ADDIS ABABA UNIVERSITY SCHOOL OF GRADUATE STUDIES

METHODOLOGY FOR TRAFFIC SAFETY AUDIT AND INSPECTION OF BRIDGES

A thesis presented for the partial fulfillment of the requirements for the Degree of Masters of Science in Civil Engineering (Road and Transport Engineering)

By

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METHODOLOGY FOR TRAFFIC SAFETY AUDIT AND INSPECTION OF BRIDGES

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DECLARATION

I certify that this research work titled "Methodology for Traffic Safety Audit and Inspection of Bridges" is my own work. The work has not been presented elsewhere for assessment and award of any degree or diploma. Where material has been used from other sources it has been properly acknowledged/ referred.

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ABSTRACT

Bridges are structures including supports erected over a depression or an obstruction for carrying traffic and other moving loads. They are crucial elements of the road design elements and transportation infrastructure. There are around 3,100 bridges registered in Ethiopia in Bridge Management System.

Although a considerable research has been carried out on Traffic safety on highways and Road Safety Audit as a whole, very little work has been done on traffic safety Audit and Inspection of bridges. Most of the inspections of bridges concentrate on the structural defects of bridges leaving the safety aspect of the bridge and approach roadway as a secondary concern. Bridges and bridge approaches have been identified as one of the leading locations for severe, single-vehicle crashes. There are many bridges and culverts on the highway system in different parts of Ethiopia. Most of the bridges have rigid rails and often span a potentially hazardous feature.

This thesis presented a methodology for traffic safety audit and inspection of bridges. Checklists were prepared for each stage of design starting from planning stage through construction stage so that safety elements aren't overlooked by the designer. The checklist incorporates important safety features to be checked such as, the adequacy of bridge width, the adequacy of pedestrian width, the application of constant width for the approach roadway as well as bridge, adverse geometric alignment at the bridge approach roadways, and the incorporation of crashworthy transitions, approach guardrail and end treatments. Sample projects which are found at different stages of design were selected for an implementation exercise. As part of this thesis, bridge safety inspection sheet was developed for the safety inspection of existing bridges. It was assumed that the results will create awareness to most bridge engineers who deal with the structural assessment of existing bridges. Bridges located on Modjo – Awassa road were used for developing the bridge safety inspection sheets. None of these bridges has end treatments, approach guardrail and transition section. The major defects noted include, cross section constriction, poor approach

alignment, sight distance constraints and high fill heights without safety barrier on the approaches. Inspection procedures and data sheets are prepared based on intensive literature review and field inspection of existing bridges. Bridge engineers and inspectors are advised to use the developed safety inspection sheet as part of their routine structural inspection of existing bridges.

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Abbreviations

AACRA	Addis Ababa City Roads Authority
AADT	Average Annual Daily Traffic
ADT	Average Daily Traffic
AASHTO	American Association of State Highways and Transportation Officials
ERA	Ethiopian Roads Authority
FHWA	Federal Highway Administration
LRFD	Load and Resistance Factor Design
NBI	National Bridge Inventory
NBIS	National Bridge Inspection Standards
NCHRP	National Cooperative Highway Research Program
M	metre (metric system measurement of length)
MS 18	Bridge Design Loading equivalent to HS 20 loading
RDG	Roadside Design Guide
SSD	Stopping Sight Distance

1. INTRODUCTION

Bridges and bridge approaches have been identified as one of the leading locations for severe, single-vehicle crashes. There are many bridges and large culverts on the highway system in different parts of Ethiopia. Most have rigid rails and often span a potentially hazardous feature. Many of these structures were built decades ago for highways of lower speed and less traffic. Because of the high cost of replacing bridges and the long service life of many bridges, replacement of the bridge or major component of a bridge, such as the bridge deck or bridge rails, may not be a priority while the bridge remains structurally adequate. In situations where it is considered inappropriate to reconstruct the bridge or some element of the bridge to current standards, improvements, while not resolving a substandard condition, can significantly contribute to improving highway safety. A temporary safety improvement may be considered when work is done to improve the safety or reduce the potentially hazardous nature of components or features of the bridge or roadway approaching the bridge.

As we know, it isn't common to carry out bridge safety audit for the design of new bridges. However, bridge safety audit should be carried out for new bridges to address safety issues and reduce mitigation works during the life time of the bridge. Thus, safety audit should be carried out starting from the feasibility stage to the final design stage and extended to construction, before and after opening to traffic. Bridge safety audit in general is the evaluation of bridge systems during design and construction to identify potential safety hazards which may affect any type of road user before the scheme is opened to traffic, and to suggest measures to eliminate or mitigate those problems. In line with this, it is necessary for road and bridge safety inspectors to be familiarized with the design considerations of the highway type and the local bridge site conditions being evaluated in order to perform an assessment of traffic safety features on the bridge system.

Earlier approaches deals with the treatment of the road safety features separately without merging with the treatment of bridge safety features. The treatment of the road system as a whole design entity calls for the development and application of uniform guidelines and protocols. The application of such guidelines and protocols in the safety evaluation of bridges and their approach roadways and roadside condition during design stage and in service will enhance the safety of all road users while implementing measures that have proven to be successful.

1.1 Statement of the Problem

Generally road safety audit is being practiced in which it considers bridge roadway as part of the road. Bridge safety audit carried out currently isn't sufficient and it needs to be considered separately. The design of new bridges mostly deals with the structural design of bridge elements such as superstructure design, substructure design, bearing design and bridge ancillaries. Most of the factors affecting the safety performance of the bridge is checked during the different stages of design. Especially the adopted practice in Ethiopia for design of new bridges is to design a bridge for an already selected bridge site and use standard superstructure, substructure, railing and bearing design. The bridge width, approach roadway alignment and crashworthy crush barrier aren't considered as a primary issue in general, no checking from the safety aspect of the bridge is taken into consideration during the design stage. No safety audit sheet is adopted for considering the safety aspects at the feasibility as well as in the design stages. Furthermore, the inspection of bridges has concentrated primarily on the structural aspects of the bridge, leaving the traffic safety components on the bridge and its approaches as a secondary concern.

The increase in traffic volume and speed of vehicles in recent years has resulted in many accidents and hence there is the need to give more attention to reduce the hazards which may be causing accidents on Bridge Approaches and on Bridge Structures. It is a significant problem that vehicles and non-motorized road users are more often involved in traffic accidents.

Although a lot of research has been carried out on the road safety audit and inspection, very little work has been done on developing methodology for Traffic safety audit and safety inspection of Bridges.

Therefore, this research is undertaken review literature and inspects the safety of existing bridges to develop procedures on how to carry out safety audits and inspections with checklist and data sheets.

1.2 Objectives

The main objective of this research was in general to develop safety audit and inspection procedure for highway bridges.

The specific objectives were to:

1. review literature on safety audit and inspection of bridges;
2. inspect/investigate the safety components of selected existing bridge structures and approach roads;
3. develop safety audit and inspection procedures, check lists, and data sheets;
4. test the developed procedures, check lists, and data sheets by undertakings safety audits of new bridge designs, and inspection of existing bridges.

1.3 Scope

The scope of this thesis was to prepare a checklist for the safety audit of new bridges and to evaluate the safety of existing bridges with respect to its traffic safety features and approach roadway alignment. The bridge design safety audit considers the traffic safety implications on new bridges.

The bridge safety audit checklist won’t consider non-safety related issues. The bridge safety audit doesn’t consider structural safety. On the other hand, the developed methodology incorporated safety inspection of existing bridges including the safety performance of traffic safety features. The research is limited to river bridges located on main highways and doesn’t include overpass/underpass/railway bridges. Due to the time constraint, different bridges are selected for checking the developed checklists while bridges on Modjo – Awassa road are selected for developing the bridge safety inspection sheets.

1.4 Expected output and benefits of the research

The research was expected to bring awareness on bridge safety and provide bridge safety audit and safety inspection procedures for implementation. It will assist and give guidance for inspectors and bridge engineers to carry out safety audit on the approach roadway, and bridge elements located on major highways. The developed safety audit sheets could be used for new bridges design during feasibility and detailed engineering design stage while developed safety inspection sheets will be used for routine data collection and the investigation of current traffic safety condition on the approach roadways and bridges. Specifically, the research is expected to provide:

- the awareness and means for road agencies to improve traffic safety at bridge structures and approach roads;
- safety auditors procedures to perform a safety audit on new bridge structures from feasibility stage to the post construction stages so that mitigation costs is reduced at the later stage.
- procedures for performing inspection and evaluation traffic safety features on existing bridge structures and approach roads.
- field inspection sheets with the purpose of data collection and the analysis of the safety level of existing bridges and approach roadways.

1.5 Organization of the thesis

Chapter 1, which is the introductory part of the thesis, introduces about safety audit and inspection of bridges. Chapter 2 presents the major tasks carried out throughout this research. Chapter 3 consists in the review of geometrics of bridges, roadside safety features, and road/bridge safety audit and bridge safety inspection from different manuals, specifications and guidelines

Chapter 4 provides the developed bridge safety audit procedures and checklists prepared to check the designs at each stage of the design process. The checklists assist in identifying for any overlooked safety features. The bridge traffic safety features inspection procedures along with the developed bridge traffic safety inspections sheets is presented in chapter 5 of this thesis. A general conclusion of the study is provided in chapter 6. Finally, chapter 7 gives recommendations for implementation and future research that can be carried out to improve the scope of this work for further development.

2. RESEARCH METHODOLOGY

This section of the thesis presents the research methodology adopted for attaining the specific objectives of this work. The methodologies are presented as follows:

A comprehensive literature review on the geometric elements of the bridge from different manuals such as ERA, AACRA and AASHTO was carried out. ERA geometric/bridge design manual was prepared in 2002. It establishes design standard and sets design criteria for roads and bridges to be designed under Ethiopian condition. The relevant section of the geometric design manual that is related to bridge geometry such as roadway width and bridge width, approach roadway alignment, approach sight distance, approach roadway grade is reviewed. Knowing the limiting values such as the one/two lane bridge width, the provision for non-motorized users, the minimum horizontal curve and the maximum approach gradient will enable to recommend appropriate safety measures. In line with this, AACRA and AASHTO geometric design manuals were also reviewed. The geometric elements of the bridge with respect to horizontal alignment, vertical alignment, width, clear zone concepts requirement of the bridge and approach roadway geometry was reviewed. In the safety inspection findings it was clearly seen that all the major safety problems are related to one of the above mentioned geometric elements. Each of the above elements is discussed in detail in chapter 3.

A review on Road safety Audit was also carried out from different road safety manuals such as Ethiopian Roads Authority Road Safety Audit Manual, Road Safety Audit Guidelines prepared by National Roads Authority and Safety recommendation prepared by National Transportation Safety Board.

A review on regulations and standards for the inspection of traffic safety features on bridges presented in FHWA, National Bridge Inspection Standards, NBIS [1995], FHWA, Recording and Coding Guide for the Structure Inventory and Appraisal of Nations Bridge, [1995], AASHTO Manual for the Condition Evaluation of Bridges [1994], and AASHTO LRFD Bridge Design Specification [2004] was also carried out.

Standard adopted on ERA bridge design manual, AACRA bridge design manual, AASHTO LRFD Bridge Design Specification and AASHTO Manual for the Condition Evaluation of Bridges [1994] was reviewed. Test level selection criteria, warrants for placing safety barrier, National bridge inspection standards requirement is also included in this study. Chapter three contains each of the topics discussed above. The height, spacing and width of crush barrier were also assessed and included in chapter three.

After making a comprehensive literature review on safety audit and inspection of bridges, inspection and investigation of selected existing bridges were carried out. The selected existing bridges are located on Modjo – Awassa road. According to Modjo-Awassa *Traffic Analysis and Safety Measures Report* (Berhanu, 2009), most of the bridges located along this project road are considered as accident black spot sites. These bridges are Meki river bridge, Bulbula River Bridge, Awade 1 river bridge, Awade Godu River Bridge and Tataba river bridges. According to the *Traffic Analysis and Safety Measures Report* (Berhanu, 2009), the average accidents per year at those bridges are 3, 5, 3, 3, and 4 respectively.

Following the identification of the bridges, field visit was made to assess the approach roadway alignment, approach sight distance, the traffic safety features, and the bridge geometry.

The following devices such as hand held GPS, vehicle Odometer, measuring tape; digital Camera, Video Camera and data collection sheet were used to measure and record the bridge dimensions, the bridge coordinate, the approach roadway details, the bridge details and the traffic safety features. The visual inspection included the inspection of the following elements:

1. Approach Alignment – (Entry & Exit)
    - presence of sharp curves
    - presence of summit or sag curves
2. Approach Sight Distance - (Entry & Exit)
    - sight distance constraints
    - vegetation overgrown adjacent to the sign posts

3. Approach Gradient - (Entry & Exit)
    - presence of steep gradient

4. Width
    - Approach roadway width
    - Sidewalk's width
    - Bridge carriageway width
5. Traffic safety feature type & length
    - flexible , semi flexible and rigid
    - Post height
    - Post Spacing
    - Railing height & spacing

Based on the existing bridge inspection findings and literature review safety inspection procedures and inspection sheets were developed. The outcome of the inspection process is the identification of possible safety treatments for typical bridge safety related issues and a traffic safety feature rating for the safety inspection elements (bridge railing, transition, approach guardrail, and end treatment). A rating is assigned to each of the traffic safety features on the bridge and it consists of seven categories: none, minor, fair, poor, sever, urgent inspection, and not applicable. The safety rating is related to the bridge and the evaluation of the existing operational situation in the bridge, and serves as an indicator of the need to identify and implement potential safety treatments.

3. After making a comprehensive literature review on road safety audit from different manuals a checklist was developed for the safety audit of new bridges. The bridge safety audit checklist is prepared for planning stage, preliminary design stage, detail design stage and construction stage. These checklists will be used to consider all factors and provide a reminder of potentially overlooked safety issues. It also provides a measure of continuity from audit to audit. The evaluation of Bridge schemes during feasibility, design, construction and post construction will help to identify potential safety hazards which may affect any type of bridge user before the

scheme is opened to traffic, and to suggest measures to eliminate or mitigate those problems.

To develop the safety inspection protocols, the visual inspection findings of the selected bridges located on Modjo – Awassa road was used. The procedures for inspecting and evaluation of the functional adequacy of existing bridges were identified. The development of the safety inspection protocol for existing bridges will enable bridge engineers for making safety inspection of bridges.

4. The testing of the developed procedures was performed by considering bridges at different stages of design. As it is difficult to get one design project from planning stage all the way to the construction stage, different design projects are selected for implementation exercise of the safety audit checklists. The implementation illustration starts from the feasibility stage and extends to the construction stage. At the time of preparation of this thesis, the available bridge design project which includes planning stage and construction stage bridge design is Gonder By-Pass project. The selected bridge for the Preliminary Design Stage and Detailed design stage check is located on Kogne – Zemute – Beke and Mazoria – Omo Road Upgrading project.

A check was done on the comprehensiveness of the bridge safety inspection protocols and inspection sheets. The bridges selected for testing the procedure are Tekur Woha and Bulbula River Bridge located at the boundary of Oromia and Southern Regions and Addis Ababa respectively.

Accordingly, minor amendments were made on the previously used safety audit check list and inspection sheets as items not considered before are included in the final inspection sheets. The developed inspection sheet includes all the necessary information that could be used for alleviating typical major deficiencies on bridges. The sample application examples in appendix F illustrates the actual scenarios and will give guidance for inspectors and junior bridge engineers to perform an evaluation of traffic safety features on bridges.

3. LITERATURE REVIEW

3.1 Introduction

This chapter presents a comprehensive review of relevant literature including manuals, specifications and guidelines. It aims to critically assess and identify geometric elements, components and features relevant to the traffic safety of bridges and approach roads.

Geometric requirement of bridges such as bridge width, approach roadway alignment and approach sight distance is presented on the first section of the literature review. The elements of the roadside like the clear zone, safety barrier warrants, bridge level selection criteria, and the approach guard rail systems are discussed in the second section of the literature review. Finally bridge safety audit and bridge safety inspection is presented in detail.

3.2 Geometric Requirement of Bridges

3.2.1 Road Functional Classification

The road functional classification concept is defined by AASHTO [2004] as the process by which streets and highways are grouped into arterials, collectors, and local roads according to the character of service they are intended to provide whereas the functional classification in Ethiopia as defined by ERA Geometric Design Manual [2002] are grouped into trunk roads, link roads main access roads, collector roads, and feeder roads according to the AADT and importance of road. The design standard to be used for typical highway system is related to road functional classification and traffic volumes. It provides necessary information such as the pavement type, the width of carriageway and shoulder, design speed for different terrain types and for urban sections. The safety performance of bridges on truck roads is different than other classes of roads. Bridges designed on trunk roads are normally undertaken with more safety considerations than other types of roads. This is because the width, pedestrian walkway, and approach roadway requirement decrease as the class of road decreases.

As per ERA Bridge design manual [2002], the geometric requirement of a bridge should fulfill the following objectives by using appropriate standards.

- Topography, land use and physical features
- Environmental considerations
- Road safety considerations
- Economic and financial considerations

3.2.2 Bridge site selection

In selecting the location of a bridge, one has often to reach a compromise between the easiest river crossing and the shortest road alignment. The choice of location then becomes an economic decision.

The cheapest bridge site and the one that has potentially the longest service life is a location that:

- is on a straight reach of the river;
- is beyond the disturbing influence of larger tributaries;
- has well defined banks;
- has reasonably straight approach roads;
- permits as square a crossing as possible;
- has good foundation conditions.

The site should allow the maximum gradient of the approach roads to be appropriate to the types of vehicle likely to travel on the road as well as offering vertical curves and sight distances suitable for the maximum speed of vehicles using the bridge.

3.2.3 Bridge width

The width of the bridge should correspond with the roadway or carriageway width as determined according to the ERA Geometric Design Manual [2002]. The width is to be measured between the inside of the railings or the curbs.

Clear width of bridge is defined as the distance between the inside of the outer railings including walkways, island/refuge and similar.

Where one lane bridges are to be designed, their minimum width suggested by ERA is 4.2m and the minimum recommended width by ERA for two lane bridges are 7.0m. The safe recommended width for two lane bridges are 7.3m as it allows 0.7m clearance between vehicles and at the sides. At higher design speed, and/or in the vicinity of densely populated areas, a bridge allowing for the shoulders width should be considered. In this case, the bridge width should be increased to 10.30m. (7.30mts plus 1*1.5 shoulders or sidewalks). This allows for opposing trucks and pedestrian to meet safely. Table 1 presents the recommended bridge width as indicated by ERA bridge design manual for one lane and two lane bridges. Table 1 below doesn't allow shoulder width for bridges located on rural areas but it is highly recommended to have shoulder width on two- lane bridges in rural areas for safety reasons. Further more, single lane bridges should be avoided by any means as they are the cause of accidents. It is advisable to construct two lane bridges by allowing rooms for future expansions including pedestrian and animal crossing.

Table 1: Bridge Width (ERA 2002)

Application	**Width(m)**
Two-lane in "urban" area	10.30
Two-lane in "rural" area	7.30
Single Lane	4.20

AACRA Bridge design manual specifies that the lane width on a bridge shall not be less than the lane width on the bridge approaches. Furthermore, it states that the width of the roadway on the bridge shall be sufficient for the kerbs on the bridge to be set back a minimum of 500mm from the edge of the adjacent traffic lane, measured to the base of the kerb. According to AACRA Bridge design manual 6.0m is considered as the minimum safe width for a two lane bridge on local roads but according to ERA and AASHTO 7.30m is considered as the minimum safe width. Table 2 provides the Bridge lane widths as presented by AACRA. The width suggested by AACRA for both single lane as well as two lane doesn't allow for the smooth flow of traffic and will cause traffic accident and delay. Moreover, non-motorized traffic isn't taken into consideration. The volume of non-motorized traffic is expected to be very high in urban section and it is advisable to provide a shoulder and a protected non-motorized crossing.

Table 2: Bridge Lane Width (AACRA 2004)

Road Classification	**AADT**	**Two Way**	**One Way**	
		Two Lane	Single Lanes	Two Lanes
Local	<100	6.0	3.0	-
	100-500	6.0	3.0	-
	500-1000	6.5	3.25	-
	1000-2000	6.5	3.25	-
Collector	2000-6000	7.0	-	7.0
Sub-arterial Arterial	6000-20000	7.0	-	7.0

Previous studies reveal that bridge width is the total width of all lanes and shoulders on the bridge, measured between the points on the bridge rail, curb, or other vertical elements. A bridge width that meets adopted criteria maintains the minimum acceptable lane and shoulder width for the particular design condition as defined by area, functional class, design speed, and traffic volume. A design exception is required when a bridge is proposed to be constructed with narrower lanes, shoulders, or both.

A report on Traffic Analysis and Safety Measures of carried out on Modjo – Awassa Road by Berhanu, (2009) showed that potential problems associated with narrow bridges are twofold. Six of the bridges located along the Modjo – Awassa road are considered to be black spots. The narrowed cross section can make some drivers uncomfortable and cause them to reduce speed dramatically, increasing the risk of rear-end crashes and degrading operations on high-speed, high-volume facilities. In narrow bridges, since the bridge rail is close enough to the travel lanes it causes drivers to shy towards the centerline entering into adjacent lanes eventually leading to traffic accidents.

The safety and operational concerns at narrow bridges are similar to those on roads with narrow shoulders. The lack of shoulder width on the bridge may make it impossible to avoid a crash or object on the roadway ahead. In addition, options are limited for non-motorized users such as bicyclists, forcing them onto the traveled lanes or close to the bridge rail. Figure 1 below shows Meki Bridge accommodating motorized and non-motorized traffic.

Figure 1: Meki Bridge accommodating motorized as well as non-motorized users .

Narrow bridges on horizontal curves can have limited horizontal stopping sight distance past the bridge rail (Figure 1). Operations can be degraded, particularly on bridges on high-speed roadways, because of speed reductions as drivers enter the narrowed cross section as well as a decrease in driver comfort on the bridge.

AASHTO (2004) summarizes the potential adverse impacts to safety and operations of a design exception for bridge width.

Table 3: Bridge Width: Potential Adverse Impacts to Safety and Operations

Safety & Operational Issues	**Freeway** [a]	**Expressway** [b]	**Rural Two Lane** [c]	**Urban Arterial** [d]
Collision with bridge rail or approach guardrail	X	X	X	X
Rear-end crashes (abrupt speed reduction)	X	X	X	
Cross-centerline crashes			X	X
Degraded operations because of abrupt speed reduction as drivers approach bridge	X	X		X
Reduced free-flow speeds	X	X	X	X
Inadequate space for enforcement activities and emergency response (long bridges)	X	X	X	X
Lane blockage from incidents (long bridges)	X	X	X	X
Shying away from the bridge rail	X	X	X	X
Inadequate space for bicyclists	X	X	X	X
Inadequate space for emergency pullover (long bridges)	X	X	X	X
Inadequate space to avoid crashes or objects on the travel lanes	X	X	X	X
Lack of storage space for disabled vehicles (long bridges)	X	X	X	X

[a] freeway: high-speed, multi-lane divided highway with interchange access only (rural or urban).
[b] Expressway: high-speed, multi-lane divided arterial with interchange and at-grade access (rural or urban).
[c] Rural 2-Lane: high-speed, undivided rural highway (arterial, collector, or local).
[d] Urban Arterial: urban arterials with speeds 45 mi/h (70 km/h) or less.

AASHTO recommends that the clear width for all new bridges on streets with curbed approaches should be the same as the curb to curb width of the approaches. For streets with shoulders and no curbs, the clear roadway width preferably should be the same as the approach roadway width and in no case less than the width in table 4 below. Table 4 shows the minimum clear roadway widths and design loadings for new and reconstructed bridges,

Table 4: Minimum Clear Roadway Widths and Design Loadings for New and Reconstructed Bridges (AASHTO 2004)

Metric			**US Customary**		
Design Volume (veh/day)	Minimum clear roadway Width for bridges [a]	Design Loading Structural Capacity	Design Volume (veh/day)	Minimum clear roadway Width for bridges [a]	Design Loading Structural Capacity
400 and under	Traveled way+0.6m (each side)	MS 18	400 and under	Traveled way+2ft (each side)	HS 20
400 to 2000	Traveled way+1.0m (each side)	MS 18	400 to 2000	Traveled way+3ft (each side)	HS 20
Over 2000	Approach roadway width [b]	MS 18	Over 2000	Approach roadway width [b]	HS 20

[a] Where the approach roadway width (traveled way plus shoulders) is surfaced, that surface width should be carried across the structures.

[b] For bridges in excess of 30 m [100 ft] in length, the minimum width of traveled way plus 1 m [3 ft] on each side is acceptable.

Where an existing road is to be reconstructed, the width of the approach roadway and the safety performance of the existing bridge need to be considered while assessing the bridge design and the required bridge width. The design loading and clear roadway width are at least equal to the values given in Table 5 for the applicable traffic volume.

Table 5: Minimum Clear Roadway Widths and Design Loadings for New and Reconstructed Bridges (AASHTO, 2004)

Metric			US		
Design volume (veh/day	Design struc capa	Minimum width (m)[a,b,c]	Design volume (veh/day)	Design structu capacit	Minimum clear width (ft)[a,b,c]
0 to 50	M 9	6.0[d]	0 to 50	H 10	20[d]
50 to	M 13.5	6.0	50 to 250	H 15	20
250 to 1500	M 13.5	6.6	250 to	H 15	22
1500 to 2000	M 13.5	7.2	1500 to	H 15	24
over	M 13.5	8.5	over 2000	H 15	28

[a] Clear width between curbs or rails, whichever is the lesser.

[b] Minimum clear widths that are 0.6 m [2 ft] narrower may be used on roads with few trucks. In no case shall the minimum clear width be less than the approach traveled way width.

[c] Does not apply to structures with total length greater than 30 m [100 ft].

[d] For single-lane bridges, use 5.4 m [18 ft].

AASHTO (2004) suggests that the values in Table 5 do not apply to structures with total lengths greater than 30 m (100 ft). These structures should be analyzed individually, taking into consideration the clear-width provided, traffic volume, remaining life of the structure, pedestrian volume, snow storage, design speed, crash history, and other pertinent factors. Even if the traffic volume is small, it will be advisable to construct a two lane bridge to reduce accidents. Narrow bridges affect the operational characteristics by affecting the driver behavior (surprising and confusing), by reducing the capacity of the bridge and by aggravating traffic accidents on bridges.

One of the most prevalent factors contributing to bridge accidents is bridge width (Berhanu, 2000). Narrow bridges restrict the lateral movement of vehicles relative to the adjoining roadway section.

The need for widening an existing bridge should be based on site specific study that reveals a safety problem. The safety inspection of existing bridges should identify the problem associated with narrow bridge and recommend appropriate safety measure such as widening of existing bridge and/or construction of new bridge that will accommodate for two lane traffic and shoulder width.

3.2.4 Approach roadway alignment

This is one of the safety factors to be checked in the design of new bridges. The horizontal alignment of the approach roadway to a bridge is an important aspect to consider in the design of bridges. The design of approach roadway curves to a bridge should be based on appropriate relationship between design speed and curvature and on their joint relationship with super elevation and side friction. AASHTO (2004) suggests the use of larger radii greater than the minimum values in the proximity of bridges for safety reason.

Bridges located on sharp bends are more dangerous and hence it is advisable to locate a bridge on a tangent section of the roadway. Figure 2 shows bridge located on sharp curves.

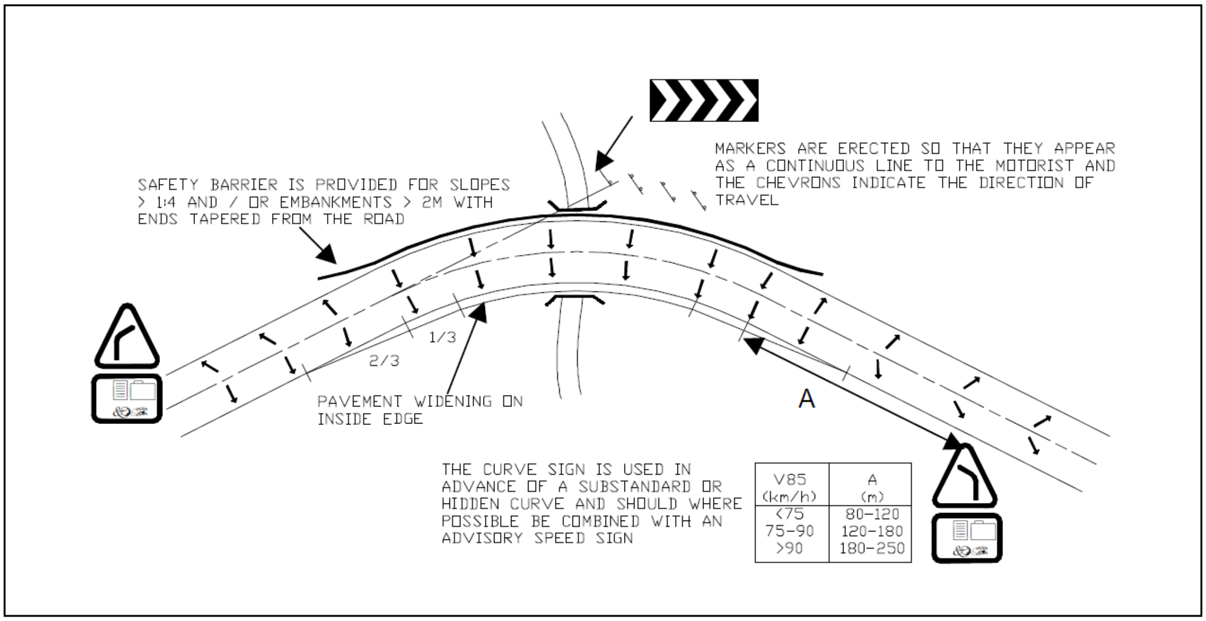


Figure 2: Bridge located on a sharp curve

At the preliminary and detail design stage, the safety audit of new bridges should check for the presence of sharp horizontal curves and sag vertical curves at the bridge approaches. Another element to be checked on the approach roadway is the proper installation of approach guardrail at the ends of the bridge rails. FWHA [2004] suggests that the use of crash cushion / an approach guardrail, or a marked appropriate Object Marker, if the end of the bridge rail has no protection. Where the bridge rail is protected by an approach guardrail, there should be a smooth, uninterrupted transition between the approach guardrail and the bridge rail. The objective is to safely transit an errant vehicle back into the roadway without impacting a blunt end on the bridge rail. AASHTO [2004] recommends the approach rail and posts should be reinforced adjacent to the bridge and attached structurally so as not to give way under impact and permit the vehicle to be directed into the end of the rigid bridge rail or parapet.

On the other hand, the vertical alignment near the bridge approach should provide the maximum gradient of the approach roads to be appropriate to the types of vehicle likely to travel on the road as well as offering vertical curves and sight distances suitable for the maximum speed of vehicles using the bridge. Bridges are often located on sag vertical curves where approach traffic is on down grades, a factor responsible for increasing speed which contributes to the losing control of vehicles (Berhanu, 2000).

FWHA (1998) states that, another typical problem associated with the bridge approach roadway is settlement of the embankment immediately behind the abutment backwall. This settlement results in a dip in the road just as traffic enters the bridge itself. If the dip is deep enough, it can cause a driver to lose control of his vehicle, possibly veering into oncoming traffic or crashing into the bridge rail. This safety problem can easily be mitigated by applying run on slabs near the two abutments.

3.2.5 Approach Sight Distance

Another important geometric element of the approach roadway which affects the safety performance of a bridge is approach sight distance. A driver's ability to see ahead is of the utmost importance in the safe and efficient operation of a vehicle on a highway. According to AASHTO [2004], sight distance is defined as the length of the roadway ahead that is visible to the driver. Normally, most highway design standards use the stopping sight distance (SSD) as a minimum value which consists of the brake reaction distance and the braking distance.

The stopping sight distance on a roadway must be sufficiently long to enable a vehicle traveling at the design speed to stop before reaching a stationary object in its path. A 2.5seconds reaction time and a minimum of 0.28 and a maximum of 0.42 coefficient of friction between tires and the roadway are suggested values by ERA Geometric Design Manual to calculate SSD. ERA SSD formula is presented as shown below:

$$d = (0.278)(t)(V) + V2/254f \qquad 1$$

Figure 3: Stopping Sight Distance Model [ERA, 2002]

A 2.5 seconds reaction time and a deceleration rate of $3.4 m/sec^2$ ($11.2 ft/sec^2$) are values suggested by AASHTO [2004] to calculate SSD using the following relationships.

Metric	US Customary
$d = 0.278 Vt + 0.039 \frac{V^2}{a}$	$d = 1.47 Vt + 1.075 \frac{V^2}{a}$ **(3-2)**
where: t = brake reaction time, 2.5 s; V = design speed, km/h; a = deceleration rate, m/s^2	where: t = brake reaction time, 2.5 s; V = design speed, mph; a = deceleration rate, ft/s^2

Figure 4: Stopping Sight Distance Model [AASHTO 2004]

The SSD model adopted by ERA and AASHTO standards use the same basic formula except the former uses coefficient of friction between tires and roadway and the latter uses deceleration rate. Taking the coefficient of friction between tires and roadway for SSD near the approach roadway is advisable as it considers different pavement surfaces.

FWHA, [1998] states that sufficient sight distance at bridge approaches is one of the most important elements of safety. Removing and maintaining vegetation that restricts sight distance is one of the cost effective ways to enhance bridge safety. Furthermore, FWHA, [1998] states that it is important to ensure at minimum that there is adequate sight distance at both bridge approaches and all regulatory or warning signs at bridge approach area. Good sight distance allows the driver to prepare for any change and take appropriate measure in a timely manner. Besides, frequency and severity of accidents at bridges can be reduced through the provision of adequate visual information to enable the driver control and navigate safely on bridges (Berhanu, 2000).

FWHA, [1998], further points out that good sight distance is particularly important when the following conditions are present:

- When there are access points at or adjacent to the bridge;
- When it is narrow; bridge width less than approach width;
- There is a possibility that pedestrian and/or animals are on the bridge or crossing the approach roadways;
- The roadway curves sharply at bridge approaches;
- When the roadway steeply descends to bridges located on sag curves.

3.3 Elements of Roadside

As defined in AAHSTO Roadside Design Guide (1989), Roadside is the area between the shoulder and the right of way limit. The definition of a safe roadside is one which is traversable throughout its length and contains no fixed objects hazards, or, if significant hazards exist, shielding is used to prevent a collision with the hazardous feature.

AASHTO Roadside design guide suggests that a good design practice should be implemented to eliminate all hazards rather than building hazards a " safe" distance from the edge of the road.

Furthermore, AASHTO Roadside design guide recommends treatments for roadside hazardous in their order of importance as follows:

- Remove the obstacle or redesign.
- Relocate the obstacle.
- Reduce impact severity by using an appropriate breakaway device.
- Redirect a vehicle by shielding the obstacle with a longitudinal traffic barrier and/or crush cushion
- Delineate the obstacle.

The most important element of the road side design is the determination of clear zone. The AASHTO Roadside design guide defines the clear zone as a variable distance, depending on design speed, ADT and embankment slope.

3.3.1 Clear Zone

AASHTO Roadside Design Guide defines clear zone as the total roadside border area, starting at the edge of the travelled way, available for safe use by errant vehicles. This area may consist of a shoulder, a recoverable slope, a non-recoverable slope, and/or a clear run-out area. The desired width is dependent upon the traffic volumes and speeds, and on the roadside geometry. A non-recoverable slope is a slope which is considered traversable but on which the errant vehicle will continue on to the bottom. Embankment slopes between 4:1 and 3:1 may be considered traversable but non-recoverable if they are smooth and free of fixed object hazards. Recoverable slope is a slope on which a motorist may, to a greater or lesser extent, retain or regain control of a vehicle. Slopes flatter than 4:1 are generally considered recoverable. A clear run-out area is area at the toe of a non-recoverable slope available or safe use by an errant vehicle.

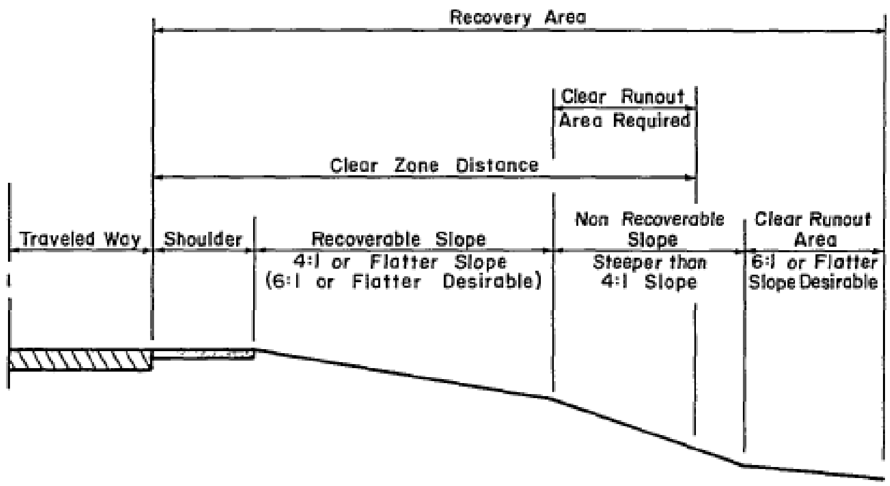


Figure 5: Recovery Area [AASHTO Roadside Design Guide]

AASHTO Road Side Design Guide suggests the use of Figure 6 and 7 to determine the suggested roadside recovery area or clear zone for selected traffic volumes and speeds.

Table 6: Clear Zone Distances (In meters from edge of driving lane)

Design Speed	Design ADT	Fill Slopes			Cut Slopes		
64 KPH or less		6:1 or flatter	5:1 to 4:1	3:1	3:1	4:1 to 5:1	6:1 or flatter
	Under 750	2.1 – 3.0	2.1 – 3.0	**	2.1 – 3.0	2.1 – 3.0	2.1 – 3.0
	750 -1500	3.0 – 3.7	3.7 – 4.3	**	3.0 – 3.7	3.0 – 3.7	3.0 – 3.7
	1500-6000	3.7 – 4.3	4.3 – 4.9	**	3.7 – 4.3	3.7 – 4.3	3.7 – 4.3
	Over 6000	4.3 – 4.9	4.9 – 5.5	**	4.3 – 4.9	4.3 – 4.9	4.3 – 4.9
72 - 80 KPH							
	Under 750	3.0 – 3.7	3.7 – 4.3	**	2.4 – 3.0	2.4 – 3.0	3.0 – 3.7
	750 -1500	3.7 – 4.3	4.9 – 6.1	**	3.0 – 3.7	3.7 – 4.3	4.3 – 4.9
	1500-6000	4.9 – 5.5	6.1 – 7.9	**	3.7 – 4.3	4.3 – 4.9	4.9 – 5.5
	Over 6000	5.5 – 6.1	7.3 – 8.5	**	4.3 – 4.9	5.5 – 6.1	6.1 – 6.7
89 KPH							
	Under 750	3.7 – 4.3	4.3 – 5.5	**	2.4 – 3.0	3.0 – 3.7	3.0 – 3.7
	750 -1500	4.9 – 5.5	6.1 – 7.3	**	3.0 – 3.7	4.3 – 4.9	4.9 – 5.5
	1500-6000	6.1 – 6.7	7.3 – 9.1	**	4.3 – 4.9	4.9 – 5.5	6.1 – 6.7
	Over 6000	6.7 – 7.3	7.9 – 9.8*	**	4.9 – 5.5	6.1 – 6.7	6.7 – 7.3
97 KPH							
	Under 750	4.9 – 5.5	6.1 – 7.3	**	3.0 – 3.7	3.7 – 4.3	4.3 – 4.9
	750 -1500	6.1 – 7.3	7.9 - 9.8*	**	3.7 – 4.3	4.9 – 5.5	6.1 – 6.7
	1500-6000	7.9 – 9.1	9.8 – 12.2*	**	4.3 – 5.5	5.5 – 6.7	7.3 – 7.9
	Over 6000	9.1 – 9.8*	11 – 13.4*	**	6.1 – 6.7	7.3 – 7.9	7.9 – 8.5
105 – 113 KPH							
	Under 750	5.5 – 6.1	7.1 – 7.9	**	3.0 – 3.7	4.3 – 4.9	4.3 – 4.9
	750 -1500	7.3 – 7.9	8.5 – 11.0*	**	3.7 – 4.9	5.5 – 6.1	6.1 – 6.7
	1500-6000	8.5 – 9.8*	10.4 – 12.8*	**	4.9 – 6.1	6.7 – 7.3	7.9 – 8.5
	Over 6000	9.1 – 10.4*	11.6 – 14.0*	**	6.7 – 7.3	7.9 – 9.1	8.5 – 9.1

* where a site specific investigation indicates a high probability of continuing accidents, or such occurrences are indicated by accident history, the designer may provide clear zone distances greater than 30 feet as indicated.

** Since recovery is less likely on the unshielded, traversable 3:1 slopes, fixed objects shouldn't be present in the vicinity of the toe of these slopes. Recovery of high speed vehicles that encroach beyond the edge of shoulder may be expected to occur beyond the toe of slope.

During the safety inspection of existing bridges any roadside objects within the clear zone should be measured and checked against the allowable clear zone distances indicated in Figure 6 and 7. For the design of new bridges, the designer should check that the end treatments, approach guardrail, transition railing, sign post, marker posts and crush barrier should be away from the clear zone.

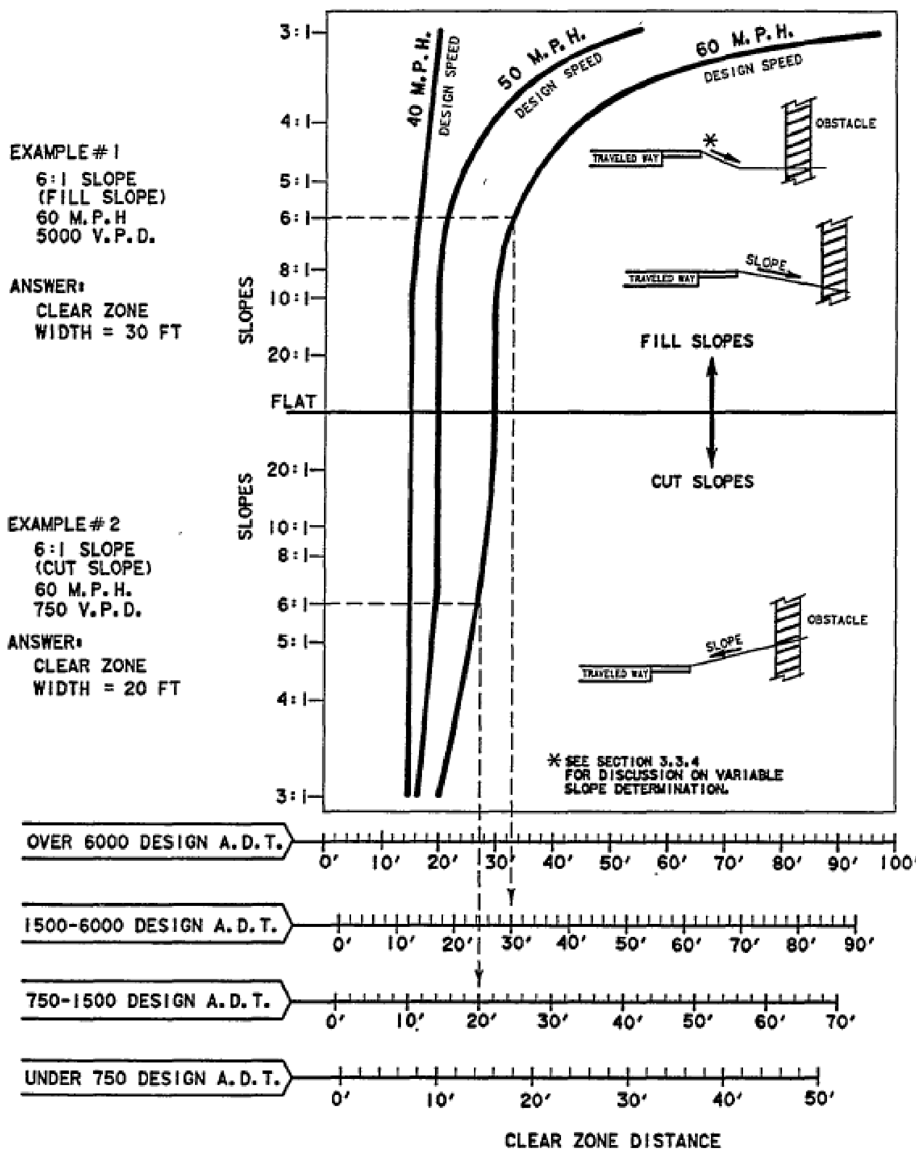


Figure 7: Clear Zone Distance Curves [AASHTO Roadside Design Guide]

3.3.2 Safety barrier

AASHTO Road Side Design Guide defines safety barrier as a longitudinal barrier used to shield motorist from hazards. It prevents a vehicle from leaving the roadway and striking a fixed object or terrain feature. Barrier warrants suggest that a traffic barrier should be installed only if it reduces the severity of potential accidents. The decision to install a traffic barrier is based on the established warrants that provide guidance to the designer in evaluating the potential safety and operational benefits of traffic control devices or safety features (AASHTO, 2006). It is important to note that the probability or frequency of run-off-the road accidents isn't directly related to the severity of potential accidents. In general, barrier warrants have been based on a subjective analysis of certain roadside elements or conditions. AASHTO Road Side Design guideline recommends the following subjective warrants to be considered for new construction or safety upgrading;

- high percentage of heavy vehicles in traffic stream
- Adverse geometrics such as sharp curvature oftentimes combined with poor sight distance
- Sever consequences associated with penetration of a barrier by large vehicle.

According to ERA/AACRA the installation of all safety features is warranted for bridges located on main highways whereas bridge railing is warranted on all bridges having span lengths of 6m and above.

3.3.3 Bridge railing system

The primary purpose a barrier is to prevent a vehicle from leaving the roadway and striking a fixed object or existing terrain feature that is considered more hazardous than the barrier itself [FWHA, 1998]. AASHTO Roadside Design Guide defines the bridge railing system as a longitudinal barrier whose primary function is to prevent an errant vehicle from going over the side of the bridge structure.

All new bridge traffic barrier systems, traffic railings, and combination railing shall be structurally and geometrically crashworthy [FWHA, 1998].

According to ERA/AACRA, bridge railing system and its connection to the deck shall be approved for all kinds of bridge. The currently in use railing system by ERA is RC post and rail while by AACRA is type "F" crash barrier. However, geometrically crash worthy hasn't been in place by ERA but by AACRA. No test has been carried out to determine the structural crashworthiness of both ERA and

AACRA bridge railing systems. In view of the fact that the dynamics of a crash are complex, the most effective means of assessing barrier performance is through full scale crash tests. By standardizing such tests, it will be easier to compare the safety performance of alternate designs.

A series of standard crash tests are presented in national Cooperative Highway Research Program (NCHRP) report no. 230. There are six test levels contained in NCHRP Report 350, Recommended Procedures for the Safety Performance Evaluation of Highway Features. There is no standard set by ERA/AACRA to check the test level selection criteria of the bridge railing systems.

One of the following test levels should be specified as per the design standard of the road,

TL-1 – Test Level One – taken to be generally acceptable for work zones with low posted speeds and very low volume, low-speed local streets;

TL-2 – Test Level Two – taken to be generally acceptable for work zones and most local and collector roads;

TL-3 – Test Level Three – taken to be generally acceptable for a wide range of high-speed arterial highways;

TL-4 – Test Level Four – taken to be generally acceptable for the majority of applications on high-speed highways, freeways, expressways, and interstate highways with a mixture of trucks and heavy vehicles;

TL-5A – Test Level Five-A – taken to be generally acceptable for the same applications as TL-4 when site conditions justify a higher level of rail resistance;

TL-5 and TL-6 – Test Levels Five and Six – taken to be generally acceptable for applications on freeways with high-speed, high traffic volume and a higher ratio of heavy vehicles.

ERA/AACRA should specify as which of the test levels is most appropriate for the type of highway under consideration.

AASHTO [2006] suggests that, the lower test levels are applicable for evaluating and selecting bridge railings to be used on segments of lower service level roadways and certain types of work zones. Whereas the higher test levels are applicable for evaluating and selecting bridge railings to be used on higher service level roadways or at locations that demand a special high-performance bridge railing. Table 6 presents the AASHTO bridge railing test levels and crash test criteria.

Table 6: Bridge Railing Test Levels and Crash Test Criteria(AASHTO, 2006)

Vehicle Characteristics	**Small Automobiles**		**Pickup Truck**	**Single-Unit Van Truck**	**Van-Type Tractor-Trailers**		**Tractor Tanker Trailers**
W (N)	7000	8000	20000	80000	220000	355000	355000
B (mm)	1700	1700	2000	2300	2450	2450	2450
G (mm)	550	550	700	1250	1630	1850	2050
Crash angle, θ	20	20	25	15	15	15	15
Test Level	**Test Speeds (km/h)**						
TL-1	50	50	50	N/A	N/A	N/A	N/A
TL-2	70	70	70	N/A	N/A	N/A	N/A
TL-3	100	100	100	N/A	N/A	N/A	N/A
TL-4	100	100	100	80	N/A	N/A	N/A
TL-5	100	100	100	N/A	N/A	80	N/A
TL-6	100	100	100	N/A	N/A	N/A	80

AAHSTO suggests that concrete railing designed with sloping traffic faces shall be at least 685 mm for TL-3 and 810 mm in height for TL-4.

The minimum height for a concrete parapet with a vertical face shall be 685 mm. The height of other combined concrete and metal rails shall not be less than 685 mm and shall be determined to be satisfactory through crash testing for the desired test level.

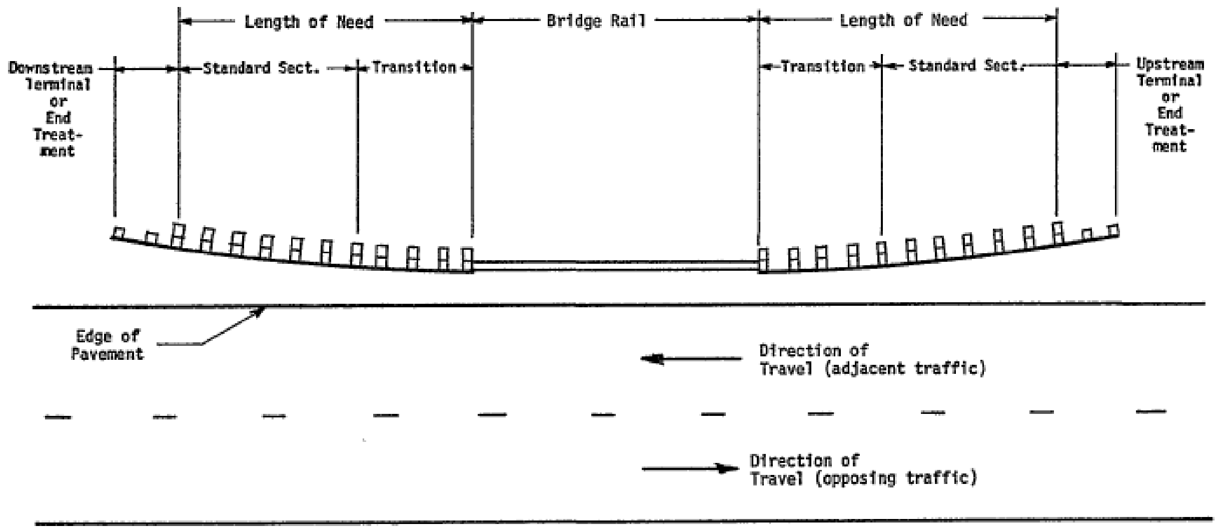


Figure 8: Roadside Barrier Elements

3.3.4 Approach guardrail

FWHA, [1998] states that the approach guardrail is often the most important safety feature at a bridge or large culvert location. The approach guardrails frequently require a greater length to shield the motorist from the potential hazards of the site than the bridge rail. It is often located on or in a curved section of highway. Additionally, guardrail must be transitioned (stiffened) from its characteristic semi-flexible design to a rigid system before it is connected to the bridge rail.

AASHTO [2006] suggests the use of approach guardrail systems at the beginning of all bridge railings in high speed rural areas.

A bridge approach guardrail system should include a transition from the guardrail system to the rigid bridge railing system that is capable of providing lateral resistance to an errant vehicle. AASHTO recommends that the approach guardrail system shall have a crashworthy end terminal at its nosing.

The approach guardrail should be structural and functionally adequacy and so that it withstands the impact of a crash and redirect the impact of a car.

FWHA, (1998), suggests the following common types of approach guardrail for high and low speed highways,

- W-beam on wood posts with wood blockouts,
- W-beam on steel posts with wood blockouts, and
- Thrie beam on wood posts with wood blockouts.

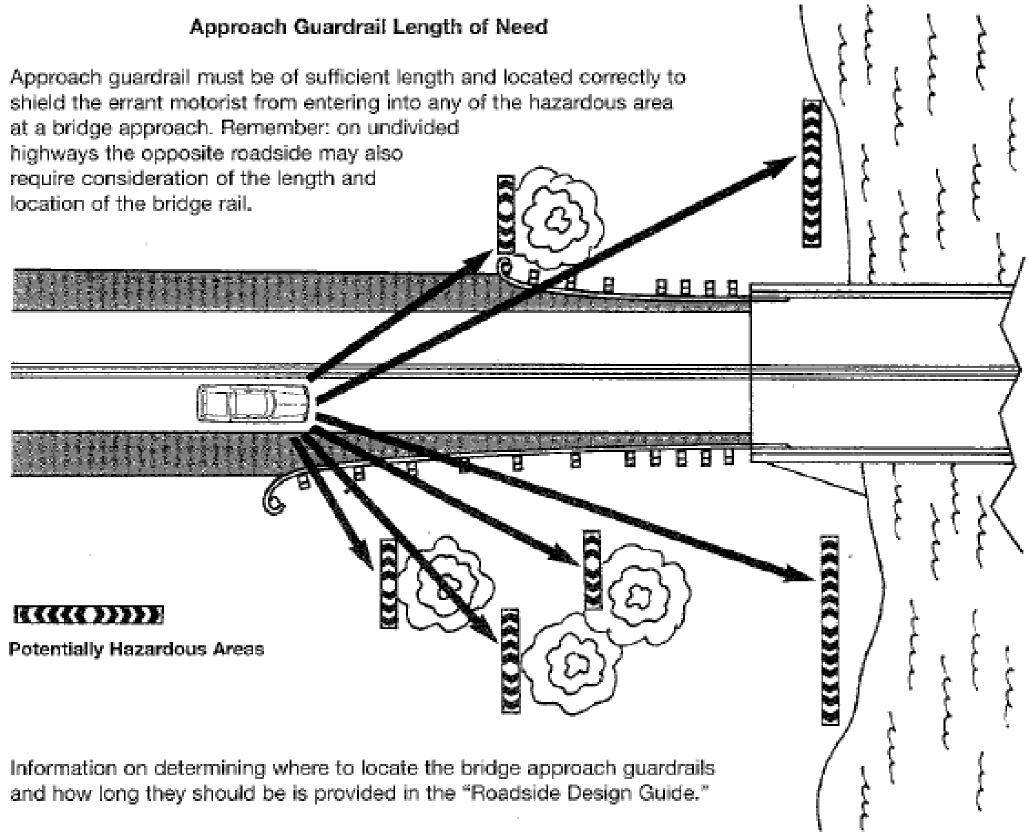
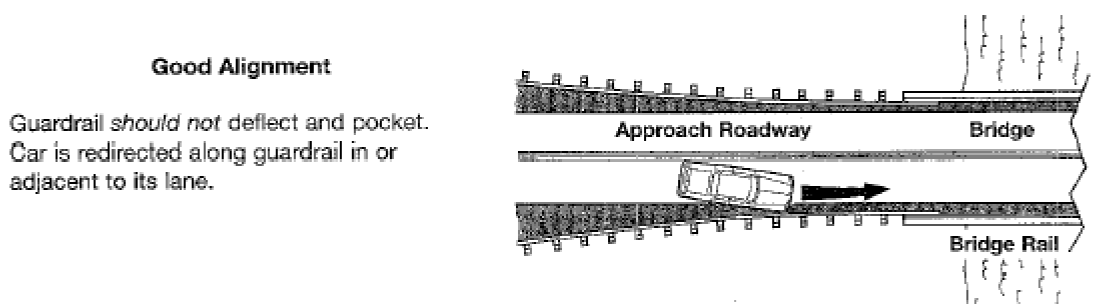


Figure 9: Shows Approach guardrail length of need [FWHA, 1998]



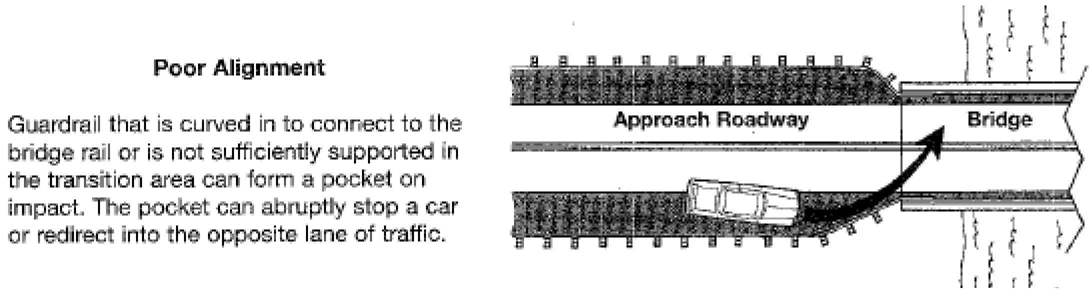


Figure 10: Approach Guardrail Alignment [FWHA, 1998]

3.3.5 End treatment

AASHTO suggests that the approach end of a parapet or railing shall have a crashworthy configuration or be shielded by a crashworthy traffic barrier.

AACRA recommends the use of end treatments that have been tested under NCHRP to determine their crashworthiness. System tested successfully under NCHRP include energy absorbing terminal (EAT), WRSB terminals, sand filled barrels, proprietary crash attenuation devices and 6m concrete ramp to type F (70km/hr and less).

3.4 Safety Audit of Bridges

Safety audit of roads mainly focuses on the road safety issues considering the bridge as part of the road. Thus, this section of the literature review mainly covers the road safety issues which include bridges.

According to the Draft ERA Road safety audit manual [2002], Road Safety Audit is a systematic procedure that brings traffic safety knowledge into the road/bridge planning and design process to prevent traffic crashes. This is usually carried out by an independent qualified auditor or a team of auditors who report on ways of minimizing risks to road users.

As per the Dublin National Roads Authority, *Road Safety Audit Guidelines*, [2004], Road Safety Audit is the evaluation of road schemes during design and construction to identify potential safety hazards which may affect any type of road user, before the scheme is opened to traffic, and to suggest measures to eliminate or mitigate those problems.

The implementation of the traffic safety knowledge into the road/bridge planning and design process is much better than the evaluation of road/bridge schemes during design and construction stages.

ERA Draft Road safety manual [2002] suggests to use in house safety experts or external specialist as an audit team. It is evident that the benefit of undertaking traffic safety audit outweighs the cost incurred to conduct it. Australia and New Zealand experiences suggests that traffic safety can add up to a maximum of 4% to the cost of road project. But, this has to be compared against the potential benefits such as saving in time and cost, reduction in the number of accidents and reductions in possible litigation costs. In the UK, the Lothian Regional Council has estimated the benefit-cost ratio of the RSA as 15:1, while TRANSIT New Zealand has estimated the benefit-cost ratio as 20:1.

3.4.1 Safety Principles

The Dublin National Roads Authority, *Road Safety Audit Guidelines*, recommends that a road/bridge safety auditor need to have a broad experience in road/bridge design, traffic and safety engineering to ensure that he has the knowledge and ability to refer back to the basic principles in bridge safety, and ask a series of pertinent questions such as the road/bridge design layout, information for road users, sight distance limitations, and the presence of adverse geometric alignment on the approach roadway. The safety of the bridge could be compromised and remedial measures may be required to remove this potential or actual deficiency if any of the above problems occur.

According to the Dublin National Roads Authority, *Road Safety Audit Guidelines*, the designer’s role is to design a safe road/bridge environment that should eliminate sharp horizontal curves and sag curves, provides consistent width on the approach roadways and the bridge, provide adequate information for road users of the layout and conditions ahead, provide adequate warning of hazards or unusual layouts ahead. The designer need to incorporate all the safety elements at each stage of design and this can easily be accomplished by using checklists prepared for each stage of design. This will greatly reduce the task of the safety auditor during the safety audit of the scheme. One of the objectives of this paper is to prepare a bridge design safety audit checklist which will assist the designer to check every safety aspect of the design at the different stages of design.

3.4.2 Conducting Road/Bridge Design Safety Audit

ERA Road Safety Manual [2002] suggests that three parties should be involved in the road safety audit, the designer(s) of the project, who had involved in the design of the project, the client, who is responsible for the project and the auditor(s), who carry out the audit. ERA recommends including a safety auditor in the ToRs for road design consultants if projects are formulated in the absence of a formal road safety audit.

3.4.3 Audit Stages

ERA Road Safety Audit Manual suggests that audit should be carried out in several successive different stages during the course of planning, designing, construction and implementation of a road/bridge project.

The five commonly used audit stages from planning to post-construction process are as follows,

Stage 1. Planning Phase

The bridge safety audit at this stage deals with traffic safety aspects of the initial design which should relate to bridge site selection, setting appropriate bridge geometrics, setting appropriate bridge design criteria, selecting the type of traffic safety barrier to be in place and the accommodation of non-motorized traffic.

Stage 2. Preliminary Design Phase

At this stage, a preliminary design which shows the general arrangement drawing consisting of plan, elevation and typical cross section of the bridge should be developed therefore the audit at this stage should examine the layout of the bridge, steep gradient at the bridge approaches, sag vertical curve at the bridge and typical cross section against the design criteria which is set at the planning stage. The width of the approach roadway and the width of the bridge should be checked for its consistency depending on the intended service of the bridge, adverse geometric alignment should be checked at both approaches, the need for a transition section between the bridge railing system and approach guardrail should be checked.

Stage 3. Detailed Design Phase

At this stage, the focus of the safety audit is on examining the approach sight distance, approach roadway alignment, the length of need of approach guardrail, the provision of pedestrian walkway, the width of the bridge, type & length of approach guardrail and checking the adequacy of deck drainage.

Stage 4: Construction Phase

The focus at this stage is a site inspection by day and at night, or just prior to opening to traffic. Placement of approach guard rail, crush barrier, narrow bridge & yield sign near the approach to the bridge, painting curbstone and crush barrier with reflectors and particular attention should be given to checking that needs of all road users, including pedestrians, cyclists, as well as motorized users (depending on the road class under consideration), are adequately catered for.

This stage also covers the audit of traffic management arrangements during construction. Especially diversions for new bridge construction should have sufficient opening to allow for safe passage of flood. Traffic using the diversion should also be given adequate advance warning and guidance as the work progresses.

Stage 5: Monitoring Existing Roads/Bridges

This stage involves monitoring a road/bridge a few months after opening to traffic to ensure that it is operating as anticipated. Because at this stage, low cost measures can easily be identified and implemented.

3.5 Bridge Safety Inspection

According to [AASHTO, 1996] bridge is a structure including supports erected over a depression or an obstruction such as water, or railway and having a track or passageway for carrying traffic or other moving loads and having an opening measured along the center of the roadway of more than 20 feet (6.10m) between abutments.

There is no manual prepared by ERA or AACRA for bridge safety inspection thus international standards set by AASHTO and FHWA will be reviewed.

As stated in AASHTO's *Manual For Condition Evaluation of Bridges* [1994], bridge inspections are conducted to determine the physical and functional condition of the bridge, to form the basis for the evaluation and load rating of the bridge, as well as analysis of overload permit applications, to initiate maintenance actions, to provide a continuous record of bridge condition and rate of deterioration, and to establish priorities for repair and rehabilitation programs.

National Bridge Inspection Standards [NBIS] is an international regulation set by FHWA and establishing requirements for inspection procedures, frequency of inspections, qualifications of personnel, inspection reports, and preparation and maintenance of bridge inventory records. The NBIS apply to all structures defined as bridges located on or over all public roads.

Bridge inspections are performed for at least three reasons to ensure the safety of bridges, to discover needs in maintenance and repair, and to prepare for bridge rehabilitation and should be performed in accordance with the inspection procedures presented in the AASHTO *Manual for Condition Evaluation* [1994].

3.5.1 Traffic Safety Features Inspection Procedures

As per AASHTO's *Manual for Condition Evaluation of Bridges* [1994], the evaluation of bridge railing and parapets should be on the structural capacity and as to the adequacy of geometry.

According to the *Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges*, Item 36 [FWHA,1995], the rating of traffic safety features is a four digit code composed of four segments composed of bridge railings, transitions, approach guardrail and approach guardrail ends. Collision damage or deterioration of the elements isn't considered when coding this item. Table 7 presents coding of Traffic safety Features in the NBI,

Table 7: Coding Traffic Safety Features NBI, [FHWA,1995]

Segment	**Description**	**Coding Length**
36A	Bridge Railings	1 Digit
36B	Transitions	1 Digit
36C	Approach Guardrail	1 Digit
36D	Approach Guardrail ends	1 Digit

The NBI suggests that the reporting of these features shall be as follows: 0 (zero), 1(one) and N (not-applicable) as shown on the table 8 below.

Table 8: Reporting Traffic Safety Feature NBI, [FWHA, 1995]

Code	Description
0	Inspected feature doesn't meet currently acceptable standards
1	Inspected feature meets currently acceptable standards
N	Non-applicable or a safety feature isn't required

3.5.2 Bridge Railings

As per the Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges, Item 36 [FWHA,1995], the inspection of bridge railing need to focus on some of the factors that affect the proper functioning of bridge rail such as, height, material, strength and geometric features. The Recording and Coding Guide recommends that bridge railings should meet specific geometric criteria and to resist specified static loads without exceeding the allowable stresses in their elements. It further states that bridge railing should be crash tested per FHWA policy. Railings that meet these criteria and loading conditions are considered acceptable. The currently in use bridge railing system by ERA and AACRA doesn't meet the functional as well as the structural adequacy. It is recommended that crashworthy bridge railing be adapted for our country.

3.5.3 Transitions

The Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges, Item 36 [FWHA,1995], suggests that the transition from approach guardrail to bridge railing should not be left without anchoring to the bridge railing. The bridge railing and the approach guardrail should be firmly attached. It requires that the approach guardrail be gradually stiffened as it comes closer to the bridge railing. ERA standard recommends the use of transition section between the approach guardrail and the bridge railing system. The ends of curbs and safety walks need to be gradually tapered out or shielded.

3.5.4 Approach guardrail

The Recording and Coding Guide recommends that the approach guardrail should be structural adequate and should be compatible with the transition designs. It further states that the approach guardrail should have adequate length and it should be structurally sound to shield motorists from the hazards at the bridge site. In addition to this, the approach guardrail should safely redirect an impacting vehicle with not causing snagging or pocketing of an impacting vehicle. AASHTO Roadside Design Guide and subsequent FHWA or AASHTO guidelines provides acceptable guardrail design. ERA standard recommends the use of flexible guardrail along the approach roadway of the bridge.

3.5.5. Approach guardrail ends

The ends of the approach guardrail should be flared, buried, made breakaway, or shielded. Design treatment of guardrail ends is given in the AASHTO Roadside Design Guide. ERA standard recommends the use of flared and buried end terminal treatment at the end of approach guardrail.

4. DEVELOPMENT OF BRIDGE SAFETY AUDIT PROCEDURES

The literature review has compiled the suggestion of different geometric manuals with regard to bridge site selection, bridge width, approach alignment and sight distance for design of new bridges. The safety effect of these factors is shown on the review. The review shows that the safety performance of bridges on trunk roads is different than other classes of roads. This is because bridges designed on trunk roads are normally undertaken with more safety considerations than other types of roads. The selection of appropriate bridge site should present the maximum gradient of the approach roads to be appropriate to the types of vehicle likely to travel on the road as well as offering vertical curves and sight distances suitable for the maximum speed of vehicles using the bridge. Previous studies reveal that narrow bridges on horizontal curves can have limited horizontal stopping sight distance. The safety and operational concerns at narrow bridges are similar to those on roads with narrow shoulders. The lack of shoulder width on the bridge may make it impossible to avoid a crash or object on the roadway ahead. Previous studies suggest that at least the bridge shoulder should be 0.90m on each side across the bridge. The review findings indicated that the safe recommended width for two Lane Bridge is 7.3m whereas 4.2m is suggested for single lane bridges. Single lane bridges aren't recommended as they are the cause of accidents. It is advisable to construct two lane bridges by allowing rooms for future expansion. Previous studies show that bridge width is the most important factor for traffic accidents at bridges. The review points out that the need for widening an existing bridge should be based on site specific study that reveals a safety problem. The safety inspection of existing bridges should identify the problem associated with narrow bridge and recommend appropriate safety measure such as widening of existing bridge and/or construction of new bridge that will accommodate for two lane traffic and shoulder width.

Previous studies show that bridges located on sharp bends and on sag vertical curves are more dangerous. Settlement of the approach roadway embankment behind the abutment results in a dip in the road and causing traffic accidents on the bridge.

Adequate sight distance at both approaches with all regulatory or warning signs at bridge approach area should be ensured at all times. Studies found that frequency and severity of accidents at bridges can be reduced through the provision of adequate visual information. The importance of roadside clear zone is vital for safe use by errant vehicles. Studies show that the provision of traffic safety barrier is important in reducing the severity of accidents on bridges. The review reveals that bridge traffic barrier systems, traffic railings, and combination railing shall be structurally and geometrically crashworthy. The use of approach guard rail at the beginning of all bridge railings in high speed rural areas is vital. The review shows that the length of need and alignment of approach guardrail is significant for shielding an errant motorist from entering into any of the hazardous area. Studies found that approach guardrail must be transitioned from its characteristics semi-flexible design to a rigid system before it is connected to the bridge rail. Design Manuals suggest that the approach guardrail system shall have a crashworthy end terminal at its nosing.

Studies show that road safety audit is vital to identify potential safety hazards which may affect any type of road user, before the scheme is opened to traffic, and to suggest measures to eliminate or mitigate those problems. Road/Bridge safety audit should be carried out from planning to construction stages. The designer of the project, the client and the safety auditor should be involved in the safety audit of the project. Recent studies show that the benefits of undertaking traffic safety audit outweighs the cost incurred to conduct it. UK and New Zealand study show that the benefit – cost ratio of the RSA equals to 15:1 and 20:1 respectively.

4.1 Safety Audit Findings

Safety audit of new bridge design is carried out on different design projects. As it is difficult to get one design project from planning stage all the way to the construction stage, different design projects are selected for checking the procedures. The audit was carried out starting from the planning stage and extends to the construction stage.

At the time of preparation of this thesis, the available bridge design project for planning stage and construction stage bridge design is Gonder By-Pass project. The bridge selected for the Preliminary Design Stage and Detailed design stage check is located on Kogne – Zemute – Beke and Mazoria – Omo Road Upgrading project.

4.2.1 Planning stage safety audit findings

The Gonder by-pass project is located in Gonder town and by-passes the town of Gonder for most of its stretch. It consists of four sections namely AB, BC, CD, and DE. The project is 75 % completed. Section CD is located on the existing town section and rehabilitation work on this section consists of overlaying one layer of wearing surface.

There is an existing Arch bridge on section CD of Gonder by-pass project. The bridge is found to be in bad condition with sever crack on the Arch Barrel. At the moment, the city administration banned heavy vehicles from using the bridge. A team of engineers mobilized to make a preliminary finding of the existing bridge with respect to structural condition. As usual, the safety aspect of the bridge that is the approach roadway alignment, bridge width and traffic safety feature isn't considered primarily.

Safety Problems of the Existing Bridge

Problem – Approach Alignment on the Southern Side

The approach alignment on the southern side has a horizontal curve at 150m from the bridge end. The town section median stops at approximately 150m from the bridge leaving a 14m undivided approach roadway and tapering to 7m on the bridge.

Recommendation

The new bridge design should be a dual carriageway bridge separated by median.

Problem – Approach Safety Barrier on the Southern Side

The existing traffic safety barrier isn't a standard flexible guardrail system. The existing safety barriers is made of metal tube posts spaced at 2m interval and two rows of metal tube rails having a height of 1m and spaced at 0.5m interval.

Recommendation

Provide flexible approach guard rail, end section with treatment and transition section.

Problem – Bridge Width

The width of the approach roadway tapers from four lanes to two lanes on the existing bridge. The width tapers from 14m on the approach roadway to 7m on the bridge.

Recommendation

The new bridge design should be a dual carriageway bridge separated by median. A clear carriageway width of 7.3m should be provided for each carriageway.

Problem – Pedestrian Crossing

There is no pedestrian crossing provided on the existing bridge. The 7m width is accommodating all kinds of traffic. Pedestrians are susceptible for accidents.

Recommendation

A segregated pedestrian crossing should be provided on both sides. A minimum of 1.5m width should be provided as per the town section requirement.

Problem – Bridge Railing System

The existing bridge consists of metal tube posts and rails having heights of 1m and post spacing of 2m and rail spacing of 0.5m.

Recommendation

Standard concrete crush barrier should be provided at the inner face to protect non-motorized users from traffic accidents. Steel post and rail should be provided at the outer face to protect pedestrian from falling of the bridge. A minimum of 1.5m width should be provided as per the town section requirement.

Problem – Deck Drainage System

There is no deck drains on the existing bridge to drain away the surface water. In addition, the deck doesn’t have longitudinal slope to drain the surface water.

Recommendation

A minimum of 0.5% longitudinal gradient and deck drains at quarter points should be provided to facilitate surface drainage.

Problem – Approach Alignment on the Northern Side

The approach alignment on the northern side has an adverse geometric alignment. The approach roadway faces right of way problem on both sides, to the east is secondary school and to the right is Atse Fassel Swimming Pool which is Historical. The approach roadway has no tangent section and curves to the right and then to the left not to demolish the historical monument and the secondary school.

Recommendation

The new bridge design should be a dual carriageway bridge separated by median.

4.2.2 Preliminary Design Stage Safety Audit Findings

The selected bridge for the Preliminary Design Stage is located on Kogne – Zemute - Beke Road Upgrading project.

There is no existing road that links the two towns and hence there is no traffic using the road. The purpose of the bridge is to provide at-grade Bridge crossing for motorized and non-motorized users.

Problem – Approach Alignment on the Western Side

This side approach alignment has an adverse geometry both vertically and horizontally. The vertical alignment has a steep grade of 10% with sag curve at the parapet end and 0% grade at the bridge. There is a 30m radius sharp curve at about 40m from the bridge end.

Recommendation

The calculated stopping sight distance for a design speed of 40km/hr is 50m. The provided tangent section isn't adequate for stopping sight distance and thus a minimum of 60m tangent section should be provided to allow for safety. Rumble strips should be provided on the steep section as a speed reduction in addition to reducing the grade to a maximum of 7%. As this is preliminary design stage audit the above recommendations should be incorporated in the final design stage.

Problem – Approach Safety Barrier on the Western Side

There is no approach safety barrier shown on the preliminary design drawing. No transition section, approach guard rail and terminal section is provided on preliminary plan drawing.

Recommendation

The provided bridge railing system is rigid and thus transition guard rail, approach guard rail and end section with treatment should be provided.

Problem - Bridge Width

Standard two lane bridge width is shown on the preliminary cross section of the bridge. This width includes 7.30m clear carriageway width and 0.80m for railing and walkway.

Recommendation

A reduce speed sign should be posted on the approach roadway. Delineation of the roadway is recommended by road marking.

Problem – Walkway for Pedestrian

The total walkway provision on the bridge is 0.8m including the width of the post and rail system. The provided walkway width isn’t sufficient to accommodate all non-motorized users.

Recommendation

A segregated pedestrian walkway is recommended on one side of the bridge. Concrete crush barrier should be used at the inner face and concrete post and rail should be used at the outer face so as to be consistent with the other side post and rail. The width of the walkway should be 1.5m inclusive of post & rail system.

Problem – Bridge Railing System

The bridge railing system designed on this bridge consists of concrete post and rail on the outer face.

Recommendation

Place concrete crush barrier at the inner face and steel post and rail at the outer face.

Problem – Approach Alignment on the Eastern Side

The approach alignment on this side has an adverse vertical alignment. The approach roadway has a constantly descending grade as the bridge is located in a valley section.

Recommendation

Rumble strips should be placed at a closer interval all alone the approach roadway along with speed reduction signs.

4.2.3 Detail Design Stage Safety Audit Findings

The selected bridge for the detailed design stage is located on Mazoria – Omo Road Upgrading project.

There is an existing gravel road that links the two towns. There is an existing bridge but new bridge is proposed at the upstream of the existing bridge. The main reason for replacement is the existing bridge doesn’t fulfill the two lane width requirement and safety requirement.

Some characteristic safety problems described which are missed by the designer are indicated below in order to improve the safety of the bridge and minimize accident occurrences.

Problem – Approach Alignment on the Mazoria Side

This side approach alignment has an adverse geometry on the horizontal alignment. There is a 60m radius sharp curve at about 20m from the bridge end. There is no stopping sight distance provision on this side.

Recommendation

The calculated stopping sight distance for a design speed of 40km/hr is 50m. The provided tangent section isn’t adequate for stopping sight distance and thus a minimum of 60m tangent section should be provided to allow for safety.

Problem – Approach Safety Barrier on the Western Side

The plan drawing shows that there is no approach guard rail , transition section, and end terminal section.

Recommendation

The preliminary bridge railing system is rigid and thus transition guard rail, approach guard rail and end section with treatment should be provided. The guard rail should extend up to the limits of the influence zone.

Problem – Bridge Width

Standard two lane bridge width is shown on the preliminary cross section of the bridge. This width includes 7.30m clear carriageway width and 0.80m for railing and walkway.

Recommendation

Speed reduction sign should be posted on the approach roadway. Delineation of the roadway is recommended by road marking.

Problem – Walkway for Pedestrian

The total walkway provision on the bridge is 0.8m including the width of the post and rail system.

Recommendation

A segregated pedestrian walkway is recommended on one side of the bridge. Concrete crush barrier should be used at the inner face and concrete post and rail should be used at the outer face so as to be consistent with the other side post and rail. The width of the walkway should be 1.5m inclusive of post & rail system.

Problem – Bridge Railing System

The bridge railing system designed on this bridge consists of concrete post and rail on the outer face.

Recommendation

Place concrete crush barrier at the inner face and steel post and rail at the outer face.

4.2.4 Construction Stage Safety Audit Findings

The selected bridge for the construction stage is located on Gonder By-pass project.

Some characteristic safety problems described which are missed by the designer are indicated below in order to improve the safety of the bridge and minimize accident occurrences.

Problem – Approach Alignment on the Southern Side

The approach alignment on the southern side has a horizontal curve at 240m from the bridge end. The new alignment departs from the existing road at the outskirts of Azezo village and starts with a right curve having a radius of 270m. At the time of the site visit the approach roadway on this side is completed upto the level of Asphalt Binder Course. The parapet isn't completed upto the top level. The carriageway width on the approach roadway is 7.0m with a shoulder width of 1.5m. A slightly higher carriageway width is provided on the bridge 7.2m and a raised walkway having a clear walkway width of 1.5m ia also provided.

Recommendation

The calculated stopping sight distance for a design speed of 80km/hr is 130m. Since a tangent section of 240m is available there is no sight distance problem. But, advance warning sign and a speed post should be placed away from the clear zone.

Problem – Approach Safety Barrier on the Southern Side

Upon reviewing the as-built drawing, there is no approach safety barrier shown on the final detailed plan drawing.

Recommendation

The designed bridge railing system is rigid and thus transition guard rail, approach guard rail and end section with treatment should be provided.

Problem – Bridge Width

In terms of clear carriageway width the bridge has a slightly wider width than the approach roadway.

Recommendation

At this stage it is impossible to provide shoulder width on the bridge as the bridge superstructure is under construction. A reduced speed should be posted on the approach roadway. Solid center line marking should be painted for guiding traffic alone its lane.

Problem – Walkway for Pedestrian

A clear pedestrian walkway width of 1.5 is provided on both sides of the bridge. However there is no protection provided to safe guard non-motorized users from vehicular collision.

Recommendation

Concrete crush barrier is recommended at the inner face and steel post and rail should be used at the outer face.

Problem – Bridge Railing System

The bridge railing system designed on this bridge consists of concrete post and rail on the outer face and no railing for the inner face.

Recommendation

Place concrete crush barrier at the inner face and steel post and rail at the outer face.

Problem – Approach Alignment on the Northern Side

The approach alignment on the northern side has an adverse geometric alignment. The approach roadway passes through a sharp curved cut section having a horizontal radius of 170m. The point of visibility is 70m from the bridge end. The bridge has 40m tangent section.

Recommendation

The calculated stopping sight distance for a design speed of 50km/hr is 65m. A posted speed of 40km/hr should be placed before the beginning of the horizontal curve. Advance warning sign should be placed at the beginning of the horizontal curve. Solid Centerline marking should be placed for both the bridge and the horizontal curve to prohibit overtaking near the bridge.

4.3 Safety Audit Checklists

All these safety factors such as width constriction, insufficient walkway width, poor approach alignment, and poor approach sight distance should be mitigated during different stages of design. The evaluation of Bridge during feasibility, design, and construction will help to identify potential safety hazards which may affect any type of bridge user before the bridge is opened to traffic, and to suggest measures to eliminate or mitigate those problems. For example, the width of the bridge, the approach roadway alignment and the use of approach guard rail is determined at the preliminary design stage while fixing the design standard and design criteria. Because, projects at the planning stage by their nature have little information about the details of design. It is vital that the designer incorporates the important safety elements during the preliminary and detail design stage. The designer of the bridge should check that all safety elements were incorporated into the design. The easy way to accomplish this is to use checklists. Checklists are prepared from planning to through construction stages so that safety issues are critically addressed at each stage of the design. They are used to consider all factors and provide a reminder of potentially overlooked safety issues. It also provides a measure of continuity from audit to audit.

One of the objectives of this thesis is to prepare checklists to be used while designing new bridges. These checklists can also be used for auditing bridge design projects. The prime purpose of these checklists presented is to provide a guide to bridge engineers in terms of the bridge safety elements which need to be considered while undertaking bridge designs, and present a user-friendly mechanism for keeping track of the progressive monitoring of the bridge design.

Bridge engineers are advised to use the prepared check list to make sure that all safety factors are included in their design. The checklists for the different stages of design are compiled in Appendix B.

4.4 Safety Audit of Bridge Design

As shown in the literature review, bridge design should be audited right from the planning stage and should continue to the detail design stage. Nevertheless, planning stage audits aren't effective because of the little information about the details of design. It is essential to carry out the preliminary and detail design stage audits to make sure that the designer have incorporated all safety elements into his design. Safety audit of bridge design can easily be achieved by the use of checklists. The audit team should use the checklists prepared for ease of checking. The checklists for the different stages of design are compiled in Appendix B.

In general, the different stages of audits which need to be carried out following the completion of each of the stages of design are summarized as follows:

Stage 1- Planning Stage Audit: A bridge safety audit starts from the planning stage. Projects at the planning stage by their nature have little information about the details of design. A preliminary layout of a bridge may be available along with information about the basic design issues (e.g., two lane bridge, walkway width). Despite limited information, at this stage there is significant opportunity to incorporate safety enhancements into the bridge design at the low cost. The audit team should give special consideration to issues such as the accommodation of all user groups, design consistency, and operational features.

Stage 2- Preliminary Design Stage Audit: A bridge safety audit should be undertaken as soon as practicable following completion of the planning stage. At this stage bridge plans are 30 to 40% complete and the project should have enough information about the details of design, such as approach roadway alignment and grade, lane and walkway widths, type of bridge railing system, approach guardrail details and road signs and markings. At this stage, the audit team should give special attention to the approach roadway alignment, sight distance constraints and the provision of approach guardrail, end treatments and transition section.

Stage 3- Detailed Design Stage Audit: A bridge safety audit should be undertaken on completion of detailed design and before tendering the works. At this stage, plans are 80 to 90% complete. All detailed aspects of the bridge design shall be finalized including traffic safety features (types and placement), traffic signs, delineation and road marking, traffic signal placement/operation. The audit team should check for any overlooked safety elements because at this stage, the bridge design has reached to a point that should be constructable.

4.5 Bridge Safety Audit Procedures

Typical bridge safety audit procedures include the following steps:

1. Identification of bridge project or bridge in-service to be audited: this is the first step to be carried out before the initiation of the audit. The bridge safety audit

program may encompass projects of any size to be audited at any stage of design.

2. Selection of Bridge Safety Audit Team: the second step on the bridge safety audit process is the selection of bridge safety team. The team should consist of the design engineer, the team leader of the project and traffic/safety engineer.

3. Audit briefing: The Audit Brief is the most important to the bridge safety audit procedure. It defines the scope of the bridge safety audit and contains all the information necessary to give Audit team a full understanding of the bridge design. After the briefing, the audit team should collect all the relevant information for the project under consideration. For example preliminary stage audit should collect all preliminary design details of the bridge layout that will assist the team for making detailed review. The detailed design stage and the construction stage audit should collect their corresponding data for comprehensive review.

4. Perform Field observations: this is the most important part of the bridge safety audit. Field observation need to be carried out for each stage of the audit to verify the incorporation of all safety issues and any site specific safety issues.

5. Conduct audit analysis and prepare report of findings: after checking all the bridge layouts, cross section drawings, as-built drawings, and performing field observations the team should carry out audit analysis and prepare report of findings. This should briefly address the safety problems and recommend appropriate safety measures.

6. Incorporate findings into the project: once the audit analysis is carried out and the report of findings complied it is necessary to incorporate the findings into the on going project so that safety improvements will be made into the existing design at the right time and at a low cost.

5. DEVELOPING BRIDGE SAFETY INSPECTION PROTOCOL

The literature review points out that, bridge inspections should be conducted to determine the physical and functional condition of the bridge. Studies show that bridge inspections should be carried out at least once in two years. Bridge safety inspection should be carried out to ensure the safety of bridges. International standards suggest that Bridge inspections should be carried out in accordance with standard inspection procedures.

Studies show that rating of traffic safety features such as bridge railing, transitions, approach guardrail and approach guardrail ends is vital to identify the extent of damage on the safety features. The review reveals that the inspection of bridge railing needs to concentrate on important safety factors such as height, material, strength and geometric features. Bridge railing should meet specific geometric criteria and should be crush tested. The inspection of transition railing should check for its proper connection with the bridge railing. The inspection should verify the gradual stiffening of the transition railing as it gets closer to the bridge railing. Approach guardrail inspection should focus on the structural adequacy, the adequate length of need, height and material. The end treatment should be flared, buried with an approved crashworthy end treatment or crush cushion.

5.1 Existing Bridge Inspection

The selected existing bridges are located along Modjo – Awassa road. These are Meki river bridge, Bulbula riverbridge, Awada 1river bridge, Awade Godu river bridge and Tataba Tinshu river bridge. According to Modjo – Awassa *Traffic Analysis and Safety Measures Report* (Berhanu, 2009), these bridges have average accident per year of 3, 5, 3, 3, and 4 respectively.

Bridge safety inspection was carried out on the selected existing bridges to assess the approach roadway alignment and to identify any safety related problems on the bridge.

The bridge safety inspection included the inspection of the approach alignment at the entry and exit, the approach sight distance at the entry and exit, the approach gradient at the entry and exit, approach roadway width and bridge width, the crush barrier type and length.

The data collected included the following, the general information of the bridge such as, the location, name of project, year constructed, number of lane, approach roadway width, bridge width, pedestrian walkway width, type of bridge railing system, post width and height, the AADT and the functional classification. All the required data on the approach roadway alignment, the approach sight distance, the traffic safety features on the approach roadway and the bridge were collected.

The findings of the inspection of the existing bridge is presented as follows,

Bridge No. 1: Meki River Bridge

This bridge is located at approximately 130.5km from Addis Ababa in Meki Town. The bridge is constructed in the year 1953 as a two lane bridge. This road has an AADT of 3754 and is functionally classified as DS3 Trunk Road.

The clear carriageway width is 7.50 meters and the width across parapets is 9.30 meters. No shoulder is provided to both sides of the carriageway. The pedestrian walk way which is provided on the bridge is 0.6m and doesn’t meet the minimum walkway requirement for town section bridges. The post and rail on the deck are of concrete construction and are in good condition. The wing walls are made stone masonry and out of the 4 approach wing walls 3 are in good condition. Wing wall at inlet Awassa side completely damaged by traffic as it is situated on sharp bend. The wearing surface is of hot mix asphalt and in good condition with no pavement marking.

Figure 11.Photo showing Awassa side Approach Roadway

i) Modjo Side: The approach roadway on Modjo side has tangent section with visible approach sight distance to the bridge. Because of the recent rehabilitation of Modjo - Awassa road the asphalt concrete wearing surface is found in good condition. The approach roadway has a width of 7.30m and a paved shoulder width of 2.20m on the left side and 1.90m on the right hand side. There is no approach guard rail for directing the traffic to the bridge. The roadway tapers from wider town section to a narrower section on the bridge. The approach roadway is on fill the right side is supported by retaining wall while the left side has 3H:1V fill slope.

ii) Awassa side: The approach roadway on this side has a reverse curve which leaves no approach sight distance to the bridge. It has an adverse geometric alignment. Because of the recent rehabilitation of Modjo - Awassa road the asphalt concrete wearing surface is found in good condition. The approach roadway has a width of 10.20m and a paved shoulder width of 2.0m on the left side and 1.80m on the right hand side. There is no approach guard rail for directing the traffic to the bridge. The roadway tapers from wider town section to a narrower section on the bridge. Shops and private estates are found to the left and right of this side approach.

Findings:

Direction of Inspection: Modjo Side

a. There is no narrow bridge sign posted before reaching this bridge.
b. There is no approach guard rail, end treatment and transition railing next to the wing walls.
c. The centerline as well as the edge marking are worn out and are barely visible throughout the approach roadway and the bridge.
d. The approach roadway has straight tangent section and flat grade.
e. The width of roadway tapers from a wider town section to a narrower bridge section.

Direction of Inspection: Awassa Side

a. The reverse curve sign isn't posted at the correct place.
b. There is no approach guard rail, end treatment and transition railing next to the wing walls.
c. The centerline as well as the edge marking are worn out and are barely visible throughout the approach roadway and the bridge.
d. The approach roadway has adverse geometric alignment with reverse curve and flat grade.
e. The width of roadway tapers from a wider town section to a narrower bridge section.

Bridge No. 2: Bulbula River Bridge

This bridge is located at approximately 184.5km from Addis Ababa in Bulbula village. The bridge is constructed in the year 1953 as a two lane bridge. This road has an AADT of 2808 and is functionally classified as DS3 Trunk Road.

The bridge is located on sag vertical curve. The clear carriageway width is 7.30 meters and the width across parapets is 9.30 meters. No shoulder is provided to both sides of the carriageway. The pedestrian walk way which is provided on the bridge is 0.65m and doesn't meet the minimum walkway requirement for town section bridges. The post and rail on the deck are of concrete construction and are in good condition. The wing walls are made of stone masonry and slanted at about 30 degree from the edge of the roadway and out of the 4 approach wing walls 3 are in good condition. Wing wall at downstream Meki side is completely damaged by traffic. The wearing surface is of hot mix asphalt and in good condition with visible centerline marking and fainted edge marking.

Figure 12.Photo showing Bulbula River Bridge, Modjo side approach

i) Modjo Side: The approach roadway on Modjo side is in a cut section with sharp horizontal curve situated at about 180m from the bridge. Because of the recent rehabilitation of Modjo - Awassa road the asphalt concrete wearing surface is found to be in good condition. The approach roadway has a width of 7.40m and a paved shoulder width of 3.0m on the left side and 3.0m on the right hand side. There is a narrow bridge sign at 100m from the bridge. There is no approach guardrail installed near the bridge, where as there is a guardrail for the horizontal curve which is situated at approximately 180m from the bridge. The guardrail on the horizontal curve is damaged as a result of traffic collision and concrete blocks are placed for safeguarding traffic. The roadway tapers from wider town section to a narrower section on the bridge. The approach roadway is on cut section with paved shoulder on both sides. Even though, there is a lined masonry ditch there exists an erosion gully adjacent to the roadway.

ii) Awassa side: The approach roadway on this side has a tangent section with mild grade. It has no adverse geometric alignment. Because of the recent rehabilitation of Modjo - Awassa road the asphalt concrete wearing surface is found in good condition. The approach roadway has a width of 7.70m and a paved shoulder width of 2.60m on the left side and 2.25m on the right hand side. There is no approach guard rail for directing the traffic to the bridge. The roadway tapers from four lane to two lane on the bridge. Shops and private estates are found to the left and right of this side approach.

Findings:

Direction of Inspection: Modjo Side

a. There is a narrow bridge sign posted before reaching this bridge.

b. There is approach guard rail for the horizontal curve but it doesn’t extend throughout the bridge approach roadway.

c. The centerline marking is clearly visible while the edge marking is worn out and is barely visible throughout the approach roadway and the bridge

d. The approach roadway has adverse geometric alignment and mild grade.

e. The width of roadway tapers from a wider town section to a narrower bridge section.

Direction of Inspection: Awassa Side

a. There is a narrow bridge sign posted before reaching this bridge.

b. There is no approach guard rail, end treatment and transition section next to the wing walls.

c. The centerline marking is clearly visible while the edge marking is worn out and is barely visible throughout the approach roadway and the bridge.

d. The approach roadway is on tangent section and has a mild grade.

e. The width of roadway tapers from a wider town section to a narrower bridge section.

Bridge No. 3: Awade 1 River Bridge

This bridge is located at approximately 225.65km from Addis Ababa in Arsi Negele town. The bridge is constructed in the year 1955 as a two lane bridge. This road has an AADT of 2808 and is functionally classified as DS3 Trunk Road.

The bridge is located on sag vertical curve. The clear carriageway width is 7.45 meters and the width across parapets is 9.35 meters. No shoulder is provided to both sides of the carriageway. The pedestrian walk way which is provided on the bridge is 0.85m and doesn't meet the minimum walkway requirement for town section bridges. The post and rail on the deck are of concrete construction and are in good condition. The wing walls are made of stone masonry and slanted at about 30 degree from the edge of the roadway and out of the 4 approach wing walls 3 are in good condition. Wing wall at the upstream Modjo side is partially damaged by traffic. The wearing surface is of hot mix asphalt and in good condition with no centerline marking and fainted edge pavement marking.

Figure 13.Approach roadway, Awade 1 bridge

i) Modjo Side: The approach roadway on Modjo side is on a tangent section with summit curve situated at about 100m from the bridge. The asphalt concrete wearing surface has two recently maintained patches near modjo side bridge approach. The approach roadway has a width of 9.60m and a paved shoulder width of 1.50m on the left side and 1.60m on the right hand side. There is a narrow bridge sign at 100m from the bridge. There is no approach guardrail installed for directing traffic to the bridge. The roadway tapers from wider town section to a narrower section on the bridge. The approach roadway has a paved shoulder and U-shaped side ditches on both sides. The U ditches are covered by pre-cast concrete cover at major junctions and at the entrance to private houses for Vehicular and Pedestrian accesses respectively. Shops, school and private houses are found to the left and right side of this approach.

ii) Awassa side: The approach roadway on this side has a tangent section with mild grade. It has no adverse geometric alignment. Because of the recent rehabilitation of Modjo - Awassa road the asphalt concrete wearing surface is found in good condition. The approach roadway has a width of 7.0m and a paved shoulder width of 3.00m on the left side and 2.80m on the right hand side. There is no approach guard rail for directing the traffic to the bridge. The roadway tapers from four lane to two lane on the bridge. Shops and private estates are found to the left and right of this side approach.

Findings:

Direction of Inspection: Modjo Side

a. There is a narrow bridge sign posted before reaching this bridge.

b. There is no approach guard rail, end treatment and transition section next to the wing walls.

c. The centerline marking is visible on the approach roadway but worn out on the bridge, while the edge marking is worn out through out the approach roadway and the bridge; there is pedestrian crossing at the crest vertical curve.

d. The approach roadway is on tangent section and has a mild grade.

e. The width of roadway tapers from a wider town section to a narrower bridge section.

Direction of Inspection: Awassa Side

a. There is a narrow bridge sign posted before reaching this bridge.

b. There is no approach guard rail, end treatment and transition section next to the wing walls.

c. The centerline marking is visible on the approach roadway but worn out on the bridge, while the edge marking is worn out through out the approach roadway and the bridge.

d. The approach roadway is on tangent section and has a mild grade.

e. The width of roadway tapers from a wider town section to a narrower bridge section.

Bridge No. 4: Awade Godu River Bridge

This bridge is located at approximately 227.00km from Addis Ababa in Arsi Negele town. The bridge is constructed in the year 1955 as a two lane bridge. This road has an AADT of 2808 and is functionally classified as DS3 Trunk Road.

The bridge is located on sag vertical curve. The clear carriageway width is 6.50 meters and the width across parapets is 7.60 meters. No shoulder is provided to both sides of the carriageway. There is no pedestrian walk way on the bridge. The post and rail on the deck are of steel post and pipe rail and are in poor condition. The wing walls are made of stone masonry and slanted at about 30 degree from the edge of the roadway and out of the 4 approach wing walls 3 are in good condition. Parapet at the downstream Modjo side is partially damaged by traffic. The wearing surface is of hot mix asphalt and in good condition with no centerline as well as edge marking.

Figure 14.Awade Godu bridge damaged post and rail system

i. Modjo Side: The approach roadway on Modjo side is on a tangent section with summit curve situated at about 100m from the bridge. The asphalt concrete wearing surface is found to be in a good condition. The approach roadway has a width of 11.00m and a paved shoulder width of 1.50m on the left and right side. There is a narrow bridge sign at 100m from the bridge. There is no approach guardrail installed for directing traffic to the bridge. The roadway tapers from wider town section to a narrower section on the bridge. The approach roadway has a paved shoulder and trapizodial-shaped side ditches on both sides. The ditches are covered by pre-cast concrete cover at major junctions and at the entrance to private houses for Vehicular and Pedestrian accesses respectively. Shops, school and private houses are found to the left and right of this approach.

ii. Awassa side: The approach roadway on this side has a tangent section with flat grade. It has no adverse geometric alignment. Because of the recent rehabilitation of Modjo - Awassa road the asphalt concrete wearing surface is found in good condition. The approach roadway has a width of 11.30m and a paved shoulder width of 1.50m on the left side and 1.60m on the right hand side. There is no approach guard rail for directing the traffic to the bridge. The roadway tapers from four lane to two lane on the bridge. Shops and private estates are found to the left and right of this approach.

Findings:

Direction of Inspection: Modjo Side

a. There is a narrow bridge sign posted before reaching this bridge.
b. There is approach guard rail for the horizontal curve but it doesn't extend throughout the bridge influence zone.
c. The centerline marking is visible while the edge marking is worn out and is barely visible throughout the bridge.
d. There is no adverse geometric alignment.
e. The width of roadway tapers from a wider town section to a narrower bridge section.

Direction of Inspection: Awassa Side

a. There is a narrow bridge sign posted before reaching this bridge.

b. There is no approach guard rail next to the wing walls.

c. The centerline marking is visible while the edge marking is worn out and is barely visible throughout the bridge.

d. There is no adverse geometric alignment.

e. The width of roadway tapers from a wider town section to a narrower bridge section.

Bridge No. 5: Tatab Tinshu River Bridge

This bridge is located at approximately 237.30km from Addis Ababa in Kuyera town. The bridge is constructed in the year 1955 as a two lane bridge. This road has an AADT of 2808 and is functionally classified as DS3 Trunk Road.

The bridge is located on sag vertical curve. The clear carriageway width is 7.40 meters and the width across parapets is 9.30 meters. No shoulder is provided to both sides of the carriageway. There is no pedestrian walk way on the bridge. The post and rail on the deck are made of concrete and are in good condition. The wing walls are made of stone masonry and slanted at about 30 degree from the edge of the roadway and out of the 4 approach wing walls 3 are in good condition. Wing wall at the downstream Modjo side partially damaged by traffic. The wearing surface is of hot mix asphalt and in good condition with visible centerline marking and fainted edge marking.

Figure 15.Tataba Tinshu River Bridge

i. Modjo Side: The approach roadway on Modjo side has a horizontal curve of 930m radius and summit curve situated at about 150m from the bridge. The asphalt concrete wearing surface is found to be in a good condition. The approach roadway has a width of 12.10m and a paved shoulder width of 1.20m on the left and 2.10m on the right side. There is no narrow bridge sign at the vicinity of the bridge. There is no approach guardrail installed for directing traffic to the bridge. The roadway tapers from wider town section to a narrower section on the bridge. The approach roadway has a paved shoulder and trapezoidal- side ditches on both sides. The ditches are covered by pre-cast concrete cover at major junctions and at the entrance to private houses for Vehicular and Pedestrian accesses respectively. Shops and private houses are found to the left and right of this side approach.

ii. Awassa side: The approach roadway on Awassa side has a horizontal curve of 320m radius and summit curve situated at about 250m from the bridge. The asphalt concrete wearing surface is found to be in a good condition. The approach roadway has a width of 7.20m and a paved shoulder width of 3.60m on the left side and 3.00m on the right hand side. There is no approach guard rail for directing the traffic to the bridge. The roadway tapers from wider town section to narrower section on the bridge. Private houses are found to the left and right of this approach.

Findings:

Direction of Inspection: Modjo Side,

a. There is a narrow bridge sign posted before reaching this bridge.

b. There is no approach guard rail, end treatment and transition section extending from the end of the parapet wall.

c. The centerline is clearly visible while the edge marking is worn out and is barely visible throughout the bridge.

d. The approach roadway is on a broken back curve with 930m radius and having mild grade.

e. The width of roadway tapers from a wider town section to a narrower bridge section.

Direction of Inspection: Awassa Side,

a. There is a narrow bridge sign posted before reaching this bridge.

b. There is no approach guard rail next to the wing walls.

c. The centerline as well as the edge marking are worn out and are barely visible throughout the bridge entry and exit zones i.e. at both approaches and on the bridge.

d. The approach roadway is on a broken back curve with 320m radius on this approach and mild grade.

e. The width of roadway tapers from a wider town section to a narrower bridge section.

5.3 Key Factors for Safety

According to the visual inspection findings, none of the bridges have adequate bridge width, pedestrian width, end treatments, approach guardrail and transition railing which are among the main causes of traffic accident and delay. Moreover, poor approach alignments and sight distance constraints were noted on most of the existing bridges. Traffic accident marks were observed on the wearing surface and on the post and railing system.

From the findings of the inspection of the selected existing bridges, the most important accident causing factors for the bridge structures can be generalized as follows:

Width Constriction: there is a width constriction on all of the existing bridge which is the main cause of traffic accident and delay. The wider town section tapers with short transition length to a narrow width on the bridge. This is a narrow bridge situation where the bridge width is less than approach roadway width. Because of the width constriction, non-motorized users are forced to use the motorized traffic lane on the bridge structure leading to traffic accidents and delay. Some of the bridges may not even accommodate two way traffic because of inadequate bridge width. The traffic coming from one side has to give way for the opposite before otherwise accident will happen. The situation will get worse while driving at night because of the absence of advance warning signs.

Insufficient walkway width: it was noted that all existing bridges doesn't have sufficient width to accommodate non-motorized traffics. A width of 0.65m is provided on all existing bridges to serve as a walkway for all non-motorized users. The pedestrians, the cattle and the carts are using the normal lane when crossing the bridge structure which is the cause of traffic accident and delay. As shown in the literature review, the provision of two lane carriageway width on the bridge structure along with shoulder and segregated pedestrian crossing is vital for reducing traffic accident and delay.

Absence of Approach Guardrail, Transition section and End treatment

As shown in the literature review, the approach guardrail is the most important safety feature at a bridge which requires greater length to protect the motorist from the potential hazards of the site than the bridge rail. The inspection of the existing bridges show that none of the existing bridges have approach guardrail, end treatment and transition section which implies that there is a potential safety problem.

Poor approach roadway alignment, horizontal and vertical

This is the most common safety problem noted on all the existing bridges. Some bridge approaches have an adverse geometric alignment like the case of Meki river bridge and Tataba river bridge. Meki River Bridge isn't at all visible when coming from Awassa side because of the introduction of reverse curve. Of course features such as sharp curves aren't easy for a driver to identify especially for unfamiliar drivers. In such a case there is a greater chance of a wrong decision to be made which leads to traffic accidents. The damaged parapet on this side is the reason of poor approach alignment. The same is true for Bulbula Bridge. There is a sharp horizontal curve coupled with steep vertical curve on Modjo side approach. The damaged parapet on this side is the result of poor approach alignment. Tataba Tinishu Bridge is located on a broken back curve and on sag vertical curve. The literature review findings reveals that bridge located on sag vertical curve with steep grades at approaches are vulnerable to traffic accidents because of increasing speed and losing control of vehicles.

Poor approach sight distance

Poor approach sight distance is the result of poor approach roadway alignment. This is an important element which affects the safety performance of a bridge. The research by Berhanu, [2000] reveals that the frequency and severity of accidents at bridges can be reduced through the provision of adequate sight distance. Meki bridge has no sight distance problems on Modjo side approach as it is situated on tangent section with flat grade. On the other hand, the Awassa side approach has a reverse curve. The reverse curve creates obstructions that can prevent the drivers from being aware of the existence of the bridge or any event that may result in safety problems. The sharp horizontal curve at the entry of Bulbula bridge from Modjo side impose a potential safety hazard because of sight distance constraints. The broken back curve coupled with the sag curve at Tataba Tinshu Bridge imposes a potential safety hazard because of sight distance constraints.

5.4 Evaluation of the Inspection Findings

Geometric Alignment

Meki Bridge has an adverse geometry on Awassa side approach roadway because of a sharp horizontal curve. There is a reverse curve with radius of 140m and 106m with no tangent in between the curves. This curve limits driver's line of sight to the influence zone limits. The entry from Awassa side imposes a potential safety hazard for drivers because of the reverse curve. The same is true for Bulbula Bridge as the approach roadway on Modjo side imposes a potential safety problem because of the existence of sharp horizontal curve. The broken back curve is also a potential safety hazard for drivers on Tataba Tinishu Bridge.

Sight Distance

Sight distance is main safety problem for this bridge because of the existence of sharp horizontal curve. The beginning and end of the influence zone is within the horizontal curve. Because of the town section, the posted speed is 30 km/hr. During inspection, the point of visibility from the bridge is found to be 60m from the bridge. There is no advance warning that informs drivers before reaching the bridge. The reverse curve creates obstructions that can prevent the drivers from being aware of the existence of the bridge or any event that may result in safety problems. There is a sight distance constraint on Bulbula Bridge because of the existence of sharp horizontal curve. The approach roadway on Modjo side is in a cut section with sharp horizontal curve situated at about 180m from the bridge. The broken-back curve along with sag curve creates a sight distance constraints on Tataba Bridge.

Change in approach roadway and bridge width

In all the bridges the approach roadway tapers with short transition length to a narrower bridge section. The total approach roadway width ranges from 14m to 12.5m and the total bridge width ranges from 9.30m to 7.60m. In majority of the cases there is a minimum difference of 4.1m between the approach roadway and the bridge which clearly shows that there is a potential safety problem.

Clear Zone

There is no approach guardrail at the entry as well as at the exit of all existing bridges that extends from the wing wall to the limits of the influence zone. Since most of the bridges are located in the town section, there are private houses and shops at most of the approaches to the bridges. This implies that there is a potential safety problem on all of the bridges.

Traffic Safety Features

Traffic safety features on bridges is composed of four elements: bridge railing, transition section, approach guardrail, and end treatment.

Except for bridge railings, none of the existing bridges have the complete traffic safety features at the entry as well as exit of the bridge structure.

i. End Treatment

There is no guardrail installed on this approach end which implies that there is no entry/exit end treatment which in turn implies that there is a potential safety problem.

ii. Approach Guardrail

There is no entry/exit approach guardrail installed on this approach end which implies that there is a potential safety problem.

iii. Transition

There is no guardrail installed on this approach end which implies that there is no entry/exit transition which in turn implies that there is a potential safety problem.

iv. Bridge Railing

Except for Awade Godu Bridge all existing bridge railing is made of reinforced concrete post and rail which is the common practice in Ethiopia and set as a standard railing by Ethiopia Roads Authority. The shape and height doesn't comply with AASHTO LRFD Bridge Design Specification. Except for Meki Bridge, none of the bridge railing system is painted white and black strip which is used as a reflector.

Road Markings

The centerline marking is visible on the approach roadway but worn out on the bridge structure, while the edge marking is worn out through out the approach roadway and the bridge on all of the bridges.

Traffic Signs

No yield sign is posted adjacent to any of the existing bridge. Narrow bridge sign is posted on the approach roadway of all existing bridges except Meki Bridge.

5.5 Recommended Safety Measures

After identifying all the specific deficiencies on the existing bridges, the next step is to recommend appropriate safety measures. As shown in section 5.3 of this thesis, the major safety deficiencies on the existing bridges can be summarized as follows:

- Sharp horizontal curves at the bridge approaches;
- No or limited sight distance to the bridge and from the bridge;
- Width constriction;
- Steep vertical grades at the bridge approach;
- Sag vertical curve at the bridge; and

- Inadequate clear zone values.

Traffic safety at bridges can be mitigated or improved at the following three main areas: bridge improvements, bridge approach improvements and operational improvements. Bridge improvements include improvements that can be made to a structurally or functionally inadequate bridge, such as improved bridge rails, sidewalks, open joints, and delineation of narrow bridges. Bridge approach improvements include improvements to the guardrail alignment, transitioning the guardrail stiffness to meet the rigid bridge rail, connection of the guardrail to the bridge rail, drainage features, curbs and sidewalks. Operational improvements include improvements to access points, signs, delineation, and pavement markings in the bridge approach area and on the bridge.

As per the safety evaluation of the existing bridges with respect to geometric alignment, inadequate walkway width, absence of traffic safety features, sight distance, change in approach roadway and bridge roadway width, and clear zone the following safety improvements are recommended.

a. With regard to the width constriction, it is recommended to widen the existing bridges to fulfill the width of town section requirement. The widening can be accomplished by constructing a similar one lane bridge adjacent to the existing bridge. This will tremendously reduce traffic accident and delay. There will be a smooth flow of traffic from the approach roadway to the bridge.

b. In connection with the absence of traffic safety features adjacent to the bridges, it is recommended to install approach guardrail, end treatment and transition section on both approaches till the limit of the stopping sight distance.

c. Regarding inadequate walkway width, it is recommended to provide a sufficient segregated non-motorized crossing (usually 1.5m exclusive of post and rail width) with inbound concrete crush barrier to protect non-motorized users from traffic accidents and outbound safety barrier to protect pedestrians from falling of the bridge.

d. Concerning the type of crush barriers, it is recommended to construct concrete crush barrier type IV as per AASHTO LRFD Bridge Design Specification on the inside face and steel post and rail on the outside face. Such objects should be adequately marked by painting or use of other high-visibility material.

e. Regarding steep gradient at approaches and sag curves at bridges, it is recommended to provide rumble strips along the approach roadway to alert drivers about possible dangers by causing a tactile vibration and audible rumbling, transmitted through the wheels into the car body.

   They are mostly applied across the travel lanes to alert drivers of the possible dangers so that they reduce speed. In Ethiopia rumble strips are applied on projects such as Awash – Hirna and Hirna – Kulubie and found to be more effective for alerting drivers on steep gradient.

f. Regarding sharp horizontal curve on the approach roadway, it is recommended to do a curve widening and eliminate the sharp curve but in the mean time it is important to place advance warning sign ahead of the curve. Pavement markings should be provided along the centerlines and edge lines with no overtaking lines on the approach roadway and the bridge.

g. Where there is a sight distance constraints, speed reduction sign should be placed in advance and the constraint should be removed as much as possible. All regulatory and warning signs should be placed in the bridge approach area. Access points on the approach roadways should be properly marked and signs should be placed in advance.

5.6 Traffic Safety Features Installation Guidelines

The inspection of traffic safety features such as bridge rail or approach guard rail, slope-faced concrete barriers requires an understanding of the selection criteria of these different elements. Inspectors should be familiar with the current standards for approach guard rail types, installation heights, and any clearances. During the site inspection each traffic safety features assembly should be checked as to its conformance to current standards. This section presents a guide for the selection of these safety features.

The following guidelines are based on literature review from Standard adopted on ERA bridge design manual, AACRA bridge design manual, AASHTO LRFD Bridge Design Specification and AASHTO Manual for the Condition Evaluation of Bridges [1994]. It is recommended to use these guidelines for the selection of traffic safety features on highway bridges.

1. Virtually all bridges located on roadways require some type of railing and a railing designed to full AASHTO standards is required for high volume roads. AASHTO, *LRFD Bridge Design Specification* [2006] suggests that pedestrian walkway should be separated from an adjacent roadway by a barrier curb, traffic railing, or combination railing, as indicated in figure 11. On high speed highways, the pedestrian or bicycle railing path should have both an outboard pedestrian or bicycle railing and an in board combination railing.

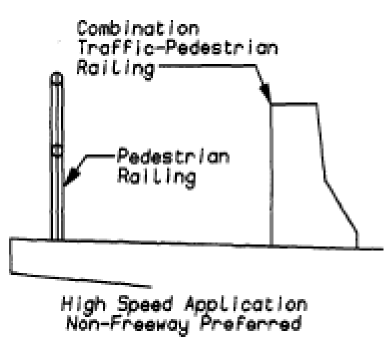


Figure 16: Combination railing [AASHTO, 2006]

2. The bridge railing elements should be in accordance with the established standards and should fulfill the test levels selection criteria. Factors such as design speed, design vehicle, geometric design conditions and the function of the bridge should be considered.

3. An approach guard rail installation requires the determination of conditions such as the approach roadway geometrics, speed and clear zone and by the need to protect road users from encroaching on the roadside and falling to any potentially fatal hazard that can be located underneath the bridge. Clear zone along the approach roadway should be checked against the recommended values established in AASHTO Roadside Design Guide [1989].

4. Transition sections are necessary to provide continuity of protection when two different roadside barriers join, mostly occurs between approach roadside barriers and bridge rail ends. A transition section isn't required when the rigidity of the bridge railing system and the approach guard rail is similar.

5. An untreated end of a roadside barrier is extremely hazardous if hit, as the beam element can penetrate the passenger compartment. A crashworthy end treatment is therefore considered essential if the barrier terminates within the clear zone and/or is in an area where it is likely to be hit head-on by an errant motorist.

5.7 Bridge Safety Inspection Procedures

In Ethiopia, structural assessment of bridges is carried out by bridge engineers and only structural defect of the bridge is noted on prepared condition survey sheet. The safety assessment of bridges is considered as a secondary concern. The safety assessment of roads and bridges are carried out by an experienced Traffic Engineers as a requirement for the preparation of safety report.

FHWA's *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* gives a complete bridge inspection including the inspection of traffic safety features. Item 36 gives the detail inspection and coding procedures.

This section deals with preparing protocols for the assessment of traffic safety features on bridges. Inspectors and Junior bridge engineers are recommended to follow the procedures for determining the functionality of the existing traffic safety features. The developed protocol includes the following five steps.

1. Bridge Identification

In Ethiopia, there is no standard set as to when the inspection of bridges should be carried out on a particular bridge. However, inspection of bridges is carried out on project basis.

As part of the road rehabilitation each structure on the road is inspected for its structural adequacy. For this particular work, bridges considered as black spots were identified based on actual accident data colleted for the study of Traffic Safety Study for Modjo – Awassa Road. Normal inspection of bridges should be carried out when the scheduled inspection time reaches and/or when there is an urgent structural or safety deficiency or problem. Before carrying out an inspection to a particular bridge, it is necessary to collect all the available inspection reports for review. Qualified personnel should be used in conducting bridge inspections. Personal protective clothing should be worn at all times including hardhats and vests.

2. Data Collection

Once the bridges are identified the next step is to collect all the required data about the site and the existing traffic safety features on the bridge. The inspection data sheets should be used for collecting the data. All the gathered information should be recorded on the inspection sheets.

3. Data Analysis

The next step after the data collection is data analysis. All the data that was collected during the field inspection with regard to the approach roadway, the bridge and traffic safety features on the approach roadway as well as the bridge should be analyzed. It should checked against the standard that is set for one or two lane, or whether or not it complies with the original bridge design or checking against the minimum recommended values given in standards such as ERA Bridge Design Manual, ERA

Geometric Design Manual, AASHTO Green Book, AASHTO LRFD Bridge Design Specifications, AASHTO Roadside Design Guide, among others.

4. Traffic Safety Features Rating

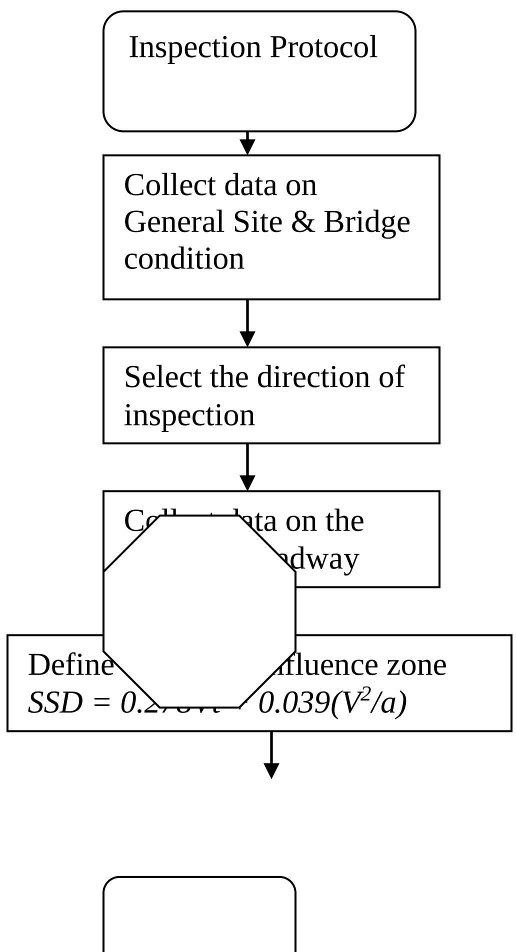
The rating of traffic safety features is one of the steps to be carried out after the data has been analyzed. A rating will be assigned to each traffic safety feature on the bridge. The creation of this rating was based on literature review carried out for this work and on the application of engineering judgment.

5. Identification of Safety Measures

After the analysis and traffic safety feature rating is completed the team responsible for the inspection should come up with potential safety treatments for any defects noted during the field inspection. The safety measures should be directed to specific deficiencies encountered during the field inspection. This work provides typical safety measures that improve the safety of the approach roadway as well as the bridge.

5.8 Developed Bridge Safety Inspection Sheet.

Inspection Protocol



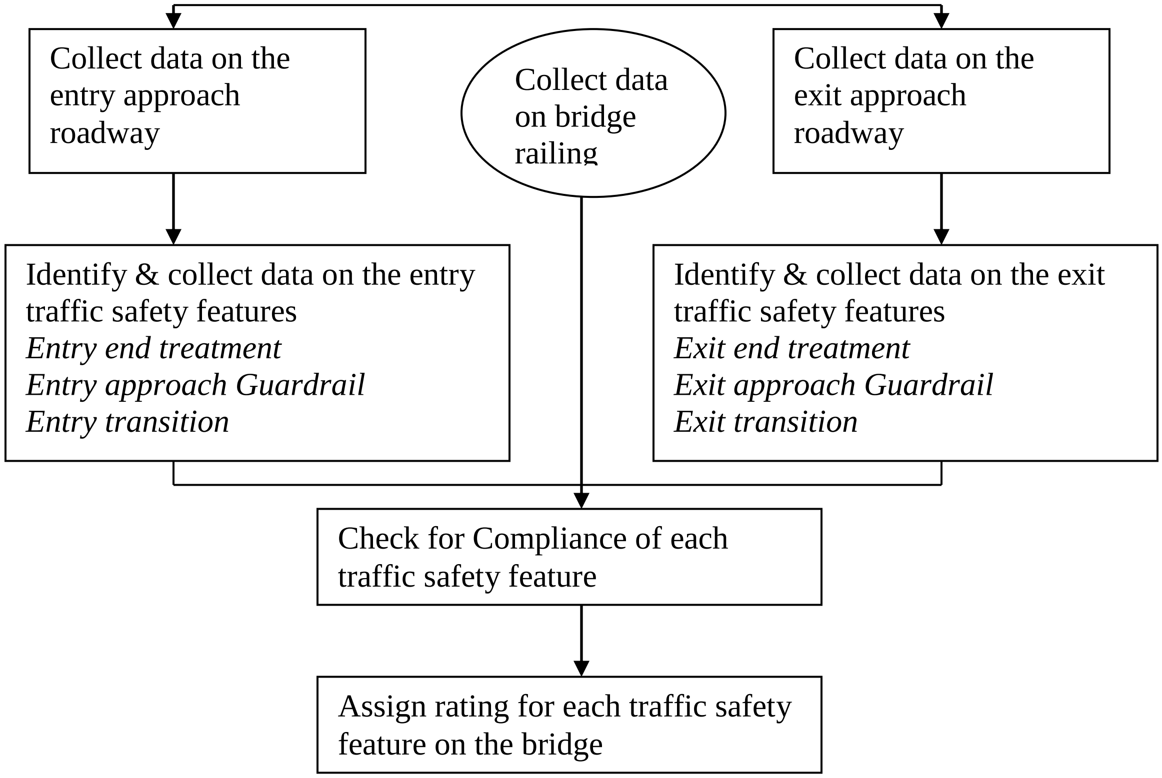


Figure 17: Inspection Protocol

Part I: General Site and Bridge Condition

1. Bridge Site and Bridge Information

This is the first section of the developed inspection sheet in which the general site and bridge information is registered. It starts with the project name and all the necessary data such as the region, road class, posted speed, the location of the project(coordinate), year constructed, ADT, direction of traffic, bridge no. (Structure no.), clear roadway width, shoulder width, pedestrian width, bridge type, bridge length, bridge material, pavement type, pavement marking, no. of Spans, no. of lanes, information regarding the person in charge of the inspection and the date of inspection should be recorded.

Part II: Bridge Entry Approach Roadway Information

2. Bridge Entry Approach Roadway Information

This is the section where the entry approach roadway information such as the approach roadway width, shoulder width, roadway grade, the presence of horizontal and vertical curve, bridge visibility, sight obstruction, ditch type and the slope of fore slope or back slope should be recorded, pavement type, pavement marking, object in the clear zone, and the length of influence zone should be recorded. Any object in the clear zone that isn't protected by a safety barrier should be measured and compared with the recommended values presented in figure 8. The length of bridge influence zone is the length that starts at the beginning of the bridge and ends at the calculated stopping sight distance (SSD) equation provided in AASHTO *Green Book* [2004], as shown on figure 6, where the recommended values for t and a are 2.5 s and 3.4 m/s2 respectively. SSD is the length of the roadway ahead that is visible to the driver, it should be enough to enable a vehicle traveling at or near the design speed to stop before reaching a stationary object in its path [AASHTO, 2004].

For highways with design speed of 100km/hr, 185m length of SSD is required. This SSD value can be assigned for highway bridges with design speed of $V \leq$ 100km/hr. AASHTO 2004 recommends adjustment to be made on the calculated SSD values for the effect of grade on vehicle speeds when the longitudinal grades, upgrades or downgrades, is higher than 3%. Two influence zones are defined, the entry and exit influence zones. Each should be calculated for each direction of traffic. Once the influence zone is identified, the presence of horizontal curve, vertical curve or combination of both should be recorded. Regarding the bridge visibility, the inspector should record the visibility from the end of the influence zone and if the bridge isn't visible from the end of this zone the point of visibility within the influence zone should be recorded.

Part III: Bridge Exit Approach Roadway Information

The same information recorded at the entry approach roadway information should be recorded at the exit approach roadway. The exit influence zone should be calculated as mentioned in part two and the presence of horizontal curve, vertical curve or combination of both should be recorded. The ditch type and the slope of fore slope or back slope should be recorded. Any obstructions that limit the line of sight to the drivers at the exit influence zone should also be recorded. Any object in the clear zone that isn't protected by a safety barrier should be measured and compared with the recommended values presented in figure 8.

3. Check for the Existence of Traffic Safety Barrier

A layout of a bridge and its approach roadway with all the elements of traffic safety barrier is presented in this section. Elements such as the end treatment, the approach guardrail, the transition and the bridge railing is assigned with a check box for identifying Purpose.

Part IV: Bridge Traffic Safety Feature Information

After checking the boxes for the existence of the traffic safety features, the section corresponding to each of the elements should be filled.

1. **End Treatment:** The type, anchorage, grading and compliance with the code should be recorded for the end treatment.

   a. **Type:** the inspector should identify the existing end treatment and its type. The inspector should be familiar the different types of crashworthy end terminal such as Energy absorbing Terminal, WRSB terminals, sand filled barrels and proprietary crash attenuation devices. The inspector should verify the compliance of the end treatment with the design plans. When the end treatment doesn't match with any of the above mentioned end treatment, the relevant section should be filled with NA (not applicable).

   b. **Anchorage:** the end treatment should have the same redirectional behavior as the approach guardrail and it should be properly anchored as the standard guardrail. Missing bolts or cables or any impacts should be properly recorded. The inspector should record one of these as per the actual condition of the anchorage. Functional, if it is properly installed and with no or minor impacts, Damaged, when impacted or not installed properly, Not present, when none is provided.

c. **Grading:** Flat grades are preferable between the traveled way and the terminal it shouldn't be greater than 1V:10H in any direction [AASHTO 2004].

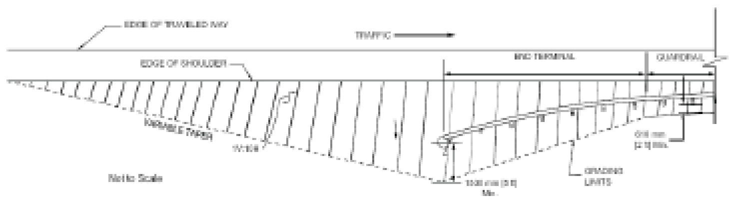


Figure 18: Grading for Flared Guardrail End Treatment [AASHTO 2004]

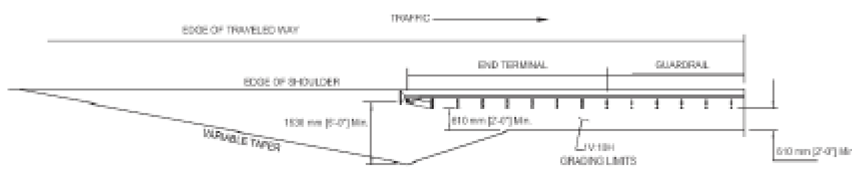


Figure 19: Grading for Non-Flared Guardrail End Treatment [AASHTO 2004]

Compliance could be checked by checking the existing end treatment against the standard grading requirement by AASHTO.

2. **Approach Guardrail:** The type, height, post spacing, lateral offset, length of need post spacing and code compliance should be recorded for the approach guard rail.

a. Type: the inspector should identify the existing approach guardrail type. He should be responsible for verifying the compliance of the approach guardrail with the design plans and if this isn't available it should checked against the specification requirement. When the approach guardrail doesn't match with any of the existing design, the relevant section should be filled with NA (not applicable).

b. Height: The height of the approach guardrail should be measured in the field and checked against the design plans or standard plans for the barrier type. ERA Standard Drawing [2002] specifies the standard height of approach guardrail.

c. Post spacing: The spacing between the posts should be measured and recorded for both entry and exit approach guardrail and should be checked for compliance against the design standards. ERA Standard Drawing [2002] specifies the standard post spacing of the approach guardrail.

d. Flare Rate: A roadside barrier is considered flared when it isn't parallel to the edge of the traveled way. Flare rate is the variable offset distance to move it further from the traveled way; ERA Standard Drawing [2002] presents the suggested maximum flare rate values; and as shown below it varies with the design speed and Shy line. The compliance of the existing flare rates should be checked against the values presented in figure 15.

FLARE RATES			
DESIGN SPEED	INSIDE SHY LINE		BEYOND SHY LINE
km\h	SHY LINE m	FLARE RATE	FLARE RATE
110	2.8	30:1	15:1 **
100	2.4	26:1	14:1 **
80	2.0	21:1	11:1 **
60	1.4	16:1	8:1 **
50	1.1	13:1	7:1 **

**suggested maximum flare rate for semi-rigid barrier systems.

Figure 20: Suggested Maximum Flare Rates [ERA, 2002]

e. Lateral Offset: a roadside barrier should be placed as far from the traveled way as conditions permit. Such placements give an errant motorist the best chance of regaining control of the vehicle without having accident. This is often described as shy line offset and is the distance at which the drivers perceives an object or roadside barrier; ERA Standard Drawing [2002] presents the suggested shy line values; and as shown above it varies with the design speed. The compliance of the existing lateral offset of the approach guardrail should be checked against the values presented in figure 15.

f. Length of Need: This is the roadside barrier length required to shield a hazard effectively. The primary variables are the Runout Length, L_R, and the lateral extent of the hazard, L_H. The length of the existing approach guardrail should be measured and checked against the calculated length of need using the equation below. Figure 16 presents the variables required for calculating the length of need by layout.

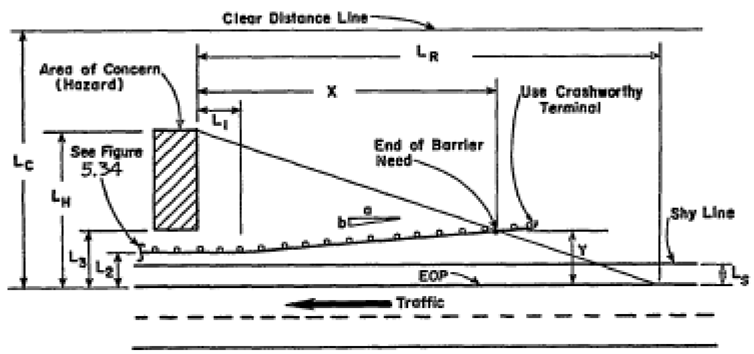


Figure 21: Length of Need Layout Variables [AASHTO, 1989]

The length of need is expresses as follows:

$$X = LH + (b/a)(L1) - L2 \Big/ (b/a + (LH)/(LR) \qquad \text{Equation ---- (2)}$$

Where:

X = Length of need,

L_H = lateral extent of the area of concern,

L_R = lateral extent of the runout length,

L1 = tangent length of barrier upstream from the area of concern,

L2 = Lateral distance from the edge of the traveled way, and

(a:b) = flare rate.

3. **Transition:** A transition section is required only when a rigid railing system joins with semi- rigid approach barrier. Transitions aren't required when bridge railings and approach guardrails are of the same rigidity. The transition should produce a gradual stiffening of the overall approach protection system. In this regard, information such as the type, height, post spacing, lateral offset, length, connection and code compliance should be recorded for the entry as well as the exit transition.

a. Type**:** the inspector should identify the existing transition type. He should be responsible for verifying the compliance of the transition with the design plans and if this isn't available it should be checked against the specification requirement. When the transition doesn't match with any of the existing design, the relevant section should be filled with NA (not applicable).
b. Height: The height of the transition should be measured in the field and checked against the design plans or standard plans for the barrier type. ERA Standard Drawing [2002] specifies the standard height of transition.
c. Length: The transition section should be long enough to avoid any significant changes in deflection within a short distance. Generally, the transition length should be 10 to 12 times the difference in the lateral deflection of the two systems in question. The inspector should measure the available length and should check against the design standard.
d. Post spacing: This plays an important role in achieving the required rigidity from less rigidity to a higher rigidity. The spacing between the posts should be measured and recorded for both entry and exit transition and should be checked for compliance against the design standards. ERA Standard Drawing [2002] specifies the standard post spacing of the transition.
e. Connection: The connection must be as strong as the approach rail itself to avoid failure on impact by pulling out. The use of cast in place anchor or through-bolt connection is recommended. During inspection the inspector

should closely see for missing bolts or nuts or if there is any loose connection. The inspector should record functional if the connection is properly installed as per the design with no missing bolts and damaged if the connection has been impacted, design elements are missing or not installed correctly and NA(not applicable) if there is no connection between the transition and the bridge rail.

4. Bridge Railing: AASHTO, ERA, and AACRA warrant the use of railing on low/high speed highways. Even though, the type of railing provided by the three agencies is different. ERA suggests the use of concrete post and rail while AASHTO and AACRA recommend the use of type F concrete crush barrier. In this section, data to be collected include, type, post spacing, lateral offset, height of post, height of rail and length.

a. Type**:** The inspector should identify the existing bridge railing type. The type specified in ERA Standard Drawing [2002] is concrete post and rail while the type specified in AASHTO and AACRA is solid concrete crush barrier.
b. Post Spacing: This applies only to concrete/steel post and rail system. The center to center spacing between the posts should be measured and recorded. ERA Standard Drawing specifies a maximum post spacing of 1.5m. The inspector should check the existing post spacing against the maximum allowable spacing and recommend for the necessary course of action.
c. Lateral offset: a roadside barrier should be placed as far from the traveled way as conditions permit. Such placements give an errant motorist the best chance of regaining control of the vehicle without having accident. This is often described as shy line offset and is the distance at which the drivers perceives an object or roadside barrier; ERA Standard Drawing [2002] presents the suggested shy line values; and it varies with the design speed. The compliance of the existing lateral offset of the bridge railing should be checked against the values presented in figure 15.

d. Height: The height of the bridge rail should be measured in the field and checked against the design plans or standard plans for the railing type. ERA Standard Drawing [2002] specifies the standard height of transition.
e. Length: The length of a bridge rail should be adequate to cover the entire bridge including the abutments to prevent an errant motorist from falling off the bridge. The design plan should clearly indicate the total length of the bridge rail including the abutments. The inspector should measure the existing bridge rail and check for compliance against the design plans and site requirement.

Part V: Assessment of Bridge Traffic Safety Features

After checking the boxes for the existence of the traffic safety features, the section corresponding to each of the traffic safety feature should be filled. As discussed elsewhere in this research, the traffic safety features includes the following elements, end treatment, approach guardrail, transition section for both entry and exit and the bridge railing system. The inspector should follow the rating legend to fill in the rating column for each of the traffic safety features.

a. Not applicable: if the traffic safety feature doesn't exist the inspector should put an X mark on the available space under rating column.
b. Urgent Inspection: if the traffic safety feature is totally damaged and if it isn't functionally and structurally adequate, the letter which is under urgent inspection (UA INSP) should be filled at the corresponding traffic safety feature.
c. None: if there is no damage due to traffic accident or if any section doesn't show any kind of deterioration due to weathering, the zero number should be placed at the corresponding traffic safety feature.
d. Minor: As the name implies, there may be minor defects such as minor hair line crack on the concrete members and loose connection on the approach guardrail. The number 1 should be placed at the corresponding traffic safety features.

e. Fair: if there is a slight bend on the approach guardrail due to traffic accident or small portion of the bridge railing knocked down, the number 2 should be placed at the corresponding traffic safety features.
f. Poor: if the approach guardrail and the bridge railing system is damaged for half of its length due to traffic accident, the number 3 should be placed at the corresponding traffic safety features.
g. Sever: if the traffic safety feature is severely damaged by traffic accident for most of its length and doesn’t serve its purpose, the number 4 should be placed at the corresponding traffic safety features.

6. CONCLUSION

The design of new bridges and the inspection of existing bridges mainly focuses on the structural design and the inspection of the structural components of the bridge respectively leaving the traffic safety components on the bridge and its approach as a secondary concern.

One of the main tasks in this paper was to present a safety audit protocols and checklist for design of new bridges and at the same time present bridge safety inspection sheet and procedures for existing bridges. The geometric elements of the bridge with respect to horizontal alignment, vertical alignment, width, clear zone concepts requirement of the bridge and approach roadway geometry was reviewed. In the safety inspection findings it was clearly seen that all the major safety problems are related to one of the above mentioned geometric elements. The literature review finding was the core to the development of bridge safety audit procedures and to the preparation of checklists.

The checklist for the safety audit of new bridges is prepared at the different stages of audit such as feasibility stage, preliminary design stage, detailed design stage, construction stage. The prime purpose of these checklists presented in this paper is to provide a guide to bridge engineers in terms of the bridge safety elements which need to be considered while undertaking bridge designs, and present a user-friendly mechanism for keeping track of the progressive monitoring of the bridge design. Important factors such as the width of the approach roadway and the width of the bridge, horizontal and vertical alignment of the approach roadway, the traffic safety features at the approach and at the bridge, the traffic signs and the marking which affect the safety performance of the bridge was indicated at each stage of the safety audit. The developed checklist will assist bridge engineers for checking any missing safety features at each stage of design.

Furthermore this paper has developed bridge safety inspection protocols and safety inspection sheets for making detailed safety inspection of existing bridges. The inspection protocol mainly focuses on the approach roadway, the bridge and the traffic safety features. These are the three primary areas in which safety can be improved or potentially hazardous features improved or mitigated at and around bridges. The traffic safety features such as the end treatment, the approach guardrail, the transition and the bridge railing are in detail reviewed from different standards such as ERA, AACRA AASHTO and FHWA. If proper installation of these traffic safety features is achieved, potential hazards may greatly be reduced. The methodology created on this work allows for all traffic safety features to be inspected and reported. The end result is that it will allow inspectors for inspecting all the existing elements of traffic safety features and identify any deficiencies there on.

7. RECOMMENDATION

The need for building a safer bridge structures will increase with ever increasing traffic volume and accident rate on bridges.

Traffic Analysis and Safety Measures Report (Berhanu, 2009) carried out on Modjo – Awassa Road showed that potential problems associated with narrow bridges are twofold. The statistics of accidents shows that the majority of bridges are Black Spot sites which demand systematic and carefully planned research work. Unfortunately, the majority of the research work carried out at present time is aimed towards highway traffic safety as there are very few programs being carried out towards specific safety considerations on bridges.

Nevertheless, there is still considerable need for research work to be carried out on traffic safety of bridges. One aspect to be considered for future work is to improve and develop more rational designs for bridge approach roadways. As we are aware, the bridge railing system of most of the bridges in Ethiopia aren't as per the international railing system. The post and rail system doesn't fulfill the NCHRP 350 requirement. Therefore, research should be carried out towards improving the bridge railing system in Ethiopia. This should also incorporate the methods of estimating the different bridge railing deformation under specified load conditions as a function of the structural and material properties. Developed railing systems should be tested on full scale so as to know the adequacy of material, structural system and behavior of vehicle in relation to impact.

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Appendix A: Safety Audit of New Bridges

Bridge on Planning Stage

Introduction

The Gonder by-pass project is an on-going construction project which departs from the existing road that traverse through Azezo near the entrance to the Airport and by-pass Gonder town. It consists of four sections namely AB, BC, CD, and DE. The project is 75 % completed. Section CD is located on the existing town section and rehabilitation work on this section consists of overlaying one layer of wearing surface.

There is an existing Arch bridge on section CD of Gonder by-pass project. The bridge is found to be in bad condition with sever crack on the Arch Barrel. At the moment, the city administration banned heavy vehicles from using the bridge. A team of engineers was mobilized to make a preliminary finding of the existing bridge with respect to structural condition. As usual, the safety aspect of the bridge that is the approach roadway alignment, bridge width and traffic safety feature isn’t considered primarily. However, the new bridge will have the same width as the approach roadway width and all the required traffic safety features will be incorporated in the new design.

The purpose of the bridge is to provide at-grade bridge crossing for vehicular traffic, Pedestrians and Cyclists across the section CD of Gonder town.

Safety Problems to be Addressed on the New Bridge

Problem – Approach Alignment on the Southern Side

The approach alignment on the southern side has a horizontal curve at 200m from the bridge end. The town section median stops at approximately 200m from the bridge leaving a 14m undivided approach roadway and tapering to 7m on the bridge.

Problem – Approach Safety Barrier on the Southern Side

The existing traffic safety barrier isn't following the approach roadway safety barriers. It consists of RHS tube posts spaced at 2m interval and two rows of RHS tube rails having a height of 1m and spaced at 0.5m interval.

Problem – Bridge Width

The width of the approach roadway tapers from four lanes to two lanes on the existing bridge. The width tapers from 14m on the approach roadway to 7m on the bridge.

Problem – Pedestrian Crossing

There is no pedestrian crossing provided on the existing bridge. The 7m width is accommodating all kinds of traffic. Pedestrians are susceptible for accidents.

Problem – Bridge Railing System

The existing bridge consists of RHS tube posts and rails having heights of 1m and post spacing of 2m and rail spacing of 0.5m.

Problem – Deck Drainage System

There is no deck drains on the existing bridge to drain away the surface water. Bridge isn't provided with sufficient cross slope as well as longitudinal slope.

Problem – Approach Alignment on the Northern Side

The approach alignment on the northern side has an adverse geometric alignment. The approach roadway faces right of way problem on both sides to the east is secondary school and to the right is Atse Fassel Swimming Pool very much Historical. The bridge has no tangent section and curves to the right and then to the left not to demolish the historical monument and the secondary school.

Bridge on Preliminary Design Stage

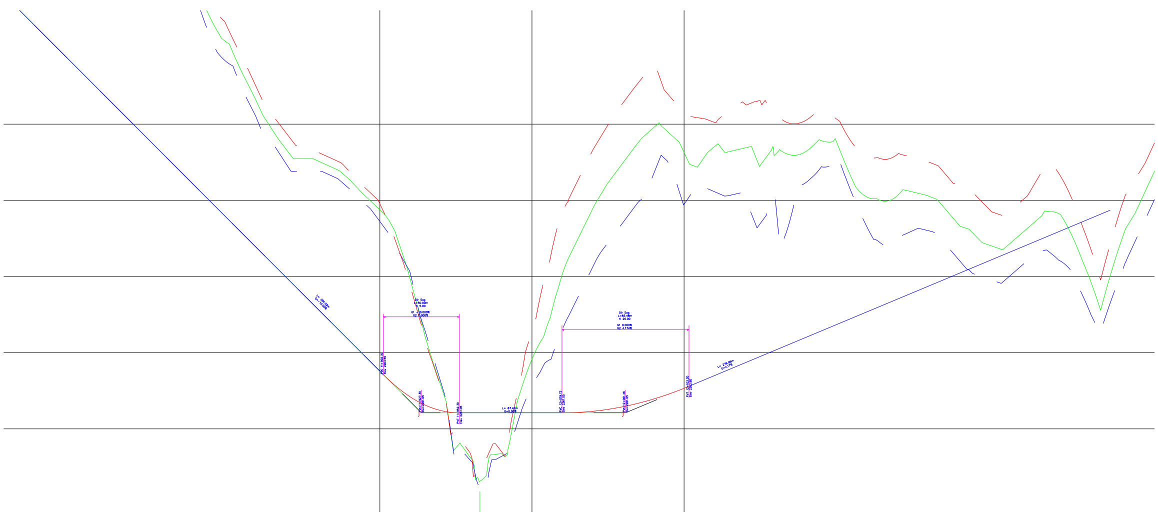
Introduction

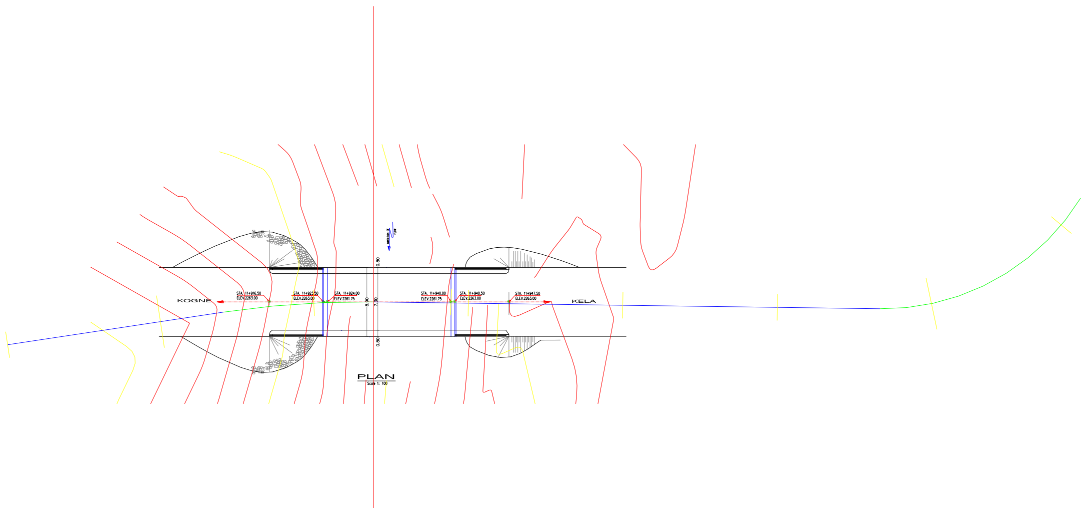
The selected bridge for the Preliminary Design Stage check is located on Kogne – Zemute - Beke Road Upgrading project.

There is no existing road that links the two towns and hence there is no traffic using the road. The purpose of the bridge is to provide at-grade Bridge crossing for vehicular traffic, Pedestrians and Cyclists across the two towns.

Some safety factors aren't considered by the designer at this stage which will require action in order to improve the safety of the bridge and minimize accident occurrences.

Safety Problems on the preliminary design





Problem – Approach Alignment on the Western Side

This side approach alignment has an adverse geometry both vertically and horizontally. The vertical alignment has a steep grade of 10% with sag curve at the parapet end and 0% grade at the bridge. There is a 30m radius sharp curve at about 40m from the bridge end.

Recommendation

The calculated stopping sight distance for a design speed of 40km/hr is 50m. The provided tangent section isn't adequate for stopping sight distance and thus a minimum of 60m tangent section should be provided to allow for safety. Rumble strips should be provided on the steep section as a speed reduction in addition to reducing the grade to a maximum of 7%. As this is preliminary design stage audit the above recommendations should be incorporated in the final design stage.

Problem – Approach Safety Barrier on the Western Side

There is no approach safety barrier shown on the preliminary design drawing. No transition section, approach guard rail and terminal section is provided on preliminary plan drawing.

Recommendation

The provided bridge railing system is rigid and thus transition guard rail, approach guard rail and end section with treatment should be provided.

Problem – Road Marking and Traffic Signs

At the preliminary design stage no road marking as well as traffic sign drawings are prepared.

Recommendation

Center line marking upto the influence zone of the bridge should be indicated by white solid line to protect overtaking near the bridge. Non passing zone for each side is calculated based on stopping sight distance and values are 50m for both sides approach. Solid yellow edge line marking should be provided for all edges of the pavement to delineate the edge of the road. Bridge sign should be placed at 100m from both ends of the bridge.

Problem - Bridge Width

Standard two lane bridge width is shown on the preliminary cross section of the bridge. This width includes 7.30m clear carriageway width and 0.80m for railing and walkway. No provision for shoulder is shown on the plan drawing.

Recommendation

Looking at the location of the bridge along the project road shoulder width isn't recommended. A reduced speed should be posted on the approach roadway. Delineation of the roadway is recommended by road marking as indicated above.

Problem – Walkway for Pedestrian

The total walkway provision on the bridge is 0.8m including the width of the post and rail system.

Recommendation

A segregated pedestrian walkway is recommended on one side of the bridge. Concrete crush barrier should be used at the inner face and concrete post and rail should be used at the outer face so as to be consistent with the other side post and rail. The width of the walkway should be 1.5m inclusive of post & rail system.

Problem – Bridge Railing System

The bridge railing system designed on this bridge consists of concrete post and rail on the outer face.

Recommendation

Place concrete crush barrier at the inner face and steel post and rail at the outer face.

Problem – Approach Alignment on the Eastern Side

The approach alignment on this side has an adverse vertical alignment. The approach roadway has a constantly descending grade as the bridge is located in a valley section.

Recommendation

Rumble strips should be placed at a closer interval all alone the approach roadway.

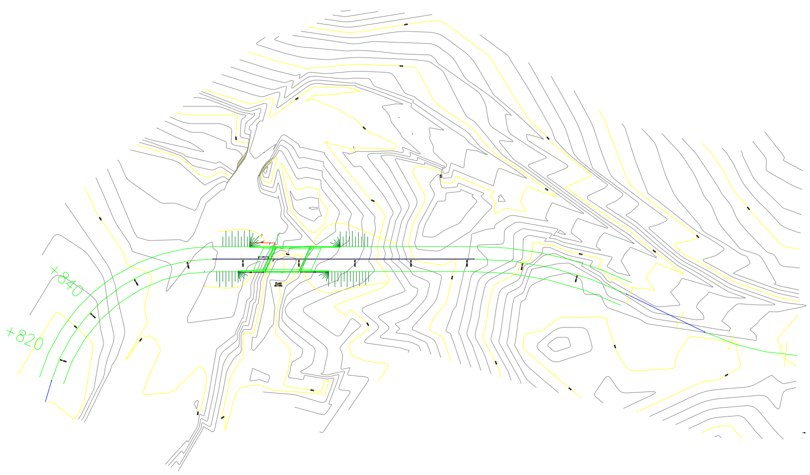
Bridge on Detailed Design Stage

Introduction

The selected bridge for the detailed design stage check is located on Mazoria – Omo Road Upgrading project.

There is an existing gravel road that links the two towns with some traffic using the road. There is an existing bridge but new bridge is proposed at the upstream of the existing bridge. The main reason for replacement is the existing bridge doesn't fulfill the two lane width requirement and is located on a sharp bend. The new bridge will provide at-grade bridge crossing for vehicular traffic, Pedestrians and Cyclists.

Some safety factors aren't considered by the designer at this stage which will require action in order to improve the safety of the bridge and minimize accident occurrences.



Problem – Approach Alignment on the Mazoria Side

This side approach alignment has an adverse geometry on the horizontal alignment. There is a 60m radius sharp curve at about 20m from the bridge end. There is no stopping sight distance provision on this side.

Recommendation

The calculated stopping sight distance for a design speed of 40km/hr is 50m. The provided tangent section isn’t adequate for stopping sight distance and thus a minimum of 60m tangent section should be provided to allow for safety.

Problem – Approach Safety Barrier on the Western Side

There is no approach safety barrier shown on the detailed design drawing. No transition section, approach guard rail and terminal section is provided on preliminary plan drawing.

Recommendation

The preliminary bridge railing system is rigid and thus transition guard rail, approach guard rail and end section with treatment should be provided. The guard rail should extend up to the limits of the influence zone.

Problem – Road Marking and Traffic Signs

On the bridge plan drawings there is no road marking as well as traffic sign.

Recommendation

Center line marking upto the influence zone of the bridge should be indicated by white solid line to protect overtaking near the bridge. This should be indicated on the bridge plan drawing. Non passing zone for each side is calculated based on stopping sight distance and values are 50m for both sides approach. Solid yellow edge line marking should be provided for all edges of the pavement to delineate the edge of the road. Bridge sign should be placed at 100m from both ends of the bridge.

Problem – Bridge Width

Standard two lane bridge width is shown on the preliminary cross section of the bridge. This width includes 7.30m clear carriageway width and 0.80m for railing and walkway. No provision for shoulder is shown on the plan drawing.

Recommendation

Looking at the location of the bridge along the project road shoulder width isn't recommended. A reduced speed should be posted on the approach roadway. Delineation of the roadway is recommended by road marking as indicated above.

Problem – Walkway for Pedestrian

The total walkway provision on the bridge is 0.8m including the width of the post and rail system.

Recommendation

A segregated pedestrian walkway is recommended on one side of the bridge. Concrete crush barrier should be used at the inner face and concrete post and rail should be used at the outer face so as to be consistent with the other side post and rail. The width of the walkway should be 1.5m inclusive of post & rail system.

Problem – Bridge Railing System

The bridge railing system designed on this bridge consists of concrete post and rail on the outer face.

Recommendation

Place concrete crush barrier at the inner face and steel post and rail at the outer face.

Problem – Approach Alignment on the Eastern Side

The approach alignment on this side has an adverse vertical alignment. The approach roadway has a constantly descending grade as the bridge is located in a valley section.

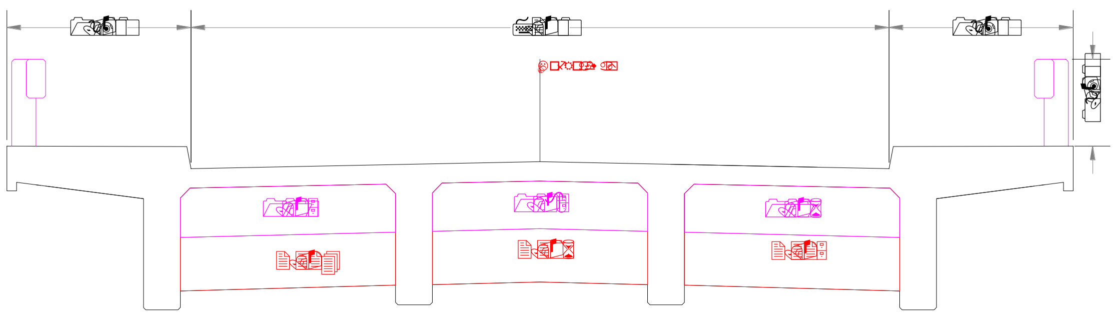
Recommendation

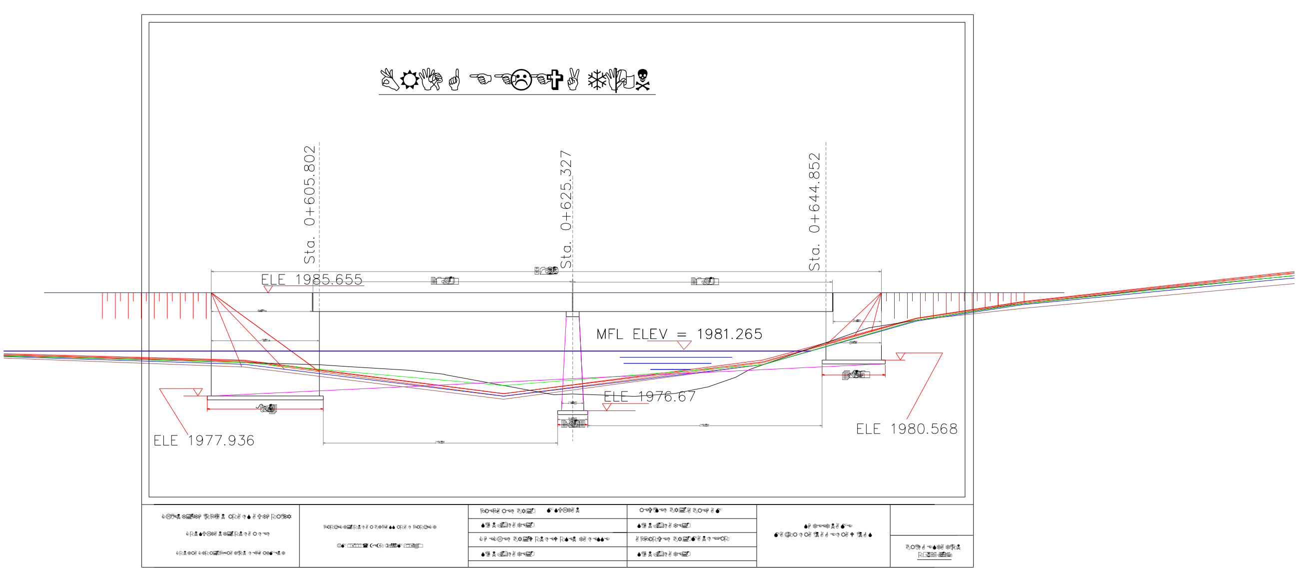
Rumble strips should be placed at a closer interval all alone the approach roadway.

Bridge on Construction Stage

Introduction

The Gonder by-pass project is an on-going construction project which departs from the existing road that traverse through Azezo near the entrance to the Airport and by-pass Gonder town. It consists of four sections namely AB, BC, CD, and DE. The project is 75 % completed. Since section AB of Gonder by-pass is a new alignment the bridge is a new bridge and it is under construction. As section AB is new alignment there is no traffic using the road.





Some characteristic safety problems described which are missed by the designer are indicated below in order to improve the safety of the bridge and minimize accident occurrences.

Problem – Approach Alignment on the Southern Side

The approach alignment on the southern side has a horizontal curve at 240m from the bridge end. The new alignment departs from the existing road at the outskirts of Azezo village and starts with a right curve having a radius of 270m. At the time of the site visit the approach roadway on this side is completed upto the level of Asphalt Binder Course. The parapet isn't completed upto the top level. The carriageway width on the approach roadway is 7.0m with a shoulder width of 1.5m. A slightly higher carriageway width is provided on the bridge 7.2m and a raised walkway having a clear walkway width of 1.5m ia also provided.

Recommendation

The calculated stopping sight distance for a design speed of 80km/hr is 130m. Since a tangent section of 240m is available there is no sight distance problem. But, advance warning sign and a speed post should be placed after from the clear zone.

Problem – Approach Safety Barrier on the Southern Side

Upon reviewing the as-built drawing, there is no approach safety barrier shown on the final detailed plan drawing.

Recommendation

The designed bridge railing system is rigid and thus transition guard rail, approach guard rail and end section with treatment should be provided.

Problem – Road Marking and Traffic Signs

At the design stage no road marking as well as traffic sign drawings are prepared and it isn't included on the as-built final plan drawings.

Recommendation

Center line marking at the influence zone of the bridge should be indicated by white solid line to protect overtaking near the bridge. Non passing zone for each side is calculated based on stopping sight distance and values are 130m for south side approach and 65m for the northern side approach. Solid yellow edge line marking should be used for all edges of the pavement to delineate the edge of the road. Bridge sign should be placed at 200m from both ends of the bridge.

Problem – Bridge Width

In terms of clear carriageway width the bridge has a slightly wider width than the approach roadway. But shoulder width wasn't provided on the bridge.

Recommendation

At this stage it is impossible to provide shoulder width on the bridge as the bridge superstructure is under construction. A reduced speed should be posted on the approach roadway. As indicated above Solid center line marking should be painted for guiding traffic alone its lane.

Problem – Walkway for Pedestrian

A clear pedestrian walkway width of 1.5 is provided on both sides of the bridge. However there is no protection provided to safe guard pedestrian from vehicular collision.

Recommendation

Concrete crush barrier should be used at the inner face and steel post and rail should be used at the outer face.

Problem – Bridge Railing System

The bridge railing system designed on this bridge consists of concrete post and rail on the outer face and no railing for the inner face.

Recommendation

Place concrete crush barrier at the inner face and steel post and rail at the outer face.

Problem – Approach Alignment on the Northern Side

The approach alignment on the northern side has an adverse geometric alignment. The approach roadway passes through a curved cut section having with a horizontal radius of 170m. The point of visibility is 70m from the bridge end. The bridge has 40m tangent section.

Recommendation

The calculated stopping sight distance for a design speed of 50km/hr is 65m. A posted speed of 40km/hr should be placed before the beginning of the horizontal curve and should continue upto the bridge. Bridge sign should be placed at the beginning of the horizontal curve. Solid Centerline marking should be placed for both the bridge and the horizontal curve to prohibit overtaking near the bridge.

Appendix B: Bridge Design Safety Audit Checklist For Planning and Feasibility Stage

Checklist	Yes	No	Comment
Are all the necessary information required for the Audit present? • Proposed bridge site location • Preliminary bridge approach roadway alignment • Proposed cross section of the approach roadway • Proposed cross section of the bridge • Preliminary bridge layout			
• Is the proposed width of approach roadway in consistent with the width of the bridge? • Is the proposed alignment show sight distance limitation at both approaches? • Is the proposed horizontal alignment has curve at bridge approaches? • Is the proposed vertical alignment has steep vertical gradient? • Is the bridge located on sag vertical curve? • Is the proposed cross-section show Pedestrians/Cyclists walkways? • Are proposed footway widths adequate? • Are proposed pedestrian guardrails functionally adequate? • Are proposed bridge railings functionally adequate? • Is transition proposed between the bridge railing and the approach guardrail? • Is approach guard rail proposed? • Are end terminals proposed?			

Appendix C: Bridge Design Safety Audit Checklist For Preliminary Design Stage

Checklist	Yes	No	Comment
Are Information required for the Preliminary Design Audit present? • Details of any Stage 1 (Feasibility Stage) Audit, including decisions made on the matters raised in that audit. • Bridge site selection report, on which the preliminary design has been based. • Preliminary bridge layout, General arrangement drawing showing plans and elevations, cross-sections, grade lines, etc to be audited.			
Design Criteria Checks? • Is acceptable standards used for determining the width of the bridge? • Is acceptable standards used for determining the vertical clearance, the cross-slope, etc			
Cross-section Checks? • Are the lane widths, shoulders, pedestrian walkway adequate? • Are the pedestrian walkway and cyclist adequate? • Are the deck drains adequately placed on the cross section of the bridge? • Are cross-section of approach roadway in consistent with the bridge cross-section? • Is there a wearing surface on the bridge deck?			
Horizontal and Vertical Alignment Check?			

• Is the design speed reduced at the bridge approach? • Is the design speed of the approach roadway and bridge the same? • Is there any substandard curve near the bridge approach? • Is there steep gradient at the bridge approaches? • Is the bridge on sag vertical curve? • Does the vertical alignment on the bridge allow for quick surface flow? • Is the approach roadway stopping sight distance sufficient? • is there any mis-phasing of vertical and horizontal alignments near the bridge approach?			
Traffic safety features Checks? • Is the type of safety barrier on the bridge as per the standard? • Is the safety barrier functionally adequate? • Is the safety barrier structurally adequate? • Are pedestrians provided with inner and outer bound safety barrier? • Are pedestrian provided with concrete crush barrier at the inner bound? • Is guardrail provision as per the length of need of approach guardrail? • Is guardrail transition section provided? • Is approach guardrail provided for the main section? • Is approach guard rail end section treated as per the standard?			

Signs Check? • Is there a bride sign at both approaches to the bridge? • Is there advance warning sign to the bridge? • Are non passing zones on the bridge approaches marked properly? • Are reflectors on the approach guard rail end and on the crush barrier placed?			

Appendix D: Bridge Design Safety Audit Checklist For Detailed Design Stage

Checklist	Yes	No	Comment
Are the following Information presented for the Audit? • Audit report and decisions on earlier stage audits • Design standard report • plans and profiles of the bridge and the approach roadway • Cross-section of the approach roadway and the bridge • Bridges layout plans including elevation • Details of traffic safety barrier systems • Traffic signing and road marking plans			
General Items to be Checked? • Are safety design elements according to the design criteria? • Is there consistency among the items relevant to bridge safety? • Is the approach roadway alignment designed as per the design standard? • Is there consistency of width , to achieve a safe cross-section? • Is pedestrian walkway as the standard? • Is bridge railing system as per the design standard? • Is approach guardrail transition and end section as per the standard?			
Geometric Elements to be checked? • Is there horizontal curve near the proximity of the bridge?			

• Is there a “Substandard” curve near the bridge? • Is the bridge on horizontal curve? • Is the gradient along both approaches acceptable? • Is there a sight distance limitation to the bridge? • Is there mis-phasing of vertical and horizontal curves near the bridge approach? • Is stopping sight distance adequate? • Is there steep downgrade on approach roadway to the bridges? • Does the bridge has longitudinal gradient? • Are the number and width of traffic lanes and width of shoulders according to the design standard? • Is sufficient pedestrian walkway width provided? • Are pedestrian protected from vehicular collision as well as falling of the bridge? • Is sufficient transition provided at location where the cross section changes significantly? • Is there sight line obstruction on approach roadway curves?			
Traffic safety feature checks? • Is the provision of clear zones applied for the traffic safety features? • Are transition sections properly bolted with the bridge railing systems? • Is the minimum length of guardrail provided? • Is the approach guardrail properly positioned on the shoulder? • Is crush worthy end terminal applied?			

• Are roadside hazards properly fenced at both bridge approaches?			
Traffic signing and road marking checks? • Are necessary warning signs provided and properly positioned to control before reaching the bridge? • Are bridge railing provided with appropriate reflectorization? • Does positioning of signs obstruct sight lines on the inside of curves? • Are signs and signposts positioned on the clear zone? • Are the correct type of longitudinal line markings shown on the bridge layout plans? • Are non-passing zones on the bridge approach and the bridge designated? • Are “stop” lines, holding (or “give way”) lines correctly placed on the approach roadway? • Are reflectorized road markings specified to enhance night time visibility? • Are retro-reflective pavement markers or road studs specified to supplement surface markings at night?			

Appendix E: Bridge Design Safety Audit Checklist For Construction Stage

Checklist			Comment
Are the following Information presented for the Audit? In the stage 4 Audit, there is less emphasis on reviewing plans and the major part of the audit will involve site inspection activities. The auditor will therefore require the following. • Are full set of construction plans, including plans for any traffic diversions and layouts associated with traffic management during construction presented? • Is measuring tape provided? • Is photographic equipment provided? • Are note taking and/or recording equipment provided?			
• Is approach roadway sight distance (e.g., stopping sight distance) over crests or on horizontal curves adequate? • Is stopping sight distance at "entry" and "exit" of the bridge adequate? • Is there mis-phasing of horizontal and vertical curves at approach to the bridges? • Is the required length of need provided for the guard rail at both approaches to the bridge? • Is the cross-section on the approach roadway and the bridge consistent?			
Bridge layout checks? • Does the approach roadway have adverse geometric alignment, particularly with respect to sharp horizontal curves and steep grades to the bridge?			

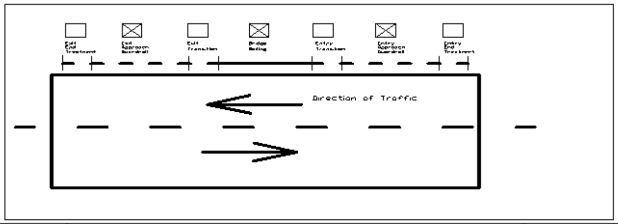
Checklist			Comment
• Are the number of lanes and width of lane as per the design layout? • Are the shoulder and walkway width according to the design layout? • Is the width of the approach roadway as per the design drawing? • Is the width of the bridge as per the design drawing? • Is the safety barrier under construction as per the design drawing?			
Traffic safety feature checks? • Is the type of guardrail or railing system appropriate to the site condition. • Is the type of guardrail or barrier, and the adequacy of its length in relation to the length of the influence zone adequate? • Is the guardrail functionally adequate? • Are the concrete blocks protected with guardrailing? • Is the location of the guardrail or barrier in the clear zone? • Is the approach end of a guardrail or barrier, end anchorage treated? • is the connection of the transition section with the rigid bridge railing system properly done? • Is a suitable “impact attenuator” or “crash cushion” provided?			
Traffic signing and road Marking checks? • Is the overall traffic signing strategy on the plans and on-site match? • Are regulatory and warning signs provision and placement as per the bridge layout? • Is advance warning sign placed before the entry of			

Checklist			Comment
the approach roadway? • Are the traffic signs obstructed by trees? • Are essential sight lines at the bridge approach obstructed by poorly located traffic signs? • Are road marking properly shown on the plan? • Are non-passing zones correctly shown on the plan? • Are raised retro-reflective pavement markers (or road studs), shown on the plan drawings?			

Appendix F: Bridge Safety Inspection Sheet

Part I: General Bridge Information	**Project:**	**Coordinate:**	**Bridge No.**	**Bridge Type:**	**Pavement Type:**
	Region:	**Year Constructed:**	**Clear Bridge Roadway Width:**	**Bridge Length:**	**Pavement Marking:**
	Road Class:	**Average Daily Traffic(ADT):**	**Shoulder width:**	**Bridge Material:**	**No of Spans:** **No of Lanes:**
	Posted Speed:	**Direction of Traffic:**	**Pedestrian Width:**	**Inspected By:**	**Date:**
Part II: Bridge Entry Approach Roadway Information	**Roadway Width:**	**Length of Influence Zone:**	**Bridge Visibility:** Yes No If No, indicate available sight distance:________	**Pavement Marking:** **Edge:** Yes No **Center:** Yes No	**Side Slope:** **Foreslope: H____:V____** **Backslope: H____:V____**
	Shoulder Width:	**Horizontal Curve** Yes No **Radius: 235m** **Superelevation: 2.5%** **Length:107m**	**Sight Obstruction** Yes No If yes, describe type of Obstruction: Horizontal Curve	**Object in Clear Zone:** Yes No **Required Clear Zone:______**	**Remark** **After the shoulder, there is a U-ditch and Retaining wall**
	Roadway Grade: **4%**	**Vertical Curve:** Yes No **Type:** Crest Sag	**Ditch Type & Width:** U-ditch Trapizodial-ditch No Ditch	**Pavement Type:** **Asphalt Concrete**	
Part III: Bridge Exit Approach Roadway Information	**Roadway Width:** **14.80m**	**Length of Influence Zone:** **50m**	**Bridge Visibility:** Yes No If No, indicate available sight distance:________	**Pavement Marking:** **Edge:** Yes No **Center:** Yes No	**Side Slope:** **Foreslope: H 2 :V 1** **Backslope: H 1 :V 1.5**
	Shoulder Width: **2m**	**Horizontal Curve:** Yes No **Radius:237.50m** **Superelevation: 2.5%** **Length:47.03m**	**Sight Obstruction:** Yes No If yes, describe type of Obstruction: Horizontal Curve	**Object in Clear Zone:** Yes No **Required Clear Zone:______**	**Remark** **After the shoulder, there is a Trapizoidal ditch and a cut section.**
	Roadway Grade: **6%**	**Vertical Curve:** Yes No **Type:** Crest Sag	**Ditch Type & Width:** U-ditch Trapizodial-ditch	**Pavement Type:** **Asphalt Concrete**	

Tick the Corresponding Box as per the availability of the Traffic Safety Feature



Insert Bridge layout here

Part IV: Bridge Traffic Safety Feature Information

Entry End Treatment: Yes / No

Type: ________, **Anchorage:** _______, **Grading:**______

Compliance: Yes / No

Entry Approach Guardrail: Yes / No

Type: RHS Tube , Length of Need:
Height: 1.0m Post Spacing: 2.0m
Flare Rate: N/A Lateral Offset: 2.0m
Compliance: No Yes / No

Entry Transition: Yes / No

Type:________ , **Length :**________
Height:_______, **Post Spacing:**_______
Connection:_______
Compliance: Yes / No

Bridge Railing:

Type: Reinforced Concrete

Post Spacing: 2.00m

Lateral Offset: 0.50m
Height : 0.90m

Length:110.0m

Exit End Treatment: Yes / No

Type: ________, **Anchorage:** _______, **Grading:**______

Compliance: Yes / No

Exit Approach Guardrail: Yes / No

Type: RHS Tube , Length of Need:________
Height: 1.0m, Post Spacing: 2.0m
Flare Rate: N/A, Lateral Offset: 2.0m
Compliance: Yes / No

Exit Transition: Yes / No

Type:________ , **Length :**________
Height:_______, **Post Spacing:**_______
Connection:_______
Compliance: Yes / No

Part V: Assessment of Traffic Safety Feature

Direction of Inspection

S.A	to	________B___	

Safety Feature	Rating
Entry End Treatment	X_______
Entry Approach Guardrail	2
Entry Transition	X_____
Bridge Rail	0
Exit Transition	X_________
Exit Approach Guardrail	3____
Exit End Treatment	X_____

Photographs

Insert Photograph here

Rating Legend	NA	UA Insp	None	Minor	Fair	Poor	Sever
	X	U	0	1	2	3	4