Specification for suitability testing of stress absorbing materials behind integral bridge abutments

Prepared for Safety, Standards and Research (Civil Engineering Division), Highways Agency

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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 TRL290 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. Suitability testing was then carried out on a comprehensive range of solid, cellular and particulate materials and is reported in TRL Report TRL552. This report presents a specification for methods of testing to assess the suitability of materials as stress absorbing layers.

The laboratory tests assess the fitness of materials for use as stress absorbing layers under the combined normal and shear forces existing behind integral bridge abutments. Results from the tests can then be compared with the performance requirements to confirm acceptability.
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° 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 can 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; England, Tsang and Bush, 2000). 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 Carder (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 Carder (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 that includes solid, cellular and particulate materials, it is anticipated that engineering judgement may be needed in using the test methods and interpreting the performance requirements. This specification superscedes earlier advice given in a consultation document by Darley and Carder (1998).

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°C from BD37 (DRMB 1.3) and a coefficient of thermal expansion of 12 × 10^-6 per °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.

A solid or cellular 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 1m;
- 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 1mm in both horizontal and vertical directions.

A full derivation of these proposed values for the various properties is given by Carder and Carder (1997) and Carder, Barker and Darley (2002). Thinner layers of down to 0.15m thickness may be considered in special cases, but only when rebound properties are good and any compression set of the material is very small. In this event, horizontal modulus requirements will reduce pro rata with the thickness.

In principle a stress absorbing layer formed from particulate material should have similar mechanical properties to those of a solid or cellular layer. However, modulus and shear strength will often depend on the confining stress at which it is used. Pending the outcome of further research it is considered that if the recommended properties for solid or cellular materials are not met by the particulate material, satisfying the following alternative criteria may indicate a potential for suitability. These criteria are:

- compression and shear moduli to be less than those of the ground retained by the abutment, although adequate to withstand horizontal loading produced by it;
- a shear strength exceeding 0.05 MPa;
- effective strength parameters (c', φ') which are smaller than those of the retained ground: this would indicate less passive pressure development and, with less cohesion, a lower risk of void formation as movement of the particulate layer would then more readily follow that of the abutment.

Generally particulate materials can be considered to be isotropic in nature but, if this is not the case, moduli and strengths will need to be determined in both the horizontal and vertical directions.

The permeability of the stress absorbing layer is not important if it is placed between a permeable backing and the abutment. Although solid and cellular layers should normally be placed in this manner, particulate layers which are free draining may alternatively be placed between the permeable backing and the retained soil. If the stress absorbing layer is to act as a permeable backing it should comply with Specification for Highway Works Clause 513 (MCHW1).
In some instances, it is advisable to provide structural cover over the stress absorbing layer (especially when it is particulate in nature) near the carriageway surface as a precaution against settlement under trafficking. Where this occurs the shear strength requirements outlined above may be deemed not relevant.

Suitable laboratory test methods are proposed in Section 3 for verifying that the installation of the stress absorbing layer will meet the performance requirements. In addition to these laboratory tests, the designer should ensure that the layer does not suffer damage during compaction of the backfill against it and is not excessively compressed during this process. A trial simulating the compaction procedure (during which layer thickness is monitored) is advisable.

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.

Table 1 Durability of materials

<table>
<thead>
<tr>
<th>Factor(s) affecting material(s)</th>
<th>Plastics</th>
<th>Rubbers</th>
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<tr>
<td>Rain, runoff, liquid chemical spills</td>
<td>ISO 175</td>
<td>ISO 1817</td>
</tr>
<tr>
<td>Fungi, bacteria</td>
<td>ISO 846</td>
<td>ISO 11346</td>
</tr>
<tr>
<td>Temperature, fire resistance</td>
<td>ISO 2578</td>
<td>ISO 188</td>
</tr>
<tr>
<td>Damp heat, water spray, salt mist</td>
<td>ISO 4611</td>
<td>ISO 188</td>
</tr>
<tr>
<td>Environmental stress cracking</td>
<td>ISO 4599</td>
<td>ISO 188</td>
</tr>
<tr>
<td>Ageing*</td>
<td>ISO 188</td>
<td>ISO 11346</td>
</tr>
<tr>
<td>Ozone cracking</td>
<td>ISO 1431</td>
<td>ISO 1431</td>
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* For cellular materials accelerated ageing tests specified in ISO 2440 may be employed.

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 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 although the manufacturer’s advice should be sought. 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.

3.4 Test method for horizontal modulus

This compression test determines the tangent modulus of the material in the direction at right angles to the vertical axis of the abutment. Tangent modulus is the slope of the stress-strain plot at the maximum service strain of the stress absorbing layer.
**Test piece**

For compression modulus tests the preferred test piece size is 1000×500×100mm.

**Required apparatus**

The apparatus required is as follows:

- 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;
- a flat metal lower platen, which does not significantly distort under the test load, with lateral dimensions greater than those of the test piece;
- 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;
- 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/+3mm.

**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 nominal speed of 0.5mm/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 tangent 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 tangent modulus should be determined at a point where the curve becomes linear after allowing for seating effects of the specimen in the box. For many, but not all, materials this will be between 1% and 2% strain to ensure elastic behaviour when in service behind an integral bridge abutment. 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 tangent modulus of the material in the direction parallel to the vertical axis of the abutment. The test is only necessary when the material is anisotropic in nature.

The test procedure is identical to that given in Section 3.4 for horizontal modulus except that the tangent 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.
Test procedure

Twelve representative test pieces should be cut or assembled with their thickness in the vertical direction of the stress absorbing layer. The effective cross-section of each test piece should be reduced to 70×60mm as shown in Figure 1(b) by vertical cuts in the centre of each test piece made using either a hot wire cutter or a fine toothed saw. Shear test assemblies, as shown in Figure 1(a), should be formed by bonding together four test pieces and the four metal plates using an adhesive giving a higher bond strength than the expected shear strength of the test material. The test assembly should be mounted in the test machine and the test pieces strained at a nominal rate of 5mm/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. This calculation should follow the approach of BS 903 Part A14: 1992 with the shear stress being calculated as F/(2A) where F is the force and A is the effective area (that is 70mm×60mm) of one test piece. 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.

For the purpose of determining the minimum horizontal shear strength, the normal pressure to be applied to the sample should be 60 kN/m². 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. 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.

If assessing suitability of particulate materials using the alternative criteria discussed in Section 2.1, effective strength parameters (c', q') should be determined in the large shear box using applied normal pressures of 30, 60 and 90 kN/m². For this purpose, the calculation procedures of plotting shear strength against normal stress referred to in Clause 5.6 of BS1377 Part 7: 1990 should be adopted. If a near linear relationship is not obtained, the procedure should be repeated on a further set of three samples.

Generally peak shear strength, τ_{peak}, should be determined provided that the required strain range, as specified in Performance Requirements, is compatible with mobilisation of peak strength (c'_{peak}, q'_{peak}) of the test sample. Otherwise, residual shear strength, τ_{res}, should be established using a multi-reversal test in accordance with Clause 5.5.5 of BS 1377 Part 7: 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 test is only necessary when the material is anisotropic in nature.

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.

Test piece

The preferred test piece size is 300×300×300mm for tests of compression set.

Apparatus required

The apparatus required is as follows:

a a metal open topped box with at least one removable side, which does not significantly distort under the test load, of internal lateral dimensions equal to those of the test piece to within +1/+3mm 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, removed from the box by releasing at least one of the box sides, and allowed to recover for 3 days (±1 hour) before measuring its recovered thickness. For marginal materials, a longer recovery period of 28 days (±1 hour) should be adopted. The measurement should be repeated for the remaining test pieces.

The percentage compression set should be calculated from:

\[ \frac{100 (h_o - h_1)}{h_o - h_s} \]

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 solid, 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). Because of the continuing development of new and innovative materials which are suited to this application, the methods of testing and performance requirements need to be kept under review.

The use of stress absorbing layers behind integral bridge abutments is likely to provide economical designs in new build situations and also to provide cost effective conversions of existing conventional bridges (if problems develop with their bearings or joints) into integral structures.

5 Acknowledgements

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6 References

British Standards Institution.

BS 903: 1992 Physical testing of rubber.
   Part A14 Method for determination of modulus in shear or adhesion to rigid plates – Quadruple shear method

BS 1377:1990 Methods of test for soils for civil engineering purposes.
   Part 1 General requirements and sample preparation.
   Part 7 Shear strength tests (total stress).

BS 903: 1999 Rubber, vulcanized.
   Part A16 Determination of the effects of liquids.


Volume 1: Section 3 General Design
   BD57 Design for durability. (DMRB 1.3.7)
   BD 37 Loads for highway bridges. Use of BS5400:Part 2. (DMRB1.3)


International Organization for Standardization.

ISO 62 Plastics; Determination of water absorption.
ISO 175 Plastics; Methods of test for the determination of the effects of immersion in liquid chemicals.
ISO 188 Rubber, vulcanized or thermoplastic; Accelerated ageing and heat resistance tests.
ISO 846  Plastics; Evaluation of the action of microorganisms.
ISO 1431  Rubber, vulcanized or thermoplastic; Resistance to ozone cracking.
ISO 1817  Rubber, vulcanized; Determination of the effect of liquids.
ISO 2440  Flexible and rigid, cellular polymeric materials; Accelerated ageing tests.
ISO 2578  Plastics; Determination of the time-temperature limits after prolonged exposure to heat.
ISO 2896  Rigid cellular plastics; Determination of water absorption.
ISO 4599  Plastics; Determination of resistance to environmental stress cracking.
ISO 4611  Plastics; Determination of the effects of exposure to damp heat, water spray and salt mist.
ISO 11346  Rubber, vulcanized or thermoplastic; Estimation of life-time and maximum temperature of use from an Arrhenius plot.
ISO TR7620  Rubber materials; Chemical resistance.


Volume 1: Specification for Highway Works (MCHW1)

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 a specification of methods of testing to assess if these requirements are satisfied.

Related publications

TRL552 Suitability testing of materials to absorb lateral stresses behind integral bridge abutments by D R Carder, K J Barker and P Darley. 2002 (price £35, code H)

TRL328 Consultation document on suitability tests for stress absorbing layers behind integral bridge abutments by P Darley and D R Carder. 1998 (price £20, code A)

TRL290 Innovative structural backfills to integral bridge abutments by D R Carder and G B Card. 1997 (price £35, code E)

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

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

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