**VOLUME 3 HIGHWAY STRUCTURES: INSPECTION AND MAINTENANCE**

**SECTION 4 ASSESSMENT**

## PART 8

## BA 54/94

# LOAD TESTING FOR BRIDGE ASSESSMENT

**SUMMARY**

This Advice Note accompanies BD 21 (DMRB 3.3.3) concerning load testing of bridges; it also reviews recent developments in this field.

**INSTRUCTIONS FOR USE**

This is a new document to be incorporated into the Manual.

1. Remove existing contents pages for Volume 3 dated February 1994.
2. Insert BA 54/94 into Volume 3, Section 4.
3. Insert new contents page for Volume 3 dated April 1994.
4. Archive this sheet as appropriate.

THE HIGHWAYS AGENCY BA 54/94

THE SCOTTISH OFFICE INDUSTRY DEPARTMENT

THE WELSH OFFICE
Y SWYDDFA GYMREIG

THE DEPARTMENT OF THE ENVIRONMENT FOR NORTHERN IRELAND

# Load Testing for Bridge Assessment

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**REGISTRATION OF AMENDMENTS**

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# LOAD TESTING FOR BRIDGE ASSESSMENT

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# 1. INTRODUCTION

1.1 The 1987 Bridge Census and Sample Survey predicted that some 66% of the older metal bridges (jack arch, trough deck, hogging plate, filler joist or similar types) and 35% of older concrete bridges would be found to be substandard when assessed using the calculation methods given in BD 21 (DMRB 3.4.3) and BA 16 (DMRB 3.4.4), the Assessment Standard and the associated Advice Note. Although precise figures are not available, as far as the overall magnitude of the problem is concerned, the predictions are certainly being borne out by the assessments carried out so far.

1.2 In many cases, bridges which seem to be carrying normal traffic satisfactorily without any undue signs of distress have "failed" assessment calculation. Understandably, assessing engineers have been reluctant to condemn such bridges on the basis of calculations alone and, consequently, there has been growing interest in load tests as a possible means for increasing the assessed capacity.

1.3 Methods used for calculating the resistance model for assessment purposes are generally conservative. For example, composite action of the deck may be ignored and the transverse load distribution characteristics are taken as the bare minimum. Collapse tests carried out on a number of older types of bridges have shown that they may possess load capacities well in excess of the calculated values. This reserve capacity comes from additional sources of strength not normally taken into account in the calculations. Load testing can be used advantageously to identify such sources and to quantify, with a degree of certainty, the hidden reserve strength of individual bridges. BD 21 (DMRB 3.4.3) recognises such possibilities and permits the use of load testing in certain circumstances.

1.4 This Advice Note is being published with a view to explaining the rationale behind the requirements given in BD 21 (DMRB 3.4.3) concerning load testing. Opportunity has also been taken to review recent developments in this field.

**Scope**

1.5 Load tests referred to in this Advice Note are those essentially intended for use in conjunction with the assessment of a bridge and not those used for research-oriented experimental investigations.

1.6 The possibility that the assessment of a particular bridge could benefit from load testing can only be recognised by the assessing engineer. However, since this type of testing is primarily aimed at seeking out the hidden reserves of strength, the bridges most likely to be involved are those which contain features where such reserves may be found, and for which load testing is a practical proposition. Although not intended to be exhaustive, the following is a list of bridge types for which load testing may be usefully employed :

i. Small span bridges where either a single axle or a two-axle bogie could simulate the required traffic effects (i.e. the assessment loading).

ii. Older bridges, of construction types now mainly unused, for which structural idealisation is particularly difficult. It is not envisaged at present that load tests will be meaningful in assessing masonry arch bridges.

iii. In general, bridges without internal structural complexities such as transverse girders although such complexities by themselves would not mean that all types of tests would be pointless.

iv. In general, bridges which, at least theoretically, can be termed as simply-supported.

v. Failure due to inadequacy with respect to shear can be sudden and hence it is not envisaged that load tests will be used for aiding assessment of bridges for which inadequacy in shear is suspected from a preliminary assessment, unless the load levels can be kept sufficiently low and extra care is taken during the tests.

1.7 Load tests are used for assessment purposes in many different ways. For the purposes of this Advice Note, however, load tests are broadly divided into the following two categories:

(i) "Proving Load Tests" which are intended as self-supporting alternatives to theoretical assessments, carried out subsequently to such assessments,

and

(ii) "Supplementary Load Tests" which are intended to be used as an adjunct to theoretical calculations.

1.8 Tests carried out on redundant bridges or tests carried out for purposes other than improving the assessed load capacity of a bridge are not covered in this Advice Note.

**Implementation**

1.9 This Advice Note should be used forthwith for any load testing required for bridge assessment, provided that, in the opinion of the Overseeing Organisation, this would not result in significant additional expense or delay progress. Design Organisations should confirm its application to particular schemes with the Overseeing Organisation.

# 2. LOAD TESTS

## General

2.1 Load tests can take many forms, depending for example on the type of structure, the possible sources of any hidden strength and the particular weaknesses identified in the theoretical assessment. It is impossible to describe in a general manner any predetermined procedures for such tests. Clearly, the test procedure has to be drawn up individually for each case. However, two broad classes of tests, as defined in paragraph 1.7, have been used so far in the United Kingdom in the context of highway bridge assessment. The following is a brief description of these two forms of tests.

## Load Tests Supplementary to Theoretical Assessments

2.2 Supplementary load tests are those where vehicle, axle or patch loads, or combinations thereof, are placed on a bridge to determine individual aspects of its load resistance capacity so that assumptions made in the theoretical assessment can be made more pertinent to the individual structure. Such tests are carried out when the assessing engineer suspects that the structure may be stronger than indicated by a purely theoretical assessment. As mentioned in 2.1 above, there is no single procedure for supplementary load tests and each case has to be treated individually. However, the following procedure is given as an example of what such tests may involve in practice.

2.3 One or more test vehicles comprising an axle or a 2-axle bogie would be placed at various positions of the bridge. This load is intended to generate, for example, the bending moments produced by the assessment live loading. The loading, applied in increments, is kept well within the elastic range of the bridge flexural behaviour. The observed strains and deflections are then compared with corresponding theoretical values. If this comparison indicates hidden reserve capacity in the bridge, each possible source of the hidden strength such as end fixity, better transverse distribution and composite action are then examined, one by one, using knowledge gained in earlier collapse tests on similar bridges, where available.

2.4 If the hidden strength indicated by the test or a proportion of it can be accounted for and is justified then the theoretical model is modified and the assessment calculations are carried out using the revised model. A number of such tests have been carried out in the UK, especially by TRL (1, 2).

## Proving Load Tests

2.5 The circumstances for which proving load tests are intended are essentially the same as in the case of supplementary load tests, ie when the assessing engineer suspects that the theoretical assessment has underestimated the actual load capacity of a bridge. The distinction between the two types of tests lies in the fact that a proving load test is not intended for improving the various assumptions made in the theoretical assessment, but to be used as a complete assessment by itself in place of the theoretical assessment. So far there have not been any reported details of such tests carried out as substitutes for BD 21 (DMRB 3.4.3) assessments, apart from the following procedure which has been used by the London Borough of Enfield in some instances (3, 4). This procedure does not appear to be an adaption of the methods practised in other countries, of which there are a number eg the Ontario method (5, 6).

2.6 An axle load is placed at critical positions on each lane of the bridge in turn. This axle load is intended to generate the load effects produced by the assessment live loading (ALL) applied to the whole bridge. The load is applied in increments until either the maximum corresponding to the full ALL is reached or until the load deflection behaviour becomes non-linear.

2.7 In order to obtain the allowable axle load, this maximum achieved axle load is divided first by a factor to allow for the fact that only one axle is used to represent the complete ALL and, secondly, by the partial safety factor for the ALL appropriate at the ultimate limit state to obtain the nominal assessment load level. Weight restriction levels, if any, are then decided from the above allowable axle load and by using Appendices D and F of BD 21 (DMRB 3.4.3).

2.8 Because there is in principle a risk of collapse during a proving test, or of damage to essential elements of the structure, use of such tests would necessarily be limited to bridges which, on the basis of their assessments, would have been closed to traffic and would otherwise require to be demolished.

2.9 Any structural damage incurred during proving load tests may initially be concealed, but such internal damage may lead to rapidly accelerated subsequent deterioration of the structure and may cause sudden collapse under permitted traffic. Hence bridges which have been subjected to proof testing procedures would need to be thoroughly inspected and reassessed at frequent intervals after the test.

# 3. GENERAL PRINCIPLES

**Basic Principles of Assessment**

3.1 The basic purpose of an assessment is to determine whether a particular bridge is able to carry the traffic of the day with adequate margins of safety. In order to satisfy this requirement, the assessment live load for short span bridges (loaded lengths less than 50m) allows for possible load increases due to axle impact effects, overloading and bunching of vehicles. The equivalent assessment live loading criteria for long span bridges are calculated by probabilistic means and have similarly been based on extreme loads. The assessment of a bridge primarily involves the checking of its adequacy at the ultimate limit state (ULS) for these extreme load conditions. The ULS conditions are, by their nature, intended to be of extremely low probability but nevertheless possible in reality. The partial safety factors are used in the calculations to ensure that sufficient margins of safety with respect to day to day loading are available and that the failure at the extreme situation remains of extremely low probability.

3.2 The adequacy of a bridge can only properly be determined, therefore, at the extreme load conditions represented by the ULS, and the commonly made observation that a particular bridge is known to be carrying certain loads regularly is of little meaning in terms of passing or failing assessment. If a bridge fails assessment at a particular load level and is used regularly without apparent distress by vehicles of that load level, it could simply mean that it has not been subjected to the most severe possible configuration of such loading and could still have less than the required margins of safety.

3.3 The assessment live loading (ALL) is a theoretical quasi-static representation of the actual traffic loading, which is composed of moving and discrete individual wheel contacts and is both repetitive and varying through time. This theoretical static loading is intended for use with calculations, which themselves have a certain degree of conservatism. The levels of the theoretical loading have been set so that when used with theoretical calculation methods, as far as past experience goes, the results will be safe. Hence it is questionable whether a static load test, without involving theoretical analysis, can adequately represent the real situation.

3.4 Highway authorities have the responsibility to maintain adequate levels of safety for their bridges. Furthermore, they may not permit any activity, other than the intended use (ie for carrying the permitted traffic), which may result in reducing the levels of safety. It is insufficient just to show that a bridge can safely carry the traffic of the day, it must be demonstrated, as well, that it can also carry all other adverse combinations of possible vehicles with the adequate margins of safety.

**Guiding Principles For Load Testing**

3.5 Any load testing of a bridge should only be considered when calculated assessments, even after using the best available methods and information, such as results of material tests, recorded information on similar bridges and materials, maintenance and strengthening records etc, show it to be inadequate. Even then, such tests should only be used if there is a realistic possibility of improving its assessed capacity to a level which will be of significant benefit. For example, a reassessed capacity of a trunk road bridge to 7.5 tonnes may be of no practical use.

3.6 In order to avoid causing any damage, either during or subsequent to testing, to a bridge which is intended to remain in service after testing, the load levels used in the tests should not result in effects which exceed those caused by the loads carried by the bridge on a day to day basis. The size and placing of any test vehicles or axles are therefore important. For instance, the vehicle should not be deliberately mounted on the footpath to examine transverse stiffness. The estimates of day to day loading required for specifying the test maximum loads should be obtained from records or surveys.

3.7 The load test should be meaningful. This means, among other things, that the loading should reproduce both transverse and longitudinal effects. Furthermore, extreme care has to be taken in using the test results in assessment, bearing in mind that a one-off static test does not fully represent real traffic conditions.

3.8 The details of any load test should be agreed with the Overseeing Organisation. The testing body must have suitably qualified personnel in charge of the tests who are able to appreciate both the theoretical and practical implications of load testing. The assessing engineer must ensure that the test conforms to established practice and is not used as an exploratory research investigation.

**Comments on Load Testing**

3.9 Based on the above principles, the following observations can be made regarding the two types of load tests.

**Supplementary Load Tests**

3.10 This type of testing can be carried out reasonably safely and follows the principles of the BD 21 (DMRB 3.4.3) requirements regarding load tests. However, extrapolation of the results of tests carried out with fairly low levels of loading to those likely to occur at the ultimate limit state needs caution. There is no safe basis for extrapolating unless the materials and their interconnections can be determined with a degree of certainty and earlier collapse tests have been carried out on bridges with similar materials and details so that some pattern of load carrying behaviour has been established.

3.11 Although the testing can be carried out by any competent test organisation in possession of the necessary equipment, it is essential to employ considerable specialist expertise in devising a load test, during the test itself and in the subsequent assessment, especially in deciding the reduction factors relating to earlier collapse tests.

3.12 When applying this method to bridges with suspected inadequate shear capacity, additional caution should be used as shear failure can be relatively sudden and the load levels used in the tests should be suitably limited.

**Proving Load Tests**

3.13 In principle, if the ultimate limit state levels of the ALL, or a reduced proportion of it, could be applied to a bridge in the manner it is intended and the bridge does not collapse, it could be deduced that the bridge is adequate for that level of load. However, in view of the caveat mentioned in 3.3, whether a static test load could adequately represent the ULS load condition is a question as yet to be addressed by the engineering community.

3.14 The London Borough of Enfield procedure of loading only a part of the deck at a time and then deducing a full loading requirement from it contains additional uncertainties. For instance, the collapse mode of a partly loaded deck is different from that when the whole deck is loaded as intended in the ALL requirements. The relationship between the two behaviours is too complex to be determined by the simple means of equating deflections as proposed in the Enfield method.

3.15 Proving load tests of any bridge with the deck under a full distribution of live loading has not yet been carried out in the UK. It is possible that, if such tests were attempted, the load levels required to prove adequacy at even the lower levels of the ALL, would prove to be too risky to apply.

3.16 Design Organisations will need to contact the Overseeing Organisation in order that full contingency plans may be agreed for the event that a bridge may collapse during a proving load test. Since proving load tests should not, in any case, be contemplated except in situations where the alternatives would involve major strengthening or replacement work, such planning is likely to be necessary in any case. The risk to the health and safety of operatives engaged in the testing work would need to be assessed and safe working arrangements prepared to cover the work.

# 4. RECOMMENDATIONS

4.1 Supplementary tests which fall under the broad principles stated in BD 21 (DMRB 3.4.3) and paragraphs 3.5 to 3.8, inclusive, of this Advice Note may be employed as an adjunct to assessment calculations.

4.2 Pending further research, proving load tests are not recommended.

4.3 Load tests should be carried out only with the approval of the Overseeing Organisation who will examine the assessing engineer's proposal and agree to the details of the tests. The assessing engineer should be directly responsible for the conduct of the tests as well as the subsequent interpolation of the results and must satisfy the Overseeing Organisation that the test itself will not reduce the existing safety levels by weakening the structure.

4.4 Considerable research work on load testing methodologies in general, and those involving the use of structural reliability concepts in particular, is being undertaken in many countries (7). Use of such methodologies, when considered to be properly developed, may be used for individual assessments with the agreement of the Overseeing Organisation.

# 5. REFERENCES

5.1 Design Manual for Roads and Bridges

Volume 3: Section 4: Assessment

BA 16 (DMRB 3.4.4) - The Assessment of Highway Bridges and Structures
BD 21 (DMRB 3.4.3) - The Assessment of Highway Bridges and Structures

5.2 The following documents have been referred to in the text of this Advice Note:

(1) Low A McC and Ricketts N.J. The assessment of filler beam bridge decks without transverse reinforcement. The Transport Research Laboratory, Crowthorne, 1993, Report RRS383.

(2) Ricketts N.J. and Low A. McC. Load tests on a reinforced beam and slab bridge at Dornie. The Transport Research Laboratory, Crowthorne, 1993, Report RR377.

(3) Test Report: Church Street Bridge over Salmon's Brook. LOBEG. London Borough of Enfield (unpublished).

(4) Providing Load Test on Small Span Bridges. Technical Note 7/1. London Borough of Enfield (unpublished).

(5) Load Test and Evaluation of the 18th Avenue Bridge. Report SRR-89-02. Ontario Ministry of Transportation.

(6) Load Testing and Evaluation of Turner's Bridge. Report SRR-88-07. Ontario Ministry of Transportation.

(7) Fu G. and Tang J., Reliability Based Proof Load Factors for Short and Medium Span Bridges. 6th International Conference on Structural Safety and Reliability, Innsbruck, 1993.

# 6. ENQUIRIES

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

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