



Performance Evaluation of Vehicle Restraint Systems in the Context of Design and Installation

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Abstract

Vehicle Restraint Systems (VRS), a necessary component of the road design, are widely implemented by transport authorities to protect vehicles from severe incidents, mainly colliding to the roadside as well as median obstacles and other potential hazards. The performance evaluation of vehicle restraint systems at the design and installation stages is largely made according to either European or American standards. The local traffic conditions and vehicle compositions in countries, which are noticeably different from Europe and North America, necessitate a customized guideline in which the design and installation of road safety barriers are more adapted to the local conditions of the country. This paper briefly reviews the main features of EN1317, and NCHRP 350/MASH standards, which are predominantly used for the design, installation, and performance evaluation of VRS in Europe and the United States respectively. Moreover, the contribution of these standards in developing the VRS guideline for the State of Qatar is explained. The study recommends customizations to the design and installation of VRS, which are presently implemented according to the guideline developed by the Public Work Authority in Qatar. The present guideline follows European as well as American standards. The recommendations are made based on empirical studies and evidence observed by undertaking a series of site visits, audits, and perform inspections of VRS components installed on Qatari roads and highways. The study findings demonstrate the performance of VRS can be enhanced by incorporating the design and selection of road safety components such as guardrails, terminals, transitions, and crash cushions at the preliminary design stage of roads and highways. This study brings about practical insights and implications for road designers, contractors, supervision teams, and road safety auditors.

Keywords: Road Safety Barriers; Vehicle Restraint Systems; EN 1317; MASH; NCHRP 350; The State of Qatar.

1. Introduction

Traffic crashes are a major concern for transport authorities worldwide. The consequences resulting from traffic crashes are within the range of property damage to loss of human life. Among many studies and analyses, it is worth mentioning the study conducted by Li and Fred [1] analyzed the injury severity and vehicle occupancy in the truck and non-truck-involved accidents. The injury severity was measured based on the most impacted vehicle occupant. Despite a tremendous increase in the number of vehicles in the past decades, particularly in developed countries, recent advancements in road safety implications have resulted in a significant reduction in injuries and fatalities amongst motorists and other road users, predominantly in suburban areas. A report from Commission for Global Road Safety

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indicates that in many high-income countries the rising trend in fatalities was reversed over the 1980s and 1990s, despite the increase in vehicle volume and distance traveled [2]. Safety enhancement has not been achieved only because of implementing restrictive traffic regulations, enforcement, and Intelligent Transport Systems (ITS). Innovations and creativity in the geometric design of roads and particularly highways have also contributed to road safety enhancement. This attainment is due to tangible changes and a revised attitude of road safety authorities dealing with the road user, the vehicle, and the road infrastructure rather than merely focusing on driving behavior.

For instance, implementing inside turning left interchange (ITL Interchange) on speedy highways showed improvement in interchange performance, construction cost, and safety, given shorter length of ramps and overpasses [3]. Haddon developed a matrix to identify risk factors pre-crash, within the crash and post-crash, concerning the person, vehicle, and environment [4]. He highlighted crash-protective roadside objects as an environmental factor to influence crash severity. The main purpose of installing Vehicle Restraint Systems so-called VRS is to (1) significantly reduce the severity of the collision and (2) avoid swift stopping of the vehicle and bouncing back to the roadway [5]. This is achievable by deformation of the restraint systems, aiming to absorb the kinetic energy of the vehicle by an acceptable value of deceleration of the body. In the same context, Zou et al. (2014) investigated the safety performance of median and roadside barriers in Indiana, United States in terms of their efficiency on diminishing risk of injury because of incidents to barriers [6]. They found the installation of almost any type of VRS, irrespective of the offset, could reduce the probability of injury. Their model demonstrated that compared to colliding with an unprotected a high-risk roadside object, striking a guardrail face could reduce the risk of injury by 65%.

In 2012 the European SAVeRS project [7], funded within the 2012 CEDR Transnational Research Programme “Safety”, has developed a practical VRS guideline alongside a user-friendly software tool that enabled consultants, planners, researchers, and road transport authorities to select the most applicable solution for road safety barrier in different road and traffic conditions and also do site-specific risk assessments. The SAVeRS guideline aimed at:

- Detecting the need for implementing VRS and determining the necessary minimum length distance to potential road hazards;
- Selecting the most fitting VRS performance class for safety barriers as well as transitions, terminals, and crash cushions; and
- Ascertaining the need for motorcycle protection systems.

SAVeRS adopt the “forgiving roadside” approach, which is an integral part of all the standards studied within the SAVeRS scheme [7]. The priority in SAVeRS is mainly to make the roadside as “forgiving” as realistically feasible. In this regard, the guideline recommends the following steps:

1. Eliminate the hazard: if possible;
2. Redesign the hazard to be safely traversable and flexible enough to be twisted by a wayward vehicle;
3. Reposition the hazard distant from the right of way where it is less probable to be hit by a wayward vehicle;
4. Convert the hazard inertly harmless: per EN12767 (CEN 2007 [8]), to scale down the severity of a potential impact;
5. Install VRS in case the above-mentioned options are not practically feasible or significantly costly; and
6. Demarcate the hazard, if the above-mentioned options are not plausible.

Road transport authorities in Europe have recommended the implementation of standard VRS in case installation required per European Standard EN 1317. For instance, Transport Infrastructure Ireland recently published a guideline for the design and installation of road restraint systems for the vehicle as well as pedestrians on Irish roads and bridges [9]. In this guideline, the requirements for positioning and specifying vehicle and pedestrian restraint systems in common situations such as permanent safety barriers, temporary safety barriers, terminals, transitions, crash cushions, vehicle parapets, pedestrian parapets, and guardrails are outlined.

Similarly, the United States National Cooperative Highway Research Program (NCHRP) comprises recommended measures for appraising the safety performance of several highway safety features including road safety barriers. Although both aforementioned standards have covered diverse aspects and provisions in the contexts of the design and installation of vehicles restraints systems, there are still opportunities for the customization of those standards, if they are supposed to be used in other countries having dissimilar driving behavior, vehicular compositions, speed limit, etc.

For instance, the hazards identification on the road network, and crash prediction models in conjunction with implementing safety standards and VRS impacts evaluation are investigated in a Polish study [10]. Parameters such as the traffic volume, percentage of barriers and embankments, percentage of trees above a certain height, and road class were taken into consideration. The aforementioned study recommends evaluating the impact of road restraint systems on crash severity prevention by developing models that combine the risk of incidents with road hazards. Moreover, the

study findings demonstrate the need for collaboration between road designers, and transport authorities for exchanging their experience with other countries' road authorities and experts in this regard.

The existing guidelines, which are commonly used around the world and are applicable to a wide range of highway features and traffic situations, may still have room for improvement and therefore should not be interpreted as all-inclusive criteria. Furthermore, specific features and road conditions may demand customized VRS design and installation guidelines. Exploring potential improvements for the VRS design and installation in a fast-growing country in the Middle East, the State of Qatar, which is undertaking tremendous civil infrastructure projects at a fast pace has been the motivation for this study. It should be noted that the country has approved both American and European standards for the design and installation of road safety features including VRS.

In this paper, an overview of European, as well as American guidelines for selection and installation of road safety barriers are presented. The standards and provisions of EN1317, which are predominantly used in Europe for VRS design, are explained. Furthermore, criteria to be taken into consideration before the installation of road safety barriers according to the German VRS installation guideline, RPS, are also pointed out. Similarly, crash tests and test settings of roadside barriers besides in-service assessment of roadside safety features based on the American guidelines developed by NCHRP are also reviewed.

The contribution of the aforementioned guidelines in developing the VRS guideline for the State of Qatar is discussed accordingly. This paper suggests some customizations of the existing VRS guideline developed by the Public Work Authority (PWA), ASHGHAL in the State of Qatar. The recommendations for the customization of PWA guidelines are made based on investigating the applicability of American and European standards in a non-EU country such as Qatar, and empirical studies, given the outcomes of a series of site visits and historical functionality observations of various types of road safety barriers installed on Qatari highways.

In other words, the direct applicability of American and European standards for design and installation of safety barriers on Qatari roads are revisited based on empirical evidence in line with safety concerns, recorded incidents, vehicular composition, posted speed versus actual speed, and dominant driving behavior in the state. Figure 1 exhibits the procedure applied in this study for revisiting and improving the efficiency of VRS in the State of Qatar.

The methodology adopted in this study considers SAVeRS recommendations as well. In case field observations indicate the lack of VRS on a road, the SAVeRS guidelines are taken into consideration to ensure if a recommendation for the design and installation of road safety barriers is indeed required. It is worth mentioning that the case study in the State of Qatar is somehow unique since the cities and towns in the country, and particularly Doha, are expanding rapidly according to the masterplan. A remarkable number of road infrastructure projects are being constructed presently in the country are generating several case studies to evaluate road safety barriers designed and installed by various designers, project management, and supervision Consultants (PMCs). More importantly, the availability of adequate right of way in most road infrastructure projects allows for incorporating VRS into the preliminary design stage of highways and roads without any restrictions.

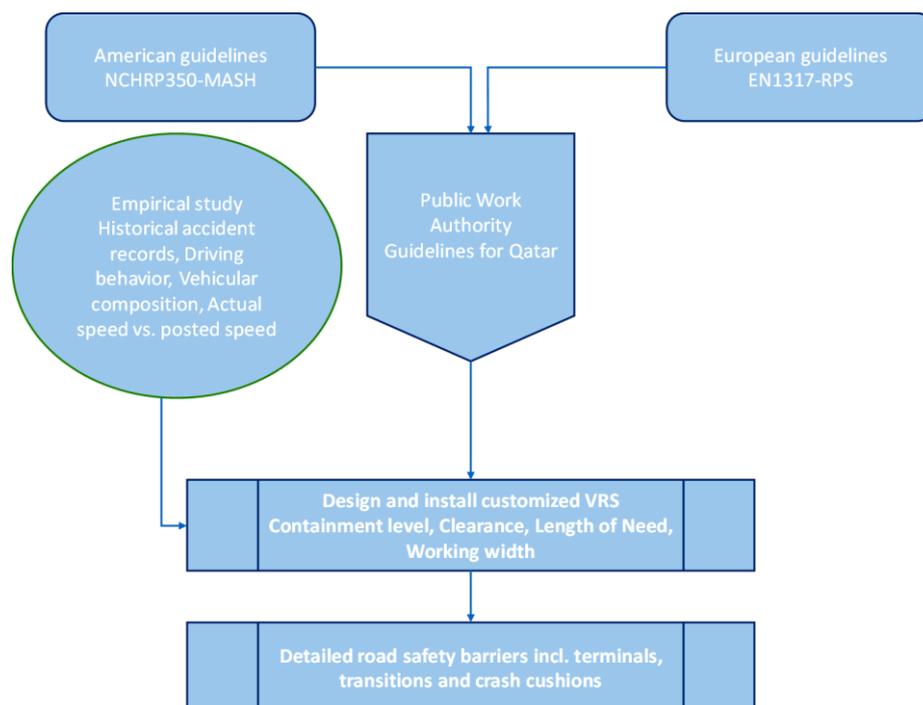


Figure 1. The study approach for improving the efficiency of VRS in the State of Qatar

2. Review of Commonly Used Guidelines for Selection and Installation of Road Safety Barriers

Design, installation, and performance evaluation of vehicle restraint systems are predominantly undertaken according to either European or American standards. For instance, EN 1317 [11, 12] is the European standard in the context of design. For the installation, RPS 2009 [13] is widely used in Europe. The aforementioned guidelines cover several types of VRS such as typical longitudinal safety barriers, terminals, transitions, mobile barriers, openings, and crash cushions.

2.1. European Union (EU) Standards and Guidelines

VRS have to fulfill the EN 1317 necessities to be implemented within Europe. This includes passing crash tests and VRS performance assessments. The outcomes of crash tests, given the performance of VRS, will lead to the classification of VRS. EN 1317 presents the provision for each type of VRS. Table 1 summarizes EN1317 standards along with their provisions.

The German installation guidelines for passive protection on roads utilizing VRS, (RPS*), are widely applied in many EU and non-EU countries, including the State of Qatar, recommend the following criteria to be taken into consideration before the installation of road safety barriers:

- Identification of hazards;
- Selection of containment level;
- Lateral placement of road equipment; and
- Installation of the necessary minimum length (length of need).

The German guideline RPS recommends the installation of VRS according to EN 1317, Containment Level H4b, and H2 [12, 13]. One reason is that most of the fatal and crashes having severe injuries impacts occur because of either lack of or the inadequacy of the protection of roadside hazards such as gantries, light poles, bridge piers, and especially trees, which is very often undermined by consulting, companies and authorities.

Table 1. EN1317 standards and provisions

Standard	Provision(s)
EN 1317-1: Terminology and general criteria for test methods	a) Evaluating the performance of products for the road restraint systems, under impact severity levels; b) Defining road restraint systems and the specifications of vehicles; c) Incorporating vehicle cockpit deformation index (VCDI) and methods of recording crash impact.
EN 1317-2 [†] : impact test acceptance criteria for roadside safety barriers	Outlining requirements on impact performance of safety barriers
EN 1317-3 [†] : impact test acceptance criteria for crash cushions	Outlining requirements on impact performance of crash cushions
EN 1317-4: impact test acceptance criteria for terminals	Determining requirements on impact performance of transitions, and terminals
EN 1317-5- VRS evaluation of conformity	Specifying transitions, terminals, vehicles parapets, crash cushions, and safety barriers
TR 1317-6: Pedestrian restraint system	Outlining geometrical details and technical specifications of pedestrian parapets on related structures such as pedestrian bridges
EN 1317-7: Performance classes for terminals of safety barriers	Determining necessities on the impact performance of terminals. This provision includes three terms of lateral displacement, and terminal direction classes
TS 1317-8: Road restraint systems for motorcycles	Determining necessities of the systems designed for the reduction of impact severity for powered two-wheelers riders

[†] In conjunction with EN 1317-1

2.2. American Standards and Guidelines

In the United States, the road safety barriers are assessed as per NCHRP and AASHTO by using the guidelines of NCHRP 230 [14] and NCHRP 350 [15]. Given the advancement in surrogate test vehicles and computer simulations, NCHRP 350 was an evolved version of NCHRP 230 after including additional measures, broader test procedures, and criteria for the evaluation of road safety barriers [16, 17].

The recent American guideline (MASH) evolved from NCHRP 350 by AASHTO in 2009 includes a series of variations, modifications, and adaptations to the vehicle structure and other types of technical criteria as of today especially in the USA [18].

* Richtlinien für passiven Schutz an Straßen durch Fahrzeug-Rückhaltesysteme

Nonetheless, there was no major difference between NCHRP 350 and MASH in evaluating the performance of hardware features, speed, angle of impact, and weight of vehicles. Both guidelines take (1) the structural adequacy, (2) vehicle trajectory, and (3) occupant risk factors into consideration in evaluating the performance of roadside barriers. The features covered by the procedures recommended by NCHRP include longitudinal barriers e.g. guardrails and transitions, median barriers, terminals, and crash cushions. The purpose of these procedures is to promote uniform testing and in-service assessment of roadside safety features.

NCHRP recommends severe vehicle impact circumstances rather than typical or average highway situations. For vehicle crash testing vehicle mass, velocity (ranging from 35 km/h to 100 km/h) and approach angle (vary from 0 to 25 degrees), and hit point on the safety feature to be crashed are defined. Mini-compact and subcompact passenger cars are considered for crash testing, alongside Single Unit (SU) trucks, and trailers. Structural adequacy, occupant risk, and after-collision vehicle trajectory are three key indicators for evaluating the crash test performance. In the last stage of developing roadside safety features, the in-service evaluation is applied. This is also the case for modified roadside safety features. The main purpose is to evaluate the actual performance of roadside features during operation and maintenance.

MASH method is applied for crash testing and evaluation of roadside safety features. The fundamental idea in the development of the MASH guidelines is the worst practical settings and situations. In other words, the worst-case scenario is applied in selecting test parameters, such as the test vehicle, the combination of velocity and angle, and hit point that would lead to the creation of critical conditions. Nonetheless, available technology and associated costs should be taken into consideration. The impact performance evaluation suggested by MASH covers longitudinal barriers along with transitions, crash cushions, terminals, and work zone channelizers.

Longitudinal barriers are tested to six levels ranging from low level to high level including heavy trucks, while other roadside features are examined using three test stages exclusively for private passenger vehicles, such as automobiles and light trucks. Low-level tests are applied on low-speed, and/or low-volume roads. While a high-test level is usually applied for freeways. By setting the primary parameters (velocity, angle, and vehicle mass), a full-scale crash test is undergone which evaluates occupant risk, vehicle trajectory, and structural adequacy post-crash.

2.3. Occupant Risk in the European Guideline vs. the American Guidelines

Occupant risk plays an important role in the safety and functionality of VRS. In this context, maintaining the structural integrity of the occupant compartment is emphasized in EN 1317 [12]. There are two requirements to ensure a vehicle restraint system does not endanger occupant life. (1) The occupant compartment has to be resistant adequately to penetration within testing, and (2) deformation must not result in disabling injuries.

The American Guideline NCHRP 350 focuses on the occupant risk factors (i.e. Occupant impact velocity limits, and Occupant ride - down acceleration limits). The guideline recommends that the aforementioned metrics maintain below the preferred values of 9 m/s and 15 G's respectively for longitudinal and lateral directions

3. Qatar Guidelines

National Road Safety Strategy (NRSS) of the State of Qatar proposed increased installation of VRS, and designing of forgiving roads to enhance safety on the country roads [19]. Consequently, the PWA, ASHGHAL, the responsible authority in the State of Qatar, has mandated the road designers/contractors to design and implement advanced road safety barriers on newly designed roads in the country [20]. PWA- ASHGHAL provides guidelines for the selection and implementation of road safety barriers in the State of Qatar [21].

In general, the abovementioned authority has approved EN1317, NCHRP350, and MASH guidelines. Nonetheless, the main criteria for approving a VRS are (a) crash testing and (b) consequent evaluation under the European standard of EN 1317. The purpose of the testing is to conclude and assess the performance of the road barrier system in collisions. The result evaluation is made based on (1) structural adequacy, (2) impact severity, (3) deflection/deformation, and (4) the post-impact vehicle response. The latter implies the avoidance of encroaching on adjacent traffic lanes.

Furthermore, the authority takes in-service performance and the availability of spare parts of VRS components into consideration for evaluating road safety barriers. In the context of in-service performance, the corresponding history plays an important role. In the lack of a demonstrable in-service history, an in-service trial may be needed. Moreover, the VRS manufacturer has to convince the authority on the availability of spare parts for maintenance and replacement in case needed.

3.1. Potentials for the improvement of the PWA- ASHGHAL guideline in the State of Qatar

It is recommended that PWA- ASHGHAL road safety barrier systems guidelines should be customized according to local conditions of roads in the country. Such customization can be made based on several aspects such as (1) requirements for roadside slope, (2) pedestrian facilities, and (3) vehicular composition.

In the context of roadside slopes and containment, the various existing national guidelines evaluate slopes as potential hazards on roads very differently [22]. Minimum slope gradient varies from 1:3 to 1:8 and minimum slope height ranging from 0.5 to 6.0 m. Such data should be taken into consideration in the PWA guideline for the State of Qatar.

In the State of Qatar, around one-third of total road fatalities are pedestrian fatalities [7]. This implies the importance and subsequent consideration of the design, selection, and installation of road safety barriers for pedestrian facilities in our road network.

From the past decade, the vehicle composition on Qatari roads is different from other developed countries, since Sport Utility Vehicles (SUVs) or four-wheel drive vehicles are highly popular in the country. Due to this specific status of traffic constellation in the State of Qatar, the vehicular composition should be taken into consideration to ensure a suitable selection of roadside, as well as median road safety barriers, is made, especially concerning the minimum height of the VRS (90 cm) and their mandatory installation according to the aforementioned installation standards. In this regard, Hernandez et al. indicate the necessity of adapting the installation parameters and setting minimum performance data in light of the actual situation of vehicles that circulate through the Spanish Roads [24].

4. Case Study - Qatari Highways

In the State of Qatar with a huge number of ongoing road infrastructure projects, both European and American Standards are currently being applied on newly built highways. Implementing VRS on the Qatari national road network with the posted speed of 80 km/h and above is mandatory according to the guidelines of the Qatari road authorities.

A team member from Qatar University together with a Volkmann & Rossbach GmbH & Co. delegate undertook two site visits in the months of December 2019 and January 2020 to the road network in the northern and southern/western parts of the State of Qatar, respectively. Figure 2, illustrates the roads that were audited. 405 km on eleven highways were surveyed in total.

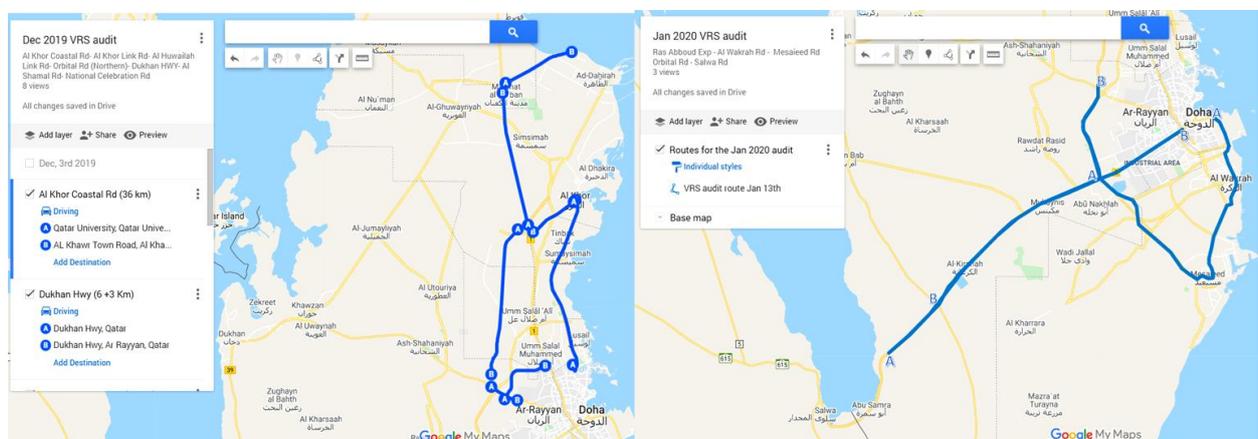


Figure 2. Routes traversed for VRS audit in 2019 and 2020 in the State of Qatar

Table 2 outlines the types of road safety barriers (median and longitudinal sections) for the aforementioned corridors. Various types of crash cushions were observed on the roads. The poles for the bridges are mostly protected by rigid concrete barriers. Gates opening and transition of the VRS are guardrail types. On Al Khor Coastal Road along the east coast of Qatar, the median barrier is rigid (made by concrete) in the major part of this section. However, on roadside longitudinal sections, VRS is largely made up of steel. This case shows a combination of rigid and deformable road safety barriers on a highway with two different functions: (a) the installation of deformable longitudinal barriers to reduce the collision severity, and (b) the installation of rigid median barriers to avoid as much as possible vehicles from crossing the central reserve and crashing to the other side of the highway.

Table 2. The specifications of VRS installed on Qatari Highways

Name of the road section	Length Surveyed (km)	Type of VRS installed on	
		Medians	Longitudinal sections
Al Khor Coastal Road	36	Concrete barriers H2 Level	Concrete barriers as well as steel guardrail H1 level
Al Khor Link Road	12	Steel Barriers H2 Level	Steel VRS and Mobile steel guardrail H2 level
Al Huwailah Link	24	Steel VRS H2 level	Steel guardrail H1 level
Al Shamal Road	75	Steel Guardrail H1 level	Steel guardrail H1/H2 /H4levels
Al Wakrah Road	9	Concrete barriers H2 Level	Steel guardrail H1/H2 levels
Mesaieed Road	22	Steel guardrail H1/H2 levels	Steel guardrail H1/H2levels
Orbital Road	70	Steel guardrail H1/H2 levels	Steel guardrail H1/ H2levels
Salwa Road	136	Steel guardrail H1/H2 levels/	Steel guardrail H1/ H2levels
Ras Abboud HWY	8	Not available	Missing protection

4.1. Audit Findings

Given 400 Kms of road safety barriers audit, in general, it was concluded that the VRS in the State of Qatar are impressive and can fulfil adequately the country's VRS safety standards adopted by PWA ASHGHAL. This is the case particularly for newly built highways having a sufficient right of way. Nonetheless, it is realized that the present standards may not capture completely all aspects of the design and installation of VRS particularly when a combination of both American and European VRS design has been implemented on a highway. Moreover, the design and installation of road safety barriers for both roadside guardrails, and median barriers deserve special attention for the highways operating predominantly at LOS A, and LOS B, which permit speedy driving. Based on the empirical study and field visits on several occasions on different highways, the following recommendations are made.

4.1.1. Containment Level

It is recommended that an upgrade be provided in medians and longitudinal barriers for Qatari highways. The containment level should be evaluated according to the hazard ranking; the speed limit versus real speed e.g. 85 percentile of observed speed, the existence of risk factors, and the percentage of heavy vehicles. For instance, the minimum containment level of H2 could be upgraded to H4 for protecting bridge piers or abutments, in case of the existence of individual hazards such as signposts, gantry legs, lighting columns, and signs that are not inertly safe. Moreover, the implementation of the higher containment level requirement is recommended in case of more than one justification for implementing a road safety barrier.

4.1.2. Road Safety Barriers Design

It was found out that there is a variety of VRS with different designs and performance levels installed on the audited road sections. Nevertheless, the majority of them fulfill the minimum standards. Some of the audited sections benefit from the advanced roadside and median safety systems installed (Figures 3a, 3c, 3d, 3e, 3f, 3g, and 3h).

In the newly designed highways such as Mesaieed highway, VRS has been incorporated in the design stage, which resulted in a well-prepared design of the cross-section, providing a safe zone for deformability between potential hazards and VRS.

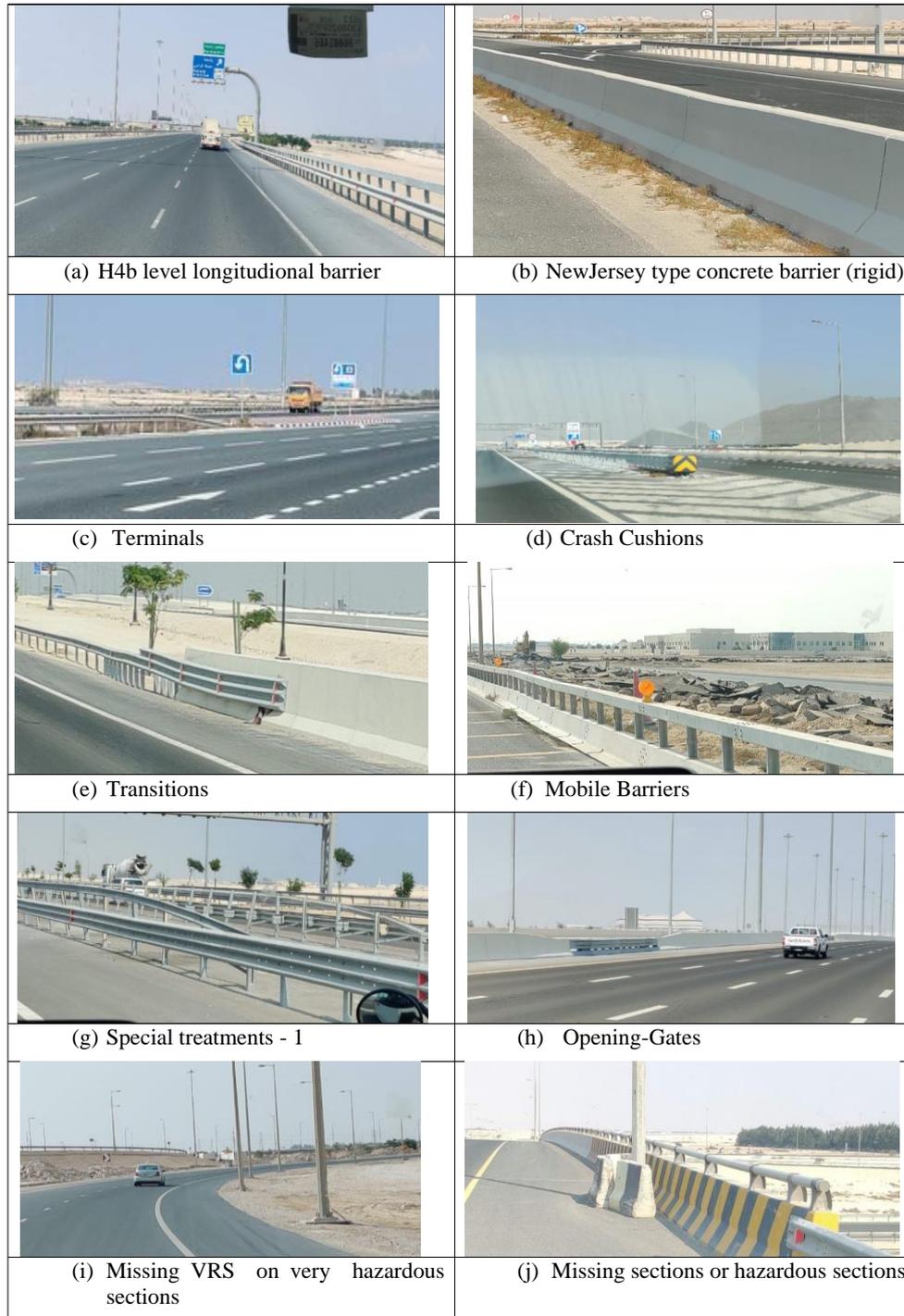


Figure 3. Treatments used for various sections on Qatari Highways

4.1.3. Road Safety Barriers Installation

The following points were observed from the site visits and audit.

- The working width provided along the median of the surveyed roads in most of the sections complies with the EU – (preferred) standards, albeit there are some rooms for improvement and higher performance levels. (i.e. higher working width and mandatory minimum height for VRS in Median)
- The bridges’ poles are predominantly protected by rigid barriers made up of concrete. This is the case for most of the newly designed roads.
- In sections with gantries, light - posts, trucks weigh - stations, and pipe/gas -lines on side roads, steel longitudinal guardrails with the highest performance level on the scale of H4b according to EN 1317 have been installed (Figure 3a).

- In case of no potential hazards, no longitudinal guardrail needs to be installed. This is the case e.g. Salwa Road, on which a dual speed limit has been set (120kph for cars and 80kph for trucks); however, no longitudinal barrier has been installed as no hazards, slopes, or obstacles endanger the road safety. Nonetheless, H4b level guardrails are installed to protect motorists from crashing into gantries.
- For isolated hazards (Figure 3j), a safety barrier should be placed as adjacent to the pole as possible and therefore a narrow working width should be selected.
- LoN (Length of Need): it is recommended that LoN is consistent with the geometry and delineation of the road alignment, the placement and type of the potential hazard, and the type of road safety barrier.
- Mobile VRS were installed in some sections, particularly on road construction sites (Figure 3f). These barriers are fixed at the beginning and end-section only. Nonetheless, such barriers may result in high safety performance despite being mobile according to test results. It is observed that the appropriate containment level has been complied with based on the type and posted speed of vehicles using the road. Furthermore, it is observed that a minimum containment level of N2 has been provided for the mobile VRS.
- Transitions: At some sections such as transitions, a combination of steel and concrete barriers is observed (Figure 3e). Transitions have been implemented properly between safety barriers with different working widths/containment levels (Figure 3e). The length of the transition is adequate which results in no tangible alterations in the dynamic deflection occur over short lengths. On average, eight meters in length has been provided for the transition.
- The connections between a crash cushion and guardrails have been properly preserved by a transition (Figure 3d).

4.2. Observed Shortcomings

It was observed the distance between longitudinal roadside safety units and potential dangerous hazardous obstacles such as lighting columns and signs, gantries poles, etc. is very often inadequate. This usually occurs because of design-related reasons for example, when poles' foundations were already made. Another example could be excavation reasons, which leads to insufficient space for the efficient working width of the VRS. Regarding the offset adequacy, it was demonstrated that the road safety barriers having adequate barrier offset might deter a high-risk event. The case study in Indiana by Zou et al. [6] showed that odds of injury could be reduced by 15% in case of a collision with a median concrete barrier wall having a larger offset (15–18 ft. vs. smaller offset 7–14 ft.). This finding makes the incorporation of VRS into the road design at the preliminary stages more essential.

Furthermore, it was seen that road beautification, landscaping, and cycle tracks expansion might deter the road designer to incorporate a longitudinal safety barrier system into the design stage. While auditing Ras Abbud Highway with the speed limit of 80 km/h and on some sections of the highway 100 km/h, the lack of adequate roads safety barrier was observed due to the beautification reasons. For the case of Ras Abubud Highway, road safety barriers should be installed between the carriageway and the pedestrian/cycle track.

The recommendation for implementing a roadside safety barrier is initially justified by considering the SAVeRS guideline. For the aforementioned highway, applying forgiving roadside principles is not the case. None of the hazard removal, hazard relocation, road layout amendment, and impact severity reduction actions is plausible in this case. For instance, it is not feasible to reposition the hazard distance from the right of way and thus widen the clearance. Besides, beautification cannot be removed. Hence, the installation of roadside barriers is necessary. It is recommended a customized type of VRS harmonized with the exiting beautification. Therefore, a steel guardrail seems to be a preferred option.

Similarly, unprotected barricades were seen on some of the bridges and flyovers (Figure 3j). To improve safety, the installation of forefront crash cushions should be taken into consideration.

Despite considerable daily traffic volumes and the percentage of heavy vehicles, the unavailability of longitudinal barriers or partially installed barriers on some ramps with the posted speed of 60 km/h and the actual speed of 70 km/h (Figure 3i) was observed.

Besides the abovementioned deficiencies, there were some other types of weakness, which could be avoided if they were taken into consideration at the installation and supervision stages. For instance, in the case of Orbital Road, which functions as a beltway with a speed limit of 120 km/h, it was observed that the height of the guardrails, albeit conforms to the existing guideline, seems to be insufficient and therefore might not fulfill the minimum barrier height (68 cm vs. min of 72 cm). This deficiency occurs for few sections of Orbital Road presumably during the VRS installation phase, which implies that continuous supervision would be required for a proper installation of road safety barriers on newly built highways.

As indicated before, it was found out there is room for safety enhancement for the highways having higher actual observed speed versus posted speed (e.g. 120 km/h and 130 km/h respectively) such as Orbital Road. Although the H2 guardrail meets the minimum requirement for the central reserve barrier, in some cases, it might be incapable to deter vehicles from crossing over the guardrail and either digressing to the other side of the highway or colliding to a light pole on a median. The installation of the H4b guardrail and the heightening of the VRS to 90 cm would tremendously improve the situation particularly, as a significant proportion of vehicles on motorways are SUVs in the case of the State of Qatar. This finding conforms to the required containment levels on bridges and retaining walls recommended by the RPS guideline.

5. Lessons Learned

It was concluded that the major parts of the northern, as well as southern roads in the State of Qatar, are equipped with advanced road safety barriers. The findings are based on two recent site visits and audits made by an expert road safety auditing team. Nonetheless, incorporating the following measures would uphold the performance of road safety barriers in the State of Qatar significantly:

- The European and American standards can be used in other countries such as the State of Qatar, however, the selection of VRS, design, and installation parameters should better be customized in consideration of the local conditions consequently.
- Depending on traffic volume i.e. ADT, the VRS maintenance interval has to be determined and authorities need to abide by it strictly.
- Regarding the central reserves, the design speed, ADT, the heavy vehicle percentage, the width of the central reserve and the presence of potential hazards such as lighting poles have to be taken into consideration before selecting and installing road safety barriers.
- The maintenance or replacement of the damaged VRS units should be a priority, particularly for roads with a significant percentage of heavy vehicles such as single-unit trucks.
- It has been found out that achieving different performance levels of a VRS type is inevitable. This predominantly depends on the original design and technical specifications as well as on the supervision during the installation of road safety barriers.
- The design and selection of VRS have to be made at the preliminary design stage of roads. By allocating an adequate right of way and deformation gap between road safety barriers and utilities such as lights, signs, and gantries poles, a proper installation is achieved which results in the highest performance level of a vehicle restraint system
- Continuous supervision during the installation of road safety barriers can enhance the functionality and efficiency of VRS.

6. Conclusions and Final Remarks

The PWA ASHGHAL in the State of Qatar, the main responsible body for the construction and maintenance of local roads and highways in the country, has set guidelines for the installation of VRS predominantly based on two most commonly used guidelines; EN1317, and NCHRP350-MASH. The aforementioned guidelines are widely practiced in the European Union and North America respectively. While, the former mainly focuses on deformation and flexibility to bounce back the colliding vehicles to the road, the latter aims at deterring the colliding vehicle to cross over the right of way given the rigid function of safety barriers.

The existing VRS guidelines, which are commonly practiced in North America, within Europe, and even in other countries may benefit from customizations according to the countries' local traffic conditions, driving behavior, vehicular compositions, and geometric design of roadways. In other words, the above-mentioned standards should not be construed as an all-encompassing guideline. To improve and customize the VRS standards in non-EU countries such as the State of Qatar, analyzing historical incidents and speed records are essential. Furthermore, site visits within the installation, field observations, and the inspection of maintenance work for the components of VRS may help uphold the performance of VRS.

The findings of two rounds of VRS audits made by road safety experts demonstrated that there is still an opportunity for improvement in the philosophy and adopted regulations for road safety barriers. The recommendations should be made according to local traffic conditions, ADT patterns, posted vs. observed speed, driving behavior as well as vehicular composition. This is particularly the case for the State of Qatar since a significant number of vehicles are Sport Utility Vehicles (SUVs) moving at higher speeds. Furthermore, setting up specific requirements in the guideline for

VRS to prevent pedestrian fatalities and enhance safety for active transportation modes in the State of Qatar is recommended.

It is expected that adopting a customized guideline, the inclusion of VRS at the early design stage of roadways together with persisting supervision at the installation phase lead to increased performance and functionality of VRS eventually and thus safety enhancement for both vehicular traffic as well as pedestrians. Furthermore, routine checks and inspections, and timely maintenance should be taken into consideration to ensure the expected level of VRS performance is always achieved. The findings stated in this article can be applied particularly at the installation stage of road safety barriers in accordance with the local road and traffic conditions of countries in which VRS are implemented.

7. Declarations

7.1. Author Contributions

Conception or design, S.T., D.M., B.W.; Data collection and processing, D.M., S.T., B.W.; Analysis and interpretation of the data, S.T.; D.M.; Formal Audits, B.W., S.T., D.M.; Supervision, B.W.; Project administration: S.T.; Writing -original draft preparation, S.T., D.M.; Writing-review and editing, S.T., D.M., B.W.; All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

No new data were created or analyzed in this study. The findings in this study are based on field observation and a series of audits. Data sharing is not applicable to this article.

7.3. Funding

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7.4. Conflicts of Interest

The authors declare no conflict of interest.

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