VOLUME 1 HIGHWAY STRUCTURES: DESIGN (SUBSTRUCTURES AND SPECIAL STRUCTURES), MATERIALS

SECTION 3 SPECIAL STRUCTURES

PART 5

BD 60/94

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 37/88.

INSTRUCTIONS FOR USE

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

1. Remove contents pages for Volume 1 dated July 1993.
2. Insert BD 60/94 into Volume 1 Section 3.
3. insert new contents page for Volume 1 dated May 1994.
4. Archive this sheet as appropriate.

BD 60/94

THE HIGHWAYS AGENCY

THE SCOTTISH DEVELOPMENT DEPARTMENT

THE WELSH OFFICE
Y SWYDDFA GYMREIG

THE DEPARTMENT OF
THE ENVIRONMENT FOR NORTHERN IRELAND

The Design of Highway Bridges for Vehicle Collision Loads

Summary: This Standard gives criteria for the design of highway bridges for vehicles collision loads. It updates and replaces in part BD 37/88.

This Standard provides advice on specification requirements for use in public purchasing contracts. It does not lay down legislative requirements for products and materials used in highway construction in the United Kingdom.

REGISTRATION OF AMENDMENTS

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

REGISTRATION OF AMENDMENTS

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

Volume 1 home page

VOLUME 1 HIGHWAY STRUCTURES: APPROVAL PROCEDURES AND GENERAL DESIGN

SECTION 3 GENERAL DESIGN

PART 5

BD 60/94

THE DESIGN OF HIGHWAY BRIDGES FOR VEHICLE COLLISION LOADS

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 recent collisions with bridges.

1.2 The Department of Transport set up a working party to examine ways of protecting existing bridges from heavy goods vehicle collisions. The working party, which originally concentrated on railway over-bridge strikes, are now considering highway bridges. Various preventative measures are being considered, some of which are already being implemented. Furthermore, as a part of the current Bridge Rehabilitation Programme, the Highways Agency is also assessing and strengthening bridge supports 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 Clauses 6.8 and 7.2 of BD 37/88 (DMRB 1.3) , which it supersedes [except for the design of certain foot/cycle track bridge supports (see 2.2)]. 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 or lighting columns.

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 Bridge Supports and Superstructures

2.1 Vehicle collision loads on supports and superstructures shall be considered for the design of bridges and other highway structures 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 within 4.5m of 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 1. 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 Clause 6.8 of BD 37/88 (DMRB 1.3), as shall all foot/cycle track bridge supports with a carriageway clearance equal to or greater than 4.5m.

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 over carriageways have a headroom clearance of less than 5.7 metres, the vehicle collision loads on superstructures shall be considered.

Nominal Loads on Supports

2.3 The nominal loads are given in Table 1 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 1: Nominal Collision Loads on Supports of Bridges over Highways

Note: Figures within brackets are applicable for lightweight structures (see paragraph 2.7)

Nominal Loads on Superstructures

2.4 The nominal loads are given in Table 2 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	kN	
250	500	On the soffit in any inclination between the horizontal and the (upward) vertical

Table 2: Nominal Collision Loads on Bridge Superstructures over Highways

General Principles

2.5 The intention behind the new 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 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 Department 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.

Lightweight Structures

2.7 For the design of supports of lightweight structures, such as foot and cycle track bridges where Table 1 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 1 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 1.

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:

The Chief Highway Engineer The Highways Agency St Christopher House Southwark Street London SE1 0TE	T A ROCHESTER Chief Highway Engineer

The Deputy Chief Engineer The Scottish Office Industry Department Roads Directorate New St Andrew's House Edinburgh EH1 3TG	J INNES Deputy Chief Engineer

The Director of Highways Welsh Office Y Swyddfa Gymreig Government Buildings Ty Glas Road Llanishen Cardiff CF4 5PL	K J THOMAS Director of Highways

Chief Engineer - Roads Service Department of the Environment for Northern Ireland Roads Service Headquarters Clarence Court 10-18 Adelaide Street Belfast BT2 8GB	W J McCOUBREY Chief Engineer - Roads Service

APPENDIX A: HGV/BRIDGE COLLISION STATISTICS

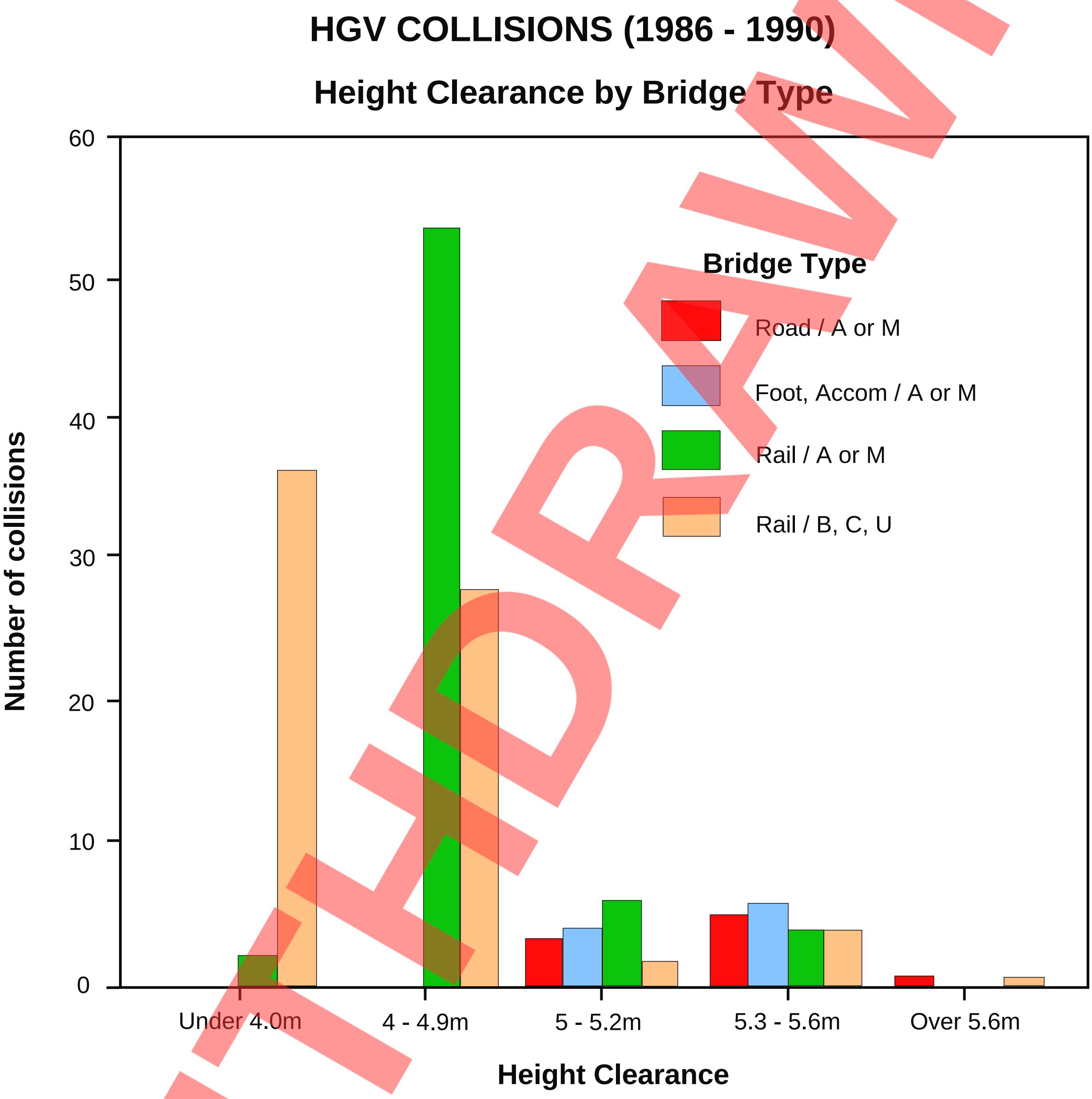

FIG A/1 DISTRIBUTION OF BRIDGE DECK COLLISIONS (England and Wales 1989 - 1990)

Volume 1 home page

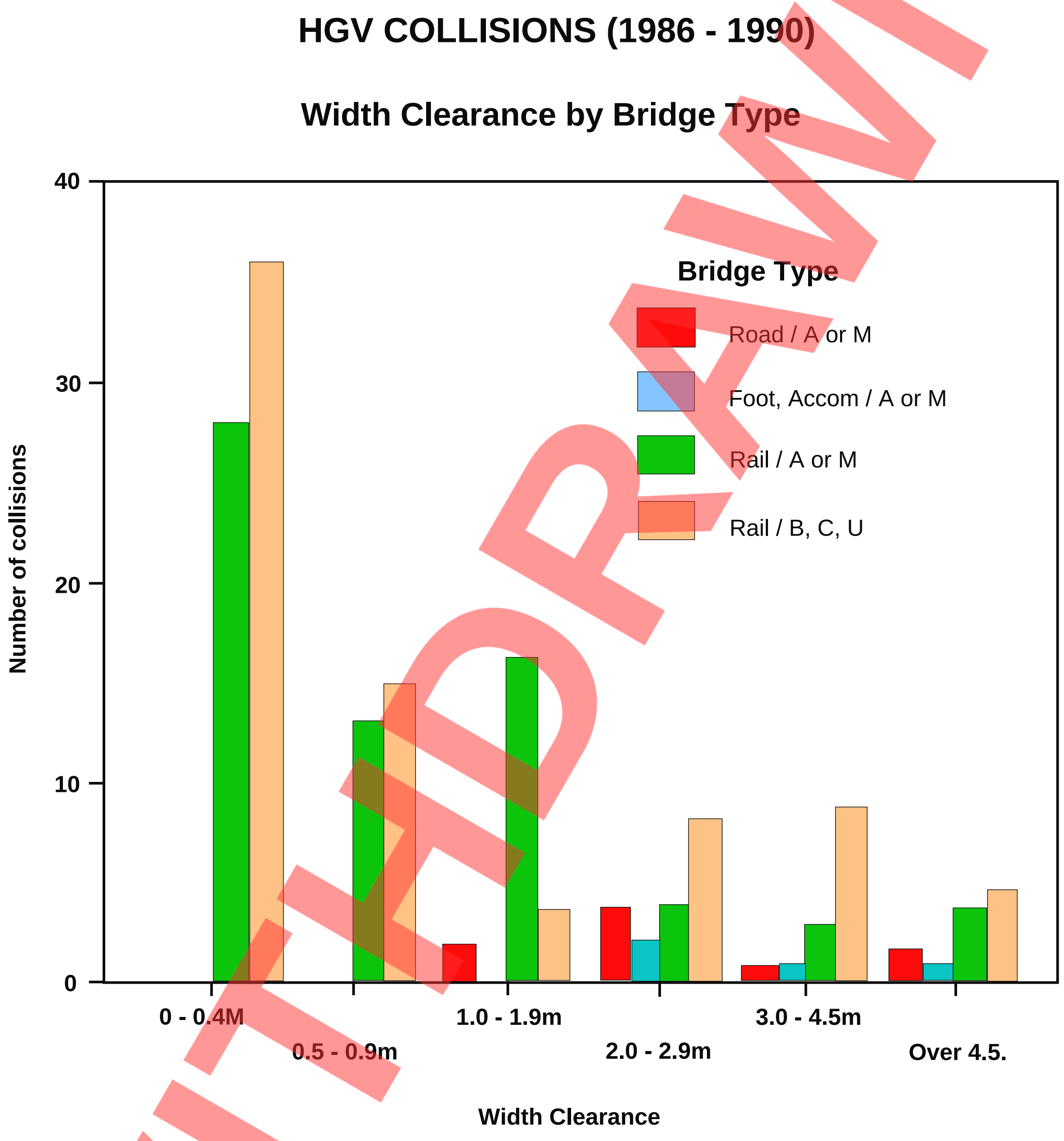

FIG A/2 DISTRIBUTION OF BRIDGE SUPPORT COLLISIONS (England and Wales 1986 - 1990)

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

Volume 1 home page

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

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 cross-bracing) 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, i.e at transverse bracing. From such positions it is transferred through the bracing members, through 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.

(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.

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 5.2. However, as a compression element, i.e 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 them 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.