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Transport Infrastructure Ireland

TII Publications

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Use of I.S. EN 1991-1-7 for the Design of the Accidental Actions

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DN Design

Standards

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For all documents that existed within the NRA DMRB or the NRA MCDRW prior to the launch of TII Publications, the NRA document reference used previously is listed above under 'historical reference'. The TII Publication Number also shown above now supersedes this historical reference. All historical references within this document are deemed to be replaced by the TII Publication Number. For the equivalent TII Publication Number for all other historical references contained within this document, please refer to the TII Publications website.

Volume 1 Section 3
Part 5A

NRA BD 60/10

National Roads Authority
An tÚdarás um Bóithre Náisiúnta

Use of I.S. EN 1991-1-7 for the Design of Accidental Actions

December 2010

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SUMMARY

This Standard gives requirements on the use of I.S. EN 1991-1-7 and criteria for the design of road bridges and gantries for vehicle collision loads.

VOLUME 1 HIGHWAY STRUCTURES: APPROVAL PROCEDURES AND GENERAL DESIGN

SECTION 3 GENERAL DESIGN

PART 5A

NRA BD 60/10

USE OF I.S. EN 1991-1-7 FOR THE DESIGN OF ACCIDENTAL ACTIONS

Contents

Chapter

1. INTRODUCTION

General

1.1 This Document contains requirements that are not covered by the Eurocodes and has been cited as reference non-contradictory complimentary information in the Irish National Annex to I.S. EN 1991-1-7. Much of the information has been derived from historical research and data formerly contained in BD 60/04.

1.2 This Standard supersedes the NRA Addendum to BD60/94 dated December 2000.

1.3 Accidental collisions of heavy commercial vehicles (HCVs) with the superstructures of road bridges occur quite frequently. There are a number of reported road bridge strikes per year and it is widely known to Bridge Managers that many more incidents remain unreported. These include impacts to soffits by overheight vehicles resulting in local damage and spalling to concrete decks and occasionally more severe and extensive damage to steel bridges as has happened on the N7 Rathcoole Overbridge, which required substantial heat straightening repairs. In the UK one road bridge has been completely dislodged by collision and several footbridges and sign/signal gantries have been partly or totally removed from their supports. One such railway bridge strike in Ireland in 1975 resulted in a train derailment in which 5 people were killed. Appendix A shows photographs of some collisions with bridges.

Scope

1.4 This Document provides non-contradictory complementary information for use in Ireland with I.S. EN 1991-1-7 and its Irish National Annex.

1.5 This Document gives the following non-contradictory complementary information:

a) requirements of vehicle impact forces on road and foot/cycle track bridge and gantry supports;

b) requirements of vehicle impact forces on road and foot/cycle track bridge decks;

c) guidance on accidental actions caused by ship traffic.

d) load factors to be applied to gantry holding down bolts and specific requirements for the design of local effects.

Implementation

1.6 This Standard (with the exception of Appendix C) should be used for all new or improved national roads and all regional and local roads affected by national road schemes. This Standard shall be applied to the design of schemes currently being prepared unless, in the opinion of the National Roads Authority, application would result in significant additional expense or delay progress. In such cases Design Organisations should confirm the application of this Standard to particular schemes with the National Roads Authority. When directed by the National Roads Authority, the superseded NRA Addendum to BD60/94, as attached at Appendix C, shall continue to apply to those schemes.

2. THE REQUIREMENTS

Accidental actions caused by road vehicles: impacts on road and foot/cycle track bridge substructures and superstructures

General design principles

2.1 Vehicle collision loads on supports and superstructures shall be considered for the design of bridges and gantries in accordance with I.S. EN 1990 to I.S. EN 1999. The loading requirements are given in I.S. EN 1991-1-7 and its National Annex.

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 I.S. EN 1991-1-7 and its National Annex) these shall be designed to withstand the vehicle collision loads given in Table NA 1 of the National Annex to I.S. EN 1991-1-7. In addition, the Designer shall also analyse the vulnerability to vehicular impact of all supports and use engineering judgment 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 either to withstand the collision loads given in the above referenced Table NA 1 or appropriate additional measures shall be provided to mitigate the risk. The Designer's chosen approach and the design collision loads shall be recorded in the Technical Acceptance Report in accordance with NRA BD 2 (DMRB 1.1).

2.3 Particular situations that would constitute a severe potential risk of unacceptable damage due to vehicular impact with supports located greater than 4.5m from the edge of the carriageway include foot/cycle track bridges with a single column support, major long span bridges etc. However, where foot/cycle track bridge ramps and stairs are structurally independent of the main road-spanning structure, their supports may be designed to the reduced loads (i.e. minimum robustness requirement) specified in Table NA 2 of the National Annex to I.S. EN 1991-1-7. Similarly all bridge supports with a carriageway clearance equal to or greater than 4.5m and not assessed to be subject to severe risk shall be designed to withstand the reduced loads specified in Table NA 2 of the National Annex to I.S. EN 1991-1-7 (see 2.13.4 and 2.13.5).

2.4 In the case of multi-level carriageways, such as those encountered in motorway and national 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.

2.5 The minimum headroom clearance to bridge superstructures shall be in accordance with NRA TD 27 (DMRB 6.1). All bridges with a headroom clearance of less than 5.7 metres plus sag radius compensation and allowance for deflection as described in NRA TD 27 (DMRB 6.1), shall be designed to withstand the vehicle collision loads on superstructures defined in Table NA 3 of the National Annex to I.S. EN 1991-1-7.

2.6 The overall structural integrity of the bridge must be maintained following an impact, whilst local damage to a part of the bridge support or deck can be accepted.

Supports and Superstructures of Bridges

2.7 Design checks must be carried out as described below in two stages, using load group grla to IS EN 1991-2 and all appropriate imposed loads to clause 6.4.3.3 of EN 1990 using $\psi 1,1$:

a) **Stage 1. At the moment of impact.** A check is to be made at ultimate limit state (ULS) only. 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. The designer must 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 shall be considered, starting with the element which sustains the immediate impact. If the element that receives the direct impact is assumed or found to be inadequate, it shall nevertheless be assumed to have affected the transfer up to the ultimate capacity of the element to the next element(s) in the load path, but then be neglected in carrying out the Stage 2 check. Each element in the load-path must be considered on the same basis. It should be noted that inadequacy of individual elements is not a cause for concern at this stage, 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 must be designed to be fully adequate to resist the impact loads (see paragraph 2.9).

b) **Stage 2. Immediately after the impact.** Immediately after the event, the bridge must be able to stand up whilst still carrying traffic which may be crossing. Since the requirement is survival and the likely traffic is of every-day intensity, a check shall be carried out at ULS. For this check, the designer has to judge what local damage might reasonably have occurred and ignore elements that were assumed or found to be inadequate at Stage 1. If the structure does not satisfy the Stage 2 check appropriate changes shall be made to the design and the Stage 1 repeated with revised assumptions regarding the adequacy of the strengthened elements in the load-path. 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 B.

Foot and Cycle Track Bridges

2.8 Supports to foot and cycle track bridges where loading to Table NA 1 of the National Annex to I.S. EN 1991-1-7 is required (see paragraph 2.5) shall be detailed to include robust plinths of 1.5m height to carry the supports. These plinths shall be designed to resist the main and residual load components given in Table NA 1 of the National Annex to I.S. EN 1991-1-7 with other appropriate loads in accordance with paragraph 2.1. The supports themselves should be designed to the reduced residual load components shown within brackets in Table NA 1 of the National Annex to I.S. EN 1991-1-7.

Bearings

2.9 The assumptions made in design of the supports shall be reflected in the design of the bearings, i.e. if the columns are designed as propped cantilevers then the bearings shall be able to transfer the resulting load at the ULS. Similarly, the resulting loads shall have a suitable load path back through the foundations to earth.

2.10 For elastomeric bearings, the effects due to vehicle collisions on superstructures need only be considered at the serviceability limit state (SLS), for which a factor of 1.0/1.9 shall be applied to the forces given in Table NA1, Table NA2 and Table NA3 of the Irish NA to IS EN 1991-1-7.

Foundations

2.11 Foundations shall be designed to resist the impact forces transmitted from the collision on the following basis:

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

b) Full loading shall be considered for checking against overturning;

c) The collision loads may be reduced by 50% when checking against sliding and bearing capacity for both spread footings and piled foundations.

Holding-down bolts for Gantries

2.12 Bases for gantries are required to have a greater reserve of strength, so that in the event of a severe impact, they will have a higher probability of survival and a replacement column support can then be fitted. Holding-down bolts, anchorages, plinth bases and structural aspects of foundations shall be checked under collision load conditions at SLS using a factor of 1.3/1.9 applied to forces given in Table NA2 of the Irish NA to IS EN 1991-1-7 and at ULS using a factor of 1.75/1.5 applied to design forces given in Table NA2 of the Irish NA to IS EN 1991-1-7.

Local Effects of Impact on Gantry Supporting Structures

2.13 The local effects of vehicle impact loads on gantry support structures may be considered by using any of the following methods:

i) Finite element model

ii) Plastic theory of plate deformation

iii) Paper by Ellinas CP and Walker AC, *Damage on offshore tubular members*, IABSE colloquium, Copenhagen Ship collision with bridge and offshore structures, 1983

iv) Standard formulae contained in *Stress and strain*, Roark RJ, 4^{th} Edition or later, McGraw Hill.

Vehicle impact forces on road and foot/cycle track bridge supports (I.S. EN 1991-1-7:2006, 4.3.1 (1) Note 1)

2.14 The design Loads given in Table NA 1 of the National Annex to I.S. 1991-1-7:2006 and modified by this document together with their direction and height of application sh**all** be considered to act horizontally on bridge supports. Supports should be capable of resisting the main and residual load components acting simultaneously. Loads normal to the carriageway should be considered separately from loads parallel to the carriageway. The controlling class of road is the road under the bridge, i.e. the road that is carrying the Heavy Commercial Vehicles (HCV) that might impact on the support.

Temporary Structures

2.15 Temporary structures may be free-standing, attached to other structures, or incomplete structures. Temporary structures are generally not considered capable of resisting the required collision loading. Provided the superstructure of a temporary structure has a headroom of 5.41m or more, plus sag radius compensation and allowance for deflection as described in NRA TD 27 (DMRB 6.1), collision loading need not be applied to temporary superstructures. Temporary supports located more than 4.5m from the edge of carriageway shall be designed to the reduced loads (i.e. minimum robustness requirement) specified in Table NA 2 of the National Annex to I.S. EN 1991-1-7. For all temporary structures with less than the above clearances lane or road closure will be required, unless the continued passage of traffic is justified by risk assessment and agreed with the Road Authority. In the case of superstructures such risk assessments may take account of nearby structures up-stream of the temporary works with lesser headroom clearance than the temporary structure. In the case of support structures specific mitigation measures should be developed as part of the risk assessment, eg. speed restrictions, protection from impact utilising barriers and impact protection bunds and/or detailing of the permanent works to include beam landing shelves with sufficient capacity at ULS to prevent collapse of the superstructure in the event of failure of the temporary supports. In all cases the risk assessment and proposed mitigation measures shall be detailed in the Submission for Temporary Works Proposals as required by Chapter 4 of NRA BD02 and shall demonstrate that measures have been taken to reduce the risk to levels acceptable to the Authority.

Other Lightweight Structures

2.16 Collapse under impact of lighting columns, CCTV poles and cantilevered traffic signal mast arms may be acceptable; however consideration should be given to passive safety and the provision of normal containment barriers (see I.S. EN 1991-2:2003, 3.1(2) Note 5)

Accidental actions on lightweight structures (I.S. EN 1991-2:2003, 4.1 (1) Note 1)

2.17 To mitigate the effects of their lightweight nature the superstructures of foot/cycle track bridges, gantries and lighting columns are required to have headroom exceeding that defined in paragraph 2.5. As such they are not required to be designed to withstand impact loads. However adequate restraint to the deck of foot/cycle track bridge must be provided to prevent the deck being removed from the support under the action of vehicle collision forces given in Table NA 1 of the National Annex to I.S. 1991-1-7:2006.

Accidental actions caused by ship traffic: vehicle impact forces on road and foot/cycle track bridges (I.S. EN 1991-1-7:2006, clause 4.6)

Combination of actions for ship impact (I.S. EN 1991-1-7:2006, Section 2 (1)P Table 2.1)

2.18 Whilst there may be a correlation between an off-course ship and high winds, i.e. ship impact is more likely in high wind, it is usually unnecessary to combine a ship impact force with wind loading because the collision forces are large compared with wind forces. It is also unlikely that a peak gust would occur at the same instant as the actual ship impact.

2.19 Ship impact is considered in the accidental combination. Clause 6.4.3.3 of I.S. EN 1990:2002 and does not therefore require consideration of wind in combination with ship impact since the value of ψ_2 for wind is set to zero in the Irish National Annex to Annex A2 of I.S. EN 1990:2005, Tables NA.A.2.1 and A.2.2. In accordance with clause A2.2.5(1) of EN1990 AMD 1:2005, wind action need not be considered in the combination of actions for accidental design situation.

Ship impact for sea waterways (I.S. EN 1991-1-7:2006, clause C.4.2)

2.20 The design ship impact frontal force F_{dx} for sea waterways shall be taken from Table C.4 of I.S. EN 1991-1-7:2006. For intermediate values of ship mass, the following formulae shall be used:

$$F = v\,(mK)^{½}$$

where:

K = 12 MN/m for $0 < m \leq 3000$ ton

K = 25.6 MN/m for $3000 < m \leq 10000$ ton

K = 57.6 MN/m for $10000 < m \leq 40000$ ton

The lateral force F_{dy} shall be taken as half the values above for F_{dx} .

3. REFERENCES

National Roads Authority Design Manual for Roads and Bridges

Volume 6: Section 1: Road Geometry

NRA TD27 (DMRB 6.1.2) Cross sections and headrooms

Standard publications

I.S. EN 1990-:2002, *Eurocode - Basis of structural design*

National Annex to I.S. EN 1990:2002, *National Annex for Eurocode 1– Basis of structural design*

I.S. EN 1991-1-7:2006, *Eurocode 1: Actions on structures – Part 1-7: General actions – Accidental actions*

National Annex to I.S. EN 1991-1-7:2006, *Eurocode 1: Actions on structures – Part 1-7: General actions – Accidental actions*

4. ENQUIRIES

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

Head of Engineering
National Roads Authority
St Martin's House
Waterloo Road
Dublin 4

T Ahern
Head of Engineering

APPENDIX A: HCV/BRIDGE COLLISION PHOTOGRAPHS

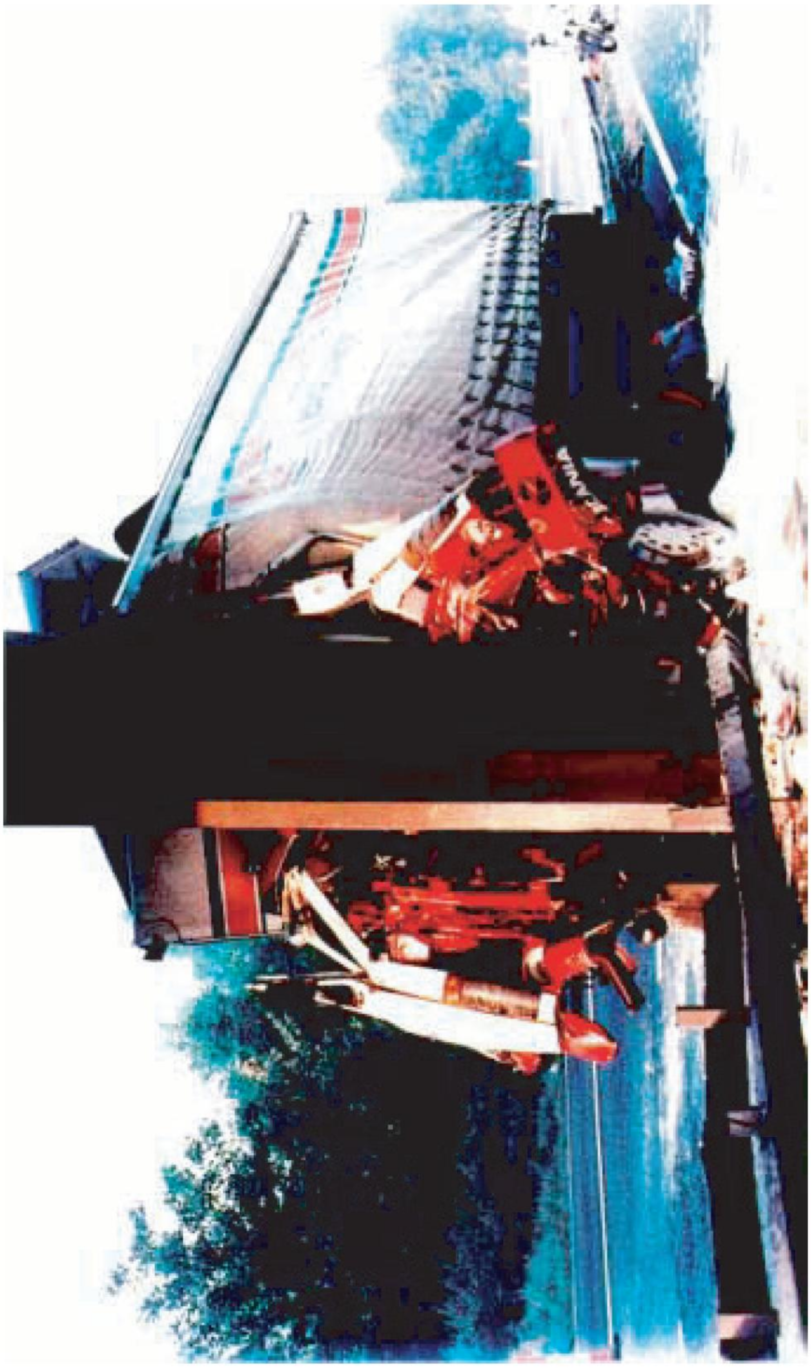

PLATE 1 COLLISION OF HGV WITH REINFORCED CONCRETE SUPPORT **M20** MOXLEY ROAD BRIDGE
(Photograph by kind permission of Director of Highways and Transportation, Kent County Council)

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 B: GUIDANCE FOR STEEL AND STEEL / COMPOSITE BRIDGE DECKS

B.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.

Composite Girder and Slab Bridge

B.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' (e.g. at transverse crossbracing) there may be slightly more local deformation than at „softer' positions (e.g. 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.

B.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 B.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

B.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.

B.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.

B.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

B.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.

APPENDIX C: NRA ADDENDUM TO BD 60/94

THE DESIGN OF HIGHWAY BRIDGES FOR VEHICLE COLLISION LOADS

Standard BD 60/94 - The Design of Highway Bridges for Vehicle Collision Loads may be used in Ireland, subject to the agreement of the National Roads Authority, with the following amendments:

GENERAL

1. Where the Standard is applied for the design of structural components which are procured through a contract incorporating the NRA Specification for Road Works, products conforming to equivalent standards and specifications of other member states of the European Union will be acceptable in accordance with the terms of Clauses 104 and 105 of that Specification. Any contract for the procurement of structural components which does not include these Clauses must contain a suitable clause of mutual recognition having the same effect, regarding which advice should be sought.

2. The Standard provides specification requirements for use in public purchasing contracts. It does not lay down legislation requirements for products and materials used in road construction in Ireland.

3. At several locations:

For: “Overseeing Department” or “Overseeing Organisation”
Read: “National Roads Authority”;

For: “highway”
Read: “road”;

For: “heavy goods vehicle”
Read: “heavy commercial vehicle”;

For: “HGV”
Read: “HCV”.

SPECIFIC

1. Page 1/1, Paragraph 1.1, line 4:
   For: "from such accidents"
   Read: "from such accidents in England and Wales".

2. Page 1/1, Paragraph 1.1, line 8:
   For: "one trunk road bridge"
   Read: "one trunk road bridge in the UK".

3. Page 1/1, Paragraph 1.2, line 1:
   For: "The Department of Transport"
   Read: "The UK Department of Transport".

4. Page 1/1, Paragraph 1.2, line 9:
   For: "Bridge Rehabilitation Programme"
   Read: "UK Bridge Rehabilitation Programme".

5. Page 1/1, Paragraph 1.6:
   Delete Paragraph 1.6 and replace with:
   "1.6 This Standard should be used forthwith for all schemes for the construction and/or improvement of national roads. The Standard should be applied to the design of schemes already being prepared unless, in the opinion of the National Roads Authority, application would result in significant additional expense or delay progress. In such cases, Design Organisations should confirm the application of this Standard to particular schemes with the National Roads Authority."

6. Page 1/1, Paragraph 1.7, line 1:
   For: "For licensing purposes"
   Read: "For licensing purposes in the UK".

7. Page 2/1, Paragraph 2.2, line 14:
   For: "motorway, trunk and principal road interchanges"
   Read: "motorway and national road interchanges".

8. Page 4/1, Section 4:
   Delete text and replace with:
   "4.1 All technical enquiries or comments on this Standard should be sent in writing to:

   Head of Project Management and Engineering
   National Roads Authority
   St Martin's House
   Waterloo Road
   Dublin 4"

…………………………………………

E O'CONNOR
Head of Project Management and
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