VOLUME 1 HIGHWAY STRUCTURES: APPROVAL PROCEDURES AND GENERAL DESIGN

SECTION 3 GENERAL DESIGN

PART 5

BD 60/04

THE DESIGN OF HIGHWAY BRIDGES FOR VEHICLE COLLISION LOADS

SUMMARY

This Standard gives criteria for the design of highway bridges for vehicle collision loads. It updates and replaces in Part BD 37/01.

INSTRUCTIONS FOR USE

This is a new document to be incorporated into the Manual.

1. Remove Contents pages for Volume 1.

2. Insert new Contents pages for Volume 1, dated May 2004.

3. Insert BD 60/04 into Volume 1, Section 3, Part 5.

4. Please archive this sheet as appropriate.

Note: A quarterly index with a full set of Volume Contents Pages is available separately from The Stationery Office Ltd.

THE HIGHWAYS AGENCY

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THE DEPARTMENT FOR REGIONAL DEVELOPMENT
NORTHERN IRELAND

The Design of Highway Bridges for Vehicle Collision Loads

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REGISTRATION OF AMENDMENTS

Amend No	Page No	Signature & Date of incorporation of amendments	Amend No	Page No	Signature & Date of incorporation of amendments

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Contents

1. INTRODUCTION

1.1 Accidental collisions of heavy goods vehicles with the supports and superstructures of highway bridges occur quite frequently on a national scale. Statistics gathered from such accidents (see Appendix A) show that collisions take place with bridge decks of standard (or greater) headroom clearance and on roads of most categories. Although, so far, only one trunk road bridge has been completely dislodged by a collision, several footbridges and sign/signal gantries have been partly or totally removed from their supports and hence the potential is there for a major catastrophe unless appropriate action is taken both for existing bridges and in respect of future bridges. Appendix B shows photographs of some collisions with bridges.

1.2 The Department of Transport set up a working party to examine ways of protecting existing bridges from large goods vehicle collisions. The working party, which originally concentrated on railway over-bridge strikes, considered highway bridges. Various preventative measures were considered, some of which were implemented. The Highways Agency also assessed and strengthened bridge supports that were considered to be particularly at risk with respect to collision loads; the requirements are contained in BD 48 (DMRB 3.4.7).

Purpose

1.3 The purpose of this Standard is to promulgate the collision loading requirements for new highway bridges and foot/cycle track bridges, as a revision of Appendix A Clauses 6.8 and 7.2 of BD 37/01 (DMRB 1.3), which it supersedes [except for the design of certain foot/cycle track bridge supports (see 2.2)]. For bridges other than highway or foot/cycle track bridges, such as rail bridges, over a highway, the application of this Standard shall be agreed with the appropriate authority. The revised loading represents, more realistically, the possible effects of heavy goods vehicle collisions and is consistent with other national and international requirements. This Standard contains the loading, broad principles for its application and some specific guidelines for design.

Sign/Signal Gantries and Lighting Columns

1.4 This Standard does not cover the design of sign/signal gantries, lighting columns or lightweight mast structures such as CCTV masts.

Geotechnical Structures

1.5 This Standard does not cover the design of geotechnical structures, such as corrugated steel buried structures or reinforced soil abutments.

Implementation

1.6 This Standard should be used forthwith for all schemes currently being prepared provided that, in the opinion of the Overseeing Organisation, this would not result in significant additional expense or delay progress. Design Organisations should confirm its application to particular schemes with the Overseeing Organisation.

Terminology

1.7 For licensing purposes an HGV (Heavy Goods Vehicle) has been recently renamed as an LGV (Large Goods Vehicle). The term HGV is used throughout this document.

2. THE REQUIREMENTS

Vehicle Collision Loads on Highway and Foot/Cycle Track Bridge Supports and Superstructures

2.1 Vehicle collision loads on supports and superstructures shall be considered for the design of bridges as secondary live loads, as defined in BD 37 (DMRB 1.3), and shall be applied in Load Combination 4, also described therein. No other live load shall be considered as coexistent.

2.2 Where bridges over carriageways have supports of which any part is located less than 4.5m from the edge of a carriageway (see BD 37 (DMRB 1.3) for definition) these shall be designed to withstand the vehicle collision loads given in Table 3. Where bridge supports are located equal to or greater than 4.5m from the edge of carriageway, the Designer is required to analyse the vulnerability of the supports to vehicular impact. The Designers should use engineering judgement and risk assessment techniques to ascertain the level of risk and vulnerability. Where the assessments indicate that the potential risk of vehicular impact is severe, the supports shall be designed to those collision loads given in Table 3 or appropriate additional mitigation measures, eg safety barriers, shall be provided. The Designer’s choice of action in this respect and the design collision loads shall be recorded as appropriate eg in AIP in accordance with BD 2 (DMRB 1.1). As a general guidance, it is intended that the definition of above-mentioned ‘severe potential risk of vehicular impact’ would only apply to special cases such as footbridges with single column support, major long span bridges etc. However, where foot/cycle track bridge ramps and stairs are structurally independent of the main highway-spanning structure, their supports may be designed to the loads specified in Appendix A Clause 6.8 of BD 37/01 (DMRB 1.3), as shall all bridge supports with a carriageway clearance equal to or greater than 4.5m except where considered vulnerable by the Designer and where additional mitigation measures are not provided (see Table 1). In the case of multi-level carriageways, such as those encountered in motorway, trunk or principal road interchanges, the collision loads are to be considered for each level of carriageway separately. Vehicle collision on abutments need not normally be considered as they are assumed to have sufficient mass to withstand the collision loads for global purposes. Where bridges have a headroom clearance of less than 5.7 metres plus sag radius compensation and deflection of structure in accordance with TD 27 (DMRB 6.1), the vehicle collision loads on superstructures shall be considered (see Table 2). The minimum headroom clearance shall be in accordance with TD 27 (DMRB 6.1). The vehicle collision loads on superstructures are not applicable to the superstructure of foot/cycle track bridges, as these are required to have headroom exceeding the applicable limit to mitigate the effects of their lightweight nature. However adequate restraint on the deck shall be provided to prevent the deck being removed from the support under the action of vehicle collision forces given in Table 4.

Collision loads on supports	**Clearance from edge of carriageway**	
	< 4.5m	**≥ 4.5m**
Highway bridges:		
Piers	Table 3	Appendix A Clause 6.8 & Table 15 of BD 37/01 OR Table 3, where applicable and where additional mitigation measures are not provided
Foot/cycle track bridges:		
Main piers including ramps and stairs	Table 3	Appendix A Clause 6.8 & Table 15 of BD 37/01 OR Table 3, where applicable and where additional mitigation measures are not provided
Ramps and stairs that are structurally independent of the main highway-spanning structure	Appendix A Clause 6.8 & Table 15 of BD 37/01	Appendix A Clause 6.8 & Table 15 of BD 37/01

Table 1: Vehicle collision loads on supports of bridges over highways

Collision loads on superstructures	**Headroom clearance**	
	< (5.7m + sag radius compensation + deflection of structure)	**≥ (5.7m + sag radius compensation + deflection of structure)**
Highway bridges:	Table 4	Not required
Foot/cycle track bridges:	Not applicable	Not required

Table 2: Vehicle collision loads on bridge superstructures over highways

Nominal Loads on Supports

2.3 The nominal loads are given in Table 3 together with their direction and height of application, and shall be considered as acting horizontally on bridge supports. Supports shall be capable of resisting the main and residual load components acting simultaneously. Loads normal to the carriageway shall be considered separately from loads parallel to the carriageway.

	Load normal to the carriageway below	**Load parallel to the carriageway below**	**Point of application on bridge support**
Main load component	kN 500	kN 1000	At the most severe point between 0.75 m and 1.5 m above carriageway level
Residual load component	250 (100)	500 (100)	At the most severe point between 1m and 3m above carriageway level

Table 3: Nominal Collision Loads on Supports of Bridges over Highways

Note: Figures within brackets are applicable for foot/cycle track bridges (see paragraph 2.7)

Nominal Loads on Superstructures

2.4 The nominal loads are given in Table 4 together with their direction of application. The load normal to the carriageway shall be considered separately from the load parallel to the carriageway. The loads shall be considered to act as point loads on the bridge superstructure in any direction between the horizontal and vertical. The load shall be applied to the bridge soffit, thus precluding a downward vertical application. Given that the plane of the soffit may follow a super-elevated or non-planar (curved) form, the load normal to the carriageway may be applicable in either sideways direction.

Load normal to the carriageway below	**Load parallel to the carriageway below**	**Point of application on bridge superstructure**
kN 250	kN 500	On the soffit in any inclination between the horizontal and the (upward) vertical

Table 4: Nominal Collision Loads on Highway Bridge Superstructures over Highways

General Principles

2.5 The intention behind these requirements is that the overall structural integrity of the bridge should be maintained following an impact but that local damage to a part of the bridge support or deck can be accepted.

Supports and Superstructures of Bridges

2.6 Design checks shall be carried out in two stages as described below:

Stage 1. At the moment of impact. A check is to be made at ULS only, using the nominal impact loads with partial factors γ_{fL} appropriate to load combination 4. No other live load is to be included in this check. Local damage is to be ignored. It is to be assumed that full transfer of the collision forces from the point of impact takes place. For the bridge, as in design for all other load cases, the designer shall determine a likely and reasonable load-path to transfer the impact loads to the bearings, supports and foundations (in the case of superstructure strikes) or to foundations, bearings or other supports (in the case of support strikes). Each structural element in the load-path is to be considered, starting with the element which sustains the immediate impact. If it is assumed or found to be inadequate, it may nevertheless be assumed to have effected the transfer to the next element(s) in the load-path, but it must be neglected in carrying out the Stage 2 check. Each element in the load-path shall be considered on the same basis. It should be noted that inadequacy at this stage is not a cause for concern, since such inadequacy generally helps to absorb the impact force. In order to prevent the whole structure being bodily displaced by the impact, its bearings or supports shall be designed to be fully adequate to resist the impact loads. Additionally, the Overseeing Organisation may require that certain other elements shall be adequate to resist the impact loads.

Stage 2. Immediately after the impact. Immediately after the event, the bridge has to be able to stand up whilst still carrying traffic which may be crossing. Since the check is one of survival and the likely traffic is of an every-day intensity, it shall be carried out at ULS only but using the partial load factors normally appropriate to SLS.

Combination 1 shall be used. The partial factors γ_m and γ_{f3} should take their usual ULS values. HA loading and/or a maximum of 30 units of HB loading shall be applied for bridges carrying public highways. For this check, the designer has to judge what local damage might reasonably have occurred and must ignore elements which were assumed or found to be inadequate at Stage 1. If the structure does not satisfy the Stage 2 check then Stage 1 will have to be repeated with different assumptions about the adequacy of some elements in the load-path. To justify such amended assumptions, elements may need to be redesigned to ensure their adequacy. Some guidance on possible local damage and the way impact forces are transmitted in the case of steel and steel/composite bridge decks is given in Appendix C.

Foot and Cycle Track Bridges

2.7 For the design of supports of foot and cycle track bridges where Table 3 loading is required (see 2.2), robust plinths of 1.5m height shall be provided to carry the supports and to resist the main and residual load components given in Table 3 with other appropriate loads in accordance with 2.1. The supports themselves shall be designed to the reduced residual load components shown within brackets in Table 3.

Elastomeric Bearings

2.8 For elastomeric bearings, the effects due to vehicle collision loads on supports and on superstructures should only be considered at the serviceability limit state. The γ_{fL} to be applied to the nominal loads shall have a value of 1.0.

Foundations

2.9 Foundations shall be designed to resist the impact forces transmitted from the collision using BD 30 (DMRB 2.1) and/or BD 32 (DMRB 2.1), as appropriate, with the following qualifications:

(a) Only ULS checks are required, both for structural elements and soil-structure interaction.

(b) When checking against the sliding of the base and bearing capacity, even for piled foundations, the collision loads shall be reduced by 50% but full loading shall be considered for checking against overturning.

3. REFERENCES

Design Manual for Roads and Bridges

Volume 1: Section 3: General Design

BD 37 (DMRB 1.3) - Loads for Highway Bridges

Volume 2: Section 1: Substructures

BD 30 (DMRB 2.1) - Backfilled Retaining Walls and Bridge Abutments

BD 32 (DMRB 2.1) - Piled Foundations

Volume 3: Section 4: Assessment

BD 48 (DMRB 3.4.7) - The Assessment and Strengthening of Highway Bridge Supports

4. ENQUIRIES

All technical enquiries or comments on this Standard should be sent in writing as appropriate to:

Chief Highway Engineer The Highways Agency 123 Buckingham Palace Road London SW1W 9HA	G CLARKE Chief Highway Engineer

Chief Road Engineer Scottish Executive Victoria Quay Edinburgh EH6 6QQ	J HOWISON Chief Road Engineer

Chief Highway Engineer Transport Directorate Welsh Assembly Government Llywodraeth Cynulliad Cymru Crown Buildings Cardiff CF10 3NQ	J R REES Chief Highway Engineer Transport Directorate

Director of Engineering The Department for Regional Development Roads Service Clarence Court 10-18 Adelaide Street Belfast BT2 8GB	G W ALLISTER Director of Engineering

APPENDIX A: HGV/BRIDGE COLLISION STATISTICS

HGV COLLISIONS (1986 – 1990)

Height Clearance by Bridge Type

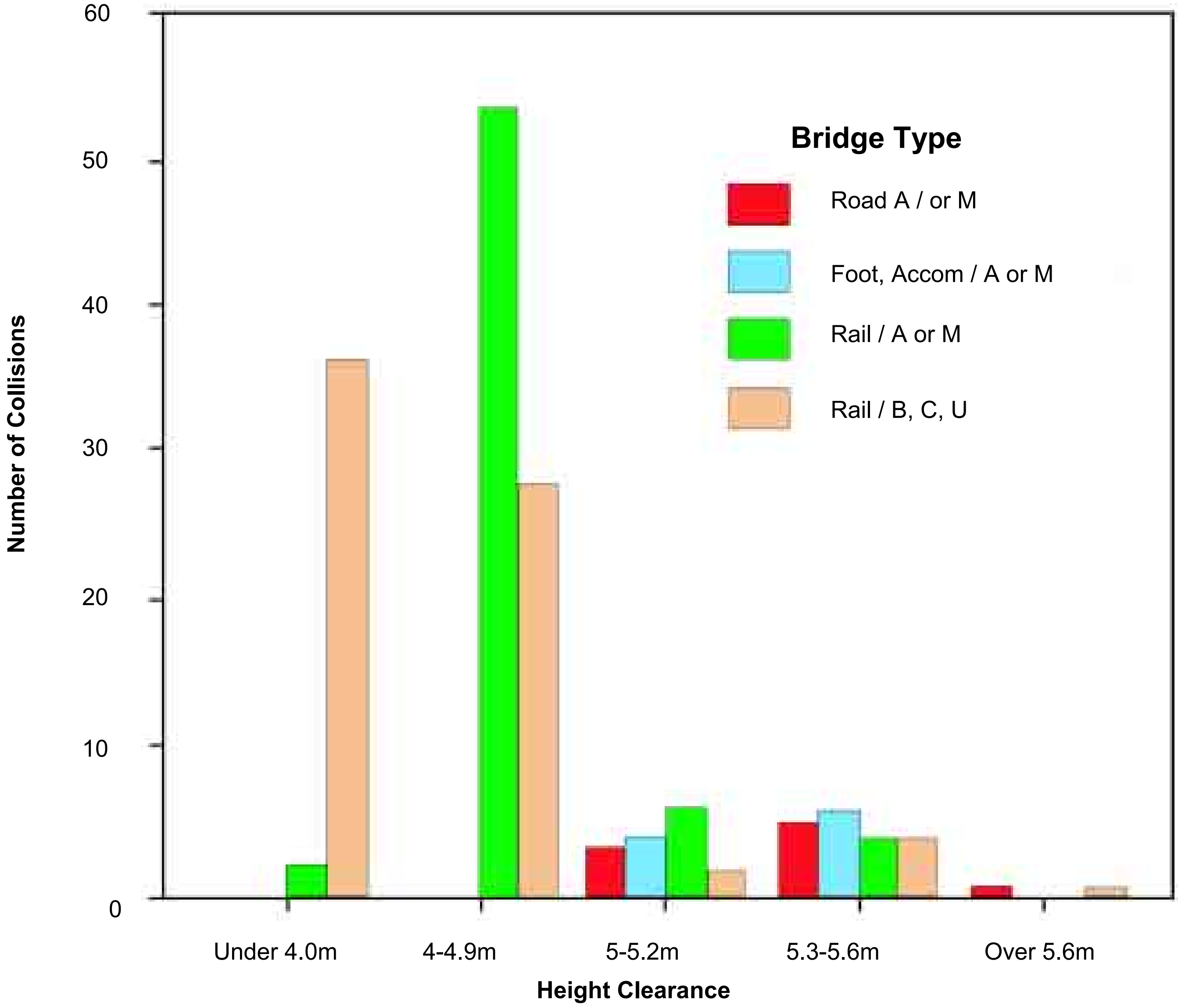

FIG A/1 DISTRIBUTION OF BRIDGE DECK COLLISIONS (England and Wales 1986 - 1990)

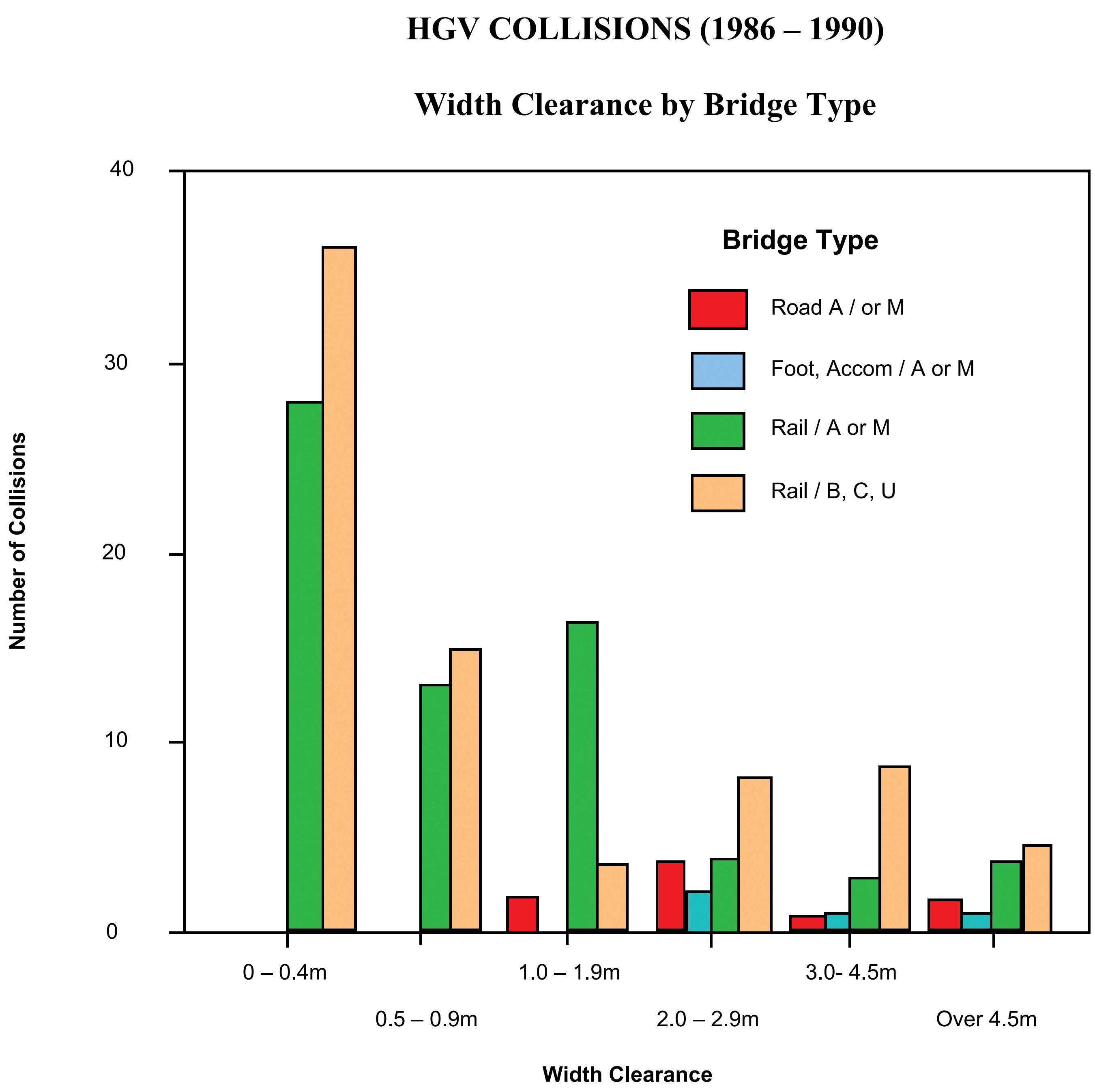

FIG A/2 DISTRIBUTION OF BRIDGE SUPPORT COLLISIONS (England and Wales 1986 - 1990)

APPENDIX B: HGV/BRIDGE COLLISION PHOTOGRAPHS

PLATE 1 COLLISION OF HGV WITH REINFORCED CONCRETE SUPPORT M20 MOXLEY ROAD BRIDGE
(Photograph by kind permission of Director of Highways and Transportation, Kent County Council)

PLATE 2 COLLAPSE OF A DECK SPAN FOLLOWING A COLLISION FROM AN EXCAVATOR TRANSPORTED ON A LOW LOADER
A2 PARK PALE ACCOMMODATION BRIDGE
(Photograph by kind permission of Director of Highways and Transportation, Kent County Council)

PLATE 3 COLLISION DAMAGE TO REINFORCED CONCRETE CENTRAL SUPPORT M74 LAIRS FLYOVER - B7078

APPENDIX C: GUIDANCE FOR STEEL AND STEEL/ COMPOSITE BRIDGE DECKS

C.1 The following guidance on possible local damage in various types of steel and steel/composite bridge decks is based on advice from the Steel Construction Institute and is being included in this Standard with their agreement.

Composite Girder and Slab Bridge

C.2 For a conventional girder-and-slab bridge with intermediate transverse bracing, impact on a bottom flange is likely to cause local plastic deformation and possibly a small amount of tearing of the flange. The flange may also be torn locally from the web. There may be considerable twisting (rotation) of the flange about its line of fixture to the web, or, in some cases, of the flange and the web about a line some distance up the web. If impact occurs at a 'hard point' (eg at transverse crossbracing) there may be slightly more local deformation than at 'softer' positions (eg between bracing).

Design against impact for such a bridge could therefore assume that in Stage 1 the specified impact force is carried as follows:

(a) Horizontal force is spread from the point of impact along the length of the girder, by bending and shear in the plane of the bottom flange, to points of lateral restraint, ie at transverse bracing. From such positions it is transferred through the bracing members to connected members. If inclined bracing members are present the impact forces will be transferred to the top flanges of the girders and into the plane of the deck slab. At the supports the force is carried down through the support bracing to the bearings and into the substructutre if transverse fixity is provided.

(b) Vertical force is applied upward in the line of the web and transferred by global bending, of the whole deck, back to the supports.

(c) Inclined forces are simply resolved into components of horizontal and vertical forces. Local effects from an inclined force on the tip of a flange may cause only local damage, and this need not be checked.

The possibility of damage to more than one main beam should be considered.

C.3 For survival in Stage 2, the effect of the damage could be as follows. As a tension element, the flange is likely still to be quite effective. It would be reasonable for a designer to make only a small allowance for loss of effective section although the moment of inertia may be significantly reduced due to the twisting described in C.2. However, as a compression element, ie in the region close to an intermediate support, the local damage may be sufficient to initiate large deflection local buckling, particularly if the flange is torn from the web locally. It may be prudent to presume the creation of a pin joint in the beam which has been struck and carry out a global analysis accordingly. The shear capacity of the webs should be considered carefully, presuming an ineffective flange and possibly a small reduction of web area; the effects of web rotation on shear capacity may be considerable.

Provided that the design of the bracing and its attachment is adequate for the Stage 1 check, there should be no significant damage to those members.

Box Girder Bridge

C.4 For a box girder bridge, local deformation of the web-flange junction is likely, possibly with minor local tearing. If the impact is at or very close to an internal diaphragm or cross-frame, some internal damage may also result.

C.5 In Stage 1 the forces would be transferred by distortional behaviour back to diaphragm or cross-frame positions and then by torsion and bending back to the supports.

C.6 Under Stage 2 for mid-span regions there should be little reduction in ultimate moment capacity, as for the beam-and-slab bridge; torsional capacity is also likely to be largely retained. Adjacent to supports the deformation of the web-flange junction will lead to some loss of moment capacity, but it is likely that the other lower corner will continue to provide some bending strength. The designer will have to judge, depending on proportions and plate thicknesses, what capacity might remain.

Half-through Bridge

C.7 The deck of a half-through bridge will provide continuous and direct restraint to the bottom flange against impact forces. Some tearing of the bottom flange might occur. If the connection or cross-beam which provide U-frame restraint could be damaged by the impact, then Stage 2 should consider the structural action without that restraint at one cross-beam. As for girder and slab bridges, the effective area of the tension flange should be reduced appropriately.