A COMPARISON OF ROADSIDE DESIGN APPROACHES IN TERMS OF ROAD SAFETY TO IMPROVE TURKISH ROADSIDE SAFETY STANDARDS

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ABSTRACT

A COMPARISON OF ROADSIDE DESIGN APPROACHES IN TERMS OF ROAD SAFETY TO IMPROVE TURKISH ROADSIDE SAFETY STANDARDS

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When an errant vehicle runs off the road, crashing into objects/ reaching places in the vicinity creates "run-off-road (ROR)" accidents, which may result in severe injuries or fatalities. Roadside designs with proper Road Restraint Systems (RRS) ideally should cause neither hazards to the third parties nor threats to the vehicle users. The major components of the RRSs are the Vehicle Restraint Systems (VRS), including the safety barriers (i.e., guardrails) designed to i) either stop the errant vehicle fully or ii) slow it down for a safe return to the lane or less severe crash. There are national or regional standards for RRS (i.e., NCHRP-350, AASHTO MASH, and EN1317) mainly define the systems, classifications, and acceptance tests. However, there are no standardized methods/tools for the design and application specifications of RRS (i.e., type, location, length of need, etc.) since they are mostly correlated with the geometric design standards of the roads, which vary across countries, socio-economic characteristics of the road users and infrastructure planning principles.

While intercity road design principles in Turkey are mostly adopted from the AASHTO codes in the US, the clear zone concept (verge/green zone in the UK) is not fully employed in Turkish road designs; it does not follow a standardized cross-section for different types/functions of roads as in the UK or Germany, either. Furthermore, Turkey's RRS design must follow the European region EN1317 standards. Current intercity roadside design in Turkey is a mix of the USA principles embedded into a rule-based approach, which is a simplified version of the German roadside design approach. This creates a unique challenge in the design and implementation of the road sides, especially in the absence of the Road Safety Audit (RSA) process.

The high share of RORs in Turkey, in the order of 15%-20% of the fatal and injury accidents every year, so it is necessary to improve the roadside designs. This thesis compares current Turkish practice with a newly proposed roadside design approach adopted from the UK approach, which also follows the same EN standards for the RSS and relies on a systematic assessment procedure for major highways (speeds higher than 90 km/h and traffic volumes greater than 5,000 veh/days). The comparisons are made over a study corridor of 15 kilometers for the safety barrier along (the nearside of) the road. Both length of needs and locations of the applications are compared between alternative approaches to understand the differences better. The new approach required the N2 containment level for most sections of the corridor, which provides a lower containment level than the H1 required by the current practice. However, the total length of safety barriers needed by the new approach was almost 2.5 times the length of the current practice, showing significant differences between the two approaches. By considering the more objective evaluation criteria of the proposed approach, a series of recommendations was provided for improving traffic safety in Turkey via safer roadside designs.

Keywords: Roadside Safety, Roadside Design, Road Safety

ÖZ

TÜRKİYE YOL KENARI GÜVENLİK STANDARTLARININ İYİLEŞTİRİLMESİ İÇİN YOL KENARI TASARIM YAKLAŞIMLARININ YOL GÜVENLİĞİ BAKIMINDAN KARŞILAŞTIRILMASI

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Hatalı bir araç yoldan çıktığında, nesnelere çarpması/yakındaki yerlere ulaşması, ciddi yaralanmalara veya ölümlere neden olabilecek “yoldan çıkma kazalarına (YÇK)” neden olur. Uygun Yolkenarı Sınırlama Sistemlerine (YSS) sahip yol kenarı tasarımları ideal olarak ne üçüncü şahıslara tehlike ne de araç kullanıcılarına tehdit oluşturmamalıdır. YSS için ulusal veya bölgesel standartlar vardır (NCHRP-350, AASHTO MASH ve EN1317 gibi) esas olarak sistemleri, sınıflandırmaları ve kabul testlerini tanımlar. Ancak, çoğunlukla ülkeler arasında değişen yolların geometrik tasarım standartları, yol kullanıcılarının sosyo-ekonomik özellikleri ve altyapı planlama ilkeleri ile ilişkili olduklarından, YSS'nin tasarım ve uygulama spesifikasyonları (tipi, konumu, ihtiyaç uzunluğu vb.) için standartlaştırılmış yöntemler/araçlar bulunmamaktadır.

Türkiye'de şehirlerarası yol tasarım ilkeleri çoğunlukla ABD'deki AASHTO kodlarından uyarlanırken, güvenli bölge kavramı (İngiltere'de yeşil bant) Türk yol tasarımlarında tam olarak kullanılmamaktadır; hatta İngiltere veya Almanya'daki gibi farklı yol türleri/işlevleri için standartlaştırılmış bir en kesiti de kullanmaz.

Ayrıca, Türkiye'nin YSS tasarımı, Avrupa bölgesi EN1317 standartlarına uygun olmalıdır. Türkiye'deki mevcut şehirlerarası yol kenarı tasarımı, temelde Alman yol kenarı tasarım yaklaşımının basitleştirilmiş bir versiyonu olan kural tabanlı bir yaklaşıma gömülü ABD ilkelerinin karışımıdır. Bu, özellikle Yol Güvenlik Teftişi (YGT) sürecinin yokluğunda, yol kenarlarının tasarımında ve uygulanmasında benzersiz bir zorluk yaratır.

Türkiye'de YÇK'ların yüksek payı, her yıl ölümlü ve yaralanmalı kazaların %15-20'si arasında yer alması, yol kenarı tasarımlarının iyileştirilmesi gerekmektedir. Bu tez, mevcut Türk uygulamasını, YSS için aynı EN standartlarını takip eden ve ana yolları (90 km/s'den yüksek hızlar ve 5.000 araç/gün'den yüksek trafik hacimleri) için sistematik bir değerlendirme prosedürüne sahip Birleşik Krallık yaklaşımından benimsenen yeni önerilen yol kenarı tasarım yaklaşımıyla karşılaştırmaktadır. Karşılaştırmalar, yol boyunca (yol kenarında) güvenlik bariyeri için 15 kilometrelik bir çalışma koridoru üzerinden yapılmıştır. Alternatif yaklaşımlar arasındaki farklılıkları daha iyi anlamak için hem ihtiyaçların uzunluğu hem de uygulamaların yerleri karşılaştırılır. Yeni yaklaşım, koridorun çoğu bölümü için mevcut uygulamanın gerektirdiği H1 engelleme düzeyinden daha düşük bir koruma seviyesi sağlayan N2 engelleme düzeyini gerektirdi. Bununla birlikte, yeni yaklaşımın ihtiyaç duyduğu toplam güvenlik bariyeri uzunluğu, mevcut uygulamanın uzunluğunun neredeyse 2,5 katıydı ve iki yaklaşım arasında önemli farklılıklar gösteriyordu. Önerilen yaklaşımın daha objektif değerlendirme kriterleri göz önünde bulundurularak, daha güvenli yol kenarı tasarımları ile Türkiye'de trafik güvenliğinin artırılmasına yönelik bir dizi öneri sunulmuştur.

Anahtar Kelimeler: Yolkenarı Güvenliği, Yolkenarı Tasarımı, Yol Güvenliği

This thesis is dedicated to the memory of my father, Nizamettin Betus.

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ABBREVIATIONS

AASHTO	:	Association of State Highway and Transportation Officials
ASHTO- MASH		ASHTO Manual for Assessing Safety Hardware
AADT	:	Average annual daily traffic
ALARP	:	As low as reasonably practicable
ASI		Acceleration Severity Index
CEN		European Standardization Committee
DfT	:	Department for Transport (the UK)
DMRB	:	Design Manual for Roads and Bridges
EN		European Standards
EU	:	European Union
FGSV	:	Road and Transportation Research Association (in Germany)
GDH	:	General Directorate of Highways
GDS		General Directorate of Security
ISL	:	Impact Severity Level
ISO		International Standardization Organization
MCHW	:	Manual of Contract Documents for Highway Works
NCHRP		National Highway Association Research Program
NCHRP-350		Recommended Procedures for the Safety Performance Evaluation of Highway Features
NGOs		Nongovernmental Organizations
RPS 2009	:	Guidelines for passive protection on roads by vehicle restraint systems regulation
RRRAP	:	Road Restraint Risk Assessment Process
RRS	:	Road Restraint System
RSA/I		Road Safety Audit/Inspection
ROR		Run-Off-Road
THIV		Theoretical Head Impact Velocity
TSE		Turkish Standards Institute
UK	:	United Kingdom
UN	:	United Nations
VRS	:	Vehicle Restraint System
WHO	:	World Health Organization

CHAPTER 1

INTRODUCTION

Unlike other transportation systems, road systems have thousands of kilometers of infrastructure available to many drivers without strict supervision. Completing the journeys safely by providing a healthy interaction between the driver, the road, and the vehicle is one of the indispensable requirements of the ideal transportation concept. Problems experienced in this interaction lead to road accidents resulting in loss of life and property (Yaman & Tuydes-Yaman, 2019).

Traffic accidents and consequences cause severe losses, especially in underdeveloped and developing countries. Global Status Report on Road Safety indicated that more than 1.35 million people lose their lives, and up to 50 million are injured in traffic accidents annually, and traffic accidents take the first place among all causes of death for people between the ages of 5 and 29 (WHO, 2018). In addition, the risk of death in traffic accidents in developing and underdeveloped countries was reported as three times higher than in developed countries due to many reasons, including driver behavior, traffic control, and security systems in vehicles, and the lack of development of traffic safety culture as a fundamental difference.

In the simplest sense, traffic safety culture can be summarised as establishing the necessary infrastructure and operating systems in all dimensions that can simultaneously affect traffic accidents. In Sweden, trying to reach zero deaths in traffic accidents, programs, campaigns, and studies have been developed for the last 30 years with a new approach that started in the 1990s. Today, a similar approach was proposed by the United Nations (UN) with the principles that

i. traffic accidents are preventable and

ii. even if road users make mistakes

iii. to prevent fatal and injury accidents

iv. a safe system approach should be developed.

The basic dimensions of this system (U.S. DOT, 2022) are;

- safe roads,
- safe speeds,
- safe vehicles
- safe users
- post-crash care

The concept of “safe roads” includes both the design of the roadside and the design of the road. These include design elements such as horizontal and vertical curves, hydraulic design, and visibility. Especially in 1960-1970, the increase in vehicle ownership and use and the subsequent increase in traffic accidents and losses were brought to the agenda again; following this, it has brought up the examination of roadside elements to reduce deaths and injuries after accidents. Roadside safety, a relatively new phenomenon, has taken its place in roadside design as an invariable part of roadside safety design, barrier end parts, crash cushions, and motorcycle protection systems (AASHTO, 2011).

Roadside safety is crucial, especially for dealing with run-off-road (ROR) accidents, Turkey's third most commonly seen accident type. When an errant vehicle runs off the road, it poses a serious hazard to third parties (i.e., other transportation systems, other road traffic users, pedestrians, cyclists, etc.). The consequences of ROR accidents may be detrimental for third parties and vehicle occupants. If a ROR accident happens in a place with fixed hazardous objects and errant vehicles reach them (see Figure 1.1), the consequences of the accident can be severe or fatal to the vehicle occupants. To minimize the number and/or the consequences of the ROR accidents, Vehicle Restraint Systems (VRS) are designed and implemented along the roadsides, such as safety barriers, crash cushions, etc.

Figure 1.1 (a) Crashing into a tree (b) Crash to utility pole (c) Prevent reaching bridge pier (d) Prevent crossing median (e) Faulty terminal design of concrete barrier (f) Faulty terminal design of steel barrier

1.1 Vehicle Restraint Systems (VRS)

The road restraint system (RRS) family tree in TS EN 1317/1 is given in Figure 1.2. In RRS, a system is installed on the roadside to keep errant vehicles on the road up to a certain level and prevent them from colliding with hazardous objects or creating treats by off-road driving conditions. The major components of the RRSs are the VRS, including the safety barriers (i.e., guardrails). The primary purpose of VRS is to prevent an errant vehicle from colliding with objects or prevent third parties from the errant vehicle. First, it is designed to i) either stop the errant vehicle fully or ii) slow it down for a safe return to the lane or less severe crash. VRS indicates to drivers that the road section is dangerous and should be careful. It redirects the errant vehicle into a safe path that cannot cause as much danger to other road users as possible. If not, VRS reduces the accident's severity by absorbing the impact momentum and emerging energy. However, it should be kept in mind that VRS is also fixed objects intentionally placed vicinity of the roads, and the wrong design of VRS turns them into a hazard.

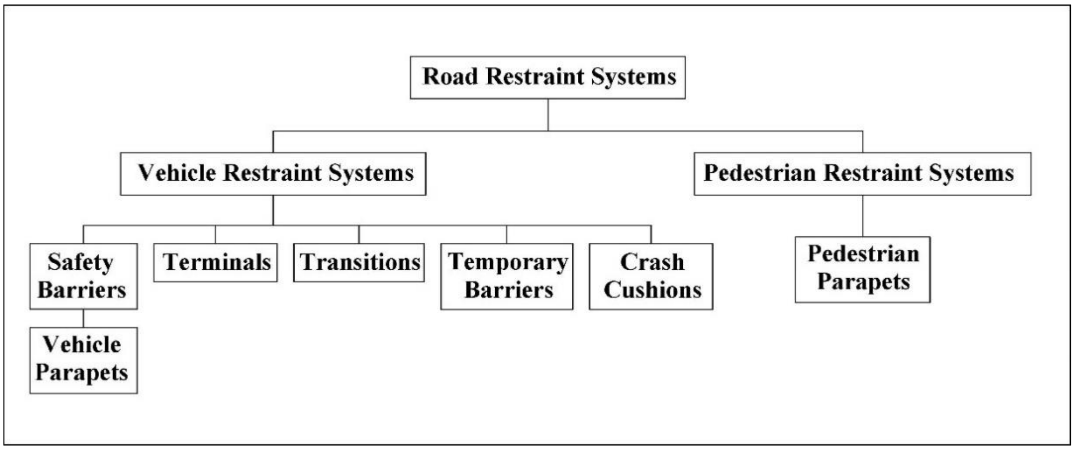

Figure 1.2 Road safety system family tree (TSE, 2011)

VRS includes safety barriers, crash cushions, terminals, transitions, and temporary barriers. However, due to losses in translations, and some inconsistencies in roadside safety terminology in Turkey, the general term “guardrail” is used interchangeably with a safety barrier in guidelines and applications in Turkey. Safety barriers are often flexible, semi-rigid, and rigid, depending on their deflection characteristics in collisions and distance from the obstacle. The systems used in these three groups are generally: rope, steel, and concrete guardrails. Flexible systems dissipate most collision energy by bending the guardrail, and less impact force is loaded on the vehicle. On the other hand, rigid systems should be preferred in heavy vehicle traffic or hazardous road sections. The concrete guardrail and steel guardrail examples are given in Figure 1.3.

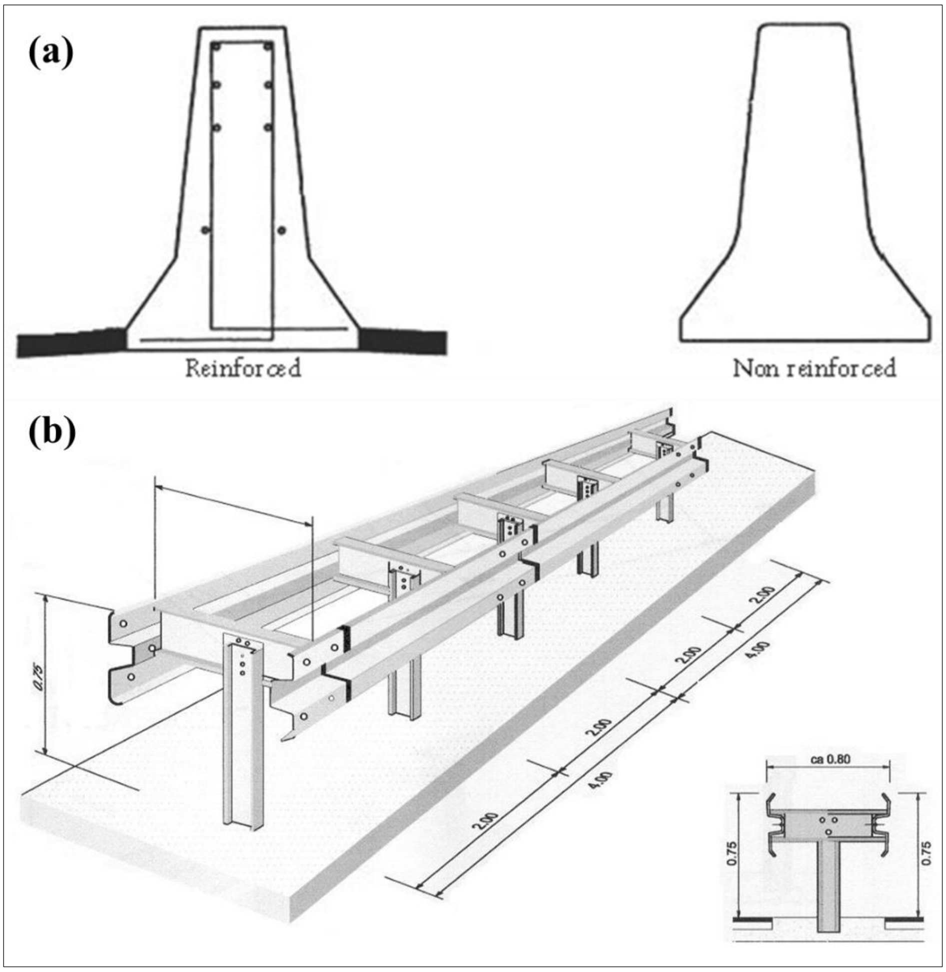

Figure 1.3 Examples of guardrails (a) concrete (b) steel (GDH, 2005)

1.2 Design Standards regarding RRSs in Turkey

The standards by which the performance criteria for RRS are determined in Turkey are under the control of the Turkish Standards Institute (TSE). TSE became a member of the International Standardization Organization (ISO) in 1955, and since January 2012, it has been a full member of the European Standardization Committee (CEN). TSE is responsible for preparing Turkish Standards and publishing internationally harmonized standards in Turkish. As a member of CEN, TSE accepts and publishes all European Standards (EN) as Turkish Standards (with the prefix TS EN). It is also obliged to withdraw pre-existing Turkish standards in case of conflict with each other. Table 1.1 shows the European standards used to determine the performance of RSSs in Turkey. CEN established a technical commission (CEN/TC 266) in the 1990s to harmonize the EN 1317 standard, which consists of five sections that serve as a guide for road safety systems in Europe, three of which are still in the draft stage.

Though they describe the testing procedures for performance evaluation of a VRS, they do not contain information about where or how long VRS should be used for roadside safety. These decisions are left to the designers and authorities. Most countries use their regulations and application principles, as they are mostly correlated with the geometric design standards of the roads, which vary across countries, as well as socio-economic characteristics of the road users and infrastructure planning principles.

While intercity road design principles in Turkey are mostly adopted from the AASHTO codes in the US, the clear zone concept (verge/green zone in the UK) is not fully employed in Turkish road designs; it does not follow a standardized cross-section for different types/functions of roads as in the UK or Germany, either. Furthermore, Turkey's RRS design must follow the European region EN1317 standards. Current intercity roadside design in Turkey is a mix of the USA principles mixed with the German roadside design approach: The General Directorate of Highways (GDH) published the highway design handbook in 2005, and the roadside safety chapter consists of a direct translation from the AASHTO Roadside Design Guide 2nd Edition, 1996. However, the current design applications are carried out according to an adapted and simplified version of the German roadside safety perspective. This approach is highly dependent on engineering judgments and consists mainly of rules of thumb, so it creates a unique challenge in the design and implementation of the road sides, especially in the absence of the Road Safety Audit (RSA) process.

Table 1.1 Standards used in determining the performance criteria of road restraint systems in Turkey

Reference	**Description**	**Status**
TS EN 1317-1: 2011	Road Restraint Systems - Part 1: Terminology and general criteria for test methods	Current Standard
TS EN 1317-2: 2011	Road Restraint Systems - Part 2: Performance classes, impact test acceptance criteria, and test methods for safety barriers, including vehicle parapets	Current Standard
TS EN 1317-3: 2010	Road Restraint Systems - Part 3: Performance classes, impact test acceptance criteria, and test methods for crash cushions	Current Standard
TS ENV 1317-4: 2011	Road Restraint Systems - Part 4: Performance classes, impact test acceptance criteria and test methods for terminals and transitions of safety barriers	Current Standard
TS EN 1317-5+A2: 2013	Road Restraint Systems - Part 5: Product requirements and evaluation of conformity for vehicle restraint systems	Current Standard
TSE CEN/TR 16949: 2016	Road Restraint Systems - Pedestrian restraint system - Pedestrian parapets	Current Standard
TSE CEN/TR 16786: 2018	Road Restraint Systems - Truck Mounted Attenuators. Performance classes, impact test acceptance criteria, and test performance	Current Standard
TSE CEN/TS 1317-8: 2019	Road Restraint Systems - Part 8: Motorcycle Road restraint systems that reduce the impact severity of motorcyclist collisions with safety barriers	Canceled Standard
TSE CEN/TS 17342: 2019	Road Restraint Systems-Motorcycle Road restraint systems reduce the impact severity of motorcyclist collisions with safety barriers	Current Standard
TS ISO 6487: 2018	Road vehicles - Measurement techniques in impact tests - Instrumentation	Current Standard

1.3 Study Goals

Preparing a good and reliable decision-making process for VRS design requires an in-depth examination of ROR accidents. Such studies were conducted in the UK in the 2000s, leading to systematic approaches and tools in roadside designs. In the UK, which also follows the EN 1317 standards, a computer-based tool is created to design VRS for major roads. So far, there are no detailed studies on ROR accidents in Turkey nor very systematic RRS design in Turkey. As an alternative to the current, rule-based approach, this thesis proposes a new roadside design approach adopted from the UK approach, which is a systematic assessment procedure for major highways (speeds higher than 90 km/h and traffic volumes greater than 5,000 veh/days). It focuses on detecting the changes in the roadside designs compared to the one according to the current Turkish practice. The comparisons are made over a study corridor of 15 kilometers for the safety barrier along (the nearside of) the road. Both locations and length of need for the safety barrier applications are compared between alternative approaches to understand the differences better.

1.4 Scope of the Study

This study summarizes the RRS standards and guidelines of leading countries like the USA, Germany, and the UK. In Turkey, road design guidelines are generally translated versions of AASHTO standards. However, since Turkey is a European region, it follows the EN1317 standards for RRS used in the EU. The current VRS applications in Turkey are conducted with a simplified German VRS application for compatibility with these EU standards. In this study, the roadside design approach of the UK, which follows the EU standards and high traffic safety results, is examined detailed. The risk-based decision-making mechanism in the UK is redefined for Turkey, and a new approach is proposed.

This study compares the proposed approach and current Turkish practice by conducting case study results. For the case study, a state road with high design speed and high traffic flow in Turkey is selected, and details are presented in related sections. The study corridor roadside design is conducted separately with current Turkish practice and the new proposed approach. The thesis investigates design decisions for only nearside (n/s), which uses to define the vehicle's passenger side in British regulations.

This study does not include the analyses for the offside (o/s), i.e., the central reserve or other VRS applications (i.e., VRS for medians, terminals, crash cushions, arrester beds). The results show the quantity of the required safety barrier lengths, their performance classes, and their locations. Unfortunately, the budget estimation could not be done due to the lack of unit price for the safety barriers. The comparisons are made based on the length of need quantified, selected types, and detected locations.

1.5 Thesis Layout

First, a general background of the roadside design is provided for discussing roadside safety in the world in Chapter 2. Chapter 3 presents the UK roadside safety in detail by giving road safety statistics and summarizing manuals and the current approach, whereas Turkey's road and roadside safety statistics, current roadside design guidelines, and design approach are discussed in Chapter 4. In Chapter 5, the methodology is presented with a new proposed roadside design approach, and the case study corridor is introduced in detail for comparative evaluation. Case study results of the current Turkey practice and the proposed approach are presented, then the comparison of the approaches is detailed in Chapter 6. The overall conclusion and further recommendations are presented in Chapter 7.

CHAPTER 2

BACKGROUND

2.1 Roadside Safety in the World

The concept of “safe roads” includes roadside design and elements as well as the geometric design of the road. As a basic principle, using barriers on the roadside is a method that is applied to minimize the losses that may occur by preventing the vehicles from running off the road or crossing the opposite traffic direction. On the other hand, barriers (concrete, steel, wood), which are fixed structures, are not desirable to be used all over the place, as they can become "obstacles" themselves; therefore, they should be used to reduce the severity of accidents by using it in places where the risk of death is high in case of leaving the road.

In developed countries, "roadside safety," which has its special legislation, has gone beyond the barrier design and has turned into a holistic concept that includes parts such as barrier ends, crash cushions, and motorcycle protection systems (Elvik et al., 2009). The holistic design of roadside elements is a process that requires consideration of more than one criterion. Since it also requires serious budgets economically, roadside barrier applications are prioritized depending on the high traffic volume (and the number of accidents as a natural result) and especially the risk of leaving the road. While the speed of the road, the geometric structure, and other structures on the roadside, which are observed to influence this risk, are the subtitles of the subject, the vulnerable road users (pedestrians and cyclists) seen in urban areas cause the concept of roadside safety to differ from location to location.

The primary aim of roadside safety design is to produce a cost-effective solution in line with the function expected of RRS. For this purpose, it is necessary to define the product that can provide the desired performance by determining how the roadside barriers to be placed on the roadside will interact and react in case of a collision with an errant vehicle leaving the road. Although the EU and the USA have developed standards for RRS, that are accepted worldwide, the procedures and principles regarding where and how RRS will be used are left to countries. This lack of consensus about the application procedure has led to different approaches between countries. When the roadside safety legislations and applications of developed countries are examined, it has been seen that the leading countries are the UK, Germany, and the USA. The development of the roadside safety concept and approaches used are compiled in the following sections.

2.2 Early Road Restraint Systems

When the roadside safety design evolution is examined, it can be said that the first RRS used on the roads was started around the 1950s. The high speeds that emerged with the applications with wider lanes and straight sections on the highways required some precautions in terms of roadside safety. Developed countries with safer roads, such as the USA, Germany, and the UK, were the pioneers of these RRS.

The first safety barrier applications in the USA started for different road sections in the 1950s, as in Figure 2.1 and Figure 2.2. In addition, while there was no roadside safety barrier application in the San Diego freeway image in 1958, the bridge side barrier application suggested that it would be similar to the beginning of the safety barrier application in England. While there was no safety barrier application in the image of 1950 on the Hollywood freeway (see Figure 2.2), it is noteworthy that safety barriers were used in 1951 at the bridge edge and in 1964 at the junction separations of the road. It is thought that safety barrier application has become widespread over the years depending on the road characteristics, as seen in Figure 2.2.

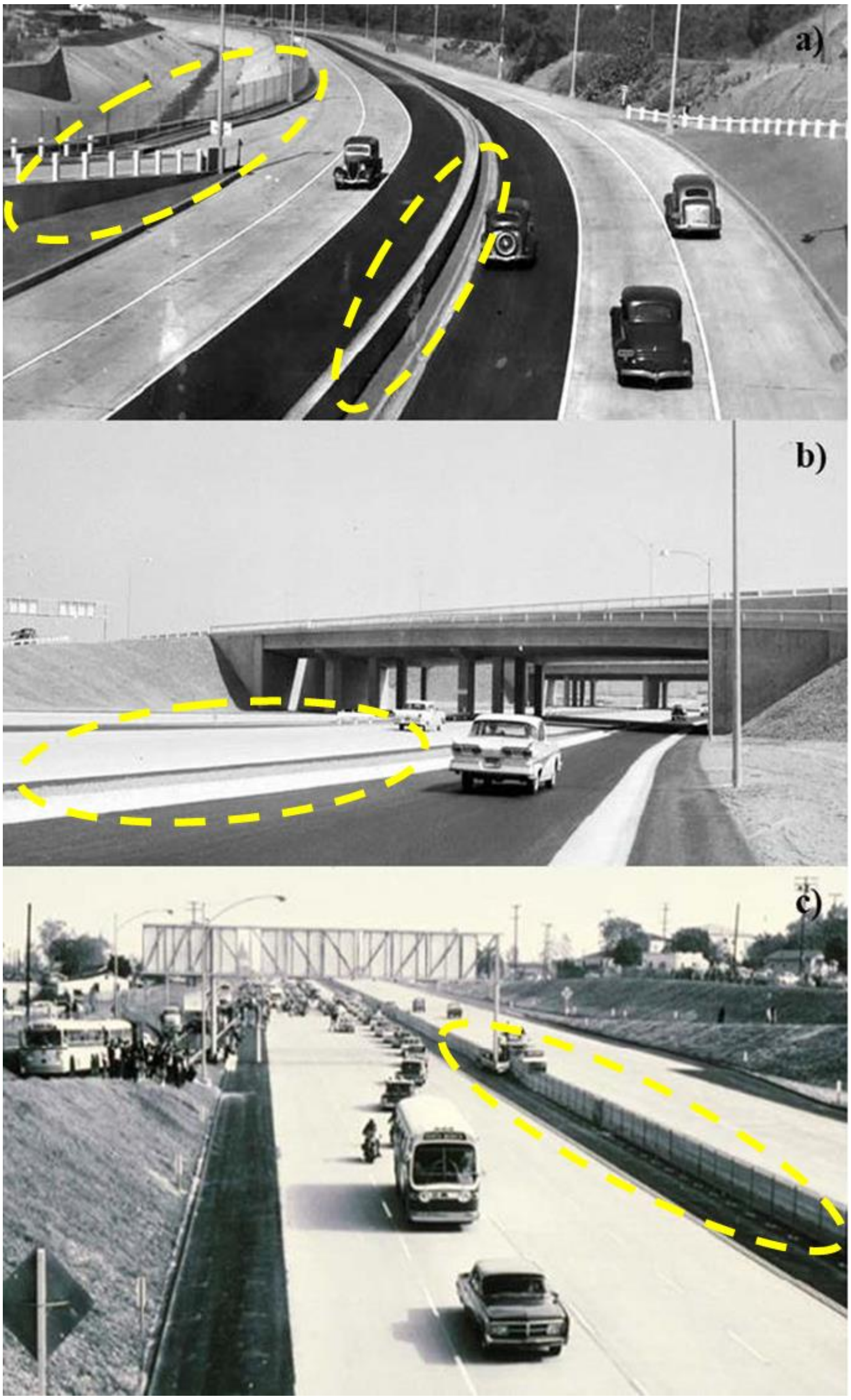

Figure 2.1 (a) Arroyo Seco Parkway (CA-110) in 1940 and (b) San Diego Freeway in 1958, and (c) Santa Monica Freeway in 1966 (Nathan Masters, 2017)

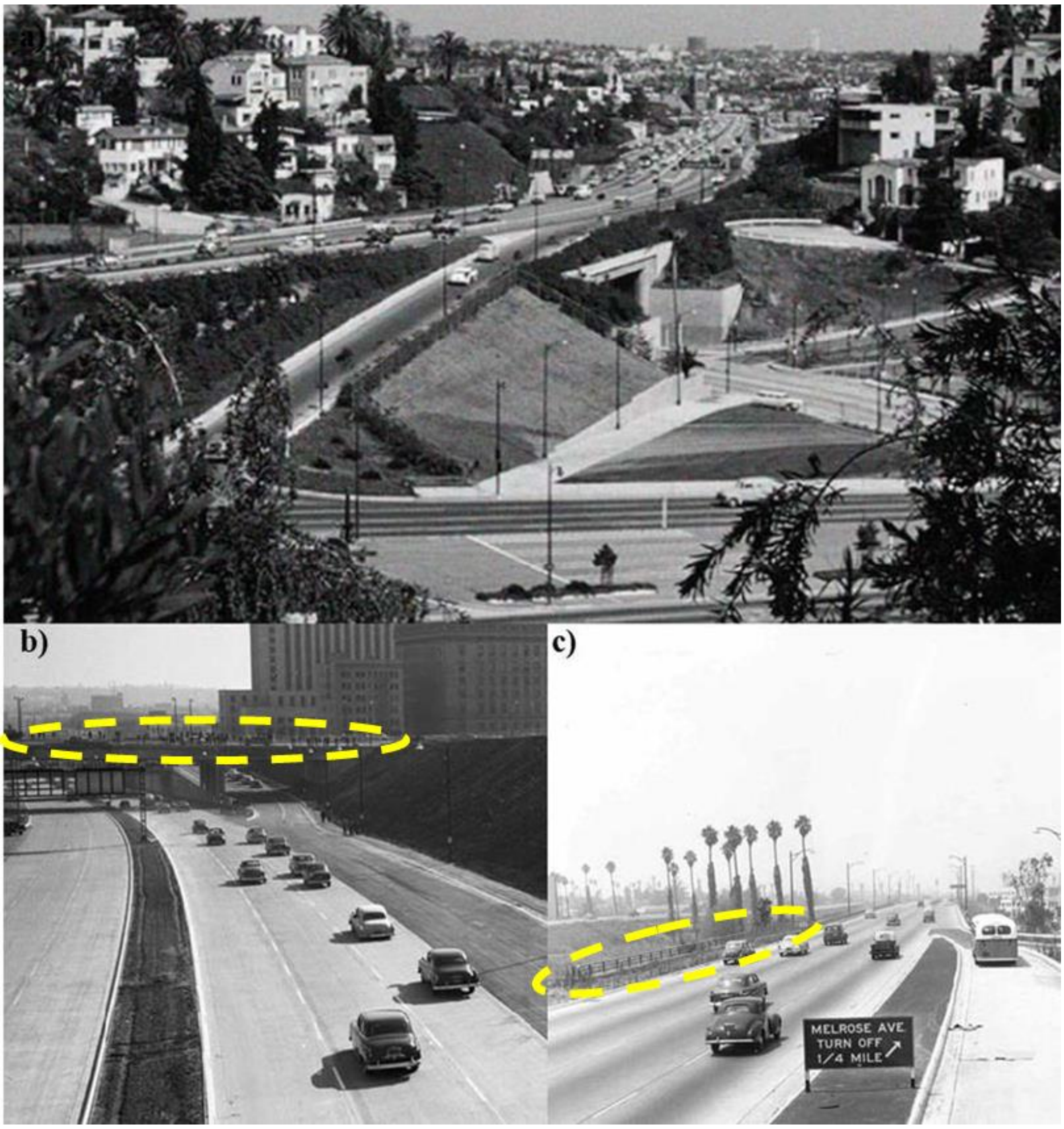

Figure 2.2 Hollywood Freeway (US 101) (a) the Hollywood Bowl in 1950 and (b) the "Downtown Slot" segment in 1951 shortly after opening, and (c) Melrose Avenue in 1954. (Nathan Masters, 2017)

Steel guardrails and concrete crash barriers have been used in Germany since the 1950s. In the 1960s and 1970s, some development and improvement of steel guardrail systems were carried out, and during these studies, crash tests were started (Ellmers, 2001). The first legislation on RRS was “Protective Devices on Roads,” prepared and used in 1989. The currently used legislation, “Guidelines for Passive Protection on Roads by Vehicle Restraint Systems Regulation,” was prepared in 2009 (Heath, 2013).

In the UK, using RRS was negligible before the 1960s. For example, on the Preston Bypass, the first motorway opened in 1958, and in England, steel ropes and guardrails were used only on bridges and bridge approaches or on very steep inclined embankments (Figure 2.3). In the 1960s, with the increase in traffic volume, crash tests were started to evaluate safety barriers' economic and crash performance (Figure 2.4).

Early scientific studies like Newland & Newby (1962) and Newby & Johnson (1964) examine cross median accidents, in which a vehicle crosses the central reserve and enters opposing lanes. In the analysis, it has been shown that two times more people are injured in cross median accidents than in the other accidents. It is also stated that approximately one-third of such accidents result in fatal or very severe injuries.

In another analysis, Moskowitz & Schaeffer (1960) determined that the risk of a head-on collision in cross median accidents is low in areas with low traffic density, and it was stated that AADT should be more than 60,000 vehicles for such accidents to occur. However, in later studies, Woodward & Dolinis (1995) concluded that it would be beneficial to use barriers in areas where the AADT exceeds 35,000.

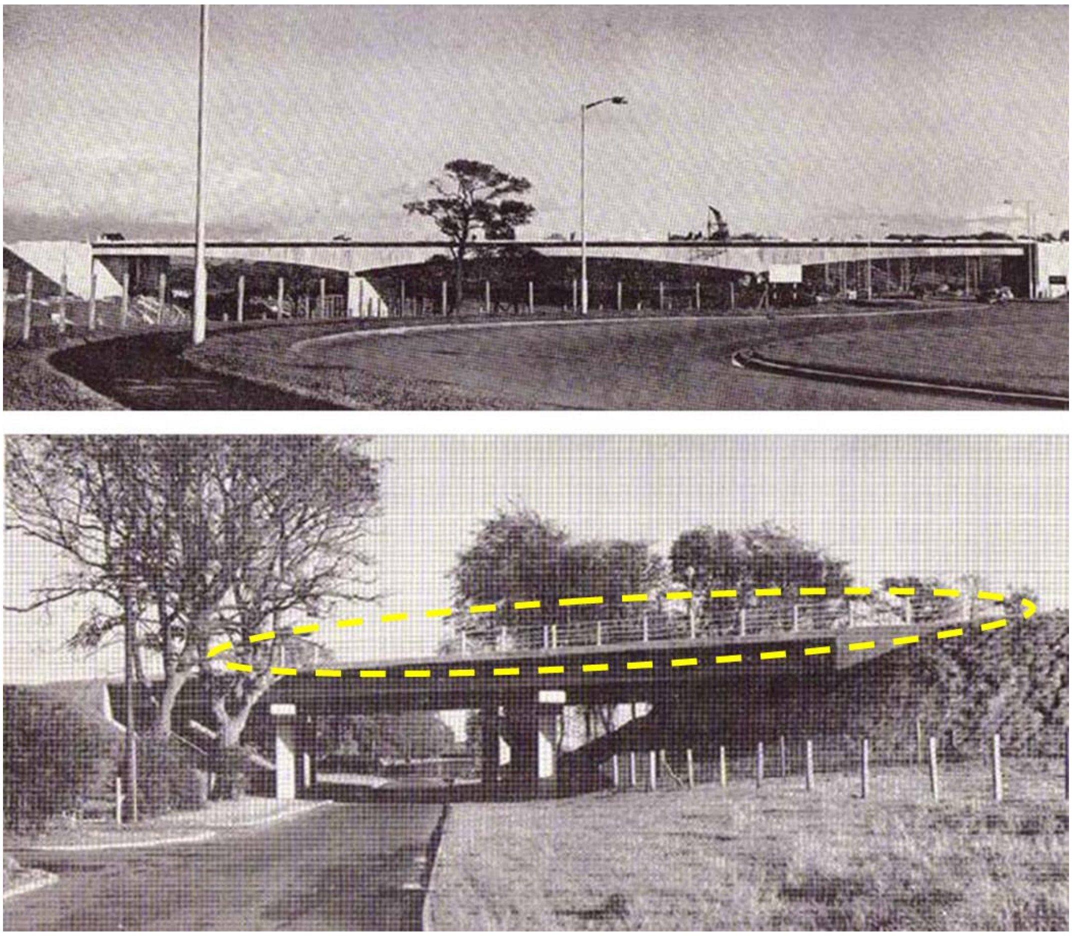

Figure 2.3 Preston by-pass motorway

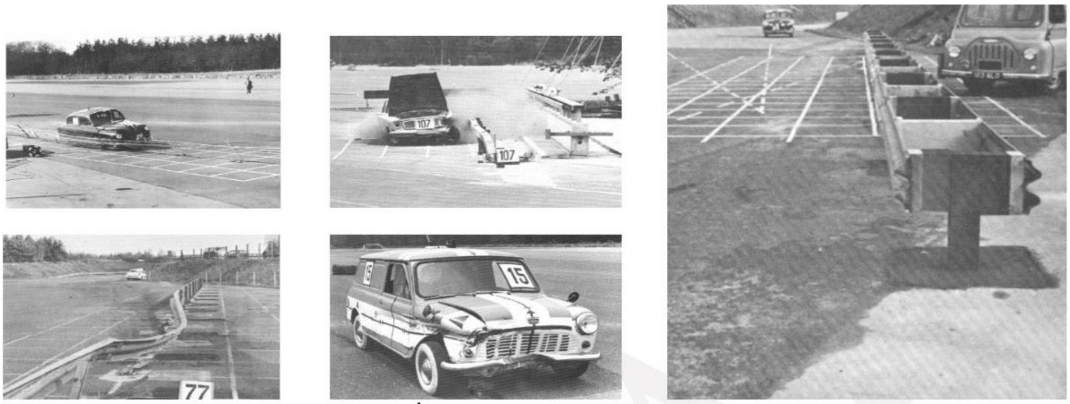

Figure 2.4 First crash tests in the UK

2.3 Roadside Design Principles

Roadside hazards could be a point or distributed, natural or artificial, fixed objects or structures that can cause significant harm to the vehicle occupants or third parties due to the reach of run-off-road vehicles. Such hazards can be found both on the roadside and in the median. The forgiving roadside philosophy includes the requirement that the roadside environment should not contain dangerous elements that could severely injure or kill the occupants of the errant vehicle leaving the road for some reason. A vital component of this philosophy is hazard free and empty safety zone next to the road. However, since this cannot always be achieved for economic and functional reasons, various systems such as RRS (safety barriers, crash cushions) are used to contain vehicles on the road and energy-absorbing (or breaking) poles to minimize potential hazards. Recognizing that all objects placed near a travel lane are potentially hazardous is crucial. Therefore, with the appropriate design of RRS, it is aimed that the possible effects of an accident with the system will be less severe than when RRS is not in place.

2.3.1 Definitions of Risk and Hazard

Although countries' concepts of hazard and risk have similarities in general, they also have some differences. For example, the concepts of “hazard” and “risk” are defined in their most basic form in the UK documents as follows:

- **Hazard:** May cause loss or harm i) road structure/feature (fill, cut, etc.) or ii) an object in the road or on its side (lighting pole, tree, etc.). This loss or harm may be a) physical, b) financial or economic, c) strategic, d) time-based or e) any combination of these.
- **Risk:** The probability that a person or an object will be harmed, either to a high or low degree, by a hazard.

In a more general view, risk can be defined as the probability of reaching the hazard (likelihood) or being hit by an errant vehicle, multiplied by the result when the danger is reached or hit (DfT, 2006).

In the American documents, a survey is conducted with the participation of road safety experts consisting of road engineers, police officers, and safety experts for risk assessment. Within the survey scope, participants are asked to determine an ordinal severity index (SI) ranging from 0 to 10 for the hazard severity of various roadside features such as barriers, geometric road features (such as trenches, slope slopes), and rigid objects, and culverts. Since the beginning of the first studies, this SI scale has been the most common method for determining crash severity. The primary data used to estimate severity is accident data collected by the police, and this data is used with a five-level injury severity scale.

According to the RPS 2009 manual in Germany, the roadside risk is categorized into four hazard levels, areas that may endanger third parties and obstacles that may endanger the passengers inside the vehicle.

<u>A. Areas that endanger third parties</u>

- Hazard Level 1: Areas with particular risk to third parties:
    - Chemical plants,
    - Intensively used locations,
    - Adjacent rapid transit lines with approved speeds of >160km/h,
    - Structures with risk of collapse.
- Hazard Level 2: Areas with particular risk to third parties:
    - Adjacent heavily used walkways,
    - Adjacent bicycle paths,
    - Adjacent rail lines with more than 30 trains every 24 hours,
    - Adjacent roads with ATD>500 vehicles every 24 hours.

<u>B. Obstacles that endanger the passengers inside the vehicle</u>

- Hazard Level 3: Obstructions with a particular risk to vehicle occupants:

    - Non-deformable extensive obstacles parallel to the direction of travel,
    - Non-deformable individual objects,
    - Noise barriers.
- Hazard Level 4: Obstructions with a special risk to vehicle occupants:
    - Rising slopes (cut) with a gradient > 1H:3W (height:width),
    - Falling slopes (embankment) with height >3m and slope >1:3,
    - Intersecting ditches,
    - Bodies of water with a depth > 1 m.

In risk assessment, first of all, the hazard must be determined, and its characteristics must be defined. However, there are differences in practices between countries. In the UK, obstacles are classified according to the impact of the hazard on user groups as "roadside obstructions," "hazards that road users may fall on or into," and "hazards to which others may be affected" (Table 2.1). Evaluation criteria for the identified obstacles as hazards are given in the table. In European countries, the hazard is generally classified as " distributed hazard," "point hazards," "safety barriers," and "other risk factors." Table 2.2 summarizes the country's limitations where the feature in question is defined as a hazard in this classification and the minimum size and location features to be identified as a hazard.

The severity index determines the type of hazard in the USA, and the impact is evaluated by creating a hazard diagram. The dimensions and location of the hazard and the size, speed, and angle of departure of the vehicle leaving the road are parameters of this assessment. In addition, charts have been developed to decide the barrier requirement for various roadside geometries. There are charts for different trench geometries, front and back-slope slopes, and fill heights. Hazards and accidents were examined in a database created within the scope of the EU project RISER, and it was concluded that the point hazards (Table 2.3) and distributed hazards (Table 2.4) indicated below cause severe or fatal injuries (Thomson et al., 2006).

Table 2.1 Some hazards that require assessment if located near roadway (UKRLG, 2011)

Example	Comments
Roadside obstacles	
Retaining walls, including crib walls and gabions, do not have a smooth face adjacent to the traffic extending for at least 1.5m above the adjacent roadway level.	A "smooth" face may include a surface that may have an irregular surface finish subject to the maximum amplitude of the steps and undulations in the surface not exceeding 50mm when measured concerning a plane through the peaks. The plane must be broadly parallel to the road alignment. A structure with a 25 mm wide chamfered construction joint on its surface would be considered smooth. Particular attention must be paid to wall ends and the end of gabion baskets.
Rock Slopes	At exposed rock faces (1 in 1 or steeper).
Reinforced cut slopes	Where there are reinforced, or geotextile reinforced cut slopes. Such slopes may not pose a particular hazard to motor vehicle users, but the consequences of a cut slope problem could be unacceptable. For example, exposed nails and anchors are likely to be a hazard.
Structures	Bridge parapets include the open ends of the edge legs or wing walls.
Trees	Young trees can be seen as a danger because they will grow.
Lighting poles	Unless the lighting column meets passive safety requirements.
Traffic signposts	Poles with a diameter of 89 mm or more unless a passive-safe mast/column is used. (But if a pole with a diameter of 89 mm has a thickness of less than 3.2 mm, then it usually does not need to be protected from vehicles.)
Control panels and poles	No comment
Hazards that road users may fall on or into	
Embankments over 3 m	Especially on the outer side of the curves, the radius is less than 850 m.
Water	A permanent or expected water hazard with a depth of water 0.6m or more, such as a river, tidal water, reservoir, stilling pond, lake/loch, or other hazards which, if entered, could cause harm to the vehicle occupants.
Retaining walls	Where the height is greater than 1.5m.
Culvert headwalls	No comment
Hazards that others may be affected	
Roads, railways, subway entrance	On embankments where there is a road, railway, or other feature, such as a subway entrance, at or near the foot of the slope.
Parks, recreational areas	Public meeting places where a number of people would be present for some time, such as schools, hospitals, recreational, retail facilities, or factories.
Flammable material storage and similar works	Chemical works, petroleum storage tanks or depots, facilities manufacturing or storing hazardous materials in bulk.

Table 2.2 Roadside hazard definitions in some European Countries

	FI Finland	FR France	DE Germany	GB England	NL Netherlands	ES Spain	SE Sweden
Ditches	0.5m; 1:3	0.5m;>1:4	Yes	Yes	>1:3	Yes	Yes
Embankments	2m; >1:3	4m; >2:3	Yes	6m; >1:1	Yes	>8:1	Yes
Earth Fill				1:1 ve >0.75m			
Rock Slopes	7:1	Yes	Yes	>1:2 ve <1.5m	No	Yes	Yes
Retaining walls		Yes		Yes			
Rows of trees/forests hazardous	Yes	Yes		Yes		Yes	Yes
Point Hazards							
Trees girth (cm)	>10cm	>10cm	>7cm	>50cm	>8cm	>15cm	>10cm
Buildings/walls	Yes	<0.7m					Yes
Bridge piers/pillars/abutments	Yes	Yes	Yes	Yes	Yes		Yes
Tunnel entrances		Yes	Yes		Yes	Yes	
Parapets	Yes	> 1.1m	Yes	Yes	Yes		Yes
Bordür / Kadırım Kenarı		>20cm	>7 cm			>10 cm	
Private Property Fences		Yes	No		Yes	Yes	
Culverts and drainage pipes	Yes	Yes	Yes	Yes	Yes	Yes	
Culvert Tips	Yes	Slope 1:2		Yes		Slope 1:6	
Culvert ends/headwalls	Yes	Yes		Yes			
Agricultural Underpasses				Yes			
Infrastructure (Electrical/Telephone) Poles	Yes	Yes	Yes			Yes	Yes
Vertical Signboard Legs	Yes	Yes	Yes	Yes		Yes	
Ramp Entrance Plate	Yes	Yes		Yes			
Large Plate Poles		Yes		<1.5m			
Overhead Signpost	Yes	Yes	Yes	Yes			
Steel Columns	Yes	Yes					
Lighting Poles	Yes	Yes	Yes	Yes			
Non-break-away poles	Yes	Yes		Yes	Yes		
Traffic sign supports	Ø 11.4cm	Yes	Yes	15cm Ø			
High voltage electricity columns	Yes	Yes					
Rocks and boulders	Yes		Yes			Yes	Yes
Electrical Transformers		Yes	No	Yes	Yes		Yes
CCTV Masts				Yes			
Control Cabinets				Yes			
Poles				Yes			
Traffic Counting Stations		Yes					
Any Obstacles on Road Level		> 20cm			> 7cm		
Existing Barrier	Yes	Yes			Yes	Yes	
Barrier Ends	Yes	Yes				Yes	
Other Risk Factors							
Streams, Canals	Yes		Yes	Yes	1m	Yes	Yes
Rivers	Yes			Yes			
Water Tanks				Yes			
Still Ponds				Yes			
Lakes				Yes			
Railway Tracks	Yes		Yes	Yes		Yes	Yes
Other Paths and Directions	Yes		Yes	Road<10m		Yes	Yes
Pedestrian Metro Entrances				Yes			
Vulnerable Road Users	Yes	Yes				Yes	
Medians	Yes			Yes			
Curves				R < 850			
Hazardous Material Storages	Dolgu=3m		R<1500m				
Counting Stations				Yes			
Counting Stations		Yes					
Poles/Columns		Yes					
4-arm junctions				Yes			
Roundabouts		Yes					
District Entrances		Yes					

Table 2.3 Point hazard characteristics for severe or fatal injuries in the RISER detailed database (Thomson et al., 2006)

Hazard	Diameter (m)	Dangerous impact speed (km/h)	Additional comments
Trees and tree stumps	>0.2	40	Typically >0.1 in many national guidelines
-Utility poles -Standard lighting poles (wood, metal and concrete)	>0.2	40	
-Posts of roadside signs	>0.1	40	
-Gantry/large traffic signs -Supports/CCTV masts/High mast lighting columns -Supports/other high mast posts/poles.	>0.1	40	
Rocks and boulders	-	-	
Bridge piers/pillars/abutments		50	
Culvert ends/ headwalls/drainage pipes		-	
Underpasses and other point hazards (rivers, railway)		-	Including those at the foot of an embankment
Safety barrier terminations		-	Blunt barrier terminations and ramped ends that do not bend towards the roadside

Table 2.4 Distributed hazard characteristics identified in the RISER detailed database (Thomson et al., 2006)

Hazard	Height/ Depth [m]	Gradient [m]	Dangerous impact speed [km/h]	Additional comments
Cut (upward) slopes	>1.0	>1:1	40	
Fill (downward) slopes/embankments	>1.0	>1:1	40	In addition, ALL embankments 6 m high or more (i.e., ALL setbacks).
Ditches and drainage gullies (fore & back slope)	>0.75	>1:3	40	
Rock face cuttings/rock fences			50	Any exposed rock face cutting slopes <1.5 m above roadway level.
Retaining walls			-	Less than 1.5 m above roadway level.
Buildings/walls			-	
Non-safety fences				Wire wildlife/boundary fences are not considered hazards.
Old design safety barriers			-	Barriers are not compliant with EN1317 and with poor performance records.
Rows of trees/forests			40	Same measures as for individual trees.
Adjacent roads, railways, water			-	

2.3.2 Clear (Safe) Zone Concept

A clear zone is a safety zone that allows a faulty vehicle to return to the road by leaving it on the side of the road. In 1974, the first applications were to start keeping a distance of 9 meters in high-volume and high-speed rural areas in the USA. It is a multi-parameter issue that considers the angle of the vehicle leaving the road, its speed, the effect of ground friction, and whether there is a dangerous object or feature. It is practiced in different ways in different countries.

Although the definition of a "clear zone" within the roadside is not clearly defined in the British legislation, it is created in practice with the outer shoulders, inner shoulders, and the verges next to the shoulders. A 0.70 m wide shoulder (hard strips) was left on both sides of the central reserve, creating a space for roadside safety applications (see Figure 2.5). On the other hand, while the outer shoulders of the road are kept at a width of 2.75 m -3.30 m, a 1.50 m wide verge is left before the slopes on the highways, creating a clear zone width.

It has been seen that the definition of the clear zone started used in AASHTO documents in the USA after the 1970s (see Figure 2.5). The clear zone distances can range from 2 m to 10 m and are defined according to the design speed, ADT, and roadside geometry. In addition, it has been determined that various charts have been created with vehicle kinematic simulations and actual field tests regarding the design of the roadside geometry and the geometry of the drainage ditches located on the roadside. Although the clear zone concept is still the designer's primary goal in urban areas, many compromises must be made in urban areas and their constrained areas. On the other hand, it is stated that operating speeds in urban areas vary more at different times of the day compared to operating speeds in rural areas, and speeds are usually much higher in free-flow conditions, especially at night, beyond the speed limit. For this reason, it is stated that the designer should consider the possible operating speed in the event of a run-off-road when designing a suitable roadside.

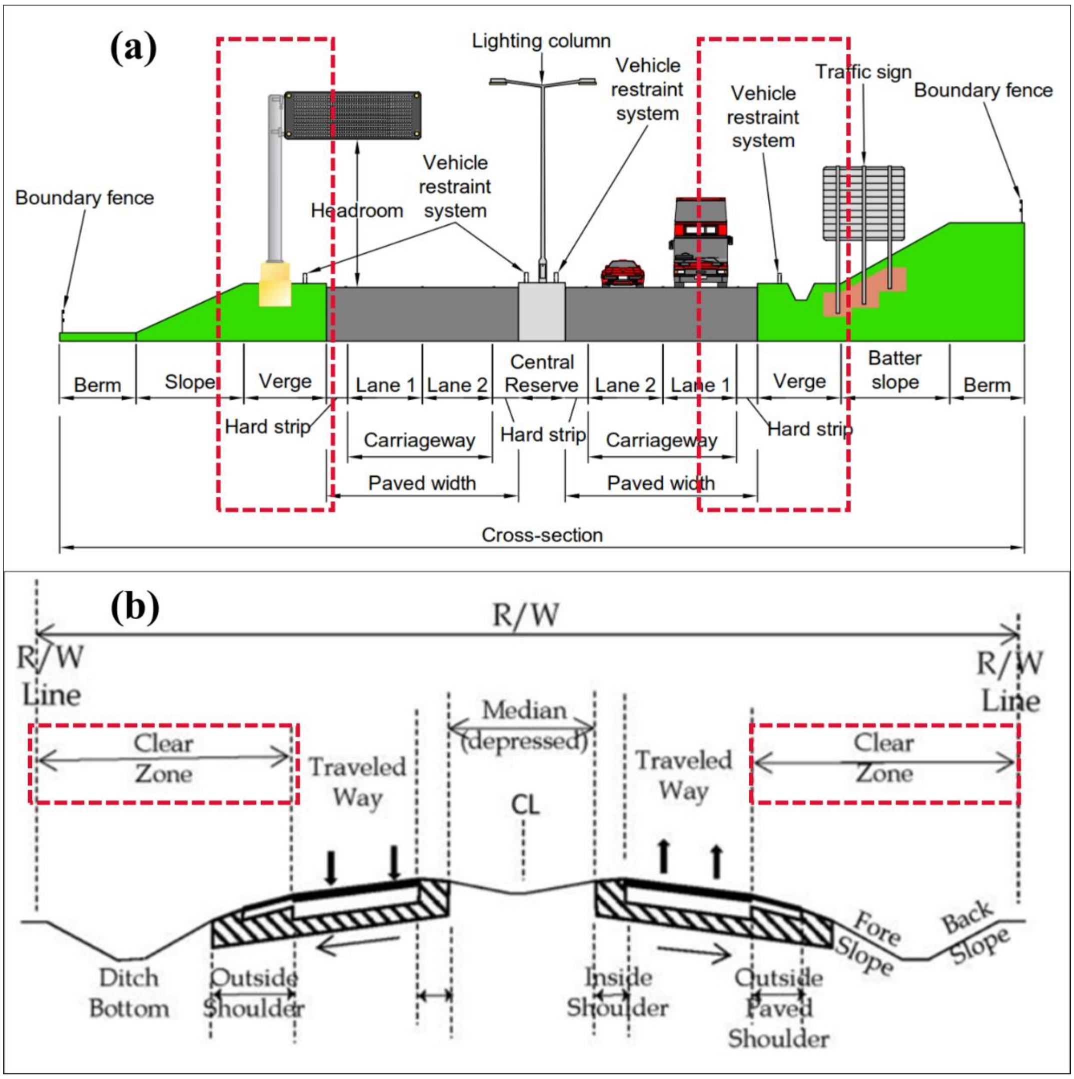

Figure 2.5 Typical rural divided road cross-section (a) in the UK (Highways England, 2021b) (b) in the USA (Tang & Zhang, 2021)

In terms of determining clear zone distances in Germany, clear zone definitions were made for different hazard levels, speed limits, and fill heights in the RPS 2009. At the highest speed limit and the highest hazard level, this zone distance can vary between 15 m and 35 m, while at the lower speed limits and the lower hazard level, this value can vary between 0 and 19 m according to the height of the embankment. Safe zone definitions, effective factors, and distances of some countries taken from Roadside Infrastructure for Safer European Roads (RISER, 2006) are given in Table 2.5, Table 2.6, and Table 2.7, respectively. As seen in Table 2.5, a safe zone definition has been made based on the philosophy of "Forgiving Roads," which assumes that road users may leave the road for some expected or unexpected reasons.

As can be seen from Table 2.6, design speed is an essential parameter in defining the safe zone distance in all countries. It defines the safe zone distance in all countries except the UK, depending on slopes. Road type is chosen as a determining parameter by all countries except Finland and Sweden. In Finland, the operating speed is also considered a parameter besides the design speed. All countries use traffic volume except the UK and the Netherlands. The philosophy used in the Netherlands is that the risk remains regardless of the traffic volume. In addition, road lane width in Spain and Sweden and heavy vehicle traffic in Finland are the other determining factors.

The information about the safe zone and speed given in Table 2.7 is presented graphically in Figure 2.6. As can be seen here, one of the most critical parameters for the safe zone distance is the design speed, although it varies from country to country. Within the scope of the RISER project, it was stated that a single safe zone definition could not be made for the European Region, and it was agreed that the safe zone distance should be wider as the speed increases.

Table 2.5 Safe zone definitions according to some European Countries

Finland (FI)	A safe zone is an object-free zone where there is no hazard.
France (FR)	The safe zone consists of a "rescue area + an empty/open, stationary object-free zone" designed to reduce the severity of an accident.
Germany (DE)	A safe zone is an object-free zone where there is no hazard.
England (UK)	The safe zone is an empty/open zone that should not contain any obstructions. However, if there are obstacles in the area, they must be protected by a safety barrier. The "safe zone" is not explicitly defined, but standard mandatory blank spaces are left for motorways and highways.
Netherlands (NL)	A safe zone is an unobstructed, minimally wide flat zone that does not cause significant vehicle disruptions.
Spain (ES)	A safe zone is an area free of obstructions, hazards, or slopes. It consists of a shoulder and verge as a safe zone in cases where a safety barrier is not required.
Sweden (SE)	Empty/open, object-free zone.

Table 2.6 Factors for safe zone distances in some countries

Factors	**FI**	**FR**	**DE**	**UK**	**NL**	**ES**	**SE**
Road class	No	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	No
Traffic flow	**Yes**	**Yes**	**Yes**	No	**Yes**	**Yes**	**Yes**
Speed	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Slopes	**Yes**	**Yes**	**Yes**	No	**Yes**	**Yes**	**Yes**
Horizontal alignment	**Yes**	No	**Yes**	No	**Yes**	**Yes**	No
Lane width	No	No	No	No	No	No	**Yes**
Others	**Yes**	No	**Yes**	No	**Yes**	**Yes**	**Yes**

Table 2.7 Safe zone distances in some countries (CEDR, 2014)

FI	Distance for the evaluation of the Safety Distance on embankments (new and existing roads)				
	Speed	**Traffic flow (AADT)**			
		<1500	1500-6000	>6000	
	120km/h			6m	There is no distinction between existing roads and new projects. Road type is not a criterion.
	100km/h	4m	4m	6m	
	80km/h	2m	4m	4m	
	60km/h	2m	2m	4m	
	50km/h			2m	
	Distance for the evaluation of the safety distance on cut slopes (existing roads)				
	Speed	**Traffic flow (AADT)**			
		<1500	1500-6000	>6000	
	120km/h			7m	There is no distinction between existing roads and new projects.
	100km/h	5m	5m	7m	
	80km/h	5m	5m	5m	
	60km/h	3m	5m	5m	
	50km/h		3m	3m	

FR	Existing roads		Road class	New roads	
	130km/h	10m	Motorways	130km/h	10m
	110km/h	8.5m	Motorways	110km/h	8.5m
	130km/h	10m	Motorways	130km/h	10m
	110km/h	8.5m	Motorways	110km/h	8,5m
	90km/h	7m	Motorways	90km/h	7m
	90km/h	4m	Expressway	90km/h	7m
	110km/h	4m	Multifunction road	110km/h	8.5m
	90km/h	4m	Multifunction road	90km/h	7m

DE	
DE	Critical distance is determined by using speed limit, hazard level and height of slope based on charts in RPS 2009

UK	Road class	Width	Comments	
	Motorways	4.5m	4.8m for signs and structures	There is no distinction between existing roads and new projects.
	Dual carriageway	4.5m	4.5m for signs and structures	
	Single carriageway	3.5m	Reduced distances in structures, roundabouts, road merging, diverging and junctions	
	Single carriageway	4.5m*		
	*For dual or single carriageways where design speed or operating speed is greater than 80 km/h			

NL	Existing roads		Road class	New roads		Minimum
	120 km/h	10m	Motorways	120km/h	13m	
	100km/h		Motorways	100km/h	10m	
	100km/h		Non-motorway,dual undivided road	100km/h	10m	8
	80km/h		Undivided road	80km/h	6m	4.5
	A 10m barrier-free zone is desired.		The safe zone distance at 100km/h can be reduced by 1.5m per 10km/h speed difference. The best solution is to provide a space of 13 meters.			

ES				Shoulder		Verge	
	Speed	**Lane width**	**Road class**	**Outer**	**Inner**	**Minimum**	**Maximum**
	120km/h	3.5m	Single carriageway	2.5	1-1.5*	0.75	1.5
	100km/h	3.5m	Single carriageway	2.5	1-1.5	0.75	1.5
	80km/h	3.5m	Single carriageway	2.5	1	0.75	1.5
	100km/h	3.5m	Toll roads	2.5	2.5	0.75	1.5
	80km/h	3.5m	Toll roads	2.5	2.5	0.75	1.5
	100km/h	3.5m	Roads	1.5-2.5	1.5-2.5	0.75	1.5
	80km/h	3.5m	Roads	1.5	1.5***	0.75	1.5**
	60km/h	3.5m	Roads	1-1.5	1-1.5***	0.75	1.5**
	40km/h	3m	Roads	0.5	-	-	-
	*For medians with barrier next to the shoulder ; **For roads in mountainous areas with low ADT *** For roads over mountainous region with low ADT. It provides a justification for taking the shoulder width as a maximum of 0.5 m.						

SE	Speed	Standard			
		High	**Moderate**	**Low**	
	110km/h	>10m	>6m	<6m	There is no distinction between existing roads and new projects.
	90km/h	>9m	>4.5m	<4.5m	
	70km/h	>7m	>3m	<3m	

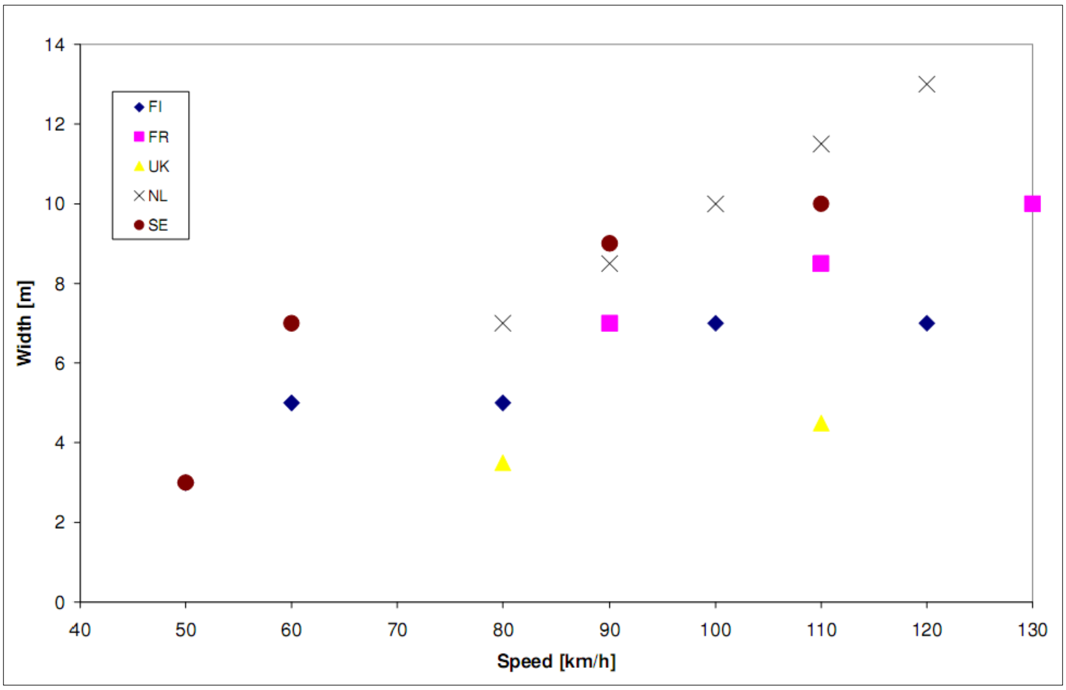

Figure 2.6 Clear zone widths as a function of speed in EU countries (la Torre et al., 2013)

2.4 Roadside Risk Assessment Processes

The "As Low As Reasonably Practicable" (ALARP) principle, used in decision processes in the UK, is not only used in the evaluation of RRS but also as a general evaluation criterion. Although it does not have an exact numerical equivalent, it becomes clear with the comments made by the experts on the subject. In addition, the monetary value of the benefit gained can be determined depending on the monetary value of the improvement investments. This concept does not exist in Turkish legislation. The values that can be used for the monetary compensation of the improvements made at the black spots (life cost, serious injury accident cost) are not included in the local legislation. For this reason, there is no roadside safety assessment system based on economic assessments.

The RRS decisions are always integrated with the UK Road Safety Audit (RSA) in the UK. The road safety audit (RSA) is a safety examination process of a planning road and intersection. This process is formal and systematic, an independent multidisciplinary team (Demirel, 2019). The RSA in Turkey conducts by the authorities instead of independent third parties; due to the conflict of interest created in the process, the evaluation process could not give reliable results.

In the UK, RSS decisions are made for major roads with high speed and flow, unlike other roads. After the major railway crash occurred at Selby in Yorkshire in 2001, a working group was assembled under Highways England (formerly Highway Agency) to prepare provision of the safety fences on major roads in the UK. This crash occurred because a run-off road vehicle landed on the railway track, and the working group examined the issues in detail and created a new risk theory-based RRS. It enables the risk analyses of all road construction processes and makes the risk assessment process transparent. The software called RRRAP is developed to make the risk assessment process consistent on all the major roads in the UK (Heath, 2013).

In Germany, the performance of a safety barrier (guardrail) is determined by the containment level, the working width class, and impact severity level in the DIN EN 1317-2 standard. A flowchart has been designed to determine these containment levels. In this flow chart, a containment level can be selected based on four different hazard levels, for different speed limits, according to AADT and HGV traffic density in cases where a run-off-road accident is probable.

According to RPS-2009, the possibility of running off the road should be considered when choosing a VRS. Areas with a high probability of running off the road could be the following road sections.

- Roads with radius connections outside the usable area according to RAS-L (road building specification)
- Multiple successive curves with radii less than 1.5 times the minimum permitted radius according to RAS-L

- Routes with unexpected significant changes of direction

The following situations should assume a higher probability of running off the road.

- In areas of existing roads with an accident frequency according to the criteria of the 3-year map under the "Code of Practice for the Assessment of Road Traffic Accidents, Part 1", in which the accident type running off-road predominates,
- for sections of existing roads, for which other apparent accidents are known

Thus, accidents involving trucks and accidents involving all vehicles that endanger third parties are decisive.

In the USA, many cost-benefit analysis methods have been developed since the 1970s. These methods are generally based on encroachment probability and crash data. The encroachment probability-based method examines the relationship between the frequency of accidents and the frequency of vehicles crossing the border. This relationship is a function of road type or functional class and average daily traffic. The encroachment is assumed to have a random and uniform distribution along straight road sections with no slope. The crash data-based method uses statistical methods such as typical regression models developed from analyzes of police crash data to estimate crash frequency and severity. The most important advantage of this method over the encroachment probability-based method is that it uses actual accident data. Studies on the estimation of accident severity first started with developing a cost-effectiveness method based on the encroachment probability-based method. Therefore, some adjustments have been made to increase the consistency of the SI scale and facilitate its use in Roadside Safety Analysis Program (RSAP). First, on the SI scale, speed was associated with impact speed rather than design speed (Mak et al., 2003). The AASHTO Roadside Design Guide (2011) determines the average intensity or SI value for various roadside objects and features according to the road types. These SI values are placed on the linear regression line for each roadside object and feature as a velocity function.

2.5 RRS Performance Standards

Since the UK and Germany are founding members of the European Committee for Standardization (CEN), they also accept the harmonized European Standards as their standards and are responsible for their use in their own countries. Although there are different prefixes (British Standard-BS and German Standard-DIN), the harmonized EN 1317 standard is used to evaluate roadside safety elements' performance in both countries.

In the USA, the crash test procedures used to evaluate the performance of roadside safety elements, which have constantly been evolving since the 1960s, were updated in 2016 with the AASHTO-MASH guide of the American Association of State Highways and Transportation Officials. Although the AASHTO-MASH evaluation criteria are required for new systems to be built and existing roadside safety systems to be replaced in the USA, the NCHRP-350 guide was developed by the National Highway Association Research Program in 1993 and is still in use in some states.

Therefore, NCHRP-350 and AASHTO MASH are used in the USA to determine the performances of roadside safety elements, and the harmonized EN 1317 standard is used in the UK and Germany. It can be said that the common feature of all three standards is the use of full-scale dynamic impact tests. These crash tests are generally performed on flat terrain with vehicles representing field conditions at certain speeds and angles. As for performance outputs, the roadside restraint systems' structural adequacy and deformation, road users' safety, and the post-collision behavior of the crashing test vehicle are evaluated. However, there are differences in the methods of assessing the risk of injury in the vehicles used in the test, the crash conditions, the performance evaluation of the roadside restraint systems, and the evaluation of the safety of road users.

According to EN 1317-2 standard for England and Germany, basic requirements such as containment level, impact severity level, working width, dynamic displacement, and vehicle intrusion distance are considered. On the other hand, in the USA, the performance of barriers is evaluated according to structural adequacy, road user safety, and post-impact vehicle behavior using similar evaluation criteria in both NCHRP 350 and MASH. The requirements for standard crash tests used in the performance evaluation of barriers for three countries are shown in Table 2.8.

Although the USA legislations inspire the road design guidelines and practices in Turkey, as stated before Turkish Standards Institute (TSE) accepts and follows the EN standards as a member of CEN. For currently using. The current standards for determining RRS performance criteria in Turkey come from the EN with the prefix TS (see Table 1.1). To better understand the crash test standards in Turkey, EN 1317-2 are summarized in the next section.

Table 2.8 Requirements for standard crash tests and containment levels for the US, UK, and Germany

a) Normal Containment Level

Country	**USA**										**UK - Germany**		
Standard	AASHTO MASH				NCHRP-350						EN 1317-2		
Containment Level	TL-1		TL-2		TL-1			TL-2			N1	N2	
Vehicle type	P	T	P	T	P	P	T	P	P	T	P	P	P
Mass of vehicle (ton)	1.1	2.27	1.1	2.27	0.7	0.82	2	0.7	0.82	2	1.5	0.9	1.5
Impact speed (km/h)	50		70		50			70			80	100	110
Impact angle (degree)	25		25		20	20	25	20	20	25	20	20	20
P: Passenger vehicle - T: Truck													

b) High Containment Level

Country	**USA**												**UK - Germany**					
Standard	AASHTO MASH					NCHRP-350							EN 1317-2					
Containment Level	TL-3		TL-4			TL-3			TL-4				H1		H2		H3	
Vehicle type	P	T	P	T	SAT	P	P	T	P	P	T	SAT	P	SAT	P	B	P	SAT
Mass of vehicle (ton)	1.1	2.27	1.1	2.27	10	0.7	0.82	2	0.7	0.82	2	8	0.9	10	0.9	13	0.9	16
Impact speed (km/h)	100	100	100	100	90	100	100	100	100	100	100	80	100	70	100	70	100	80
Impact angle (degree)	25		25	25	15	20	20	25	20	20	25	15	20	15	20	20	20	20
P: Passenger vehicle - T: Truck - SAT: Single axle truck- B: Bus																		

c) Very High Containment Level

Country	**USA**														**UK - Germany**			
Standard	AASHTO MASH						NCHRP-350								EN 1317-2			
Containment Level	TL-5			TL-6			TL-5				TL-6				H4a		H4b	
Vehicle type	P	T	AT-T	P	T	AT-T	P	P	T	AT-T	P	P	T	AT-T	P	AT	P	AT-T
Mass of vehicle (ton)	1.1	2.27	36	1.1	2.27	36	0.7	0.82	2	36	0.7	0.82	2	36	0.9	30	0.9	38
Impact speed (km/h)	100	100	80	100	100	80	100	100	80	80	100	100	100	80	100	65	100	65
Impact angle (degree)	25	25	15	25	25	15	20	20	25	15	20	20	25	15	20	20	20	20
P: Passenger vehicle - T: Truck - AT: Articulated truck																		

2.5.1 Crash Test Standards EN 1317-2

The crash test acceptance criteria and test methods of the performance classes of safety barriers, including vehicle parapets, are designed to protect passengers and other road users and to keep vehicles running off the road safely on the road, by being installed on the side of a road or in the median, are detailed in the EN 1317-2 standard. When the performance requirements of safety barriers are examined, it is seen that the EN 1317-2 standard includes basic requirements such as containment level, impact severity level, standardized working width, standardized dynamic displacement, and standardized vehicle intrusion distance regarding dynamic crash tests. Performance requirements for dynamic crashes are derived from standardized crash tests. Information on these standardized tests is given in Appendix B.

The requirements for the containment levels of safety barriers are given in Table 2.9. As seen from the table, 15 levels were determined for four different containment level groups, and it was stated which of the dynamic crash tests should be applied for each containment level. Although it is stated that the crash tests for low angles should only be applied to temporary safety barriers, they can also be tested at higher road containment levels if desired. Again, as can be seen from the table, two different tests are required for small vehicles and heavy goods vehicles for the containment levels in the "H" group. For the road containment levels in the "L" group, three tests must be carried out with the addition of a 1500 kg vehicle at high speed.

Table 2.9 Acceptance tests for containment levels specified in EN 1317-2 (CEN, 2010)

Containment levels		**Acceptance tests**
Low angle containment	T1	TB21
	T2	TB22
	T3	TB41 and TB21
Normal containment	N1	TB31
	N2	TB32 and TB11
Higher containment	H1	TB42 and TB11
	L1	TB42 and TB32 and TB11
	H2	TB51 and TB11
	L2	TB51 and TB32 and TB11
	H3	TB61 and TB11
	L3	TB61 and TB32 and TB11
Very high containment	H4a	TB71 and TB11
	H4b	TB81 and TB11
	L4a	TB71 and TB32 and TB11
	L4b	TB71 and TB32 and TB11

In addition, two indices are developed for driver's safety during the crash tests. The acceleration intensity index (ASI) measures the impact's severity, and the theoretical head impact velocity (THIV) measures the severity of the driver's head during the impact. The impact severity level is defined as three classes A, B, and C. For a passenger in a run-off-road vehicle, crash level A provides higher safety than level B, and level B provides higher safety than level C. These levels are calculated only in crash tests, index values, and the impact severity level shown in Appendix B.

Finally, the deformation of the safety barriers during the crash tests is expected to be within certain limits. Expected deformation of safety barriers, dynamic displacement (D_m), working width (W_m), and vehicle intrusion distance (VI_m) are measured by three parameters (Figure 5-1). Dynamic displacement (D_m) refers to the maximum dynamic lateral displacement at any point of the barrier facing the road at impact. The working width (W_m) is the distance between any point of the pre-impact barrier facing the road and the point where the maximum lateral displacement occurs after the impact. Vehicle intrusion distance (VI_m) is defined as the distance between the maximum lateral position of the vehicle at the time of impact and any point of the barrier facing the road before the collision. These parameters, which are determined with the help of high-speed cameras, are standardized using post-test measurements. Dynamic displacement, working width, and vehicle intrusion distance are also used to define the requirements for installing each safety barrier and the distances that must be left in front of the barriers to ensure satisfactory operation of the system. During the test, the vehicle's behavior is also observed since more than one wheel of the vehicle is not desired to cross the barrier. Also, the vehicle is expected to stay in the lane at a certain distance without overturning. Appendix B presents working width (W_m), vehicle intrusion distances, and classes (VI_m) in EN 1317-2.

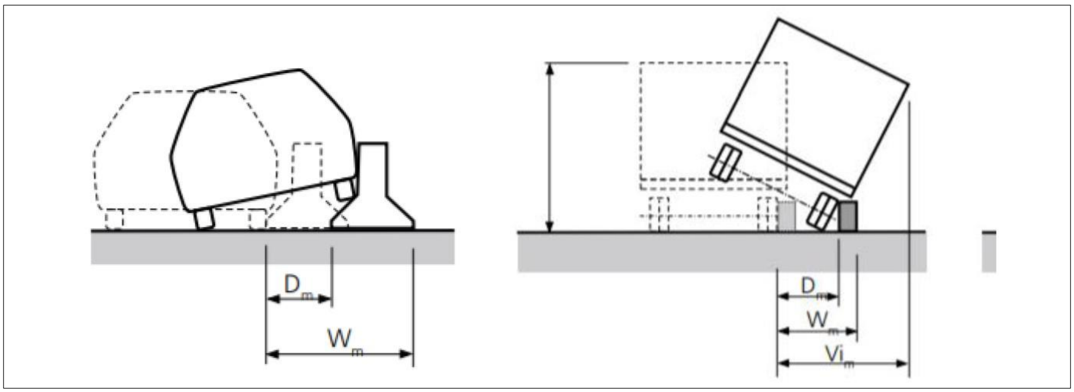

Figure 2.7 Dynamic displacement (D_m), Working Width (W_m), and Vehicle Intrusion distance (VI_m)

2.5.2 Design Criteria of Road Restraint Systems

In the UK and Germany, the harmonized EN 1317-2 standard is used in the design of safety barriers since both countries comply with the European Union Acquis. It has been explained in the previous section that NCHRP-350 and AASHTO-MASH, which have crash test criteria used in the USA, show some differences according to the EN 1317-2 standard. These standards determine barrier performance according to containment level, working width class, and impact severity level.

As the minimum performance criteria for safety barriers in the UK, the N1 containment level is sought on roads where the speed limit is lower than 80 km/h. N2, H1, H2, and H4a containment levels are sought on roads with a speed limit above 80 km/h. The containment level for high-speed and high traffic flow is determined by RRRAP and can exceed the minimum when necessary. Although the impact severity levels are desired to not exceed the B class, in cases where the working width is insufficient, ASI $\leq$ 1.9 and THIV $\leq$ 33 km/h criteria are sought. As the working width class, the design organization is required to choose the largest working width class that the road geometry will allow. The lengths of the safety barriers can vary between 30 to 45 m before and between 7 to 18 m after the hazard, based on the determined containment level.

In Germany, a flow chart shown in RPS 2009 is used to determine the containment level. In this flow chart, for four different danger levels and speed limits, a containment level can be selected according to AADT and heavy vehicle traffic density in cases where there is a possibility of leaving the road. When this flowchart is examined, it will be seen that the minimum containment level is N2, unlike in the UK. For the highest risk level, if there is a possibility of leaving the road on the road above 50 km/h and there is a density of more than 3000 trucks per day, this containment level is chosen as H4b. Again, even if there is no possibility of leaving the road at the same risk level and there is no 3000-truck traffic per day, the containment level is determined as H1. It was stated that the minimum B should be chosen as the impact severity level, but it was stated that C could also be used in areas where the probability of heavy vehicles running off the road is high. In terms of working width, it is also stated that in the hazards arising from embankments and rivers, if the targeted containment level cannot be selected in the flow chart, the next working width class can be selected if necessary.

Roadside barriers used in the USA are generally classified as flexible, semi-rigid, or rigid depending on their deflection characteristics due to an impact. AASHTO and FHWA list all approved barriers. In order to decide on the use of the barrier, a chart has been developed according to the height and slope rate of an embankment. Also, another similar chart was prepared to include ADT. In addition, it has been stated that some objective criteria for pedestrians, cyclists, and motorcyclists have not been developed yet, and some practices related to roadside design have been shared. For example, the application of raised curbs on low-speed limits or creating a buffer zone on roads with speeds over 40 km/h. It has been stated that TL-3 barriers are the most widely used systems in the USA, and TL-2 barriers have been developed for passenger and light commercial vehicles where a speed limit of 70 km/h or less is declared. When the crash tests used in the USA and the EU are compared only in kinetic energy, it can be said that the TL-3 barriers commonly used in the USA correspond to the H1 inhibition level according to EN 1317 (Hubbell, 2013).

Similarly, TL-2 barriers correspond to the N2 inhibition level. On the other hand, after it was decided that a roadside barrier would be installed in the USA, an unambiguous definition of which class it would be selected was not made, and some general rules that could be followed were mentioned. It is stated that road classification, speed, traffic volume and composition, road alignment, working width of the barrier, intersection visibility, impact frequency, and construction and maintenance problems should be considered as factors to be considered in the selection of the barrier, and a benefit/cost analysis should be made.

It can be seen that the standards for RRS are prepared only with cars and heavy vehicles in mind. Also, based on the crash test speed limits, it can be said that standards are for high-speed roads. Since urban speed limits are low and many other factors affect the RRS provision, studies and standards focus on rural areas. There are ongoing researches and studies on draft version standards for vulnerable road users such as motorcyclists, cyclists, and pedestrians. However, the manuals and standards do not cover these vulnerable users in detail; they make recommendations about the issues. Since the city crossings are urban areas with vulnerable road users, the design speeds are lower than the rural sections. The safety barrier provisions for the rural areas could not be applied to city crossing.

Although there are standards for RRS that focus on rural roads, there is no consensus on the design and application of roadside design globally. Many countries have local legislations for roadside design principles, mostly in association with Road Safety Audit/Inspection (RSA/RSI) mechanisms. However, the UK and Germany USA are leading countries with thorough documentation affecting many other countries. The UK and Germany have well-documented roadside design approaches in the European region. While German regulations are more based on rule-of-thumb principles, UK legislation has a more structured approach. Especially for major roads, it uses software to assess the risk with many parameters as a decision support tool. Since the UK approach is well documented and includes a different perspective from the German approach, which inspires the Turkish practice, this study aims to show how different roadside design results could be achieved if the UK approach is adopted in Turkey.

CHAPTER 3

ROADSIDE SAFETY IN THE UK

3.1 Road Network and Road Safety in the UK

The Department of Transport (DfT) is the administration that creates high-level transportation plans and policies with its subordinate Nongovernmental Organizations (NGOs). Highways Agency, another important highway infrastructure institution, was transformed into a state-owned limited company after the new regulations and was named Highways England. This company is responsible for managing both highways and some main intercity arteries.

In the UK highway definitions, some corridors are considered major roads by emphasizing their regional importance, while the remaining ones are called minor roads. This road classification system guides drivers to the most suitable routes to reach their destination. The Road network classification in the UK is shown in Figure 3.1. Motorways are included in the class of major roads; all roads other than these are classified into four groups Class A road (A-road), Class B Road (B-road), Class C Road (C-road), and unclassified road (U-road). A-roads are major roads that form the main network of arteries. B-roads are a lower volume class of roads generally of a lower geometric standard and form connections to A-roads. They often serve smaller settlements or connect roads in urban areas with higher flow roads. C roads are considered less critical than B or A roads, and they are usually undivided highways consisting of two lanes and carry less traffic volume. They connected A and B roads to unclassified roads and generally have a low volume intended to connect a residential area or a village to the transport network. Unclassified (U) roads serve urban and rural residential areas with very low traffic volumes.

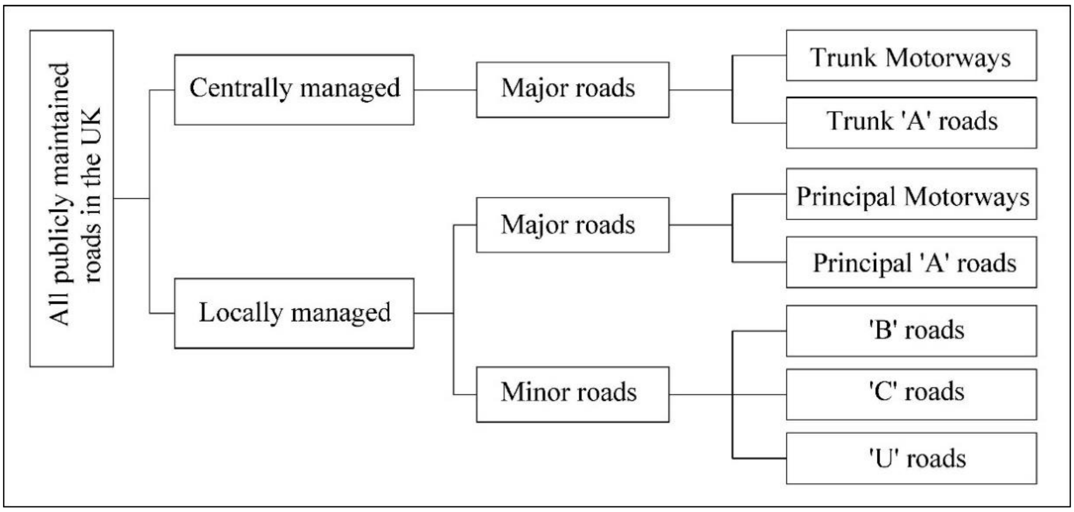

Figure 3.1 Road network classification in the UK (DfT, 2019)

The speed limits according to vehicle types on different road classes in the UK road network are shown in Figure 3.2. As can be seen, even on motorways, the speed limit is defined for cars, buses, and light commercial vehicles with a maximum speed of 70 mph (112km/h). Local governments can reduce these speed limits where necessary (e.g., 50 mph instead of 60 mph in sharp curves). Speed limiter usage is mandatory for vehicles with a passenger capacity of more than eight people and all commercial vehicles with a laden weight of more than 3.5 tons. The speed limit of 30 mph, i.e., 48 km/h (approximately 50 km/h), has been set legally for all vehicles on built-up roads. The safety of pedestrians and cyclists in urban areas or on the streets of rural settlements is a priority; in settlements with heavy pedestrian and cyclist traffic, the speed limit is 20 mph (approximately 32 km/h) (DfT, 2013).

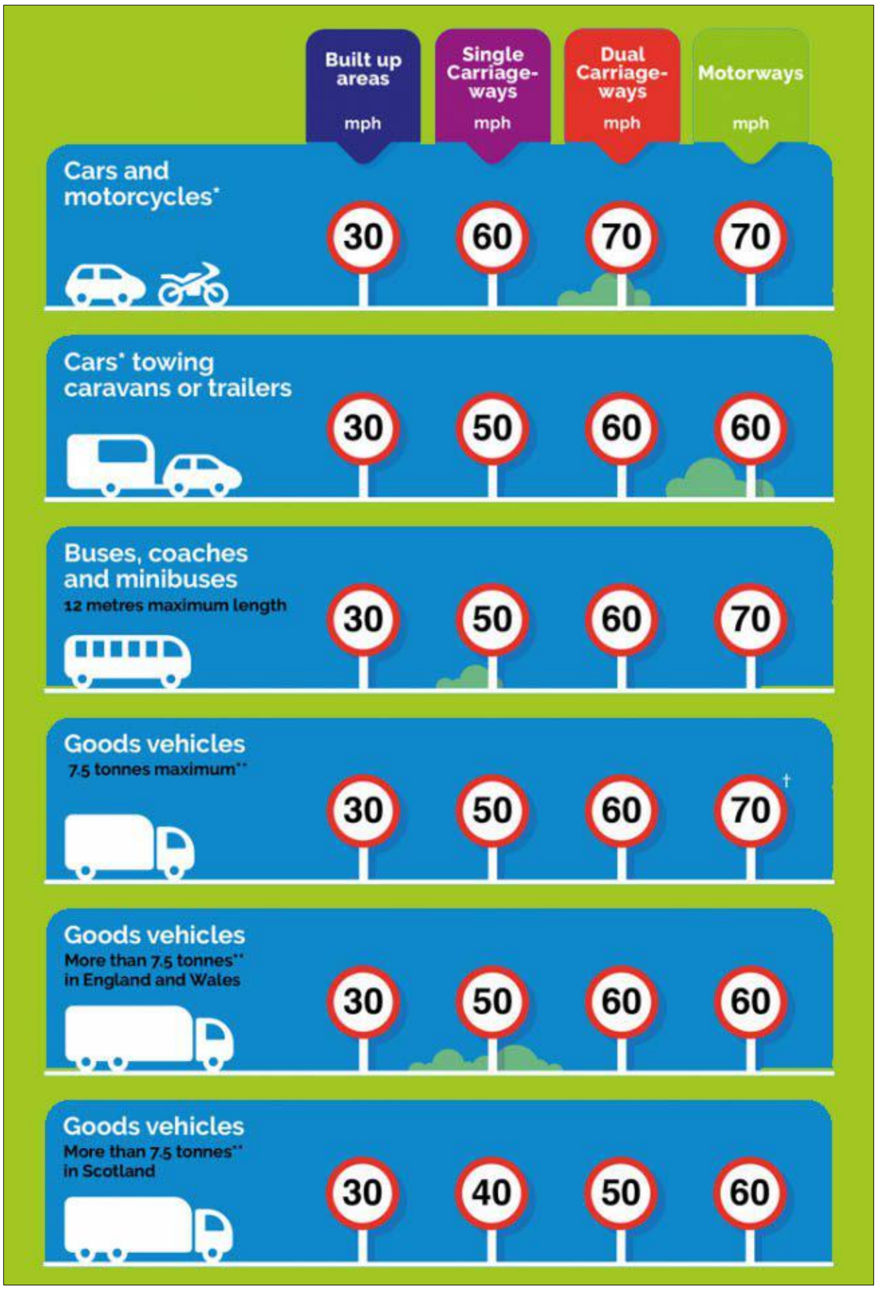

Figure 3.2 Speed limits on the UK road network

In the post-World War II period, when motor vehicle ownership increased rapidly, traffic accidents also increased in serious numbers in the UK. As seen in Figure 3.3, at the end of the 1970s, the number of deaths in traffic accidents reached 6,352 people, while the total number of vital damaged people (number of dead and injured) reached 334,513.

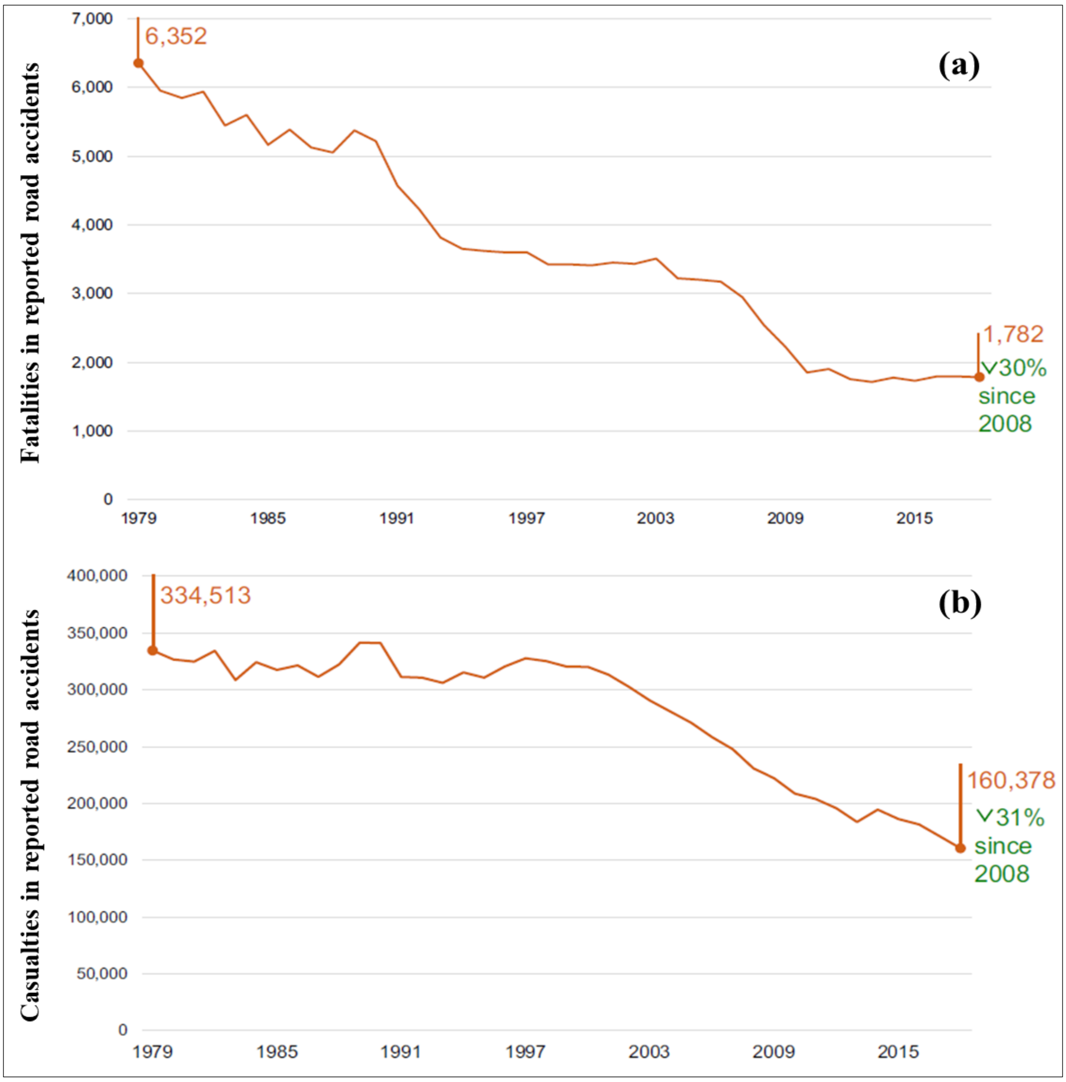

Figure 3.3 Between 1979 and 2018, (a) the number of deaths and (a) total vital damaged people (dead or severely injured) in traffic accidents (DfT, 2019)

Over the past three decades, the UK has significantly reduced casualties from traffic accidents. The number of deaths in traffic accidents was reduced to 4,000 people per year at the beginning of the 1990s. Thanks to measures and efforts, it decreased to 1,782 people in 2018, especially with the improvements after 2005. At the end of 40 years, a 72% decrease in the number of dead was achieved. Although the same success was not achieved in the total number of dead and injured, an improvement of 52% was achieved by decreasing to 160,378 people.

When we look at the normalized values proportional to the total number of accidents or losses as well as traffic volumes (see Figure 3.4), the number of fatalities per billion vehicle miles traveled fell substantially from 2008 (8.1) to 2010 (6.0), then fell slightly more in 2018, with 5.4 fatalities per billion miles traveled. The number of people killed or severely injured per billion vehicle miles decreased substantially until 2010 and then decreased slightly to 89.3 people killed or severely injured per billion vehicle miles in 2018. The reason is that the number of fatalities and serious injuries has remained relatively consistent since 2010, but traffic has grown during the same period. From 2008 to 2018, the casualty rate per billion vehicle miles declined by 34%, from 735.7 to 483.9 casualties per billion vehicle miles.

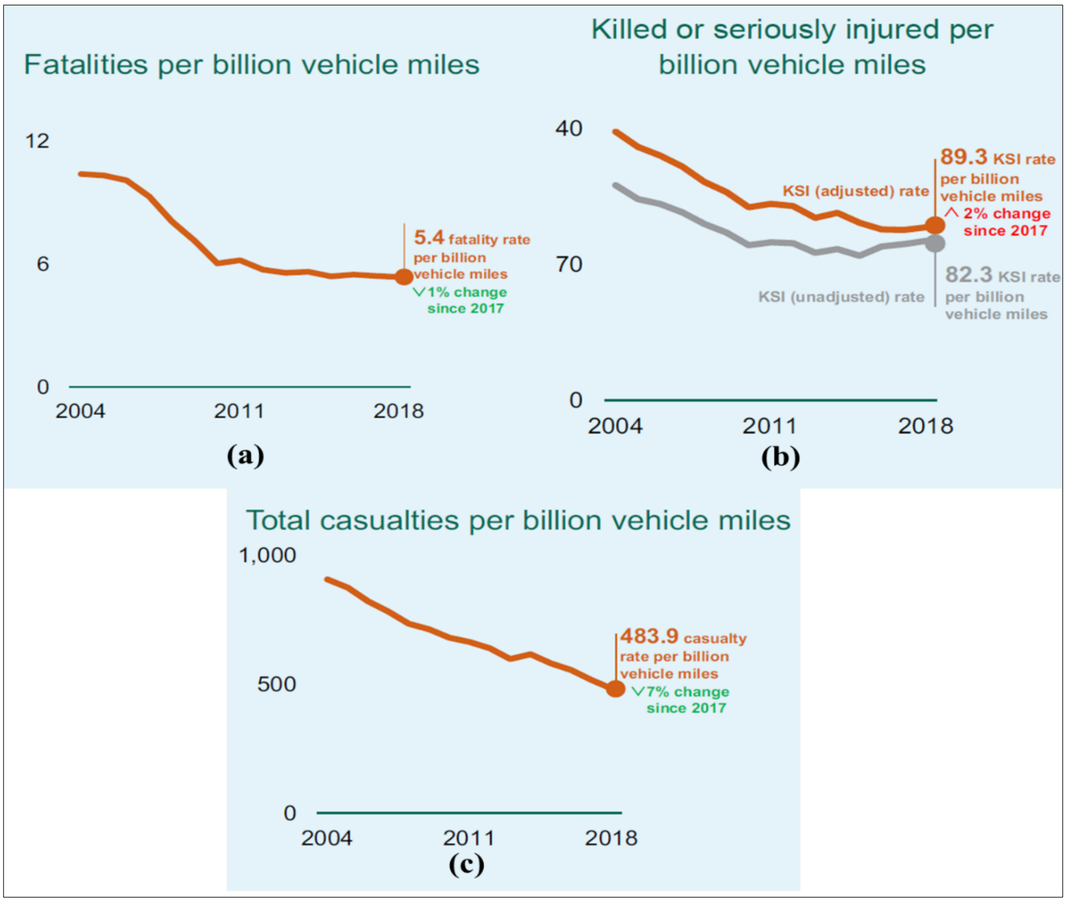

Figure 3.4 Change in (a) number of deaths, (b) number of dead-serious injuries, and (c) the total number of dead-injured per billion vehicle-km between 2004-2008 (DfT, 2019)

3.2 Run-off-Road (ROR) Accidents in the UK

Although the UK is one of the leading countries in the world in traffic safety and safe road design, when the accident rates are considered, it is seen that the losses in traffic accidents are at a high rate. Although the risk per mile is low, the number of ROR killed or severely injured in accidents is very high and accounts for most road traffic accidents. For example, 2,057 fatal accidents occurred in 2009 on all roads of the UK, which means that the ROR accidents proportion accounts for nearly half of all fatal accidents in the UK (UKRLG, 2011). For this reason, data from annual accident statistics reports of the DfT were analyzed for ROR accidents. These analyses were conducted separately for different road types (motorways, built-up roads, non-built-up roads), and a general evaluation was carried out for all roads. The statistics obtained through a detailed examination of both the return periods and the objects hit in ROR accidents are shown in Table 3.1, Table 3.2, and Table 3.3 (UKRLG, 2011).

When ROR accidents with severe consequences (including fatal and severe injury accidents) are examined (see Table 3.1) according to the road type, it is seen that the return period in the urban A-Road network is 1.9 years, while the frequency of occurrence in the rural A-Road network is 4.8 years, which is very close to that of the urban B-Road network. In the urban C-Road network, the frequency of ROR accidents is 18.7 years on average, while in rural C-Road sections, this rate is seen on average once in 61.4 years. The lowest fatal-severe injury ROR accidents occur in the urban U-Road network.

When the ROR accident data in 2009 is examined according to the road type and the object hit in Table 3.2 and Table 3.3, it is seen that there are frequent collisions with lamp posts, trees, post road signs, or traffic signals in built-up roads. While the most frequent situation on non-built-up roads is hitting the trees, hitting the crash barrier number can also be significant. The crash barriers, lamp posts, and trees are the most common objects that errant vehicles hit on motorways due to the precautions and structural features of the motorway.

Table 3.1 Return period of KSIs per mile on typical route classifications in the UK (UKRLG, 2011)

ROAD CLASS	KSI RETURN PERIOD (IN YEARS) PER MILE
Urban A Roads	1.9
Rural A Roads (exc. A(M))	4.8
Urban B Roads	5.8
Rural B Roads	15.1
Urban C Roads	18.7
Rural U Roads	22.4
Rural C Roads	61.4
Urban U Roads	144
All routes	20.4

Table 3.2 Severity analyses of accidents in built-up and non-built-up (UKRLG, 2011)

	Object Hit	Fatal	Serious	Slight	All	KSI	KSI %
Built up roads (excl. motorways)	**None**	366	5,733	23,733	29,832	6,099	20.4
	Road sign or traffic signal	14	102	508	624	116	18.6
	Lamp post	31	218	920	1,169	249	21.3
	Telegraph Pole/Electricity pole	7	51	232	290	58	20.0
	Tree	32	216	562	810	248	30.6
	Bus stop or shelter	3	17	75	95	20	21.1
	Crash barrier	8	48	317	373	56	15.0
	Submerged	1	1	3	5	2	40.0
	Entered ditch	6	27	156	189	33	17.5
	Other permanent objects	64	496	2,087	2,647	560	21.2
	Not known	0	1	0	1	1	100.0
	Total	**532**	**6,910**	**28,593**	**36,035**	**7,442**	**20.7**
Non-built-up roads	**None**	95	977	3,089	4,161	1,072	25.8
	Road sign or traffic signal	18	121	486	625	139	22.2
	Lamp post	9	65	283	357	74	20.7
	Telegraph Pole/Electricity pole	7	53	251	311	60	19.3
	Tree	132	543	1,482	2,157	675	31.3
	Bus stop or shelter	0	2	8	10	2	20.0
	Crash barrier	22	118	715	855	140	16.4
	Submerged	2	4	13	19	6	31.6
	Entered ditch	20	247	1,191	1,458	267	18.3
	Other permanent objects	66	470	2,161	2,697	536	19.9
	Not known	95	977	3,089	4,161	1,072	25.8
	Total	**371**	**2,600**	**9,679**	**12,650**	**2,971**	**23.5**

Table 3.3 Severity analyses of accidents in motorways and all roads (UKRLG, 2011)

	Object Hit	Fatal	Serious	Slight	All	KSI	KSI %
Motorways	None	10	68	297	375	78	20.8
	Road sign or traffic signal	3	11	32	46	14	30.4
	Lamp post	1	10	28	39	11	28.2
	Telegraph Pole/Electricity pole	0	0	2	2	0	0.0
	Tree	11	32	93	136	43	31.6
	Bus stop or shelter	0	0	0	0	0	-
	Crash barrier	16	103	689	808	119	14.7
	Submerged	0	0	0	0	0	-
	Entered ditch	5	13	48	66	18	27.3
	Other permanent objects	2	26	111	139	28	20.1
	Not known	10	68	297	375	78	20.8
	Total	**48**	**263**	**1,300**	**1,611**	**311**	**19.3**
All Roads	None	471	6,778	27,119	34,368	7,249	21.1
	Road sign or traffic signal	35	234	1,026	1,295	269	20.8
	Lamp post	41	293	1,231	1,565	334	21.3
	Telegraph Pole/Electricity pole	14	104	485	603	118	19.6
	Tree	175	791	2,137	3,103	966	31.1
	Bus stop or shelter	3	19	83	105	22	21.0
	Crash barrier	46	269	1,721	2,036	315	15.5
	Submerged	3	5	16	24	8	33.3
	Entered ditch	31	287	1,395	1,713	318	18.6
	Other permanent objects	132	992	4,359	5,483	1,124	20.5
	Not known	0	1	0	1	1	100.0
	Total	**951**	**9,773**	**39,572**	**50,296**	**10,724**	**21.3**

UKRLG summarized information obtained after all accident severities analyses as follows:

- Small differences in crash severity results in built-up and non-built-up roads, indicates that speed limits are not a significant factor when the vehicle leaves the paved surface.
- The proportion of fatal or severe injury due to hitting a tree is 31%.
- Although there are very few accidents where a vehicle runs off-road and submerges in water, these accidents are the most severe in terms of their consequences, with a fatality or serious injury accident rate of 33%.

- High-severity consequences also result from embankments/cuttings and hitting posts/poles.
- The severity of accidents caused by cuttings and embankments in rural areas is also relatively high.

Some additional data from the DfT benefit understanding the nature of the problem and provide limited information for risk assessment purposes. According to this:

- Accidents at the junctions are more common on built-up roads than on non-built-up roads.
- Accidents at junctions on built-up roads are at a significant rate.
- Accidents on horizontal curves have a higher proportion.
- A high rate of fatal or severe injury accidents may occur on roads operated at low speed (30 km/h – 50 km/h).
- Many accidents can occur even in slow maneuvers, such as parking or reversing.
- Roundabouts, both built-up and non-built-up areas, do not seem to be a significant problem.

On the other hand, it should be noted that some roadway accidents involve undesirable road user behaviors, such as speeding, drunk driving, and not using seat belts, which road infrastructure is not designed to prevent.

3.3 Road Restraint Systems and Roadside Safety Regulations in the UK

In the UK, the EN1317 standards are used for RRS, and Figure 3.5 shows the RRS family tree in the UK. RRS is divided into the VRS and the pedestrian restraint system. VRS is used on the roadsides to protect the ROR vehicles from hazards in the vicinity of the road, and pedestrian restraint systems are established to guide and limit pedestrians. It is based on the principle that different users use the road safely on their road section.

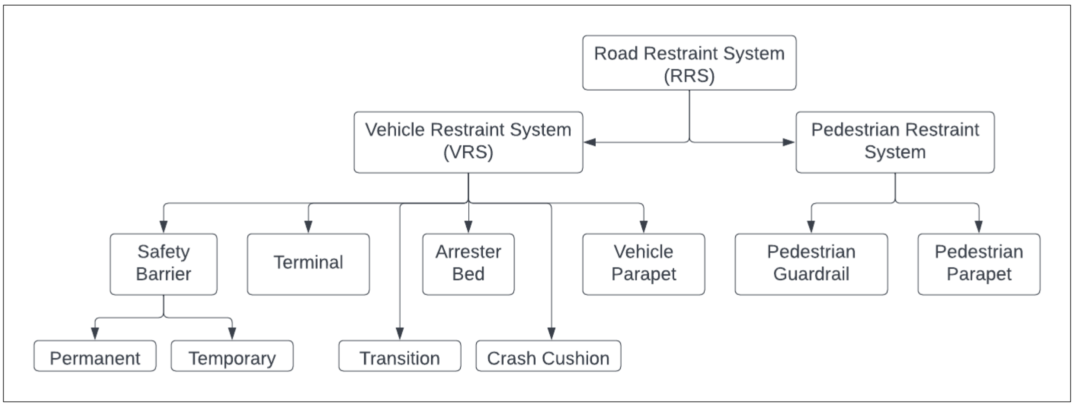

Figure 3.5 Road Restraint System Family (UKRLG, 2011)

After the studies in VRS, six main subcategories were identified based on the different applications and designs. These can be detailed as follows:

1. Safety Barrier: A VRS installed along the nearside, or central reserve typically comprises steel, concrete, or plastic components.
2. Arrester Bed: The purpose of arrester beds is to decelerate and stop runaway vehicles on long, steep descending gradients without severe injury or severe damage to vehicles, adjacent property, or other road users.
3. Transition: The section between VRS of different performance types provides a gradual change from the first to the second to avoid the risk of sudden change.
4. Terminal: Intervention of the ending or beginning of a safety barrier so that the barrier ends do not present a hazard for head-on vehicle impacts.
5. Crash cushion: An energy absorbing device is used in front of rigid hazards to reduce the severity of a crash. There are two types of crash cushions: re-directive crash cushions and non-re-directive crash cushions.
6. Vehicle Parapet: A protective barrier is used at the edge of a bridge, retaining wall, and similar elevated structures with a vertical drop, which may include additional protection and restraint for pedestrians and other road users.

Safety barriers are grouped into three categories: permanent and temporary, rigid and flexible, and single-sided and double-sided:

1. Permanent and temporary barriers: Safety barriers could be installed and served throughout their service life or easily removed during road works, emergencies, or similar situations. The ones installed to contain and re-direct vehicles in the direction of travel and prevent them from rotating or overturning are called permanent safety barriers. The ones placed and removed easily in case of emergency or road work are called temporary safety barriers.
2. Rigid and flexible barriers: Safety barriers that bend in a way that can be ignored during vehicle impact are rigid. In contrast, safety barriers that are deformed during vehicle impact and can be subjected to permanent deformation are defined as flexible.
3. Single-sided or double-sided barriers: Safety barriers, each surface providing containment in different traffic flow directions, are defined as double-sided, while only installed on one side of the road are called single-sided barriers.

Crash cushions are collected in two groups: re-directive crash cushions and non-re-directive crash cushions. Re-directive crash cushions are designed to decelerate smoothly and re-direct the vehicle; conversely, non-re-directive crash cushions aim to decelerate and stop a crashing vehicle.

The terminals are divided into two groups according to installation at the beginning and end of the barriers. These are called the front end or last end, depending on the beginning and end of the barrier.

Pedestrian restraint systems are examined in two parts: pedestrian guardrail and pedestrian parapet. Pedestrian guardrails prevent pedestrians and other road users from potentially dangerous actions such as stepping or crossing into flowing traffic by designing along the pedestrian walkway or sidewalks. A pedestrian parapet is a restraint system developed for pedestrians or other users along the edge of a bridge, retaining wall, or similar structure and does not function as a VRS.

There are two guidelines for selecting and applying RRS in the UK. Which of these guides should be used under which conditions is determined as follows, taking into account the AADT and speed limit (see Figure 3.6):

- Requirements for road restraint systems (CD 377): Guidance for use on roads with a speed limit of 50 mph (80 km/h) or more and AADT is more than 5000 vehicles. This guideline is formerly called TD 19/06.
- Provision of road restraint systems on local authority roads: Guidance for other roads where CD 377 is not used.

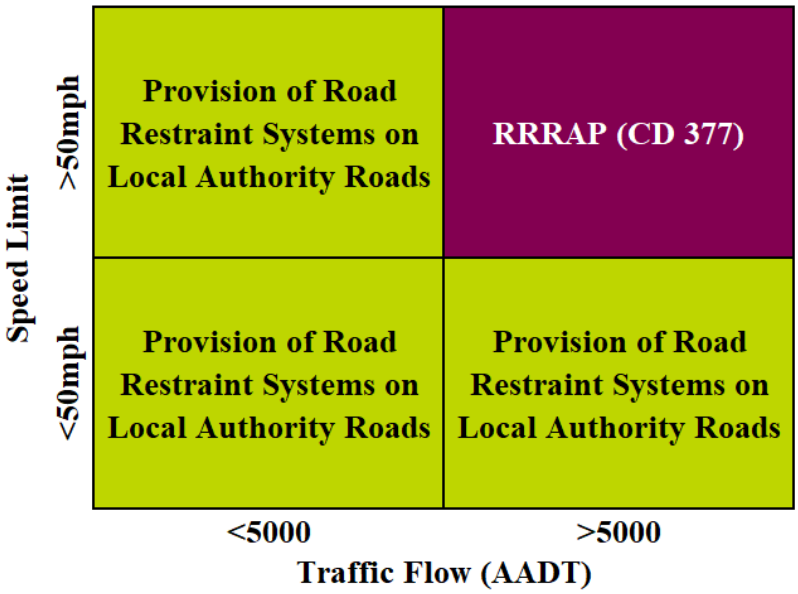

Figure 3.6 Applicable guidance for determining when an RRS is needed

However, regardless of which guidelines are chosen and used, the following features must be provided in the roadside safety approach:

i. All safety barriers must meet the test acceptance criteria in EN 1317-2 (local code BS EN 1317-2 for the UK), mandatory for the European region. In addition, it is sought to meet the test acceptance criteria specified in draft form standards DD ENV 1317-4, prEN 1317-5, and prEN 1317-6.

ii. The roadside design company should determine some performance classes for all safety barriers. These should be expressed in terms of:
    - Containment Level (N1, N2, H1, H2, or H4a),
    - Impact Severity Level (ISL) (class A, B, or C)
    - Working Width (from W1 to W8)

iii. In addition, the designing company or administration must define specific requirements such as maximum safety barrier height that provides adequate visibility by the contractor concerning the provision of safety barriers that may affect system selection.

iv. Finally, the designing company or administration must identify the hazards near the road that the method described in the guidelines should be examined. For example, hazards could endanger the ROR vehicle occupants or cause a secondary event due to reaching the hazard. The risk to others from an errant vehicle should also be examined.

v. Road Safety Audit (RSA) is mandatory for all RRS installation, cancellations, and improvements to be carried out on the roads.

3.4 Risk Definition and Management in Roadside Safety in the UK

Designers must consider many factors when choosing between providing or not providing an RRS. On major roads (with high speed/high volume traffic), the decision to implement RRS can be taken quickly compared to roads where the frequency of ROR accidents is low. Even if the accident risk and severity are less in areas with low volume or low speeds, an individual ROR accident on these roads may create a public consideration (therefore, implementation needs). For this reason, accident risk ceases to be a factor that directly affects RRS implementation decisions in areas with a low frequency of road lapses. In this case, the decision-making process is operated with a more comprehensive point of view.

The concept of risk management focuses on keeping the risk at an acceptable level with practices that will eliminate or reduce the risk by accepting that there will always be a risk. For this purpose;

- identification of the hazard,
- risk level assessment for each hazard,
- and identification of appropriate actions to eliminate the hazard or enable risk reduction

stages can be outlined. In Figure 3.7, the evaluation process is summarized, considering the RRS implementation decisions. According to this figure;

- First, it is necessary to define risk. Before applying the RRS, it should be checked whether it is possible to reduce the existing risk with solutions and regulations that do not require RRS, especially during the risk assessment process.
  - These options should be used if the risk can be reduced without RRS.
  - Nothing can be done if the level of risk does not require intervention or risk reduction is impossible.
- If an RRS is required, its feasibility study should be done.
- Where feasible, the next step should be the Benefit/Cost (B/C) assessment.
- In non-feasibility cases, non-RRS options should also be explored.
- If the B/C evaluation approves the RRS application, at the final stage, by evaluating whether it has a priority in the budget;
  - Either application of RRS decision is made
  - or revert to non-RRS solutions as interim action until RRS implemented.

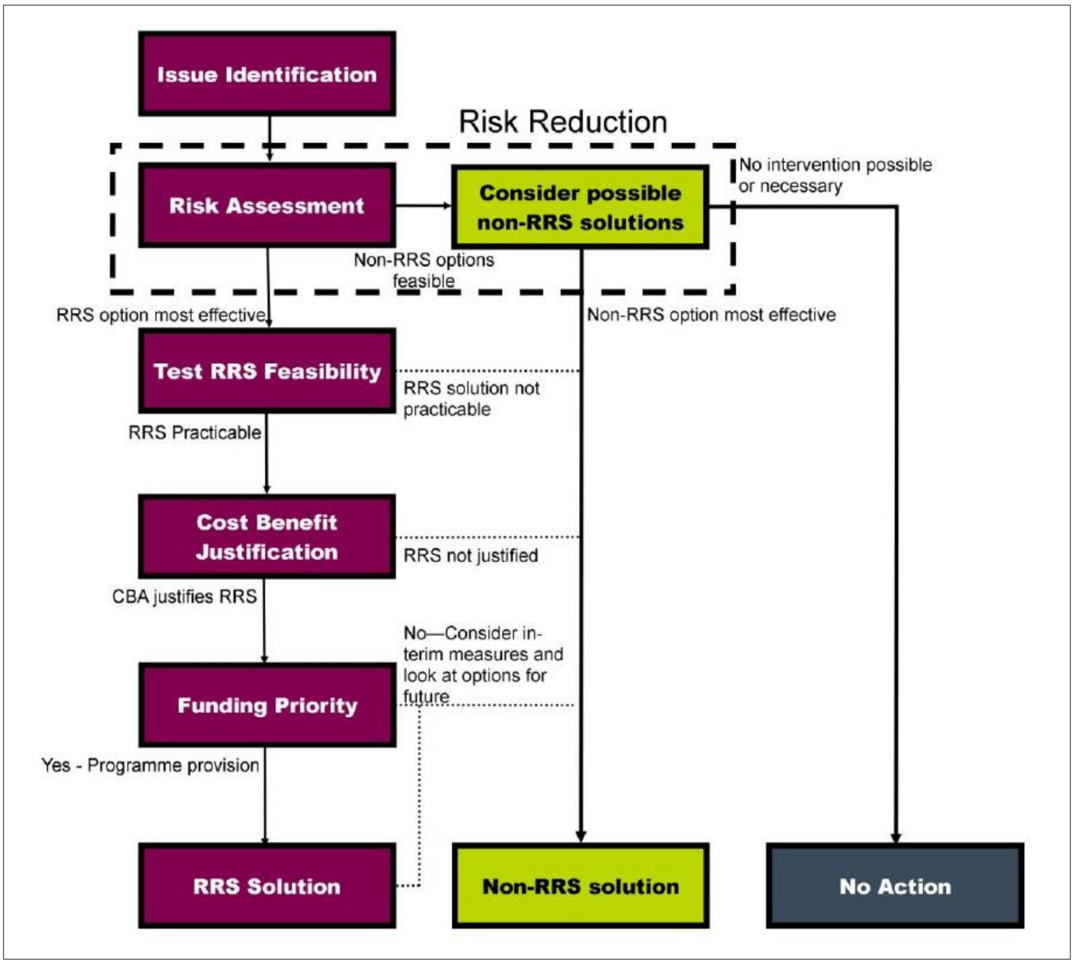

Figure 3.7 Appraisal Process of RRS in the UK (UKRLG, 2011)

3.4.1 Identification of Risk in Roadside Safety

In the UK, “hazard” and “risk” are defined in their most basic form in regulations as follows:

- **Hazard:** May cause loss or harm i) road structure/feature (fill, cut, etc.) or ii) an object in the road or on its side (lighting pole, tree, etc.). This loss or harm may be a) physical, b) financial or economic, c) strategic, d) time-based or e) any combination of these.
- **Risk:** The probability that a person or an object will be harmed to a high or low degree due to a hazard.

In a more general view, risk can be defined as the probability of reaching the hazard (likelihood) or being hit by an errant vehicle, multiplied by the result when the danger is reached or hit (DfT, 2006).

Figure 3.8 Risk Model

The hazard can be inside or outside the road boundaries. The risk can also arise from the post-collision hazard of being knocked down, thrown out, and causing injury or harm to others. In addition, it can break off parts of the hazardous object and cause injury and greater damage to people, such as errant vehicle occupant injury and temporary inability to use electricity or drinking water.

There are many studies for selecting the appropriate "safe zone": it is a multi-parameter issue that considers the angle of the vehicle leaving the road, its speed, the effect of surface friction, and whether there is an object or feature that poses a hazard. Without a hazardous object or a feature at the roadside, the errant vehicle will move off the road at a certain residual speed, but when there is a hazardous object, the percentage of fatal or severe injury accidents increases significantly, even at residual speeds of 50 km/h.

Also, studies conducted by Lynam & Kennedy (2005) on the errant vehicle behavior after leaving the road show that: on high-speed roads, the initial speed of vehicles leaving the road is usually around the speed limits; on the other hand, most vehicles leaving the road on low-speed roads are more likely to be speeding. Even if the operating speed is slightly higher than the design speed, an extensive roadside area should be left for the width of the safe zone. Since it is impossible to create wider safe zone boundaries on existing or new roads, an approach based on minimizing the risk instead of zeroing it or establishing a roadside RRS in areas where the risk is high has been developed. Some examples of hazards that require a risk assessment for RRS are given in Table 2.1.

3.4.2 Roadside Risk Assessment

Risk is determined by the effects at both the individual and societal levels. The triangle diagram in Figure 3.9 shows the regions for risk levels, considering the increasing individual risk and social anxiety from bottom to top:

- The region at the top of the diagram indicates the “Unacceptable” risk level. Regardless of the B/C ratio at this point, no justification can be produced. Taking risks at this level will disturb the social conscience.
- For example, there is a bridge over a high-speed road, and no parapets or safety barriers have been built. When a faulty vehicle leaves the road, the occupants of the vehicle and the users on the lower road can have life-threatening or severe losses. Without any VRS, such an event could happen, and society would not consider multiple casualties acceptable. On the other hand, using a safety barrier or parapet with a low level of protection can reduce the risk of loss. A higher containment level barrier or parapet can further reduce the risk of loss; however, depending on the traffic volume and distribution, the cost of this will be very high compared to the safety it will bring, so it may not be practical and not applicable.
- The region at the bottom of the triangle diagram represents the “Broadly Acceptable” risk level. Risks falling into this zone are considered low importance, insignificant, or adequately controlled. According to cost-benefit analysis, using resources to reduce the risk level further is not appropriate.
- For example: Not applying RRS to a lighting pole at a suitable distance from the roadside and placing an RRS in front of a pole close to the road.

- The region in the middle of the triangle diagram represents the “Tolerable” risk level. The risks in this region should be examined with the principle of “As low as reasonably practicable (ALARP)” (DfT, 2006).

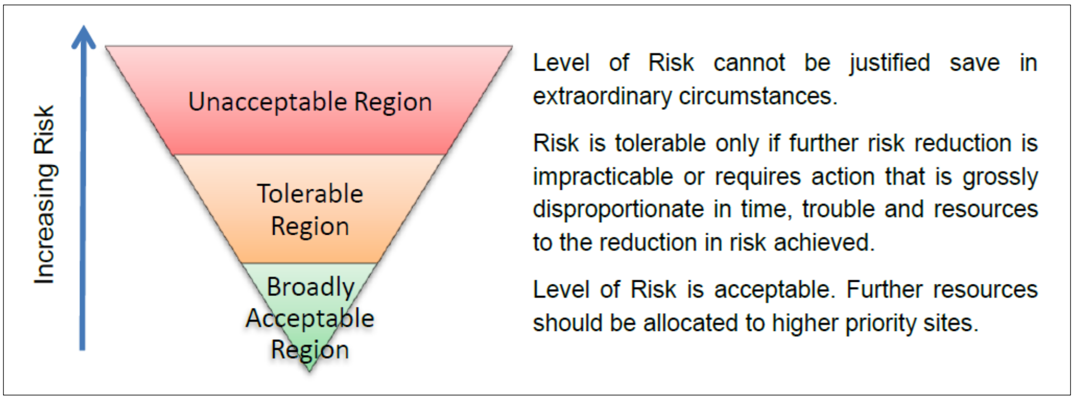

Figure 3.9 Levels of risk defined in the UK legislations (CEDR, 2014)

The risks in the "Unacceptable" and "Tolerable" regions should be reduced to the "Broadly Acceptable" region or kept at a reasonably practicable level. If an option is not reasonably practicable at the design stage, the lowest risk level in the acceptable region should be chosen as the design option and gradually reduced until the risk is brought to a reasonably practicable level. With this approach, in which factors such as cost and time required to reduce the risk are taken into account, changes in risk can be determined at each step, and the most appropriate one among various options can be determined (see Table 3.4).

Table 3.4 Site Risk Categories (UKRLG, 2011)

CATEGORY	RISK LEVEL	OUTCOMES
Higher Priority Site	Risk cannot be accepted save in extraordinary circumstances.	Where the risk assessment has defined a site as Higher Priority, the installation of an RRS is justified in terms of the level of risk. A further consideration is then required to determine if the site meets the other appraisal criteria. Even at high-risk sites, non-RRS interventions may reduce the risk to a level where an RRS can be omitted.
Medium Priority Site	Intervention may be required to introduce control measures to drive residual risk towards the Lower Priority Site category. The residual risk can be tolerated only if further risk reduction is impracticable or requires action that is grossly disproportionate to the reduced risk.	Where the risk evaluation has identified a site as Medium Priority, an RRS may be justified; however, a non-RRS approach to reducing the risk may prove sufficient to negate the need for an RRS. If suitable effective measures cannot be introduced, then the appraisal process would normally continue to consider the other criteria.
Lower Priority Site	The level of risk is regarded as generally acceptable. Further effort to reduce risk is not likely required as resources to reduce risk would be grossly disproportionate to the risk reduction achieved.	Where the risk evaluation identifies a site that is a lower priority, a further appraisal is not required, and the level of risk does not normally support the installation of an RRS. Simple, low-cost measures that could reduce the risk can still be considered.

In most cases, examining the questions below will help produce a design demonstrating that the risk is low enough to be reasonably practicable.

i. Can the hazard be eliminated?
   - For example, is it necessary to put a traffic sign/post at that location?

ii. Can the location of the hazard be changed to be safer?
   - For example, can it be moved away from the roadside or behind an existing safety barrier?

iii. Can the hazard be redesigned and made safer?

iv. Is it possible to protect against danger with the VRS?

v. Can the road layout or cross-section be revised to reduce the risk?
   - For example, can it be done by increasing shoulder width, road alignment improvement, etc.?

vi. Can other measures be taken to improve the situation?

- For example, can a lower speed limit be set?

On the other hand, the risk assessment reveals the level of risk and does not express how the risk will be mitigated. However, the effects of hazards on the risk level should be assessed and recorded, allowing options to control or eliminate hazards or mitigate risks to be tested. At this stage, for example, the following options should be considered:

- to eliminate the hazard,
- to relocate the hazard,
- redesign (like making the hazard passive safe),
- making changes to the geometry or cross-section of the road to reduce the possibility of ROR accidents,
- increase the VRS length
- consider combinations of the above options to achieve the maximum benefit/cost ratio.

3.5 Design Manual "CD-377 Requirements for Road Restraint Systems"

CD 377 design manual, formerly TD19/06, used in the UK for high-speed and high-density road sections, includes a risk-based assessment. The latest version of this manual is revision 4, which considers the new EU legislation and standards. Determining where RRS with minimum parameters is required is being carried out with the help of CD 377 and the RRRAP software (Highways England, 2021a).

CD 377 details the requirements of the RRS family in the UK (see Figure 3.5). These RRS members are permanent and temporary safety barriers, vehicle parapets, terminals, transitions, crash cushions, pedestrian parapets and guardrails, vehicle arrester beds, anti-glare systems, and cattle grids. CD 377 is applied on motorways and all-purpose roads with speed limits equal to or greater than 50 mph and traffic flow in both directions of 5,000 or more on average annual daily traffic (AADT). (Highways England, 2021a)

More specifically, it is applied:

- in the design of all new roadways,
- whenever the road cross-section is permanently changed,
- whenever the RRS needs to be replaced due to the expiration of its useful life
- whenever a new hazard is introduced, relocated, or modified on a highway
- when the hazard changes the vicinity of the edge of the roadway
- when an RRS must be dismounted (except when individual parts must be removed to gain access), such as for planned maintenance.

In addition to these, CD 377 should also be used,

- while other works (other than maintenance) are carried out near a hazard without provision or near existing RRS that does not satisfy the requirements,
- while other works (other than maintenance) carried out in the vicinity of an existing VRS with expired service life,
- while other works (other than routine maintenance) are carried out near an existing RRS with a service life of fewer than five years without expecting maintenance.

CD 377 applies to all structures accommodating vehicles and vulnerable users where the Overseeing Organization is responsible for that structure. (Highways England, 2021a). CD 377 also contains some guidance of RRS for low-speed and or low-flow roads.

The requirements of RRS should be assessed at the early stage of the project for the design process to:

- ensure that the factors like land use, horizontal and vertical geometry, cross-section, hazardous locations, the safety of road users and workers, and other parties are taken into account for the optimum solution,
- meet the requirements with minimum adjustments and revisions
- avoid inefficient work.

3.6 The Road Restraint Risk Assessment Process (RRRAP) Software

The Road Restraint Risk Assessment Process (RRRAP) captures adjacent roadway features and helps designers determine vehicle restraint needs and their performance criteria for each location in the proposed road design layout. It allows optimization or refinement of solutions by selecting mitigation measures: e.g., removal, repositioning, reduction of roadside aggressiveness, balancing between these measures, and reduction of land use/offset/hazard through redesign or implementation of measures to protect roadside elements. (Highways England, 2020a).

The RRRAP used to be an Excel spreadsheet (see Figure 3.10), but the new version is a web-based online application (see Figure 3.11). A vital function of the RRRAP is to provide an audit trail for the designer and the monitoring organization. The RRRAP requires the designer to enter hazard identification and mitigation information to provide background information for the audit trail.

When there are improvements in functionality or changes to some of the parameters used in the RRRAP process, the software is updated, and Highways England provides the updated version of the RRRAP. This cloud-based tool is available for road design organizations upon request. The latest version of the RRRAP should be checked from its website and used for the new projects. For existing projects, the version of RRRAP used to start the project can continue to be used until that portion of the project is complete (Highways England, 2020a).

While using the software, it should be kept in mind that the risk-based RRS standard consists of two parts, which should be used together. The first is the CD 377 manual which consists of the written standards for the RRS. The second part is the RRRAP software, which helps the designer determine the VRS and its performance requirements.

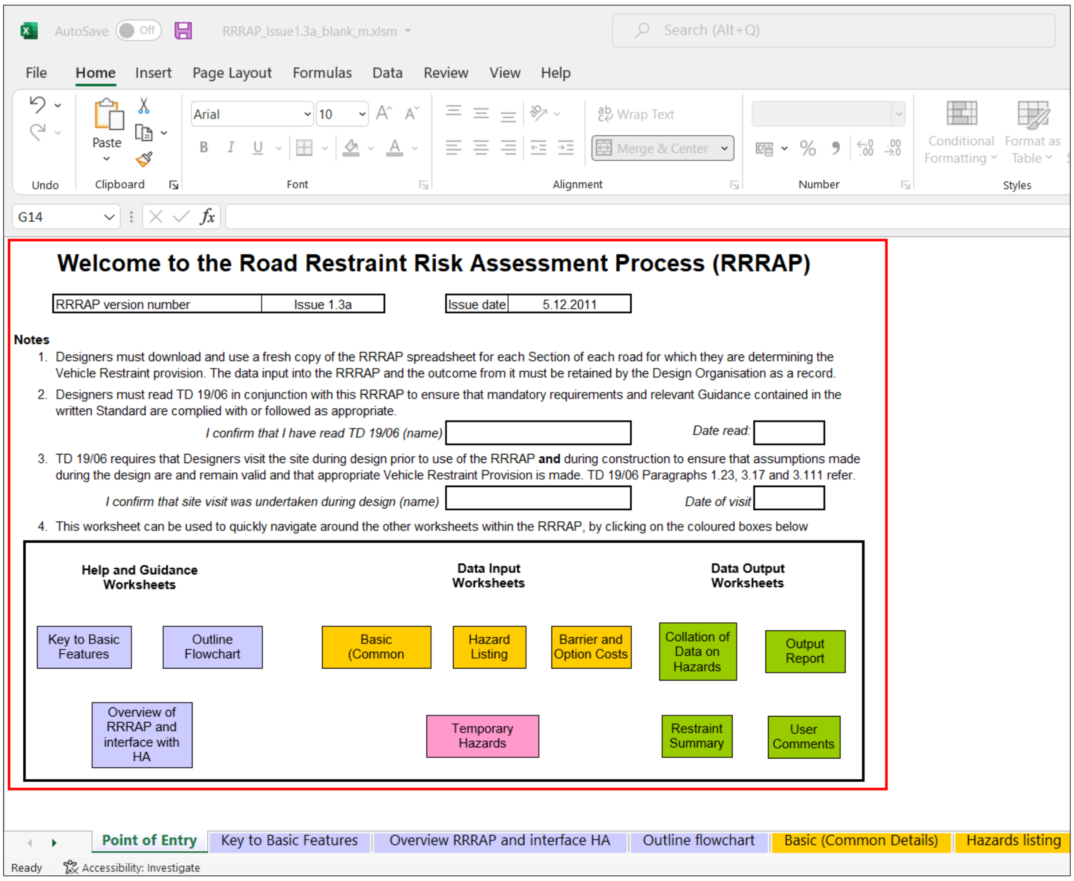

Figure 3.10 Early excel version of the RRRAP

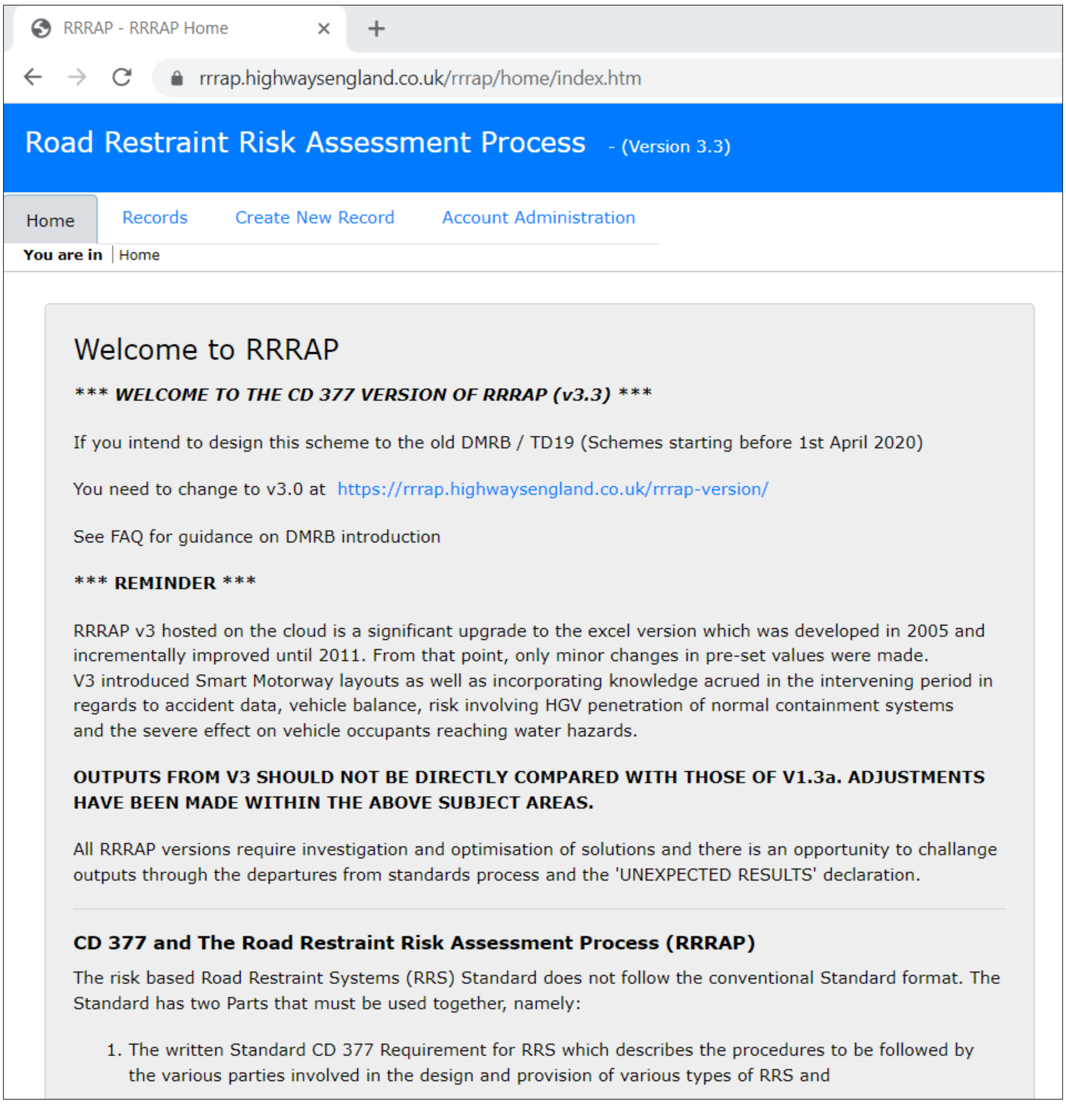

Figure 3.11 Current web-based version of the RRRAP

The RRRAP tool provides the client with a verifiable roadside hazard record consisting of roadside furniture, structures, water hazards, roads, railways, and other features that may be hazardous to vehicles leaving the roadway. It also provides a record of the solution that the designer has optimized through hazard design, relocation or removal of hazards, determination of combinations of setback and working width, and benefit-cost analysis for installation specification and future maintenance (Highways England, 2020b).

The RRRAP considers site-specific data for each hazard so that the impact risk and likelihood of injury to occupants can be assessed with several factors that can affect the risk of life-changing injury. These factors can include topography, distance to the lane, the aggressiveness of the hazard, and others such as traffic volume, vehicle type distribution, accident history, and effects on third parties.

The formulas in the RRRAP reflect research findings that reflect risk factors from several research reports in the UK and around the world. The RRRAP results have been benchmarked against the IRRS, TD19/85, and developed as a continuous improvement process over the last 15 years. The RRRAP results provide a solid foundation for hazard mitigation solutions, whether hazard elimination, installing passively safe furniture, or protection through VRS (Highways England, 2020b).

3.7 Current UK Practice of Roadside Design with the RRRAP

The designer's experience and judgment significantly contribute to the decision to use a safety barrier during the roadside design. The aggressiveness of roadside objects and their potential hazardous outcome may differ from designer to designer due to their own experiences. The UK approach uses CD 337 standard and the RRRAP program to achieve unity in thinking about roadside object hazard factors. Establishing the roadside object aggressiveness factor standards makes the decision-making process more objective. The RRRAP tool assigns these aggressiveness scores to each hazard defined and then quantifies the risk according to likelihood and consequences by estimating equivalent fatalities per 100 million vehicle kilometers. One fatal accident equal to 10 severe and 100 slight injuries is. Likelihood has two piers: the probability of a vehicle leaving the road and an errant vehicle reaching the object. These are dependent on road type, alignment, traffic flow, speed, vehicle type, topography, hazard location, and accident history. Consequences would affect both errant vehicle occupants if they reached the hazard and the others using the adjacent road or occupying a facility. Aggressiveness values that the RRRAP assigns automatically are based on the statistics and research from the UK.

In the RRRAP, thresholds are set to determine the need for a VRS independent of the road's traffic flow. For example, if the risk posed by a hazard with the aggressiveness of 1.5 is unacceptable over a range of offsets, it becomes acceptable when far enough from the roadway or when a safety barrier protects it. The hazards with different aggressiveness result in unacceptable risk in offset areas. The relationship between the offset of hazard and VRS is presented in Figure 3.12

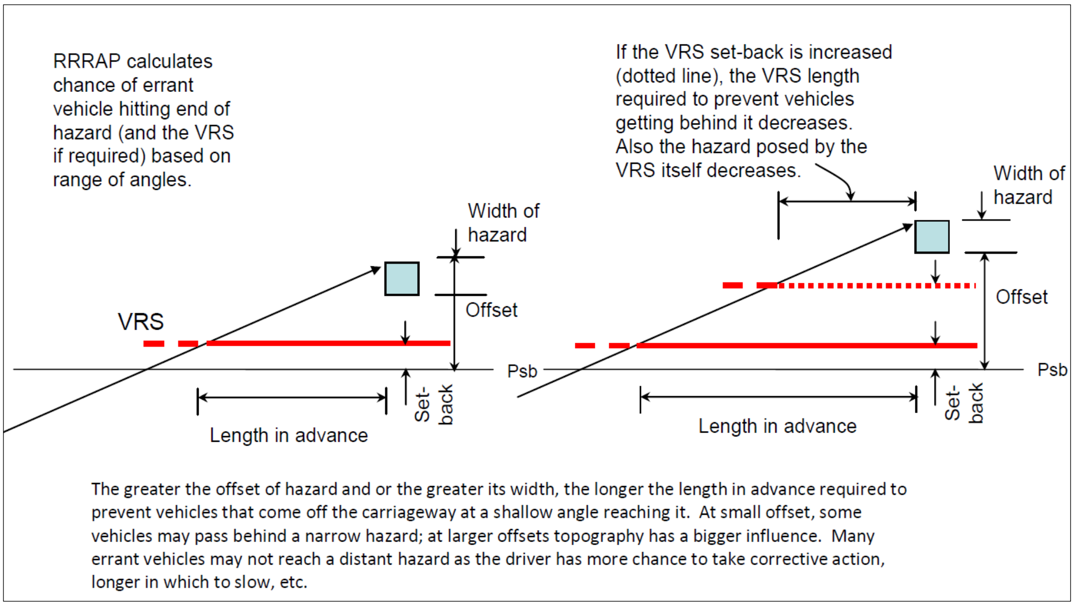

Figure 3.12 Relationship between VRS and offset of hazard (Highways England, 2020a)

Positional information about the hazards is given to the RRRAP (see Figure 3.13), and then the RRRAP calculates whether the risk is acceptable, tolerable, or unacceptable for a given type and length of VRS in advance of the hazard. If vehicles can approach the hazard from both directions, the VRS requirement is calculated in advance and beyond the hazard. To get an acceptable level of risk for the hazard, the designers use the results of the RRRAP and decide the containment level and the length of VRS.

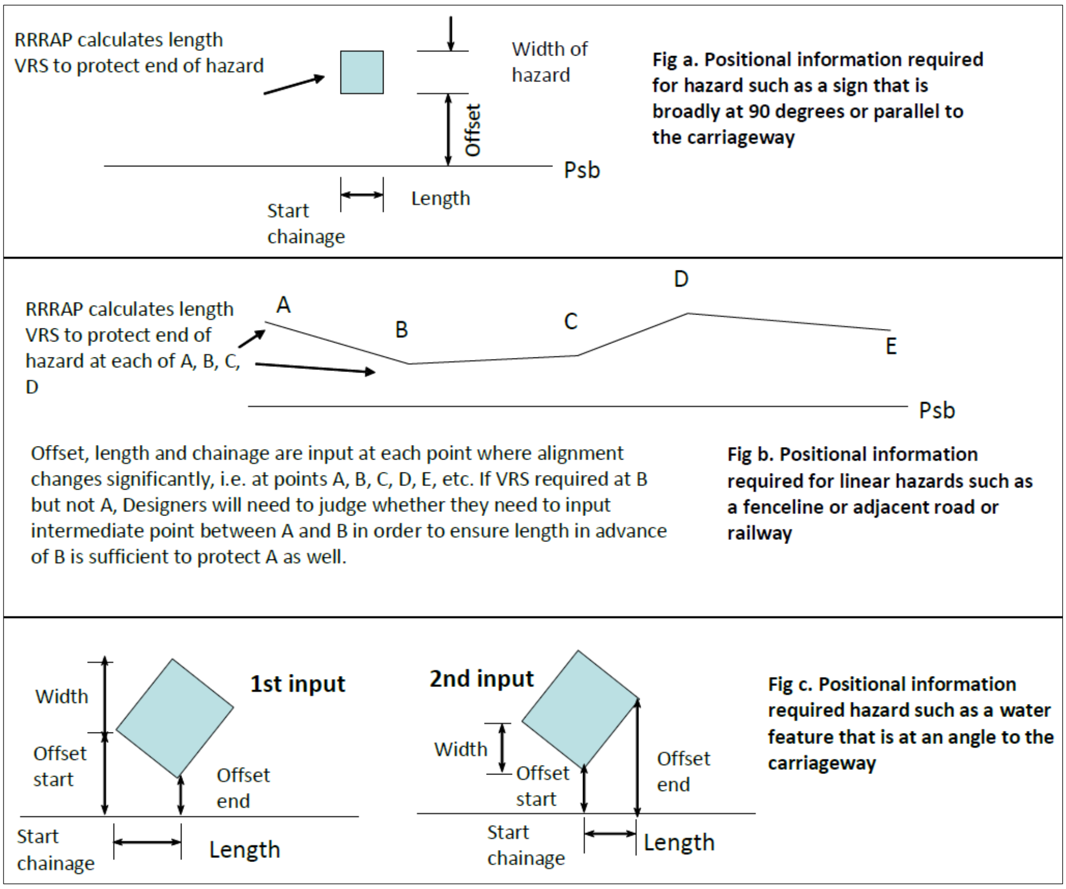

Figure 3.13 Hazard position information for VRS calculation (Highways England, 2020a)

The RRRAP uses the same identification system as the Manual of Contract Documents for Highway Works (MCHW) for the hazards. There are two main categories of hazards (see Figure 3.14). The first one is within the highway boundary, and the second is that others can be affected. If a hazard is present inside or within the 5 m range beyond the highway boundary, where the cutting section is higher than the 3m, or hazard is present inside or within the 15m range for other sections, this hazard’s information is given into the first hazard category. If the hazard possibly affects the others within 100m range from the carriageway is considered. These hazards include adjacent roads and railways. If the designer decides that there is no chance that an errant vehicle reaches the hazard, then there is no need to assess the hazard.

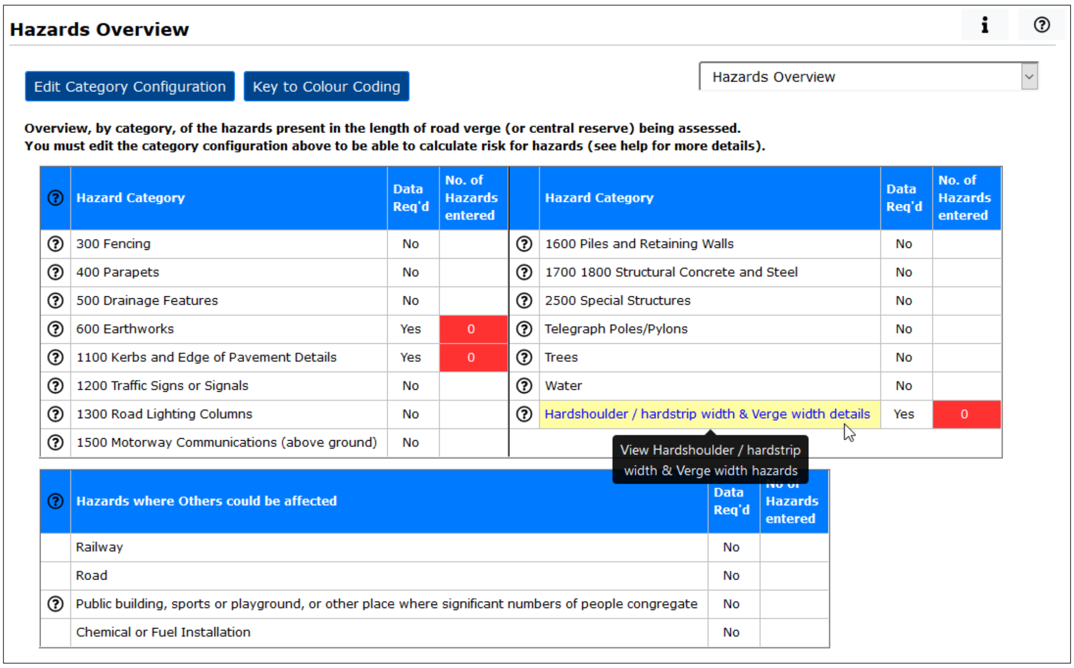

Figure 3.14. Hazard overview in the RRRAP

There are three mandatory hazard categories to enter due to how the RRRAP works. These are earthworks, kerbs and edge of pavement details, and hard-shoulder/hard-strip width & verge width details. Earthworks, hard-shoulder, and verge details are used to calculate the offset and risk of the hazard. Kerbs and pavement edge information are for auditing and completeness purposes. When a hazard is entering, for many of them, detailed data need to be specified like local alignment, sleep-related site, speed, and site-specific hazards increasing the chance of road traffic accident. This data is entered via drop-down lists for the data entry page (Figure 3.15).

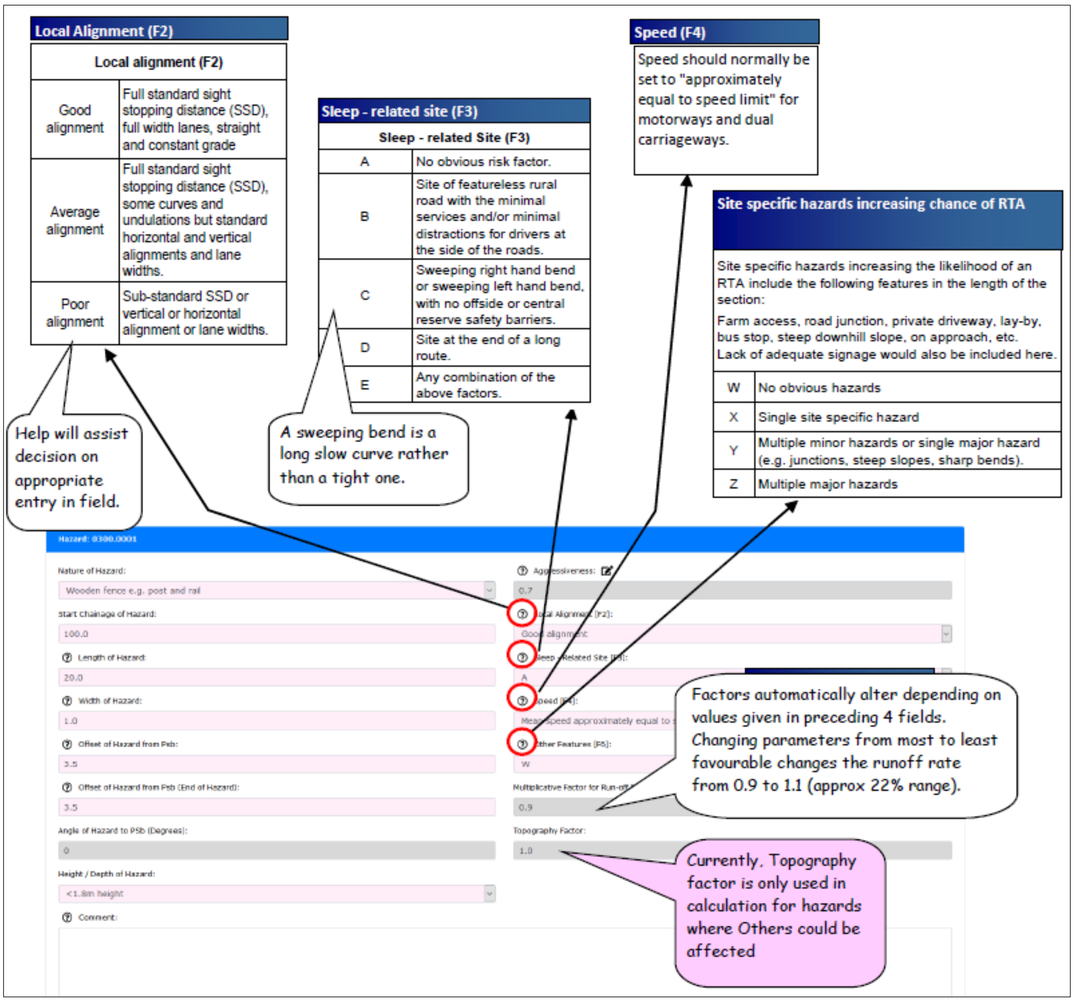

Figure 3.15 Hazard data entry field (Highways England, 2020a)

After giving all the relevant data for the hazards, the risk calculation due to every hazard's presence is automatically done by the RRRAP. If the calculated risk without a restraint system is acceptable, the RRRAP indicates no need to use VRS for the hazard. If the calculated risk is not acceptable without the VRS, the RRRAP indicates that with optimum length and default N2 containment level, the risk is acceptable, tolerable, or unacceptable. If the risk is acceptable with default values of VRS, then the minimum length of the need to be used before the hazard is calculated and presented as results.

The default containment level and working-with in the RRRAP are N2 and W2, respectively. However, designers do not have to use these values in their designs; they can use higher containment levels and choose the higher working width class. The minimum length of need can be recalculated by choosing the desired containment level and working width class in the software. The calculated length is the effective containment length, and based on the requirements of CD 377, designers decide the length of the safety barrier.

The length of the need for a safety barrier at an individual hazard is shown in Figure 3.16. The RRRAP indicates the value for full containment length, the section between B to C and D to E. However, the D to E distance returns 0m (zero) if the considered route is a divided highway. The section between B to E is the minimum length of need to provide adequate containment for the hazard. Points A to B and E to F are the additional length of safety barriers to achieving full containment at points B to E. These additional lengths are product specific and chosen based on the manufacturer’s declaration.

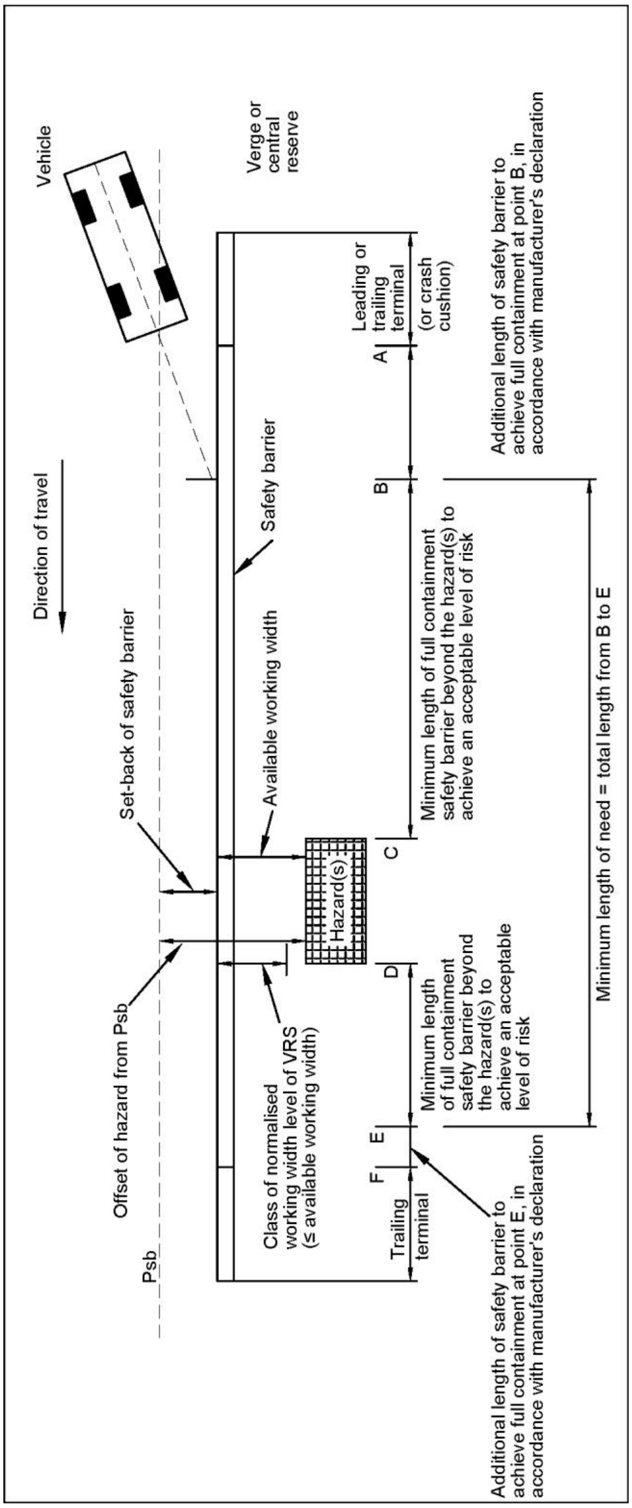

Figure 3.16 Length of need and working width of safety barrier at an individual hazard (Highways England, 2021a)

CHAPTER 4

ROADSIDE SAFETY IN TURKEY

4.1 Road Safety Statistics

According to the Turkish Statistical Institute (TUIK), a total of 1 million 186 thousand 353 traffic accidents occurred in the Turkish road network in 2021 (see Table 4.1). 998 thousand 390 of these accidents are property damage only, and 187 thousand 963 traffic accidents with death and injury. 78.6% of traffic accidents with death and injury occurred within the residential area and 21.4% outside. While 5 thousand 362 people lost their lives in traffic accidents, 274 thousand 615 people were injured. As a result of 187 thousand 963 fatal and injury traffic accidents that occurred in Turkey in 2021, 2,421 people died at the accident site, 2 thousand 941 people were injured and died within 30 days due to the cause and effect of the accident after they were transferred to health institutions. While 49.3% of the deaths and 72.0% of the injuries occurred within the urban area, these ratios are 50.7% and 28.0%, respectively, in rural areas.

Also, Insurance Information and Monitoring Center (IIMC) in Turkey publishes the number of accident scene reports prepared by those involved in the accident. From 2008 to 2021, the number of property damage only accident records held by those involved in the accident is presented in Figure 4.1. According to this figure, the average number of records is around 850 thousand annually. Due to the global pandemic Covid-19 lockdowns, the number of accident reports decreased in 2019 and 2020, but it reached 786,424 in 2021.

Table 4.1 Number of accidents, persons killed and injured, 2010-2021 (TUIK, 2022b)

Year	Total number of accidents	No. of acc. involving death or injury	No. of acc. involving property damage only	Number of persons killed			Number of persons injured
				Total	At accident scene	Accident follow-up*	
2010	**1,106,201**	116,804	989,397	**4,045**	4,045	-	211,496
2011	**1,228,928**	131,845	1,097,083	**3,835**	3,835	-	238,074
2012	**1,296,634**	153,552	1,143,082	**3,750**	3,750	-	268,079
2013	**1,207,354**	161,306	1,046,048	**3,685**	3,685	-	274,829
2014	**1,199,010**	168,512	1,030,498	**3,524**	3,524	-	285,059
2015	**1,313,359**	183,011	1,130,348	**7,530**	3,831	3,699	304,421
2016	**1,182,491**	185,128	997,363	**7,300**	3,493	3,807	303,812
2017	**1,202,716**	182,669	1,020,047	**7,427**	3,534	3,893	300,383
2018	**1,229,364**	186,532	1,042,832	**6,675**	3,368	3,307	307,071
2019	**1,168,144**	174,896	993,248	**5,473**	2,524	2,949	283,234
2020	**983,808**	150,275	833,533	**4,866**	2,197	2,669	226,266
2021	**1,186,353**	187,963	998,390	**5,362**	2,421	2,941	274,615

** Includes the deaths within 30 days after the traffic accidents due to related accidents and their impacts on injured people and sent to health facilities.*

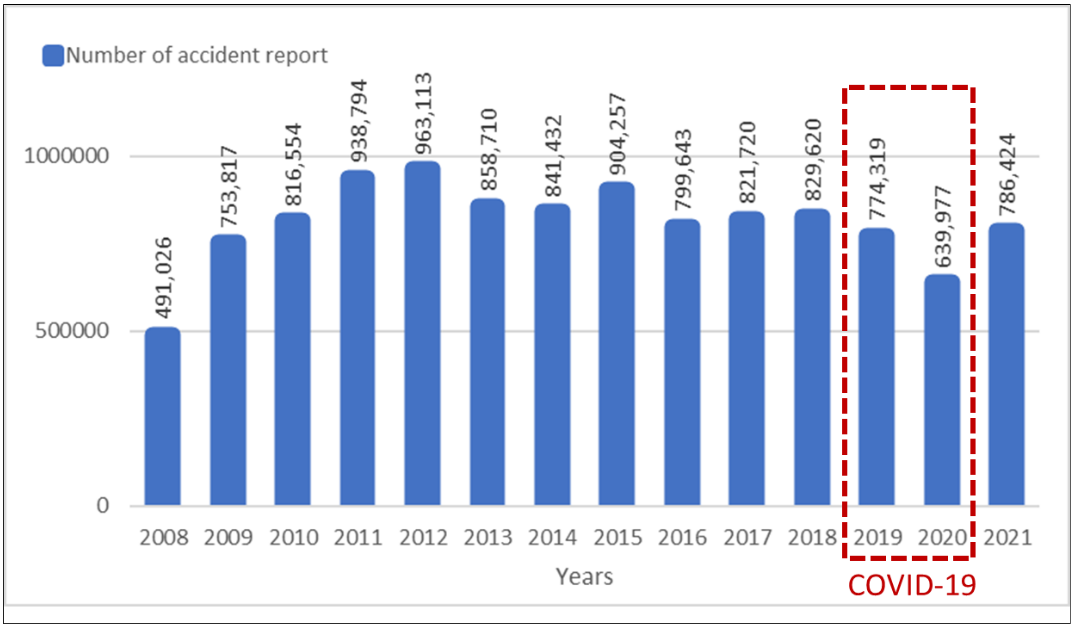

Figure 4.1 Number of accident scene reports prepared by those involved in the accident (IIMC, 2022)

GDH has published the fatal or injury accidents in 2021 according to the way they occur in Table 4.2. It was observed that the most accidents were recorded in the side impact type (61,003 accidents - 32.45%), followed by pedestrian collisions (30,072 accidents-16.00%) and ROR accidents (23,323 -12.41%) third. Considering that there may be ROR type accidents among other accident types, it can be said that the share of ROR type accidents in total accidents is 15%-20%.

Also, the distribution of fatal and injury accidents in 2021 by vehicle types is shown in Table 4.3. As can be seen here, automobiles are the first in-vehicle type (49.5%), followed by motorcycles (17.5%) and pickup trucks (15.1%). When vehicle ownership is considered, the automobile has the highest rate in Turkey, so the number of accidents involving automobiles is also the highest. The number of automobiles per thousand people in Turkey is 162 (see Table 4.4). In addition, due to the Covid-19 effects and increasing fuel prices in Turkey, the use of motorcycles is becoming widespread, and as a result, the number of motorcycles involved in fatal or severe injury accidents is seen as the second highest (see Table 4.3).

Although there has been a decrease in the number of deaths due to accidents compared to previous years, according to TUIK data for 2021, the average number of deaths per million automobiles was 391, and the number of deaths per million people was 63. These fatalities are high compared to EU countries (see Table 4.4). When we compare Turkey with Italy, which has a close number of accidents involving fatality or injury, the number of deaths per accident is 2.9% for Turkey and 1.8% for Italy. This ratio drops 1.0% for Germany, but for the EU average, this ratio is 2.4% is calculated.

Table 4.2 Types of traffic accidents involving fatality or injury (GDH, 2022b)

	Urban		Rural		Total	
Type of Accident	**No. of Acc.**	**%**	**No. of Acc.**	**%**	**No. of Acc.**	**%**
Side-Impact Collision	54,876	37.15	6,127	15.23	61,003	32.45
Collisions with Pedestrian	28,976	19.61	1,096	2.72	30,072	16.00
Run-off-Road	**8,465**	**5.73**	**14,858**	**36.93**	**23,323**	**12.41**
Rollover/Sway	16,087	10.89	5,368	13.34	21,455	11.41
Rear-End Collision	14,960	10.13	6,017	14.96	20,977	11.16
Head-On Collision	9,254	6.26	2,308	5.74	11,562	6.15
Collisions with fixed objects	6,959	4.71	2,644	6.57	9,603	5.11
Sideswipe Collision	2,129	1.44	357	0.89	2,486	1.32
Crashing into Stationary Vehicle	2,006	1.36	405	1.01	2,411	1.28
Crash into Parked Vehicle	1,385	0.94	110	0.27	1,495	0.80
Human Falling from Vehicle	1,341	0.91	141	0.35	1,482	0.79
Collisions with Animal	471	0.32	504	1.25	975	0.52
Pile-up	402	0.27	132	0.33	534	0.29
Multiple Vehicle Collision	375	0.25	119	0.30	494	0.26
Object Falling from Vehicle	47	0.03	44	0.11	91	0.05
Total	**147,733**	**100**	**40,230**	**100**	**187,963**	**100**

Source: Traffic accident data of the General Directorate of Security and the Gendarmerie General Command.

Table 4.3 Distribution of accidents by vehicle types (GDH, 2022b)

	Number of Vehicles Involved in the Accident				Number of Drivers Killed			
Vehicle Type	**Urban**	**Rural**	**Total**	**%**	**On-Site**	**30-day Period***	**Total**	**%**
Automobile	120,657	31,610	152,267	49.5	547	435	982	38.4
Motorcycle	49,216	4,821	54,037	17.5	229	458	687	27.0
Pickup Truck	36,048	10,391	46,439	15.1	162	120	282	11.1
Tractor	1,379	1,484	2,863	0.9	95	45	140	5.5
Bike	8,693	212	8,905	2.9	33	90	123	4.8
Articulated Truck	2,647	4,350	6,997	2.3	71	25	96	3.8
Motor Bike	9,927	515	10,442	3.4	24	66	90	3.5
Truck	3,684	2,859	6,543	2.1	48	16	64	2.5
Other	4,449	571	5,020	1.6	6	22	28	1.1
Minibus	5,846	1,360	7,206	2.3	11	11	22	0.9
Special use vehicle	523	223	746	0.2	6	4	10	0.4
Bus	4,192	701	4,893	1.6	5	3	8	0.3
Electric Scooter	791	20	811	0.3	0	7	7	0.3
Construction Machinery	278	108	386	0.1	4	0	4	0.2
Cross Country Vehicle	111	42	153	0.0	2	1	3	0.1
Tanker	92	107	199	0.1	1	1	2	0.1
Horse Carriage	59	21	80	0.0	0	1	1	0.0
Ambulance	255	89	344	0.1	0	0	0	0.0
Tramway	68	1	69	0.0	0	0	0	0.0
Train	32	10	42	0.0	0	0	0	0.0
Total	**248,947**	**59,495**	**308,442**	**100**	**1,244**	**1,305**	**2,549**	**100**

** It covers those who were injured in a traffic accident, were referred to health institutions, and died within thirty days due to the cause and effect of the accident.*

Source: Traffic accident data of the General Directorate of Security and the Gendarmerie General Command.

Table 4.4 Traffic accident information of the EU states and Turkey (GDH, 2022b)

Country	Number of Fatal and Injured Accidents	Number of Deaths	Number of Automobiles per Thousand People	Number of Death per Million Automobile	Number of Death per Million People
Turkey	**187,963**	**5,362**	**162**	**391**	**63**
Germany	300,143	3,046	574	64	37
Austria	35,736	416	566	83	47
Belgium	37,699	646	511	110	56
Bulgaria	6,730	628	407	224	90
Czech Republic	20,890	618	554	106	58
Denmark	2,808	199	455	76	34
Estonia	1,413	52	598	67	39
Finland	4,002	211	647	60	38
France	56,006	3,244	569	85	48
Greek Cypriot Adm.	490	52	645	93	59
Croatia	9,694	297	425	175	73
Netherlands	19,046	586	499	68	34
Ireland	6,093	140	442	65	28
Spain	104,080	1,755	519	72	37
Sweden	13,684	221	473	45	22
Italy	172,183	3,173	663	81	53
Latvia	3,729	132	381	184	69
Lithuania	2,926	186	536	127	67
Luxembourg	987	22	681	52	35
Hungary	16,627	602	390	162	62
Malta	1,346	16	597	53	32
Poland	30,288	2,909	642	122	77
Portugal	37,251	688	530	128	67
Romania	31,146	1,864	357	279	96
Slovakia	5,105	270	439	115	50
Slovenia	6,023	102	556	88	49
Greece	10,712	688	504	129	64
Member States (EU-28)	936,837	22,763	524	93	51
1. TUİK (Turkey data are for 2021)					
2) Other Countries - EU Transport in Figures Statistical Pocketbook 2021 (data for 2019) https://ec.europa.eu/transport/facts-fundings/statistics/pocketbook-2021_en					

4.2 Run-off-Road (ROR) Accidents in Turkey

As can be seen easily from Table 4.2, ROR accidents are the third highest type of accident in Turkey. This table considers the total number of accidents in urban and rural areas. When only rural areas are considered, ROR accidents are the most common type in road networks under the responsibility of the GDH (see Table 4.5). The number of dead and severely injured people on rural roads in 2021 is 648 and 22,695, respectively. The roads under the responsibility of GDH are rural area roads, which are state roads, provincial roads, motorways, and their link roads. On these roads, the speed limits are higher, so the severity of ROR accidents could be much higher than other accidents due to the possibility of colliding with a rigid object. There should make in-depth analyses and research about these types of accidents.

In this study, three consecutive years of accident data in Turkey are examined to better understand the ROR accident in Turkey. Data from 2016 to 2018 is used due to the global pandemic of Covid-19. Turkey has applied a series of lockdowns, so transportation and accident data for 2019 and 2020 may lead to misleading results for research and studies. The spatial accident data provided by GDH was used after clearing some systematic and random errors common in this type of data. Common problems include mistakes of x and y coordinates and coordinates that do not match the road section. Table 4.6 details the accident data used in the study. When the accidents are analyzed according to the type of occurrence, Figure 4.2 is obtained. As can be seen here, the total number of ROR accidents is 77,178, and its rate has been the third-highest accident type with 14.2% in these three years. When ROR accidents are analyzed according to the location (by taking a 100-meter buffer zone around the road network), it is determined that approximately 54% of ROR accidents occur in the GDH road network and approximately 77% in non-residential areas. More importantly, it is noteworthy that ROR accidents are clustered in certain road sections in the road network and are not randomly distributed (see Figure 4.4).

Table 4.5 Types of traffic accidents involving fatality or injury on roads under the responsibility of GDH (GDH, 2022a)

	TOTAL		
Type of Accident	**No. of accident**	**No. of deaths***	**No. of Injured**
Run-off-Road	**12,264**	**648**	**22,695**
Rear-End Collision	8,225	489	15,831
Side-Impact Collision	8,777	433	18,217
Collisions with Pedestrian	2,070	410	1,969
Head-On Collision	1,854	358	4,998
Rollover/Sway	5,305	263	9,345
Collisions with fixed objects	3,161	131	5,186
Crashing into Stationary Vehicle	488	56	958
Sideswipe Collision	462	20	880
Collisions with Animal	527	19	831
Pile-up	224	17	566
Multiple Vehicle Collision	169	16	455
Crash into Parked Vehicle	121	7	196
Human Falling from Vehicle	122	3	139
Object Falling from Vehicle	44	2	68
TOTAL	**43,813**	**2,872**	**82,334**

** It covers those who were injured in a traffic accident, were referred to health institutions, and died within thirty days due to the cause and effect of the accident.*

Table 4.6 Descriptive Statistics of Accident Data from 2016 to 2018

	2016	2017	2018	Total
Number of accidents	180,057	178,133	184,587	542,777
Number of fatal accidents	6,105	6,210	5,556	17,871
Number of Death	7,029	7,209	6,579	20,817
Number of Injured Accidents	173,952	171,923	179,031	524,906
Number of injured	286,231	283,016	295,076	864,323

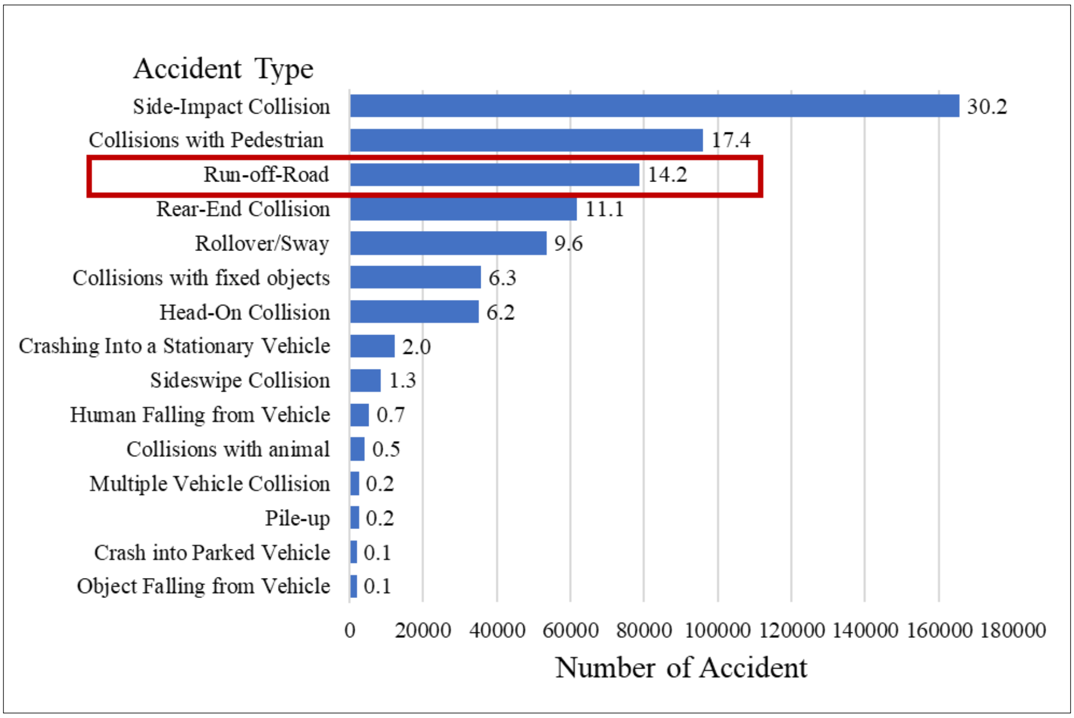

Figure 4.2. Distribution of Accidents Type from 2016 to 2018

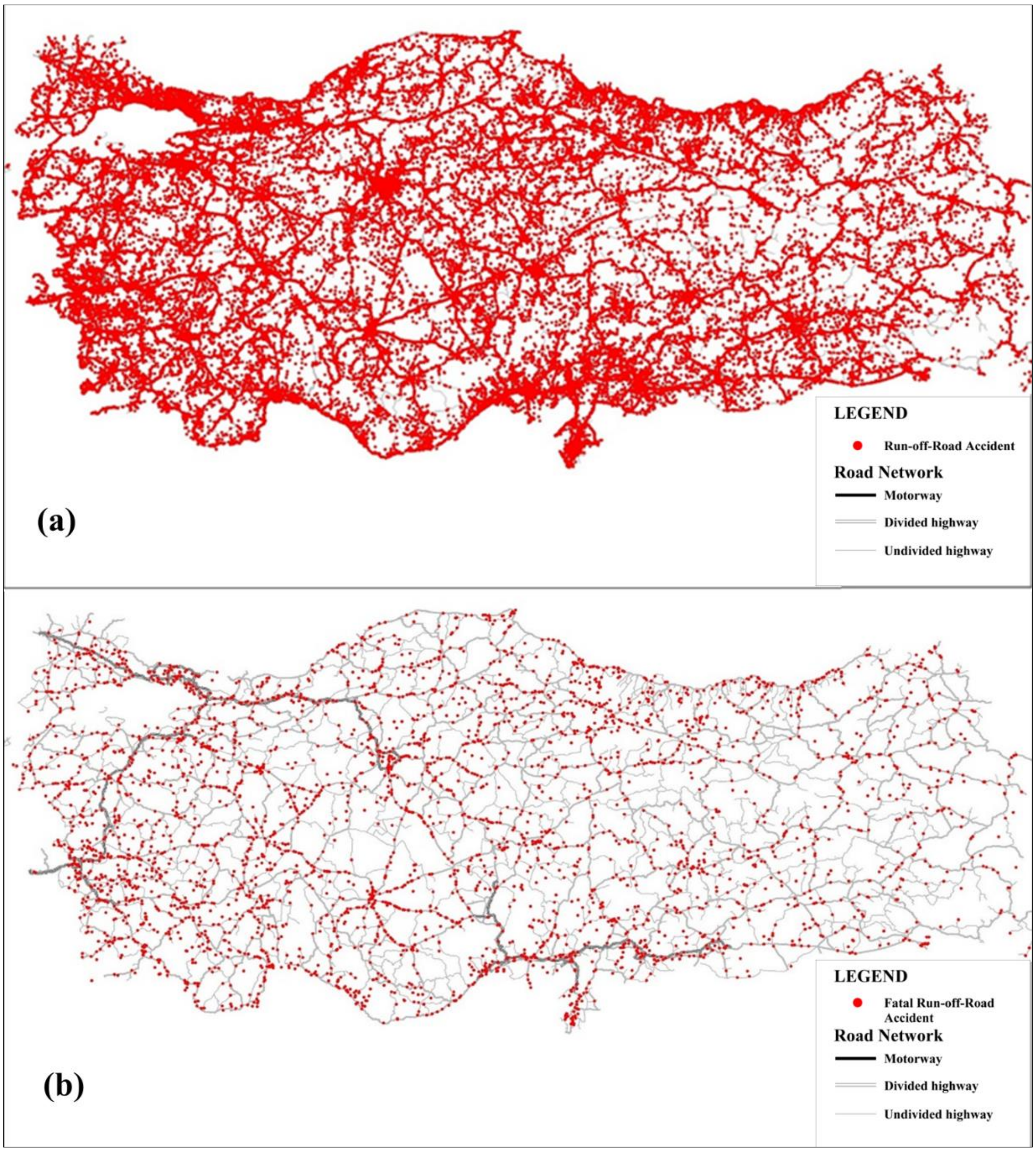

Figure 4.3. In 2017 (a) Run-off-Road accidents and (b) Run-off-Road accidents resulted in fatalities on the Turkish road network

4.3 Roadside Safety Regulations in Turkey

In Turkey, the highway design handbook was prepared and published in 2005 by GDH. This handbook explains and contains information about every stage of road design. Since the GDH is responsible for motorways, state roads, and provincial roads, the design handbook applies to rural intercity roads. For the urban roads, the responsible authorities are the local municipalities, and the GDH design handbook is not mandatory while designing the urban roads.

Roadside design and RRS application is the 7th chapter of this manual, and this chapter is a direct translation of AASTO 1996 Roadside Design Guide 2nd Edition. However, currently using approach and practice while designing the roadside comes from German standards. In Germany, the legislation on RRS was first published by FGSV(Road and Transport Research Association) in 1989, and additions were made in 1996, and the RPS 2009 was created under the name of "Guidelines for passive protection on roads by vehicle restraint systems regulation." The German VRS application guidelines consist of charts based on assumptions regarding site conditions. Also, in application practice rule of thumb is used by designers.

Since guidelines and design practices are a direct translation of the AASHTO and RPS 2009 without making adjustments and adaptations for Turkish road design practices, incompatibilities are inevitable in roadside design. These translated rules and regulations force designers to follow a hybrid approach with many assumptions and use their engineering judgment and experience while designing the roadsides. Therefore VRS applications in Turkey proceed inconsistent and subjective manner.

4.4 Current Turkish Practice of Roadside Design

The roadside (areas between the inner edges of the shoulders and the expropriation boundary) should be considered during road design as it poses a significant danger to vehicles leaving the road for an unintentional reason. In cases where it is not possible to return to the road, to prevent vehicles from hitting a stationary object, or if a collision happens to reduce the intensity of the consequences, some measures should constitute the design principles of the elements of the vehicles.

Forgiving roadsides; regardless of the reason for the vehicle's departure from the road, it aims to have the area covered by the roadside on a slope close to flat, free of fixed objects that will cause a collision and will not cause overturning. It supports a roadside design that can allow vehicles to run off the road and reduce the severe consequences of such a situation. It reduces the risk and severity of accidents. Here are the design options to apply to reduce and clear roadside obstacles:

1. Identify and eliminate obstacles
2. Redesign obstacle safely
3. Place the obstacle by moving it to a point where it will be in a more secure position
4. Reduce impact intensity using a suitable playable-breakable system
5. Shield the obstacle with autocorrect or impact pads designed to reroute crashing vehicles to the road
6. Warn drivers about obstacles if the above alternatives cannot be applied.

Roadside elements such as roadside topography and geometry, fill and cut slopes, roadside ditches, drainage structures, traffic signposts, lighting poles, supports, and safety barriers should be designed to increase road safety. Roadside design is presented in GDH 2005 highway design handbook as a chapter with recommendations from the AASHTO standards. Detailed information from the GDH design handbook is given in Appendix C.

First, the speed limit on that road should be checked to decide whether using guardrails on the roadside is necessary. As a main rule, there is no need to use guardrails where the operating speed is $V_{85} < 60$ km/h. However, accident history on that road section should be examined according to their types and frequency of occurrence. If the existence of accidents caused by ROR vehicles is determined under the following principles, all necessary precautions should be taken, including the use of guardrails.

In sections where the operating speed is $V_{85} \geq 60$ km/h, within the geometric standards of the road, whether there is a possibility of vehicles leaving the road and whether this probability is high should be examined. In this context, guardrails should be used on the road sections where severe accidents are likely to occur if there is a possibility or high probability of ROR. As a rule, it should be accepted that vehicles traveling within the operating speed do not have the possibility of leaving the road on a road section constructed according to geometric standards.

Before the planning and decision-making stages regarding using guardrails in a road section, examinations should be made on the route, and it should be investigated whether there is a possibility of the vehicle leaving the road in that road section, and the results should be evaluated.

<u>Investigating the Probability of Vehicles Leaving the Road</u>

Vehicles may be more likely to run off the road if road sections have:

- High traffic volumes (on two-way roads, AADT ≥ 5,000 vehicles/day),
- Horizontal curves with radius values smaller than the minimum curve radius values determined in the GDH design handbook depending on speed, superelevation rate, and lateral friction factor,
- Continuous horizontal curves in succession,
- Horizontal curves with high slopes and small radius, which are not expected by drivers and noticed quite late,

- Narrowing road sections where vehicles traveling within the speed limit must brake effectively for 2.5 seconds,
- Unusual external factors that could not have been anticipated by the drivers, such as an extremely strong crosswind from a cut to an embankment,
- Road sections with sudden changes in direction,
- Road sections where black ice is likely to occur.

If the issues are determined, it should be planned to install guardrails in these sections. In addition, on roads with low traffic volume (AADT < 5,000 vehicles/day), accident reports for three consecutive years should be examined, and any accidents in the style of leaving the road should be analyzed. If it is observed that there is an increase in the run-off road accident in the road section according to the 3-year accident data, or if it is determined as the accident black spot based on the analyzes made in the sections where the ROR accidents are concentrated, it should be planned to install a guardrail.

In the RPS 2009, VRS is divided into four categories according to performance categories based on the DIN EN 1317. Figure 4.4 shows the definition of these performance classifications results from the respective parts of DIN EN 1317.

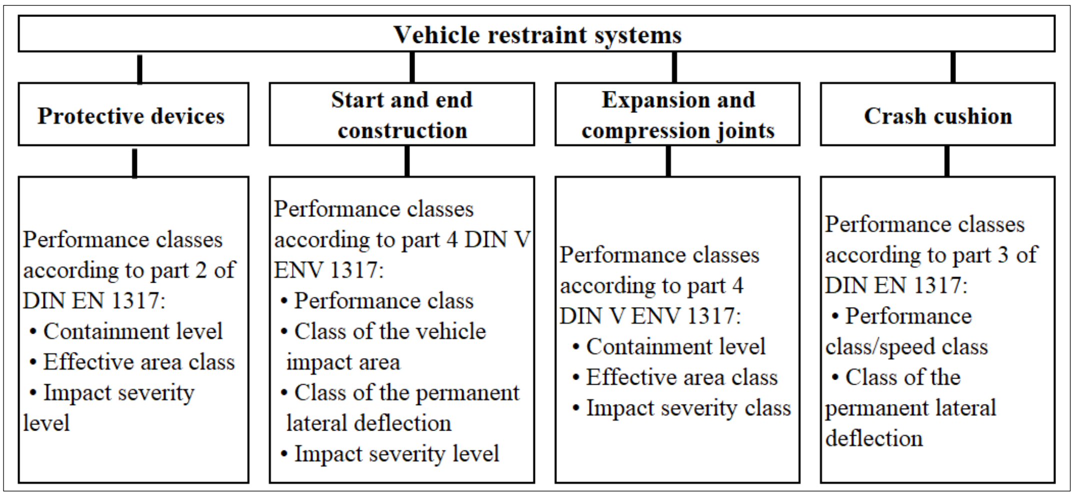

Figure 4.4. Definition of the performance levels according to DIN EN 1317 (FGSV, 2009)

According to RPS 2009, roadside hazard potential is divided into two that may endanger third parties and endanger occupants in the vehicle. Then it again is divided into four danger levels with their sub-breakdowns;

Areas that endanger third parties

1. Hazard Level 1: Areas that require protection, especially where there is a serious risk to third parties (e.g., chemical plants with explosion hazards, heavily used residential areas, adjacent high-speed train routes with permissible speeds above 160 km/h, buildings at risk of collapse)
2. Hazard Level 2: Areas that require protection, especially where third parties are at risk (e.g., adjacent very busy walking and cycling paths, railways with more than 30 trains in 24 hours, adjacent roads with AADT > 500)

Obstacles that endanger the passengers inside the vehicle

3. Hazard Level 3: Obstacles that are particularly dangerous to vehicle occupants (e.g., large non-deformable obstacles perpendicular to the driving path, non-deformable point barriers, sound-absorbing barriers)
4. Hazard Level 4: Obstacles where vehicle occupants are at risk of danger (e.g., embankments that can still deform but are not moved/cut around, multi-slope embankments (height > 3 m and slope > 1:3), rivers with a depth of >1 m).

The high and wide concrete piers of bridges should not be classified as “structures at risk of collapse” but as “non-deforming extensive obstacles” and therefore hazard level 3. Signage for small and medium-sized traffic signs (tube posts and fork stands made of steel pipes with outside diameters larger than 76.1 mm and wall thickness wider than 2.9 mm or aluminum pipes larger than 76.0 mm and wall thicknesses wider than 3.0 mm) can still be deformed, but not moved around must be classified as unsafe and hazard level 4. For signs, other supporting structures (e.g., made of profile carriers, pipe structures) should be included in the non-deforming point individual barriers and therefore classified in hazard level 3. A rising slope steeper than 1:3 should be classified in hazard level 4 if the slope is not sufficiently rounded or if rocky, large boulders or stone slopes are in concern (FGSV, 2009).

Poles that can be moved around, easily deformed, or collapsed are not considered obstacles under the RPS-2009 regulations. The same is true for the poles of light signal systems and lighting poles at intersections with traffic signals systems, regardless of their constructive formation.

According to RPS-2009, the possibility of running off the road should be considered when choosing a VRS. Areas with a high probability of running off the road could be the following road sections.

- Roads with radius connections outside the usable area according to RAS-L (road building specification)
- Multiple successive curves with radii less than 1.5 times the minimum permitted radius according to RAS-L
- Routes with unexpected significant changes of direction

The following situations should assume a higher probability of running off the road.

- In areas of existing roads with an accident frequency according to the criteria of the 3-year map under the "Code of Practise for the Assessment of Road Traffic Accidents, Part 1", in which the accident type running off-road predominates,
- for sections of existing roads, for which other apparent accidents are known

Thus, accidents involving trucks and accidents involving all vehicles that endanger third parties are decisive.

Two different definitions of the safe zone critical distance have been made because particular attention will be paid to the protection of third parties, and these persons are generally faced with severe accidents resulting from vehicles leaving the road.

- Extended AE distance for areas (hazard levels 1 and 2) that need to be protected for third parties
- Distance A is defined for obstacles (hazard levels 3 and 4) that may endanger vehicle occupants.

The critical distances A and AE depend on the clearance V_{allow} (maximum allowable speed limit) and the embankment height (see Appendix D). The V_{85} can be used as an alternative to V_{allow} on routes where the actual speeds are far below the allowable speeds.

The determining factor for assessing whether a hazard is within the safe (critical) zone is the distance between the edge of the traffic area and the edge of the danger zone. The boundary of the traffic area, usually the edge of the paved area, is taken as the reference line (see Appendix D). The edge of the danger zone is the starting point facing the road in areas requiring protection and the leading edge for obstacles.

In deciding whether using guardrails on the road is necessary, the design speed limit should be considered at the beginning of every road design process. As a main rule, there is no need to use guardrails in places where the operating speed is $V_{85} < 60$km/h. However, accidents on that road section should be examined according to their types and frequency. In this context, if the existence of accidents caused by ROR vehicles is determined under the following principles, all necessary precautions should be taken, including the use of guardrails.

In places where the operating speed is $V_{85} \geq 60$km/h, within the geometric standards of the road, whether there is a possibility of vehicles going out of the road and whether this probability is high should be examined. As a main rule, it should be accepted that vehicles traveling within the operating speed do not have the possibility of leaving the road on a road section made by geometric standards.

Before the planning and designing the use of guardrails in a road section, examinations should be made on the route, and it should be investigated whether there is a possibility of the vehicle leaving the road in the said section, and the results obtained should be evaluated.

According to RPS 2009, the minimum containment levels of guardrails according to their usage areas are shown in Figure 4.5. If the distance of the hazard to the road is equal to or less than the distance to the safe zone, it is used from the flowchart in Figure 4.6 to decide whether a safety barrier is necessary and what minimum level of containment level it should have. The maximum working width class depends on the local situation. In principle, a safety barrier should be chosen so that its working width is less than or equal to the distance between the safety barrier's front face and the hazard's front face (see Figure 4.7).

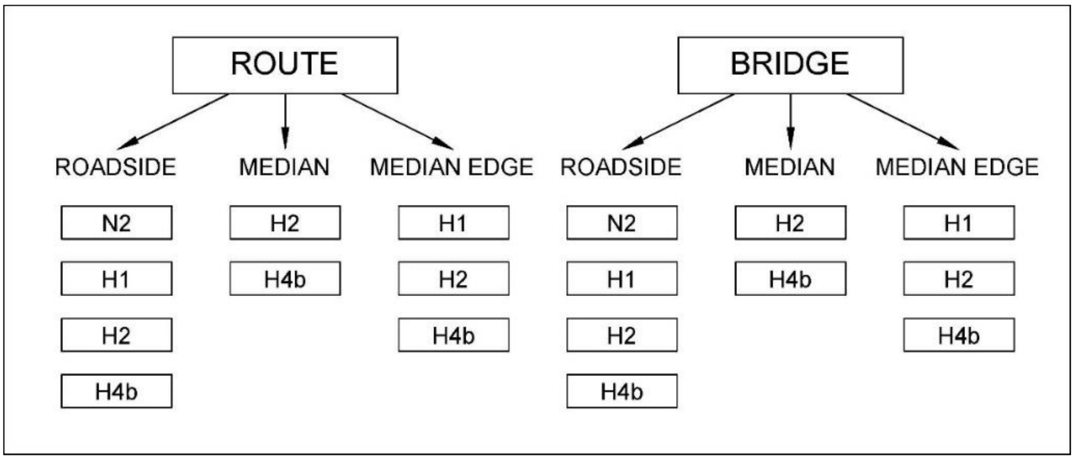

Figure 4.5 The places of use of guardrails and their minimum containment level according to RPS-2009

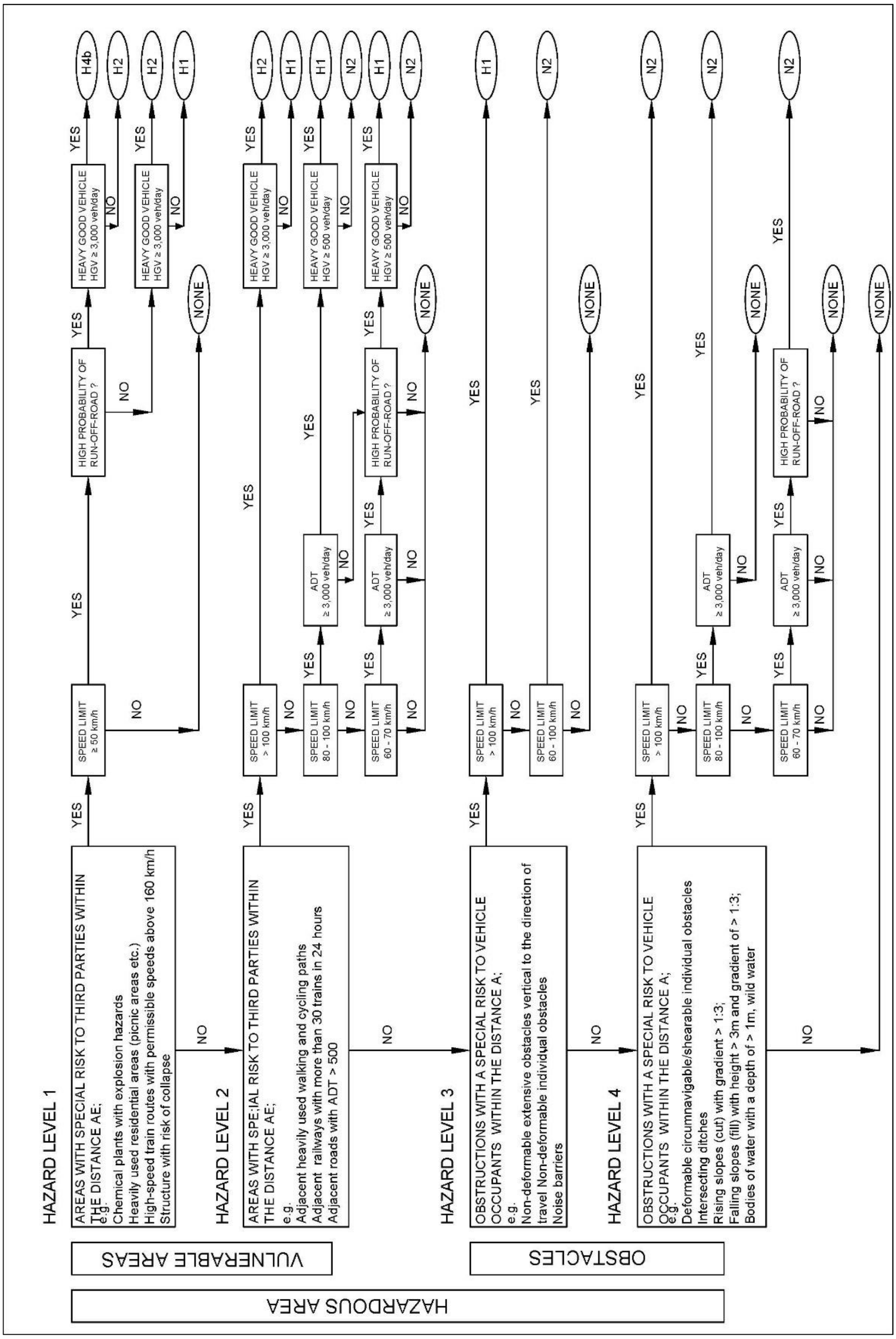

Figure 4.6 Criteria for the use of protective equipment on the outer edge of the road (FGSV, 2009)

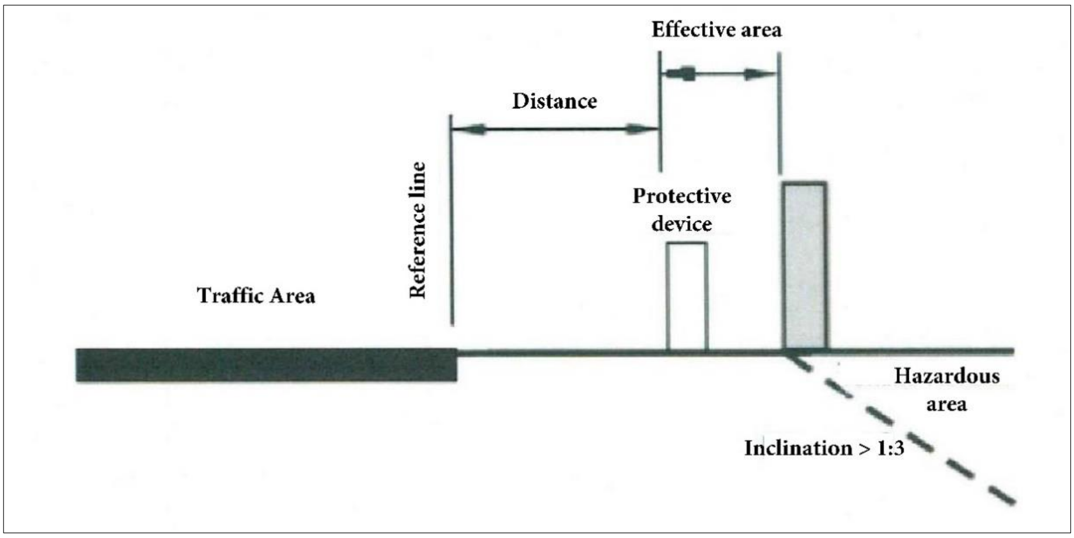

Figure 4.7 Arrangement of protective equipment according to the effective area and traffic area (FGSV, 2009)

The distance of the front edge of the safety barrier from the reference line should be 0.5 m. It is possible to descend below this minimum in proven exceptional cases, such as obstacles within the working width. Greater distances may be required if the required fields of view are not provided.

If site conditions allow or traffic conditions require (e.g., roads without dedicated walking and cycling paths), the safety barrier should be arranged between 1.0 m and 1.5 m from the reference line. In these cases, the shoulder should be adequately fixed, and the effectiveness of the protective device should be ensured.

ISL-A represents a lower impact for the errant vehicle occupants than ISL-B and is preferred in comparable situations. ISL-C, the highest impact on the errant vehicle occupants, can be used in hazardous areas containing a ROR vehicle (such as a heavy goods vehicle), which is of primary importance.

RPS 2009 states that the minimum required lengths of the safety barriers are determined from bullet points a to f.

a) Safety barriers must have a certain minimum length in order to be effective. This L_1 minimum length is given in the crash test reports for each barrier system under DIN EN 1317-2.

b) Safety barriers must have at least one L_2 distance in front of the hazardous zone to prevent the vehicle involved in the accident from sliding over the barrier or getting behind it (see Table 4.7 and Figure 4.8). On single-lane roads with two-way traffic, distance L_2 should be given on both sides (Figure 4.8). Also, reducing the containment level by one step within the distance L_2 is possible at the $0.5xL_2$ distance. For example, for a safety barrier with containment level H4b, it is possible to reduce the stop stage to H2 after a distance of $0.5xL_2$.

Table 4.7 Required L_2 length to prevent the vehicle from sliding on or driving behind (FGSV, 2009)

<table>
<tr><th rowspan="2">Criterion</th><th rowspan="2">Type of road</th><th colspan="2">Arrangement of the safety barrier</th></tr>
<tr><th>Parallel To the road</th><th>Laterally offset</th></tr>
<tr><td rowspan="2">Sliding on when the hazardous area > 1.5 m behind the front edge of the safety barrier</td><td>single lane</td><td>100 m</td><td>-</td></tr>
<tr><td>two lanes</td><td>140 m</td><td>-</td></tr>
<tr><td rowspan="2">Driving behind</td><td>single lane</td><td>80 m</td><td>60m</td></tr>
<tr><td>two lanes</td><td>100 m</td><td>60m</td></tr>
</table>

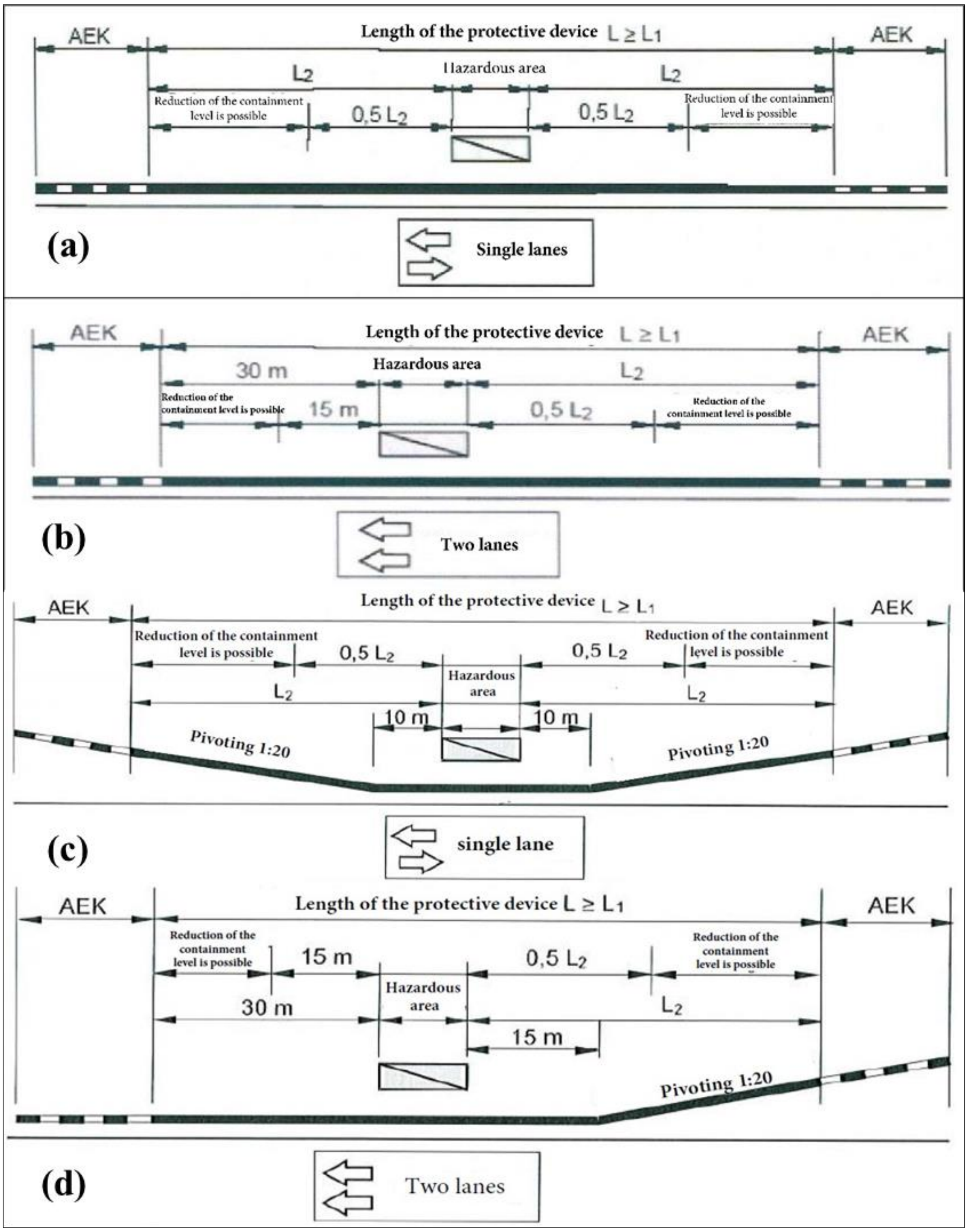

Figure 4.8 Minimum lengths for safety barriers (a) on single-lane roads(b) on two-lane roads (c) in case direction changes on single-lane roads (d) in case direction changes on two-lane roads (FGSV, 2009)

c) In cases where the errant vehicle is not allowed to pass behind the safety barrier (e.g., on a high embankment) and the slip criterion of the errant vehicle on the barrier is not met, according to Table 4.7 the distance L_2 should be taken as 40 m, and no reduction of the containment level is allowed within this distance.

d) The length of L_2 can be reduced if the safety barrier is offset laterally outward with an offset of 1:20, in exceptional cases, 1:12 (see Table 4.7). In this case, the side turn is not applied immediately before and after the hazard, and the safety barrier guided at least 15 m parallel to the two-lane roadway and at least 10 m on single-lane roads before the start of the hazard zone (Figure 4.8). This length corresponds to the lengths given in Table 4.7

e) If the beginning of the safety barriers is inside the embankment, it should be offset laterally outward with a ratio of 1:20 and, in exceptional cases, 1:12.

f) Safety barriers must always have an adequate length forwards and backward across the hazard area to be effective. This length is at least 30 m. and at least 20 m on single-lane roads on two-lane roads. 15 m from the hazard zone on two-lane roads, the containment level can be reduced by one level. It can downgrade from protection level H4b to protection level H2.

CHAPTER 5

METHODOLOGY

The main goal of this study is to compare Turkey's roadside design practice with a different design approach from a country with safer roadside design. The study focuses on the safety barrier provision at the nearside of high-speed and high-traffic volume rural roads. Since one of the best ways to make a comparison is to show the application with an example, a case study is prepared, and results are used to compare the design approaches. A rural intercity road is selected for a case study, and roadside design is carried out according to Turkish practice and a new proposed approach redefined from the UK approach. In this comparison, evaluation of the nearside of a traffic flow has been conducted only; in other words, the VRS requirements of the road's median are exempted from design. The main questions are throughout the design processes;

1. where the safety barrier should be installed,
2. and how many meters of safety barrier is needed

according to Turkish and proposed approach.

The answer to the first question shows the differences in hazard consideration and risk assessment between these two approaches. Which situations and hazards are perceived hazardous for the errant vehicles and whether or not they need to be shielded with safety barriers. The answer to the second question shows the quantity and type of the safety barrier needed. Two approaches determine the containment level, working width, and length of need. The quantity-take-off of the safety barrier is calculated and presented. Due to the complexity and lack of unit price information, the economic comparison could not proceed in this study.

5.1 Proposing a New Roadside Design Approach for Turkey

Although the written guidelines are translated versions of the AASHTO roadside design guide, applications are conducted with modified and simplified German standards in Turkey. Throughout the roadside design, rules of thumbs, engineering assumptions, and judgments are used. Hence, the decision for the VRS application is highly dependent on the designers' experiences and judgments, and this makes the decision process subjective.

This research requires preparing a new roadside design approach as an alternative to current Turkish practice. The proposed approach aims to create a more objective and risk-based decision-making process for VRS provision. The proposed approach is inspired by the UK roadside design manuals and application practices. The reasons for choosing the UK practice as a model are:

- EN1317 standards are followed,
- ROR accidents are examined in-depth,
- the systematic and objective process is using,
- risk-based assessment (the RRRAP) tool assisting the designer.

The proposed approach consists of three main stages: data collection, risk assessment, and design decision. The framework of the proposed approach is presented in Figure 5.1.

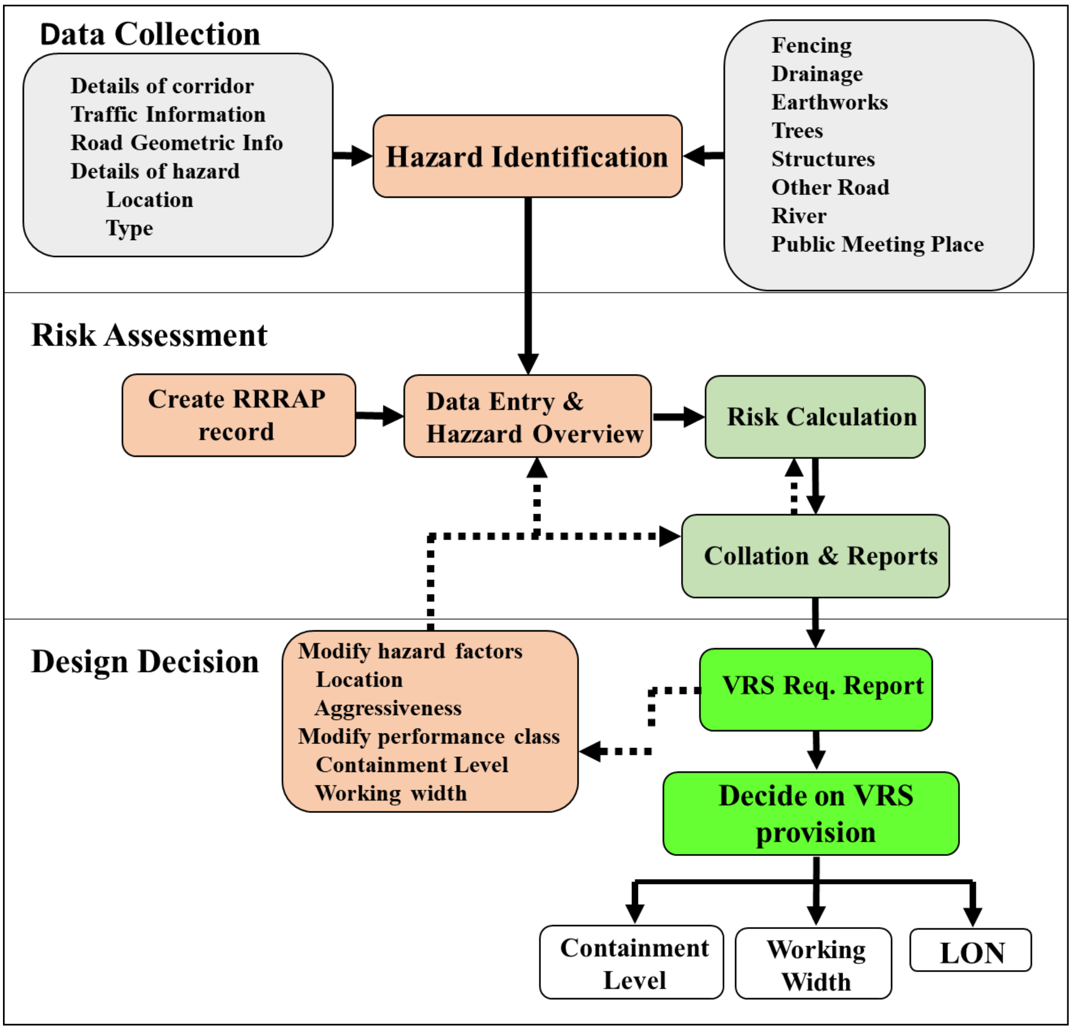

Figure 5.1 Framework of the proposed approach

In the data collection stage, details of the corridor and hazards that need to be considered along the corridor are identified. Traffic flow and composition, road type and geometry information, and hazard details are obtained. The length, width, and offset from the road information are detected for hazards such as fences, drainage elements, earthworks, trees, structures, other roads, rivers, public meeting places, etc., by site visits and the current corridor map.

In the risk assessment stage, the RRRAP software is used for the risk assessment of the hazards. Some assumptions are made about the Turkish road conditions to be able to use the RRRAP tool, but the algorithm behind the tool is not modified. Firstly, a record is created for the study corridor, and information about the corridor is given like traffic flow, composition, and road type. For each hazard that details are gathered in the data collection stage are introduced to the RRRAP software., Some assumptions were made while using the RRRAP since the software was created for British roads.

The first assumption is about the traffic flow direction. Although the UK and Turkey have opposite traffic flow directions, the flow direction of the study corridor is unchanged. The charts, illustrations, and comments regarding flow direction are followed and carefully adapted for the Turkish traffic flow direction.

The second assumption is about the centerline of the road. The centerline is one of the first and most essential road features when designing a road. It is an imaginary line along the center of two opposite flowing traffic and consists of horizontal curves and straight lines. The centerline helps and guides the designer while constructing horizontal and vertical alignment. It is a handy feature to indicate the location on the roadway corridor since it is a vector line of data that assigns the numerical indicator to locations. As an assumption, two dummy centerlines are used in increasing order through the traffic flow direction instead of the actual corridor centerline. These dummy centerlines pass through the pavement's outer edges. Kilis direction dummy centerline has the exact station kilometers with the actual centerline, but the station kilometer of Hassa direction dummy centerline starts with additional 100 kilometers to distinguish the difference and overcome any confusion (see Figure 5.2 and Figure 5.3).

The third assumption is about the typical cross-sections of the road. The differences in dimensions and definitions of a typical cross-section of Turkish roads and British roads are considered during the design. The most noticeable difference is the verge section, which does not exist in Tukey cross-sections (see Figure 2.5). The verge is a mandatory space in the UK legislation, and its width must be equal to or bigger than the default values based on the type of road. On the other hand, a typical cross-section in Turkey does not have this requirement; it has a 1-meter safety barrier edge width at fill sections if the safety barriers are required (see Figure 5.2). The RRRAP needs to verge information to calculate the risk and length of need of safety barrier. For this reason, the verge section is assumed for the study corridor by dividing and narrowing the outer shoulder. The shoulders and verge widths are assumed to be 1.9 meters and 0.6 meters, respectively (see Figure 5.3). Other than these three major assumptions, while entering the hazard information in the RRRAP software, some minor assumptions are made about the embankment heights, cut sections, culvert headwalls, and retaining walls based on the software's requirements and guidelines.

In the final stage, the design decision, the designer examines the VRS requirement report obtained from the RRRAP. The first calculations are conducted with default containment level N2 and working width W2. The calculation results state whether the hazard risk is acceptable, tolerable, or unacceptable with these default values, but the designers may need to conduct an iterative solution process by changing the default values. In addition, they can revise the hazard information that is given. After the required changes are completed, the risk calculation is repeated. This iterative process is repeated until the risks of the hazards become acceptable, then the designers decide the VRS provision for hazards. Since risk assessment is made for every hazard individually in the RRRAP, designers should look at the result comprehensively. For example, if the distance between two consecutive hazards is close and reports suggest VRS requirements for both hazards, the safety barriers should be combined, and continuity should be ensured.

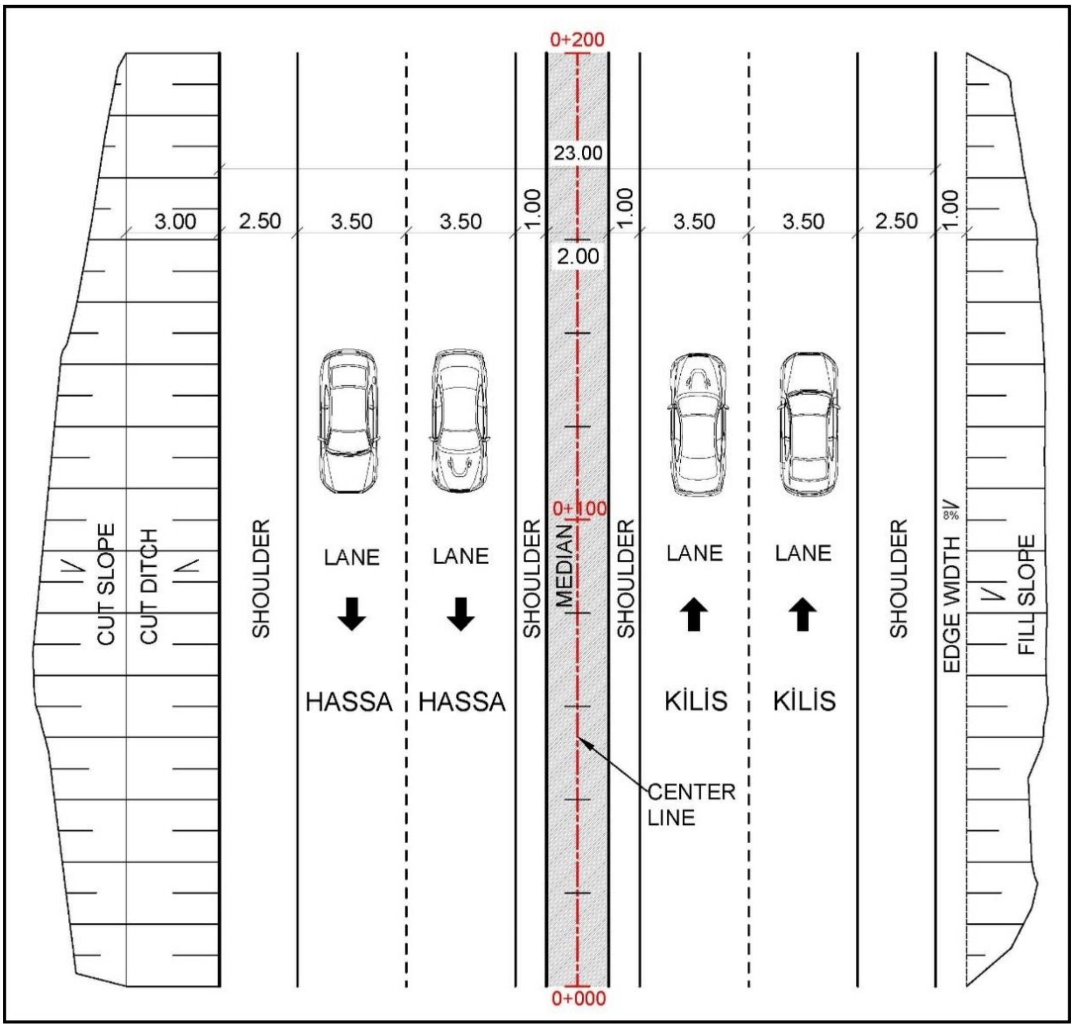

Figure 5.2 Typical plan view of non-junction sections

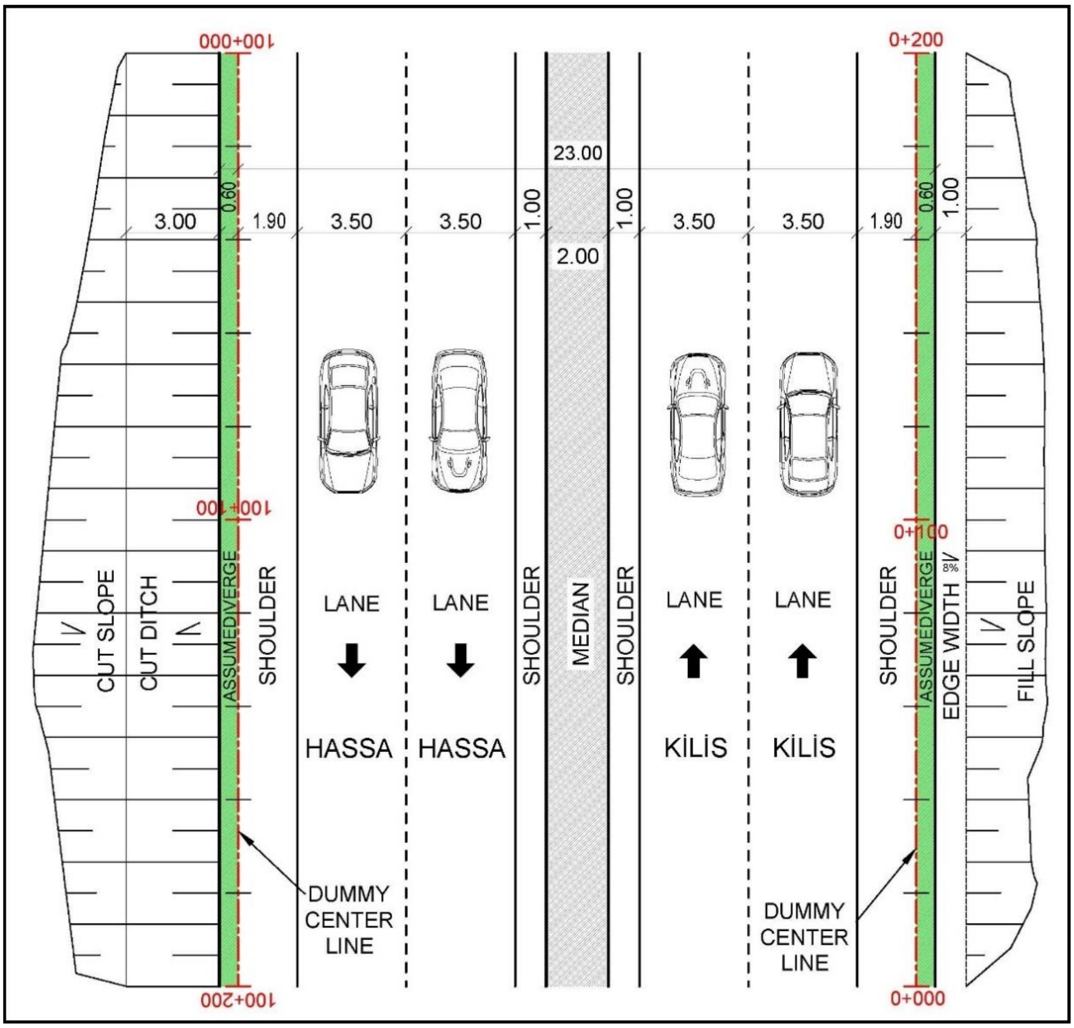

Figure 5.3 Assumed plan view for the UK roadside design

5.2 Case Study

The study corridor starts at the junction of the Musabeyli District of the Hassa-Kilis D410 state road, proceeds in the east-southeast direction, and ends at the TOKİ Residences junction of Kilis. The study corridor is the state road with control section number 410-03, and its total length is 17,270 km. The corridor's location on the GDH Map is presented in Figure 5.4, and the general layout drawing is shown in Figure 5.5.

Figure 5.4 Site location map of study corridor on D410-03

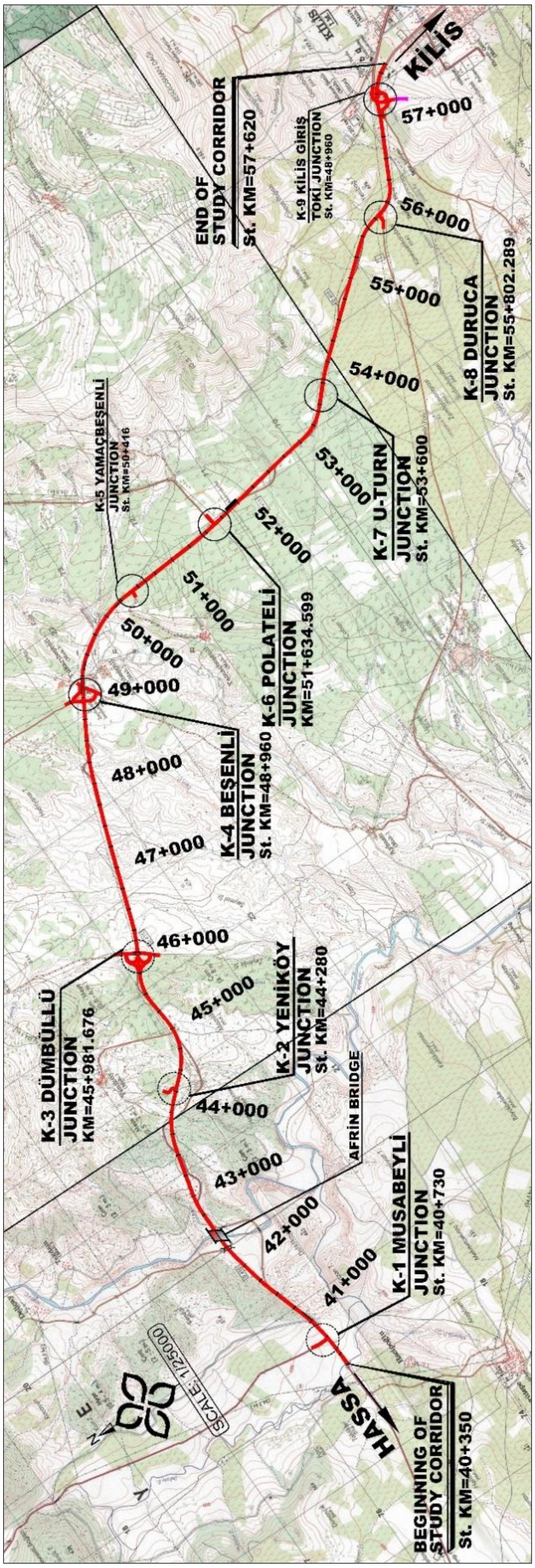

Figure 5.5 General layout drawing of Study Corridor on D410-03

To understand the economic and social contributions of the road to the region, it is necessary to summarize the general information about the area. Gaziantep is located in the east, west, and north of Kilis, and Syria is in the south. Kilis is 58 km from Gaziantep and 10 km from the Syrian border. The road through Kilis reaches the Syrian city of Aleppo after passing through Azez beyond the borders of Turkey.

According to TUIK (2022a), the population of Kilis was 145,826 in 2021. People living in rural areas make their living based on agriculture. In the southeast of Kilis and the border strip, viticulture and olive cultivation are very developed, and there are arable lands. Olive, grape, and wheat products, which are important in Kilis agriculture, are also used in the manufacturing industry as inputs in molasses, alcohol, olive oil, and bulgur production facilities. Especially grapes and olives are two crucial agricultural products that add value to Kilis. Kilis Province has a significant export potential for Turkey regarding border trade. It has many advantages of being located at the intersection of the Mediterranean and the Southeastern Anatolia regions, being close to Mersin and Iskenderun ports, and being a border neighbor with Syria. According to TUIK data, a big part of exports consists of furniture, food, beverages, textile, clothing, agriculture, and livestock products. Exports of livestock, and food products, which have a very high potential, are made especially to the Middle East countries. When it is considered that these countries are food importers, improving the transportation infrastructure of Kilis, whose economy is based on agriculture, will provide many economic advantages.

It will not be surprising that the traffic volume on the road network will increase when the existing road is updated and become a major road. The project route has a traffic flow of around 5,000 vehicles per day (see Table 5.1). When upgrading this route and the export potential of Kilis considered, an increase in heavy good vehicle flow and traffic flow is inevitable.

Table 5.1 Traffic flow AADT (veh/day) information in 2021 (GDH, 2022c)

Control Section No	**St. Km**	**Private vehicle**	**Medium Commercial Vehicle**	**Bus**	**Truck**	**Articulated Truck + Semi-Trailer**	**Total**
410-03	40+000 - 52+000	2656	354	5	225	565	3805
	52+000 - 61+000	3412	451	7	317	527	4714

The existing road is a 2x1 undivided state road with a width of 8-12.00 m. The new design aims to improve the geometric standards and superstructure of the existing road and turn it into a 2x2 divided highway. The newly designed road consists of 9 junctions, six at-grade junctions, and three grade-separated junctions, and project information is presented in Figure 5.6. The design speed for the upgraded road is 90km/h in rural areas, but in the junction areas, speed limits are reduced to 70km/h. For the urban areas, which is Kilis city crossing in the study corridor, the design speed also is 70km/h. For the cross-section, a 2x2 divided highway is shown in Figure 5.7 and is used for the rural areas. The median section is widened or narrowed in the junction areas according to geometric requirements.

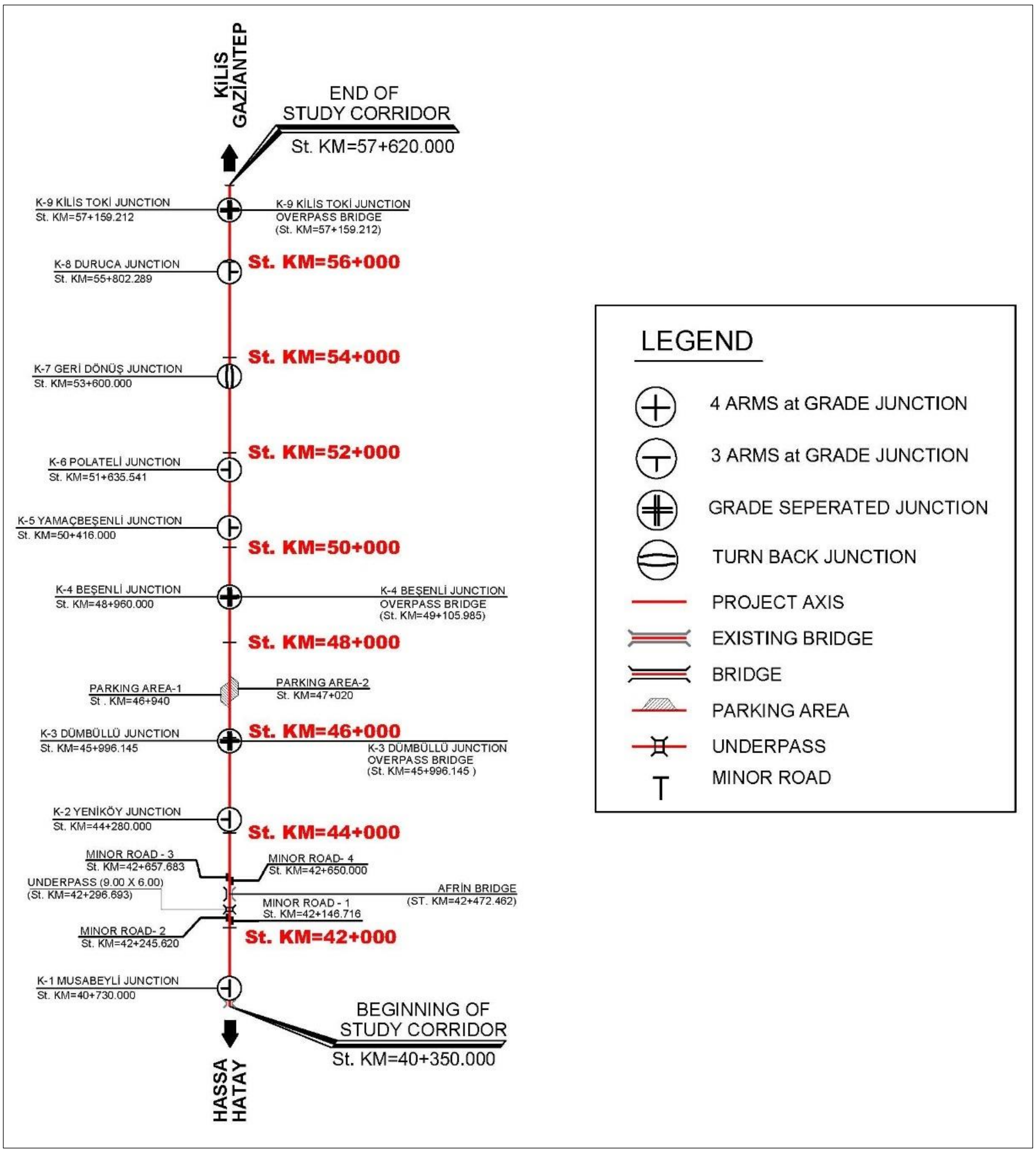

Figure 5.6 Study Corridor itinerary information

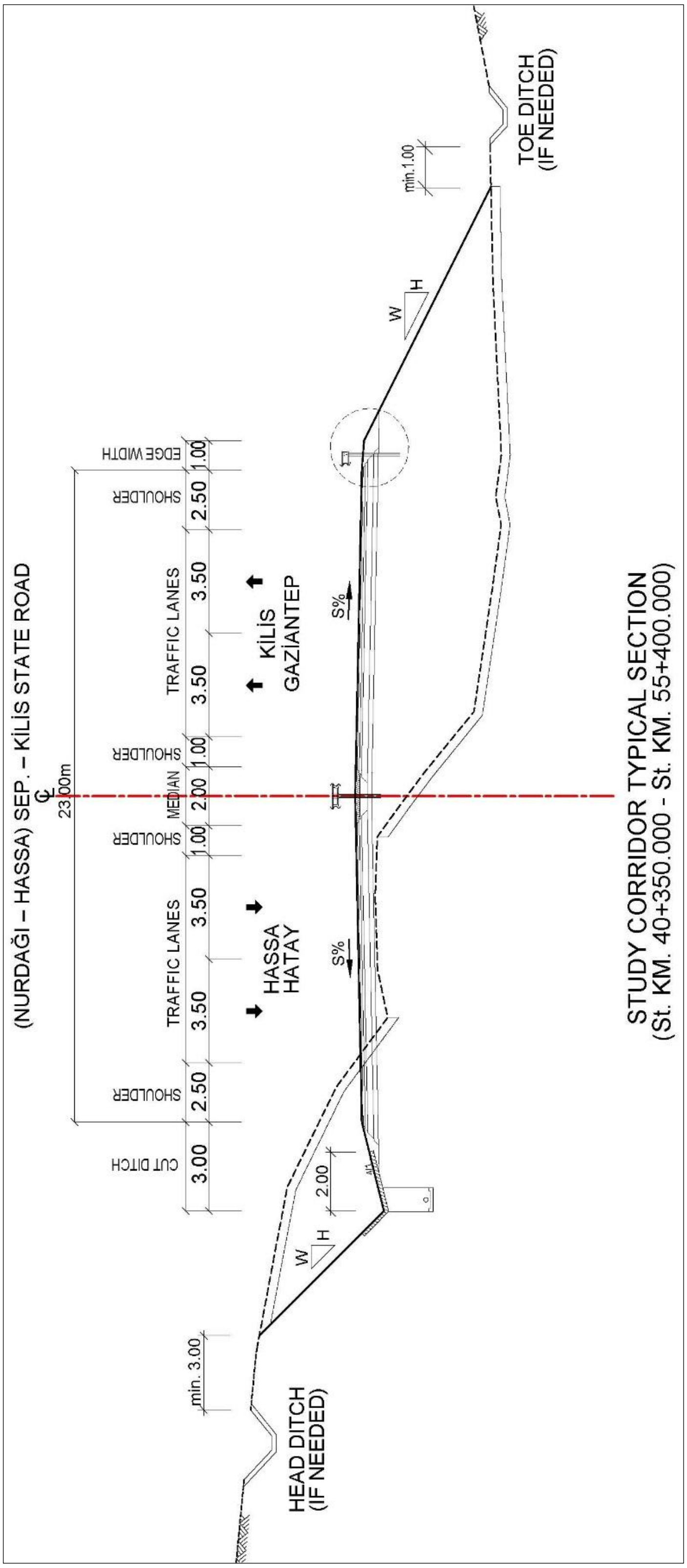

Figure 5.7 Typical cross-section of study corridor (St. Km. 40+350 to St. Km. 55+400)

5.3 Study Corridor Segmentation

The provisions for RRS for urban and junction areas have different factors to consider, such as speed, turning movements, and pedestrians. Also, the manuals and the risk assessment process for these areas have different approaches from the rural area routes. In the scope of this study, the junction areas and the city crossing are exempt from the case study, and only the segments between junction areas are considered. Hence case study consists of 7 corridor segments total length of 12,180 meters, which is St. Km, and the lengths are presented in Table 5.2. Also, the corridor segments are shown in Figure 5.8 on the general layout of the study corridor.

For the current Turkish practice, the study corridor centerline is used as it is, and the beginning and end of the required safety barrier are identified according to the station kilometers of the centerline. Since there is only one centerline for the Turkish practice, Kilis direction segment station kilometers are also valid for the Hassa direction (see Table 5.2). However, for the proposed approach, the assumption is to use dummy centerlines along the roadway edges (see Figure 5.3). The Kilis direction roadway dummy centerline starts with the same station kilometer as the principal centerline of the study corridor due to traffic flow direction. The Hassa direction roadway dummy centerline starts with additional 100 kilometers to starting station kilometer of the project. Hence, information on the starts and ends of these dummy centerlines, the considered corridor segments, is shown in Table 5.2. These corridor segments are called CS and are risk assessment calculations conducted using the RRRAP software by creating 14 records. Each CS plan view is detailed in Figure 5.9 to Figure 5.15. In these figures, the major concerning hazardous areas and the exempted sections are pointed out by identifying by prefix point of interest (POI).

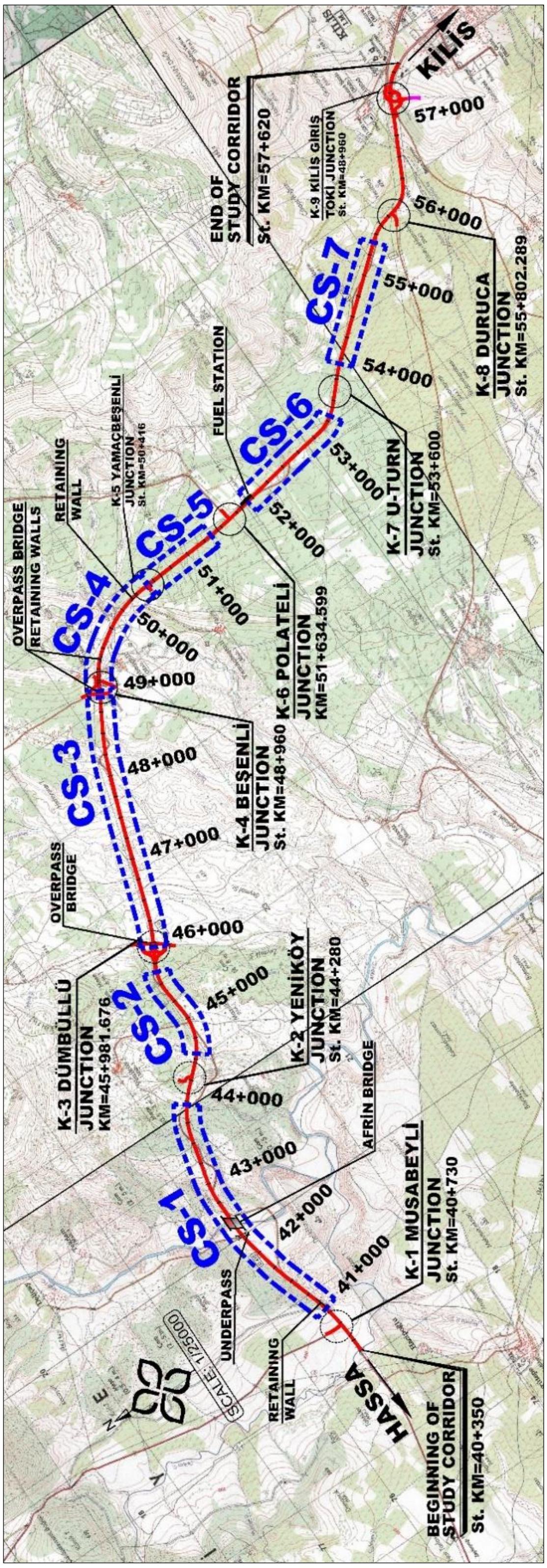

Figure 5.8 Case study corridor segments on the general layout

Table 5.2 Case study corridor segments

		Kilis Direction Segments [a]		**Hassa Direction Segments** [b]	
	Total Length (m)	**From (St. Km)**	**To (St. Km)**	**From (St. Km)**	**To (St. Km)**
CS-1	2,960	40+990	43+950	151+800	154+790
CS-2	1,090	44+560	45+650	150+110	151+190
CS-3	2,980	45+940	48+920	146+830	149+810
CS-4	1,380	49+000	50+380	145+325	146+760
CS-5	910	50+430	51+340	144+390	145+325
CS-6	1,390	51+920	53+310	142+440	143+820
CS-7	1,470	53+930	55+400	140+350	141+820

[a] *These station kilometers are valid for the Hassa direction in Turkish practice due to only one principal centerline being used. Also, it represents the dummy centerline station kilometers for the proposed approach.*
[b] *Dummy centerline assumption with additional 100 kilometers for the Hassa direction in the proposed approach*

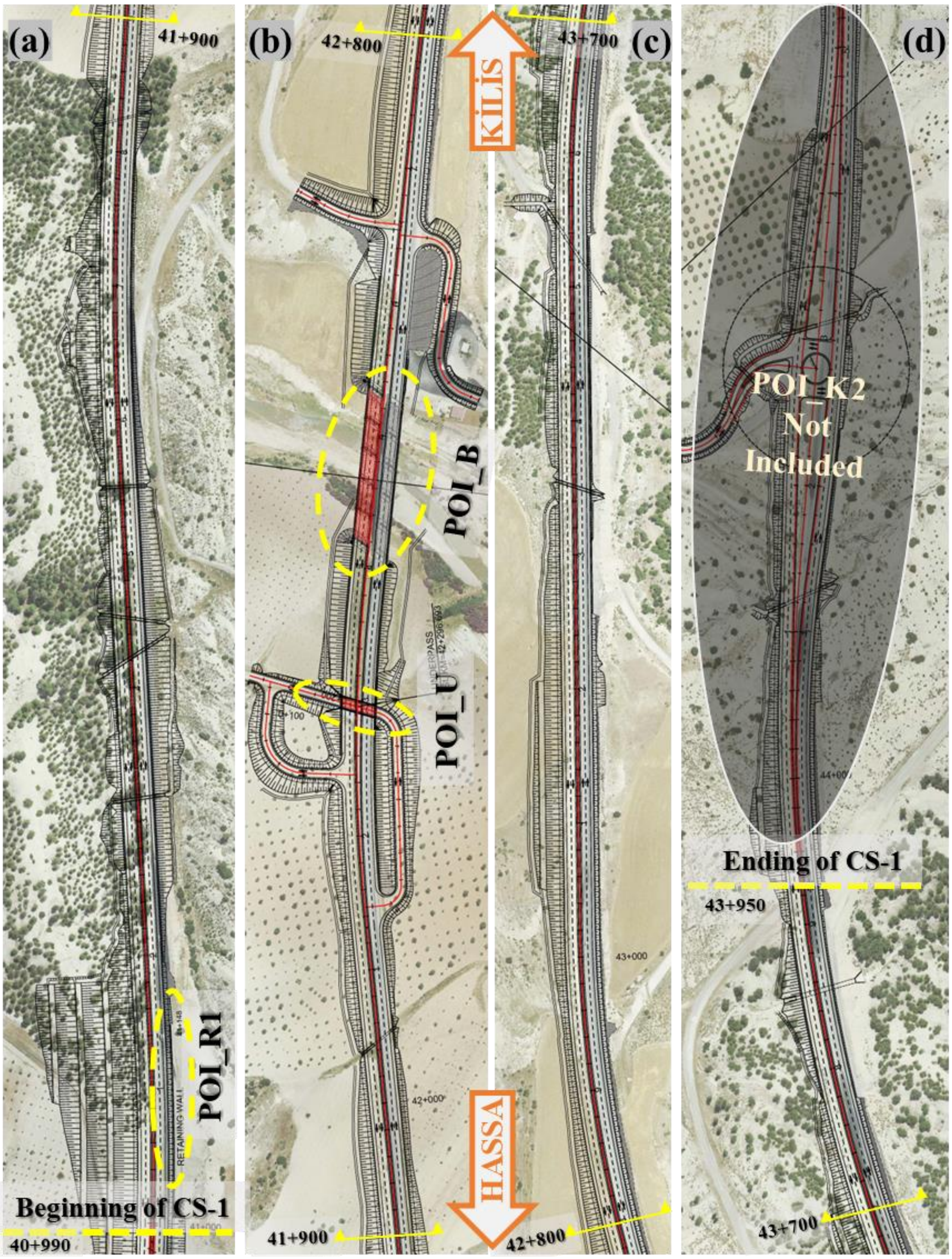

Figure 5.9 Plan view of CS-1 (a) St. Km 40+990 to St. Km 41+900 (b) St. Km 41+900 to St. Km 42+800 (c) St. Km 42+800 to St. Km 43+700 (d) St. Km 43+700 to St. Km 43+950

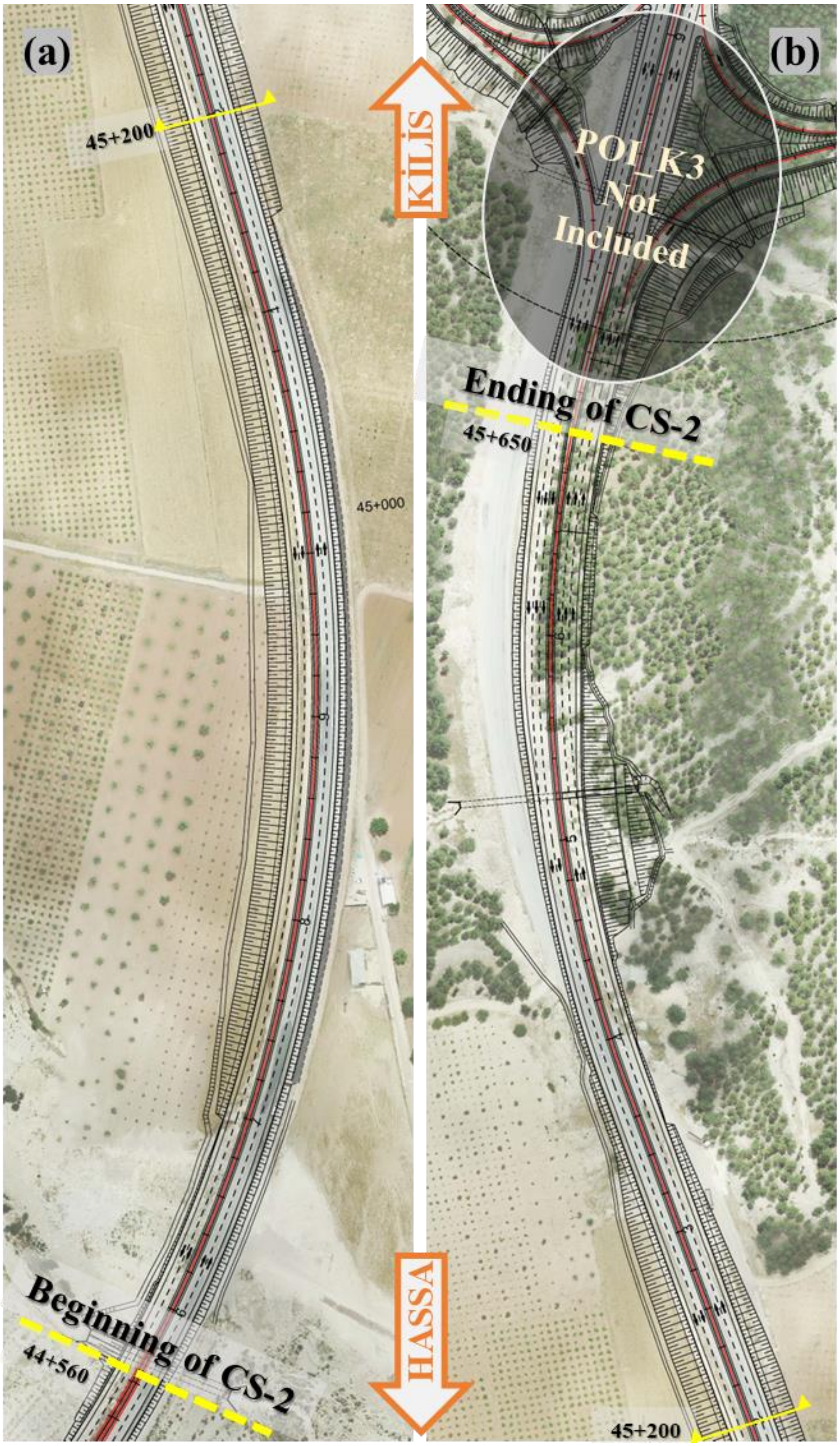

Figure 5.10 Plan view of CS-2 (a) St. Km 44+560 to St. Km 45+200 (b) St. Km 45+200 to St. Km 45+650

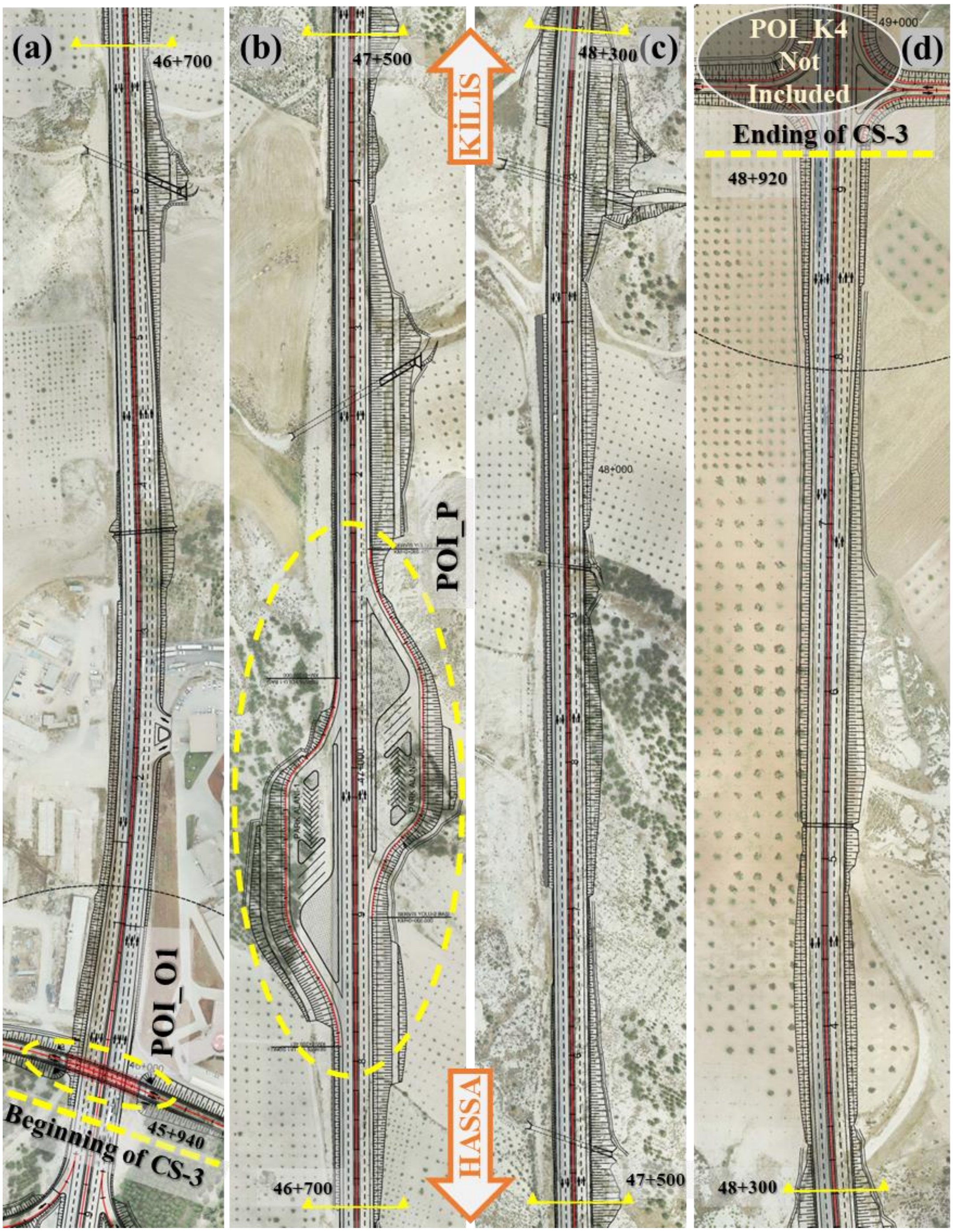

Figure 5.11 Plan view of CS-3 (a) St. Km 45+940 to St. Km 46+700 (b) St. Km 46+700 to St. Km 47+600 (c) St. Km 47+600 to St. Km 48+300 (d) St. Km 48+300 to St. Km 48+920

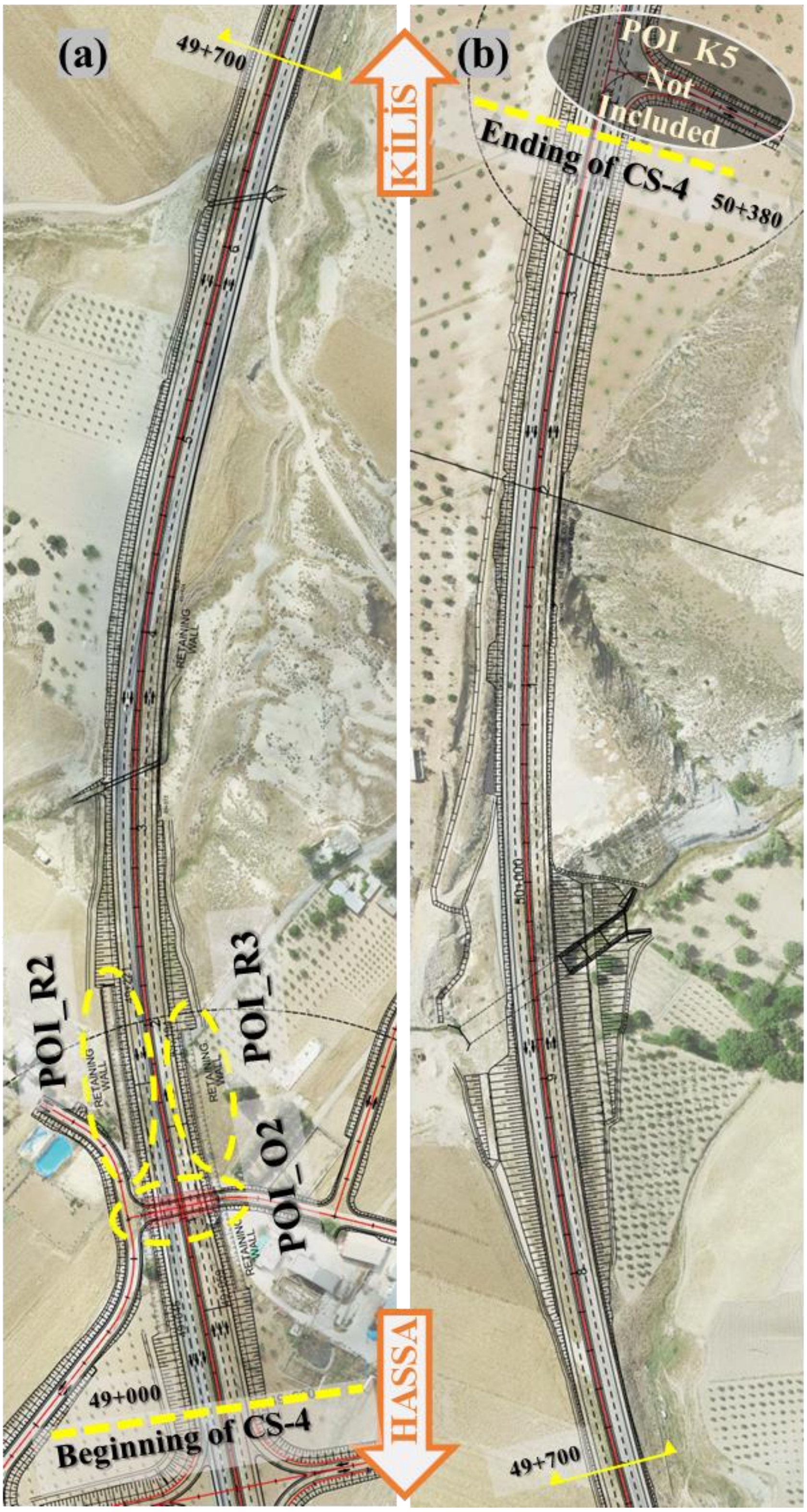

Figure 5.12 Plan view of CS-4 (a) St. Km 49+000 to St. Km 49+700 (b) St. Km 49+700 to St. Km 50+380

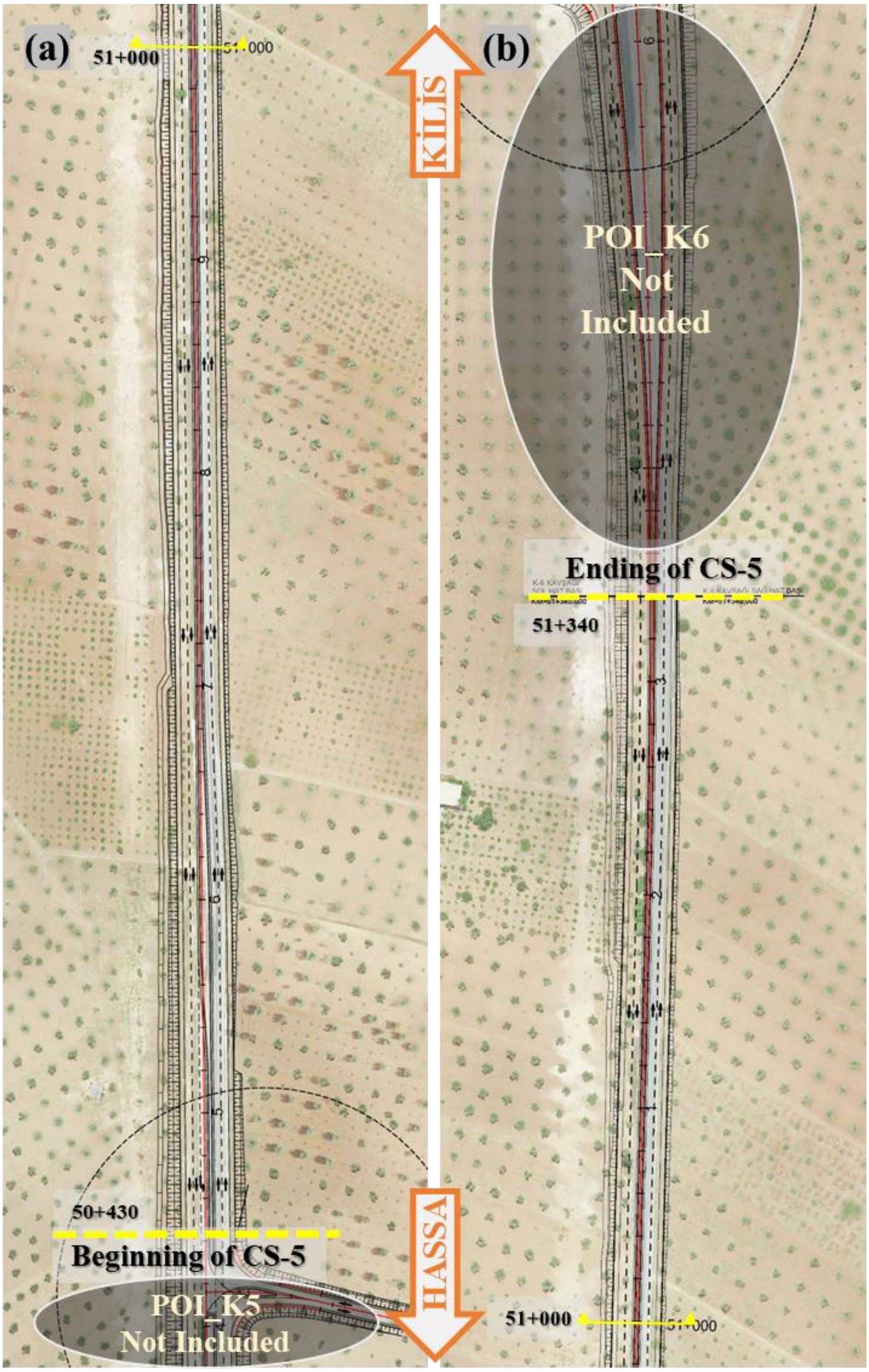

Figure 5.13 Plan view of CS-5 (a) St. Km 50+430 to St. Km 51+000 (b) St. Km 51+000 to St. Km 51+340

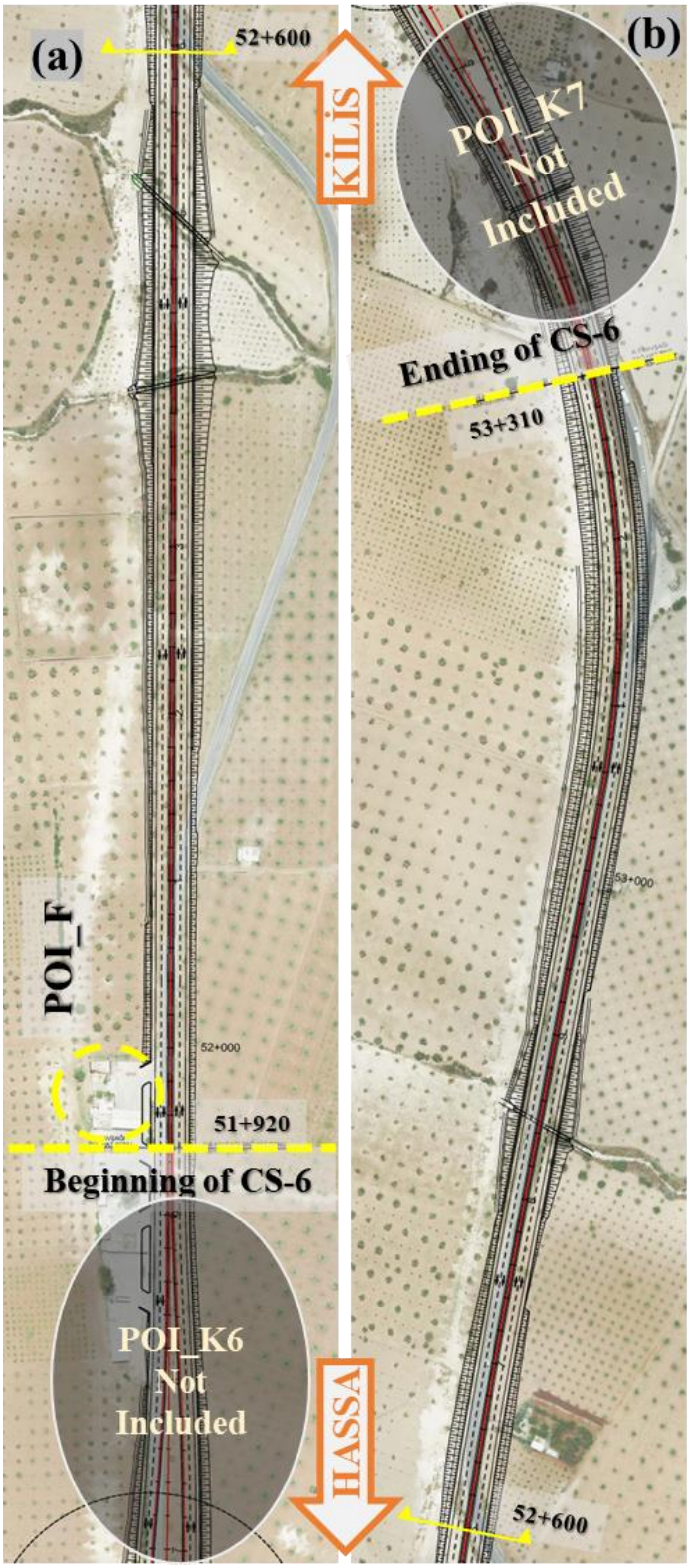

Figure 5.14 Plan view of CS-6 (a) St. Km 51+920 to St. Km 52+600 (b) St. Km 52+600 to St. Km 53+310

Figure 5.15 Plan view of CS-7 (a) St. Km 53+930 to St. Km 54+600 (b) St. Km 54+600 to St. Km 55+440

The study corridor's right-hand platform, which progresses towards the Afrin Stream in its kilometers, is wholly built on top of the existing platform. With the L=112.80 m long (5x22 m) Afrin Bridge, the existing platform crosses the Afrin Stream (see Figure 5.16). This existing bridge will serve the Kilis direction of the divided highway, and a new bridge will be constructed for the Hassa direction adjacent to the existing bridge.

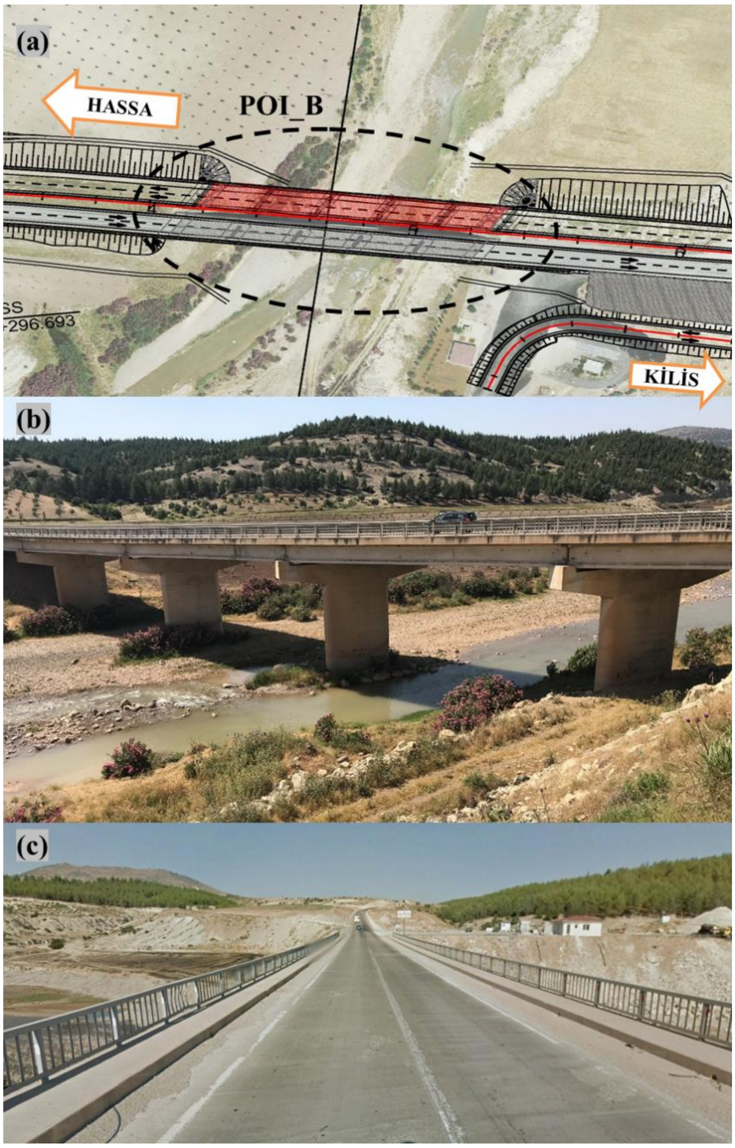

Figure 5.16 Afrin Bridge (a) POI_B on plan view (b) existing bridge (c) a view of the existing bridge platform

Since the vertical geometry of the designed road primarily aims to protect the existing Afrin Bridge, the longitudinal slope at the exit of the Afrin Bridge (Km ahead) is designed as an 8.00% upgrade to coincide with the vertical geometry of the existing road. Another reason for this situation is that the existing route is connected to the vertical crest curve approximately 600 meters after the Afrin Bridge exit. The vertical line coming out of the Afrin Bridge with a slope of 8.00% is connected to the 1.2% downgrade slope parallel to the existing vertical geometry with the vertical curve at Km: 43+335.00 in a way to provide sufficient visibility. After the Afrin Bridge, the roadway toward Kilis, up to approximately St. Km: 45+200, is designed to be placed on the existing platform. Yeniköy connection is currently a T-junction for the village road at St. Km: 44+280 and is designed as an at-grade roundabout (see Figure 5.17).

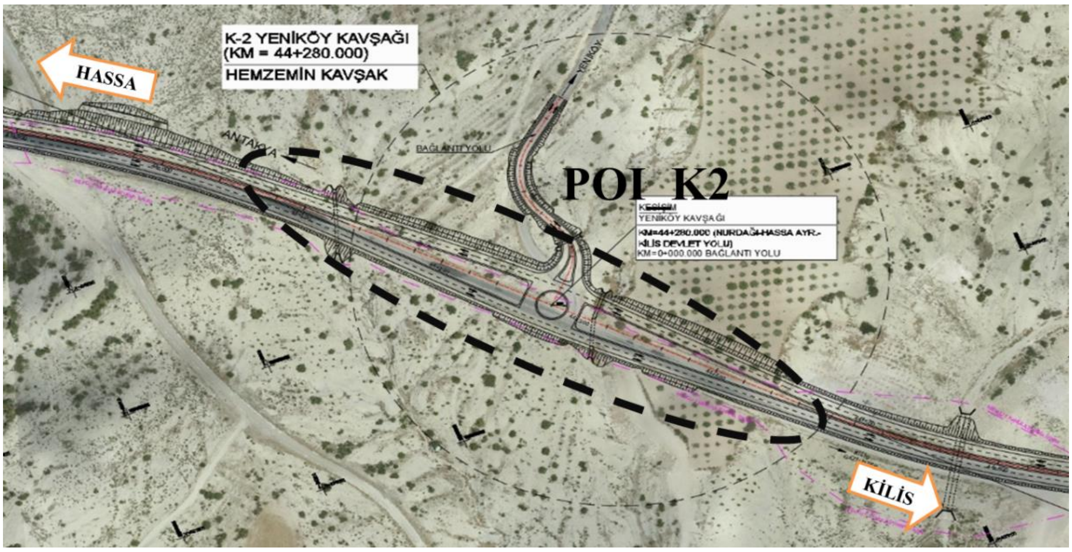

Figure 5.17 POI_K2 Yeniköy Junction area general layout St. Km: 44+280

K-3 Dümbüllü Junction, at a grade-separated junction, has been designed at St Km: 45+981.676, and one of the critical facilities operating on the project route is the cement plant, located at approximately Km:46+000 (see Figure 5.18). This plant employs the people of the city center and the residents in the nearby districts, as well as making products for export purposes. As a result of the observations made during the field trips, it was determined that there was an increase in heavy vehicle traffic on the route due to this facility. The purpose of the K-3 junction is to serve the high heavy vehicle traffic due to the cement plant and, in addition, provide transportation to the Dümbüllü village. K-3 Junction is designed to use public land as much as possible without interfering with the areas of the facilities located on both sides of the existing road, so junction ramps pass through forest land.

The vertical geometry of the route at K-3 Dümbüllü Junction and afterward up to approximately St. Km: 48+800.00 conforms to the vertical geometry of the existing 2x1 road. Starting from KM=46+200, the roadway going to Hassa direction was placed on the existing platform as much as possible, aiming to protect the existing engineering structures and minimize the expropriation requirement. At St. Km 47+000, parking areas are designed for the heavy goods vehicles and for the earthwork material need (see Figure 5.19).

At St. Km:49+000, CS-4 stars, and the route turns relatively south direction. At this point, the vertical geometry of the existing route has very low standards, and the current upward and downward slopes are around 7.00%. In addition, the current crest curve standard is relatively low and does not meet the required geometric criteria for 90km/h design speed. For this reason, the vertical curve was enlarged by lowering the elevation of the proposed vertical alignment and creating cut sections at the sides of the road for the designed speed of 90 km/h (see Figure 5.20).

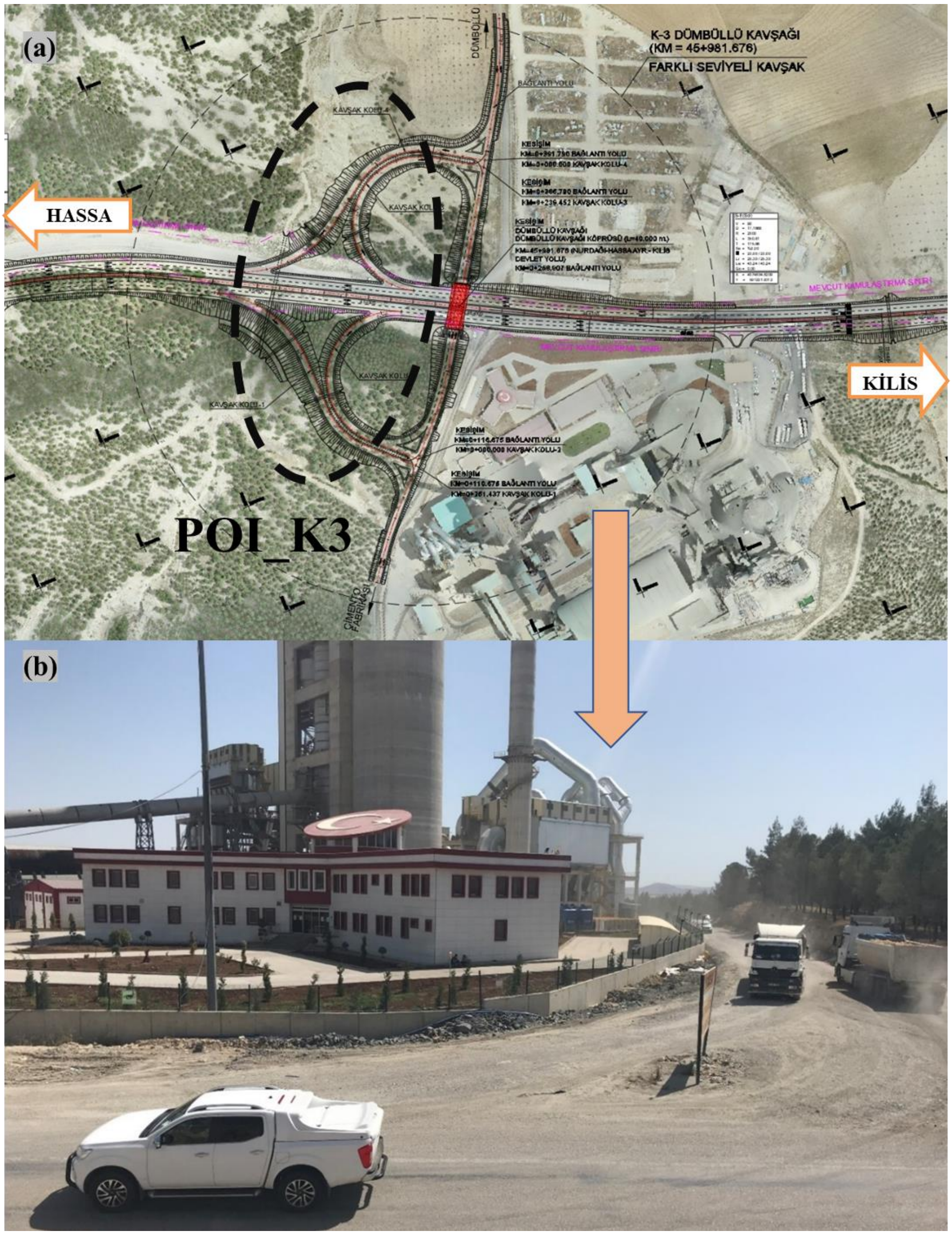

Figure 5.18 (a) POI_K3 Dümbüllü Junction area general layout at St. Km: 45+981.676 (b) Cement plant at St. Km: 45+980

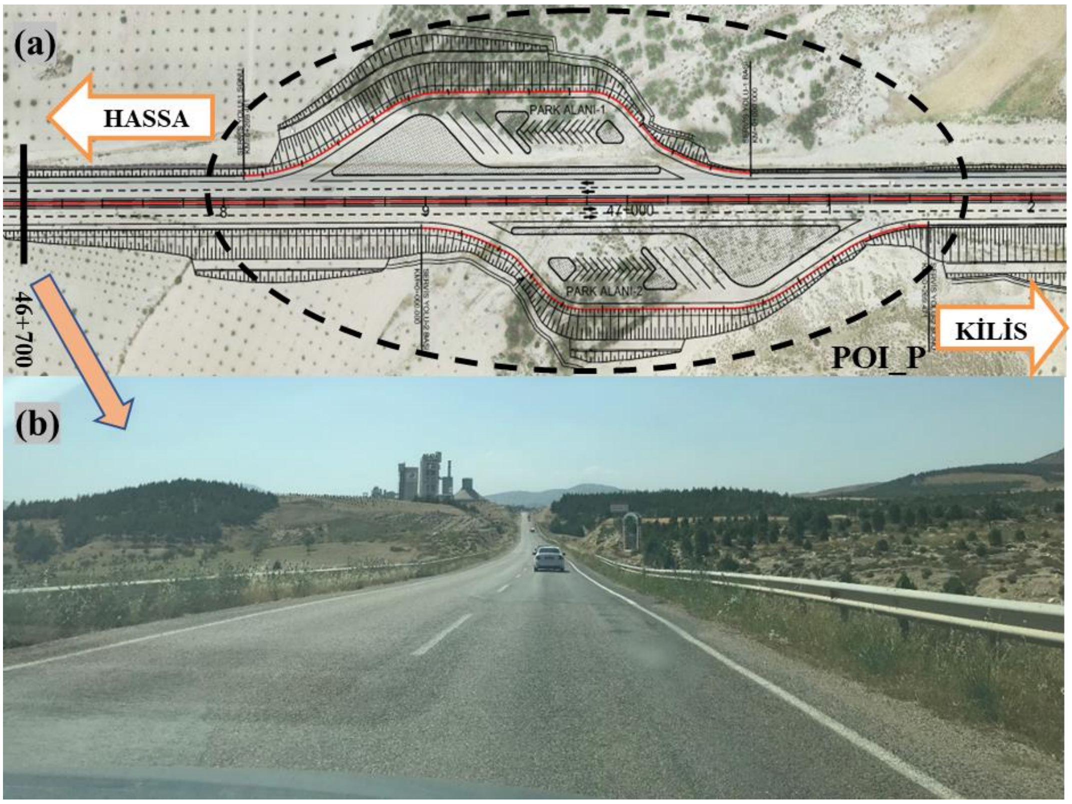

Figure 5.19 (a) POI_P Parking areas at St. Km 47+000, (b) A view of the station kilometer from St. Km: 46+700

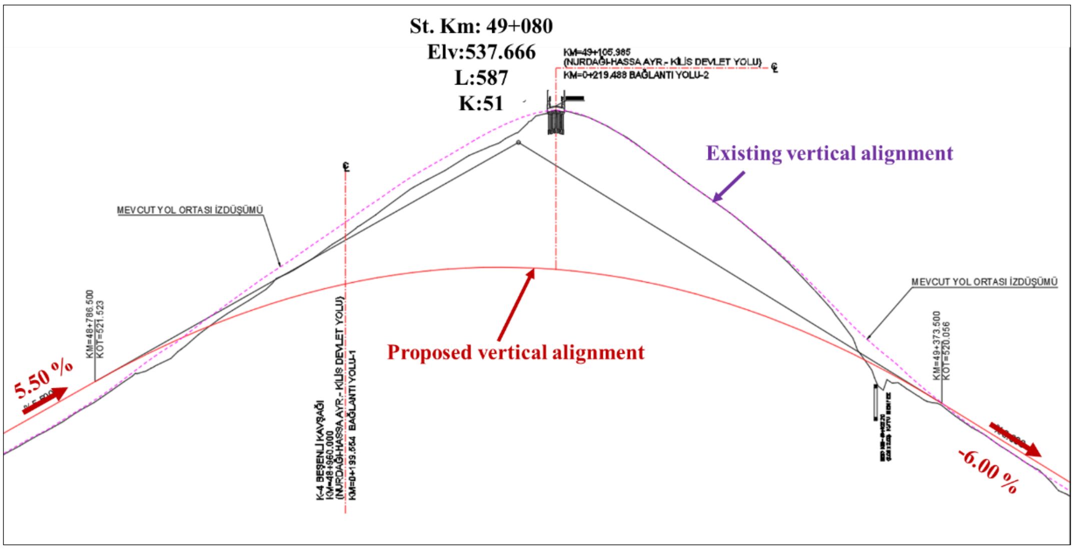

Figure 5.20 Improvement in vertical geometry from St. Km 48+7000 to St. Km 49+400

At St Km: 49+106, the villages of Bağarası and Yukarıbeşenli in the north and Aybastı in the south are connected to the newly designed route with K4 Beşenli Junction (Figure 5.21). In vertical geometry, the sight distance increases by decreasing the slope rates and increasing the vertical curve length. With this vertical geometry, excavation works are needed on the existing road to provide suitable conditions for a grade-separated junction with an overpass bridge (see Figure 5.21). In this junction area, the most crucial factor in placing the left platform on the existing road is the cemetery located on the left and right around Km: 49+110. Therefore, the horizontal/vertical geometry of the route was carefully designed considering the current conditions, and pile retaining walls were designed on the right and left sections of the route in the cemetery area.

The most critical factors in the design of the horizontal geometry of the route after the K-4 Beşenli junction:

1. Determining the corridor suitable for the current expropriation border and observing the construction cost,
2. The drinking water transmission line runs on the left of the platform parallel to the existing platform along the route,
3. Olive trees and olive groves on the right and left sides of the existing platform along the route,
4. The need for improvement in the pavement of the existing road

It is aimed to design a high-standard divided highway by keeping the horizontal geometry to be improved within the existing expropriation limits, minimizing the vertical geometry and earthworks to be improved, and reconstructing the necessary parts of the existing route. For these reasons, the left roadway of the 2x2-designed road between Km: 48+960 – Km: 56+300 was placed on the existing road to a large extent, and it was essential to preserve the existing engineering structures.

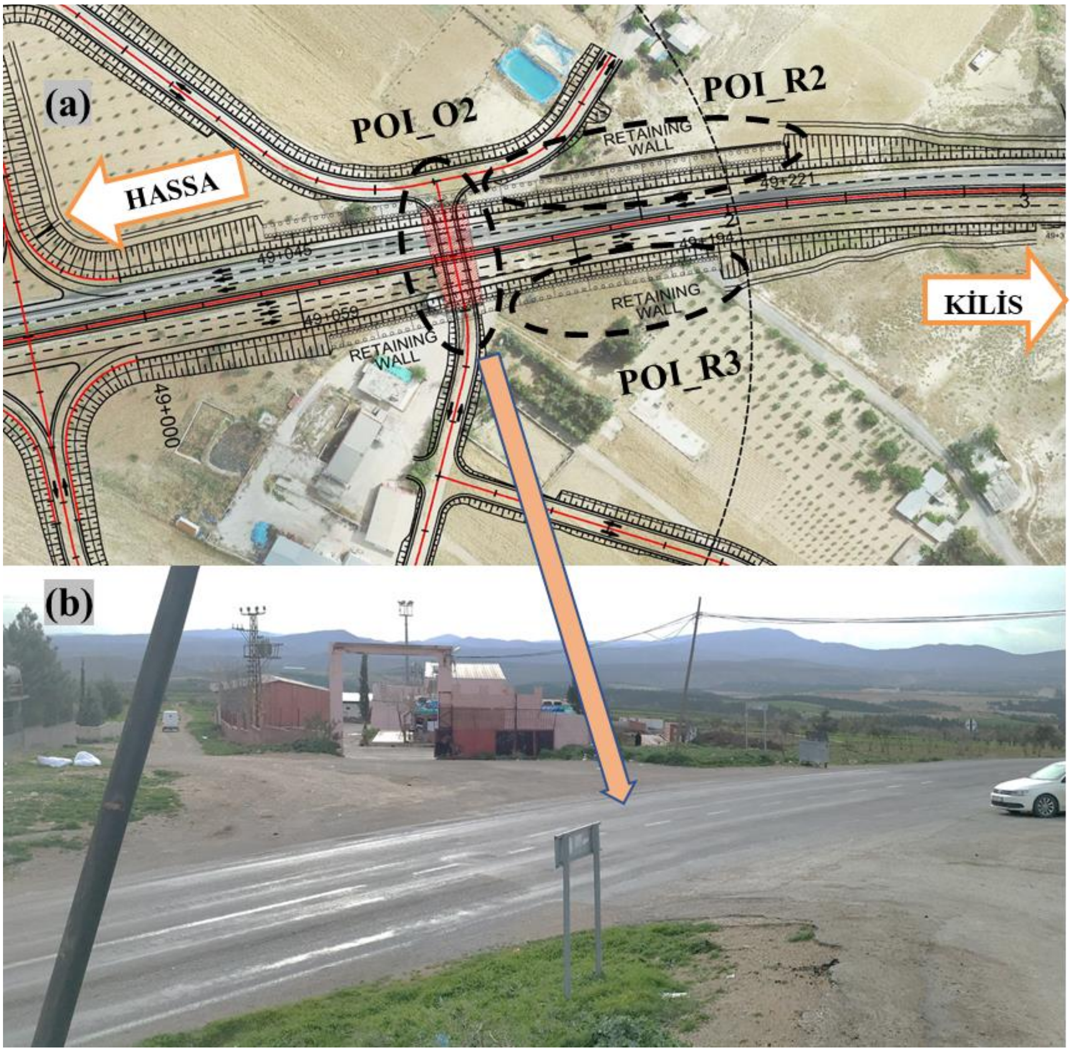

Figure 5.21 (a) POI_ O2, POI_R2, and POI_R3 at K-4 Beşenli Junction area general layout at St. Km: 48+960.000 (b) a view of the existing situation at POI_O2 Overpass bridge location

K-5 Yamaçbeşenli Junction was designed to connect the route to Yamaçbeşenli village at St. Km: 50+416.00 (see Figure 5.22). This junction is designed as an at-grade T junction with a left turn slip lane to keep the junction area as small as possible due to the expropriation consideration. Although this type of junction is preferred in urban areas, this design has been made considering the low traffic on the village road and the construction cost.

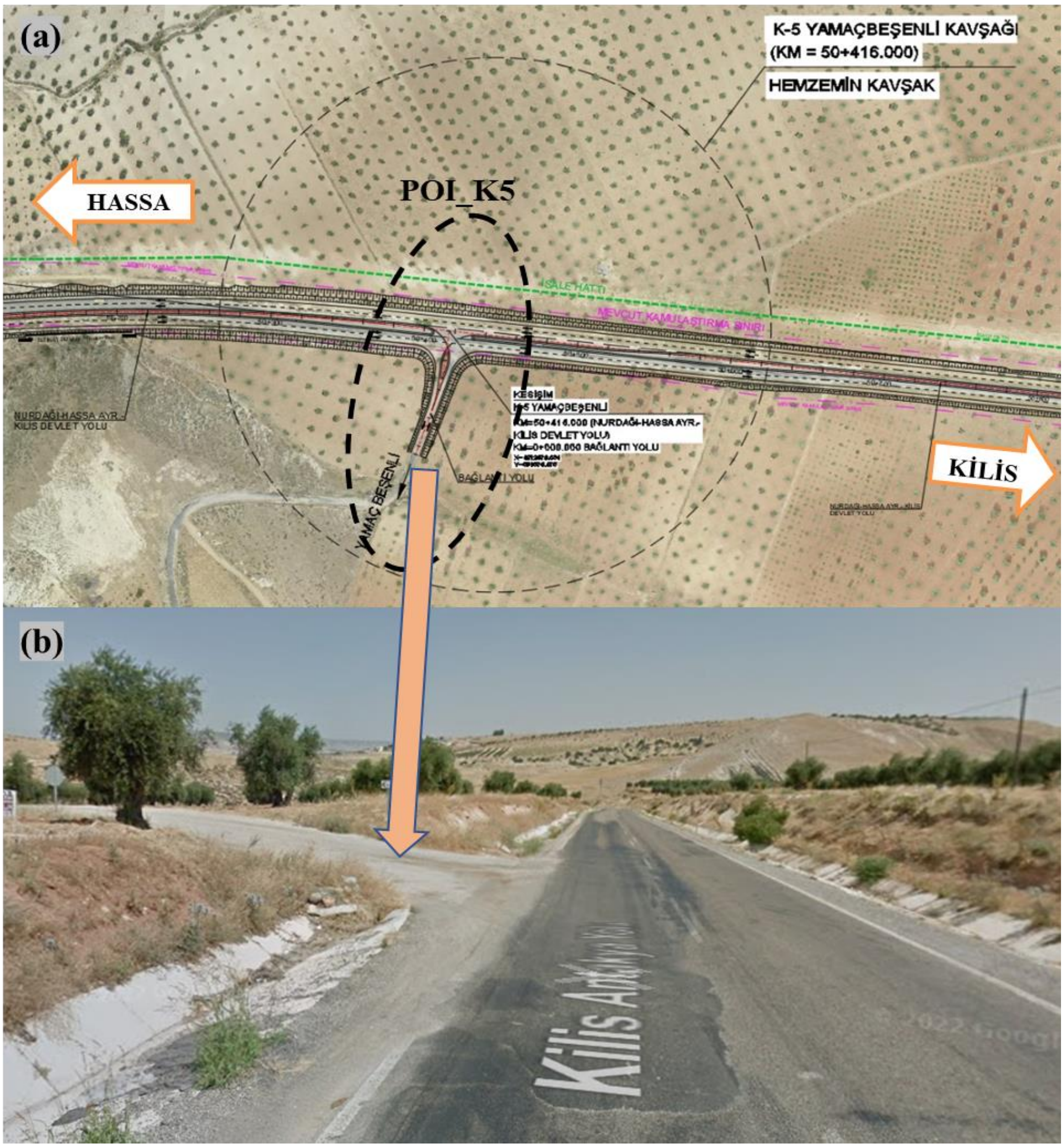

Figure 5.22 (a) POI_ K5 Yamaçbeşenli Junction area general layout at St. Km: 50+416.000 (b) a view of existing Yamaçbeşenli separation

While moving towards Km 56+300, K-6 Polateli Junction was designed at Km: 51+634.599 at the intersection of the existing 2x1 road and the existing Polateli road (see Figure 5.23). The horizontal and vertical geometry of the route, which proceeds within the framework of the previously mentioned criteria, has been improved, and the K-6 Polateli Junction has been designed accordingly. This junction is positioned on the vertical crest curve, and the visibility at the junction becomes sufficient.

K-6 Polateli junction provides a return opportunity for vehicles traveling on the route and provides access to the Polateli district (see Figure 5.23). Due to the petrol station located on the left of the existing road after the Polateli Junction, the newly designed road was expanded to the right of the existing road. It is observed that the current route moves horizontally to the right of the road with three reverse curves between Km: 52+000 – Km: 52+700. This section has been improved, and a more comfortable transition has been achieved by ensuring its continuity with alignment (see Figure 5.24). The vertical geometry designed to meet the 90 km/h design speed requirements as a result of the horizontal improvement made between St. Km: 52+000 – St. Km: 52+700 is shown in Figure 5.24. The vertical geometry of the route was adjusted to be 3.5 meters above the existing surface elevations at the maximum, and sufficient vertical clearance was provided for positioning two hydraulic culverts in this section.

In order to stay within the existing expropriation boundaries and not damage the olive groves, the existing road is placed on the median of the new design in the required sections. Also, after St. Km 52+100, the horizontal and vertical geometry of the route has been moved from the existing road geometry to keep the corridor within the expropriation boundaries. At St. Km: 53+600, the K-7 U-Turn Junction has been designed on the route (see Figure 5.25). K-7 Junction is approximately 1,950 meters from the K-6 Junction, allowing the vehicles to make U-turns, and approximately 2200 meters from the next junction.

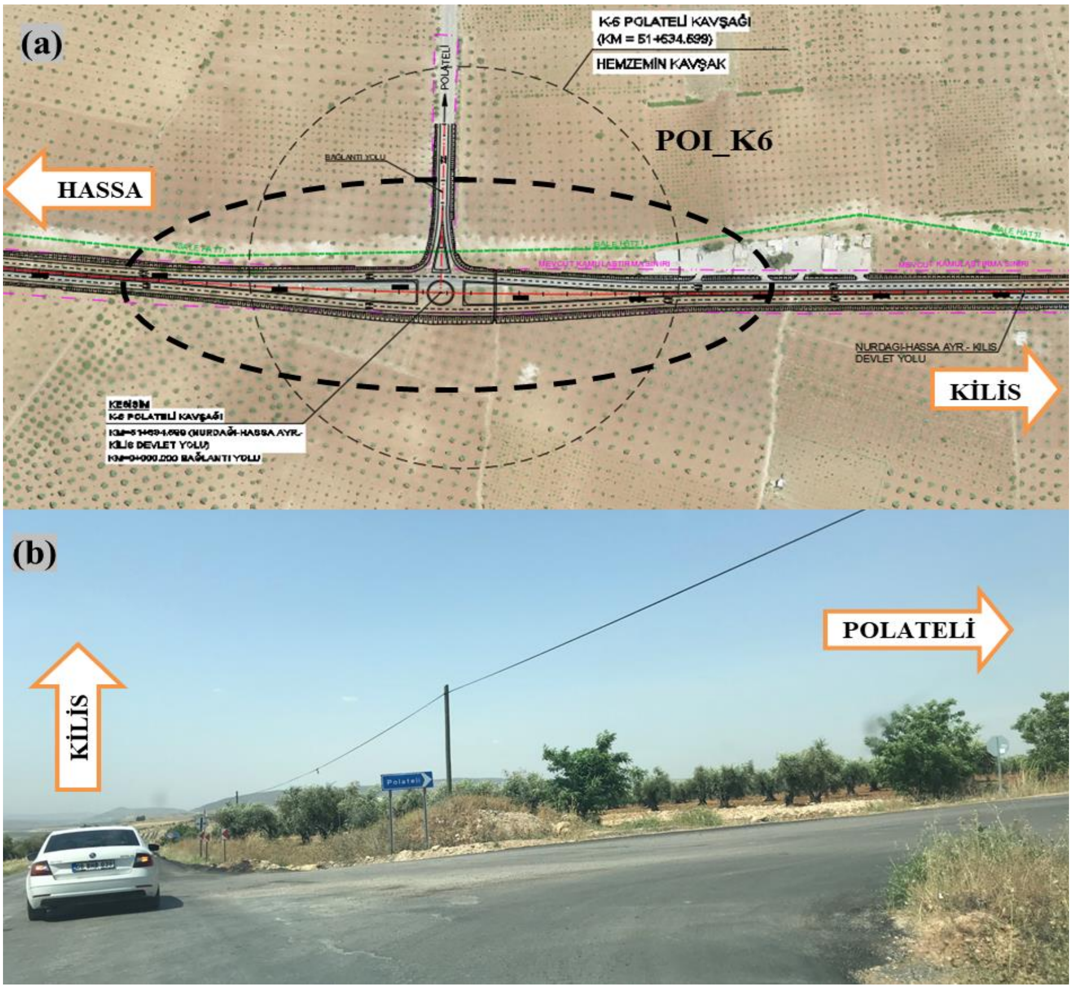

Figure 5.23 (a) POI_ K6 Polateli Junction area general layout at St. Km: 50+416.000 (b) a view of existing Polateli separation

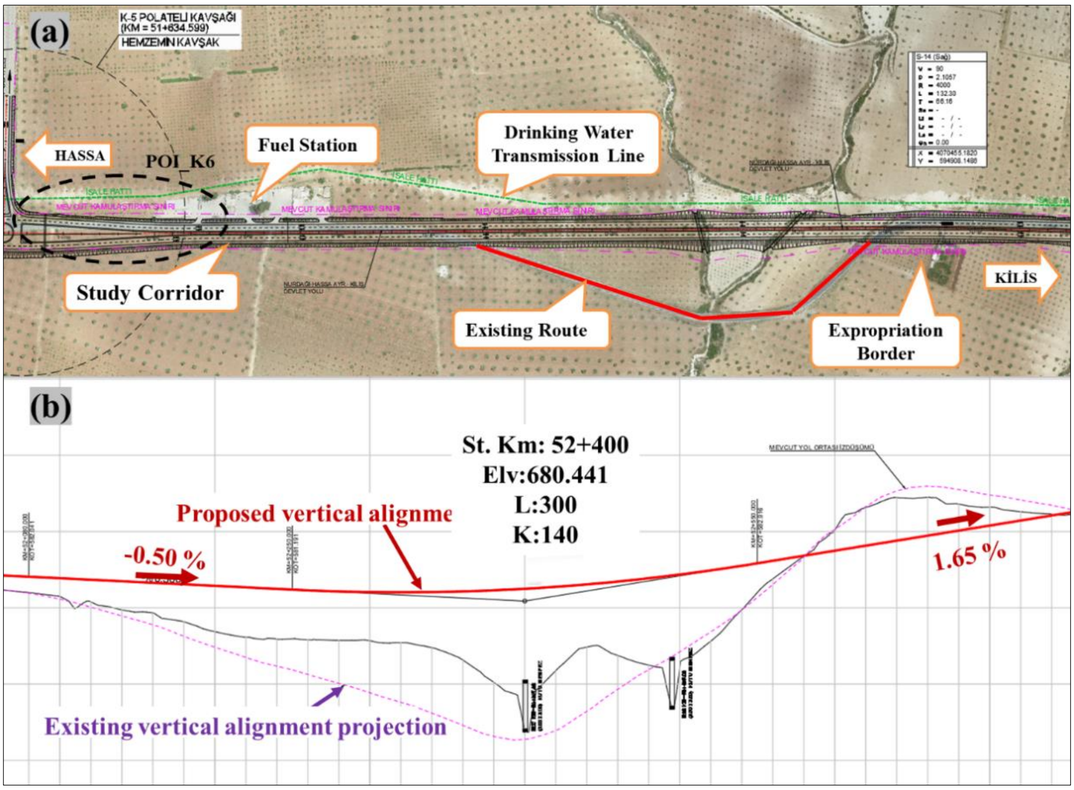

Figure 5.24 (a) Horizontal geometry improvement, (b) Vertical geometry improvement from St. Km: 52+000 to St. Km: 52+700

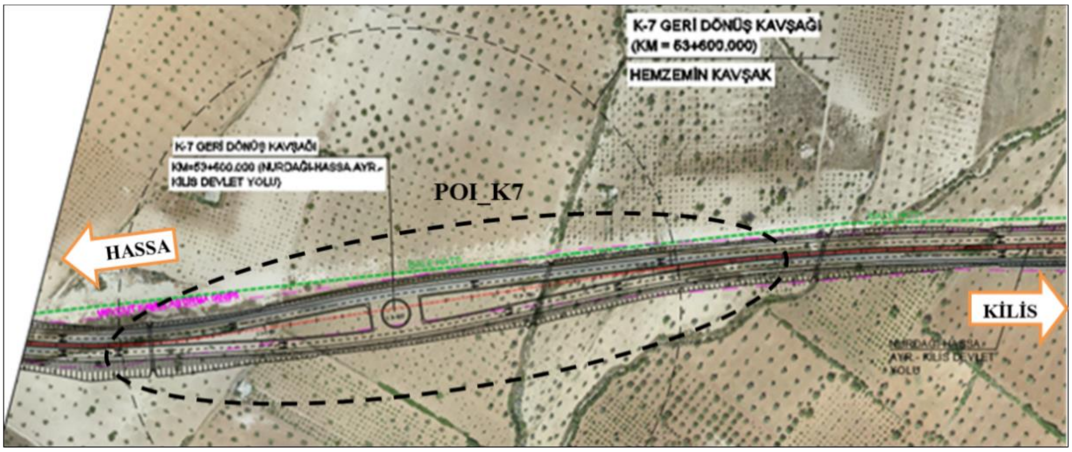

Figure 5.25 POI_K7 U-Turn Junction area general layout at St. Km: 53+600

In the last CS 7, which is CS-7, between St. Km:53+600 and St. Km: 55+400, the horizontal geometry constraints are in order of priority can be listed;

- complying with the existing expropriation limit,
- preserving the Kilis drinking water transmission line, which is parallel to the existing road on the left of the axis,
- protecting olive groves along the route,
- designing corridors with up-to-date standards by minimizing earthworks.

In line with these purposes, sections where the existing road is not used or the designed road does not fully comply with the existing road can be seen to design an economical and high standard road. The main section where the existing road is abandoned and reverse curves are used in succession are between St. Km: 54+500 and St. Km: 55+500. In these sections, small horizontal curve radii of R=140 m are observed on the existing road. The horizontal geometry of the route, which is designed following current standards, does not follow the existing route with reverse curves in this interval; the mentioned interval is passed with straight alignment (see Figure 5.26).

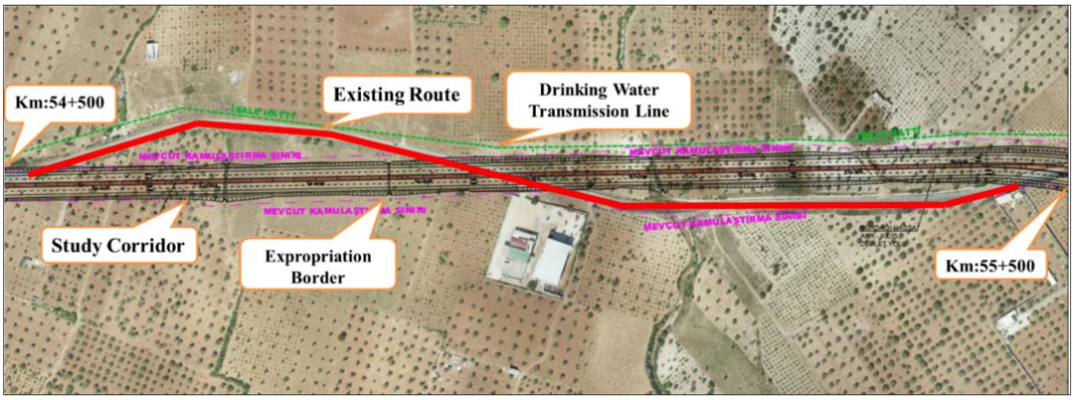

Figure 5.26 Horizontal geometry improvement from St. Km: 54+500 to St. Km: 55+500 in CS-7

5.4 Comparative Evaluation of the Proposed Approach

The case study corridor is examined according to the Turkish and UK roadside design approaches. After completing both roadside designs, the road sections and the required length of safety barriers could be compared. According to the result of both approaches, questions like

- which places and hazards are required to guard with safety barriers,
- when these approaches give different results,
- which type and how many meters length of need the safety barriers are required,
- which approach is more conservative,
- where these results overlap or differ from each other

could be answered.

CHAPTER 6

CASE STUDY RESULTS

6.1 Roadside Design with Current Turkish Practice

According to Turkish practice, the cut slope sections are not considered hazardous unless it has a rough-surfaced slope in rocky topography is present. The embankments are considered potentially hazardous for ROR vehicles if they are 3 meters or higher. Due to hydraulic capacity reasons, the culverts are generally placed at the deepest section of an embankment, and generally, these sections already need protection due to the embankment height. However, the designers must use their judgments for the safety barrier requirement if the culvert is placed in a shallow embankment section. In Turkish practice, the trees in the expropriation area of the road are generally assumed to be relocated, so these areas are not protected with VRS.

The case study corridor is considered in hazard level 2 and hazard level 4 according to future projected traffic flow (see Figure 4.6). Although hazard level 4 indicates that the N2 containment level could be selected for the corridor, by considering the future HGV traffic and hazard level 2, the H1 containment level is applied throughout the corridor. Also, in Turkish practice, generally, H1 is used as the default containment level, and the normal containment level classes are not preferred. This containment level selection process from the flow chart is presented in Figure 6.1.

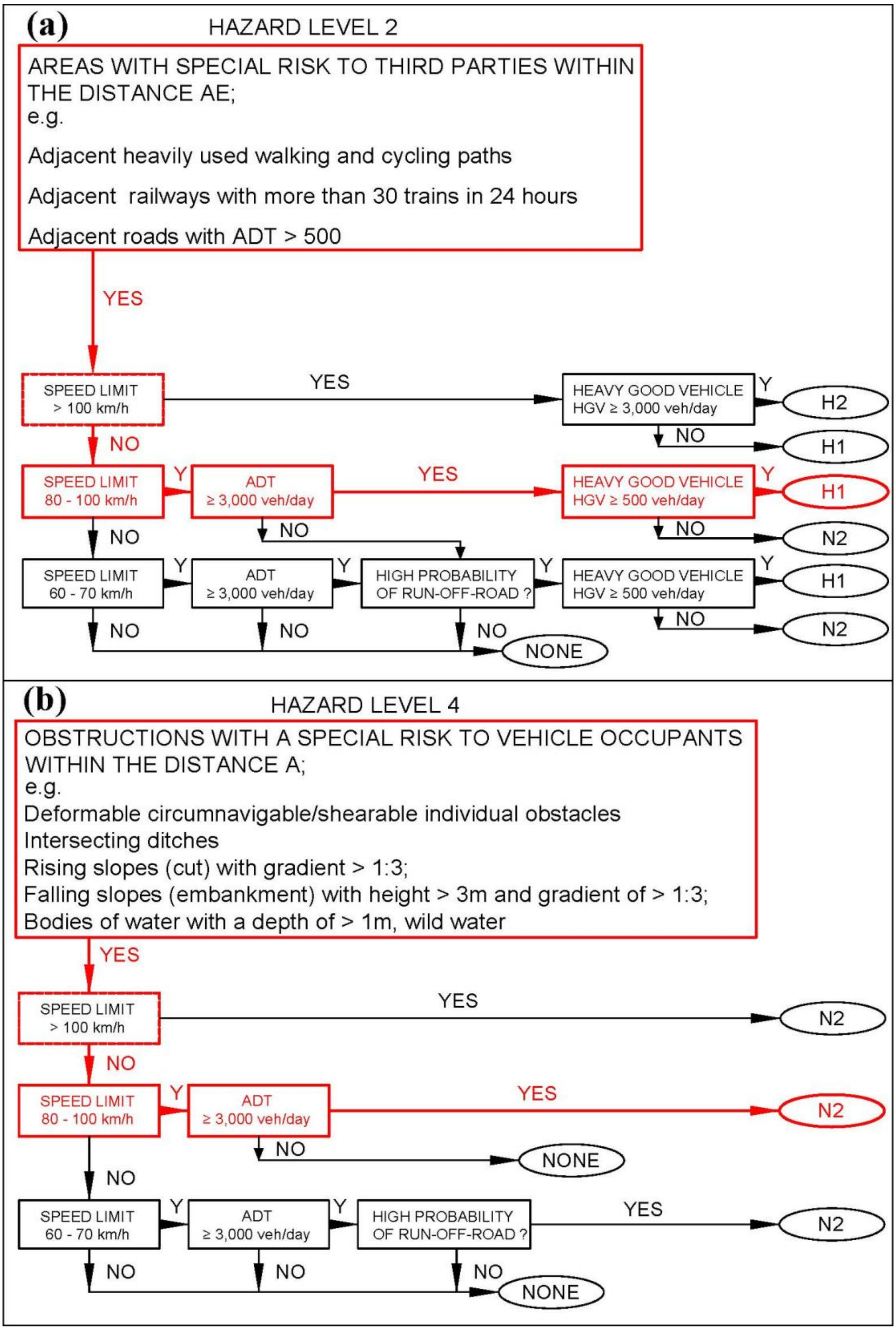

Figure 6.1 Containment level selection from flowchart (a) hazard level 2 (b) hazard level 4

The rule of thumb of working width is W4, which is controversial and dangerous when examining the typical cross-section of state roads. However, with the suggestion of GDH engineers, the W4 working width is selected for this route. Also, the rule of thumb for working width on the bridges is W2, which could be debatable and should be chosen according to bridge cross-sections.

Lastly, the impact severity level (ISL) could be chosen as A or B while constructing the road. At the end of the design, it was found that the total length of the safety barriers needed is 6,662 meters H1-W4 and 241 meters H2-W2, according to Turkish roadside design practice. Safety barrier requirements are given according to CS in Figure 6.1.

Corridor Segment (CS) 1: This segment is one of the most extended segments in the case study, with a length of 2,960 meters. The significant hazards in this segment are the Afrin Bridge and an underpass planned to build for the village road. Other hazards could be high embankments and culverts. At the beginning of the segment, there is the highest cut section in the entire corridor, almost 40 meters in height, and every 10 meters height 5 meters width berm located to prevent slope stability problems. Even for this cut section, the safety barrier placement is thought unnecessary. The bridge is treated as the most hazardous section of the route, so it needs to be protected with a higher containment level. Instead of the H1 containment level, H2 was chosen on the bridge, a rule of thumb in Turkish practice. However, for the underpass, the H2 containment level is not considered.

Corridor Segment (CS) 2: This segment has one of the shortest lengths, at 1,090 meters. At the beginning of this segment, a high embankment and an existing culvert with a rectangular section dimensions width of 6 and depth of 2 meters. This segment follows the existing route for the Kilis direction, and the expanded side for the Hassa direction mostly has cut sections. While approaching the grade-separated junction at the end of the segment, there is a high embankment area with an existing culvert.

Table 6.1 Safety barrier St. Kms according to Turkish practice

Hassa Direction				**Kilis Direction**			
LON (m)	**Beginning St. Km**	**Ending St. Km**	**Type**	**LON (m)**	**Beginning St. Km**	**Ending St. Km**	**Type**
CS-1				**CS-1**			
224	41+262	41+486	**H1**-W4	661	41+194	41+855	**H1**-W4
72	41+769	41+841	**H1**-W4	247	42+157	42+404	**H1**-W4
144	42+276	42+420	**H1**-W4	120	42+404	42+524	**H2**-W2
121	42+420	42+541	**H2**-W2	32	42+524	42+556	**H1**-W4
100	42+541	42+641	**H1**-W4	228	43+310	43+538	**H1**-W4
120	43+782	43+902	**H1**-W4	133	43+777	43+910	**H1**-W4
CS-2				**CS-2**			
48	44+560	44+608	**H1**-W4	102	44+560	44+662	**H1**-W4
				158	45+436	45+594	**H1**-W4
CS-3				**CS-3**			
80	46+330	46+410	**H1**-W4	360	46+330	46+690	**H1**-W4
160	46+510	46+670	**H1**-W4	267	47+117	47+384	**H1**-W4
373	47+007	47+380	**H1**-W4	262	47+446	47+708	**H1**-W4
180	47+470	47+650	**H1**-W4	72	47+886	47+958	**H1**-W4
180	48+150	48+330	**H1**-W4	212	48+128	48+340	**H1**-W4
				252	48+480	48+732	**H1**-W4
CS-4				**CS-4**			
237	49+780	50+017	**H1**-W4	124	49+306	49+430	**H1**-W4
				340	49+670	50+010	**H1**-W4
				90	50+120	50+210	**H1**-W4
CS-6				**CS-6**			
216	52+348	52+564	**H1**-W4	396	52+178	52+574	**H1**-W4
114	52+790	52+904	**H1**-W4	114	52+790	52+904	**H1**-W4
CS-7				**CS-7**			
128	53+930	54+058	**H1**-W4	84	53+930	54+014	**H1**-W4
				80	54+680	54+760	**H1**-W4
				72	55+082	55+154	**H1**-W4

<u>Corridor Segment (CS) 3:</u> This segment is one of the most extended segments besides CS-1 at 2,980 meters. At the beginning of the segment, overpass bridge piers of grade-separated junctions could be considered hazardous. Since the left-hand side bridge pier is 10m away from the traffic lane, and the right-hand side bridge pier is on the cut slope, they do not pose a hazard, and safety barriers are unnecessary. Following the corridor, there is a cement factory, and the corridor goes through this factory. The facilities are far enough from the traffic lanes, and speeds around this factory would be low since this area is close to the junction, so there is no need to place a safety barrier.

There are two parking areas around the St. Km 46+840 to 47+140. These parking areas are not on the embankment; on the contrary, these areas are planned to obtain filling material, and the hilly location was chosen to be in the cut section. In the Kilis direction roadway, the approaching slopes to the parking area are cut slopes, so they are not protected. On the other hand, in the Hassa direction, the approaching slope to the parking area is a fill slope, and safety barriers are needed to protect errant vehicles in this section. After these parking areas, the segment has three high embankment areas that need safety barriers to protect errant vehicles.

Corridor Segment (CS) 4: This segment has a moderate length among the other segments, with a length of 1,380 meters. At the beginning of this segment, vertical elevations are below the existing ground, and residential areas are close to the corridor. A grade-separated junction is designed so that the main road would be in almost 15 meters of cutting section with the retaining walls to support these cutting sections. The retaining walls are designed at the back of the cutting drainage ditches, and it is thought that the surface of this wall is not harmful to an errant vehicle, so no safety barrier protection is needed.

In this corridor segment, two other retaining walls are on the fill sections to support the Kilis direction roadway. The sections that these two walls designed have high vertical elevation differences. The filling of these sections is not reasonable, so retaining walls are designed instead of the embankment. The probability of fatal or severe injury accidents due to vertical drops from these retaining walls is high, so the H1 containment level safety barriers are selected in these sections.

Corridor Segment (CS) 5: This segment is the shortest among the others, with 910 meters. The Kilis direction roadway follows the existing roadway by expanding the lane widths. The corridor is expanded for the Hassa direction roadway and goes through the agriculture fields with olive trees. During the site inspection, these fields are visited, and it is observed that these olive trees are young and may be removed or relocated away from the roadway. The safety barrier protection for these fields is not considered. Lastly, this segment's vertical alignment is close to the existing ground, so shallow cut and fill slope sections exist. The ROR vehicles at these sections could end up in fields without being severely damaged. Hence, there is no need to use safety barriers in these sections.

Corridor Segment (CS) 6: This segment is also a moderate-length segment, which is only 10 meters longer than CS-4 and has a total length of 1,390 meters. The most prominent hazard in this segment is the existing fuel station at the beginning. There are rules and regulations for the fuel station layouts, and this existing station satisfies those rules and requirements. The newly designed corridor follows the existing roadway, so there is no significant need to change the fuel station layout. The pumps are almost 12 meters away from the traffic lanes, and the buildings are 25 meters away. The safety barrier placement is thought to be unnecessary for this fuel station. In addition to the fuel station, two relatively high embankments could be hazardous in this segment. These embankments also have culverts at their deepest points, so safety barriers are placed in these sections.

Corridor Segment (CS) 7: This segment is the last one for the case study corridor, with 1,470 meters. The existing road has small radius horizontal curves, and the new design bypasses these curves by using straight-line alignments. The vertical alignment passes close to the existing ground, so there is no need to high-cut or fill sections in this segment. There is a settlement around St. Km 54+980 with a fence wall 8 meters close to the traffic lane, but it is not considered hazardous, and a safety barrier is not placed between the wall and roadway. Other than this wall, two culverts in relatively high embankment are decided to be protected.

6.2 Roadside Design with The Proposed Approach

The proposed approach requires the use of the RRRAP software to make the risk-based decisions for the safety barrier provision on the corridor. To use the RRRAP, designers must have an account provided by Highways England. An application request layout needs to be followed to get an account. This account application process has been carried out for this thesis study, and Highways England authorities provided an account for Middle East Technical University (METU).

The risk assessment stage of the proposed approach is carried out with this account. The case study corridor segments are introduced to the RRRAP tool. Since each direction of the corridor has assumed dummy centerlines total of 14 records were created. The data collected for each CS in the first stage of the proposed approach are given into software by following the guidance of the RRRAP tool. Initial risk calculation was conducted with default containment level N2 and default working width class the W2.

The results showed the places that need protection and length o need of safety barriers, but these results were not used directly. Iterative calculation processes were done by changing the parameters like containment level and working width class. Also, the entered hazard details were modified in the necessary sections. Until the optimum results were reached, these iterative calculations were continued. Since each hazard is assessed individually in the software, designers must assess the corridor comprehensively while deciding on safety barrier requirements.

The N2 containment level is chosen for the case study corridor after a series of risk calculations with the RRRAP. For some sections like bridges and retaining walls, the N2 containment level gave an unacceptable risk level, so with the iterative calculations, the H2 containment level for the bridge and the H1 containment level for retaining walls were chosen. Since the RRRAP design guide suggests that using the bigger the working width class decreases the safety barrier cost. The W3 working width class was chosen for the study corridor since the maximum allowable working distance is 1-meter edge width.

For the impact severity level, the RRRAP does not calculate any specific level but states that level A provides a higher level of safety for the occupant of an errant vehicle than level B, and level B is superior to level C. Like Turkish design, ISL could be chosen when constructing the road between A or B. After the design total length of the safety barrier needed is calculated as 15,491 meters N2-W3, 309 meters H2-W3, and 220 meters H2-W3. This total length is almost two and a half times the Turkish design requirement. Safety barrier requirements for the study corridor were concluded with the proposed approach, and St. Km and length of need of safety barriers are given according to CS in Table 6.2.

Corridor Segment (CS) 1: The details of the hazards like Afrin Stream Bridge, underpass, drainage channels, and culverts were identified. In addition to the mandatory sections like earthworks, kerbs, and shoulder information,

- the bridge and underpass parapets; into 400 parapet sections,
- drainage channels and culverts; into the 500 drainage features,
- existing as clusters of trees; into the trees section,
- the Afrin Stream is a large body of water; into the water section,
- the village road data; into the road section that others in danger

are given to the assessment tool (see Appendix E).

The RRRAP results stated that using the H2 containment level for the parapets on the underpass and bridge gives an acceptable risk level. The H2 containment level was chosen on the bridge like in Turkish practice, but for the working width class, W3 was chosen instead of the Turkish rule of thumb class W2. Also, the H2 containment level was chosen for the underpass, unlike the H1 in Turkish practice.

Table 6.2 Safety barrier St. Kms according to the proposed approach

Hassa Direction				Kilis Direction			
LON (m)	**Beginning St. Km**	**Ending St. Km**	**Type**	**LON (m)**	**Beginning St. Km**	**Ending St. Km**	**Type**
CS-1				**CS-1**			
308	41+263	41+571	**N2**-W3	660	41+000	41+660	**N2**-W3
53	41+797	41+850	**N2**-W3	112	41+744	41+856	**N2**-W3
23	42+037	42+060	**N2**-W3	46	42+030	42+076	**N2**-W3
35	42+260	42+295	**N2**-W3	105	42+175	42+280	**N2**-W3
25	42+295	42+320	**H2**-W3	40	42+280	42+320	**H2**-W3
98	42+320	42+418	**N2**-W3	84	42+320	42+404	**N2**-W3
124	42+418	42+542	**H2**-W3	120	42+404	42+524	**H2**-W3
102	42+542	42+644	**N2**-W3	198	43+024	43+222	**N2**-W3
988	42+916	43+904	**N2**-W3	665	43+292	43+957	**N2**-W3
CS-2				**CS-2**			
39	44+567	44+606	**N2**-W3	69	44+547	44+616	**N2**-W3
723	44+696	45+419	**N2**-W3	641	44+707	45+348	**N2**-W3
183	45+486	45+669	**N2**-W3	256	45+398	45+654	**N2**-W3
CS-3				**CS-3**			
86	45+966	46+052	**N2**-W3	650	46+256	46+906	**N2**-W3
151	46+114	46+265	**N2**-W3	236	47+140	47+376	**N2**-W3
72	46+333	46+405	**N2**-W3	220	47+446	47+666	**N2**-W3
225	46+464	46+689	**N2**-W3	902	47+896	48+798	**N2**-W3
328	47+046	47+374	**N2**-W3	36	48+882	48+918	**N2**-W3
182	47+486	47+668	**N2**-W3				
598	48+105	48+703	**N2**-W3				
118	48+812	48+930	**N2**-W3				
CS-4				**CS-4**			
337	48+993	49+330	**N2**-W3	330	48+980	49+310	**N2**-W3
132	49+528	49+660	**N2**-W3	122	49+310	49+432	**H1**-W3
313	49+747	50+060	**N2**-W3	577	49+553	50+130	**N2**-W3
				98	50+130	50+228	**H1**-W3
CS-5				**CS-5**			
				45	50+595	50+640	**N2**-W3
				111	50+739	50+850	**N2**-W3
CS-6				**CS-6**			
582	52+190	52+772	**N2**-W3	796	51+914	52+710	**N2**-W3
503	52+823	53+326	**N2**-W3	545	52+768	53+313	**N2**-W3
CS-7				**CS-7**			
655	53+934	54+589	**N2**-W3	130	53+910	54+040	**N2**-W3
26	54+713	54+739	**N2**-W3	282	54+628	54+910	**N2**-W3
271	54+867	55+138	**N2**-W3	365	54+985	55+350	**N2**-W3
79	55+329	55+408	**N2**-W3				

<u>Corridor Segment (CS) 2:</u> There is a high embankment at the beginning of this segment, and then almost all the left side is in the cutting section with a steep slope rate. It is mandatory to give earthwork data to the RRRAP because of how the software works. These earthworks data consist of the height and slope rates of the fill and cut slopes. Drainage channels and culverts information were given in the drainage feature section, and risk calculations were conducted.

<u>Corridor Segment (CS) 3:</u> This segment starts with overpass bridge piers of grade-separated junctions considered in 1700 structural concrete in the RRRAP. These piers are far away from the traffic lanes, and risk is acceptable without safety barriers, according to the RRRAP. However, since the bridge's left pier is located on the steep cut slope, this area should be protected due to this steep cut slope. While approaching parking areas in this CS, the approaching fill and cutting slopes pose a high risk and should be shielded. The cutting slopes are also considered hazardous, and risk assessment should be done based on the slope rate and height in the proposed approach, contrary to Turkish practice.

<u>Corridor Segment (CS) 4:</u> At the beginning of this segment, the retaining walls at both sides of the road support the cutting slopes. The bridge piers of the grade-separated junction are located on these walls. According to the RRRAP, safety barriers should place between the roadway edge and the face of these walls. In addition to these walls, the details of retaining walls in filling sections forward kilometers of the segment are given into 1600 retaining walls, and the results show that risk with safety barriers that have the N2 containment level is acceptable. However, the vertical drop from these walls causes a high probability of fatality or a severe injury accident, so the H1 containment level is chosen for these sections.

<u>Corridor Segment (CS) 5:</u> This segment goes through the fields with young olive trees, considered hazardous to ROR vehicles, unlike Turkish practice. In addition, there are two embankment sections in the Kilis direction, which have relatively moderate heights, and in Turkish practice, these are not required safety barriers. However, the height and slope rates are above the threshold values of the RRRAP, so safety barrier application is necessary according to the proposed approach, and the N2 containment level was chosen in these embankments.

Corridor Segment (CS) 6: The details of the existing fuel station at the beginning of this segment were given in the RRRAP tool. The calculated risk was acceptable without a safety barrier since the distance between the hazard, and the traffic lane is far enough. Also, details of the culverts were given in the drainage feature sections, and the safety barrier requirements for these hazards were determined.

Corridor Segment (CS) 7: This segment has relatively shallow fill and cut slope sections and goes through the fields with olive trees. In addition to these data, the drainage features and the settlement fence wall around St. Km 54+980 are given the related sections of the RRRAP tool to calculate the risks. Since the distance between the face of the wall and the road is far enough, calculated risk is acceptable for this hazard without a safety barrier.

6.3 Comparison of Current and Proposed Roadside VRS Design Approaches

The proposed approach has three main stages of determining safety barrier requirements at the nearside of a major road. In the second stage, risk assessment is done by using the RRRAP software. It forces designers to follow a systematic procedure while making risk calculations. Also, the RRRAP enables making a risk-based assessment and results in objective and compatible roadside designs. On the other hand, the current Turkish practice is a simplified German roadside design approach and follows the German roadside design guideline. For this reason, Turkish practice depends more on designers and their experiences, making the decision-making process difficult and subjective.

Since different guidelines and approaches inspire current Turkish practice and the proposed approach, the design results of safety barrier requirements have similarities and differences. One of the prominent differences between the two approaches is the cut slope sections. In Turkish practice, in the cut slope sections, there should be a drainage ditch with 1H:4W, which is more shallow than the critical gradient of 1H:3W. It is assumed that the ROR vehicles can gain control in the ditch and turn back to their lanes, so cut ditches are not considered a hazard. The cut slopes' gradient or the height are not considered while deciding on safety barrier requirements. However, the proposed approach treats slope rates and heights for fill and cut sections similarly. If the cut slope gradient is steep and the height is bigger than the critic value, the RRRAP assigns a high aggressiveness rate and considers protections in front of these sections (see Figure 6.2).

Both approaches consider embankments a hazard and decide whether a safety barrier should be used based on the slope rate and height. The threshold values for critical height in the proposed approach are smaller than in Turkish practice, so the beginning point of the barriers shows a difference for the embankments (see Figure 6.2). In current Turkish road design practice, higher than 3 meters fill sections are designed with a 2H:3W (2 in height 3 in width) slope rate. Also, this is the threshold value for the safety barrier requirement on the embankments. According to the RRRAP, the critical height of the 2H:3W sloped fill sections is 1.6 meters. If the embankments are deeper than the critic height, the software warns the designers and states the safety barrier requirement.

Culverts are also considered hazards due to their headwalls in the proposed approach, but they are treated differently in Turkish practice. The headwalls of the culverts in the case study are generally close to the roadside; the proposed approach suggests protecting culverts with safety barriers (see Figure 6.2). Turkish practice also considers culverts as hazards, but on some occasions, like the embankment height is shallow, or the culverts are located on cut sections, designers could decide that the safety barrier is unnecessary based on their judgments. In this case study corridor, some culverts are located on shallow embankments and cut sections, and for these culverts, the decision was not to use safety barriers.

High vertical drops are considered the most dangerous places in both approaches, and higher containment level safety barriers are suggested. Bridges and retaining walls built instead of the embankment have high vertical drops, and they have significant risks for the errant vehicles and the others around the structure. Falling from bridges after a run-off road can create secondary events if the bridge is used as an overpass for the railway or another road. Also, falling from the retaining wall can have similar effects as falling into the abyss, and the consequences of this type of accident could be much more severe. For the Afrin Stream in the case study corridor, both approaches choose the H2 containment level. Also, both approaches used higher containment levels on the case study corridor's retaining walls (see Figure 6.3).

In the case study corridor, pile retaining walls were designed on the right and left sections of the corridor in the cemetery area in CS-4. The purposes of these retaining walls are to support the cut sections and provide suitable elevations for the overpass bridge at the junction area. These walls are not considered to be shielded with safety barriers in Turkish practice, but their risk assessment states that risk is unacceptable without the safety barriers in the proposed approach.

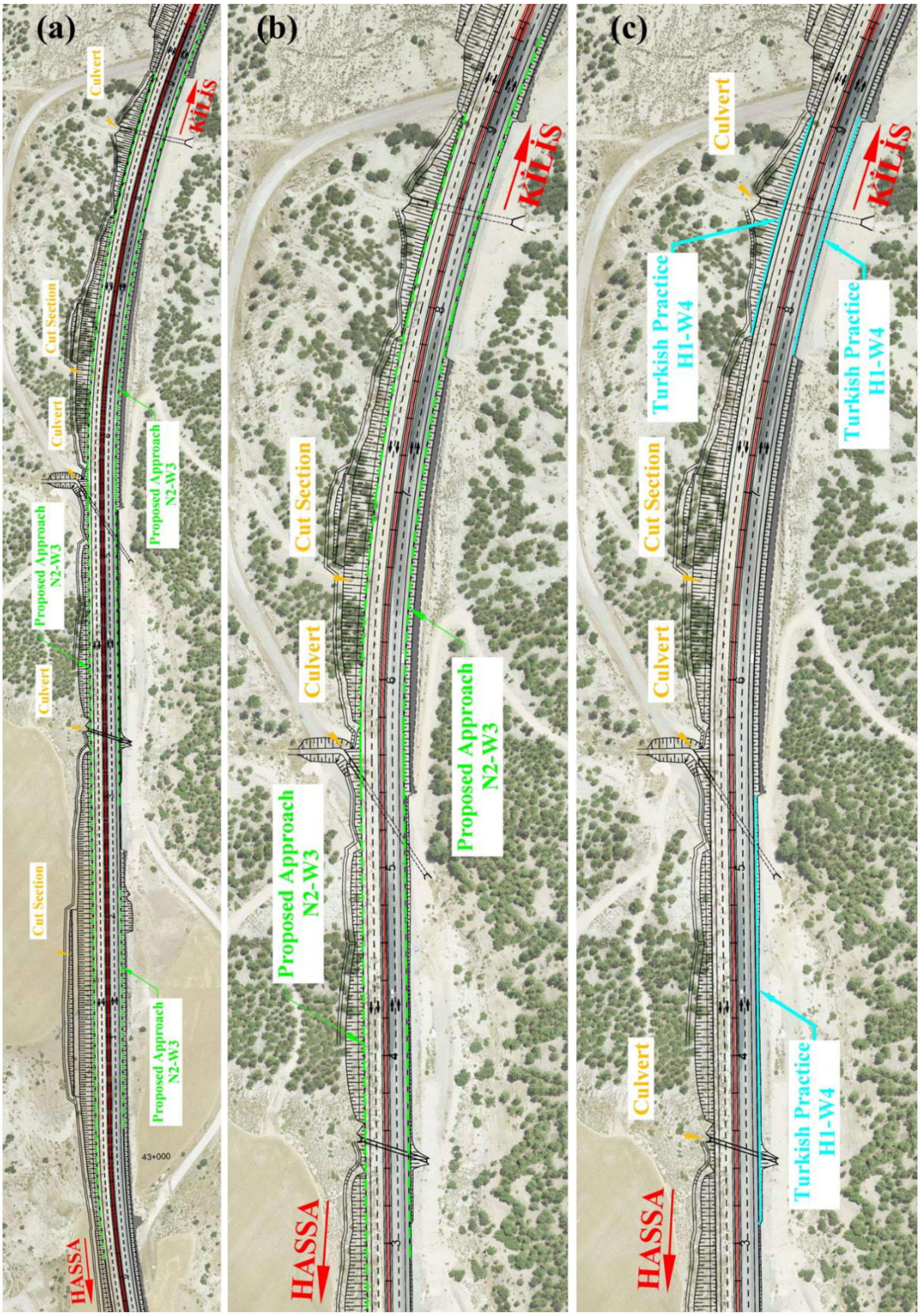

Figure 6.2 Safety barrier requirement in CS-1according to (a) & (b) the proposed approach and (c) Turkish practice

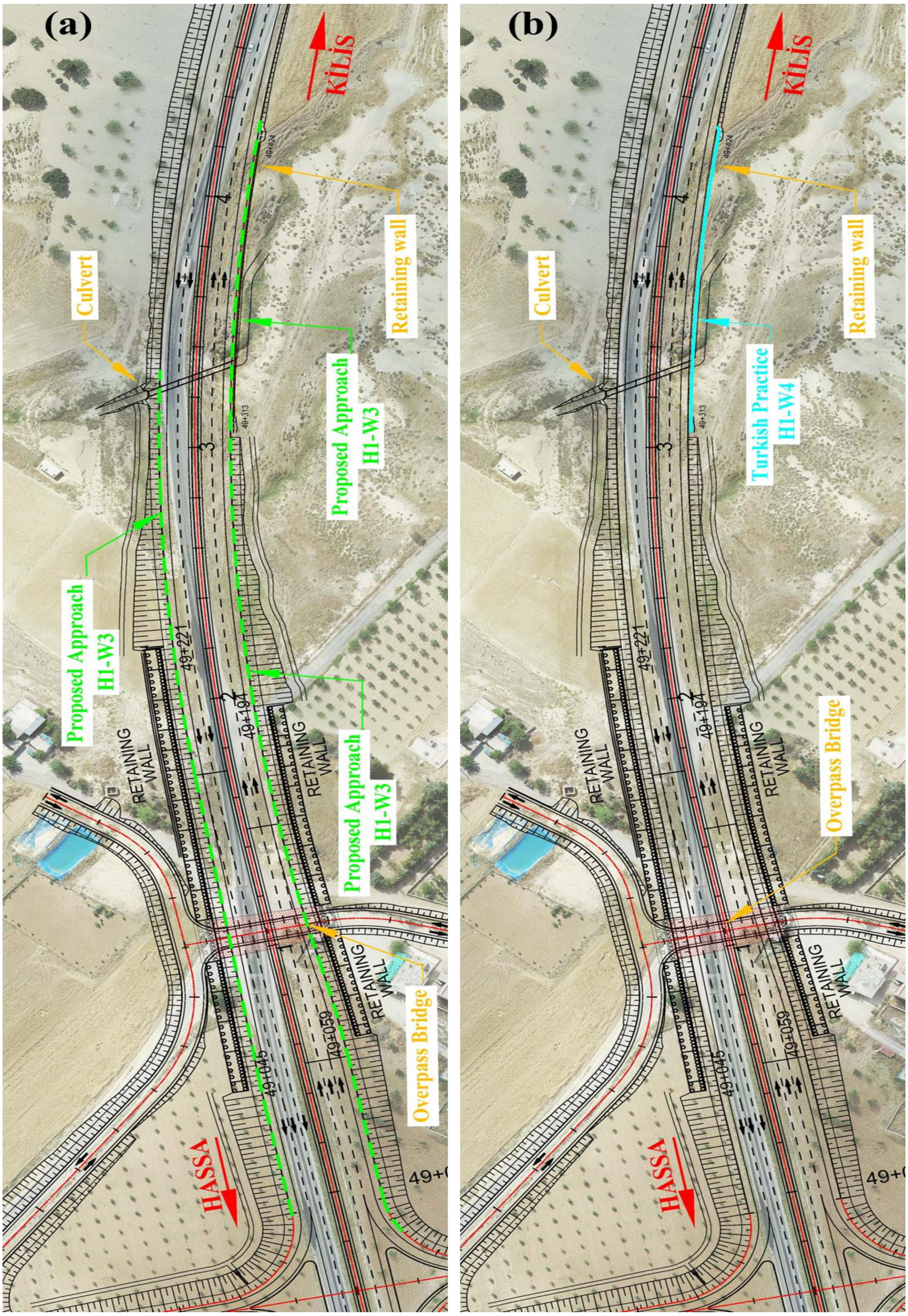

Figure 6.3 Safety barrier requirement in CS-4 according to (a) the proposed approach and (b) Turkish practice

The trees are treated differently in these two approaches. They can be removed or relocated from the roadside, so young trees are not shielded from safety barriers in Turkish practice. In this case study, trees, mainly olive trees, are considered during horizontal geometry design, and the corridor is passed where the trees are least affected. The sections where the density of trees is high are considered for the safety barrier applications based on the distance to the roadway. However, in the proposed approach, trees are treated as a point or continuous hazards based on their proximity, and risk calculation in the RRRAP is decided whether to protect them or not. According to analyses of the ROR accident history in the UK, trees are one of the most common objects to hit, and they have a higher fatality and severe injury rate than other objects. For these reasons, the RRRAP assigns a higher aggressiveness value for trees and states that risk is unacceptable without a safety barrier if they are close to the roadway. Even young trees are considered hazardous when they are located near the roads, and safety barriers are placed since the girth width of these trees get more prominent over time.

Traffic flow information is one of the main factors considered in almost every roadside design application. Due to the region's export potential and the cement factory on the road, it is assumed that the HGV rate, which is high even under current conditions, will increase significantly after the road is built. For this reason, the H1 containment level is chosen in Turkish practice. However, although the same assumptions are also made in the proposed approach, the risk calculations conclude that N2 is an adequate containment level for the corridor and is used in the roadside design. The proposed approach results length of need being almost two and a half times in length of Turkish practice. The safety barriers type and length of need results according to these two approaches are presented in Table 6.3.

Table 6.3 Summary of safety barrier quantity takeoff according to Turkish practice and the proposed approach

	Turkish Practice		Proposed Approach	
	Type	**Length (m)**	**Type**	**Length (m)**
CS-1	H1-W4	1,961	N2-W3	3,477
	H2-W2	241	H2-W3	309
CS-2	H1-W4	308	N2-W3	1,911
CS-3	H1-W4	2,398	N2-W3	3,804
CS-4	H1-W4	791	N2-W3	1,909
			H1-W3	220
CS-5			N2-W3	156
CS-6	H1-W4	840	N2-W3	2,426
CS-7	H1-W4	364	N2-W3	1,808
Study Corridor			N2-W3	15,491
	H1-W4	6,662	H1-W3	220
	H2-W2	241	H2-W3	309

CHAPTER 7

CONCLUSION AND FURTHER RECOMMENDATIONS

7.1 Conclusions

After the latest paradigm shift in traffic safety, a safe system approach has been adopted worldwide. The number of fatal and severely injured accidents is targeted to be reduced and vanished With the help of five pillars of the safe system. These five pillars are safe roads, safe vehicles, safe road users, safe speeds, and post-crash care. As a system requirement, safe roads should be designed, and one of the main requirements to design safe roads is designing safe roadsides. Roadsides are the areas along the traveling lanes; they are driver-side (offside) or passenger-side (nearside). The object in these areas may pose a hazard to ROR vehicles. Removing, relocating, and making these objects passively safe are the first three options to create safe roadsides. However, if these steps are not feasible or applicable, the RRS should shield these hazardous objects. VRS and pedestrian restraint systems are the sub-categories of RRS, and the standards were prepared for these systems' performance and acceptance tests. These standards include only the material and performance-related aspects of the RRS, but there is no consensus on application guidance for these systems. The USA, Germany, and the UK have their application guidelines, procedures, and other countries use these leading countries' approaches by adapting and modifying.

Turkey uses modified and translated AASHTO standards in written guidelines for road designs. For the roadside design section of the GDH highway design handbook, the AASHTO 1996 roadside design guideline was translated and used. This handbook states the requirements for the rural intercity and provincial roads, but it is not entirely applicable for urban roads due to the low speed and complexity of the road. However, Turkey is in the European region and uses the EN standards. A simplified German approach is used when deciding on RRS instead of a written manual for the compatibility between the EN standards and the application process. The German guidelines are prepared with assumptions, charts, and rules of thumb, making the decision process easy and fast for designers. However, the rule of thumb and assumptions create subjective results for the VRS decisions since the engineering experience and judgment play a significant role in decision-making. Hence the lack of firm provisions for RRS decisions and compatibility issues between design guidelines and the application process creates ambiguity and inconsistency in roadside designs in Turkey.

Within the scope of this study, the roadside design approach of the UK, which has one of the best road safety statistics and a more objective assessment process for the RRS, is examined in detail. It is understood that the assessment process consists of two parts that must be used together for the major roads with high speed and high traffic flow. The first part is the written manual called CD377, and the second is the cloud-based software, the RRRAP. Since the UK uses EN standards and has a systematic roadside design approach, the UK approach is redefined, and a new approach is proposed for Turkish roads in this study. This thesis aims to compare the current Turkish roadside design and the proposed design approach results. For this comparison, Turkey's one of the newly designed high-speed and high-traffic flow state roads is used as a case study corridor. The study corridor's design speed is 90km/h, and the future projected traffic flow is greater than 5,000 veh/day.

The study focused on the safety barrier need and quantified the length of the safety barrier for nearside of a state road with high-speed and high traffic flow. As a methodology, the study corridor roadside is designed with current Turkish practice first, and the required places and lengths of safety barriers are determined. After that, the same route is designed with the proposed roadside design approach, and the results are compared with the Turkish practice results. The median section risk assessment is not conducted in this study. The RRRAP states that wide central reserves (those over 10m in width) may be assessed with the software, but this assessment does not include crossover incidents within the calculation.

The study and results show that although the same conditions are investigated in both approaches, there are differences in hazard definitions. For similar hazards in these two approaches, embankments and vertical drops can be given as examples. Both approaches consider embankments hazardous if they have height and inclination above the critical threshold values. Threshold values for whether or not the embankment is hazardous show differences in Turkish and the proposed approach. Both practices suggest that high vertical drops should be shielded with higher containment level safety barriers. Both approaches consider cutting slope sections and trees along the roadside differently. The cut slope sections may be considered hazardous based on the slope rates according to the proposed approach. However, in Turkish practice, unless the cut slope has a rocky and abrupt surface, they do not pose a hazard to ROR vehicles, thanks to the ditches before the slope. Trees are one of the most hazardous objects in the proposed approach based on the distance from the roadway, so they must be guarded with safety barriers. In Turkish practice, trees are not given enough attention because it is assumed that trees in expropriation boundaries are relocated or removed easily. However, if the road passes through forest land and the trees can not be removed, a safety barrier could be needed based on the design speed and probability of a ROR accident.

Also, results show that the safe zone concept is not used effectively because of the inconsistencies between the written handbook and design applications in Turkey. Besides the safe zone concept, the verge section is not defined in Turkish road cross-sections. The confusion and lack of firm regulations make decision-making of VRS difficult for engineers and designers. The decision to use VRS is up to designers in both approaches, but in the proposed approach, there is a tool that helps designers distinguish and calculate the risks at the roadside. This tool creates an objective assessment process, unlike the current Turkish practice. Turkish practice depends on engineering assumptions, judgment, and experiences, creating a subjective assessment for the roadside designs. Due to these differences, there are differences in required places and the length of needs of safety barries.

The proposed approach resulted that the containment level for this case study could be chosen as N2 despite the Turkish practices H1 level. Also, it concludes that the length of need is almost two and a half times that of the Turkish practice. However, it should be kept in mind that, in Turkey, the road design practices and cross-section definitions come from the AASHTO standards, so to use the decision-making tool, there are some assumptions regarding road cross-section. Also, the hazard definitions and their aggressiveness in the RRRAP are defined according to crash history and research on the UK roads, so the conditions in Turkey could be different. Lastly, this study is performed in the design stage of the state road. The results may change if it performs at other stages, such as construction or operation, due to changes in the conditions of hazards.

7.2 Further Recommendations

The definition of the safe zone and verge width in road cross-section in Turkish road traffic legislation has not yet been made. Due to expropriation cost, also the shoulder widths are selected narrow. For these reasons, the containment levels should be chosen higher, and working widths should be high class, which causes a higher cost of safety barrier design. The initial and maintenance costs are higher for these barriers; without proper maintenance, they do not work as expected, so the consequences of ROR accidents become severe.

For a good design and maintenance of RRS, Road Safety Audit (RSA) should be mandatory because one of the subsections of RSA contains roadside safety evaluation. Independent third parties should conduct the RSA process to eliminate the conflict of interest. In Turkey, RSA is done by the GDH, the authority of motorways and rural roads, so the conflict of interest in the road safety audit makes the whole process questionable.

As a further study, the medians' safety could be investigated in Turkey. The median widths are also narrow on state roads, and steep-sloped ditches are used for drainage purposes, which are hazardous for ROR vehicles. In addition, the lighting poles and traffic signs that are not passively safe, such as signal gantries and trees, create hazards for the ROR vehicles (see Figure 7.1).

Also, other developed countries, especially those with safe road designs, could be investigated in detail as a further recommendation. After that, the ones possibly suitable for Turkey are selected, adjusted, and adapted to create and prepare a new roadside design approach and written guidelines. As a suggestion, the proposed approach for this thesis study could be improved. The risk assessment tool could be modified with ROR accident data and in-depth analyses in Turkey, or maybe a new assessment tool could be created for the RRS application from scratch.

The prepared new approach could be merged into the current road design programs. For example, with a patch or update in road designer software like Bentley Openroads, and Autodesk 3D, the roadside design process could be completed without external programs. With this improvement in the road design programs, the roadside design process could be more objective and autonomous.

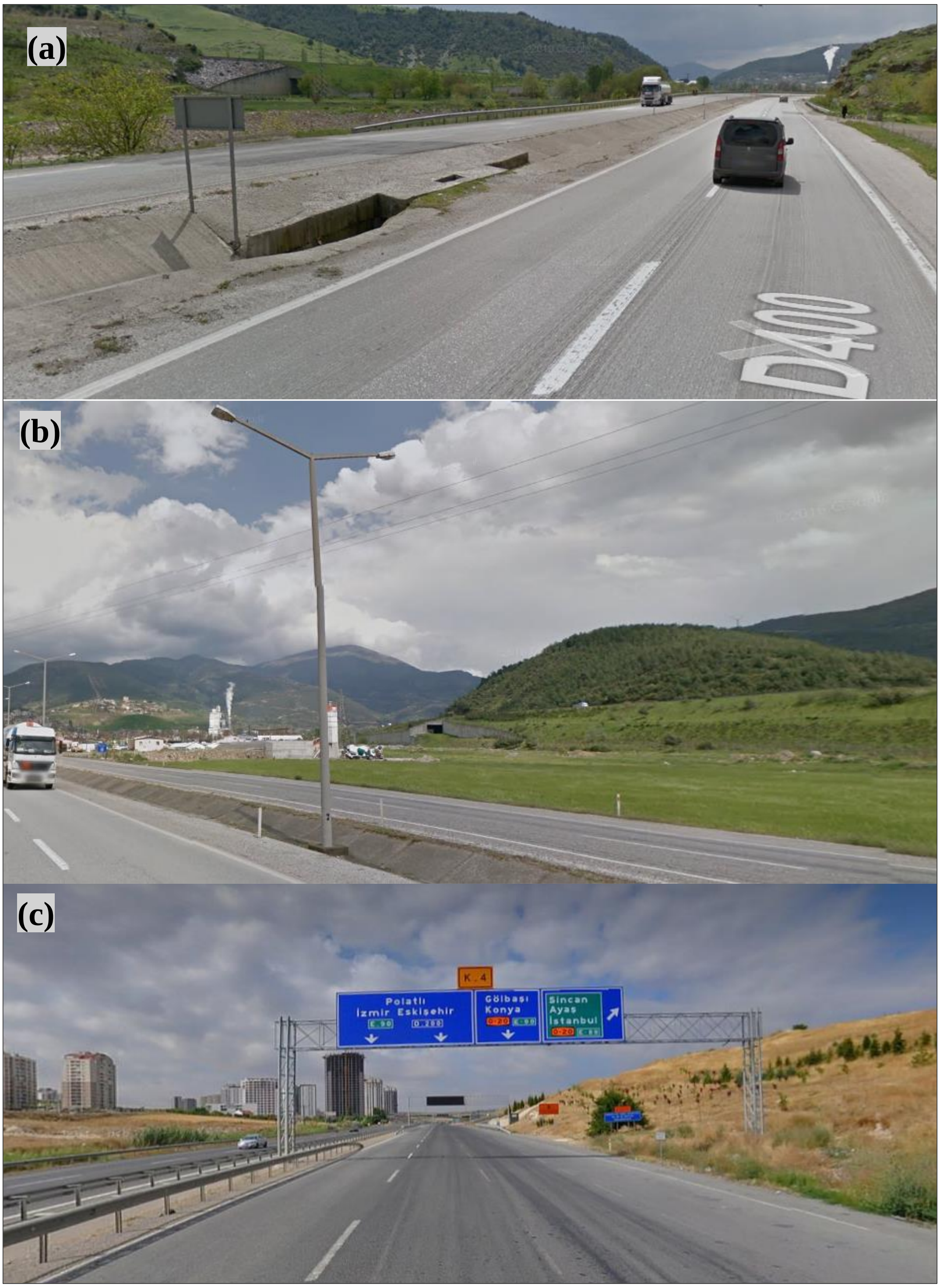

Figure 7.1 (a) Drainage ditch (b) Lighting pole (c) Signal gantries in the median of state roads

REFERENCES

AASHTO. (2001). *A policy on geometric design of highways and streets, 2001*. American Association of State Highway and Transportation Officials.

AASHTO. (2006). *Roadside design guide*. American Association of State Highway and Transportation Officials.

AASHTO. (2011). *Roadside Design Guide* (4th ed.). American Association of State Highway and Transportation Officials.

CEDR. (2014). *CEDR Transnational Road Research Programme Call 2012: Safety: Use of Vehicle Restraint Systems SAVeRS Defining the Different Parameters which can influence the need and selection of VRS Deliverable D1.1*. www.cedr.fr

CEN. (2010). *Road restraint systems-Part 2: Performance classes, impact test acceptance criteria and test methods for safety barriers including vehicle parapets*.

Demirel, M. (2019). *Road Safety Evaluation of Urban Major Arterials Case Study of 1071 Malazgirt Boulevard in Ankara*.

DfT. (2006). *Design Manual for Roads and Bridges Volume 2 Highway Structures Design (Substructures and Special Structures) Material Section 2:Special Structures Part 8 TD19/06 Requirement for Road Restraint Systems*.

DfT. (2013). *Department for Transport SETTING LOCAL SPEED LIMITS*. www.gov.uk/dft

DfT. (2019). *Reported Road Casualties in Great Britain: main results 2018*. https://www.gov.uk/government/

Ellmers, U. (2001). *Do German road restraint systems meet European requirements? : Test, in accordance with the current European standards,* *of passive road restraint systems used in Germany*. http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A673768&dswid=169

Elvik, R., Høye, A., Vaa, T., & Sørensen, M. (2009). *The Handbook of Road Safety Measures (Second Edition)* (Second Edition). Emerald Publications.

FGSV. (2009). *Guidelines for passive protection on roads by vehicle restraint systems RPS*.

GDH. (2005). *Karayolu Tasarım El Kitabı*. Karayolları Genel Müdürlüğü.

GDH. (2022a). *2021 Yılı Karayolları Genel Müdürlüğü Sorumluluğundaki Yol Ağında Meydana Ggelen Trafik Kazalarına Ait Özet Bilgiler*.

GDH. (2022b). *Trafik Kazaları Özeti 2021*. www.kgm.gov.tr

GDH. (2022c). *2021 Trafik ve Ulaşım Bilgileri: Otoyollar ve Devlet Yollarının Trafik Dilimlerine Göre Yıllık Ortalama Günlük Trafik Değerleri ve Ulaşım Bilgileri*. https://www.kgm.gov.tr/SiteCollectionDocuments/KGMdocuments/Istatistikler/TrafikveUlasimBilgileri/21TrafikUlasimBilgileri.pdf

Heath, M. (2013). Latest Update to the British Vehicle Restraint Assessment Process. *International Workshop-Transportation Research Circular (E-C172)*, 38–39. www.TRB.org

Highways England. (2020a). *Road Restraint Risk Assessment Process (RRRAP) V3.1 User Guide Issue 4*.

Highways England. (2020b). *Road Restraints Risk Assessment Process (RRRAP)*. https://www.standardsforhighways.co.uk/ha/standards/tech_info/rrrap.htm

Highways England. (2021a). *Design Manual for Roads and Bridges Highway Structures & Bridges Design CD 377 Requirements for road restraint systems Revision 4*.

Highways England. (2021b). *Road Layout Design CD 127 Cross-sections and headrooms (formerly TD 27/05, TD 70/08) Revision 1*.

Hubbell, J. (2013). Can EN 1317 and NCHRP 350–MASH Be Used Interchangeably? . *International Workshop-Transportation Research Circular (E-C172)*. www.TRB.org

IIMC. (2022). *Maddi Hasarlı Kaza (KTT) - Sigorta Bilgi ve Gözetim Merkezi*. https://www.tramer.org.tr/tr/maddi-hasarli-kaza-raporlari(ktt)

la Torre, F., Domenichini, L., Mercaldo, A., Fagerlind, H., Martinsson, J., Book, D., Saleh, P., & Helfert, M. (2013). *Forgiving roadsides design guide*. http://www.irdes-eranet.eu.

Lynam, D. A., & Kennedy, J. v. (2005). The travel of errant vehicles after leaving the carriageway (Report PPR298). *TRL*.

Mak, K. K., Sicking, Dean., National Cooperative Highway Research Program., National Research Council (U.S.). Transportation Research Board., American Association of State Highway and Transportation Officials., & United States. Federal Highway Administration. (2003). *Roadside Safety Analysis Program (RSAP)-- engineer's manual*. Transportation Research Board.

Moskowitz, K., & Schaeffer, W. E. (1960). California median study:1958. *Highway Research Board*, *266*, 34–62.

Nathan Masters. (2017). *Concrete Fantasy: When Southern California's Freeways Were New (And Empty) | Lost LA | Food & Discovery | KCET*. https://www.kcet.org/shows/lost-la/concrete-fantasy-when-southern-californias-freeways-were-new-and-empty

Newby, R. F., & Johnson, H. D. (1964). *Changes in the numbers of accidents and casualties on main roads near the London -Birmingham Motorway.*

Newland, V. J., & Newby, R. F. (1962). Changes in Accident Frequency after the Provision of By-Passes. *Traffic Engineering and Control*.

Tang, C. K., & Zhang, L. (2021). *Principles and Practices of Transportation Planning and Engineering* (1st Edition). CRC Press.

Thomson, R., Fagerlind, H., Martinez, A. V., Amengual, A., Naing, C. L., Hill, J., Hoschopf, H., Dupre, G., Bisson, O., Kelkka, M., van der Horst, R., & Gracia, J. M. (2006). *Roadside infrastructure for safer European roads: D06 European best practice for roadside design: guidelines for roadside infrastructure on new and existing roads.*

TSE. (2011). *Türk Standardı Yol Güvenlik Sistemleri -Bölün 1: Terminoloji ve Deney Yöntemleri için Genel Kriterler, Road restraint systems-Part 1: Terminology and general criteria for test methods*.

TUIK. (2022a). *Adrese Dayalı Nüfus Kayıt Sistemi Sonuçları, 2021*. https://data.tuik.gov.tr/Bulten/Index?p=Adrese-Dayali-Nufus-Kayit-Sistemi-Sonuclari-2021-45500

TUIK. (2022b). *Road Traffic Accident Statistics, 2021*. https://data.tuik.gov.tr/Bulten/Index?p=Karayolu-Trafik-Kaza-Istatistikleri-2021-45658

UKRLG. (2011). *Design & Maintenance Guidance for Local Authority Roads Provision of Road Restraint Systems on Local Authority Roads*. Department for Transport.

U.S. DOT. (2022). *What is a Safe System Approach?* https://www.transportation.gov/NRSS/SafeSystem

WHO. (2018). *Global status report on road safety 2018*. World Health Organization. https://www.who.int/publications/i/item/9789241565684

Woodward, A. J., & Dolinis, J. (1995). Vehicle speed and risk of a severe crash. *Epidemiology*, *6*(3), 258–262. https://doi.org/10.1097/00001648-199505000-00012

Yaman, İ. Ö., & Tuydes-Yaman, H. (2019). *Türkiye Prefabrik Birliği | Sayı: 127*. https://ebrosur.net/prefab/prefab_127/18/

APPENDICES

A. Glossary

B. Excerpts from the EN 1317-2

C. Current Turkish Guideline GDH Highway Design Handbook

D. Excerpts from the RPS 2009

E. Hazard Overviews of Proposed Approach in CSs

A. Glossary

Term		Definition
AADT	:	Annual Average Daily Traffic is the total volume of vehicle traffic on a highway or road for a year divided by 365 days.
ASI	:	Acceleration Severity Index describes the impact severity of an accident.
Central reserve	:	An area that separates the roadways of divided highways.
Clear (safety) zone	:	Also called "Safety zone." The clear zone is the zone adjacent to the roadway for which measures should be taken to avoid severe consequences for drivers and passengers of vehicles that accidentally leave the road and enter this zone. The desired width depends on traffic volume, speed, and road geometry.
Culvert	:	A structure to channel water under the road. It can be made of concrete, steel, or plastic.
Cut slope	:	The sections are created when a road is excavated through a hill, which slopes upwards from the level of the roadway.
Design Speed	:	The speed that selected to determine the geometric features of the roadway. The maximum safe speed can be maintained over a specified section.
Ditch	:	Ditches are drainage features that run parallel to the road. Excavated ditches are distinguished by a fore slope (between the road and the ditch bottom) and a back slope (beyond the ditch bottom and extending above the ditch bottom).
Embankment	:	Compacted earth material to raise the elevation of the roadway or railway. The term “Fill section” is used interchangeably.
Encroachment	:	A term describes the situation when the vehicle leaves the roadway and enters the roadside area.
Fill slope	:	An earth embankment created when extra material is packed to create the roadbed, typically sloping downwards from the roadway.

Forgiving roadside	:	A forgiving roadside mitigates the consequence of the "run-off-rad" accidents and aims to reduce the number of fatalities and severe injuries from these events.
Guardrail	:	A guardrail is another name for a metal post and rail safety barrier. Also, used interchangeably with a safety barrier in Turkey.
Headwalls	:	Headwalls are attached to the ends of the culvert to reduce erosion, prevent seepage, protect the fill, improve aesthetics and hydraulic performance, and stabilize the ends structurally.
Impact angle	:	For a longitudinal safety barrier, it is the angle between a tangent to the face of the barrier and a tangent to the vehicle’s longitudinal axis at impact. For a crash cushion, it is the angle between the axis of symmetry of the crash cushion and a tangent to the vehicle’s longitudinal axis at impact.
Length of need	:	The length of a longitudinal safety barrier needed to protect an area of concern.
Median	:	See "Central reserve."
Nearside	:	A term used when discussing right and left-hand traffic infrastructure. The side of the roadway closest to the vehicle's traveled way (not median).
Offside	:	A term used when discussing right and left-hand traffic infrastructure. The side of the roadway closest to opposing traffic or a median.
Pedestrian restraint system	:	A road restraint system installed to provide restraint for pedestrians.
Retaining wall	:	A wall is built to resist lateral pressure, particularly a wall built to support or prevent the advance of a mass of earth.
Road restraint system (RRS)	:	The general name for all vehicle and pedestrian restraint systems used on the road (EN 1317).
Road Safety Audit/Inspection	:	RSA and RSI are formal, detailed, and systematic audits of road infrastructure projects at various stages of planning (e.g., feasibility stage, draft design, detailed design, pre-opening, and early operation) and existing roads. Auditors should be a third party that is well-trained and independent from the designer and the contractor.

Roadside	:	The area beyond the edge line of the roadway and central reserve also be considered roadside.
Roadside hazards	:	Roadside hazards are fixed objects or structures endangering an errant vehicle leaving its path. They can be continuous or punctual, natural, or artificial. The risks associated with these hazards include high decelerations to the vehicle occupants or vehicle rollovers.
Safety barrier	:	A road vehicle restraint system installed alongside or on the central reserve of roads.
Safety (clear) zone	:	Also called "Clear zone.” The safety zone is the zone adjacent to the roadway for which measures should be taken to avoid severe consequences for drivers and passengers of vehicles that accidentally leave the road and enter this zone. The desired width depends on traffic volume, speed, and road geometry.
Shoulder	:	The portion of the roadway contiguous with the travel lane for the accommodation of stopped vehicles, emergency use, and lateral support of the roadway.
Underpass	:	A structure (including its approaches) allows one road or footpath to pass under another road (or an obstacle).
Vehicle Restraint System (VRS)	:	A system installed on the road to prevent an errant vehicle from colliding with objects beside the road. This includes a safety barrier, a crash cushion, etc.
Verge	:	An unpaved level strip adjacent to the shoulder. The road equipment, such as safety barriers and traffic signs, is on the verge. Also, the verge's purpose is drainage, which can sometimes be lightly vegetated.
Working width	:	The distance between the traffic face of the barrier before the impact and the maximum lateral position of any major part of the system or vehicle during the impact.

B. Excerpts from the EN 1317-2

Table B.1 Standard impact tests specified in EN 1317-2 (CEN, 2010)

Test	Impact speed (km/h)	Impact angle (degree)	The total mass of the vehicle (tone)	Vehicle type
TB11	100	20	0,9	Passenger vehicle
TB21	80	8	1,3	Passenger vehicle
TB22	80	15	1,3	Passenger vehicle
TB31	80	20	1,5	Passenger vehicle
TB32	110	20	1,5	Passenger vehicle
TB41	70	8	10	Truck
TB42	70	15	10	Truck
TB42	70	15	10	Truck
TB42	70	15	10	Truck
TB42	70	15	10	Truck
TB42	70	15	10	Truck
TB51	70	20	13	Bus
TB61	80	20	16	Truck
TB71	65	20	30	Truck
TB81	65	20	38	Articulated Truck

Table B.2 Impact severity levels specified in EN 1317-2 (CEN, 2010)

Impact Severity Level	Index Values	
A	ASI ≤ 1.0	THIV ≤ 33 km/h
B	1.0 < ASI ≤1.4	
C	1.4 < ASI ≤ 1.9	

Table B.3 Working width (Wm) and vehicle intrusion distance classes (VIm)

W_1	$W_N \leq 0{,}6$ m	VI_1	$VI_N \leq 0{,}6$ m
W_2	$W_N \leq 0{,}8$ m	VI_2	$VI_N \leq 0{,}8$ m
W_3	$W_N \leq 1{,}0$ m	VI_3	$VI_N \leq 1{,}0$ m
W_4	$W_N \leq 1{,}3$ m	VI_4	$VI_N \leq 1{,}3$ m
W_5	$W_N \leq 1{,}7$ m	VI_5	$VI_N \leq 1{,}7$ m
W_6	$W_N \leq 2{,}1$ m	VI_6	$VI_N \leq 2{,}1$ m
W_7	$W_N \leq 2{,}5$ m	VI_7	$VI_N \leq 2{,}5$ m
W_8	$W_N \leq 3{,}5$ m	VI_8	$VI_N \leq 3{,}5$ m

C. Current Turkish Guideline GDH Highway Design Handbook

Roadside Topography and Geometry

The hazard-free roadside is between the inner edge of the shoulder and the expropriation limits. It should be arranged to ensure the safety of vehicles going off the road, i.e., to minimize the severity of accidents by preventing them from returning to the road or overturning or hitting an object. Therefore, the unobstructed roadway area is

- Preventing it from hitting dangerous stationary objects
- To ensure that vehicle can move safely and get back on track

should be provided along the way. The width of the clear zone is determined from Figure C.1 based on AADT, cut, fill slope, and design speed. The values in Figure C.1 can also be used for the clear-zone width.

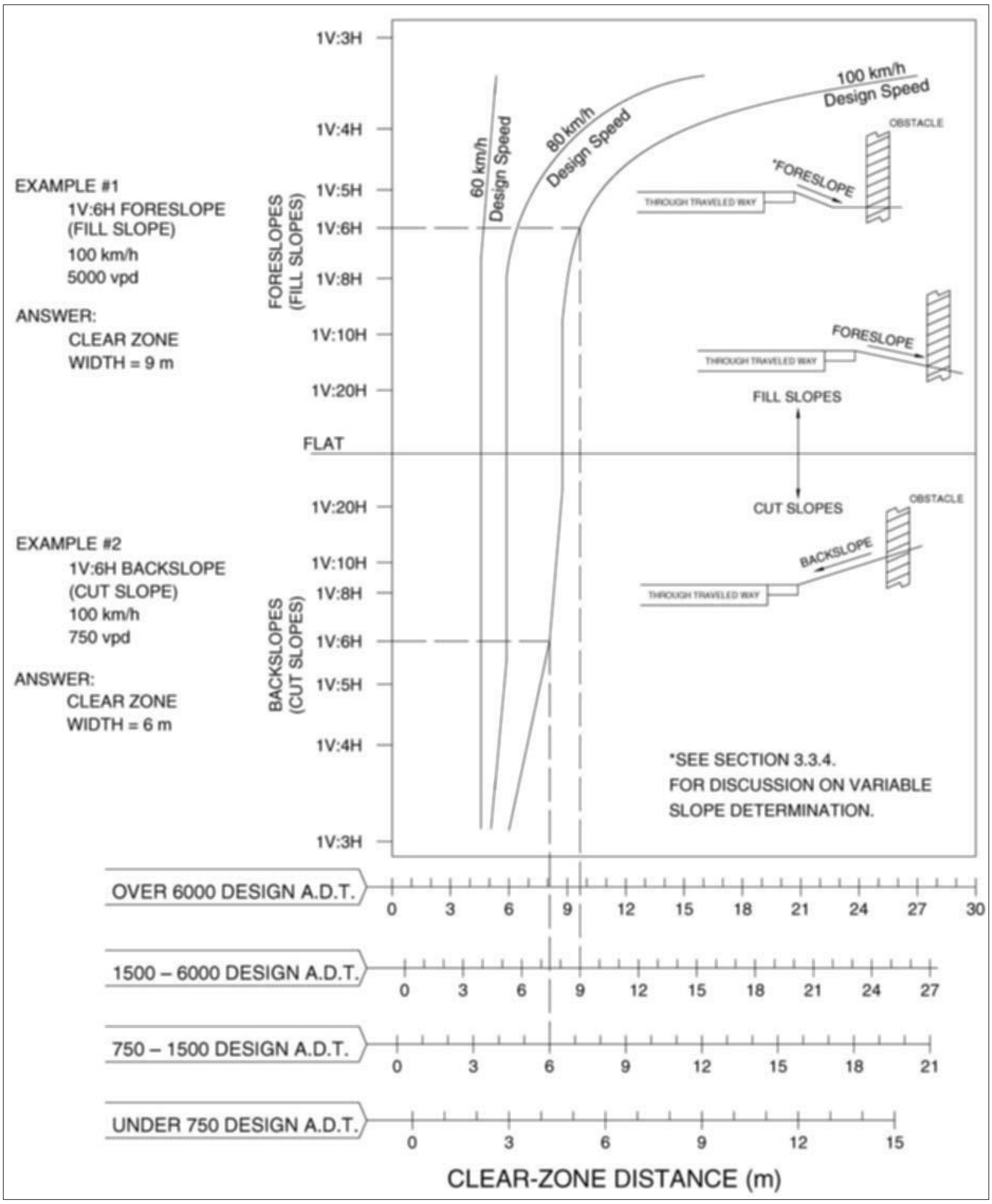

Figure C.1 Roadside clear-zone width (AASHTO, 2006)

Table C.1 Suggested clear-zone distances in meters from the edge of through traveled lane (AASHTO, 2011)

Design speed (km/h)	**Design ADT (veh)**	**Foreslopes**			**Backslopes**		
		1V:6H or flatter	**1V:5H to 1V:4H**	**1V:3H**	**1V:3H**	**1V:5H to 1W4H**	**1V:6H**
≤ 60	≤ 750	2,0 – 3,0	2,0 – 3,0	*	2,0 – 3,0	2,0 – 3,0	2,0 – 3,0
	750 – 1500	3,0 – 3,5	3,5 – 4,5	*	3,0 – 3,5	3,0 – 3,5	3,0 – 3,5
	1500 – 6000	3,5 – 4,5	4,5 – 5,0	*	3,5 – 4,5	3,5 – 4,5	3,5 – 4,5
	> 6000	4,5 – 5,0	5,0 – 5,5	*	4,5 – 5,0	4,5 – 5,0	4,5 – 5,0
70 – 80	≤ 750	3,0 – 3,5	3,5 – 4,5	*	2,5 – 3,0	2,5 – 3,0	3,0 – 3,5
	750 – 1500	4,5 – 5,0	5,0 – 6,0	*	3,0 – 3,5	3,5 – 4,5	4,5 – 5,0
	1500 – 6000	5,0 – 5,5	6,0 – 8,0	*	3,5 – 4,5	4,5 – 5,0	5,0 – 5,5
	> 6000	6,0 – 6,5	7,5 – 8,5	*	4,5 – 5,0	5,5 – 6,0	6,0 – 6,5
90	≤ 750	3,5 – 4,5	4,5 – 5,5	*	2,5 – 3,0	3,0 – 3,5	3,0 – 3,5
	750 – 1500	5,0 – 5,5	6,0 – 7,5	*	3,0 – 3,5	4,5 – 5,0	5,0 – 5,5
	1500 – 6000	6,0 – 6,5	7,5 – 9,0	*	4,5 – 5,0	5,0 – 5,5	6,0 – 6,5
	> 6000	6,5 – 7,5	8,0 – 10,0[1]	*	5,0 – 5,5	6,0 – 6,5	6,5 – 7,5
100	≤ 750	5,0 – 5,5	6,0 – 7,5	*	3,0 – 3,5	3,5 – 4,5	4,5 – 5,0
	750 – 1500	6,0 – 7,5	8,0 – 10,0[1]	*	3,5 – 4,5	5,0 – 5,5	6,0 – 6,5
	1500 – 6000	8,0 – 9,0	10,0 – 12,0[1]	*	4,5 – 5,5	5,5 – 6,5	7,5 – 8,0
	> 6000	9,0 – 10,0[1]	11,0 – 13,5[1]	*	6,0 – 6,5	7,5 – 8,0	8,0 – 8,5
110	≤ 750	5,5 – 6,0	6,0 – 8,0	*	3,0 – 3,5	4,5 – 5,0	4,5 – 5,0
	750 – 1500	7,5 – 8,0	8,5 – 11,0[1]	*	3,5 – 5,0	5,5 – 6,0	6,0 – 6,5
	1500 – 6000	8,5 – 10,0[1]	10,5 – 13,0[1]	*	5,0 – 6,0	6,5 – 7,5	8,0 – 8,5
	> 6000	9,0 – 10,5[1]	11,5 – 14,0[1]	*	6,5 – 7,5	8,0 – 9,0	8,5 – 9,0

1. In cases where the number of accidents is high, the designer may provide clear-zone distances greater than the clear zone shown in Table C-1.

** There should be no objects at the foot of the enthusiasm as it is difficult for the vehicle going off the road to return to the road at 1V:3H enthusiasm.*

Fill and Cut Slopes

Side fill slopes at intersections constitute a hazard for traffic flows on the main road. For this reason, the road fill slopes in the minor road connection sections should be made as flat as possible. Roadside drainage structures should be designed not to endanger road safety. The cut slopes within the clear zone should be protected with safety barriers to protect vehicles that go out of the way. The slope of the drainage ditches perpendicular to the road axis should be reduced as much as possible, and the safety of ROR vehicles should be ensured.

A ROR vehicle, depending on whether the road is on a fill or in a cut

- Negative slope in fill slope
- The negative and then positive slope on the cut slope

will encounter. If these slopes can be built with a sufficiently low slope, the vehicle that goes off the road can return to the road without overturning. Maximum effort should be made to ensure that the fill and ditch slopes are below values for road safety. In Figure C.1 or Table C.1, the clear-zone width is determined for the curve radius of the road axis. Therefore, it should be corrected by multiplying the coefficients in Table C.2 for the outer edge of the curve.

If the embankment slopes are 1V:4H or milder, road safety will be ensured since it is possible for the vehicles runout the road to return to the road or to stop safely outside the slope without overturning. While the embankment slope is between 1V:3H and 1V:4V is critical for road safety, vehicles leaving the road on slopes steeper than 1V:3H will not be able to return to the road and road safety will decrease due to the high risk of overturning. Especially, fill sections higher than 3 m and steeper than 1V:3H slope is at risk of road safety. Steep, rough, and rocky cut slopes should usually start outside the clear zone or be shielded with safety barriers.

Table C.2 Horizontal curve correction factor (AASHTO, 2001)

Radius (m)	**Design Speed (km/h)**					
	60	**70**	**80**	**90**	**100**	**110**
00	1.1	1.1	1.1	1.2	1.2	1.2
700	1.1	1.1	1.2	1.2	1.2	1.3
600	1.1	1.2	1.2	1.2	1.3	1.4
500	1.1	1.2	1.2	1.3	1.3	1.4
450	1.2	1.2	1.3	1.3	1.4	1.5
400	1.2	1.2	1.3	1.3	1.4	
350	1.2	1.2	1.3	1.4	1.5	
300	1.2	1.3	1.4	1.5	1.5	
250	1.3	1.3	1.4	1.5		
200	1.3	1.4	1.5			
150	1.4	1.5				
100	1.5					

Roadside Ditches and Drainage Structures

Drainage ditches made to provide surface drainage in cut sections should have appropriate slopes and sections not to pose a danger to ROR vehicles. In addition, since the cut drainage ditches are located within the clear zone, the accident severity of the ROR vehicles increases. If a triangular cut ditch or a trapezoidal cut ditch with a base width of fewer than 1.2 m will be built-in cuts, the appropriate slopes should be determined from Figure C.2 for road safety. If trapezoidal channels with bottom widths equal to or greater than 1.2 m are planned for the cut sections, the slopes should be determined according to Figure C.3.

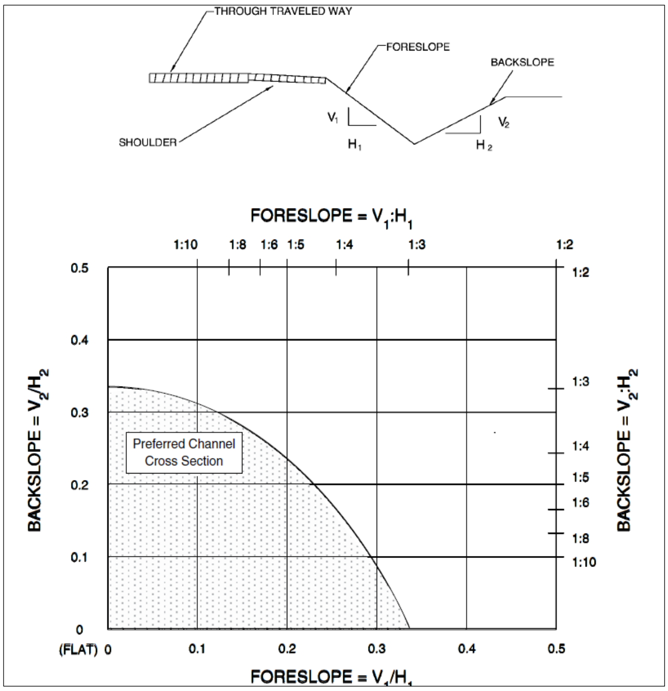

Figure C.2 Preferred cross-sections for abrupt slope changes channels (AASHTO, 2011)

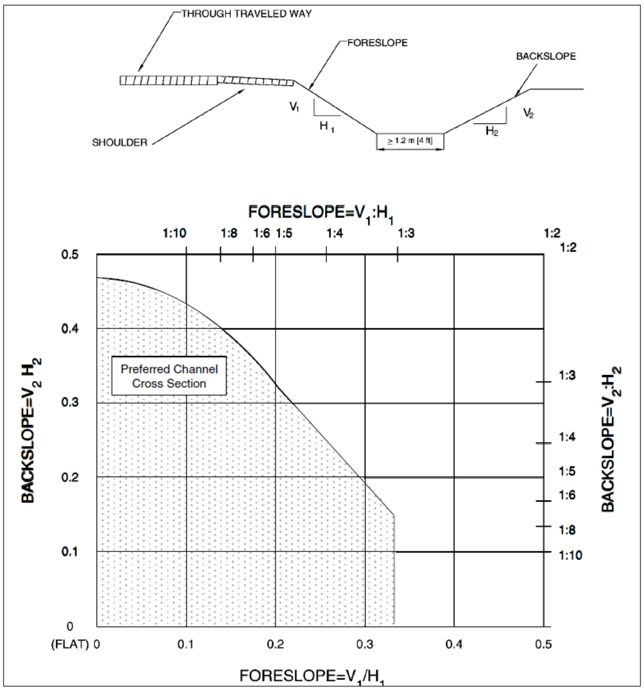

Figure C.3 Preferred cross-sections for gradual slope changes channels (AASHTO, 2011)

An effective drainage system is one of the most critical elements in designing highways and streets. Drainage structures should be designed with the effects on the roadside environment should be kept in mind.

In addition to roadside ditches, the design of pavement kerbs, parallel and interfered culverts, and drain grids should ensure road safety and hydraulic performance. The considerations should be made for:

- Hydraulic structures that are out of use should be removed.
- The engineering structures should be designed to cause the minimum damage to the vehicles and be passed safely.
- If the engineering structure cannot be designed and placed effectively or is in an unsuitable location, it should be protected with an appropriate VRS.

Pavement kerbs are generally used to design an effective drainage system and pavement edge support, reduce expropriation width and aesthetic appearance, and reduce pedestrian pavement and maintenance work. They are generally classified as barrier type or mountable kerbs. Barrier-type kerbs are relatively high and are designed to intimidate drivers who may leave the road.

A minimum of 0.5m horizontal clearance should be provided between the pavement kerb and its obstacles on urban roads. Using kerbs on high-speed roads in front of safety barriers is not preferred. It should be placed behind the safety barriers if it is required to be used. Particular attention should be paid to this for bridge safety barriers.

The drainage structures’ inlet (upstream) and outlet (downstream) sections consist of concrete headwalls and wing walls in large structures and angled end sections in smaller conduits. While these designs increase hydraulic capacity and minimize erosion, they can be hazardous ROR vehicles. They can create a stationary object protruding above a transposable roadside or cause vehicles to fall vertical. Below are the options that should be implemented to minimize these obstacles:

- The obstacles are designed to be traversed safely

- The structure should be extended to reduce the possibility of collision.
- Drainage structures should be shielded with safety barriers
- If the above alternatives are unsuitable, drivers should be warned about the structure.

If the fill slope is not traversed, the necessary improvement for drainage structures is to extend or shorten the structure to cut through the road fill and adjust the structure's entrance and exit slopes to the fill slope.

Drainage structures wider than 1 m can be traversed for cars using iron grates or pipes that reduce the opening at their ends. Safety improvements should not affect hydraulic capacity. Regarding the hydraulic efficiency of drainage structures, applying iron grates to more extensive angled wing walls or angled end sections is more appropriate.

If the entrance and exit sections for medium-sized concrete pipes and culverts cannot be transposable, the engineering structure obstructing ends should be extended just beyond the clear zone.

It is often the most effective safety practice to shield the ends of large drainage structures, whose extension is not economical and whose ends cannot be passed, with a suitable safety barrier.

While the drain grids in urban crossings are designed according to the calculation flow rate, they should be designed to bear the load applied by the vehicle wheel and not create an obstacle for pedestrians.

Drainage grids can also be used in the medians of divided roads and sometimes in roadside ditches. Their purpose is to collect surface water run-off, and they should be designed and installed in such a way as to cause the least possible obstruction to motorists. It is possible if the drain grids are at the same level as the ditch bottom or slope to which they are attached. The openings of the drain grids should be improved to prevent the wheels of vehicles from falling into them.

Traffic Signs, Lighting Poles, and Supports

Although a hazard-free and transposable roadside is desired in terms of safety, service tools such as vertical traffic signs, road lighting, signaling poles, railway warnings, and telephone and electricity poles should be placed on the edge of the road platform.

The breakaway or frangible support is a system designed to be used in traffic signs and signaling poles, as seen in Figure C.4, and that does not show a rigid support strength in the event of a vehicle impact and moves as if it has been broken at the joint, thus providing minor damage to the crashing vehicle. Generally, frangible bearings should be considered in urban and state roads where the design speed is above medium and high.

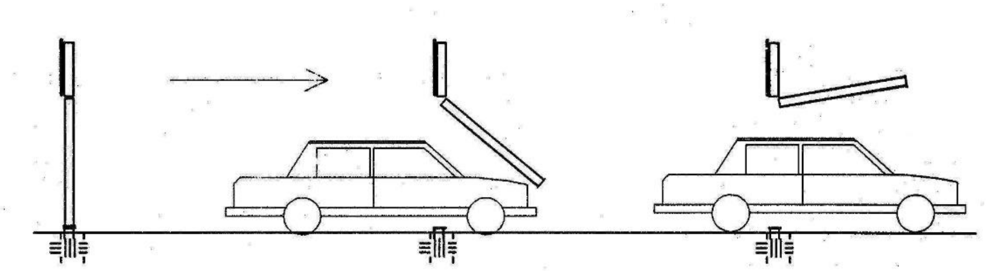

Figure C.4 Frangible support effect (AASHTO, 2001)

Guardrails (Safety Barriers)

The types and design principles determined by the Maintenance Department will be considered in the design and application of guardrails, which are among the roadside elements.

Guardrails are constructed along the nearside of the roadway edge or median edge to re-direct the errant vehicles to the direction of departure after the collision and protect the occupants from natural or artificial obstacles. For this reason, in places where the risk of ROR is high, the accident's severity can be reduced when the obstacles that cannot be removed are shielded with guardrails.

Some of the roadside obstacles that require the use of guardrails are:

- Steep fill slopes (slopes steeper than 1V:3H)
- rocky surfaced cut slopes
- Ditches
- Puddles with a depth of more than 0.6m
- Large trees over 1m in diameter
- The shoulder edge falls more than 0.6m deep and steeper than 1V:1H
- Bridge piers, bridge abutments, and bridge approach embankments
- Retaining walls
- Rigidly fixed signposts
- The culverts and bridge openings on the side road
- Headwalls and end portions of pipes and box culverts

The purpose of guardrails is to reduce the severity of the accident rather than to prevent the accident, and one of the following options is decided to ensure roadside safety:

- Arranging the roadside topography so that guardrails are not needed.
- Installing guardrail
- Not installing guardrail

The third option is preferred on roads with low traffic volume, the first option is more economical than guardrail construction, and the second option is preferred in mandatory situations.

Requirement of Guardrail Installation

The need for guardrails on fill sections is decided according to Figure C.5 and Figure C.6. Figure C.5 shows the need for the barrier based on the height and slope of the embankments, while Figure C.6 is based on fill height, slope, and traffic volume.

Roadside guardrails should be placed as far from the lane edge as possible. In this case, it will be possible for the vehicle to be taken under control by the driver before it hits the guardrail. In addition, the greater the lateral clearance distance, the greater the visibility, especially at intersections. If possible, the lateral distance of the roadside guardrail should not be less than the values in Table C.3

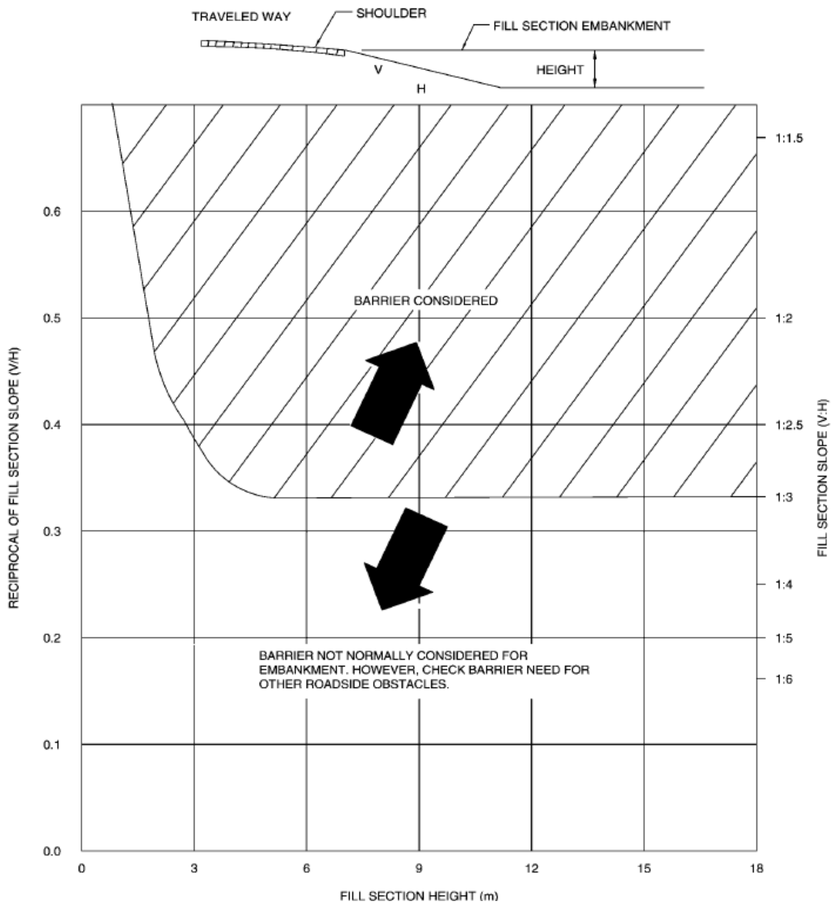

Figure C.5 Comparative barrier consideration for embankments (AASHTO, 2011)

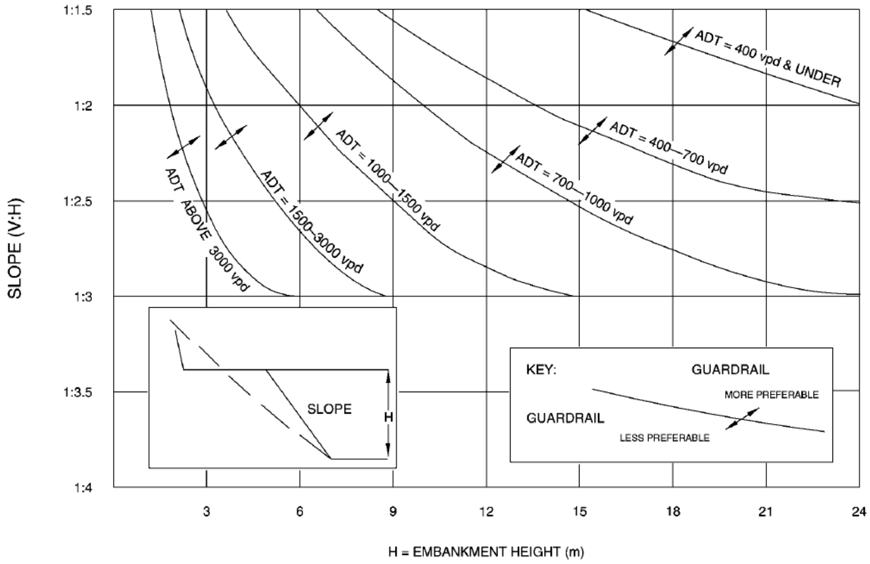

Figure C.6 Design chart for embankment barrier consideration based on fill height, slope, and traffic volume (AASHTO, 2011)

Table C.3 Roadside guardrail lateral distance (AASHTO, 2001)

Design Speed (km/h)	**Distance to Inner Edges of Shoulder (m)**
130	3,7
120	3,2
110	2,8
100	2,4
90	2,2
80	2,0
70	1,7
60	1,4
50	1,1

The placement of roadside guardrails should be as seen in Figure C.7. For this, the guardrail deflection at the time of collision of the vehicle with the guardrail is considered. Although deflection (stretching after impact) varies depending on the guardrail's rigidity, type, impact angle, and impact force, the guardrail position is determined based on the maximum dynamic deflection values recommended by the manufacturer.

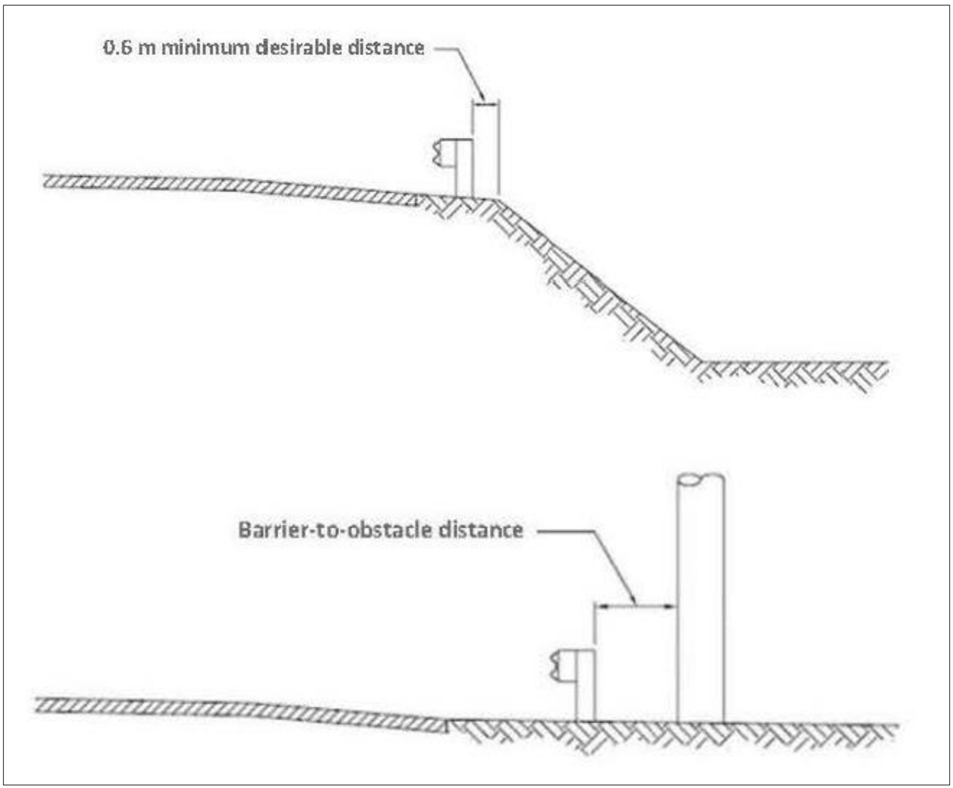

Figure C.7 Recommended barrier placement for optimum performance (AASHTO, 2011)

Guardrail Selection

The number of variables to be selected when using a guardrail is made. Due to the lack of an objective selection process, general guidelines may be followed. A sound system provides the required performance at the lowest cost. Some factors that should be considered before selecting are summarized in Table C.4. It should be considered in selecting the guardrail to protect the roadside, bridge, or object. Performance capability is the most important of all criteria.

Table C.4 Selection Criteria for Roadside Barriers (AASHTO, 2011)

Criteria	Comments
1. Performance Capability	Barrier should be structurally able to contain and redirect the design vehicle for the appropriate test level.
2. Deflection	Expected deflection of barrier should not exceed available deflection distance. ZOI should be considered.
3. Site conditions	Slope approaching the barrier and distance from traveled way may preclude use of some barrier types.
4. Compatibility	Barrier should be compatible with planned terminal or anchorage and capable of transitioning to other barrier systems (such as bridge railing).
5. Cost	Standard barrier systems are relatively consistent in cost, but high-performance railings can cost significantly more.
6. Maintenance	
A. Routine	Few systems require a significant amount of routine maintenance.
B. Collision	Generally, flexible or semi-rigid systems require significantly more maintenance after a collision than rigid or high performance railings.
C. Material storage	The fewer the number of systems used, the fewer inventory itemslstorage space required.
D. Simplicity	Simpler designs, besides costing less, are easier to maintain and more likely to be reconstructed properly by field personnel.
7. Aesthetics	Occasionally, barrier aesthetics are an important consideration in the selection of barrier design.
8. Field Experience	The performance and maintenance requirements of existing systems should be monitored to identify problems that could be lessened or eliminated by using a different barrier type.

Guardrail Layout

Guardrails to be constructed for roadside obstacles should be positioned in the approach direction, as indicated in Figure C.8. In this situation,

- Runout Length (L_R), and
- The lateral distance from the edge of the traveled way to the back of the hazard (L_A)

detection is important. Guardrail extension distance (L_R) is the theoretical distance required to stop the run-off vehicle, and its values are taken from Table C.5, considering its extension in the direction of approaching the hazard.

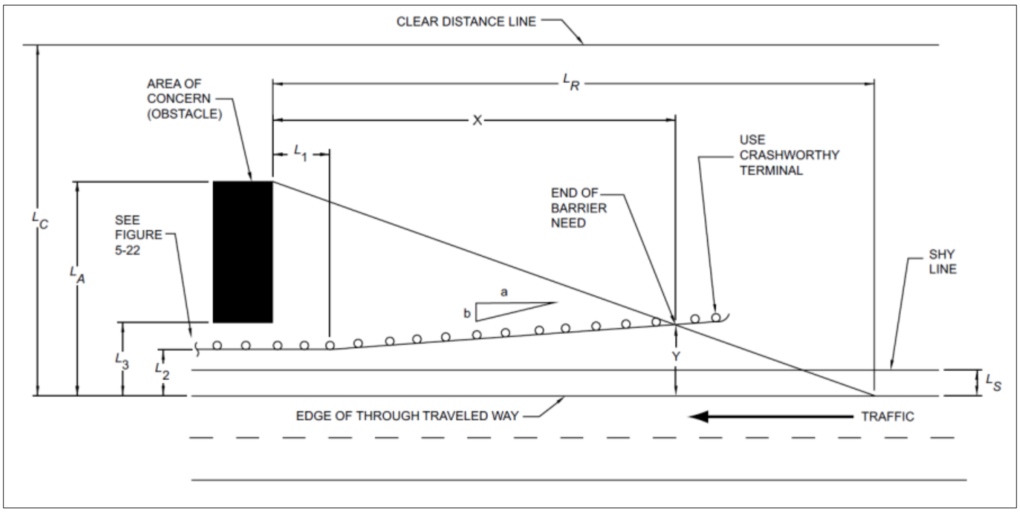

Figure C.8 Guardrail Approach Layout (AASHTO, 2011)

Table C.5 Suggested runout distance for barrier design (AASHTO, 2011)

Design Speed (km/h)	**AADT (veh/day)**			
	> 6000	**2000 – 6000**	**800 – 2000**	**< 800**
110	145	135	120	110
100	130	120	105	100
90	110	105	95	85
80	100	90	80	75
70	80	75	65	60
60	70	60	55	50
50	50	50	45	40

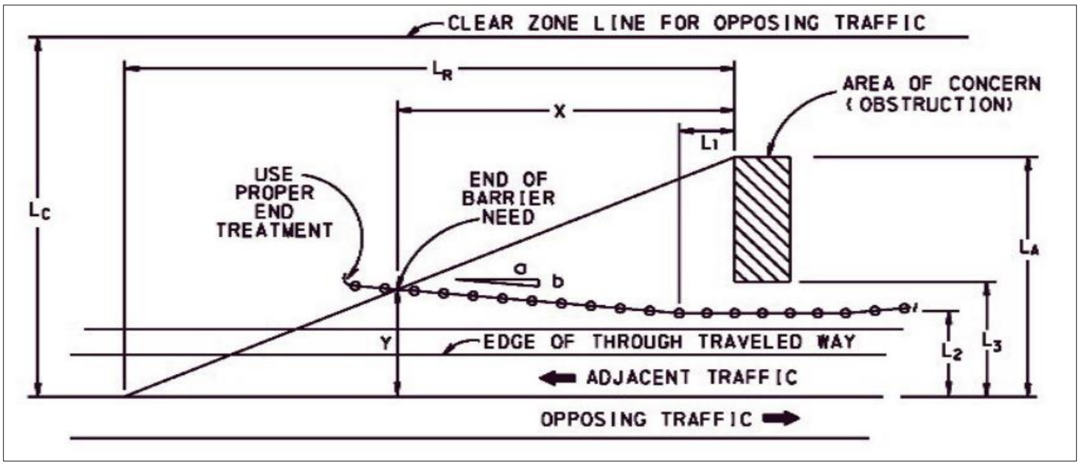

Figure C.9 Approach barrier layout for opposing traffic (AASHTO, 2011)

Guardrails to be made for roadside obstacles are positioned in the direction of departure (or end), as indicated in Figure C.9. After determining the L_R and L_A lengths during the placement of the guardrails, L_1 (parallel to the road or tangential length), L_2 (lateral distance between the road platform and the guardrail, $L_2 \geq L_S$), and the transition ratio (a:b) are taken from Table C.6.

Table C.6 Transition Ratios for Guardrails(AASHTO, 2011)

Design Speed (km/h)	**Transition Rate for guardrail within Ls Limit**	**For guardrail outside Ls Limit**	
		Rigid guardrail	**Semi-Rigid guardrail**
110	30: 1	20: 1	15: 1
100	26: 1	18: 1	14: 1
90	24: 1	16: 1	12: 1
80	21: 1	14: 1	11: 1
70	18: 1	12: 1	10: 1
60	16: 1	10: 1	8: 1
50	13: 1	8: 1	7: 1

The transition ratio required for guardrail placement is required to determine the transition length at the beginning and end of the guardrail and adapt the driver to the guardrail or reduce its length.

The designer determines the required L1 length for guardrail layout design if it is not less than 1 m. In addition, X and Y distances are calculated with the following formulas.

$$X = \frac{L_A + (b:a)(L_1) - L_2}{(b:a) + (L_A/L_R)} \qquad \text{Eq C.1}$$

$$X = \frac{L_A - L_2}{L_A/L_R} \qquad \text{Eq C.2}$$

$$Y = L_A - (L_A/L_R)X \qquad \text{Eq C.3}$$

Equation C.1 is used for straight or nearly straight alignments; Equation C.2 is used when the guardrail is parallel to the road (no transition). The lateral offset (Y) from the edge of the moving road to the beginning of the required length can be calculated using Equation C.3. Since guardrail beams are manufactured in a certain length, it should be tried to determine the appropriate guardrail length for the number of beams. Guardrail length includes the summation from start to finish and object length (including L_1).

The endpoint of the guardrail should be rounded or inclined towards the ground and embedded in the ground to avoid significant damage to the vehicles running off-road when hitting the guardrail. The guardrail beyond length (after the obstacle) is calculated as the advanced length (before the obstacle). However, the lateral distance from the edge of the opposite direction lane (or road axis) should be considered. Also, as can be seen in Figure C.9:

- If the guardrail is outside the clear zone width (L_C), the endpoint and endpoints are unnecessary.
- If the guardrail is within the width of the clean zone, but outside the obstacle area, the endpoint is needed, although there is no need for additional guardrails.
- If the obstacle area is outside the width of the clean zone (for example, if there is a river at the bridge approach), a particular section of the road can be protected by a guardrail as $L_C = L_A$.

If the distance between the guardrails is less than the values below, no gaps should be left between the guardrails, and they should be connected.

Speed (km/h)	: 50	70	90	110
Distance (m)	: 20	50	90	100

Median Guardrails on Divided Roads

Guardrails used in the median are mostly longitudinal systems placed on the left side of the road to separate the arrival and departure traffic on divided roads. It is also used on high-volume roads to separate transit traffic from local or other road users. The median guardrail requirement on divided roads should be determined in Figure C.10 as a combination of the average daily traffic within the designated area and the median width.

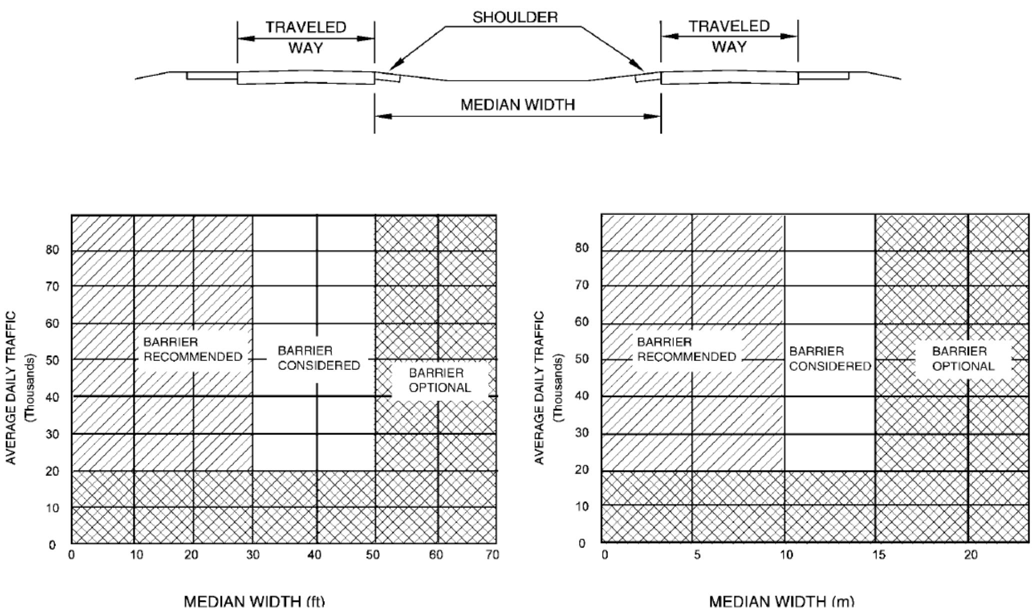

Figure C.10 Guidelines for median barriers on high-speed, fully controlled-access roadways (AASHTO, 2011)

Use of Guardrails on Bridges

Guardrails used on bridges are longitudinal systems designed to prevent vehicles on the bridge or culvert from falling over the edge. They are usually made with steel or concrete piles and railings, as a concrete type or a combination of steel and concrete. Most guardrails used on bridges are an integral part of the structure – physically connected – unlike roadside guardrails. Generally, it should be designed of the reinforced type so as not to allow large deformations when struck by drivers (see Figure C.11). If there is pedestrian traffic on the bridge, a guardrail system should be considered to protect them from vehicular traffic. This design depends on the traffic volume, speed, the number of pedestrians using the bridge, and the physical conditions at both ends of the bridge.

Factors to consider in the selection of a bridge guardrail should be:

- Performance of guardrail: It must have sufficient strength to prevent the impact of vehicles.
- Compatibility: An appropriate transition section is required if the bridge approach side guardrails differ significantly in strength, height, and deformation properties.
- Cost: It should be examined in three groups, the cost of construction, long-term maintenance costs, and expenses from hitting guardrails.
- Field experience: It is essential to see if the commonly used bridge guardrails work as designed.
- Aesthetics: Unless an aesthetic bridge guardrail on the park, forest, and touristic roads comes to the fore, the system's safety should not be compromised.

On bridges where pedestrian crossing is low in rural areas, a kerbside pavement should be designed for pedestrians if there is no guardrail between the pavement and the traffic lane. Especially on bridges on low-speed roads, kerbless sidewalks can provide little protection for pedestrians without guardrail systems. The guardrail system between traffic lanes and walking sections on bridges on extra-urban roads will provide pedestrians with the desired level of protection. There is also a need for a railing system outside the pedestrian walkway. At the same time, end improvements of bridge guardrails are essential for vehicle and pedestrian safety.

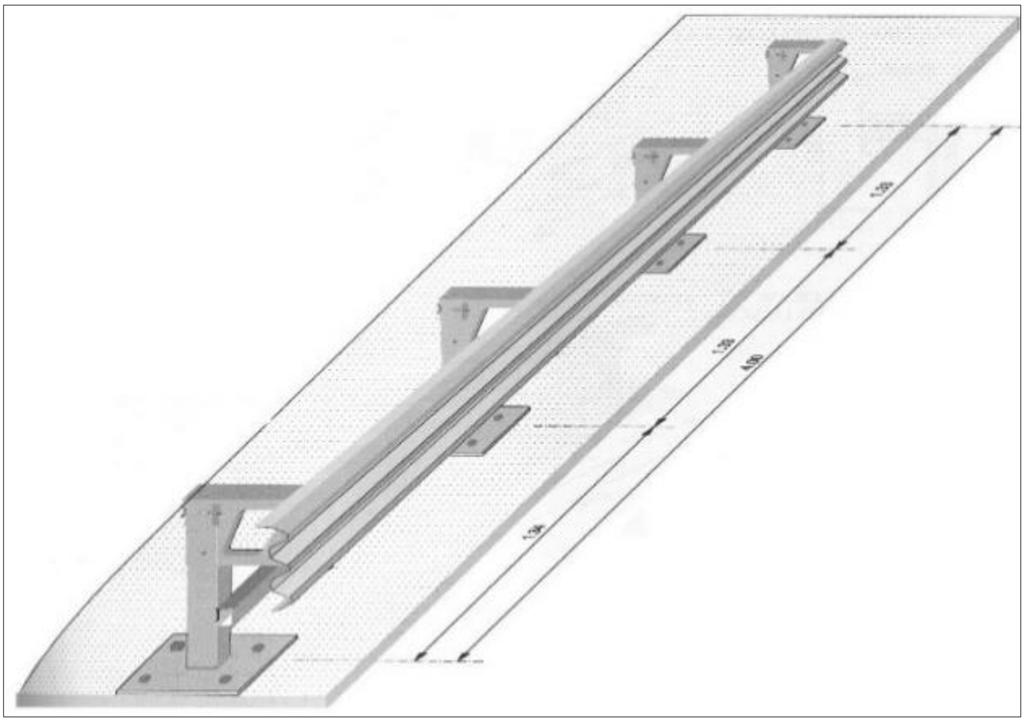

Figure C.11 Example of reinforced guardrail that can be used on bridges (GDH, 2005)

D. Excerpts from the RPS 2009

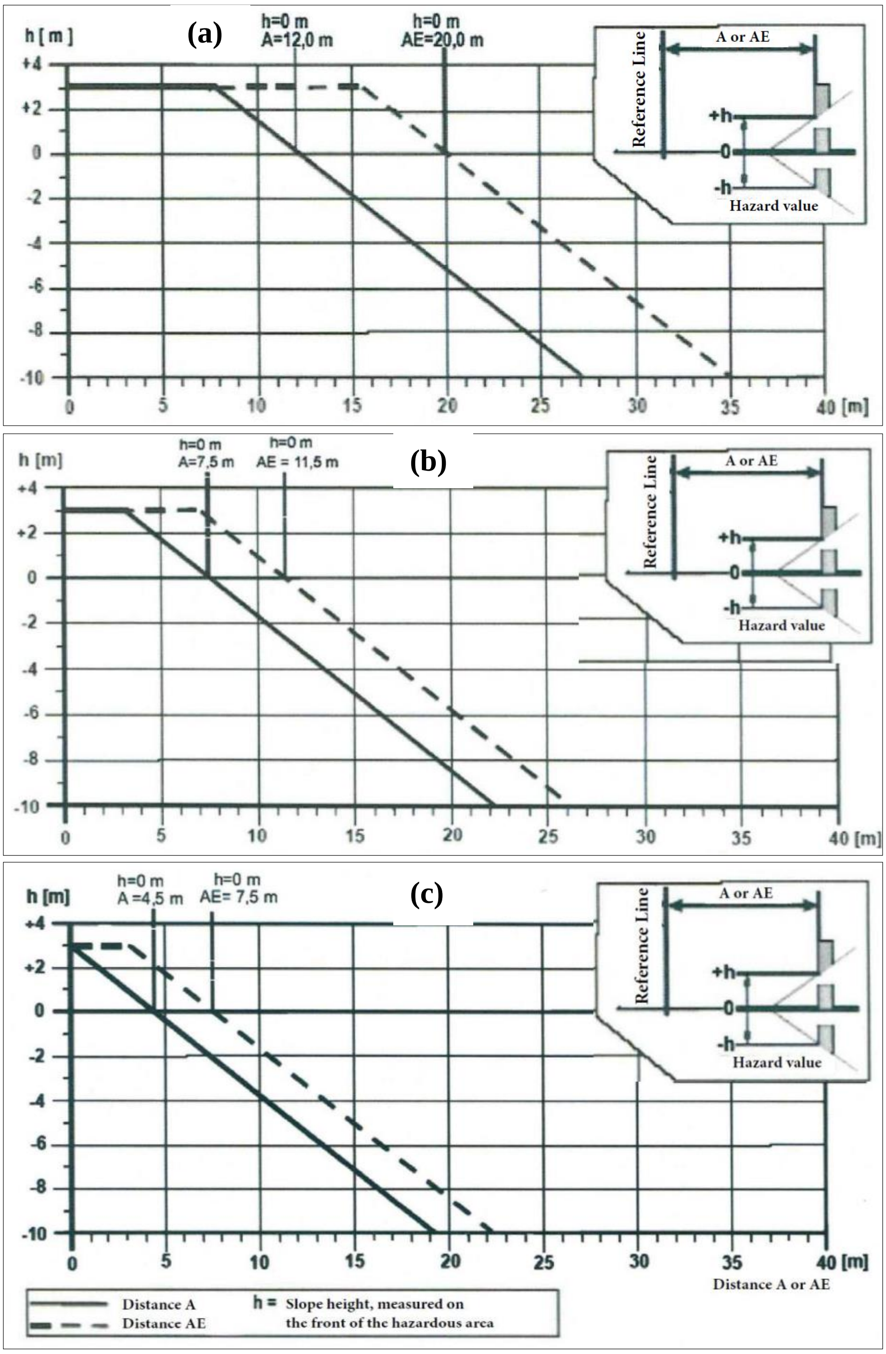

Figure D.1 Critical distances for roads (a) $V_{allow} \geq 100$ km/h, (b) 80 km/h $\leq V_{allow} < 100$ km/h, (c) 60 km/h $\leq V_{allow} < 70$ km/h (FGSV, 2009)

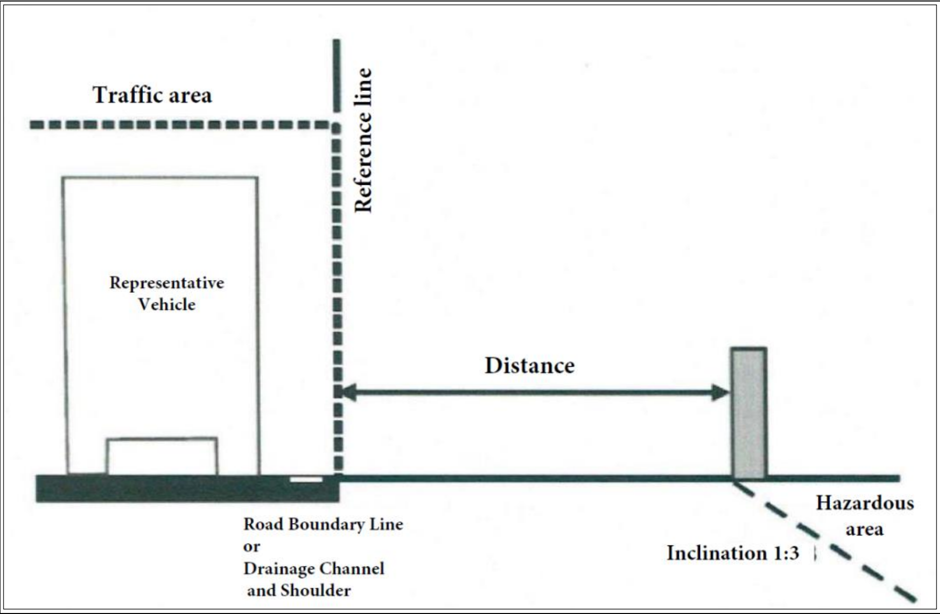

Figure D.2 Detection of the decisive distance (FGSV, 2009)

E. Hazard Overviews of Proposed Approach in CSs

Hazard Category	Data Req'd	No. of Hazards entered	Hazard Category	Data Req'd	No. of Hazards entered
300 Fencing	No		1600 Piles and Retaining Walls	No	
400 Parapets	Yes	2	1700 1800 Structural Concrete and Steel	No	
500 Drainage Features	Yes	17	2500 Special Structures	No	
600 Earthworks	Yes	308	Telegraph Poles/Pylons	No	
1100 Kerbs and Edge of Pavement Details	Yes	2	Trees	No	
1200 Traffic Signs or Signals	No		Water	Yes	1
1300 Road Lighting Columns	No		Hardshoulder / hardstrip width & Verge width details	Yes	4
1500 Motorway Communications (above ground)	No				

Hazards where Others could be affected	Data Req'd	No of Hazards entered
Railway	No	
Road	Yes	1
Public building, sports or playground, or other place where significant numbers of people congregate	No	
Chemical or Fuel Installation	No	

Figure E.1 Hazard overview of Kilis direction in Corridor Segment (CS) 1

Hazard Category	Data Req'd	No. of Hazards entered	Hazard Category	Data Req'd	No. of Hazards entered
300 Fencing	No		1600 Piles and Retaining Walls	No	
400 Parapets	Yes	2	1700 1800 Structural Concrete and Steel	No	
500 Drainage Features	Yes	18	2500 Special Structures	No	
600 Earthworks	Yes	162	Telegraph Poles/Pylons	No	
1100 Kerbs and Edge of Pavement Details	Yes	2	Trees	Yes	3
1200 Traffic Signs or Signals	No		Water	Yes	1
1300 Road Lighting Columns	No		Hardshoulder / hardstrip width & Verge width details	Yes	2
1500 Motorway Communications (above ground)	No				

Hazards where Others could be affected	Data Req'd	No of Hazards entered
Railway	No	
Road	Yes	1
Public building, sports or playground, or other place where significant numbers of people congregate	No	
Chemical or Fuel Installation	No	

Figure E.2 Hazard overview of Hassa direction in Corridor Segment (CS) 1

Hazard Category	Data Req'd	No. of Hazards entered	Hazard Category	Data Req'd	No. of Hazards entered
300 Fencing	No		1600 Piles and Retaining Walls	No	
400 Parapets	No		1700 1800 Structural Concrete and Steel	No	
500 Drainage Features	Yes	4	2500 Special Structures	No	
600 Earthworks	Yes	115	Telegraph Poles/Pylons	No	
1100 Kerbs and Edge of Pavement Details	Yes	2	Trees	Yes	1
1200 Traffic Signs or Signals	No		Water	No	
1300 Road Lighting Columns	No		Hardshoulder / hardstrip width & Verge width details	Yes	3
1500 Motorway Communications (above ground)	No				

Hazards where Others could be affected	Data Req'd	No of Hazards entered
Railway	No	
Road	No	
Public building, sports or playground, or other place where significant numbers of people congregate	No	
Chemical or Fuel Installation	No	

Figure E.3 Hazard overview of Kilis direction in Corridor Segment (CS) 2

Hazard Category	Data Req'd	No. of Hazards entered	Hazard Category	Data Req'd	No. of Hazards entered
300 Fencing	No		1600 Piles and Retaining Walls	No	
400 Parapets	No		1700 1800 Structural Concrete and Steel	No	
500 Drainage Features	Yes	2	2500 Special Structures	No	
600 Earthworks	Yes	46	Telegraph Poles/Pylons	No	
1100 Kerbs and Edge of Pavement Details	Yes	2	Trees	No	
1200 Traffic Signs or Signals	No		Water	No	
1300 Road Lighting Columns	No		Hardshoulder / hardstrip width & Verge width details	Yes	4
1500 Motorway Communications (above ground)	No				

Hazards where Others could be affected	Data Req'd	No of Hazards entered
Railway	No	
Road	No	
Public building, sports or playground, or other place where significant numbers of people congregate	No	
Chemical or Fuel Installation	No	

Figure E.4 Hazard overview of Hassa direction in Corridor Segment (CS) 2

Hazard Category	Data Req'd	No. of Hazards entered	Hazard Category	Data Req'd	No. of Hazards entered
300 Fencing	No		1600 Piles and Retaining Walls	No	
400 Parapets	No		1700 1800 Structural Concrete and Steel	Yes	1
500 Drainage Features	Yes	13	2500 Special Structures	No	
600 Earthworks	Yes	315	Telegraph Poles/Pylons	No	
1100 Kerbs and Edge of Pavement Details	Yes	2	Trees	No	
1200 Traffic Signs or Signals	No		Water	No	
1300 Road Lighting Columns	No		Hardshoulder / hardstrip width & Verge width details	Yes	4
1500 Motorway Communications (above ground)	No				

Hazards where Others could be affected	Data Req'd	No of Hazards entered
Railway	No	
Road	No	
Public building, sports or playground, or other place where significant numbers of people congregate	No	
Chemical or Fuel Installation	No	

Figure E.5 Hazard overview of Kilis direction in Corridor Segment (CS) 3

Hazard Category	Data Req'd	No. of Hazards entered	Hazard Category	Data Req'd	No. of Hazards entered
300 Fencing	No		1600 Piles and Retaining Walls	No	
400 Parapets	No		1700 1800 Structural Concrete and Steel	Yes	1
500 Drainage Features	Yes	14	2500 Special Structures	No	
600 Earthworks	Yes	106	Telegraph Poles/Pylons	No	
1100 Kerbs and Edge of Pavement Details	Yes	2	Trees	Yes	1
1200 Traffic Signs or Signals	No		Water	No	
1300 Road Lighting Columns	No		Hardshoulder / hardstrip width & Verge width details	Yes	6
1500 Motorway Communications (above ground)	No				

Hazards where Others could be affected	Data Req'd	No of Hazards entered
Railway	No	
Road	No	
Public building, sports or playground, or other place where significant numbers of people congregate	No	
Chemical or Fuel Installation	No	

Figure E.6 Hazard overview of Hassa direction in Corridor Segment (CS) 3

?	Hazard Category	Data Req'd	No. of Hazards entered	?	Hazard Category	Data Req'd	No. of Hazards entered
?	300 Fencing	No		?	1600 Piles and Retaining Walls	Yes	2
?	400 Parapets	No		?	1700 1800 Structural Concrete and Steel	Yes	1
?	500 Drainage Features	Yes	4	?	2500 Special Structures	No	
?	600 Earthworks	Yes	148	?	Telegraph Poles/Pylons	No	
?	1100 Kerbs and Edge of Pavement Details	Yes	2	?	Trees	No	
?	1200 Traffic Signs or Signals	No		?	Water	No	
?	1300 Road Lighting Columns	No		?	Hardshoulder / hardstrip width & Verge width details	Yes	3
?	1500 Motorway Communications (above ground)	No					

?	Hazards where Others could be affected	Data Req'd	No of Hazards entered
	Railway	No	
	Road	No	
?	Public building, sports or playground, or other place where significant numbers of people congregate	No	
	Chemical or Fuel Installation	No	

Figure E.7 Hazard overview of Kilis direction in Corridor Segment (CS) 4

?	Hazard Category	Data Req'd	No. of Hazards entered	?	Hazard Category	Data Req'd	No. of Hazards entered
?	300 Fencing	No		?	1600 Piles and Retaining Walls	No	
?	400 Parapets	No		?	1700 1800 Structural Concrete and Steel	Yes	1
?	500 Drainage Features	Yes	6	?	2500 Special Structures	No	
?	600 Earthworks	Yes	41	?	Telegraph Poles/Pylons	No	
?	1100 Kerbs and Edge of Pavement Details	Yes	2	?	Trees	No	
?	1200 Traffic Signs or Signals	No		?	Water	No	
?	1300 Road Lighting Columns	No		?	Hardshoulder / hardstrip width & Verge width details	Yes	4
?	1500 Motorway Communications (above ground)	No					

?	Hazards where Others could be affected	Data Req'd	No of Hazards entered
	Railway	No	
	Road	No	
?	Public building, sports or playground, or other place where significant numbers of people congregate	No	
	Chemical or Fuel Installation	No	

Figure E.8 Hazard overview of Hassa direction in Corridor Segment (CS) 4

Hazard Category	Data Req'd	No. of Hazards entered	Hazard Category	Data Req'd	No. of Hazards entered
300 Fencing	No		1600 Piles and Retaining Walls	No	
400 Parapets	No		1700 1800 Structural Concrete and Steel	No	
500 Drainage Features	Yes	1	2500 Special Structures	No	
600 Earthworks	Yes	94	Telegraph Poles/Pylons	No	
1100 Kerbs and Edge of Pavement Details	Yes	2	Trees	Yes	1
1200 Traffic Signs or Signals	No		Water	No	
1300 Road Lighting Columns	No		Hardshoulder / hardstrip width & Verge width details	Yes	2
1500 Motorway Communications (above ground)	No				

Hazards where Others could be affected	Data Req'd	No of Hazards entered
Railway	No	
Road	No	
Public building, sports or playground, or other place where significant numbers of people congregate	No	
Chemical or Fuel Installation	No	

Figure E.9 Hazard overview of Kilis direction in Corridor Segment (CS) 5

Hazard Category	Data Req'd	No. of Hazards entered	Hazard Category	Data Req'd	No. of Hazards entered
300 Fencing	No		1600 Piles and Retaining Walls	No	
400 Parapets	No		1700 1800 Structural Concrete and Steel	No	
500 Drainage Features	Yes	2	2500 Special Structures	No	
600 Earthworks	Yes	16	Telegraph Poles/Pylons	No	
1100 Kerbs and Edge of Pavement Details	Yes	2	Trees	Yes	1
1200 Traffic Signs or Signals	No		Water	No	
1300 Road Lighting Columns	No		Hardshoulder / hardstrip width & Verge width details	Yes	4
1500 Motorway Communications (above ground)	No				

Hazards where Others could be affected	Data Req'd	No of Hazards entered
Railway	No	
Road	No	
Public building, sports or playground, or other place where significant numbers of people congregate	No	
Chemical or Fuel Installation	No	

Figure E.10 Hazard overview of Hassa direction in Corridor Segment (CS) 5

Hazard Category	Data Req'd	No. of Hazards entered
300 Fencing	No	
400 Parapets	No	
500 Drainage Features	Yes	6
600 Earthworks	Yes	144
1100 Kerbs and Edge of Pavement Details	Yes	2
1200 Traffic Signs or Signals	No	
1300 Road Lighting Columns	No	
1500 Motorway Communications (above ground)	No	

Hazard Category	Data Req'd	No. of Hazards entered
1600 Piles and Retaining Walls	No	
1700 1800 Structural Concrete and Steel	No	
2500 Special Structures	No	
Telegraph Poles/Pylons	No	
Trees	Yes	2
Water	No	
Hardshoulder / hardstrip width & Verge width details	Yes	2

Hazards where Others could be affected	Data Req'd	No of Hazards entered
Railway	No	
Road	No	
Public building, sports or playground, or other place where significant numbers of people congregate	No	
Chemical or Fuel Installation	No	

Figure E.11 Hazard overview of Kilis direction in Corridor Segment (CS) 6

Hazard Category	Data Req'd	No. of Hazards entered
300 Fencing	No	
400 Parapets	No	
500 Drainage Features	Yes	6
600 Earthworks	Yes	56
1100 Kerbs and Edge of Pavement Details	Yes	4
1200 Traffic Signs or Signals	No	
1300 Road Lighting Columns	No	
1500 Motorway Communications (above ground)	No	

Hazard Category	Data Req'd	No. of Hazards entered
1600 Piles and Retaining Walls	No	
1700 1800 Structural Concrete and Steel	No	
2500 Special Structures	No	
Telegraph Poles/Pylons	No	
Trees	Yes	2
Water	No	
Hardshoulder / hardstrip width & Verge width details	Yes	2

Hazards where Others could be affected	Data Req'd	No of Hazards entered
Railway	No	
Road	No	
Public building, sports or playground, or other place where significant numbers of people congregate	No	
Chemical or Fuel Installation	Yes	1

Figure E.12 Hazard overview of Hassa direction in Corridor Segment (CS) 6

?	Hazard Category	Data Req'd	No. of Hazards entered	?	Hazard Category	Data Req'd	No. of Hazards entered
?	300 Fencing	No		?	1600 Piles and Retaining Walls	No	
?	400 Parapets	No		?	1700 1800 Structural Concrete and Steel	No	
?	500 Drainage Features	Yes	6	?	2500 Special Structures	Yes	1
?	600 Earthworks	Yes	152	?	Telegraph Poles/Pylons	No	
?	1100 Kerbs and Edge of Pavement Details	Yes	2	?	Trees	Yes	3
?	1200 Traffic Signs or Signals	No		?	Water	No	
?	1300 Road Lighting Columns	No		?	Hardshoulder / hardstrip width & Verge width details	Yes	2
?	1500 Motorway Communications (above ground)	No					

?	Hazards where Others could be affected	Data Req'd	No of Hazards entered
	Railway	No	
	Road	No	
?	Public building, sports or playground, or other place where significant numbers of people congregate	No	
	Chemical or Fuel Installation	No	

Figure E.13 Hazard overview of Kilis direction in Corridor Segment (CS) 7

?	Hazard Category	Data Req'd	No. of Hazards entered	?	Hazard Category	Data Req'd	No. of Hazards entered
?	300 Fencing	No		?	1600 Piles and Retaining Walls	No	
?	400 Parapets	No		?	1700 1800 Structural Concrete and Steel	No	
?	500 Drainage Features	Yes	8	?	2500 Special Structures	No	
?	600 Earthworks	Yes	55	?	Telegraph Poles/Pylons	No	
?	1100 Kerbs and Edge of Pavement Details	Yes	2	?	Trees	Yes	3
?	1200 Traffic Signs or Signals	No		?	Water	No	
?	1300 Road Lighting Columns	No		?	Hardshoulder / hardstrip width & Verge width details	Yes	2
?	1500 Motorway Communications (above ground)	No					

?	Hazards where Others could be affected	Data Req'd	No of Hazards entered
	Railway	No	
	Road	No	
?	Public building, sports or playground, or other place where significant numbers of people congregate	No	
	Chemical or Fuel Installation	No	

Figure E.14 Hazard overview of Hassa direction in Corridor Segment (CS) 7