TRANSPORT RESEARCH LABORATORY

Consultation document on suitability tests for stress absorbing layers behind integral bridge abutments

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Executive Summary

In principle Highways Agency recommends that all bridges should be continuous over intermediate supports and bridges with overall lengths of less than 60m and skews not exceeding 30° should be integral with their abutments. Joint-free integral bridges are generally considered more durable and cheaper in whole life cost than conventional bridges with joints and bearings. However seasonal cyclic thermal movements of the deck cause interactions between the bridge abutments and the retained soil such that lateral earth pressures behind the abutments are likely to progressively increase with time. One method of avoiding the development of these high lateral pressures is to use a low stiffness but compressible elastic backfill as a stress absorbing layer behind the abutment. This, in turn, would allow a more economical design for the construction of new integral bridges. In addition the method may also provide an economical conversion of existing conventional bridges into integral structures as part of the need to reduce long-term maintenance costs.

TRL Report 290 identified various compressible materials, such as polymeric and geocomposite materials, which may be suitable for use as innovative backfill behind integral bridge abutments. In addition the engineering properties of these materials were reviewed from available literature and their likely performance evaluated in terms of the loading existing in an integral bridge situation. This report proposes methods of testing to assess suitability of materials for use as stress absorbing layers.

Methods of test are tentatively proposed in the report for assessing suitability of materials for use as stress absorbing layers under the combined normal and shear forces existing behind integral bridge abutments. Results from the proposed tests can then be compared with the performance requirements to confirm acceptability. Because of the large range of possible materials, which includes cellular and particulate materials, it is anticipated that both the test methods and performance requirements may need further refinement.

1 Introduction

In principle Highways Agency recommends that all bridges should be continuous over intermediate supports and bridges with overall lengths of less than 60m and skews not exceeding 30^{o} should be integral with their abutments (BD57, DMRB 1.3.7). Joint-free integral bridges are generally considered more durable and cheaper to maintain. However thermal strains in an integral deck cause cyclic loading on the soil behind the abutments which may result in the development of passive pressures (Card and Carder, 1993; Springman, Norrish and Ng, 1996; England and Dunstan, 1994). One method of avoiding the development of these high lateral pressures is to use a low stiffness but compressible elastic backfill as a stress absorbing layer behind the abutment. This, in turn, would allow a more economical design for the construction of new integral bridges. In addition the method may also provide an economical conversion of existing conventional bridges into integral structures as part of the need to reduce long-term maintenance costs.

Carder and Card (1997) identified various compressible materials, such as polymeric and geocomposite materials, which may be suitable for use as innovative backfill behind integral bridge abutments. They reviewed from available literature the engineering properties of these materials and evaluated their likely performance in terms of the loading existing in an integral bridge situation. The performance requirements identified by Carder and Card (1997) for efficient stress absorbing behaviour have been adopted for the purpose of this report and these are summarised in Section 2.

In this report, methods of test are tentatively proposed in Section 3 for assessing suitability of materials for use as stress absorbing layers under the combined normal and shear forces existing behind integral bridge abutments. Results from the proposed tests can then be compared with the performance requirements to confirm acceptability. Because of the large range of possible materials, which includes cellular and particulate materials, it is anticipated that both the test methods and performance requirements may need further refinement. For this reason, this report is prepared as a consultation document for discussion within the civil engineering industry.

2 Performance requirements

2.1 Engineering properties

Each complete stress absorbing layer installation should accommodate cyclic movement in the horizontal direction of ±0.015% of the span of the bridge (based on an operational range of 46^{o}C from BD37 (DRMB 1.3) and a coefficient of thermal expansion of 12×10^{-6} per ^{o}C for concrete and composite decks). This movement may be modified pro rata for other temperature cycles and for lightweight aggregate concrete or steel decks which will have different coefficients of thermal expansion. If the movement range is modified the values of horizontal compression modulus and horizontal shear strength proposed below should be similarly modified.

The stress absorbing layer should have the following properties:

- a horizontal compression modulus within the limits of 1 to 2MPa for a layer thickness of 0.3m rising linearly to between 3 and 6MPa for a thickness of 1.0m
- a minimum horizontal shear strength of 0.15MPa for a layer thickness of 0.3m falling linearly to 0.05MPa for a thickness of 1.0m
- a vertical compression modulus greater than 3MPa
- a vertical shear strength greater than 0.02MPa
- any void caused by compression set of the layer should be less than 2mm in both horizontal and vertical directions.

A full derivation of these proposed values for the various properties is given by Carder and Card (1997).

The permeability of the stress absorbing layer is not important if it is placed between a permeable backing and the abutment. If the stress absorbing layer is to act as a permeable backing it should comply with Specification for Highway Works Clause 513 (MCHW1).

Suitable test methods are proposed in Section 3 for verifying that the installation of the stress absorbing layer installation will meet the performance requirements.

2.2 Durability

The design life of the stress absorbing layer should be 120 years and the material should be fit for purpose during this period. The materials of which the stress absorbing layer is made should be resistant to degradation by oxygen, acids, alkalis, common chemicals, fuels, bacteria, fungi and moulds occurring in soils and highway construction materials.

The contractor should demonstrate by standard or other tests and verified extrapolation protocols or by other evidence the lifetime during which the stress absorbing layer will continue to meet the performance requirements.

Particular standards relevant to the durability of the materials are summarised in Table 1.

In general it is recommended that the equilibrium water absorption of the stress absorbing material should not exceed 5%. The test method used may be based on ISO 62, BS 903 Part A 16 or ISO 2896.

3 Tests to verify suitability

3.1 Introduction

A stress absorbing layer is a compressible backfill material with elastic properties to accommodate cyclic movement of the abutment. The materials of which the stress absorbing layer is made may be cellular, non-cellular or separate particles or may be a composite of these. The layer may be preformed sections assembled on site or materials formed on site. The materials forming the stress absorbing layer should be treated so that they are protected from the deleterious effects of short term exposure to sunlight.

The stress absorbing layer will normally have a thickness of between 0.3m to 1.0m and extend from the

Table 1 Durability of materials

Factor(s) affecting material(s)	*Plastics*	*Rubbers*
Rain, runoff, liquid chemical spills	ISO 175	ISO 1817 ISO TR 7620
Fungi, bacteria	ISO 846	
Temperature, fire resistance	ISO 2578	ISO 188
Damp heat, water spray, salt mist	ISO 4611	
Environmental stress cracking	ISO 4599	
Ageing*		ISO 188 ISO 11346
Ozone cracking		ISO 1431

** For cellular materials accelerated ageing tests specified in ISO 2440 may be employed.*

top of the abutment as far down as is shown to be necessary in the design to fulfil its function.

3.2 Installation and handling

The handling and installation on site of components of the stress absorbing layer should be carried out under conditions such that no contaminants are introduced, with any material which becomes contaminated being replaced. Exposure to daylight or any other source of ultraviolet radiation for a period exceeding a cumulative total of 50 hours should generally be avoided. For materials formed on site, the conditions of temperature and humidity should be within the range specified by the supplier for the production of satisfactory material.

A geotextile layer should be placed between the stress absorbing layer and the backfill if there is any possibility of fines migrating into the stress absorbing layer. Any drainage layer should normally be on the backfill side of the stress absorbing layer.

The backfill is required to pre-compress the stress absorbing layer to a strain greater than the thermal contraction strain resulting from the temperature difference between the installation temperature and the minimum operational temperature of the bridge deck. For this reason, the backfilling should be programmed to take place at a temperature below the midpoint of the operational range.

The contractor should provide the following information for each consignment of stress absorbing layer delivered to site:

- name, grade and lot identification
- names and addresses of manufacturers
- description of chemical nature and physical form
- consignment number and copy of the site delivery note.

3.3 Test pieces for performance tests

Test pieces should be of such dimensions and obtained in a such a way that they are representative of the complete stress absorbing layer installation and protocols can then be applied to scale results to the full size installation. For shear tests on solid and cellular composites the test pieces should be cut from the weakest component.

For compression modulus tests the preferred test piece size is 1000 x 500 x 100mm. For shear tests on solid and cellular materials the preferred test piece size (per element) is 120 x 100 x 20mm. The preferred test pieces size is 300 x 300 x 300mm for tests of compression set.

3.4 Test method for horizontal modulus

This test determines the secant modulus of the material in the direction at right angles to the vertical axis of the abutment. Secant modulus is the ratio of stress at the maximum service strain of the stress absorbing layer to the maximum service strain.

Required apparatus

The apparatus required is as follows:

a a compression testing machine or equivalent of adequate load capacity complying with ISO 5893 Part 1, force grade B and capable of measuring compression strain to ±2% of the test strain

b a flat metal lower platen, which does not significantly distort under the test load, with lateral dimensions greater than those of the test piece

c a metal loading platen, which does not significantly distort under the test load, of lateral dimensions equal to those of the test piece to within +0/-1mm

d metal containment to prevent lateral displacement of the test piece, which does not significantly distort under the test load, of internal lateral dimensions equal to those of the test piece to within +1/-0mm .

Test procedure

Three representative test pieces should be cut or assembled with their thickness in the horizontal direction of the stress absorbing layer. The first test piece should be placed in the steel containment on the lower platen of the testing machine and compressed using the upper loading platen at a speed of 5±1mm/min to a strain greater than the maximum percentage strain, to which the stress absorbing layer will be subjected in service due to thermal movement of the bridge. The force deflection curve should be recorded and the test repeated using the other two test pieces.

The secant modulus at the maximum service strain for each of the test pieces should be calculated together with the mean value of the three tests. The report of the results should include the sample identification details, individual and mean moduli, and details of any deviation from the specified test procedure.

3.5 Test method for vertical modulus

This test determines the secant modulus of the material in the direction parallel to the vertical axis of the abutment.

The test procedure is identical to that given in Section 3.4 for horizontal modulus except that the secant modulus is determined using the test pieces with their thickness in the vertical direction of the stress absorbing layer.

3.6 Test method for horizontal shear strength (solid and cellular materials)

This test determines the shear strength of the material in the direction at right angles to the vertical axis of the abutment.

Required apparatus

The apparatus required is as follows:

a a tensile testing machine or equivalent of adequate load capacity complying with ISO 5893 Part 1, force grade B

b metal plates, which do not significantly distort under the test load, of width equal to that of the test piece to within +0/-1mm with means of attachment to the fixed and moving members of the test machine.

Test procedure

Twelve representative test pieces should be cut or assembled with their thickness in the vertical direction of the stress absorbing layer. Shear test assemblies should be formed by bonding together four test pieces using an adhesive giving a higher bond strength than the expected shear strength of the test material. This sandwich of material should then be bonded to the metal plates using the same adhesive. The test assembly should be mounted in the test machine and the test pieces strained at a rate of 5+/-1mm/min until failure occurs. The maximum force should be recorded and the test repeated using the other two test pieces.

The shear strength of the material should be calculated for each of the test assemblies and the mean value determined. The report of the results should include the sample identification details, individual and mean shear strengths, and details of any deviation from the specified test procedure.

3.7 Test method for horizontal shear strength (particulate materials)

The shear strength should be measured in general accordance with BS 1377 Part 7: 1990 Methods of test for soils for civil engineering purposes, Part 7 Shear strength tests (total stress), *Clause 5 Determination of shear strength by direct shear (large shearbox apparatus).*

Required apparatus

The apparatus required is a large shearbox and associated equipment as specified in Clause 5 of BS 1377 Part 7.

Test procedure

The test should be performed in the laboratory on remoulded samples compacted to the dry density and moisture content expected to be achieved in the field. Testing of the material should take place with the sample orientated such that the vertical direction of the stress absorbing layer is normal to the plane of shear. The material should be compacted in accordance with either Clause 5.4.5 or 5.4.6 of BS 1377 Part 7: 1990.

The normal pressure to be applied to the sample should be taken as the greater of the vertical effective stress equivalent to half the full height of the layer due to self weight, or a nominal surcharge of 10 kN/m^2. The rate of strain of the sample should be determined in accordance with Clause 4.5.2.5 and 4.5.2.6 of BS 1377 Part 7: 1990.

Peak shear strength, $\tau_{peak'}$ should be determined provided that the required strain range, as specified in *Performance Requirements*, is compatible with mobilisation of peak strength ($c'_{peak'}$ ϕ'_{peak}) of the test sample. Otherwise, residual shear strength, $\tau_{res'}$ should be established using a multi-reversal test in accordance with Clause 5.5.5 of BS 1377 Part 7: 1990.

The test should be carried out on three samples and the average shear strength recorded. The test results and calculations should be reported in accordance with the requirements of Clause 5.7 of BS 1377 Part 7: 1990 and Clause 9 of BS 1377 Part 1: 1990.

3.8 Test method for vertical shear strength

This test determines the shear strength of the material in the direction parallel to the vertical axis of the abutment.

The shear strength test for solid and cellular materials is identical to that given in Section 3.6 except that the vertical shear strength, as appropriate for the material, is determined using the test pieces with their thickness in the horizontal direction of the stress absorbing layer. For particulate materials, a separate test is unlikely to be necessary as the results for horizontal shear strength (Section 3.7) should be relevant, unless the material is markedly anisotropic.

3.9 Test method for compression set

This test determines the percentage unrecovered strain after release from compression.

Apparatus required

The apparatus required is as follows:

a a metal open topped box, which does not significantly distort under the test load, of internal lateral dimensions equal to those of the test piece to within +1/-0mm and depth at least equal to the test piece thickness

b a metal loading platen, which does not significantly distort under the test load, of lateral dimensions equal to those of the test piece to within +0/-1mm

c a means of compressing the test piece through the loading platen to a given strain and holding it compressed for the test duration

d a means of measuring the original and recovered heights of the test piece to ±0.01mm.

Test procedure

Three representative test pieces should be cut or assembled with their thickness in the horizontal direction of the stress absorbing layer and three with their thickness in the vertical direction. The thicknesses of the test pieces should be measured and one of the test pieces placed in the compression box. The test piece should be compressed through the loading platen to a strain of 10% for a 300mm thick stress absorbing layer falling linearly to a strain of 3% for a 1m thick stress absorbing layer (or pro rata for a non-preferred test piece thickness). After 28 days (±1 hour) the test piece should be released and allowed to recover for 3 days (±1 hour) before measuring its recovered thickness. The measurement should be repeated for the remaining test pieces.

The percentage compression set should be calculated from:

$$100\,(h_o - h_1) / (h_o - h_s)$$

where h_o = initial thickness, h_1 = recovered thickness, and h_s = compressed thickness.

Finally the mean of the results for horizontal and vertical directions should be calculated. The report of the results should include the sample identification details, individual and mean compression sets, and details of any deviation from the specified test procedure.

4 Summary

This report proposes methods of testing compressible materials, including cellular and particulate materials, to assess their suitability for use as stress absorbing layers behind integral bridge abutments. The use of such layers avoids the development of high lateral soil stresses due to thermal expansion of the bridge deck. The proposed performance requirements in terms of engineering properties and durability criteria are based on earlier work by Carder and Card (1997).

Both the performance requirements and test methods may need to be updated after consultation within the civil engineering industry. It is also recommended that a range of materials are tested according to these laboratory test methods and the assessment of the results fed back into the subsequent update.

5 Acknowledgements

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ISO 2440: 1997 *Polymeric materials, cellular flexible; Accelerated ageing tests*

ISO 2578: 1993 *Plastics; Determination of time-temperature limits after prolonged exposure to heat*

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ISO 4599: 1986 *Plastics; Determination of resistance to environmental stress cracking*

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Springman S M, Norrish A R M and Ng C W W (1996). *Cyclic loading of sand behind integral bridge abutments*. TRL Report 146. Transport Research Laboratory, Crowthorne.

Abstract

In general joint-free integral bridges are considered more durable and cheaper in whole life cost than conventional bridges with joints and bearings. However seasonal cyclic thermal movements of the deck cause interactions between the bridge abutments and the retained soil such that lateral earth pressures behind the abutments are likely to progressively increase with time. One method of avoiding the development of these high lateral pressures is to use a low stiffness but compressible elastic backfill as a stress absorbing layer behind the abutment. The performance requirements for stress absorbing layers have been previously identified and this report provides an initial proposal of methods of testing to assess if these requirements are satisfied.

Related publications

TRL290 *Innovative structural backfills to integral bridge abutments* by D R Carder and G B Card. 1997 (price code E, £20)

TRL146 *Cyclic loading of sand behind integral bridge abutments* by S M Springman, A R M Norrish and C W W Ng. 1996 (price code T, £75)

TRL178 *Seasonal thermal effects on the shallow abutment of an integral bridge in Glasgow* by P Darley, D R Carder and G H Alderman. 1996 (price code E, £20)

PR52 *A literature review of the gbeotechnical aspects of integral bridge abutments* by G B Card and D R Carder. 1993 (price code J, £35)

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