Andrews) to avoid bias during the interviews and data analysis.

## **DEVELOPMENT OF INTERVIEW MATERIALS**

Interview materials included the protocol and geometric design problems. These problems included typical homework-like problems as well as open-ended design-type problems. Three civil engineering professors who had taught the introductory course within the last year at WSU or UI reviewed all problems and helped identify concepts needed to solve the problem,

noted misleading aspects, and provided suggestions for refinement. From an initial pool of 25 questions, 9 were chosen to maximize question-to-concept mapping on SD and SSD topics. Questions in the interview protocol were carefully structured to encourage discussion and gain insight into students' thought processes [24] in the application of fundamental concepts of geometric design [19]. All participants were presented with the same set of interview problems and interview questions, as summarized below in Table 1. Some questions only warranted verbal explanations (e.g., Questions 1-3), while others were accompanied by figures. These typically asked students to discuss their thought processes regarding SD and SSD as well as to perform calculations (e.g., Questions 7 and 9).

**TABLE 1: Summary of Interview Problems and Questions**

Problem	Figures	Interview Questions:	Key Concepts	
			SD	SSD
#1		What is geometric design? What does geometric design mean to you?	X	X
#2		What comes to mind when you hear the term 'sight distance?' How is the concept of sight distance used in highway design?	X	
#3		Explain the term 'stopping sight distance.'		X
#4	Diagram showing two unconnected tangent roads	How you would design a horizontal curve to connect the tangent roadways?	X	X
#5	Diagram showing a vehicle traveling through a horizontal curve, with an obstruction near the end of the curve	How would you determine the driver's reaction time? Does reaction time vary from driver to driver? Does the stopping sight distance changes from driver to driver? Does the obstruction affect the driver's reaction time?		X
#6	The same horizontal curve as #5 was presented, except a building was introduced inside the curve, blocking the driver's view of the obstruction at the end of the curve.	Predict if the driver's SSD would change from #5? If so, is it larger or smaller than the SSD in problem #5?	X	X
#7	A different diagram of a horizontal curve, where a house inside the curve created a sight restriction for the driver.	How would you calculate the driver's SSD? What variables would be useful to know in a SSD calculation? If the horizontal sight offset=6 meters, and the radius=350 meters, can you perform a calculation for the driver's SSD? If vehicle velocity=110 km/hr, R=350 meters, HSO=6 meters, can you determine if this curve is safe for the driver at the given design speed?	X	X
#8	Diagram of two unconnected, non-parallel roadways	How would you connect the two roadways with vertical curve(s)?	X	X
#9	Two similar diagrams were used. The first showed a small passenger car traveling over a crest vertical curve with an obstruction near the end of the curve. The second showed a larger semi truck at the exact same curve location as the passenger car, with the same obstruction location as well.	Predict which vehicle would have the greater SD. What variables affect SD? Calculate the SD for the passenger car and the semi-truck if values for driver height, obstruction height, curve length, and tangent grades are provided? Did you predictions match your calculations?	X	
End of interview		TOTAL COVERAGE	9	11

## **INTERVIEW PROCEDURE**

Following McDermott and PERG, the interviews were based on Piaget's clinical interviewing methods [15] with the goal of characterizing conceptual understanding of SD and SSD. Typical clinical interviews are reflective and slow. Instruction is rare, and judgment on subject's responses is withheld [10]. The tone of the interview was largely casual and informal, with sufficient process time between question and response for both the interviewer and interviewee to reflect [10, 15, 19]. Students were encouraged to think out loud, write down affirming statements, and clarify any questions. The interviews were audio-recorded for later transcription, and lasted approximately 30-45 minutes.

In clinical interviews, probing questions are critical, because the interviewer cannot guess what the participant knows or how that knowledge is organized. These probing questions further elucidated students' understanding of geometric design. The order and timing of verbal questions were organized to facilitate this exploration. In this way, while clinical interviews are less developed, rationalized, and codified compared with their familiar quantitative counterparts, they still offer valuable techniques as a means of scientific data collection [15, 25-27].

## **DATA ANALYSIS**

Student interviews were audio-recorded, and interview packets were collected to record student notes, sketches, and calculations. In the first stage of analysis, the primary researcher (Brock Andrews) read through the transcripts multiple times while coding pertinent student statements. This process was slow; as organizing data into categories, collecting new information, and comparing new information with previously materialized categories required a substantial amount of time. Analysis in this manner followed an interpretive perspective, where



data reduction was focused on addressing the beliefs, views, and assumptions held by the participants.

This qualitative analysis relied on an iterative process of coding, or labeling, and categorizing data. Each iteration of coding involved more interpretation than the last. The first codes are groups based entirely on types of things that were said. Examples of first-pass codes are *Road Conditions*, which labeled any student comments about road conditions, and *Homework*, which labeled any references to previous homework. The next set of codes, and each iteration after that, grouped the previous level of codes while refining them and looking for internal consistency. Codes that were found not to refer to student beliefs and understanding were also eliminated at each stage. By the end of the analysis, 25 codes were reduced to 3 primary themes. Instead of representing ideal knowledge, the goal of the methods employed in this research was to determine what the participant knew, and how that knowledge influenced the way they reasoned and solved problems [25].

While coding, it was important to distinguish statements indicating mature understanding from those demonstrating weak conceptual development. Responses indicating mature understanding tend to be internally consistent, consistent with observable phenomena, and can be used in communications with others in the discipline [23]. Because experts in transportation engineering (represented in this study by engineering faculty at Washington State University and the University of Idaho) share internally and externally consistent knowledge structures of transportation engineering, experts' understanding was used as a guideline in examining students' understanding.

The applicability of results to the sample from which the participants were drawn depends on data saturation. Saturation occurs when in the analysis of an interview, no new codes

or themes are found in addition to those in the previous interviews analyzed. In other words, regardless of the order of analysis of the interviews, the codes generated during analysis of the first interviews were sufficient to completely characterize the final few interviews.

## **CHAPTER THREE**

### **RESULTS**

Three of the 18 students interviewed performed exceptionally well on all aspects of the interview and displayed conceptual understanding of SD and SSD. These students were also had the highest course grades. These students correctly linked their personal experiences with the concepts of SD and SSD, correctly defined SD and SSD, identified relevant variables in the open-ended questions, and answered all the calculation-based questions correctly. The results presented below largely describe the remaining 15 students interviewed. Of these students, there was no relation between course grade and interview performance.

#### **PERSONAL EXPERIENCE**

Individual driving experiences played a crucial role in how students thought about geometric design criteria. Some students were able to capitalize on personal experiences, linking them successfully to their conceptual framework of geometric design. Most students indicated they had felt the negative affects centripetal acceleration has on the driver, with comments such as, “You wouldn’t want to experience one of those roller coaster feelings. That’s the thing with vertical curves.” Students openly discussed personal experiences with environmental factors and how they influenced braking distance, “Obviously, if the roadway is in ideal conditions (dry, smooth surface), it’s going to be safer than a wet, slippery surface, or icy, or if its gravel. There’s

going to be a higher chance of the brakes sliding.” This participant went on to link his own driving experiences to SSD, “...If it’s snowing and it’s really slick out, and you think that you’re fine but really you’re not, you have the same reaction time, but the distance that it actually takes your car to stop is going to be greater than what you think it’s going to be in normal conditions.”

Unfortunately, other students failed to connect their unique driving experiences to the information they had been presented with while discussing fundamental geometric design criteria. Often, these students struggled to differentiate SD from SSD, which will be discussed more thoroughly in the following sections. These students had ample opportunities to form their own understanding of both SD and SSD, whether in class, on homework and tests, in the interview, and from their personal driving experiences. Yet they consistently reverted to their initial preconceptions of SD and SSD, often erroneously combining both views into one concept. They were unsuccessful in providing proper definitions of SD and SSD, even though their personal experiences told a different story.

For example, when asked, “What comes to mind when thinking about sight distance?” one student responded, “Sight distance? Um, let’s see. Stopping sight distance usually comes to mind.” When further probed to discuss how transportation engineers use the concept of SD in highway design, they continued to define SD in terms of SSD: “I don’t know much more than what I just said. It’s used to kind of find the distance you can safely stop...and you set a posted speed based on that.” Although they were confused about the distinction between SSD and SD, later in the interview she drew upon her personal experiences traveling over vertical curves to illustrate the importance of SD in highway design:

“I’d want to feel comfortable...And that, I forget what the value is, but the wide open clearance....The drivers won’t feel comfortable maneuvering the curve if they can only see 20 or 30 feet in front of them with stuff in their way.... Definitely stopping sight distance comes into play in night and day.... If you’re sitting here [at the crest of a vertical curve], you can see the bottom of the curve during the day, but at night you won’t be able to see that.”

By requesting a wide open clearance, she infers that ample sight distance will make drivers more comfortable. In general, this notion is correct. When discussing differences in SSD during night and day, she clearly used her experiences while driving at night to shape how they thought SSD and SD played into vertical and horizontal curve design. Yet the distinction remains in that, with all their experience, they failed to adequately separate and compartmentalize her understanding of both SD and SSD. By trying to combine the two concepts, she limits her potential understanding of either.

In another example of how students combine SSD and SD into one concept, the interviewer asked “What comes to mind when you think of sight distance?” One student answered, “I think how far ahead of me I can see an object. Like if there’s a rock in the road, how far ahead of me I can see that object and be able to react to stop.” The interviewer then asked, “So what about stopping sight distance then? What does that mean to you?” and the student responded “Um, the same.” While he went on to generally describe SSD and what variables would be useful in a calculation, he progressed through the interview believing that SSD was the same as SD. Yet, within the context of personal experiences, it was obvious that he had observed how vehicle height affects SD and not SSD:

“It depends on how tall your vehicle is... because each person when they sit in the vehicle...when you’re sitting in a Corvette, you’re really low to the ground. And if you’re in a semi, you’re up high, and you’re going to be able to see the obstacle sooner.”

It is interesting that the students quoted above, as well as a few other participants, could not adequately answer the questions “What is sight distance?” and “How is sight distance used in highway design?” Yet they consistently referenced the importance of providing ample SD during discussions of their personal experiences of driving over vertical curves or through horizontal curves (either at night or during the day). Clearly, some students preferred to think of SD and SSD within the conceptual framework they have created based of their personal driving experiences. However, other students disregarded their personal experiences as drivers, displaying considerable misunderstandings about SSD and SD. In any roadway design scenario, it is essential to provide more SD than SSD. In this manner, cars should ideally be able to stop before hitting any obstructions warranting stoppage [8]. If students fail to distinguish SD from SSD, how are they able to meet this fundamental requirement? Extensive research investigating conceptual understanding consistently shows that without directly addressing these misunderstandings, there is little opportunity for students to independently resolve their confusion between SD and SSD [19-20, 28].

### **EQUATIONS OUT OF CONTEXT**

Although the development of the interview protocol was focused largely around maximizing verbal responses to questions based on geometric design criteria like SD, SSD, and curve design, a few calculation-based questions were also included. The combination of questions warranting verbal responses with calculation-based problems followed the

methodology used in the vast body of research conducted to investigate conceptual understanding of STEM courses like physics, thermodynamics, and calculus [3, 15, 21, 28]. By offering both verbal and calculation-based options, students who were more comfortable talking about geometric design criterion had the same opportunities to justify their knowledge as the other students who preferred working in terms of calculations. From the analysis and coding of the student interviews, it became evident that some students demonstrated considerable difficulty in both solving problems and verbalizing definitions for SD and SSD. Often, these students were incapable of solving calculation-based problems.

While this was not surprising--it was expected that not *every* student would be able to perform all the calculations successfully--what was unforeseen was a tremendous reliance on equations and previously performed homework problems to solve unfamiliar problems. PERG investigations of student understanding of the concepts of velocity and acceleration in one dimension found that many students were unable to acquire a working understanding of such concepts even when they had memorized the relevant formulas. Even in simple physics problems, these students chose equations based on convenience instead of meaning, and had trouble discriminating between the concepts of velocity and acceleration [15]. The same dependence on equations out of context and subsequent lack of problem-solving capabilities was observed during our interviews.

### **EQUATIONS AND VARIABLE REQUESTS**

As previously discussed, many students struggled through calculations on the interview protocol. An equation sheet with three equations and definitions of variables was provided to all participants. These equations encompassed the calculation-based questions and could be utilized

to solve all questions on the interview protocol. These equations were also directly from the coursework in the Introduction to Transportation Engineering courses, in which all participants were enrolled. While the calculations typically involved solving for either SD or SSD values, there were no unfamiliar concepts incorporated into these questions.

Even with equations provided, it was common for students to ask for additional variables and equations. A few students even requested charts or tables before they could determine answers for these calculation-based problems. Of these three requests (equations, variables, and tables/charts), it was most common for students to justify their inability to perform calculations because an equation they had used previously was not provided, for example, “If I remembered ... like, the equation, I’d probably be able to figure it out... but I really don’t remember.” Again, the provided equation sheet could have been used to solve the question the student was facing.

When asked to solve for SSD, it was typical for students to immediately revert to equations they had used previously in homework or in class:

Interviewer: You can see in this picture that the driver is travelling along a horizontal curve, and he notices the obstruction ahead. Can you discuss the stopping sight distance?

Student: Oh, I feel like I’m not very good at equations.

Interviewer: That’s okay.

Student: There’s an equation that gives you your reaction time, your perception time. Oh, yeah, there were a few equations.

Later, when asked to discuss how she would actually perform a calculation for the SSD, this student gave a similar answer:

Student: Um, OK, let's see. I don't really remember. I know you would need, like, the length....Oh. I think you would need, ...I don't really remember the equation. I know there's, like, your perception time to react...I can't remember very well....I think I'm doing it wrong.

Interviewer: That's okay. You can walk me through what you're thinking.

Student: OK, well, I wasn't sure if...See, I feel bad because, like, I don't remember if this is the equation we used in class.

This interaction again suggests that this student was evaluating the usefulness of equations based on unproductive criteria. She was prevented from moving forward in problem-solving, even when provided with the pertinent equation, because she was unsure if the equation provided was "used in class." Reliance on out-of-context equations heavily influenced how another participant thought about a different problem, "I would think that stopping sight distance and the radius of the vertical curve were interconnected. But I can't remember the equations for those."

Surprisingly, given the fact that students seemed to apply equations to problems somewhat haphazardly, many considered equations as central to their understanding of SD and SSD. For example, one student was asked to "discuss the stopping sight distance. How would you determine the reaction time?" He responded, "Well, there's a standard reaction time, obviously you will have... I haven't really seen any equations for this type of scenario. But I thought it was based on a straight line...Yeah. I remember, like, there's a table where you can go find road conditions, so you can look up and find the concept and equations, stuff like that." This student's first reaction to the problem was uncertain, indicating that he didn't have a clear understanding of the problem or question. It was unlikely that a table providing both the



“concept and equation” existed, but it was interesting that this student expected to be able to look up a form of conceptual understanding in a table.

Without sufficient concept development, students are left to solve problems based on a few variables they vaguely remember from such equations. It is not surprising, then, that these three participants could not calculate SSD when presented with a situation and provided equations. As these students demonstrated, poor conceptual understanding of SD and SSD in conjunction with partially memorized equations makes solving new problems very difficult.

### **PROBLEM RELIANCE**

While these three students unsuccessfully incorporated equations into their conceptual framework of SD and SSD, other students shaped their understanding of geometric design criteria around problems they had previously calculated in class. If an unfamiliar, calculation-based problem was presented (as in Questions 7 and 9), these students labored to compute acceptable answers. They often requested additional variables, like those in their homework or test problems, before setting out to solve the new questions from the interview protocol. Further, students who requested additional variables often had no validation for why they would be important in such a calculation:

Interviewer: ...So how would you determine the stopping sight distance?

Student: You obviously want your radius or length there. And I know you can work between those two...., I think your inside angle would probably be helpful.

Interviewer: Why is that?

Student: Because that might help you to determine...I don't know...I'm trying to remember the equation for it.

It seems that even if a value for the inside angle was provided (as this student requested), they would still strain to obtain an answer for this problem as he had no justification for why it would be important to know the inside angle value, and further, no equation to plug it into. He just knew that it should be provided, likely because the problems he had previously calculated in class provided this value. In a different interview, variable requests again controlled the student's ability to solve for the SSD. While talking through the problem, he reasoned:

“Ok. So the R [Radius]. Might use this... I have R. And HSO [Horizontal Sight Offset]...so, looks like I'd be able to calculate the SSD...from using this equation. Actually... Well, SSD....from what I've done in the homework, I always calculated the SSD and then I got the HSO from that. So, take that back. I won't be able to calculate it [the SSD]. I want the speed first.”

Even when the speed was introduced in the next section of this problem (7c), this student was unable to solve the problem and make predictions as to whether the horizontal curve was safe for the driver. As the interviewee inferred, because this problem was not like the one's he had performed in his homework, (“I always calculated the SSD and *then* I got the HSO from that”), he concluded that he couldn't calculate the SSD.

The participants quoted above had very poor understandings of SD and SSD. They thought of SD and SSD as a singular concept, wrongly combining both into one view within their conceptual frameworks. Without adequate understandings of what SD and SSD are, as well as how they differ, these students showed they were incapable of calculating answers for questions 7 and 9. As they demonstrated, weak conceptual development of SD and SSD provided

little opportunity to think about the problem critically. Because they lacked the ability to draw upon their knowledge of SD and SSD (thus differentiating them and applying them to contexts outside of those presented in class), they were left with few problem-solving options. Thus, many students immediately began solving new questions with reliance on tables, charts, equations, or problems they previously had encountered or remembered. As they found out, without providing these elements, they lacked the ability to determine reasonable answers.

### **SD VERSUS SSD**

While it seems problematic that some students demonstrated poor computational abilities based on their heavy reliance on equations, previously calculated problems, or personal experiences, students displayed some correct understanding for some other questions in the interview protocol. Every participant was asked the same set of three questions designed to gain insight into their thought processes regarding variables that affect SD and SSD.

The first of these questions asked the interviewee to explain perception reaction time and discuss whether reaction time changes from driver to driver or if remains the same. AASHTO considers reaction time as, “The interval from the instant that the driver recognizes the existence of an obstacle on the roadway ahead that necessitates braking to the instant that the driver actually applies the brakes” [8]. Of the 18 students interviewed, 15 correctly believed that reaction time would vary from driver to driver. Often, their answers were based on age, eyesight, and driver awareness, and how those differences affected reaction time:

Interviewer: So you mentioned reaction time being an average. So does that ever vary from person to person or is it going to be the same from person to person?

Student: Um...a lot of times young people are able to stop or react within like a second.

A drunk driver takes 5 seconds. An old person takes 4 or 5 seconds. Or you can be on your cell phone and take 7 seconds. So there's a lot of variability there.

Still, two students believed reaction time was constant for all drivers. One said, "I guess it depends on what standards you're using. But I'm saying it probably, it should be the same [from driver to driver]." Another participant stated, "I, from what I've, from what we've went over in class it's just a standard. I don't know. Probably some kind of survey was taken on it." While AASHTO sets an average reaction time at 2.5 seconds in their highway design manual, this is only the most common amount of time it takes people to react, encompassing all possible reaction times [8]. It is an average, not a concrete standard. These students failed to think critically about reaction time. There is little doubt that they have encountered driving experiences where their personal reaction time fluctuated. If so, how would it be possible for *all* drivers to have the same reaction time, across *all* possible driving scenarios? Intuitively, it just doesn't make sense.

Another question that generated consistently correct answers asked students to predict whether every vehicle traveling through a horizontal curve would have the same SSD. Vehicle performance (braking mechanisms, deceleration rates), roadway conditions (wet vs. dry road surface, frictional requirements), and driver attentiveness (reaction time) are a few factors that dramatically change SSD from driver to driver [8]. Fourteen of the 18 interview participants predicted that SSD would change based on these factors. However, the remaining four participants failed to make the correct assumption. Here, one student requested an additional equation before forming an opinion on SSD:

Interviewer: Would the stopping sight distance change for different vehicles or is it

always going to be the same?

Student: My guess is that it would be the same, but I have to actually look at the equation for it.

Another student could not remember if SSD was incorporated into the design of horizontal curves, and therefore believed SSD would be the same from vehicle to vehicle:

Student: Well, I know that vertical curves have a little bit of a dimension of height. But as far as horizontal curves, I don't recall there being much of a change [in SSD] from one vehicle to the next. If there was, I forgot.

The last of these three questions asked the interviewee to make a prediction on available SD. Question 9 included two simple illustrations, as discussed in Table 1, and students were asked to predict which vehicle would have a larger SD. All students correctly stated that the truck would have a larger SD because the driver sits higher off the ground. After all participants made their predictions on available SD, they were then asked to calculate values for SD in the second part of this problem. From there, the participants discussed if their predictions matched their calculations for available SD. Although all 18 students made the correct assumption that the truck would have a larger SD than the smaller passenger car, only 13 students performed the calculation correctly. This calculation was straightforward, with all parameters provided except for SD, which was intended to be calculated. While problem-solving, one student explained his thought process, giving insight as to why some of these students may have determined incorrect SD values: "Well, it's just kind of hard. You know, like, usually when I do these kinds of homework problems, I have my books or notes in front of me. So I haven't committed a whole lot to memory.

## RESULTS SUMMARY

In order to loosely quantify the results from this investigation, profiles were created based on characteristics exhibited by students during the interviews:

**TABLE 2: Student Profile Characteristics**

Profile	Characteristics	Number of Students
Profile A	<ul style="list-style-type: none"> <li>-Proper definitions of SD and SSD</li> <li>-Personal experiences correlate with SD/SSD definitions</li> <li>-Capable of correctly solving all problems</li> <li>-Identified/outlined important design considerations in open-ended problems</li> </ul>	4
Profile B	<ul style="list-style-type: none"> <li>-Often correctly defined SSD, but struggled to define SD</li> <li>-Personal experiences correlate with SSD definitions</li> <li>-Equation reliance hindered ability to correctly solve <b>all</b> problems</li> <li>-Relied on personal experiences/problems to answer open-ended problems</li> </ul>	6
Profile C	<ul style="list-style-type: none"> <li>-Could not distinguish SD from SSD</li> <li>-No connection between personal experiences and SD/SSD definitions</li> <li>-Heavy equation reliance, could not solve &gt;50% of calculation-based problems</li> <li>-Poor answers to open-ended questions, heavy reliance on personal experiences. Often avoided answering questions with pertinent information</li> </ul>	8

Out of eighteen students interviewed, four students fit into profile A which was characterized by students being able to give proper definitions of both SD and SSD as well as being able to correctly perform all calculation-based questions on the protocol. In addition, Profile A students openly discussed their personal driving experiences which typically related to problems they encountered as drivers with their vehicle's braking distance in poor environmental conditions, or hindrances in their available SD driving through crest and sag vertical curves at night. These students demonstrated they were capable of successfully linking their personal driving experiences with the definitions they created for the phenomenon of SD and SSD. Lastly,

Profile A students answered open-ended design problems with engaging discussions of not only what variables would be needed to solve the problem, but why they were important and how they would be utilized in an iterative design solution.

Although profile B students shared some characteristics with Profile A students, mainly both profiles were able to properly define SSD, Profile B students often struggled to delineate and classify SD. Likewise, six students in the Profile B category successfully linked their driving experiences with the definitions they created for SSD, but did not consciously recognize how SD played into their personal driving experiences. Profile B students demonstrated a moderate reliance on equations, tables, or previously performed homework problems, where this reliance left them incapable of solving *all* the calculation-based problems on the interview protocol.

In contrast, eight students of the eighteen interviewed, or roughly 45% fit into Profile C. These students could not distinguish SSD from SD even with multiple opportunities to justify their knowledge of both concepts in the interview protocol. Profile C participants relied heavily on equations, and were incapable of solving more than 50% of the calculation based problems. Often, when presented with a new unfamiliar problem, Profile C students requested additional variables or equations they had previously used in class before attempting to solve the problem. Again, an accompanying equation sheet could have been employed to solve all calculation-based problems. The combination of heavy equation reliance in conjunction with poor definitions of SD and SSD left Profile C students very few options to adequately answer the open-ended design questions.

Students were placed in their respective profiles based on loose methods of classification: if greater than 80% of the characteristics for a particular profile were met by an interviewee, they were grouped into that profile. Although this is a loosely quantifiable means of

gathering data, it still shows that many students struggled to define, interpret, and answer questions based on the most fundamental geometric design concepts. Roughly 45% of students participating in the interviews demonstrated poor understandings of SD and SSD, as well as a heavy reliance on equations. They failed to link the definitions of SD and SSD they had been presented with in class to their personal driving experiences. Overall, they were left with few options to solve new unfamiliar problems. Yet other students, mainly the Profile A participants, demonstrated they were capable of solving calculation-based problems based on succinct definitions of SD and SSD and slight equation reliance. These students capitalized on their driving experiences, and integrated this knowledge successfully with the SD and SSD meanings they had been presented with in class.

## **CHAPTER FOUR**

### **TRANSFERABILITY AND IMPLICATIONS**

The findings presented above are representative of students in the transportation courses from both universities, based on the concept of saturation discussed above. The ability to apply qualitative results to other settings is known as transferability, and is dependent on the similarity between the research setting and the setting to which the results will be applied. All students in this research are from public land grant institutions in the Pacific Northwest and it is likely that the findings would be similar from other comparable universities. Future research at other settings, such as private institutions, could validate the transferability of these findings to other settings.

The interviews provide insights into the struggles students face in their understanding of geometric design. The two concepts investigated in this study, sight distance and stopping sight



distance, were difficult for many students to define or use in calculations. Many introductory courses emphasize solving problems by finding the correct formula and applying it effectively. Without the development of important concepts, correctly memorized formulas are often forgotten after the course ends, and the ability to apply them is lost. These students' difficulties in explaining and applying the concepts of SD and SSD suggest that they will have to re-learn geometric design fundamentals before being able to apply them in later classes, or as engineers. While it is certainly not expected that students in introductory courses have developed a full expert conceptual understanding of SD and SSD and their relation to geometric design, this research provides additional evidence that many students develop little or no meaningful, long-lasting understandings in engineering courses. This is not an indictment of the instructors of these courses or any other transportation engineering faculty, but is instead is an observation of the traditional engineering education system, which is currently being refined by theoretical and methodological advances in educational research.

## **CHAPTER FIVE**

### **CONCLUSIONS**

The ways in which students attempted to overcome these difficulties, by referring to previously completed problems, equation reliance, or life experiences as drivers, supports the constructivist stance to learning, and suggests some possible approaches that instructors could use to address these difficulties. When instructors present new information, students use their pre-established conceptual frameworks to make sense of the lectures; either adjusting what they hear to fit their beliefs, change their beliefs, or ignore the contradiction. Chi found that students rarely change their existing beliefs due to lectures, because traditional instruction and assessment

offer little opportunity for students to resolve prior misconceptions or those developed while studying a subject [11].

If this study was to be replicated, it would be interesting to explore in more detail how personal driving experiences influence student's understanding of SD and SSD. Almost every student participating in the interviews openly discussed problems they encountered as drivers. As discussed in the results, these experiences varied from interviewee to interviewee. Often, they involved typical worst case scenarios they had while driving: swerving to avoid a deer in the roadway, braking on an icy road, or driving through fog with the uncomfortable feeling of reduced available SD. The distinction remains that although all students openly discussed driving experiences, only Profile A students capitalized on these experiences and linked them to the information they had been presented with in class while discussing geometric design criterion.

It seems from this interviewee sample that students who took the time to interpret their driving experiences; critically analyzing how the situation fit into their understanding of SD and SSD, performed much better on questions from the interview protocol. Likely, because they successfully incorporated personal driving experiences into their previous understanding of both SD and SSD, these students relied less on equations and more on the existing knowledge they already created. This is in sharp contrast to the problem solving methods adopted by Profile C students, who relied heavily on equations and problems before setting forth to answer different questions.

Instructors of introductory transportation courses would likely increase student understanding of SD and SSD by incorporating the results of this investigation with alternative traditional education methods. Here, alternatives to "traditional" educational methods are abundant, but a useful definition has been provided by Hake in his survey of over 6500 students'

conceptual understanding as it developed in an introductory physics course [2]. Hake found that “interactive-engagement” pedagogy lead to significant improvements in student understanding as compared to traditional, lecture-based methods. Hake defines interactive-engagement as “...Designed, at least in part, to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors” [2]. Building on Hake’s findings, the PERG group has developed a full course of interactive tutorials and homework assignments for introductory physics [28]. These materials are based on examples of student difficulties identified in extensive student interviews.

These alternatives could be applied directly to transportation engineering courses to address conceptual difficulties found in this research. Some lecture time could be committed to interactive engagement on SD and SSD. For example, students could work in pairs and using a real-life driving situation from their past, apply the principles of SD and SSD to this situation. To provide an opportunity for feedback a couple of groups could be selected to defend their scenario in front of the class. Similar to tutorials in physics mentioned above, students could be required to analyze student comments from this paper, and determine and defend the correctness of these statements.

These examples highlight the importance of identifying and understanding specific student difficulties with conceptual understanding in each field. Future work in transportation engineering education could build on this study by investigating more students’ conceptual understanding of more concepts. A truly broad-scale investigation of student understanding would likely require the development of a concept-inventory of fundamental geometric design concepts. Further exploratory, qualitative studies could serve as the foundation for this inventory

and for other curricular materials to improve students' conceptual understanding in transportation engineering. This would ultimately serve to improve the quality of our nation's roadways and thus the safety of its citizens as well as improving engineering education.

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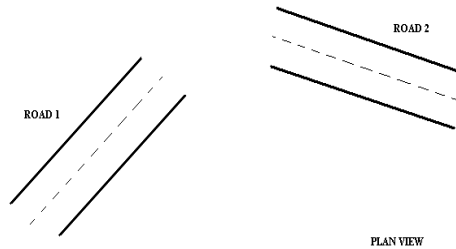
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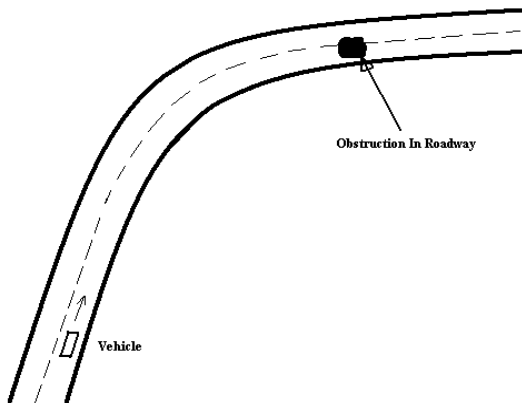
## APPENDIX

### INTERVIEW PROTOCOL:

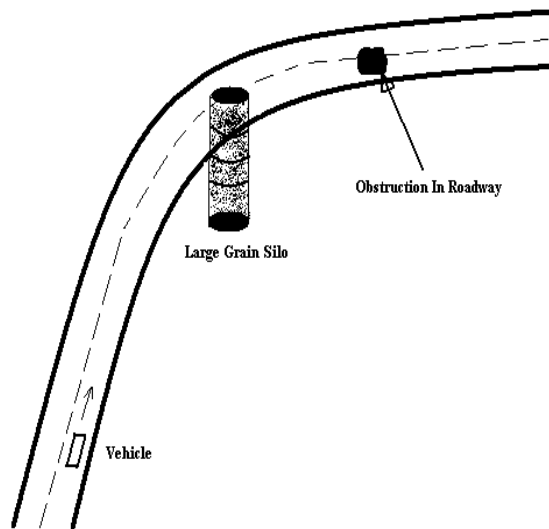
- 1) Tell me about geometric design
- 2) What comes to mind when you think of 'sight distance'?
  - a. How is the concept of sight distance used in highway design?
- 3) Explain the term 'Stopping Sight Distance.'
- 4) Look at the figure below. Road 1 and Road 2 are two tangent roads that need to be connected using a horizontal curve. Keeping sight distance in mind, discuss how you would design the curve?



- 5) Referring to the picture below a driver is traveling around a horizontal curve. Noticing the obstruction ahead, discuss the stopping sight distance.
  - i. How would you determine the reaction time? Does it vary?
  - ii. Does the SSD change? Is it always the same?
  - iii. How does the obstruction itself affect the reaction time?

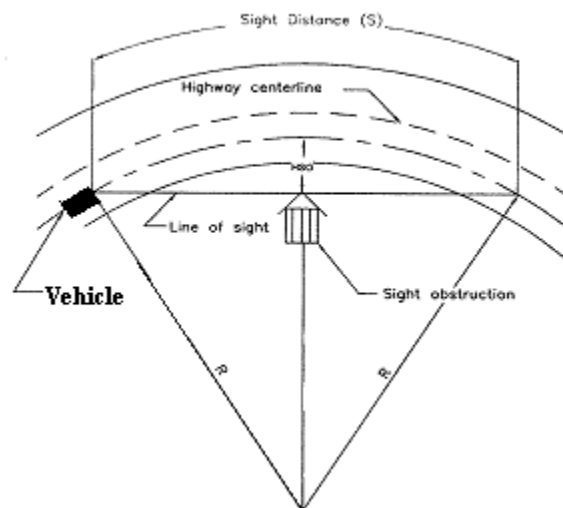


- 6) Refer to the picture below. It is the exact same figure as #5, except a large silo is introduced to the diagram. Discuss stopping sight distance
- Is the SSD different than #5. Why?
  - If so, what changes?



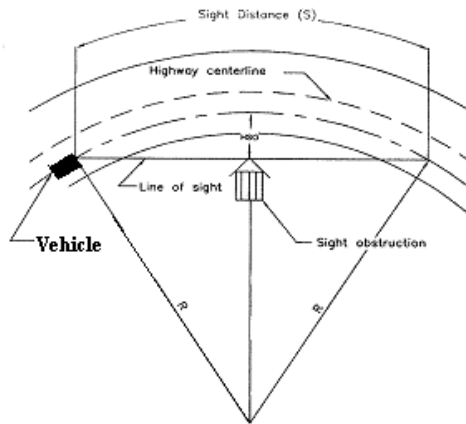
- 7a) Take a moment to look at the figure below. The car is traveling through the horizontal curve where a house provides a sight obstruction for the driver. How would you determine the Stopping Sight Distance?

- What variables would you need? Do you need more information?





7b) If the Radius of the Curve is 350m, and the HSO is 6 m, can you calculate the SSD?

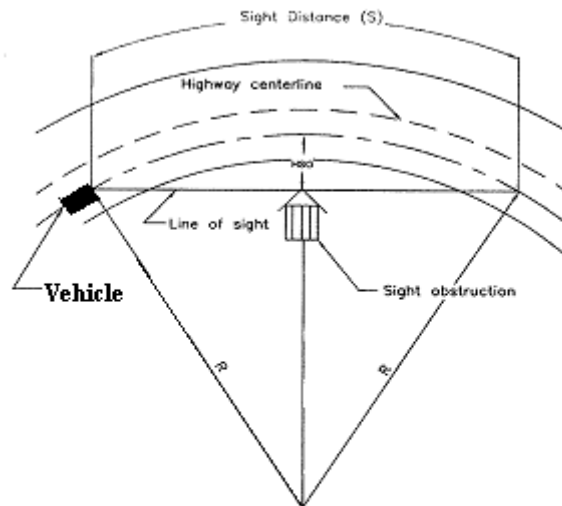


**HSO = Horizontal Sight Offset = 6 m**

**R=Radius of Curve = 350 m**

7c) If the design speed for this highway is 110km/hr, is this horizontal curve safe?

i. *If not, what could be changed to make this a safer roadway?*

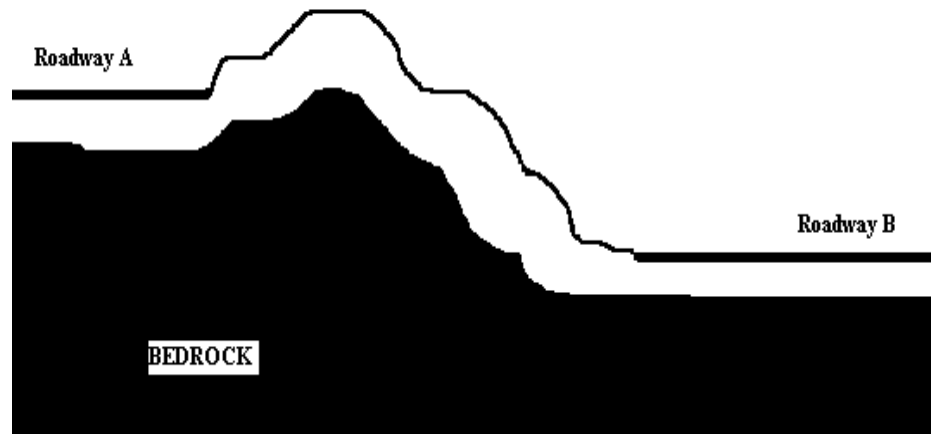


**HSO = Horizontal Sight Offset = 6 m**

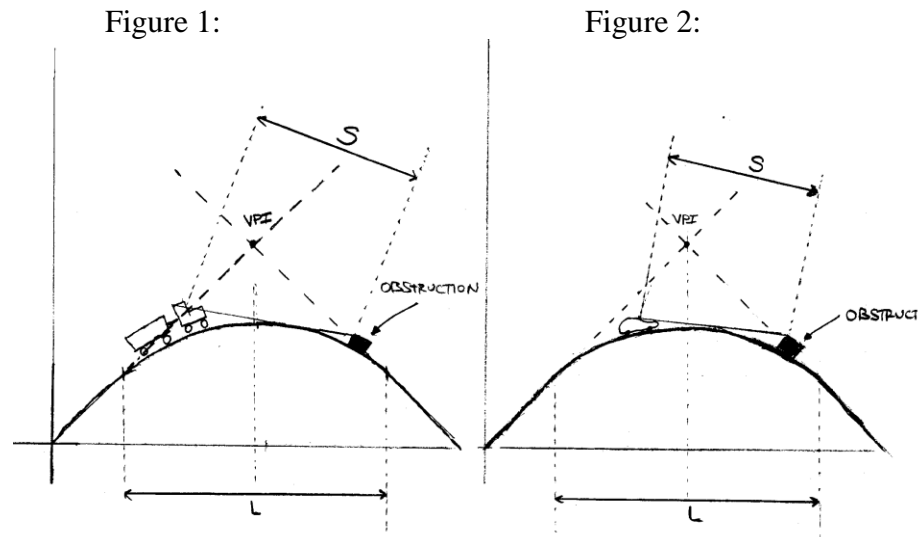
**R=Radius of Curve = 350 m**

**V = Vehicle Speed = 110 km/h**

- 8) Look at the simplified topography profile below. A vertical curve is the only option to connect roadway A with roadway B. Discuss how you would design the vertical curve.



- 9) Refer to the two diagrams below. Figure 1 shows a large semi-truck traveling over a crest vertical curve with an obstruction ahead. Figure 2 shows the same crest vertical curve with the same obstruction, except a small passenger car is traveling over the curve. If the length of the vertical curve, 'L', is the same for both scenarios, discuss which vehicle would experience a larger sight distance, 'S'?



9a) Now, determine the available sight distance for both the truck **AND** the passenger car using the following information:

i. Truck:

1.  $L$  = length of curve = 500 meters
2.  $h_1$  = height of eye above roadway=2.4 meters
3.  $h_2$  = height of hazard above roadway=0.61 meters
4.  $G_1$  = tangent grade=(4%)
5.  $G_2$  = tangent grade=(-2%)

ii. Passenger Car:

1.  $L$  = length of curve = 500 meters
2.  $h_1$  = height of eye above roadway=1.08 meters
3.  $h_2$  = height of hazard above roadway=0.61 meters
4.  $G_1$  = tangent grade=(4%)
5.  $G_2$  = tangent grade=(-2%)