Bonneagar Iompair Éireann
Transport Infrastructure Ireland

TII Publications

GE PE DN CC OP AM RE

The Assessment of Bridge Substructures and Foundations, Retaining Walls and Buried Structures

AM-STR-06015
June 2014

AM Asset Management & Maintenance

Standards

About TII

Transport Infrastructure Ireland (TII) is responsible for managing and improving the country's national road and light rail networks.

About TII Publications

TII maintains an online suite of technical publications, which is managed through the TII Publications website. The contents of TII Publications is clearly split into 'Standards' and 'Technical' documentation. All documentation for implementation on TII schemes is collectively referred to as TII Publications (Standards), and all other documentation within the system is collectively referred to as TII Publications (Technical). This system replaces the NRA Design Manual for Roads and Bridges (NRA DMRB) and the NRA Manual of Contract Documents for Road Works (NRA MCDRW).

Document Attributes

Each document within TII Publications has a range of attributes associated with it, which allows for efficient access and retrieval of the document from the website. These attributes are also contained on the inside cover of each current document, for reference. For migration of documents from the NRA and RPA to the new system, each current document was assigned with new outer front and rear covers. Apart from the covers, and inside cover pages, the documents contain the same information as previously within the NRA or RPA systems, including historical references such as those contained within NRA DMRB and NRA MCDRW.

Document Attributes

TII Publication Title	*The Assessment of Bridge Substructures and Foundations, Retaining Walls and Buried Structures*
TII Publication Number	*AM-STR-06015*

Activity	*Asset Management & Maintenance (AM)*
Stream	*Structures (STR)*
Document Number	*06015*

Document Set	*Standards*
Publication Date	*June 2014*
Historical Reference	*NRA BA 55*

NRA DMRB and MCDRW References

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NRA MCDRW prior to the launch of TII Publications, the NRA document reference used previously is listed above under 'historical reference'. The TII Publication Number also shown above now supersedes this historical reference. All historical references within this document are deemed to be replaced by the TII Publication Number. For the equivalent TII Publication Number for all other historical references contained within this document, please refer to the TII Publications website.

An tÚdarás um Bóithre Náisiúnta
National Roads Authority

Volume 3 Section 4
Part 7
NRA BA 55/14

The Assessment of Bridge Substructures and Foundations, Retaining Walls and Buried Structures

June 2014

St. Martin's House, Waterloo Road, Dublin 4. Tel:+353 1 660 2511 Fax +353 1 668 0009
Email : info@nra.ie Web : www.nra.ie

Summary:

This Advice deals with the assessment of structures and structure elements where their behaviour is directly influenced by soil-structure interaction.

Published by National Roads Authority, Dublin 2014

VOLUME 3 ROAD STRUCTURES: INSPECTION AND MAINTENANCE

SECTION 4 ASSESSMENT

PART 7

NRA BA 55/14

THE ASSESSMENT OF BRIDGE SUBSTRUCTURES AND FOUNDATIONS, RETAINING WALLS AND BURIED STRUCTURES

Contents

Chapter

1. INTRODUCTION

1.1 The basic requirements for the assessment of bridge substructures (abutments and wing walls including cantilevered wing walls and skeletal abutments) and foundations, retaining walls and buried structures are given in NRA BD 21. NRA BD 86 gives requirements for the assessment of structures for the effects of Realistic Abnormal Vehicles and Exceptional Abnormal Load Vehicles. Further detail on the management of structures that fail assessment is given in NRA BD 79.

1.2 In general, the structural behaviour of substructures is more complex than that of superstructures. Loading applied to superstructures is largely unaffected by the resulting deformations and movements, whereas earth pressures at soil/structure interfaces can be influenced by movement of the structure, e.g. changes in backfill pressure due to the forward rotation of a retaining wall on its base or soil reaction pressures on an integral-bridge end support due to temperature generated expansion and contraction of the supported bridge deck. A further source of complexity with the design or assessment by calculation of sub-structures is the means of ensuring internal and external stability. Internal stability is demonstrated when it is shown that the materials comprising the fabric of the structure are capable of safely resisting the most extreme combination of adverse effects. For a proper assessment of external stability the structure is assumed to be a rigid body subjected to the most adverse combination of applied forces and support conditions.

1.3 Considerations influencing the means of assessing the internal and external ability of an existing structure differ from those influencing design. An existing structure represents a capital investment and the fact that it has survived until the time of assessment demonstrates that the full-scale model has fulfilled its functional purpose. For that reason it can be permissible to assume that the internal and external stability is acceptable without calculation. In cases where there are signs of distress indicating problems with internal stability it may be permissible to allow the structure to remain in service without carrying out remedial works with the risks being managed in real-time in accordance with the guidance given in NRA BD 79. It may also be permissible to allow a structure to remain in service where there are signs of external instability e.g. where a retaining wall of robust construction has slid forward but where the consequences of that and any further sliding would not be serious. Again NRA BD 79 would be used to manage the risk in real time.

1.4 Superseded design standards, used prior to the introduction of the Eurocodes are available for substructures and foundations, retaining walls and buried structures, such as NRA BD 30, NRA BD 31 and NRA BD 42. These documents were originally intended for design and not the assessment of structures, and as such, they are likely to produce unrealistically conservative estimates of load carrying capacity.

1.5 Realistic assessment requires that account be taken of the ability of the structure to redistribute load, recognising that the point at which an element within a structure first reaches its capacity, and perhaps first shows local signs of movement or cracking, does not necessarily constitute the ultimate limit state, particularly for ductile structures. The ability of structures to redistribute load is, therefore, particularly relevant in assessment.

Scope

1.6 This Advice Note is intended to cover the assessment of structures and structural elements where their behaviour is directly influenced by soil structure interaction. It does not deal with the structural aspect of stems of free-standing piers and columns but it does cover assessment of their foundations.

Definitions and Symbols

1.7 The following are definitions of terms used in the Advice Note:

(1) 'Abutment' means an end wall to which horizontal earth pressure loads are applied.

(2) 'Cover' means the depth of fill between ground level and the top of a structure.

(3) 'Effective barrier' means a system that is in place that provides defined vehicle restraint against impact or against a vehicle crossing the barrier.

(4) 'Ground level' means finished carriageway level, or the temporary ground level on which traffic can run during construction.

(5) 'Longitudinal' means perpendicular to the abutment walls, or in the direction of traffic.

(6) 'Substructure' means the part of the structure that supports the superstructure, and includes abutments and wing walls, cantilevered wing walls and skeletal abutments.

(7) 'Superstructure' means the section of the structure over which traffic can pass (i.e. the bridge deck).

(8) 'Traction' means the longitudinal live load arising from braking and acceleration of vehicles.

(9) 'Transverse' means parallel to the abutment walls, or perpendicular to the direction of traffic.

1.8 The following are symbols used in the Advice Note:

(1) H The depth of cover (m).

(2) K Earth pressure coefficient to be used for a given load in the assessment.

(3) K_a Coefficient of active earth pressure.

(4) K_p Coefficient of passive earth pressure.

(5) K_0 Coefficient of lateral earth pressure 'at rest'.

(6) V Weight of one axle (kN).

(7) V_{tot} Total weight of combined axles (including any applied impact factor) (kN).

(8) Ω Lateral dispersal distance (m).

(9) Ω_{eq} Lateral dispersal distance for a pair of axles of equal magnitude (m).

(10) Ω_{if} Lateral dispersal distance for a pair of axles with an impact factor applied to one axle only (m).

Implementation

1.9 This Advice Note shall be used for the assessment of bridge substructures (abutments and wing walls including cantilevered wing walls and skeletal abutments) and foundations, retaining walls and buried structures. Its application to particular assessments should be confirmed with the National Roads Authority.

2. PRESENT REQUIREMENTS

Basic Principles

2.1 The purpose of an assessment is to ensure that structure is adequate for the loading applied by present day traffic when assessed in accordance with current technical standards. Loading has increased since the structures were built and the requirements may have become more onerous. A further objective is to determine the operational abnormal indivisible load capacity of the structure through determining reserve factors in accordance with NRA BD 86.

Summary of Relevant Requirements

2.2 NRA BD 21 states that if a foundation, retaining wall or a substructure shows no sign of movement or cracking, such items may be assumed to be adequate and no further assessment is necessary.

2.3 NRA BA 16 deals with spandrel and dry-stone walls, substructures and foundations. It states that the adequacy of such items is to be determined from qualitative assessments of their general condition including the significance of any defects.

2.4 Retaining walls providing structural support to a road and not designed for Type HA surcharge or equivalent are to be assessed. Furthermore, structures that are thought to have a reduced load capacity as a result of serious deterioration, foundation deficiency, inadequacy of backfilling materials or damage are also to be assessed. Bridges, culverts, buried structures etc. of clear spans less than 2.0m and retaining walls with retained heights less than 1.5m need not be assessed. Additionally, culverts and buried structures of 3m or less span with cover of 1m or more, or buried to an extent that road loading is only of marginal significance when compared to earth pressures, need not be assessed.

2.5 Factors of safety stipulated for design purposes may be relaxed for assessments with the agreement of the National Roads Authority. When a superstructure is to be strengthened or replaced, the adequacy of the substructure and foundations should be checked as for any new design.

Approach

2.6 The basic purpose of any assessment is to determine whether the structure will have adequate strength for the worst credible combinations of loading and strength conditions at the ultimate limit state (ULS), but the means of achieving this objective will vary.

2.7 In cases where the final conclusion of the assessment process is that a structure is substandard the structure may be strengthened, modified, replaced or allowed to remain in service in accordance with NRA BD 79. For bridge decks, it is essential to check this requirement explicitly since any failure is likely to have serious consequences. Due to this a bridge deck may be considered inadequate even without any signs of movement or cracking. For substructures and foundations, retaining walls and buried structures, failure is likely to be progressive and there will usually be some warning signs (such as movement, settlement, foundation erosion, rotation, cracking, evidence of reinforcement corrosion, locked bearings, etc.) well before final collapse takes place. However, it should be recognised that due to the location of the substructure, foundations, retaining walls or buried structures, these warning signs may not be readily visible during a Principal Inspection.

Generally, substructures and foundations, retaining walls and buried structures need not be assessed by calculation unless there are evident signs of movement or cracking determined from an inspection for assessment or any other inspection of the structure, or where traffic loading has a significant effect on the structure. The structural aspects of piers are excluded from the remit of this Advice Note (refer to 1.6).

2.8 When assessment by calculation is deemed necessary for substructures and foundations, retaining walls or buried structures, realistic parameters (such as earth pressure coefficients) should be used as far as practicable. An initial assessment may be carried out using the soil parameters estimated or established from any available structural records. Alternatively, cautious estimates or default values taken from the design standards may be used for such parameters. If the initial assessment concludes that the structure is substandard the National Roads Authority should be consulted on the way forward.

2.9 In cases where the final conclusion of the assessment process is that a structure is substandard the structure may be strengthened, modified, replaced or allowed to remain in service in accordance with NRA BD 79.

3. ASSESSMENT BY CALCULATION

3.1 When assessment by calculation is considered to be necessary, in the absence of assessment standards, design standards may be used. Advice on the use of design provisions for assessment purposes for certain types of structures and structural elements are given in the following sections.

Backfilled Retaining Walls and Bridge Abutments

3.2 NRA BD 30 may be used for assessing by calculation all backfilled retaining walls and bridge abutments including the older types such as mass concrete, mass brick or cellular brick walls and abutments. Clause 5 of NRA BD 30 is applicable, using the following qualifications:

(1) Clause 5.1 – Design: Embedded retaining walls are assessed to NRA BD 42. Further guidance is given in 3.5.

(2) Clause 5.2.2 – Ultimate Limit State of Structural Elements: Instead of NRA BD 24, NRA BD 44 should be used. The structure should be considered inadequate if calculations confirm any specific deficiency indicated by visible signs of movement or cracking.

(3) Clause 5.2.3 – Serviceability Limit State of Structural Elements: Not appropriate; however, if cracks etc. have been noticed, close monitoring should be carried out, although it should be recognised that cracking may occur at the buried face, which is unlikely to be apparent during inspection.

(4) Clause 5.2.4 – Ultimate Limit State of Soil: Applicable, but with the minimum factors of safety specified in CP2. Nominal values of dead and road live loads should be as given in NRA BD 21 and NRA BD 86. 12 kN/m^2 of vertical live load surcharge may be used in place of the Annex D and E vehicles from NRA BD 21. 20 kN/m^2 of vertical live load surcharge should be used in conjunction with loading in NRA BD 86. Alternatively, subject to the agreement of the National Roads Authority, a rigorous analysis of surcharge pressure accounting for soil strengths may be appropriate.

The structure should be considered inadequate if calculations confirm any deficiency indicated by visible signs of movement or cracking.

(5) Clause 5.2.5 – Serviceability Limit State of Soil: Not applicable in general; however, if movements are noticed, and the structure passes the ULS checks, close monitoring should be carried out.

(6) Clause 5.3.2: ‘Active’ earth pressure should be used instead of ‘at rest’ earth pressure.

(7) Clause 5.4 – General Design Considerations: Wherever possible, soil parameters should be confirmed by tests.

Buried Concrete Box Structures

3.3 For the assessment of buried concrete box and portal frame structures, for example, culverts and subways, the superseded design standard NRA BD 31 may be used, based on the following guidelines. Further guidance on buried concrete box structures may also be found in NRA BA 88.

(1) Clause 2.1 – Limit States: The assessment of structural elements may be carried out using the provisions of this clause except that assessed inadequacy for serviceability does not in itself mean that any remedial action has to be taken. NRA BD 79 provides further guidance on the management of substandard structures.

(2) Clause 2.2 – Design principles of structural elements: Assessment of reinforced concrete section capacities should be in accordance with NRA BD 44.

(3) Clause 2.3 – Design principles of foundations: Foundations need only be assessed if there is evidence of settlement, tilting or sliding.

(4) Clause 2.4 – Loads: Loading requirements for assessment should be in accordance with NRA BD 21. Assessment for longitudinal forces should only be carried out if there are signs of tilting, or cracking adjacent to the junction of the walls and roof, which may be the result of traction or unbalanced live load surcharge forces.

(5) Clause 2.5 – Load combinations: Only Load Combination 1 (permanent loads, vertical live loads and horizontal live load surcharge) should be considered except where an assessment for traction is required as described in 3.3(4) of this Advice Note.

(6) Clause 3.1.3 – Horizontal earth pressure (permanent): Where the assessment shows that the structure is not adequate to resist the assumed earth pressures, consideration should be given to carrying out a site investigation to determine the nature of the backfill (including SPT values) and to reassess the structure using earth pressures derived in accordance with BS 8002 and Appendix B of NRA BD 31.

However, the value of the minimum earth pressure coefficient (K=0.2) given in clause 3.1.3(a)(i) and Diagram A/3 should be retained regardless of the result of site investigation. Also the value of the restoring earth coefficient (K = 0.6) given in Clause 3.1.3(a)(ii) and Diagrams A/4 and A/5 should be retained regardless of the result of the site investigation unless a higher value can be justified by a rigorous analysis of the soil-structure interaction.

(7) Clause 3.2.1 – Vertical Live Loading:

(a) The carriageway loading for structures where the cover depth is 0.6m or less should be Assessment Live Loading based on the type HA UDL and KEL, single wheel load and single axle load as described in NRA BD 21. If required by the National Roads Authority, the loads in NRA BD 86 should be used to assess the effects of Abnormal Vehicles and Exceptional Abnormal Vehicles.

(b) Where the depth of cover exceeds 0.6m, the loads given in Annex D or E of NRA BD 21 should be used, with a minimum transverse spacing of 1.5m between wheel centres of vehicles in adjacent lanes, except that the impact factor should be reduced as described in (i) of this clause. If required by the National Roads Authority, the loads in NRA BD 86 should be used to assess the effects of Abnormal Vehicles and Exceptional Abnormal Vehicles. The dynamic amplification factor for Special Vehicle (SV) loading should be reduced as described in 3.3(b)(i) of this Advice Note. The associated HA loading should be replaced by Construction & Use (C&U) vehicles as given in Annex D of NRA BD 21, and applied as a single vehicle or convoy of vehicles, except that the impact factor should be reduced as described in

(i) of this clause. A minimum transverse spacing of 0.7m should be provided between wheel centres of vehicles in adjacent lanes. The travelling speed of SV vehicles may be different from that of the associated C&U vehicles. However, if a convoy of vehicles is assumed for the associated C&U vehicles, SV vehicles should only be considered at the “low” speed case.

(i) Provided that there are no abrupt surface irregularities such as potholes or poorly backfilled trenches in the carriageway over the structure, the dynamic effects of vehicle loading may be reduced to account for the damping effect of the depth of cover.

For C&U vehicles, the reduced impact factor may be taken as:

$$1 + 0.8(1 - 0.5H)$$

but not less than 1.2, where H is the depth of cover, in metres.

For SV vehicles, the reduced dynamic amplification factor may be taken as:

$$1 + (DAF – 1)(1 - 0.5H)$$

but not less than 0.75 + 0.25DAF, where DAF is the dynamic amplification factor specified in NRA BD 86.

(ii) Dispersal of wheel loads through the fill should be carried out as described in 3.4 of this Advice Note.

(8) Clause 3.2.2 – Live Load Surcharge: 12 kN/m² of vertical live load surcharge should be used in place of Annex D and E vehicles. 20 kN/m² of vertical live load surcharge should be used in place of loading in NRA BD 86.

(9) Central Reserves that are not protected from vehicular traffic by an effective barrier should be assessed for the local effects of the Accidental Wheel Loading. Areas confined for Central Reserves with an effective barrier need not be assessed.

3.4 Dispersal of wheel and axle loads from clause 3.3(7):

(1) For buried structures with less than 0.6m depth of cover, wheel loads may be dispersed using the method in NRA BD 21.

(2) For assessments based on a 2D frame analysis of a buried structure with greater than 0.6m depth of cover, the following method should be used for dispersal of wheel loads. The background to this method is given in Annex A. In the event that these methods indicate that a structure is under- strength, it should be reassessed using the Boussinesq distribution.

(a) Single lane of vehicles: Where there is only a single lane of vehicles, the wheel loads should be dispersed from the edges of the wheels at a slope of two vertically to one horizontally. If the dispersal zones of wheels on the same axle overlap in the transverse direction (parallel to the axles), the load per metre width for each axle should be calculated by treating the axle as a whole and dispersing the load from the edges of the outer wheels. However, where the longitudinal dispersal zones for adjacent axles overlap, the axle loads should not be combined and distributed jointly. The effects of adjacent axles should be considered separately and superimposed to give the total effect.

(b) Multiple lanes of vehicles: Where there are two or more lanes of vehicles, the load per metre width in the transverse direction (parallel to the axles) should be determined using the method in (i) and (ii) of this clause for NRA BD 21 loading and NRABD 86 loading respectively. In the longitudinal direction (perpendicular to the axles), the load due to each axle should be dispersed from the edges of the loaded area at a slope of two vertically to one horizontally. Where the longitudinal dispersal zones for adjacent axles overlap, the loads should not be combined and distributed jointly. The effects of adjacent axles should be considered separately and superimposed to give the total effect.

(i) **NRA BD 21 loading**

The following method should be used to determine the load per metre width in the transverse direction for the vehicle loads specified in Annex D and E of NRA BD 21 in both 'single vehicle' and 'convoy of vehicles' configurations, with a transverse spacing of 1.5m between wheel centres of vehicles in adjacent lanes.

Where the axles from vehicles in adjacent lanes have equal load magnitudes, the load per metre width associated with each pair of axles should be taken as:

$$\frac{2V}{\Omega_{eq}} \quad \text{kN/m}$$

where V is the weight of one axle in kN and Ω_{eq} is given by the minimum of

$$\Omega_{eq} = 1.7H + 3.8$$

and

$$\Omega_{eq} = 0.75H + 4.75$$

in metres, where H is the depth of cover in metres.

Where an impact factor as defined in 3.3(7)(b)(i) is applied to only one of the axles, the load per metre width associated with the pair of axles should be taken as:

$$\frac{V_{tot}}{\Omega_{if}} \quad \text{kN/m}$$

where V_{tot} is the total weight of both axles (including the effect of the impact factor on one of the axles) in kN and Ω is given by the minimum of

$$\Omega_{if} = 1.9H + 2.8$$

and

$$\Omega_{if} = 0.9H + 4.3$$

in metres.

(ii) **NRA BD 86 loading**

The following method should be used to determine the load per metre width in the transverse direction for SV vehicle loads in accordance with NRA BD 86, with associated C&U loading, with a transverse spacing of 0.7m between wheel centres of adjacent vehicles.

Since the axle spacings are different for SV and C&U vehicles, each axle must be considered separately and then superimposed to give the total effect. The load per metre width for each axle should be taken as:

$$\frac{V}{\Omega} \quad \text{kN/m}$$

where V is the weight of the axle in kN and Ω depends on the axle type, as follows:

Although SV-80, SV-100, SV-150, and SV-Train vehicles are not used in Ireland, for the axles of these vehicles and the front axles of the SV-TT vehicle, Ω is given by the minimum of:

$$\Omega = 2.1H + 1.3$$

and

$$\Omega = 1.3H + 2.9$$

in metres, where H is the depth of cover in metres.

For the rear axles of the SV-TT vehicle, Ω is given by:

$$\Omega = 1.14H + 3.69$$

For the axles of an associated C&U vehicle, Ω is given by the minimum of:

$$\Omega = 1.6H + 2.2$$

and

$$\Omega = 1.2H + 2.8$$

For the assessment of Abnormal and Exception Abnormal Vehicles that are outside of the scope of the SV models defined in NRA BD 86, the Boussinesq distribution may be used.

(c) For assessments based on a 3D analysis of an in situ concrete buried structure with greater than 0.6m depth of cover, unless a more rigorous method is used, the wheel loads should be dispersed from the edges of the wheels at a slope of two vertically to one horizontally, and the effects of each wheel should be considered separately and superimposed to give the total effect.

Embedded Retaining Walls

3.5 NRA BD 42 should be used for the assessment of embedded retaining walls, embedded cut and cover tunnel walls and bridge abutments. This Standard is applicable to retaining structures whose main stability is provided by having a significant length of wall stem embedded in the ground. The wall may be cantilevered, propped at either the top or at excavation level, doubly-propped or anchored.

3.6 Guidance is given for retaining walls embedded in over consolidated stiff or firm clay and also granular materials. Walls in soft clay are not covered by this Standard.

3.7 Assessment of embedded retaining walls should be carried out using the limit state design principles described in NRA BD 42. Assessment should additionally consider the serviceability limit state for walls embedded in over-consolidated soils as this is often more onerous than the ultimate limit state. The following adaptations to NRA BD 42 apply to its use for assessment purposes:

(1) Clause 2.6: Only necessary to consider global and local movements that are due to post construction changes and in the long term. Adjacent and supported structures should be examined for signs of movement or cracking.

(2) Clause 2.11: Not appropriate.

(3) Clause 3.3: Applicable. First assessment of ground movements should be based upon relevant field data and from experience of similar structures in similar ground conditions. Adjacent structures and buried services should be inspected for signs of movement or cracking and monitored closely where appropriate.

(4) Clause 3.4: Not applicable for construction stage. Deformation analysis may be required for consideration of the long-term condition.

(5) Clauses 3.5 to 3.8 – Ultimate Limit State of Structural Elements: Confirm any specific deficiency.

(6) Clause 3.5: Replace reference to NRA BD 13, NRA BD 24 and NRA BD 16 with reference to NRA BD 56, NRA BD 44 and NRA BD 61.

(7) Clause 3.7: Replace reference to NRA BD 37 with reference to NRA BD 21.

(8) Clause 3.9: Wherever possible, soil parameters and pore pressure distributions should be confirmed by investigation and testing.

(9) Clause 3.10: Care must be taken to assess the K_0 likely to be present at the time of assessment. The value of K_0 will vary from the in situ value initially present. It will have been influenced by the construction process, the flexibility of the retaining wall system and the in service period. Assessment by calculation should use the most appropriate limit equilibrium approach described in Clause 3.10.

(10) Clause 4.3: Drainage systems should be examined to assess their effectiveness. Account should be taken of any malfunction of the drainage system.

(11) Chapter 5: Assessment for durability should take account of possible member deficiencies due to corrosion, cracks, damage, etc. observed during the inspections required by NRA BD 21.

(12) Clause 6.8: Where a hard-soft piling system is used, a visual examination of the structure should be made to assess if there is evidence of any undue seepage through the soft piles.

(13) Clause 6.9: Integral bridges are designed using the guidance given in NRA BA 42. For such structures, the abutments should be examined for signs of cracking caused by movements resulting from the thermal expansion and contraction of the bridge deck.

(14) Clause 7.5: A visual inspection of the prop slab (or the carriageway over it) should be carried

out to assess if there is any sign of movement.

(15) Clause 8.4: For doubly-propped structures, such as cut-and-cover tunnels, a visual inspection of the tunnel roof and the lower prop slab (or the carriageway over it) should also be carried out.

(16) Clause 9.5: For structures with a stabilising base, a visual inspection of any carriageway over the base should be carried out. If there is movement, cracking is likely to develop above the end of the base remote from the wall.

(17) Chapter 10: Use of the Observational Method is only applicable if there are signs of movement which need to be monitored and controlled.

(18) Chapter 11: Not appropriate.

Foundations

3.8 Foundations in general should be assessed by using NRA BD 74 with the following qualifications:

(1) Structural elements of concrete and steel piles should be assessed using NRA BD 44 and NRA BD 56, the assessment version of BS 5400: Part 4 and Part 3, respectively.

(2) Load transferred from the structure above, and the appropriate load factors, should be in accordance with NRA BD 21. Only Load Combination 1 should be considered.

Reinforced Concrete Arch Bridges

3.9 Reinforced concrete, spandrel filled, arch bridges should be assessed using the same requirements as any other type of concrete bridges except that the restraining action of the surrounding fill should be taken into account in the analysis as appropriate. The approach used to account for soil-structure interaction should be agreed with the National Roads Authority.

Reinforced Soil Structures

3.10 As there are only two resistance elements providing global stability in reinforced soil structures (the soil and the reinforcement) it is unlikely that there will be signs of movement or cracking at the facing unless there is loss of strength in the soil or the reinforcement. It is anticipated that reinforced soil structures could have potentially serious global failure modes, although this opinion is not based upon experience because the reinforced soil form of structure is relatively new and there has not been sufficient time for these structures to deteriorate to the extent where failure occurs. Reinforced soil structures can suffer local failure of the facing, without danger of global failure, where the reinforcement attached to the rear of the facing fails due to local corrosion or some other form of deterioration in non-metallic elements.

3.11 Reinforced soil structures that show no signs of movement or cracking need not be assessed by calculation unless there is evidence of corrosion or some other form of deterioration of the reinforcement that exceeds that allowed for in the design. It should be appreciated that the original design should have used the deteriorated material properties appropriate to those that were calculated to exist at the end of the design life, e.g. the cross-sectional dimensions of steel reinforcing straps should have been reduced to allow for corrosion over the design life. When assessing such structures, special guidance should be sought from the manufacturers of such items or other specialists. It will not be possible to assess the structure without 'as built' information on the fill and reinforcement properties and layout. While the factors of safety used in assessment should not be lower than those used in design, realistic, rather than design values of soil parameters may be used based upon the findings of soil investigation.

3.12 For anchored earth structures, the facing panels play a major role in providing global stability.

Corrugated Steel Buried Structures

3.13 Corrugated steel buried structures need not be assessed by calculation unless there is evidence of corrosion or deterioration of the corrugated steel or movement of the structure's profile. When assessing such structures, special guidance should be sought from the manufacturers of such items or other specialists. It should be noted that these structures have potentially serious failure modes, although such events are rare and extremely unlikely for structures designed to NRA BD 12.

3.14 When assessing corrugated steel buried structures up to 8m span the analysis may follow the design method of NRA BD 12, if considered applicable, although the assessment loading should be agreed with the National Roads Authority. The 'two-to-one' method for the dispersal of wheel and axle loads through the fill given for HB loading in NRA BD 12 may not be appropriate for vehicles with unequal wheel loads or spacings. Guidance on an alternative approach is given in 3.3(7), 3.4 and Annex A of this Advice Note.

3.15 The structure should be assessed based on the present remaining steel thickness, which should be measured. No deductions should be made for future corrosion although the method of NRA BD 12 may be used to predict the future remaining life of the structure. The factors of safety used in assessment should not be lower than those used in design. Realistic, rather than design, values of soil parameters may be used based upon the findings of soil investigation.

3.16 Further guidance on corrugated steel buried structures may be found in NRA BA 87.

4. INTERIM MEASURES AND STRENGTHENING

4.1 In general, bridge substructures and foundations, retaining walls and buried structures covered by this Advice Note need not be assessed by calculation unless there are evident signs of movement or cracking determined from an inspection for assessment or any other inspection of the structure, or where traffic loading has a significant effect (>25%) on the structure.

4.2 If the structure is assessed to have adequate capacity, it should be observed carefully for signs of progressive deterioration. Inadequate structures should be strengthened or replaced as necessary. In some cases, it may be permissible not to carry out any remedial work and to manage the structure in accordance with NRA BD 79. This should be agreed with the National Roads Authority who will be responsible for implementing this option.

4.3 Before strengthening or replacing a concrete box structure that has failed an assessment, the guidance in NRA BD 79 should be followed. For this form of structure, a further assessment using some or all of the following may be beneficial:

(1) reassessment to the current version of NRA BD 21 and consider Departures from standards where appropriate, if the original assessment was undertaken in accordance with an earlier version;

(2) use of soil parameters obtained from testing;

(3) moment redistribution;

(4) yield line analysis;

(5) use of worst credible strength (WCS) for concrete and reinforcement obtained from testing.

4.4 The form of any interim measures necessary following an apparent assessment failure should be determined on the basis of the severity of the signs of movement or cracking, the nature of the deficiency and the factors of safety (i.e. reserve strength) available for the particular relevant aspects of structural response, in accordance with NRA BD 79.

5. REFERENCES

1. NRA Design Manual for Roads and Bridges, (NRA DMRB)

NRA BD 24 – The Design of Concrete Bridges. Use of BS 5400: Part 4: 1990.

NRA BA 87 – Management of Corrugated Steel Buried Structures.

NRA BA 88 – Management of Buried Concrete Box Structures.

NRA BA 16 – The Assessment of Road Bridges and Structures.

NRA BD 21 – The Assessment of Road Bridges and Structures.

NRA BD 44 – The Assessment of Concrete Road Bridges and Structures.

NRA BD 56 – The Assessment of Steel Road Bridges and Structures.

NRA BD 61 – The Assessment of Composite Road Bridges and Structures.

NRA BD 79 – Management of Sub- Standard Road Structures.

NRA BD 86 – Assessment of road bridges and structures for the effects of Abnormal and Exceptional Abnormal Load Vehicles using SV and SOV Load Models.

NRA BD 13 – Design of Steel Bridges. Use of BS 5400-3:2000.

NRA BD 16 – Design of Composite Bridges. Use of BS 5400: Part 5: 1979. [Incorporating Amendment No. 1 dated December 1987]

NRA BD 37 – Loads for Highway Bridges.

NRA BA 42 – The Design of Integral Bridges [Incorporating Amendment No. 1 dated May 2003]

NRA BD 74 – Foundations.

NRA BD 30 – Backfilled Retaining Walls and Bridge Abutments.

NRA BD 42 – Design of Embedded Retaining Walls and Bridge Abutments.

NRA BD 74 – Foundations.

NRA BD 12 – Corrugated Steel Buried Structures with Spans Greater than 0.9 Metres and up to 8.0 Metres.

NRA BD 31– The Design of Buried Concrete Box Type and Portal Frame Structures.

NRA BD 34 – Technical Requirements for the Assessment and Strengthening Programme for Highway Structures. Stage 1 – Older Short Span Bridges and Retaining Structures.

2. Highways Agency Standards

BE 3 – Reinforced and Anchored Earth Retaining Walls and Bridge Abutments for Embankments [Revised 1987] replaced by Highways Agency BD 70/03 (DMRB 2.1.5), Strengthened/Reinforced Soils and other Fills for Retaining Walls and Bridge Abutments.

3. British Standards

BS 8002: Earth Retaining Structures.

4. Code of Practice

Institution of Structural Engineers (Joint Committee) Civil Engineering Code of Practice No. 2 (1951) CP 2 - Earth Retaining Structures. (Withdrawn)

5. Legislation

Road Traffic (Construction and Use of Vehicles) Regulations 2003, SI No. 5/2003, as amended

6. ENQUIRIES

6.1 All technical enquiries or comments on this document or any of the documents listed as forming part of the NRA DMRB should be sent by e-mail to infoDMRB@nra.ie, addressed to the following:

"Head of Network Management, Engineering Standards & Research
National Roads Authority
St Martin's House
Waterloo Road
Dublin 4"

……………………………………………
Pat Maher
Head of Network Management,
Engineering Standards & Research

ANNEX A DISPERSAL OF LOADS

1 Introduction

1.1 This Annex provides background to the simplified dispersal method given in 3.4.

1.2 Previously, the standard method of dispersal, as given in NRA BD 21, was to disperse the loads at a slope of 2 vertically to 1 horizontally. Where the dispersal zones for adjacent wheels overlapped, the loads were to be considered as a group and dispersed from the edges of the group. This method is only appropriate for design loading where the wheel loads are uniform, e.g. for the HB vehicle. However, it can be unsafe where the wheel loads vary in magnitude and spacing. It is therefore inappropriate for the assessment vehicle loading specified in NRA BD 21 and NRA BD 86 for buried structures.

2 Dispersal Method for 2D Analysis

2.1 Since buried structures are frequently modelled with a 2D frame analysis, it is particularly important to ensure that the critical load per metre width to be applied to the model is accurate, and so the transverse dispersal method has a significant effect on the analysis. However, the precise modelling of the longitudinal dispersal has a much smaller effect on the analysis of the structure. The simplified dispersal method therefore comprises separate processes for transverse and longitudinal dispersal.

2.2 The transverse dispersal method allows a critical load per metre width to be calculated for each axle position. The method has been calibrated using the Boussinesq analysis method, and is described in detail for each configuration in the following section.

2.3 This load per metre width for each axle position is then dispersed in the longitudinal direction using a simple 2:1 rule. However, the effects of adjacent axles are not combined into a group where the dispersal zones overlap because the axle loads will have different magnitudes and combining them could be unsafe. Instead, each axle is considered separately and the effects superimposed to give the total effect. This approach also ensures that the centroid of the dispersed load is aligned longitudinally with the centroid of the vehicle loads. Where the dispersal zones overlap there will be a step in the load intensity, as illustrated in Figure 1.

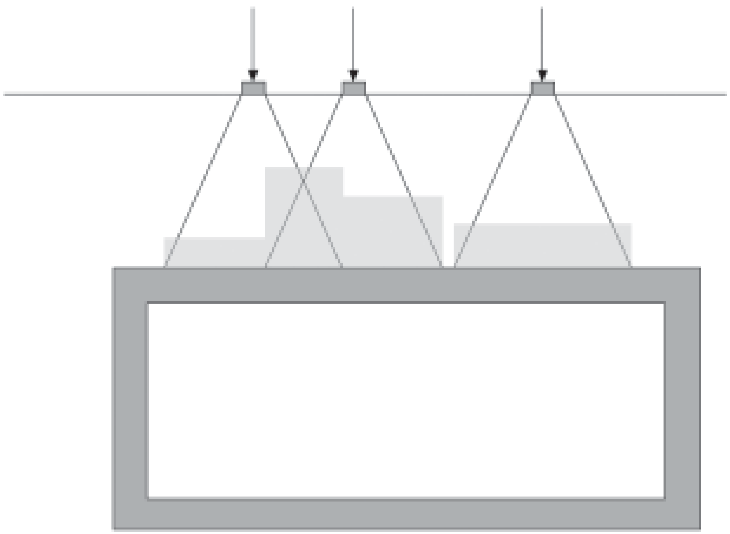

Figure 1: Illustration of Longitudinal Dispersal Method

3 NRA BD 21 Loading

3.1 The loading specified in NRA BD 21 for buried structures with greater than 0.6m fill requires vehicles from Annex D or E of NRA BD 21 to be applied, in either a 'single vehicle' configuration or a 'convoy of vehicles' configuration. The transverse separation of vehicles in adjacent lanes is 1.5m between wheel centres.

Convoy of Vehicles

3.2 For the convoy situation, no impact factor is to be applied. The critical loading is assumed to comprise identical vehicles in adjacent lanes, with the axles of the vehicles aligned. It is therefore necessary to determine the transverse dispersal for each axle position, based on two equal axles side by side, as illustrated in Figure 2. The effects of vehicles in two lanes only are modelled, since vehicles in other lanes have a negligible effect on the critical load per metre width.

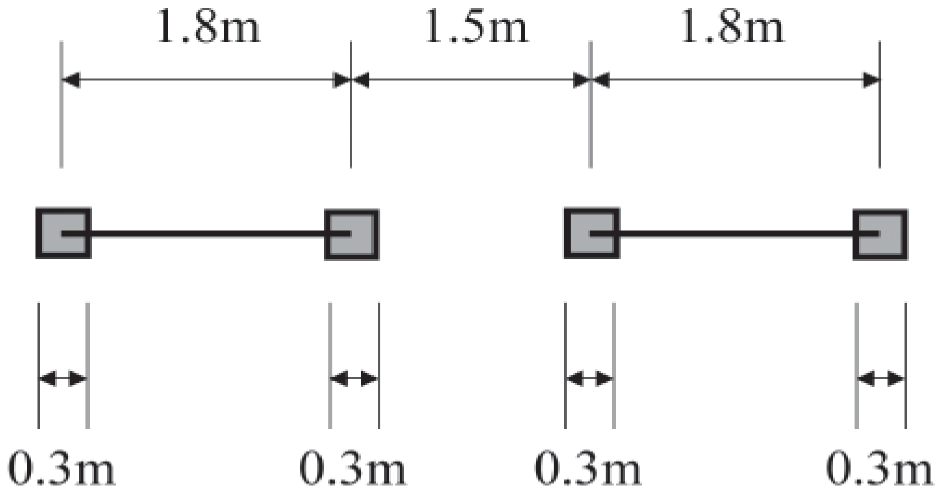

Figure 2: Equal Axles in Adjacent Lanes for BD 21 Loading

3.3 The loading in Figure 2 is applied to a model using the Boussinesq method at various depths. For each depth, the vertical pressures due to these loads are calculated. Then the total load acting on a metre-wide strip at any transverse position is found by integrating the vertical pressures over the area of the strip. In this way the critical load per metre width V_L is calculated.

3.4 The Ω_{eq} parameter for the 'equal axles' situation illustrated in Figure 2 is calculated by dividing the sum of the two axles, 2V, by the critical load per metre width, V_L.

$$\Omega_{eq} = 2V/ V_L$$

3.5 Figure 3 illustrates the variation of Ω_{eq} plotted against the depth of cover H, for the results of the Boussinesq analysis. It is possible to approximate this graph using two straight lines that lie on the safe side of the Boussinesq results, as shown in Figure 3, and taking the minimum value from the following equations:

$$\Omega_{eq} = 1.7H + 3.8$$

and

$$\Omega_{eq} = 0.75H + 4.75$$

Figure 3 also shows the equivalent results using the 2 to 1 method in NRA BD 31, combining the wheel loads. For depths greater than around 1m, the critical load per metre width using the 2 to 1 method would be on the unsafe side of the Boussinesq results.

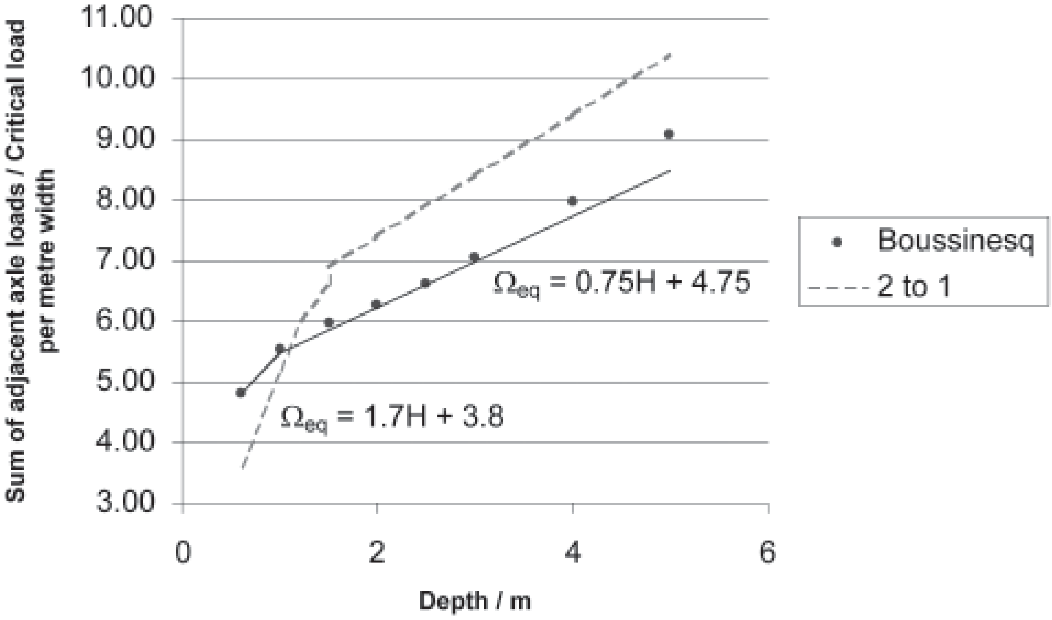

Figure 3: Transverse Dispersal for the Equal Axle Scenario

Single Vehicle

3.6 As well as the 'convoy' loading configuration, NRA BD 21 requires the 'single vehicle' configuration to be applied. In this situation, one vehicle has an impact factor applied to one axle, while vehicles in other lanes do not have any impact factors applied to them. A loading situation is assumed where the vehicles in adjacent lanes have axles aligned, with 1.5m transverse spacing between wheel centres of vehicles in adjacent lanes. As before, only two lanes are modelled explicitly. At each axle position, there is either a pair of equal axles, or, at the critical axle position, a pair of axles of different magnitudes (because only one vehicle has an impact factor applied to it).

3.7 The load per metre width for each pair of equal axles can be calculated using the Ω_{eq} values described previously. However, a slightly different method is needed for the critical axle position, where the axles have unequal magnitudes. Using the impact factor as defined in BA 55, which reduces linearly with depth of cover, it is possible to repeat the Boussinesq analysis for a pair of axles with impact factor on one axle only, at various depths.

3.8 The Ω_{if} parameter for the 'impact factor' situation is calculated by dividing the sum of the two axles, V_{tot}, by the critical load per metre width, V_L.

$$\Omega_{if} = V_{tot} / V_L$$

The variation of Ω_{if} with depth of cover H is illustrated in Figure 4. The 2 to 1 method is on the unsafe side of the Boussinesq results, as illustrated in Figure 4. The curve derived from the Boussinesq analysis can be approximated by the minimum of the following equations:

$$\Omega_{if} = 1.9H + 2.8$$

and

$$\Omega_{if} = 0.9H + 4.3$$

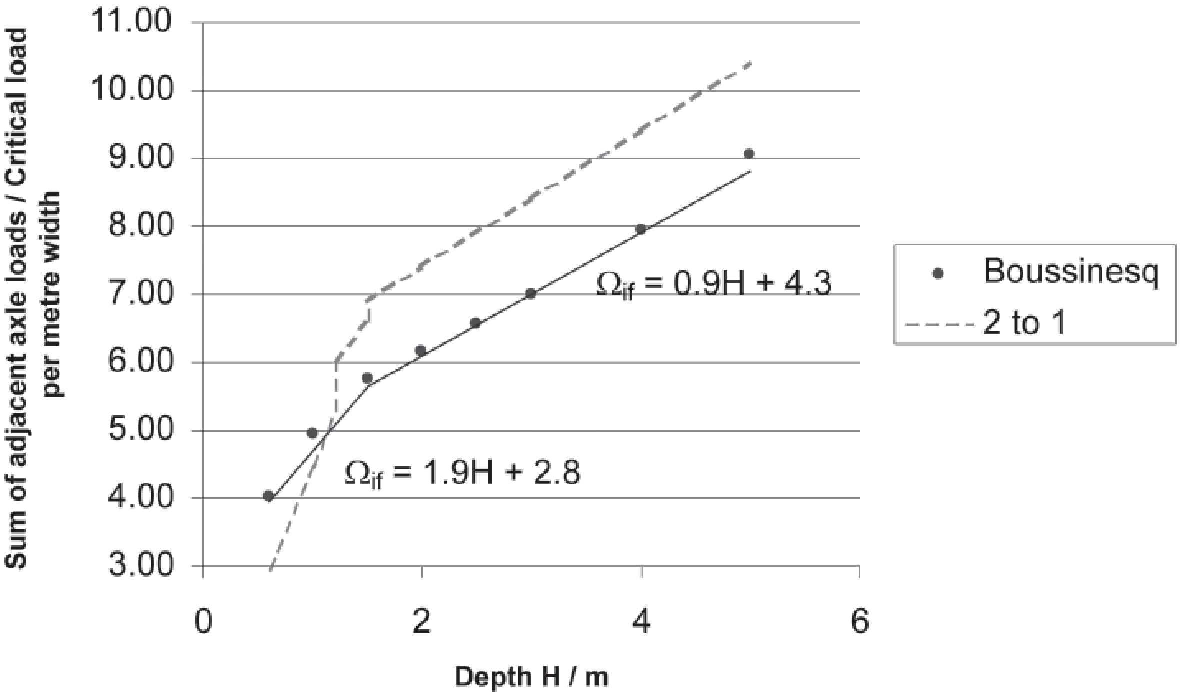

Figure 4: Transverse Dispersal for the Impact Factor Scenario

For the 'single vehicle' loading situation, the transverse location of the critical load per metre width for each pair of equal axles might not be aligned with the critical load per metre width for the critical axle position, where the impact factor is applied to one axle. However, it is conservative to base the design loading on the worst case for each axle position.

4 NRA BD 86 Loading

4.1 The loading specified in NRA BD 86 comprises an SV Load Model (or Abnormal or Exceptional Abnormal Vehicle) with associated HA loading. However, for buried concrete box structures with greater than 0.6m depth of cover, the associated HA loading is replaced with C&U vehicles from Annex D of NRA BD 21.

4.2 The C&U vehicle loading does not have the same axle spacings as the SV loading, and so the approach used for NRA BD 21 loading (where the axles are assumed to be aligned) cannot be used. Instead, each axle is considered separately, and the results are superimposed.

4.3 As specified in NRA BA 55, the transverse spacing between the SV and C&U vehicles is 0.7m between wheel centres.

4.4 The position of the critical load per metre depends on a large number of variables, including the relative magnitude and geometry of the vehicle loading, and the structure span. For the purposes of developing a simplified method, it has been assumed that the critical load per metre width occurs at some position between the edge wheel of the SV Load Model and 0.35m from the centre of the edge wheel of the SV Load Model (i.e. midway between the edge wheels of adjacent vehicles). It then follows that the critical load per metre width can be conservatively estimated by considering the load per metre width of each SV axle under the edge wheel, and the load per metre width of each C&U axle at a position 0.35m from the edge wheel.

4.5 For each axle type, the load per metre width at the relevant location, V_L, is calculated using a Boussinesq analysis, and the Ω parameter for that axle type is then calculated as

$$\Omega = V/ V_L$$

where *V* is the axle load. Four axle types are considered, as illustrated in Figures 5-8. Figure 5 illustrates the axle layout and analysis for an C&U vehicle axle.

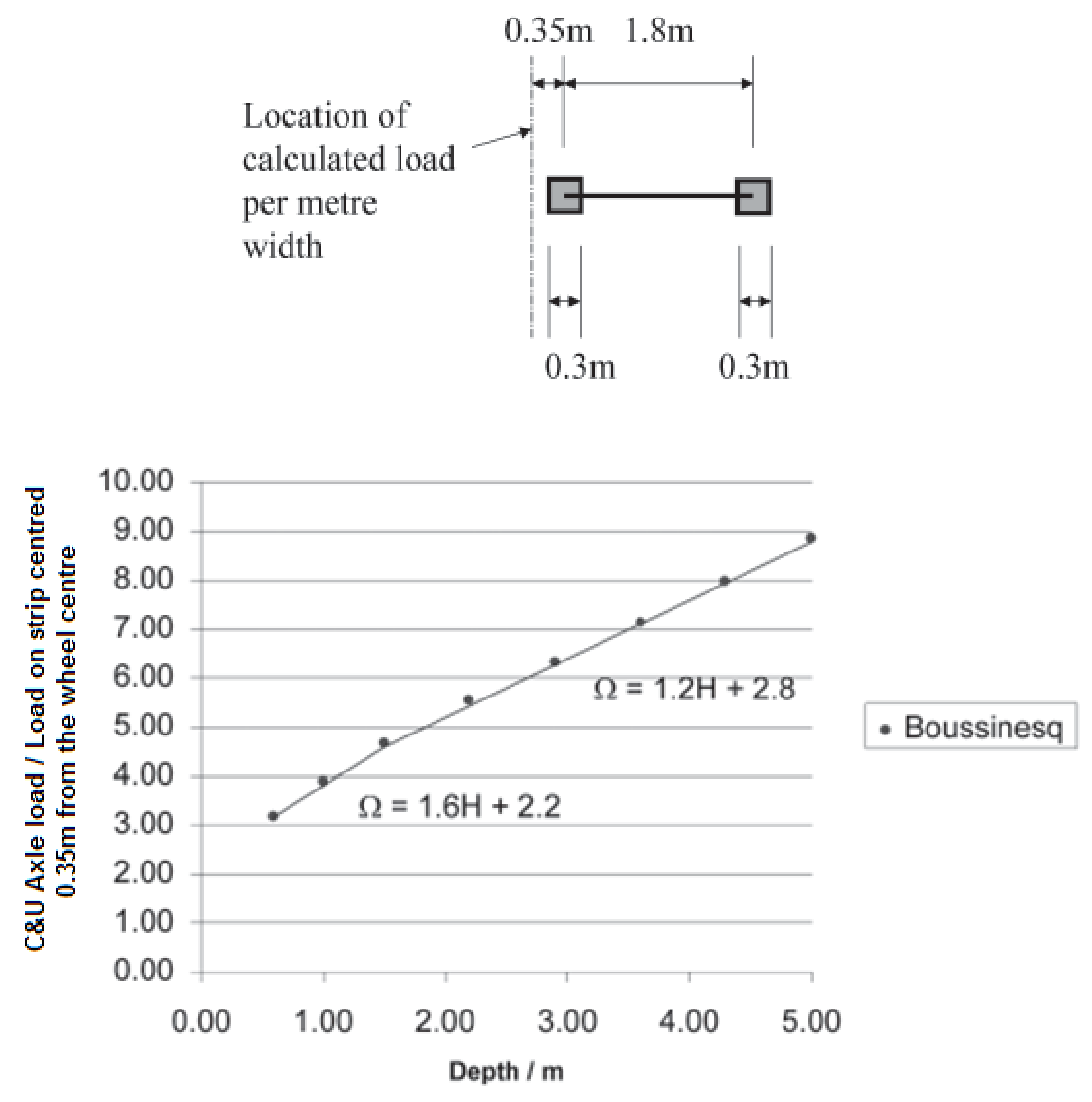

Figure 5: C&U Axle Analysis

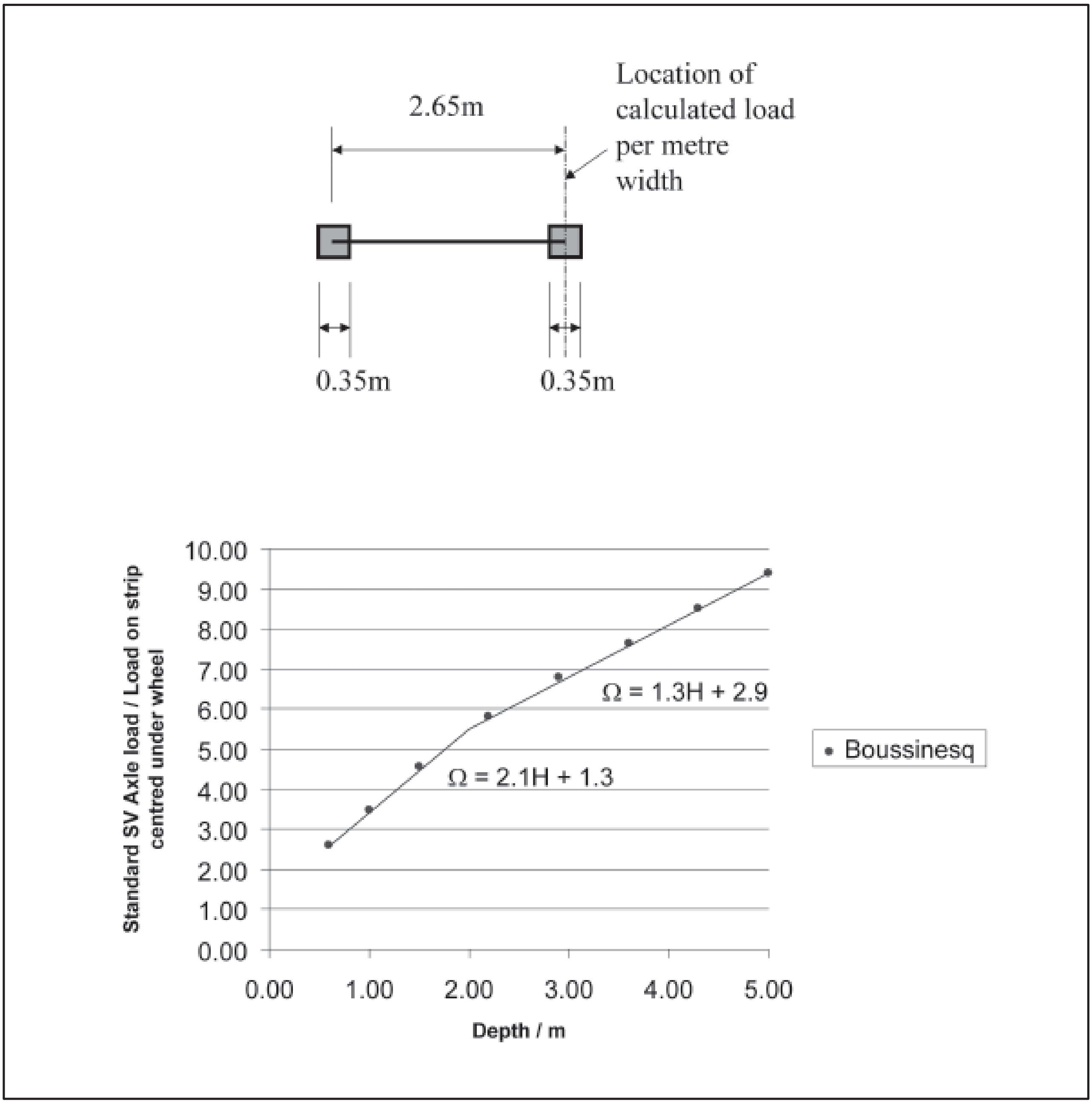

Figure 6: Standard SV Axle Analysis

4.6 Figures 6 and 7 illustrate the analyses for the standard SV axle (i.e. the axle for SV-80, SV-100, SV-150 and SV Trailer Train vehicles) and the front axles of the SV-TT vehicle, respectively. Since the results for these axle types are similar, the results for the standard SV axle are used for both axle types in NRA BA 55.

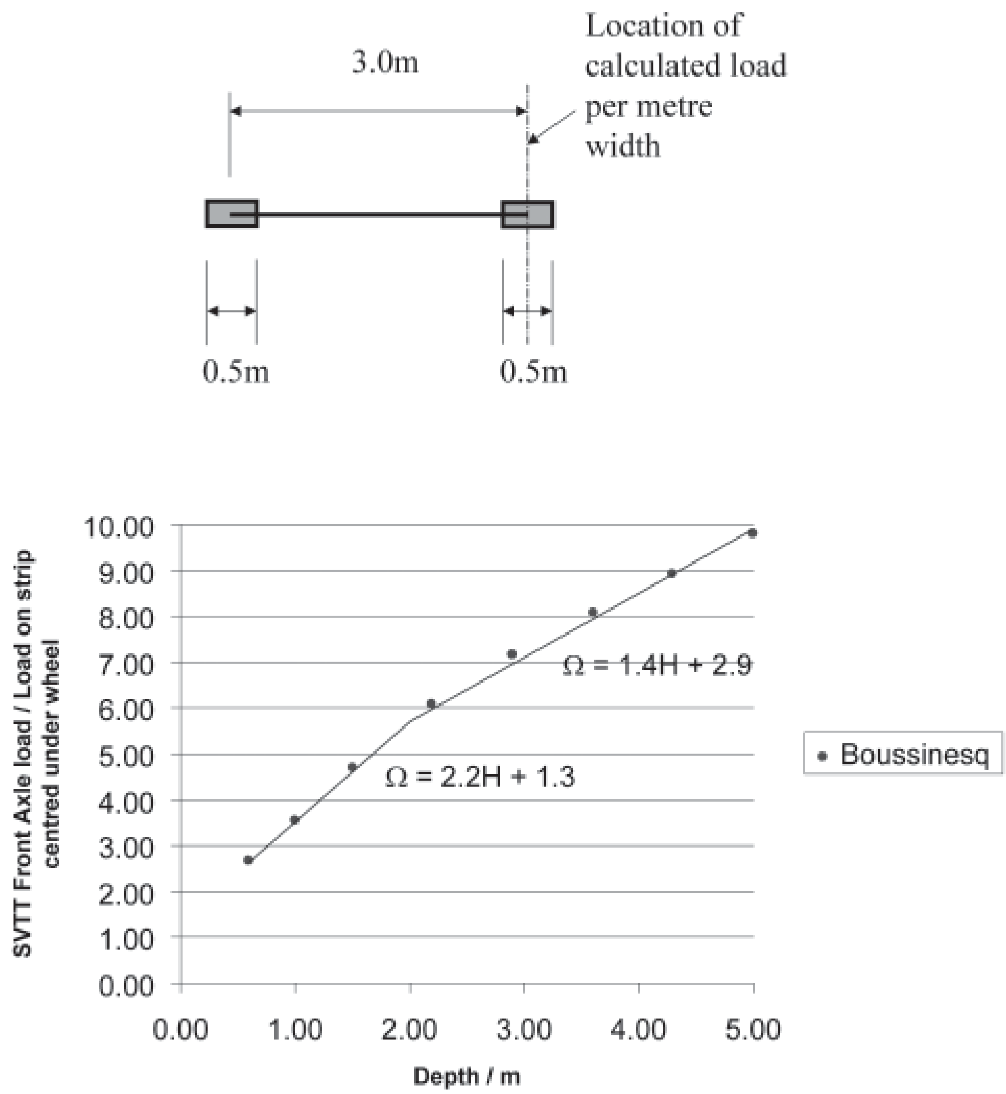

Figure 7: SV-TT Front Axle analysis

4.7 The analysis for the SV-TT rear axles is illustrated in Figure 8. The axle is similar to an HB axle in that there are 4 equal wheel loads at approximately 1m spacing. The transverse dispersal of this axle is similar to a 2:1 dispersal of an HB axle, since Ω is approximately linear with increasing H. The 2:1 dispersal would give:

$$\Omega = H + 3.5$$

whereas the Boussinesq approach approximates to:

$$\Omega = 1.14H + 3.69$$

4.8 In this case, the 2:1 method results, would suggest that these were on the safe side of the Boussinesq output, as for HB loading. However, the simplified Boussinesq approach in Figure 8 is nevertheless used in NRA BA 55 for consistency with the other axle types and for improved accuracy.

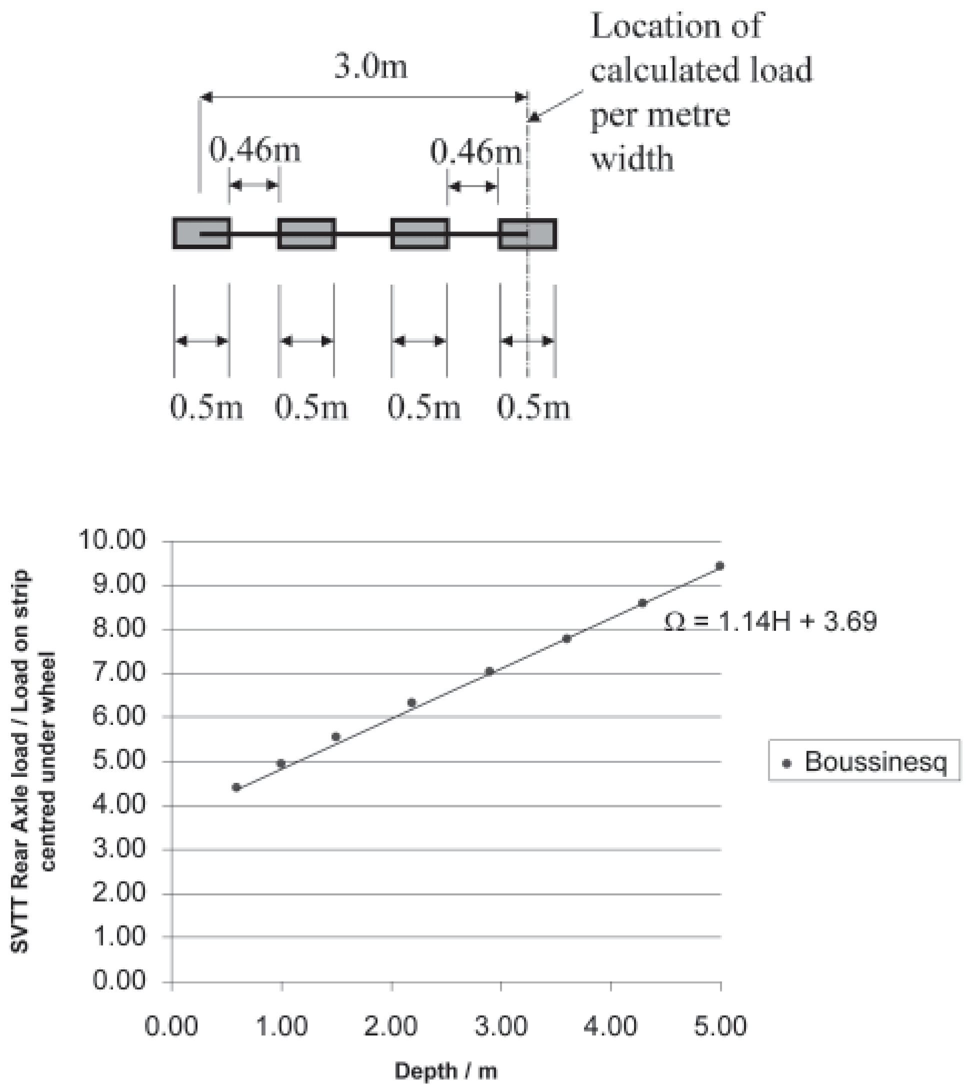

Figure 8: SV-TT Rear Axle Analysis

Bonneagar Iompair Éireann
Transport Infrastructure Ireland

Ionad Ghnó Gheata na Páirce,
Stráid Gheata na Páirce,
Baile Átha Cliath 8, Éire

Parkgate Business Centre,
Parkgate Street,
Dublin 8, Ireland

www.tii.ie

info@tii.ie

+353 (01) 646 3600

+353 (01) 646 3601