OKU Fen Bilimleri Enstitüsü Dergisi
6(Ek Sayı): 105-118, 2023

OKU Journal of The Institute of Science and Technology, 6(Suppl): 105-118, 2023

Osmaniye Korkut Ata Üniversitesi Fen Bilimleri Enstitüsü Dergisi

Osmaniye Korkut Ata University Journal of The Institute of Science and Technology

Forgiving Road Design and Improvement of Accident Black Spots: A Case Study for Düzce City

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Research Article

Article History:
Received: 04.10.2022
Accepted: 16.05.2023
Published online: 20.12.2023

Keywords:
Accident black spot
Forgiving road
Roadside safety

ABSTRACT

The aim of changing the causes and consequences of traffic accidents, preventing possible human deaths, and providing more comfortable navigational safety is a common situation especially in the highway sections of our country where traffic accidents occur mortally. In the study, the concept of the forgiving road, which was brought to the agenda of our country by the General Directorate of Highways (KGM) in 2013 and still has problems in implementation, was examined. Investigations have been made on the highway sections where the same type of accidents occur frequently, and it has been emphasized how these highway sections can be forgiving roads. A correct and planned road design or improvement directly contribute to a dramatic reduction in accident rates. In this context, two accident black points that need improvement in 2016 within KGM and one point with the potential to become an accident black point were determined. Considering the forgiving road design features based on a total of three highway sections, on-site investigations were made, and recommendations were made.

Affeden Yol Tasarımı ve Kaza Kara Noktalarının İyileştirilmesi; Düzce Örnek Durum İncelemesi

Araştırma Makalesi

Makale Tarihçesi:
Geliş tarihi: 04.10.2022
Kabul tarihi:16.05.2023
Online Yayınlanma: 20.12.2023

Anahtar Kelimeler:
Kaza kara noktası
Affeden yol
Yol kenar güvenliği

ÖZ

Bu noktada, trafik kazalarının neden ve sonuçlarını değiştirmek, olası insan ölümlerinin önüne geçmek, daha konforlu seyir güvenliğini sağlamak amacı, özellikle ölümlü trafik kazalarının gerçekleştiği ülkemiz karayolu kesimlerinde olağan bir durumdur. Çalışmada, ülkemiz gündemine 2013 yılında Karayolları Genel Müdürlüğü (KGM) tarafından getirilen ve halen uygulama konusunda aksaklıkları bulunan affeden yol kavramı irdelenmiştir. Aynı tip kazaların sık gerçekleştiği kara yolu kesimlerinde incelemeler yapılmış, bu karayolu kesimlerinin nasıl affeden yol olabileceği üzerinde durulmuştur. Doğru ve planlı bir yol tasarımı veya iyileştirmesi, kaza oranlarının büyük ölçüde azalmasına doğrudan katkıda bulunacaktır. Bu kapsamda KGM tarafından belirlenen, 2016 yılı içerisinde iyileştirilmesi gereken iki kaza kara noktası ve kaza kara noktası olma potansiyeline sahip bir nokta belirlenmiştir. Toplam üç karayolu kesimi üzerinde affedici yol tasarım özellikleri göz önünde bulundurularak yerinde incelemeler yapılmış, tavsiyelerde bulunulmuştur.

To Cite: Serin S., Önal Y., Kayadelen C., Mutlu MF. Forgiving Road Design and Improvement of Accident Black Spots: A Case Study for Düzce City. Osmaniye Korkut Ata Üniversitesi Fen Bilimleri Enstitüsü Dergisi 2023; 6(Ek Sayı): 105-118.

Introduction

A traffic accident is an event that results in one or more material damage, injury, or death resulting from one or more of the human, vehicle, road, and sometimes environmental conditions, which are the essential elements of transportation or the interaction of these elements with each other (Kihlberg and Tharp, 1968). The main criterion of road safety is traffic accidents; theoretically, if there is no accident, there is no problem (Güçmen, 1975). According to the statistics of Turkey, the first factor that causes accidents is drivers with a rate of 91.5%. Road and vehicle defects make up only a small percentage of 0.74% and 1.19%. Road and vehicle defects make up only a small percentage of the causes of accidents since accident reports are prepared by those who have not been trained in detecting these defects in vehicles or on the road (Kahramangil and Şenkal, 1999).

Road factors, including road and roadside design elements, play an important role in determining traffic accident risk. Adverse road engineering aspects include factors in which some elements of the road environment that directly triggered the accident mislead the user and thus were created by human error (KİTGİ, 2001).

Numerous research studies have been done on the effectiveness of engineering measures, and estimations have been made on how these measures play a role in reducing the number of accidents and/or the severity of accidents. With the application of engineering measurements taken in the research, it is possible to achieve significant reductions in accidents quickly (Ergün, 1999).

The places where the same type of traffic accidents is occurred at the same highway section or point are defined as accident black spot (ABS). In other words, ABS is the section or point where accident frequency is experienced for a specific reason.

It is precisely in this context that the "Forgiving Road Description", "Design," and "Positive Guidance" approaches should be integrated into the engineering design of roads to minimize the risk of road accidents (KİTGİ, 2001).

ABSs should be identified carefully; furthermore, the necessary improvements should also be made to these ABSs to reduce potential traffic accidents due to non-implementation or incomplete implementation of forgiving road design. In this context, in the literature, many researchers have concentrated on the identification of ABSs and investigated the potential solution to reduce traffic accidents at these points (Gkemou et al., 2019; Roque et al., 2019; Thangavel et al., 2019; Zhang et al., 2019; Chaudhary, 2020; Mecheri et al., 2022). Zhang et al. (2019) proposed a model for the identification of ABSs using machine learning algorithms. They found a good correlation between ABSs and the type of accident, responsibility, time, and accident location type. They also concluded that this study might offer reference evidence for identifying and preventing ABSs, which would considerably improve traffic safety. In their study, Thangavel et al. (2019) developed a GPS-based smartphone application alerting the user before 500m, enabling the user to manually reduce the vehicle speed to the appropriate limits before the vehicle reaches the ABS. Then, they integrated Internet of Things (IoT) components into the vehicle to reduce the vehicle's speed and modified the

application to control the accelerometer and offer voice notifications. Kurakina et al. (2020) aimed to find a novel methodology for enhancing the process of identification of ABSs utilizing IT computational methods, probability theory methods, and research results processing. They suggested a comprehensive method to improve ABS identification process. Fan et al. (2019) combined data from several sources about traffic accidents over time and space. In their study, they identified and examined ABSs using the support vector machine (SVM) and deep neural network (DNN). They also enhanced the accuracy of ABSs identification of SVM and DNN. They also suggested a future-based ABS identification method depending on depth neural network. Iqbal et al. (2020) carried out a study analyzing road traffic accidents and identifying ABSs on the Lahore-Islamabad Highway M-2. They used the accident point weightage (APW) method to identify ABSs and rank of top ten ABSs. They deduced from the results that as the primary contributing component in traffic accidents, human error makes up 66.8% of the causes. They also concluded that it is necessary to raise public knowledge about traffic safety and employ a dozen alerts to prevent drivers from dozing at the wheel. Tanprasert et al. (2020) suggested a new method to identify ABSs utilizing street view images. They compared success of the suggested method with other suggested methods. Also, they claimed that their suggested method classified black and safe spots in Thailand with an accuracy of 69.91%, correctly identifying 75.86% of the black spots.

In Turkey, especially in recent years, the applications to prevent/reduce traffic accidents have gradually increased. Forgiving roads, which KGM has made a current issue in our country in 2013, aim to reduce the accident rates at the accident black points in Turkey. For this purpose, improvements have been made with various applications made at specific ABS (Kahramangil and Şenkal, 1999).

The forgiving roads application of KGM aims to minimize accident losses by compensating for reasonable errors of road users and vehicles within the scope of sustainable highway safety.

Road network has an important place in accident risk on highways because how drivers perceive the road network is the direct cause of accidents. In this sense, the road offers and even should provide drivers with instructions on what to do.

According to studies, there are three factors in the occurrence of accidents:

- Human factors
- Vehicle factors
- Road/Environmental factors (La Torre, 2012).

Every year, 43,000 people in Europe have traffic accidents with injury or death. Although 10% of all accidents are caused by a single vehicle accident, when fatal accidents are considered, the rate of these incidents rises to 45%. The most important reason for this high death rate is the 'unforgiving' roadside design. Various recent studies have been carried out to make roadside designs that forgive human errors (La Torre, 2012). At this stage, the first thing to do is to perform analyses in regions where accidents are common. Thus, obstacles and objects that distract drivers and cause accidents can be identified.

The roadside features developed/need to be developed in the forgiving road design guide are:

- Highway guardrails
- Shoulder rumble strips
- Medians
- Forgiving support structures for road equipment

One of the most crucial safety factors in highway design is the design of the roadside and any objects that may be found there. Accidents on highways frequently stem from objects that should not be near the road (Figure 1). These objects need to be made safe or removed from the roadside (KTR, 2000; Thomson et al., 2006a).

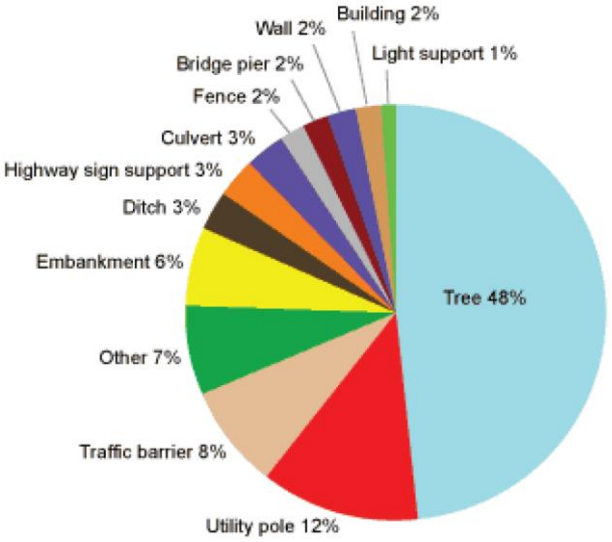

Figure 1. Percentage distribution of accidents due to fixed object resulting in death (Thomson et al., 2006b).

Some road safety elements and their contribution to road safety can be briefly examined as follows. Shoulder rumble strips are road safety structures that warn drivers against straying off the road or drifting into other driving lanes and have both a perceivable vibration and an audible warning feature. These are designed against the possibility of careless drivers causing an accident (Thomson et al., 2006b). Energy-absorbing mechanisms are needed in the areas where the guardrails end to prevent fatal accidents and dangers caused by highway guardrails. For example, absorber mechanisms (Atahan, 2003) and the outer shoulder width allow faulty drivers to correct their trajectory without going off the road. On the other hand, it has been observed that the coated shoulder is safer than the uncoated one. In addition, the improved shoulder design effectively reduces reverse crashes (Figure 2) (Armour and McLean, 1983; Zegeer et al., 1992; Zegeer et al., 1994; Karaşahin and Bağırgan, 2007).

Figure 2. a) Tangent terminal (Thomson et al., 2006b), b) flared terminal of guardrail (La Torre, 2012), c) typical shoulder rumble strip (Thomson et al., 2006b).

The highway factors covered in this study include highway and roadside design elements. While conducting the forgiving road research, no examination was made on human and vehicle factors; however, an examination was made of how different road sections can be transformed into forgiving road status in terms of road factors. In this context, two points within the borders of the 4th Regional Directorate of Highways, defined as ABS by KGM, and an accident point with the potential to become an accident black spot, are discussed. Considering the forgiving road design, on-site investigations were made on a total of three highway sections, which were determined to need improvement by KGM. The situation was analyzed, and recommendations were made.

Case Study: Düzce Example

It has been discussed which implementation can be done to make it a forgiving road to two spots, which are within the borders of the 4th Regional Directorate of Highways and defined as ABS by KGM, and one accident spot having the potential to be an ABS. In this context, on-site investigations were made at the determined points, the situation was analyzed, and recommendations were made.

Descriptive information for the ABS examined in the study is summarized in Table 1. Within the scope of the study, each accident spot was discussed, and evaluated individually.

Table 1. Information about ABS.

No	Name of the road	Region No	City	Km
1.	4+800th kilometer of Düzce-Kaynaşlı Road	4-Ankara	Düzce	26+800
2.	Between 16+000 - 64+000 kilometers of Hendek-Bolu Road			0+000-48+000
3.	Between 23+000 - 24+000 kilometers of Düzce-Akçakoca Road			23+800

Analysis of the First ABS

The 4+800th kilometer of Düzce-Bolu road was stated by KGM as an accident black spot that needs improvement in 2016. The fact that the side road connections connecting to the highway on the main route are planned to cause problems in the flow of traffic lead to similar accidents at the same point. Although the traffic signs seem to be adequate and the road design seems to be appropriate, it is striking that there are problems in the planning of the connection between the side road and the main road on the route, which causes the accidents.

In the examinations made, it was observed that there was a water accumulation near the middle part of the road. This reveals the possibility that the superelevation corresponding to that region was misapplied. This accumulated water causes accidents by reducing the safety of the vehicles in the left lane known as the accelerating lane.

The side road planning that connects to the highway on the same route is not at the desired level, causing accidents. Although the necessary traffic signs and road design seem to be at the desired level, it is seen that there are still problems in the planning of the side road and main road connection on this route.

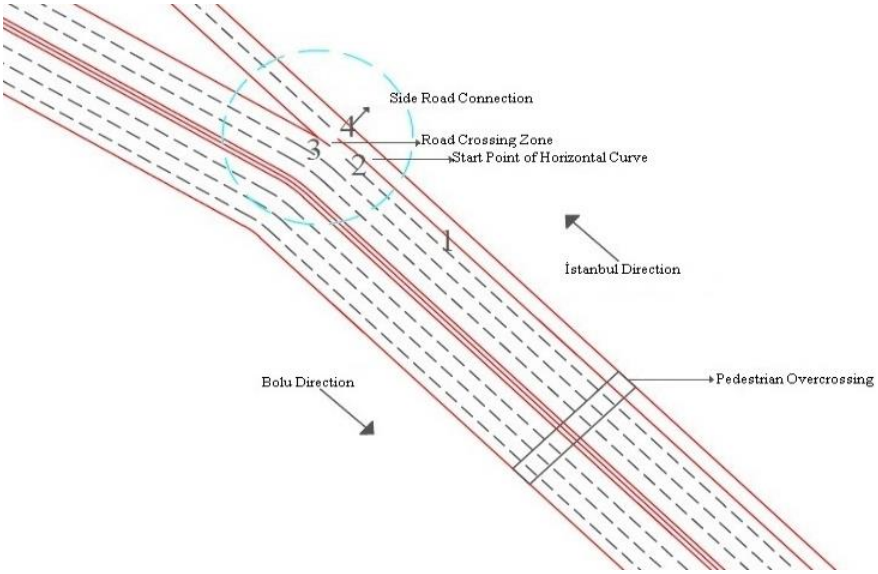

Figure 3. Plan view of the First ABS.

On the D100 Highway, the lane width is 3.5 m, and the outer shoulder width is 2.5 m. In the direction of Istanbul, there is a transition zone towards Zonguldak at point 3, as seen in Figure 3, while the vehicle is in motion. While the outer shoulder serves as 2.5 m before reaching zone 3 (zone 1), it reaches the width of the lane (3.5 m) in the transition zone (in zone 3); however, there is not enough

width in this area to fully ensure navigational safety. The shoulder width should be increased in the previous section, and the lane width should be regulated to 3.5 m before reaching the transition zone. In addition, at this point, the fact that the region close to the transition zone (zone 2) is the beginning of the horizontal curve causes some problems. In this part of the road, the lane direction and guardrail directions were constructed in accordance with the horizontal curve direction. However, the construction of the guardrail in the transition zone in accordance with the horizontal curve causes the vehicle to be disturbed by the guardrail during the passage (zone 3). In this section, the driver may experience discomfort with the psychology of entering a narrow area directly from a wide area. Figure 4 and Figure 5 show the view of the road.

Figure 4. a) The course of the highway in the direction of Hendek, b) Transition zone.

On the other hand, centrifugal force acts on the vehicles in the horizontal curve. Sudden maneuvers of vehicles under the influence of centrifugal force towards the transition zone cause loss of control, thus reducing driving safety (Figure 5).

Before the start of the horizontal curve (close to zone 1), a direction sign placed on the highway section will increase the awareness of the drivers of vehicles going in that direction and prevent sudden slowdowns and maneuvers.

Figure 5. Side road connection.

The lane width in the transition zone should be reconsidered in accordance with the conditions to transform the specified accident black spot into forgiving road status. The fact that the highway section, which serves as an outer shoulder width of 2.5 m, has been transformed into a normal lane in the transition zone and serves vehicle traffic, causes the drivers to be extra careful and make an effort,

and the risk of accident. Continuing the application of additional shoulders to the lane at the transition point where the connection to the side road is made, even if it is minimal, will eliminate the risk of an accident.

Shoulder rumble strips should be applied to warn careless or distracted drivers, which will use the transition zone, and to reduce their speed before they reach this zone (Figure 3, between zones 1-2). Considering the forgiving road design, constructing energy-absorbing guardrails at the intersection will ensure that possible accidents are avoided with less damage.

Placing a direction sign indicating the direction of Zonguldak Province for early warning of vehicle drivers before they reach the transition zone will prevent late maneuvering of vehicle drivers who will pass in this direction. In addition, direction markings to be placed on the road before coming to the transition zone will ensure the safer passage of vehicles.

Analysis of the Second ABS

The junction point located around Düzce on the Hendek-Bolu road, defined as the accident black spot by KGM in 2016, was included in the study by making on-site investigations, and it was tried to observe the situations that could cause the accident. The plan view of the specified intersection is given in Figure 6.

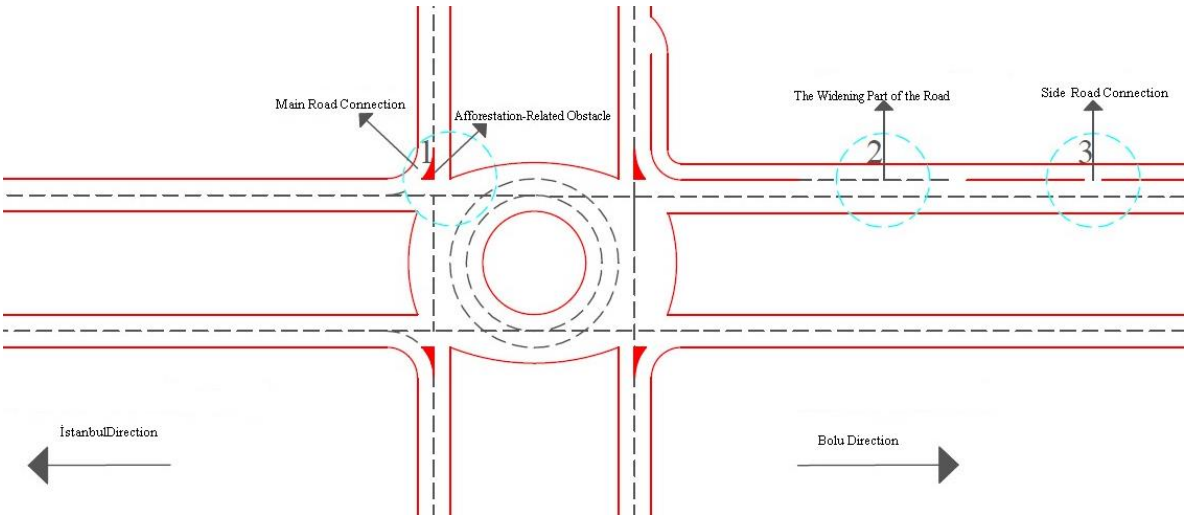

Figure 6. Plan view of the second ABS.

In the examination, it is seen that the intersection is four-legged. It has been determined that the necessary traffic signs for the vehicles that want to change their directions to the İstanbul-Bolu Road from other directions are not made at a sufficient level, and the vehicles are given the right of slow and controlled passing. In addition, there are obstacles originating from the landscape at the median that restricts the view of the vehicle drivers on the main road (Figure 6 (zone 1) and Figure 7).

Figure 7. a) View of the intersection, b) the tree that does not allow safe passage and obstructs the view.

In addition, as a result of the examinations, it was determined that the road expanded and then narrowed just before the traffic warning lamps at the intersection while driving from Düzce to the direction of İstanbul (Figure 6 (zone 3)). The reason for this sudden expansion is due to the fact that there is a side road connection to the highway before the traffic warning lamps, and the road widens at that connection section (Figure 8). The road widening in the connection section narrows in the area where the traffic warning lamps are located. This causes the vehicles on the road to be disturbed by the vehicles connected to the road by the side road in certain areas.

Figure 8. Section with side road connection, b) the section where the highway narrows after the side road connection.

Considering the plan view, both the traffic warning light and the tree that obstruct the driver's view should be removed from their location to ensure that the vehicles connecting to the main road from the north can pass slowly and carefully.

The section where the road suddenly widens needs to be improved. This improvement can be made, albeit partially, by shifting the area that connects to the main road from the side road further back. A warning sign should be placed to warn the vehicle drivers traveling on the main road for vehicles that can be connected from the side road in case this improvement does not be made (Figure 6 (zone 3)).

Since the speed of vehicles using the main road on the right of way can be high, the vehicles coming from other roads connected to the main road will cause traffic accidents. Speed warning signs should be placed next to traffic warning lamps at the connection points to the highway.

Analysis of the Third ABS

The 23+000-24+000 km of Düzce-Akçakoca Road was not stated as a point to be improved by KGM. However, the situation of this road section, the type of accidents, and statistics reveal that this section needs to be examined and improved. This section was examined at the site. The traffic flow, the adequacy of the traffic signs, and the transition zones were analyzed in detail. Thus, the following situations were encountered.

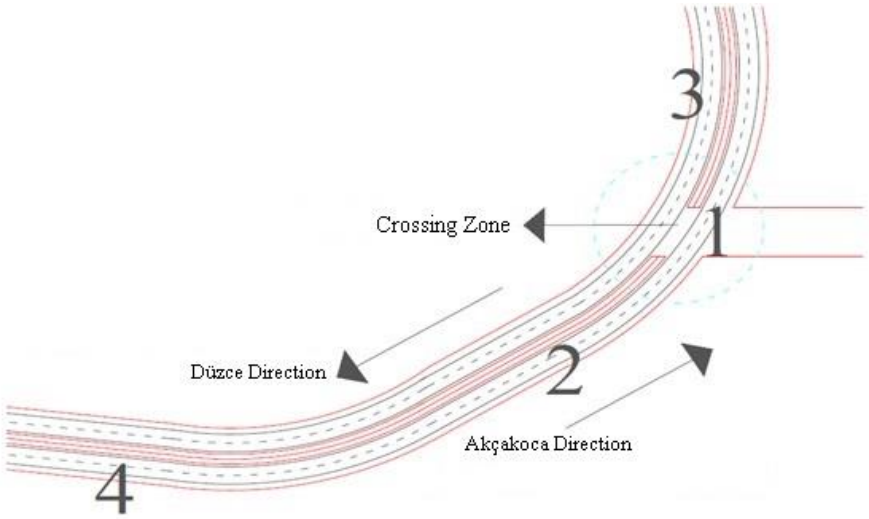

Figure 9. Plan view of the third ABS.

In the section shown in Figure 9, vehicles that enter the horizontal curve while driving (vehicles going from zone 4 to Akçakoca direction) encounter the intersection (zone 1) before the vehicles have fully corrected their driving style and come face to face with the vehicles that will cross the intersection. This situation causes a sudden slowdown and an accident for vehicles that cannot slow down. There are speed warning signs long before the horizontal curve; however, it was determined that these warning signs were not found before entering the horizontal curve (zone 4). In addition, since this road section is a section where the vehicle accelerates vertically (between 4-2 zones), other vehicles that can suddenly come across the vehicle in motion create hazardous situations. Figure 10 and Figure 11 show the view of the road from different perspectives.

Figure 10. Direction of arrival to Tepeköy intersection (Düzce-Akçakoca direction), b) road section with vehicle passage.

Figure 11. Rural road connecting to main road, b) the direction and form of connecting vehicles to the main road.

There is also a different danger for vehicles connecting in the opposite direction (vehicles connecting in the direction of Düzce from zone 1). There is no speed warning sign or shoulder rumble strip application for vehicles traveling in the opposite direction (Figure 9, zone 3). Passage safety of vehicles passing in the opposite direction is deficient. For vehicles going from Akçakoca to Düzce, warning signs should be placed to reduce their speed, and shoulder rumble strips should be placed on the road to reduce the speed of vehicles before they reach the transition zone (Figure 9, zones 2 and 3). Speed warning signs should be placed before entering the horizontal curve to warn the drivers of vehicles traveling in the direction of Akçakoca (Figure 9, zone 4). Considering that the speed of vehicles traveling in the direction of Akçakoca may be high when they exit the horizontal curve, it is necessary to apply a shoulder rumble strip just before the transition zone (Figure 9, zone 2). The current application is insufficient and incomplete. To increase the awareness of drivers traveling in both directions, there should be warning signs indicating the transition zone. It should be ensured that the vehicles reduce their speed before they come to this area.

The maneuverability of vehicles entering the horizontal curve decreases with centrifugal force. Since it is difficult for the vehicle driver traveling in this direction to see the transition zone, a sudden slowdown may occur. Warning signs should be placed to warn the vehicle drivers traveling in the direction of Düzce, indicating that the speed should be reduced (Figure 9 zone 2).

Since there is a transition zone, the median guardrail is divided in this part. Placing the guardrail in the median area further back (towards zone 2) so that the vehicles that will pass can pass more quickly and safely will facilitate the navigation of the vehicles that will pass from Tepeköy to the opposite direction.

Conclusions and Recommendations

The concept of "Forgiving Roads" made the current issue by KGM in our country covers subjects such as examining the characteristics of these points on the road sections where traffic accidents frequently occur, investigating the causes of the accident, and eliminating the reasons that may cause the accident. Practices carried out in this context have resulted in a 50% reduction in traffic accidents.

In the context of the forgiving road concept, three different accident black points were examined, and improvement works on these points were mentioned. Considering the forgiving road design, investigations were made, and recommendations were made on what to do.

Within the scope of forgiving road design in Turkey, there are great administrative deficiencies in terms of eliminating the existing problems at the ABS. KGM knows the ABSs that need improvement and it also states that improvements have been made or will be made on these road sections where accidents are common. Nevertheless, it is seen that there are some problems in the applications.

Traffic accidents occurring at these points are generally caused by not analyzing the traffic situation completely, not making the necessary markings for the safe passage of vehicles, and inaccurate and inappropriate road geometry.

In addition to the recommendations for improving highway/environmental factors (road sections) as a result of the examinations, the importance of the driver factor in forgiving road design should not be forgotten. It should always be mentioned that it is a factor that should be kept on the agenda and directly affects traffic accidents. A conscious driver has the potential to ensure safe traffic. Uncovering this potential will also facilitate the improvement of road sections.

All the comments and recommendations in the study aim to eliminate the existing problems in the light of forgiving road design and to comprise a basis for the correct and safe construction of new road sections. An expert report should be prepared by people who are well-equipped and familiar with the concept of a forgiving road design for the sections with a very high probability of an accident in the three different ABS examined. Furthermore, this report should be submitted to the institution that can perform the improvement quickly and accurately.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authorship Contribution Statement

Sercan Serin: Conceptualization, Methodology, Visualization, Investigation, Supervision, Writing - review & editing.

Yakup Önal: Methodology, Visualization, Investigation, Data curation, Writing - original draft.

Cafer Kayadelen: Methodology, Data curation, Supervision, Writing - review & editing.

Muahmmet Fatih Mutlu: Investigation, Data curation, Writing - original draft.

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