
**VOLUME 3 HIGHWAY STRUCTURES:
INSPECTION AND
MAINTENANCE**
SECTION 4 ASSESSMENT

PART 9

BA 55/06

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

SUMMARY

The Advice Note deals with the assessment of structures and structure elements where their behaviour is directly influenced by soil-structure interaction. The advice is updated to be consistent with BD 21/01, BA 79/01 and the Boussinesq method for load dispersal is introduced.

INSTRUCTIONS FOR USE

1. Remove Contents pages from Volume 3 and insert new Contents pages for Volume 3 dated May 2006.
2. Remove BA 55/00 from Volume 3, Section 4, which is superseded by this Advice Note and archive as appropriate.
3. Insert BA 55/06 into Volume 3, Section 4, Part 9.
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The Assessment of Bridge Substructures and Foundations, Retaining Walls and Buried Structures

Summary: The Advice Note deals with the assessment of structures and structure elements where their behaviour is directly influenced by soil-structure interaction. The advice is updated to be consistent with BD 21/01, BA 79/01 and the Boussinesq method for load dispersal is introduced.

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1. INTRODUCTION

1.1 The Steady State Assessment Programme involves the assessment of bridge substructures (abutments and wing walls including cantilevered wing walls and skeletal abutments) and foundations, retaining walls and buried structures. The basic requirements for the assessment of such elements and structures are given in BD 21 (DMRB 3.4.3). BD 86 (DMRB 3.4.19) gives requirements for assessment of structures for the effects of Special Types General Order (STGO) and Special Order (SO) vehicles. Advice on the management of structures that fail assessment is given in BA 79 (DMRB 3.4.18).

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 BA 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 BA 79 would be used to manage the risk in real time.

1.4 Design standards are available for substructures and foundations, retaining walls and buried structures, such as BD 30 (DMRB 2.1), BD 31 (2.2.12) and BD 42 (DMRB 2.1.2). These documents are intended for design and not 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.

Clause References

1.7 It is necessary that this Advice Note should refer to specific clauses of relevant Standards and Advice Notes. The particular versions of the documents, which are referred to by clause numbers in the text, are indicated by including the year of document publication with the document reference.

Definitions and Symbols

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

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

- (ii) 'Cover' means the depth of fill between ground level and the top of a structure.
- (iii) 'Effective barrier' means a system that is in place that provides defined vehicle restraint against impact or against a vehicle crossing the barrier.
- (iv) 'Ground level' means finished carriageway level, or the temporary ground level on which traffic can run during construction.
- (v) 'Longitudinal' means perpendicular to the abutment walls, or in the direction of traffic.
- (vi) 'Substructure' means the part of the structure that supports the superstructure, and includes abutments and wing walls, cantilevered wing walls and skeletal abutments.
- (vii) 'Superstructure' means the section of the structure over which traffic can pass (i.e. the bridge deck).
- (viii) 'Traction' means the longitudinal live load arising from braking and acceleration of vehicles.
- (ix) 'Transverse' means parallel to the abutment walls, or perpendicular to the direction of traffic.

The following are symbols used in the Advice Note:

- (i) H The depth of cover (m).
- (ii) K Earth pressure coefficient to be used for a given load in the assessment.
- (iii) K_a Coefficient of active earth pressure.
- (iv) K_p Coefficient of passive earth pressure.
- (v) K_0 Coefficient of lateral earth pressure 'at rest'.
- (vi) V Weight of one axle (kN).
- (vii) V_{tot} Total weight of combined axles (including any applied impact factor) (kN).
- (viii) Ω Lateral dispersal distance (m)
- (ix) Ω_{eq} Lateral dispersal distance for a pair of axles of equal magnitude (m).
- (x) 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 should be used forthwith for the assessment of bridge substructures (abutments and wing walls including cantilevered wing walls and skeletal abutments) and foundations, retaining walls and buried structures. The advice should be applied to assessments already in progress provided that, in the opinion of the Overseeing Organisation, this would not result in significant additional expense or delay. Its application to particular assessments should be confirmed with the Overseeing Organisation.

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 BD 86 (DMRB 3.4.19).

Summary of Relevant Requirements

[Refer to para 1.7 for the need to cross-refer to specific versions of DMRB Standards and Advice Notes]

2.2 BD 21 (DMRB 3.4.3) 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 BA 16 (DMRB 3.4.4) 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 BD 34 (DMRB 3.4.17) states that retaining walls providing structural support to a road and not designed for Type HA surcharge or equivalent are to be assessed. Furthermore it states that 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. It also states that bridges, culverts, buried structures etc. of spans less than 1.8m (or 5m total when multi span) and retaining walls of height 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 highway loading is only of marginal significance when compared to earth pressures, need not be assessed.

2.5 BA 34 (DMRB 3.4.17) contains advice on substructures and foundations. Factors of safety stipulated for design purposes may be relaxed for assessments with the agreement of the Overseeing Organisation. 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 BA 79 depending upon future functional requirements of the highway and the duty under the legislation in BA 55 to safeguard the highway user. 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 structural 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 OA 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 BA 79 depending upon future functional requirements of the highway and the duty under the legislation in BA 55 to safeguard the highway user.

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.

[Refer to para 1.7 for the need to cross-refer to specific versions of DMRB Standards and Advice Notes]

Backfilled Retaining Walls and Bridge Abutments

3.2 BD 30 (DMRB 2.1.5) 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 BD 30/87 (DMRB 2.1.5) is applicable, using the following qualifications:

- (1) Clause 5.1 – Design: Embedded retaining walls are assessed to BD 42 (DMRB 2.1.2). Further guidance is given in 3.5.
- (2) Clause 5.2.2 – Ultimate Limit State of Structural Elements: Instead of BD 24 (DMRB 1.3.1), BD 44 (DMRB 3.4.3) 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 highway live loads should be as given in BD 21 (DMRB 3.4.3) and BD 86 (DMRB 3.4.19). 12 kN/m² of vertical live load surcharge may be used in place of the Annex D and E vehicles from BD 21 (DMRB 3.4.3). 20 kN/m² of vertical live load surcharge should be used in conjunction with loading in BD 86 (DMRB

3.4.19). Alternatively, subject to the agreement of the Overseeing Organisation, 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 design standard BD 31 (DMRB 2.2.12) may be used, based on the following guidelines. Further guidance on buried concrete box structures may also be found in BA 88 (DMRB 3.3.5).

- (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. BA 79 (DMRB 3.4.18) 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 BD 44 (DMRB 3.4.15).
- (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 BD 21 (DMRB 3.4.3). 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 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 BD 21 (DMRB 3.4.3). If required by the Overseeing Organisation, the loads in BD 86 (DMRB 3.4.19) should be used to assess the effects of STGO and SO vehicles.
- (b) Where the depth of cover exceeds 0.6m, the loads given in Annex D or E of 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 Overseeing Organisation, the loads in BD 86 should be used to assess the effects of STGO and SO 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 Authorised Weight (AW) vehicles as given in Annex D of 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 AW vehicles. However, if a convoy of vehicles is assumed for the associated AW 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 AW 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 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 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 BD 21 (DMRB 3.4.3).
- (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 BD 21 (DMRB 3.4.3) loading and BD 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) **BD 21 (DMRB 3.4.3) 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 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:

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

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:

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

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

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

and

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

in metres.

(ii) BD 86 (DMRB 3.4.19) 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 BD 86, with associated AW loading, with a transverse spacing of 0.7m between wheel centres of adjacent vehicles.

Since the axle spacings are different for SV and AW 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:

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

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

For the axles of the SV-80, SV-100, SV-150, and SV-Train 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 AW vehicle, Ω is given by the minimum of:

$$\Omega = 1.6H + 2.2$$

and

$$\Omega = 1.2H + 2.8$$

For the assessment of STGO and SO vehicles that are outside of the scope of the SV models defined in 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 BD 42 (DMRB 2.1.2) 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.

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.

Assessment of embedded retaining walls should be carried out using the limit state design principles described in BD 42 (DMRB 2.1.2). 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 BD 42 (DMRB 2.1.2) 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.
- (1) Clause 3.5: Replace reference to BD 13 (DMRB 1.3.14), BD 24 (DMRB 1.3.1) and BD 16 (DMRB 1.3.14) with reference to BD 56 (DMRB 3.4.12), BD 44 (DMRB 3.4.14) and BD 61 (DMRB 3.4.16).
- (7) Clause 3.7: Replace reference to BD 37 (DMRB 1.3.14) with reference to BD 21 (3.4.3).
- (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 BD 21 (DMRB 3.4.3).
- (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 BA 42 (DMRB 1.3). 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

3.6 Foundations in general should be assessed by using BD 74 (DMRB 2.1.8) with the following qualifications:

- (1) Structural elements of concrete and steel piles should be assessed using BD 44 (DMRB 3.4.14) and BD 56 (DMRB 3.4.11), 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 BD 21 (DMRB 3.4.3). Only Load Combination 1 should be considered.

Reinforced Concrete Arch Bridges

3.7 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 Overseeing Organisation.

Reinforced Soil Structures

3.8 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.

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.

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

Corrugated Steel Buried Structures

3.9 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 BD 12 (DMRB 2.2.6).

When assessing corrugated steel buried structures up to 8m span the analysis may follow the design method of BD 12, if considered applicable, although the assessment loading should be agreed with the Overseeing Organisation. The 'two-to-one' method for the dispersal of wheel and axle loads through the fill given for HB loading in 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.

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 BD 12 (DMRB 2.2.6) 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.

Further guidance on corrugated steel buried structures may be found in BA 87 (DMRB 3.3.4).

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.

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 BA 79 (DMRB 3.4.18). This should be agreed with the Overseeing Organisation who will be responsible for implementing this option.

4.2 Before strengthening or replacing a concrete box structure that has failed an assessment, the guidance in BA 79 (DMRB 3.4.18) should be followed. For this form of structure, a further assessment using some or all of the following may be beneficial:

- (a) reassessment to the current version of BD 21 (DMRB 3.4.3) and consider Departures from standards where appropriate, if the original assessment was undertaken in accordance with an earlier version;
- (b) use of soil parameters obtained from testing;
- (c) moment redistribution;
- (d) yield line analysis;
- (e) use of worst credible strength (WCS) for concrete and reinforcement obtained from testing.

4.3 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 BA 79 (DMRB 3.4.18).

5. REFERENCES

1. Design Manual for Roads and Bridges, The Stationery Office

Volume 1: Section 3: General Design

BD 13/06 (DMRB 1.3.14) – Design of Steel Bridges. Use of BS 5400-3:2000.

BD 16/82 (DMRB 1.3.14) – Design of Composite Bridges. Use of BS 5400: Part 5: 1979. [Incorporating Amendment No. 1 dated Devember 1987]

BD 24/92 (DMRB 1.3.1) – The Design of Concrete Bridges. Use of BS 5400: Part 4: 1990.

BD 37/01 (DMRB 1.3.14) – Loads for Highway Bridges.

BA 42/96 (DMRB 1.3.12) – The Design of Integral Bridges [Incorporating Amendment No. 1 dated May 2003]

BD 74/00 (DMRB 2.1.8) – Foundations.

Volume 2: Section 1: Substructures

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

BD 30/87 (DMRB 2.1.5) – Backfilled Retaining Walls and Bridge Abutments.

BD 42/00 (DMRB 2.1.2) – Design of Embedded Retaining Walls and Bridge Abutments.

BD 74/00 (DMRB 2.1.8) – Foundations.

Volume 2: Section 2: Special Structures

BD 12/01 (DMRB 2.2.6) – Corrugated Steel Buried Structures with Spans Greater than 0.9 Metres and up to 8.0 Metres.

BD 31/01 (DMRB 2.2.12) – The Design of Buried Concrete Box Type and Portal Frame Structures.

Volume 3: Section 3: Repair

BA 87/04 (DMRB 3.3.4) – Management of Corrugated Steel Buried Structures.

BA 88/04 (DMRB 3.3.5) – Management of Buried Concrete Box Structures.

Volume 3: Section 4: Assessment

BA 16/97 (DMRB 3.4.4) – The Assessment of Highway Bridges and Structures.

BD 21/01 (DMRB 3.4.3) – The Assessment of Highway Bridges and Structures.

BD 34/90 (DMRB 3.4.17) – Technical Requirements for the Assessment and Strengthening Programme for Highway Structures. Stage 1 – Older Short Span Bridges and Retaining Structures.

BD 44/95 (DMRB 3.4.12) – The Assessment of Concrete Highway Bridges and Structures.

BD 56/96 (DMRB 3.4.12) – The Assessment of Steel Highway Bridges and Structures.

BD 61/96 (DMRB 3.4.16) – The Assessment of Composite Highway Bridges and Structures.

BA 79/01 (DMRB 3.4.18) – Management of Sub-Standard Highway Structures.

BD 86/04 (DMRB 3.4.19) – Assessment of highway bridges and structures for the effects of special types general order (STGO) and special order (SO) vehicles.

2. British Standards

BS 8002: Earth Retaining Structures.

3. Code of Practice

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

4. Legislation

The legislation in BA 55.

6. ENQUIRIES

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

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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 BD 31 and 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 'BD 31 method' is appropriate for design loading where the wheel loads are uniform, as 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 BD 21 and 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.

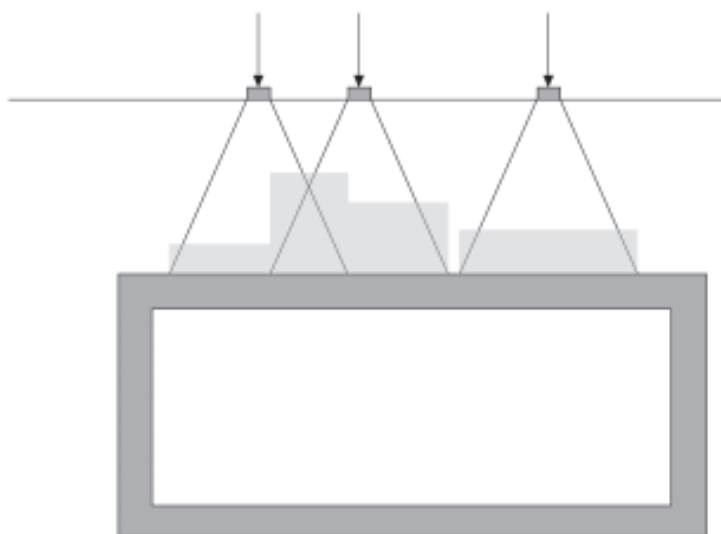


Figure 1: Illustration of Longitudinal Dispersal Method

3. BD 21 Loading

3.1 The loading specified in BD 21 for buried structures with greater than 0.6m fill requires vehicles from Annex D or E of 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.

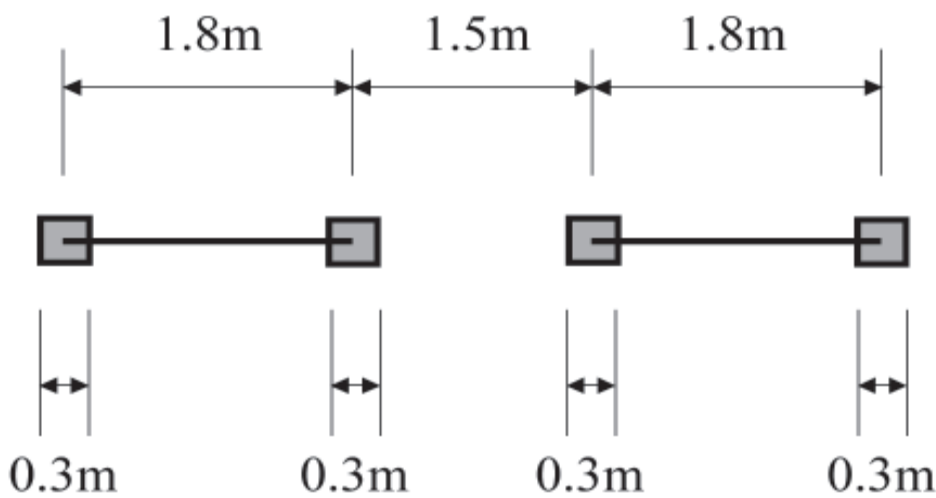


Figure 2: Equal Axles in Adjacent Lanes for BD 21 Loading

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 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.

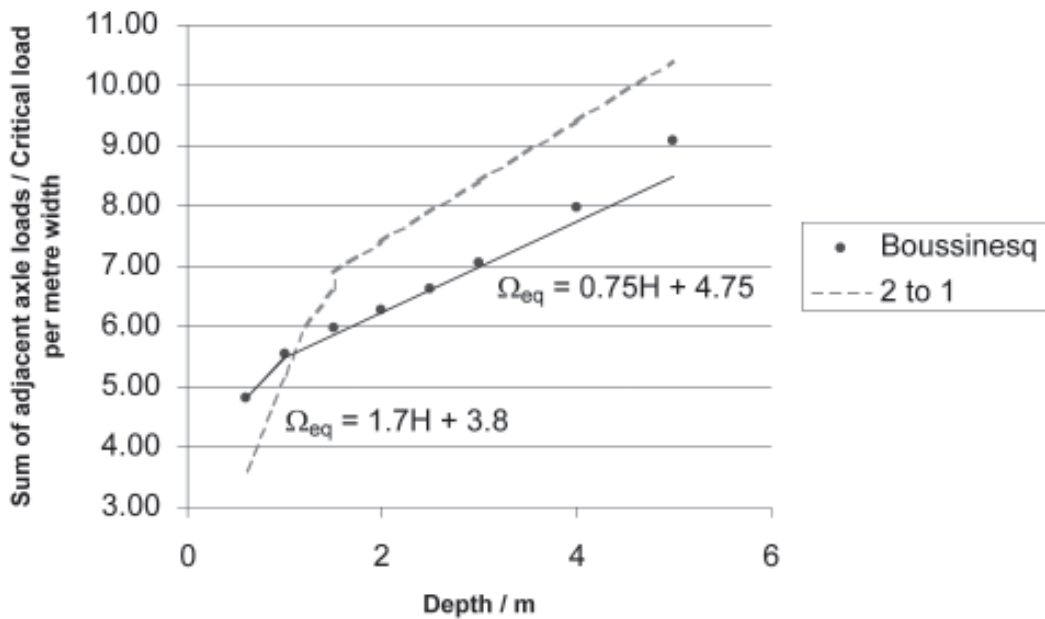


Figure 3: Transverse Dispersal for the Equal Axle Scenario

Single Vehicle

3.6 As well as the ‘convoy’ loading configuration, 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).

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

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

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

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 .

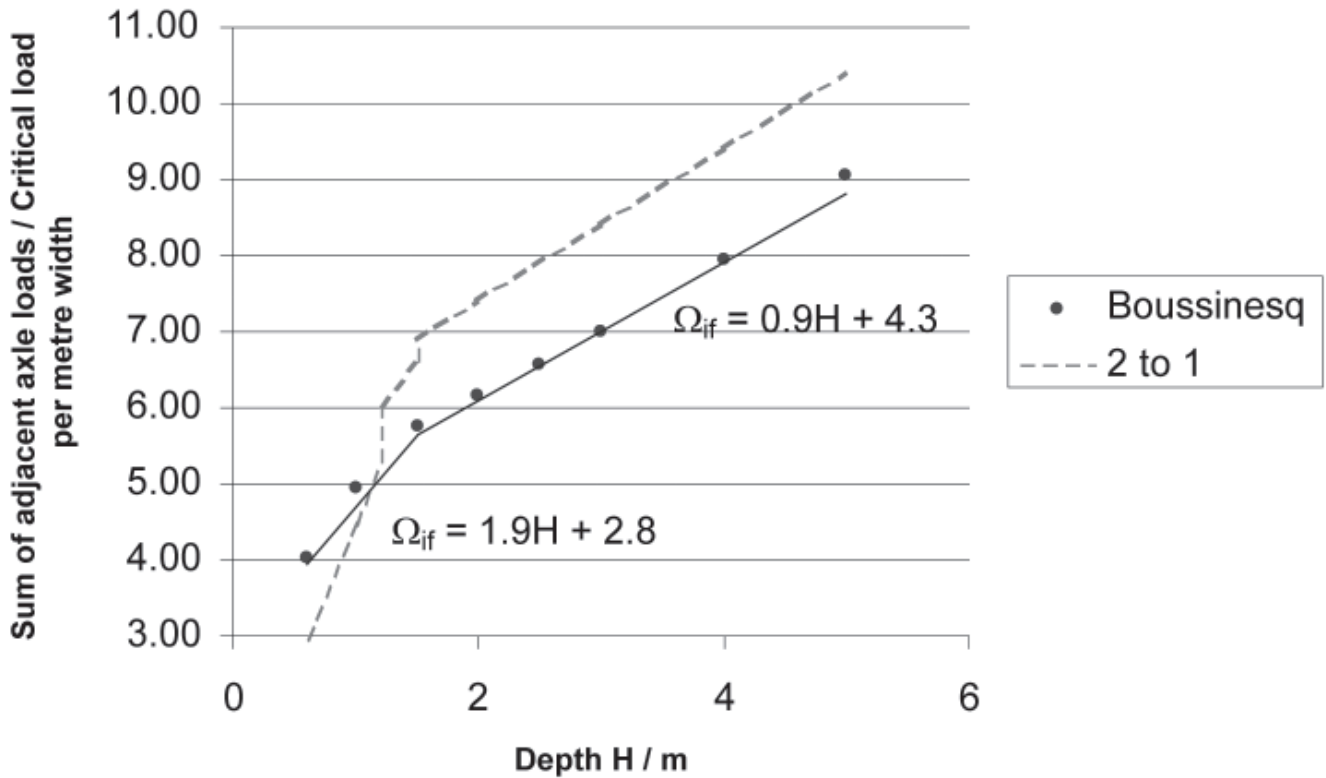


Figure 4: Transverse Dispersal for the Impact Factor Scenario

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 BD 86 Loading

4.1 The loading specified in BD 86 comprises an SV vehicle (or STGO or SO 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 AW vehicles from Annex D of BD 21.

4.2 The AW vehicle loading does not have the same axle spacings as the SV loading, and so the approach used for 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 BA 55, the transverse spacing between the SV and AW 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 vehicle and 0.35m from the centre of the edge wheel of the SV vehicle (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 AW 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 AW vehicle axle.

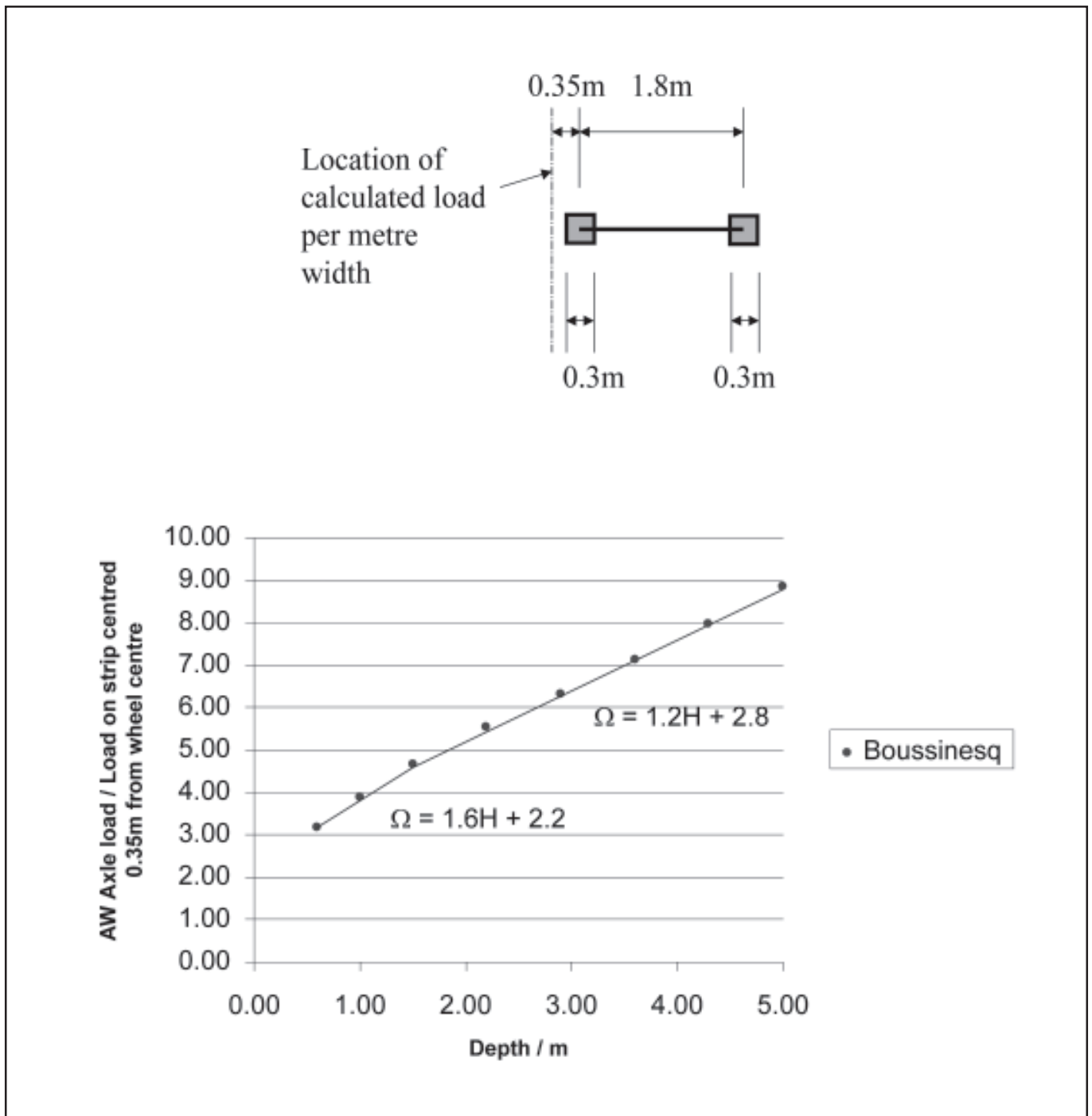


Figure 5: AW Axle Analysis

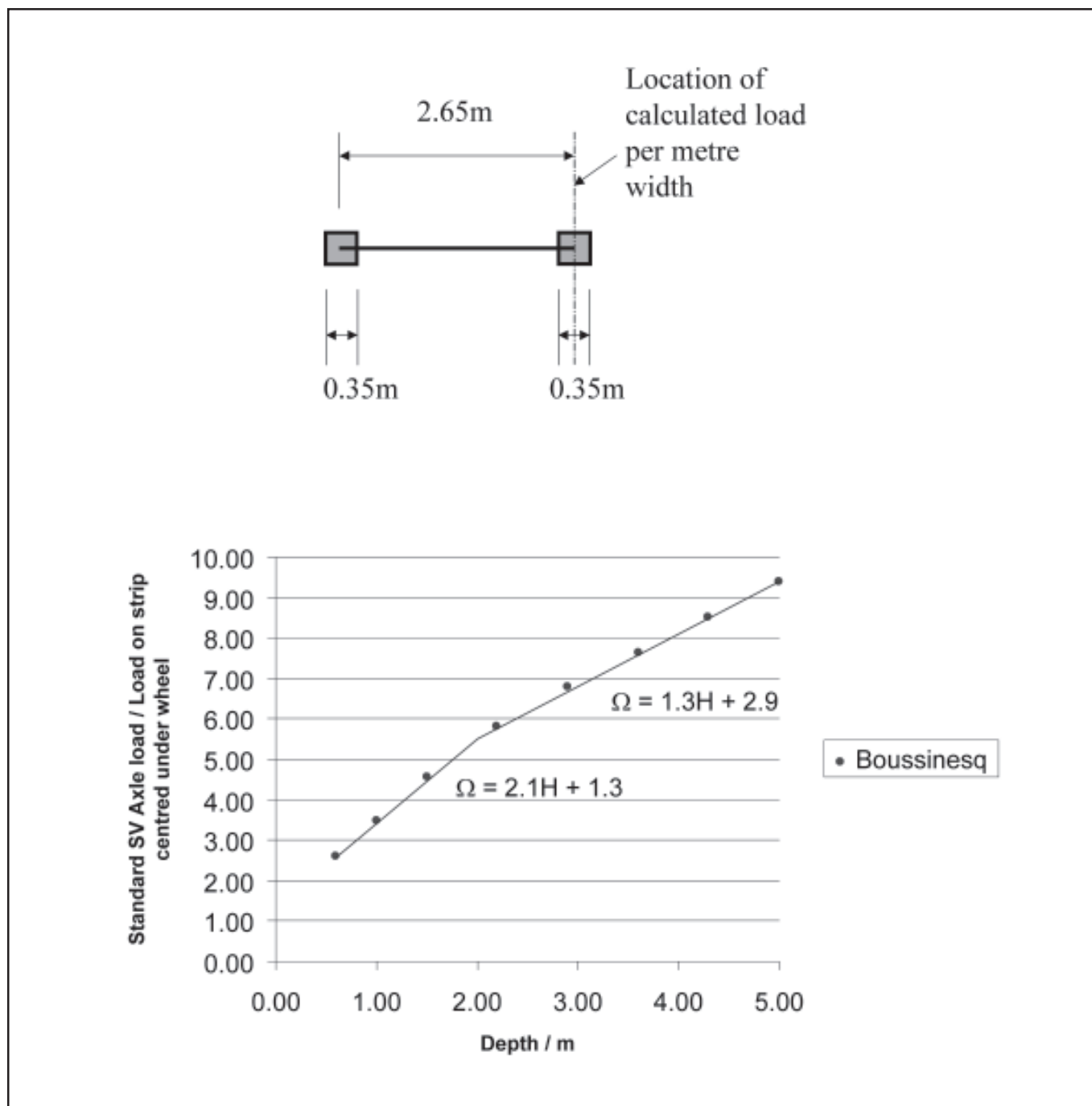


Figure 6: Standard SV Axle Analysis

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 BA 55.

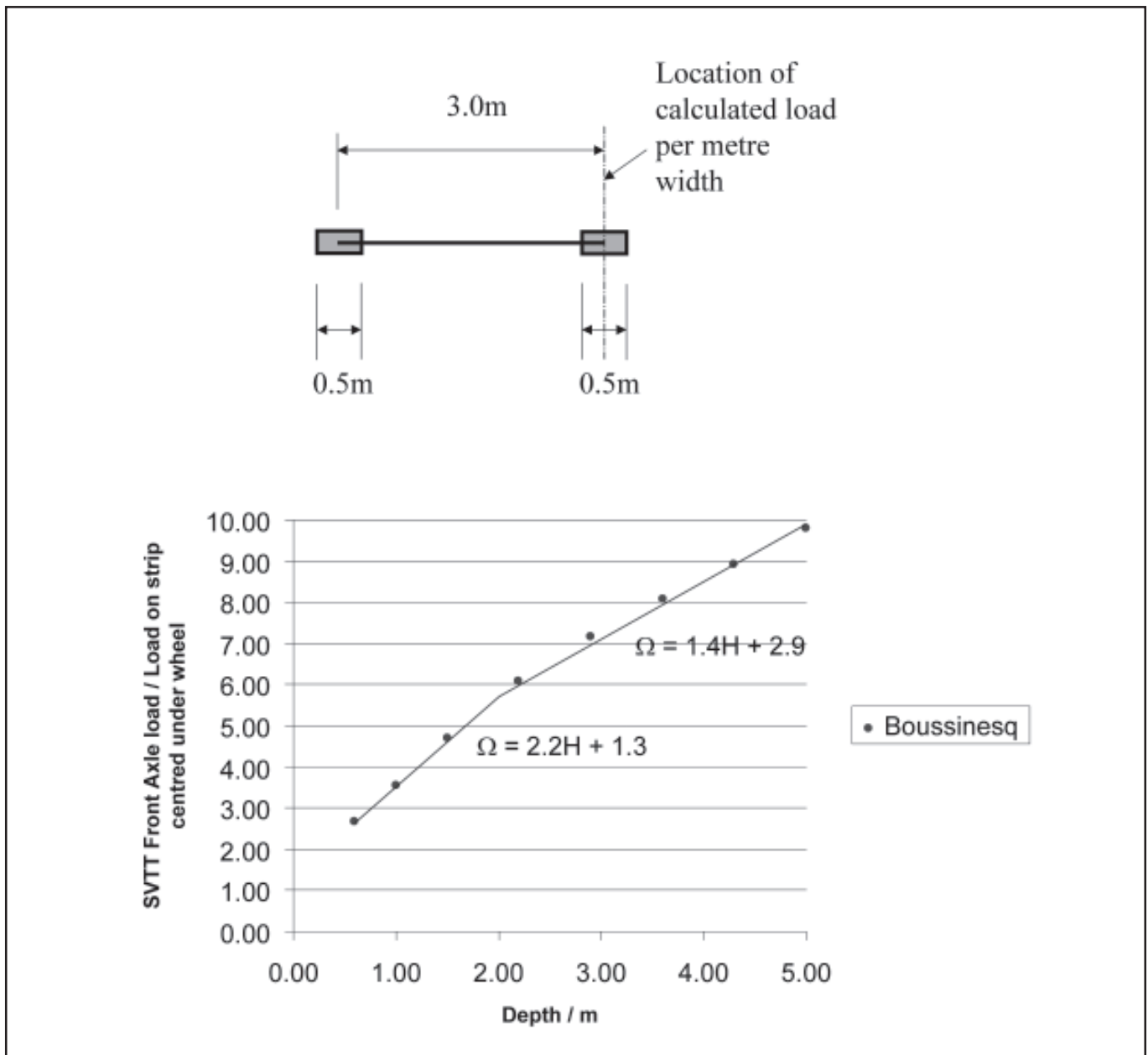


Figure 7: SVTT Front Axle analysis

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 BA 55 for consistency with the other axle types and for improved accuracy.

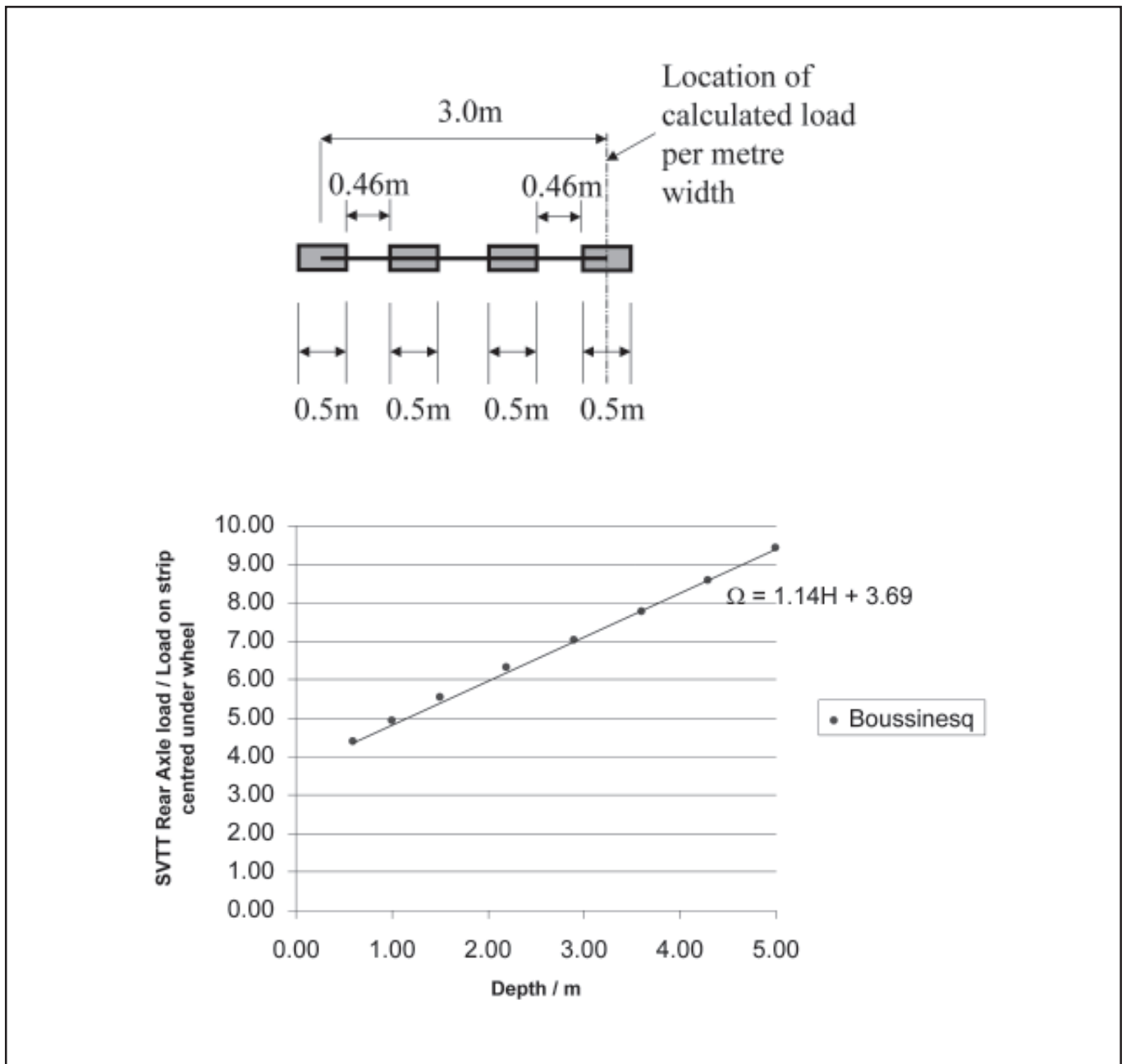


Figure 8: SVTT Rear Axle Analysis