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VEHICLE COLLISION LOADING CRITEIA FOR BRIDGE PIERS

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1. Introduction

The Highways Agency (HA) is responsible for specifying the loading criteria for highway bridges in the UK. The design and assessment loading criteria for a Heavy Goods Vehicle (HGV) collision have been specified in BD60 and BD48 [1] and [2].

Following the tragic rail incursion at Great Heck, near Selby, in February 2001, the reports from Health and Safety Commission (HSC) [3], Department for Transport (DfT) [4] and HA [5] showed the way forward in managing risk where roads meet, cross or run close to railways.

This paper provides a brief discussion on the possible future changes to the current loading criteria for a HGV collision on bridge piers.

2. Existing Criteria

The requirements to design bridge piers to withstand HGV collision loads was first introduced in the UK in the 1978 publication of BS 5400: Part 2 [6]. The loading was later increased ten-fold by the Department of Transport in BD 60/94 [7]. The static load is derived from the principles given in BS6779 Part 1:1992 Appendix A [8], assuming a 90 degree impact for a 40 tonne HGV at 50 mph and allowing the vehicle to slew or swing round parallel to the support at the end of the incident. It is assumed that a slowing down of 10 mph can be reasonably expected as the effect of the driver braking and/or the presence of soft verge, safety fences etc. on most high speed roads, giving the maximum design travelling speed as 60 mph. More importantly the large collision loads are only applied where the bridge support is located at less than 4.5m from the edge of the carriageway.

3. Selby Incident

On 28 February 2001 a vehicle came off the M62 motorway at Great Heck, near Selby, ran down the railway embankment and onto the East Coast Main Line, where it was struck by a passenger train. The passenger train was derailed and then struck by a freight train travelling in the opposite direction. 10 people on the trains were killed.

The subsequent reports by HSC, DfT and HA [3, 4 and 5] form the basis to develop guidance on the application of measures to manage risk where roads meet, cross or run close to railways.

The DfT report [4] considers:-

i) Risk assessment;
ii) Ranking sites to assess comparative risk: highlight the highest risk areas;
iii) Assessing scope for treatment: work out at which part of the site the worst might occur;

iv) Deciding how much to spend: best use of available resources
v) Assessing cost-effectiveness of mitigating measures.

The DfT report [5] considers:-
i) Risk assessment;
ii) Analysis of accidental data: ascertain reasons of vehicles leaving the carriageway;
iii) Hazards;
iv) Consequences: economic risk value;
v) Comparison with international standards

4. Review of Existing Criteria

The approach adopted in BD60 and BD48 [1 and 2] may be appropriate when it was prepared in the 1970s. However designers are increasingly willing to provide the bridge support with a lateral clearance of exactly 4.5m so that the large collision loads would not be required. This is done without due consideration of other factors which might affect the risk of impact, as it is not specified in the standards. While recognising that the current standards are easy to use by the designers, they would probably need to be revised in order to fall in line with the principles recommended in the Selby reports.

5. Possible Future Criteria

Future revised criteria should therefore consider for each specific site, the following issues:-

i) Risk Assessment

The probability of a HGV impact on a bridge support is quite low, however the consequences could be very severe if the impact led to the collapse of the bridge. Risk assessment would provide an approach to identity the hazards and to understand the relationship between the probability of such hazards occurring and the consequences. It also provides a strategic basis through the definition of an acceptable level of risk that the duty holder is willing to tolerate.

ii) Risk Methodology

In general terms, the risk can be expressed as the product of the probability and the consequence, so that for a pier impact the risk may be written as:

$$\text{Risk} = P(\text{Vehicle leaves carriageway and impacts pier}) \times P(\text{Impact load} > \text{Load capacity}) \times \text{Consequence of pier failure.} \quad [1]$$

A risk based approach for determining the impact loads for a specific pier could estimate all of the terms on the right of Equation [1], except for the load capacity. It would then be possible to calculate an impact load that is appropriate to the accepted level of risk on the left of Equation [1].

iii) Probability of Pier Impact and Probability of Impact Load greater than Load Capacity

The probability of a vehicle leaving the carriageway and hitting the pier and/or the probability of impact load greater than load capacity could be assessed, based on parameters such as:

a) Lateral clearance from the carriageway;
b) Likely speed of impact (e.g. initial typical vehicle speed, ground profile, verge type (e.g. paved/grass) and terrain (e.g. flat, upward/downward slope), possible braking effects);
c) Slewing of vehicle after impact;
d) Vehicle mass, type, construction, brakes etc;
e) Tendency of vehicle to deviate from the carriageway;
f) Highway characteristics (e.g. type of road, type of junctions, no. of lanes/carriageways, volume of traffic, %HGV on route, horizontal and vertical road alignments, highway lighting/signing/lane marking)
g) Site topography (how far an errant vehicle would travel after leaving a high-speed road)
h) Site-specific hazards (e.g. unusual traffic movements)
i) Provision of barriers or kerbs

For practical reason, it may be more appropriate to consider the more important factors and allow appropriate weighting.

iv) Consequences

The consequences of collapse of the pier could also be assessed, initially by evaluating the robustness of the bridge and determining whether the whole bridge would collapse. Then, if appropriate, the consequences of a bridge collapse could be estimated, perhaps based on the bridge size and the type of roads that would be affected.

If the bridge were to collapse, there would be a risk of injury to the vehicle occupants, as well as other road users both on the carriageway running under the bridge and on the bridge itself.

The consequence outcomes could be measure by a number of different impacts, such as:

- Injury to road users (both from the primary incident and any secondary incident)

- Cost of repair or replacement of the structure (related to extent of damage and type of structure)

- Effects on the road network due to closure or restriction

The typical groups of event sequence from an initiating event may be illustrated as follows:

Event	Consequence outcome	Impact
HGV leaves carriageway and strikes bridge support	Damage to pier Possible bridge collapse Potential for collateral damage	Injury and fatality to road users Cost of repair or replacement

	Injury to road collision vehicle occupant Secondary effects, injury to other road users	Effects on road network due to closure or restriction

v) Risk Acceptance Criteria

Figure 1 illustrates that, by understanding the risk relationship and defining appropriate risk-acceptance criteria, a corresponding accidental impact load can be defined to meet the required level of risk.

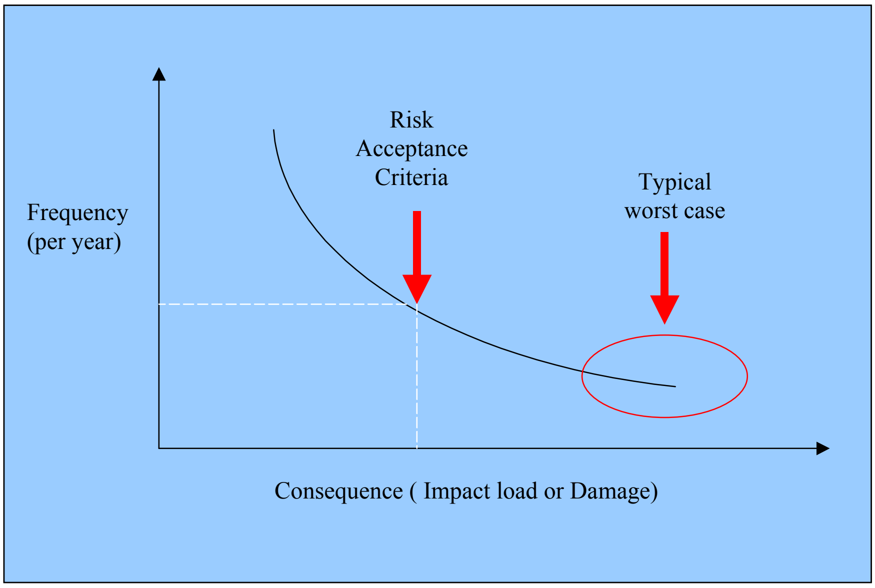

Figure 1 Typical risk acceptance curve

The development of design criteria based on a risk assessment would require the following issues to be addressed:

- Definition of risk acceptance criteria
- Definition of the type of consequence outcome and impacts to be included in the consequence analysis
- Assessment of influencing factors associated with the probability of vehicle impact
- Modelling the severity of the collision for the consequence analysis

The decision on the type and level of risk acceptance criteria is critical to the risk management process and outcome. There are a number of approaches for defining risk criteria, such as

- Reliability based approach
- Loss of life

- ALARP (As Low As Reasonably Practicable)

Some recommended target reliability levels are shown in Table 1, related to consequences of failure.

Standards	**Recommended target failure probability**	**Classes of structure stated**
AASHTO LRFD	10^{-3} p.a. to 10^{-4} p.a.	Bridge collapse from vessel collision
EN 1990:2002	10^{-5} p.a. to 10^{-7} p.a.	Ultimate limit state failure
Nordic Committee for safety of Structures	10^{-3} p.a. to 10^{-7} p.a.	Consequences ranging from not serious to very serious, structures ductile with reserve capacity to brittle instability
JCSS Probabilistic Model Code	10^{-3} p.a. to 10^{-6} p.a.	Structures with consequences of failure ranging from large to minor. Costs of safety measure large, medium or small.

Table 1: Recommended target failure probabilities

Risk criteria are often defined in terms of risk to life. The Health and Safety Executive (HSE) provides guidance on tolerability limits to these risks, suggesting that an individual risk of death of one in a million (10^{-6}) per annum for both workers and the public corresponds to a very low level of risk, and should be used as a guideline for the boundary between the broadly acceptable and tolerable regions. HSE suggests that an individual risk of death of one in a thousand (10^{-3}) per annum should represent the dividing line between what could be just tolerable for any substantial category of workers for any large part of a working life, and what is unacceptable for all but exceptional groups.

The DfT set out its strategy for improving road safety over the next decade, which included targets to reduce the number of people killed or seriously injured (KSI) by 40 per cent, child deaths and serious injuries by 50 per cent, and the slight casualty rate expressed as the number of people slightly injured per 100 million vehicle kilometres by 10 per cent, by 2010 compared with the average for the years 1994 to 1998. The data are presented in Table 2 for the whole network.

	1994 - 1998 Average	**2001**
KSI casualties	57,656	40,560
Childs KSI casualties	6,860	4,988
KSI casualty rate per 100 million vehicle kilometres.	11	8
Slight casualty rate per 100 million vehicle kilometres.	61	57

Table 2: Casualties data

The HSE risk criteria and DfT safety targets are expressed as the total risk criteria that may be experienced by the individual. However the risk of vehicle collision with a bridge is only one of many hazards that road users are exposed to. Therefore from the overall risk criteria, the risk target specific to bridge collision must be assigned.

UK Health and Safety regulations require risks to be ALARP. Therefore in addition to compliance with specific risk acceptance criteria the risk has to be demonstrated to be ALARP. This will usually involve some trade-off assessment, such as cost benefit analysis, that demonstrates that all appropriate safety measures have been taken.

6. Summary

This paper describes the current loading criteria for a HGV collision for highway bridges in the UK and then compares with the recommendations given in the Selby reports. It is considered that the current loading criteria may need to be revised to adopt a risk assessment approach. Some aspects of this new approach have been discussed.

7. References

[1] BD60/04: The design of highway bridges for vehicle collision loads.

[2] BD48/93: The assessment and strengthening of highway bridge supports.

[3] Obstruction of the railway by road vehicles. Health and Safety Commission February 2002

[4] Managing the accidental obstruction of the railway by road vehicles. Department for Transport February 2003

[5] To review the standards for the provision of nearside safety fences on major roads. Highways Agency 2003

[6] BS5400: Steel, concrete and composite bridges, Part 2 Loading. 1978

[7] BD60/94: The design of highway bridges for vehicle collision loads.

[8] BS6779: Part 1 specification for vehicle containment parapets of metal construction. 1992