SECTION 8: NONDESTRUCTIVE LOAD TESTING

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SECTION 8:

NONDESTRUCTIVE LOAD TESTING

8.1—INTRODUCTION

8.1.1—General

Load testing is the observation and measurement of the response of a bridge subjected to controlled and predetermined loadings without causing changes in the elastic response of the structure. Load tests can be used to verify both component and system performance under a known live load and provide an alternative evaluation methodology to analytically computing the load rating of a bridge.

Literally thousands of bridges have been load tested over the last 50 years in various countries. In some countries, load tests are used to verify the performance of new bridges compared to design predictions. The aim of this Section is to emphasize the use of load testing as part of bridge load-rating procedures.

8.1.2—Classification of Load Tests

Basically, two types of load tests are available for bridge evaluation: diagnostic tests and proof tests. Diagnostic tests are performed to determine certain response characteristics of the bridge, its response to loads, the distribution of loads; or to validate analytical procedures or mathematical models. Proof tests are used to establish the maximum safe load capacity of a bridge, where the bridge behavior is within the linear-elastic range.

Load testing may be further classified as static load tests and dynamic load tests. A static load test is conducted using stationary loads to avoid bridge vibrations. The intensity and position of the load may be changed during the test. A dynamic load test is conducted with time-varying loads or moving loads that excite vibrations in the bridge. Dynamic tests may be performed to measure modes of vibration, frequencies, dynamic load allowance, and to obtain load history and stress ranges for fatigue evaluation. Diagnostic load tests may be either static or dynamic tests. Proof load tests are mostly performed as static tests.

C8.1.1

The procedures outlined in this Section for the nondestructive load testing of bridges were developed in NCHRP Project 12-28(13)A and reported in *NCHRP Research Results Digest*, November 1998—Number 234, “Manual for Bridge Rating Through Load Testing,” and include certain modifications necessary to ensure consistency with the load and resistance factor load-rating procedures presented in this Manual.

8.2—FACTORS WHICH INFLUENCE THE LOAD-CARRYING CAPACITY OF BRIDGES

8.2.1—General

The actual performance of most bridges is more favorable than conventional theory dictates. When a structure's computed theoretical safe load capacity or remaining fatigue life is less than desirable, it may be beneficial to the Bridge Owner to take advantage of some of the bridge's inherent extra capacity that may have been ignored in conventional calculations.

Several factors not considered in routine design and evaluation could affect the actual behavior of bridges. Load testing is an effective methodology to identify and benefit from the presence of certain load capacity enhancing factors as outlined below.

8.2.2—Unintended Composite Action

Field tests have shown that a noncomposite deck can participate in composite action with the girders in carrying live load, provided the horizontal shear force does not exceed the limiting bond strength between the concrete deck slab and steel girder flanges. However, as test loads are increased and approach the maximum capacity of the bridge, slippage can take place and composite action can be lost, resulting in a sudden increase in main member stresses. Thus, it is important that for noncomposite steel bridges, load test behavior and stress values taken at working loads or lower not be arbitrarily extrapolated to higher load levels. The unintended composite action contributes to both the strength of a girder bridge and its ability to distribute loads transversely. Advantage can be taken of unintended composite action in fatigue evaluation computations provided there is no observed slippage between the deck and stringer flange under normal traffic.

8.2.3—Unintended Continuity/Fixity

Simply supported bridges are assumed to be supported on idealized rollers that do not carry any moment. However, tests have shown that there can be significant end moments attributable to the continuity provided by the deck slab at stringer-to-floorbeam connections and to frozen bearings. Frozen bearings could also result in unintended arching action in the girders to reduce the applied moments at midspan by a significant margin. For load-rating purposes, it may not be justified to extrapolate the results of a load test done at moderate-load levels when such restraints are detected during the test. It is quite possible that the enhanced behavior attributable to unintended continuity and frozen bearings would not be present at extreme load levels.

8.2.4—Participation of Secondary Members

Secondary bridge members are those members which are not directly in the load path of a structure, such as: diaphragms, cross-frames, lateral bracing members, and wind bracing. In some bridge types, secondary members enhance the load-carrying capacity by increasing the stiffness of the bridge. Advantage can be taken of the effects of secondary members provided that it can be shown that they are effective at the designated service load level.

8.2.5—Participation of Nonstructural Members

Load distribution, stresses, and deflections may be affected by the stiffness contribution from nonstructural members such as railings, parapets, and barriers, and to a lesser extent by the curbs and utilities on the bridge. Since the stiffness contribution from such members cannot be relied upon at the ultimate load condition, it is important that their contributions be considered in comparing the bridge-test-load response with the calculated response.

8.2.6—Portion of Load Carried by Deck

Depending on the bridge span and the thickness of the deck, there may be a portion of the load carried directly by the deck slab spanning between end supports of the bridge. The deck may, however, not be able to carry significant amounts of load at higher load levels so that any portion carried during the diagnostic test should be determined and transferred back, if necessary, into the main load-carrying members.

8.3—BENEFITS OF NONDESTRUCTIVE LOAD TESTS

8.3.1—Unknown or Low-Rated Components

Load tests may provide sufficient data to establish safe live-load levels for older bridges. In some instances, the make-up of the bridge members, the members' response to loading, or both cannot be determined because of lack of existing as-built information. In other cases, theoretical rating calculations may result in a low live load requiring posting of the rated bridge, and nondestructive load tests may provide a more realistic safe service live-load capacity. In some instances, the test results may indicate that the actual safe service live-load capacity is less than computed, thus alerting the Bridge Owners to speedy action to reinforce or close the bridge.

Existing bridges that have been strengthened over the years may not be accurately load rated due to the unknown interaction of the various elements of the repaired structure in supporting live loads.

Nondestructive load tests can help evaluate the performance of such a bridge, and generally improve its load rating.

8.3.2—Load Distribution

An important part of the rating equation concerns the distribution of the live loads to the main load-carrying members of the bridge and to the individual components of a multicomponent member. Typically, in design and rating, the load distribution to main supporting members is based on design distribution factors. These factors are known to generally result in conservative approximations of the actual distribution. A major aim of diagnostic testing is to confirm the precise nature of the load distribution. In a multicomponent member, such as truss chords, test results could reveal if the components share the load equally as is assumed in the analysis.

8.3.3—Deteriorated or Damaged Members

It is often difficult to analyze the effects of observed deterioration or damage on the load-carrying capacity of the bridge and on load distribution, especially in the case of heavily deteriorated bridges. In such cases, field load testing serves as a powerful tool to identify existing behavior.

8.3.4—Fatigue Evaluation

In assessing the remaining fatigue life of steel bridges, both the range of stress and the number of stress cycles acting on a member need to be evaluated. Field load testing can provide data for both of these parameters. The range of live-load stress is influenced by the enhanced section modulus evidenced by most beam and slab sections. Measured stresses can be used in place of computed stresses in making remaining life assessments. In addition, stress spectra may be obtained for distortion-induced stresses, which have been found to be a major cause of distress in steel bridges and can lead to cracking of components and eventual failure.

8.3.5—Dynamic Load Allowance

Design dynamic load allowance is generally conservative for most spans. Dynamic load allowance is influenced primarily by the surface roughness of the deck and approaches. The use of full-scale dynamic testing under controlled or normal traffic conditions remains the most reliable and cost-effective way of obtaining the dynamic load allowance for a specific bridge. Measured dynamic load allowance may be used in place of code-specified value in load-rating calculations.

8.4—TYPES OF NONDESTRUCTIVE LOAD TESTS

8.4.1—Static Tests

8.4.1.1—Diagnostic Tests

Diagnostic load tests are employed to improve the Engineer's understanding of the behavior of a bridge and to reduce uncertainties related to material properties, boundary conditions, cross-section contributions, effectiveness of repair, influence of damage and deterioration, and other similar variables. Diagnostic load tests include the measurement of load effects in one or more critical bridge members and comparison of the measured load effects with that computed using an analytical model (theory). Diagnostic tests serve to verify and adjust the predictions of an analytical model. The calibrated analytical models are then used to calculate the load-rating factors. During a diagnostic load test, the applied load should be sufficiently high to properly model the physical behavior of the bridge at the rating load level.

Bridges for which analytical methods of strength evaluation may significantly underestimate the actual strength (e.g., redundant spans, spans with boundary conditions different from assumed idealized behavior, etc.) are candidates for diagnostic load testing. Thus, candidate bridges are limited to those bridges for which an analytical load-rating model can be developed.

8.4.1.2—Proof Tests

In this form of field load testing, a bridge is subjected to specific loads, and observations are made to determine if the bridge carries these loads without damage. Loads should be applied in increments and the bridge monitored to provide early warning of possible distress or nonlinear behavior. The proof test is terminated when:

1. A predetermined maximum load has been reached, or

2. The bridge exhibits the onset of nonlinear behavior or other visible signs of distress.

Although simple in concept, proof testing will in fact require careful preparation and experienced personnel for implementation. Caution is required to avoid causing damage to the structure or injury to personnel or the public.

Bridges that are candidates for proof load testing may be separated into two groups. The first group consists of those bridges whose make-up is known and which can be load rated analytically. Proof load testing of "known" bridges is called for when the calculated load ratings are low and the field testing may provide realistic results and higher ratings. Bridges with large dead loads compared with the live loads are also suitable candidates for proof load testing.

The second group consists of "hidden" bridges, those bridges which cannot be load rated by computations because of insufficient information on their internal details and configuration. Many older reinforced concrete and prestressed concrete beam and slab bridges whose construction plans, design plans, or both are not available need proof testing to determine a realistic live-load capacity. Bridges that are difficult to model analytically because of uncertainties associated with their construction and the effectiveness of repairs are also potential candidates and beneficiaries of proof load testing.

8.4.2—Dynamic Tests

8.4.2.1—Weigh-In-Motion Testing

The actual site survey of truck weight spectra and volume can be determined by weigh-in-motion systems (WIM). WIM systems utilize axle sensors and other measurement systems which make use of the bridge as the scale. Such WIM techniques could provide data on vehicle arrivals; and determine axle and gross loads, axle configurations, and speeds of passing vehicles. The WIM data can be utilized to provide a precise site-specific load model and can also be utilized in fatigue evaluation.

8.4.2.2—Dynamic Response Tests

Dynamic response tests, under normal traffic or controlled conditions using test vehicles, can be performed to obtain realistic estimates of the dynamic load allowance and live-load stress ranges that can be used in load rating and fatigue evaluation calculations. Dynamic load allowance is influenced primarily by the surface roughness of the deck and the bridge approach, and to a lesser extent by the bridge frequency and the weight and dynamic characteristics of the vehicle. Many of these parameters are difficult to quantify without the use of full-scale dynamic testing.

The dynamic load allowance may be estimated from the peak dynamic strain and the corresponding peak static strain for vehicles on the same path or transverse position on the bridge. A variety of vehicle types, speeds, weights, and positions should be considered in estimating the appropriate dynamic load allowance. A representative estimate of the dynamic load allowance can be obtained from statistical analyses of measured values.

C8.4.2.2

Dynamic tests preferably should use heavy test vehicles since load rating is governed by heavy vehicles with much lower dynamic impact effects.

8.4.2.3—Vibration Tests

Vibration tests are used to determine bridge dynamic characteristics such as frequencies of vibration, mode shapes, and damping. Earthquake response is strongly influenced by bridge frequency and damping. Vibration testing can sometimes be used to evaluate defects and deterioration as they affect the vibration characteristics. The principal results of a dynamic response test may be the bridge natural frequencies and corresponding mode shapes as well as damping values. Vibration tests may be conducted by means of portable sinusoidal shakers, sudden release of applied deflections, sudden stopping of vehicles by braking, and impulse devices such as hammers.

8.5—LOAD TEST MEASUREMENTS

Load test instrumentation is used to measure the following: 1) strain (stresses) in bridge components, 2) relative or absolute displacement of bridge components, 3) relative or absolute rotation of bridge components, and 4) dynamic characteristics of the bridge.

Prior to conducting a field test, the Engineer must determine the goals of the test and the types and magnitude of the measurements to be made. Preliminary calculations may be needed to estimate the range of the measurements as well as the best locations for the instrumentation.

C8.5

Strain Measurements

Strain sensors are usually attached on critical members to monitor response. Different types of gages are available for steel and concrete structures. The locations should be selected so that the analytical model can be validated. The most common sensors for field measurement of strains are electrical resistance gages (bonded or welded), strain transducers (clamped or anchored), and acoustic strain gages. Careful selection of gage characteristics is required to optimize gage performance for specified environmental and operating conditions.

Displacement Measurements

Three methods of monitoring displacements are mechanical, optical, and electrical. Dial gages are mechanical devices that are easy to set up and monitor, and their accuracy is usually sufficient for load tests. Optical methods include laser methods and other surveying tools that can be used when higher accuracy is required.

Electrical methods include displacement transducers such as Linear Variable Differential Transformers (LVDT) that transform displacement to a proportional change of electrical voltage. They can be used to monitor both static and dynamic displacements.

Rotation Measurements

Mechanical tiltmeters can be installed on beam webs to monitor beam rotations. The measurement of end rotations can establish the extent of end restraint at bearings. The elastic curve for a bending member can be developed by measuring rotations along the length of the member.

Measurement of Dynamic Characteristics

Accelerometers are used if the modal frequencies, mode shapes, and damping ratios are to be obtained. Accelerometers are usually placed at midspan and quarter-span points to determine first and second longitudinal mode shapes, and on either side of the bridge to determine torsional mode shapes.

8.6—WHEN NOT TO LOAD TEST

The following conditions could render a bridge an unsuitable candidate for load testing:

- The cost of testing reaches or exceeds the cost of bridge strengthening.
- Pretest evaluation shows that the load test is unlikely to show the prospect of improvement in load-carrying capacity.
- According to calculations, the bridge cannot sustain even the lowest level of load.
- There is a possibility of sudden failure (shear or fracture).
- Load tests may be impractical because of access difficulties or site traffic conditions.

8.7—BRIDGE SAFETY DURING LOAD TESTS

An element of risk is inherent in all load testing. The Bridge Owner and evaluators must be aware of the risks and their consequences. In assessing the risks, consideration should be given to safety of the public, safety of personnel, possible structural damage, traffic disruption, and possible load posting. Bridge load testing should not be attempted by inexperienced personnel. Common sense, good engineering judgment, and sound analytical principles are not to be ignored.

8.8—LOAD RATING THROUGH LOAD TESTING

8.8.1—Introduction

Diagnostic and proof load tests can be employed to improve the evaluator's understanding of the behavior of the bridges being tested and to identify and quantify in a scientific manner their true inherent reserve capacity. A major part of the evaluator's responsibility is in determining how much of any potentially enhanced load-carrying capacity observed during the load test, as compared to the values predicted analytically, could be reliably utilized in establishing the bridge load rating. Article 8.8 outlines methods and procedures for the application of nondestructive load tests in the load rating process and translating the results of the bridge load tests into bridge load ratings.

C8.8.1

General load testing procedures are contained in Appendix A8 following this Section. For additional guidance, evaluators should consult *NCHRP Research Results Digest* No. 234.

8.8.2—Diagnostic Load Tests

8.8.2.1—Introduction

Prior to initiating a diagnostic load test, the bridge should be rated analytically using procedures contained in this Manual. The procedures outlined in Article 8.8.2 will enable the Engineer to re-examine the theoretical values and adjust these ratings to reflect the actual performance of the bridge obtained from the diagnostic test results.

8.8.2.2—Approach

As long as a bridge exhibits linear behavior, a diagnostic load test can be used to validate an updated analytical model. It is thus important that the test load be placed at various positions on the bridge to determine the response in all critical bridge members. Further, the magnitude of the test load must be sufficiently high so that there is little likelihood of nonlinear behavior at the anticipated service-load levels. If the Engineer is satisfied that the model is valid, then an extrapolation to load levels higher than those placed on the bridge during the test may be feasible. The following Articles present a method for extrapolating the results of a diagnostic load test.

8.8.2.3—Application of Diagnostic Test Results

A major part of diagnostic testing is the assessment of the differences between predicted and measured responses for subsequent use in determining the load rating of the bridge. Article 8.8.2.3 provides guidelines for modifying the calculated load rating for a bridge based on the results of a diagnostic load test.

The following equation should be used to modify the calculated load rating following a diagnostic load test:

$$RF_T = RF_c K \qquad (8.8.2.3\text{-}1)$$

RF_T = load-rating factor for the live-load capacity based on the load test result

RF_c = rating factor based on calculations prior to incorporating test results (Eq. A6.4.2.1-1 should be used).

K = adjustment factor resulting from the comparison of measured test behavior with the analytical model (represents the benefits of the field load test, if any)

C8.8.2.3

The appropriate section factor (area, section modulus) to be used in calculating RF_c should be determined after evaluation of the load test results, including observations made during the placement of the test vehicle on the bridge. Observed enhancement to the section factor resulting from unintended composite action needs to be critically evaluated. Analytical evaluation of composite action in slab-and-girder bridges without mechanical shear connection and the reliability of composite action found by a diagnostic test is discussed in *NCHRP Research Results Digest* No. 234.

For composite structures with shear connectors, the full composite section as defined by the *AASHTO LRFD Bridge Design Specifications* should be used unless observations during the test indicate slippage at the deck-girder interface. Noncomposite structures which show no evidence of composite action under the test load should be evaluated based on noncomposite section factors.

8.8.2.3.1—Determining K

The Adjustment Factor K is given by:

$$K = 1 + K_a K_b \qquad (8.8.2.3.1\text{-}1)$$

where:

K_a = accounts for both the benefit derived from the load test, if any, and consideration of the section factor (area, section modulus, etc.) resisting the applied test load

K_b = accounts for the understanding of the load test results when compared with those predicted by theory

Without a load test, $K = 1$. If the load test results agree exactly with theory, then $K = 1$ also. Generally, after a load test K is not equal to one. If $K > 1$, then response of the bridge is more favorable than predicted by theory and the bridge load capacity may be enhanced. On the other hand, if $K < 1$, then actual response of the bridge is more severe than that predicted and the theoretical bridge load capacity may have to be reduced.

The following general expression should be used in determining K_a:

$$K_a = \frac{\varepsilon_c}{\varepsilon_T} - 1 \qquad (8.8.2.3.1\text{-}2)$$

where:

ε_T = maximum member strain measured during load test

ε_C = corresponding calculated strain due to the test vehicle, at its position on the bridge which produced ε_T

K_a may be positive or negative depending on the results of the load test.

In general:

$$\varepsilon_c = \frac{L_T}{(SF)E} \qquad (8.8.2.3.1\text{-}3)$$

where:

L_T = calculated theoretical load effect in member corresponding to the measured strain ε_T

SF = member appropriate section factor (area, section modulus, etc.); see C8.8.2.3

E = member modulus of elasticity

C8.8.2.3.1

The intent of "Can member behavior be extrapolated to $1.33W$?" in Table 8.8.2.3.1-1 is to provide some assurance that the structure has adequate reserve capacity beyond its rating load level W. Normally this would be established by calculation, but proof testing would also be acceptable.

Examples of typical calculations which could be performed to check this criterion include:

1. Load the analytical model with $1.33W$ and determine whether there is linear behavior of the components of the structure. The model could be based on the LRFD specifications or a three-dimensional computer model.
2. Using the procedures given in *NCHRP Research Results Digest* No. 234, determine whether there is composite action at $1.33W$ where none was intended.

Diagnostic load test does not specifically address the fatigue limit state. However, at the time of the test it may be necessary to measure stresses at fatigue sensitive details to determine if fatigue cracking is possible.

The theoretical strain ε_C resulting from the test load should be calculated using a section factor which most closely approximates the member's actual resistance during the test. (See example in *NCHRP Research Results Digest* No. 234, pages 46–47.) For noncomposite sections, the factor K_a represents the test benefit without the effect of unintended composite action.

K_b takes into account the analysis performed by the load test team and their understanding and explanations of the possible enhancements to the load capacity observed during the test. In particular, the load test team should consider the items below and reduce K_b to account for those contributions that cannot be depended on at the rating load level. Table 8.8.2.3.1-1 provides guidance based on the anticipated behavior of the bridge members at the rating load level, and the relationship between the unfactored test vehicle effect T and the unfactored gross rating load effect W.

Table 8.8.2.3.1-1—Values for K_b

Can member behavior be extrapolated to 1.33W?		Magnitude of Test Load			
Yes	No	$\frac{T}{W} < 0.4$	$0.4 < \frac{T}{W} \leq 0.7$	$\frac{T}{W} > 0.7$	K_b
√		√			0
√			√		0.8
√				√	1.0
	√	√			0
	√		√		0
	√			√	0.5

The factor K_b should be assigned a value between 0 and 1.0 to indicate the level of test benefit that is expected at the rating load level. $K_b = 0$ reflects the inability of the test team to explain the test behavior or validate the test results, whereas $K_b = 1$ means that the test measurements can be directly extrapolated to performance at higher loads corresponding to the rating levels.

8.8.3—Proof Load Tests

8.8.3.1—Introduction

Proof load testing provides an alternative to analytically computing the load rating of a bridge. A proof test "proves" the ability of the bridge to carry its full dead load plus some "magnified" live load. A larger load than the live load the bridge is expected to carry is placed on the bridge. This is done to provide a margin of safety in the event of an occasional overload during the normal operation of the bridge.

The proof loads provide a lower bound on the true strength capacity of the components and hence leads to a lower bound on the load-rating capacity. A satisfactory proof load test usually provides higher confidence in the load capacity than a calculated capacity.

8.8.3.2—Approach

During a proof load test, the loads must be incremented and the response measured until the desired load is reached or until the test is stopped for reasons cited below. Loads must also be moved to different positions to properly check all load path components. Upon load removal, the structure should again be inspected to see that no damage has occurred and that there are no residual movements or distress.

Usually, the loads are applied in steps so that the response of the bridge under each load increment can be monitored for linear-elastic behavior and to limit distress due to cracking or other physical damage. The proof load test is usually terminated when either of the following occurs:

1. The desired live load plus the appropriate margin of safety is reached.
2. The bridge response exhibits the start of nonlinear behavior or other visible signs of distress, such as buckle patterns appearing in compressive zones in steel or cracking in concrete.

The test loads must provide for both the rating vehicles, including the dynamic load allowance, and a load factor for the required margins of safety. The load factor may be as described in Article 8.8.3.3 or as specified by the Bridge Agency.

8.8.3.3—Target Proof Loads

8.8.3.3.1—Selection of Target Live-Load Factor

X_p represents the target live-load factor (applied to the test load) needed to bring the bridge to a rating factor of 1.0. If the test safely reaches this level of load, namely the legal rating plus impact allowance magnified by the factor X_p, then the rating factor is 1.0. The proof test load factors are calibrated to provide the same safety targets implicit in the calculated ratings using load and resistance factor rating procedures. Only the live load is factored during the proof test. The dead load is assumed to be the mean value.

Higher proof loads may also be warranted to incorporate ratings for permit vehicles, and in this instance the permit load vehicle plus dynamic load allowance should be magnified by X_p.

Several site conditions may have an influence on the load rating. These factors are included herein by making adjustments to X_p to account for such conditions. Each of these adjustment quantities is presented below. After X_{pA} (the adjusted X_p) is obtained, this value is multiplied by the rating load plus dynamic load allowance to get the proof-load magnitude that is needed to reach a rating factor of 1.0.

C8.8.3.3.1

A proof test provides information about the bridge capacity including dead-load effect, live-load distributions, and component strengths. However, other uncertainties, in particular the possibility of bridge overloads during normal operations as well as the impact allowance, are not measured during the test. These remaining uncertainties should be considered in establishing a target proof load.

The recommended base value for X_p before any adjustments are applied is 1.40. This value was calibrated to give the same overall reliability as the level inherent in the calculated load capacity. The 1.40 factor on live loads may be reduced if the purpose of the test is solely to verify a rating for a permit load. In this case the corresponding permit load factors given in Table 6A.4.5.4.2a-1 should be used.

For strength based on test:

$$R_n = 1.40(L+I)+D \tag{8.8.3.3.1-1}$$

For strength based on calculation:

$$R_n = \gamma_L(L+I)+\gamma_D D \tag{8.8.3.3.1-2}$$

The reliability levels associated with Eqs. 8.8.2.3.1-1 and 8.8.2.3.1-2 are equivalent because the strength value obtained from a proof test is more reliable than that obtained solely by analytical methods.

The following are some of the adjustments to X_p that should be considered in selecting a live-load test magnitude to achieve a rating factor of 1.0, as given in Table 8.8.2.3.1-1. Any of these adjustments may be neglected, however, if the posting and permit policies of the agency already include allowances for these factors.

1. For most situations, the live-load factor applies to a test with loads in two lanes. If one-lane load controls response, then increase X_p by 15 percent. This increase is consistent with overload statistics generated for the *AASHTO LRFD Bridge Design Specifications*.
2. For spans with fracture-critical details, the live load factor X_p shall be increased by ten percent in order to raise the reliability level to a safer level. A similar increase in test load shall be considered for any structure without redundant load paths.
3. Increase X_p by ten percent for structures in poor condition (NBI Code 4 or less) to account for increased uncertainties in resistance and future deterioration. A five-percent reduction in test load may be taken if an in-depth inspection is performed.
4. If the structure is rateable, that is, there are no hidden details, and if the calculated rating factor exceeds 1.0, X_p can be reduced by five percent. The test in this instance is performed to confirm calculations.
5. Reduction in test load is warranted for bridges with reduced traffic intensity.

Table 8.8.3.3.1-1—Adjustments to X_p

Consideration	Adjustment
One-Lane Load Controls	+15%
Nonredundant Structure	+10%
Fracture-Critical Details Present	+10%
Bridges in Poor Condition	+10%
In-Depth Inspection Performed	–5%
Rateable, Existing $RF \geq 1.0$	–5%
$ADTT \leq 1000$	–10%
$ADTT \leq 100$	–15%

The adjustments described above should be considered as minimum values; larger values may be selected by the Engineer as deemed appropriate.

8.8.3.3.2—Application of Target Live-Load Factor, X_{pA}

Applying the adjustments recommended above leads to the target live-load factor X_{pA}. The net percent increase in X_p (Σ percent) is found by summing the appropriate adjustments given above. Then:

$$X_{pA} = X_p\left(1+\frac{\Sigma\%}{100}\right) \qquad (8.8.3.3.2\text{-}1)$$

The target proof load L_T is then:

$$L_T = X_{pA}L_R\left(1+IM\right) \qquad (8.8.3.3.2\text{-}2)$$

where:

L_R = comparable unfactored live load due to the rating vehicle for the lanes loaded

IM = dynamic load allowance

X_{pA} = target adjusted live-load factor

In no case should a proof test load be applied that does not envelop the rating vehicle plus dynamic load allowance. For multiple-lane bridges, a minimum of two lanes should be loaded concurrently.

X_{pA} should not be less than 1.3 or more than 2.2.

The target proof load L_T should be placed on the bridge in stages, with the response of the bridge to the applied loads carefully monitored. The first-stage loading should not exceed $0.25L_T$ and the second stage loading should not exceed $0.5L_T$. Smaller increments of loading between load stages may be warranted, particularly when the applied proof load approaches the target load.

8.8.3.3.3—Load Capacity and Rating

At the conclusion of the proof load test, the actual maximum proof live load L_p applied to the bridge is known. The Operating level capacity OP is found as follows:

$$OP = \frac{k_O L_p}{X_{pA}} \qquad (8.8.3.3.3\text{-}1)$$

where:

X_{pA} = target live load factor resulting from the adjustments described in Article 8.8.3.3.2

k_O = factor which takes into consideration how the proof load test was terminated and is found from Table 8.8.3.3.3-1

Table 8.8.3.3.3-1—Values for k_O

Terminated	k_O
Reached Target Load	1.00
Reached Distress Level	0.88

If the test is terminated prior to reaching the target load, the load L_P to be used in Eq. 8.8.3.3.3-1 should be the load just prior to reaching the load causing the distress which resulted in the termination of the test.

The rating factor at the operating level RF_o is:

$$RF_o = \frac{OP}{L_R(1+IM)} \qquad (8.8.3.3.3\text{-}2)$$

The Operating capacity, in tons, is the rating factor times the rating vehicle weight in tons.

8.9—USE OF LOAD TEST RESULTS IN PERMIT DECISIONS

Load tests may be used to predict load capacity for purposes of reviewing special permit loads which exceed the normal legal levels. These tests should be carried out using a load pattern similar to the effects of the permit vehicle. Special consideration should be given in the interpretation of the tests and the review of the permit load calculations to the following:

1. Will other traffic be permitted on the bridge when the permit load crosses the structure?
2. Will the load path of the vehicle crossing the bridge be known in advance, and can it be assured?
3. Will the speed of the vehicle be controlled to limit dynamic impact?
4. Will the bridge be inspected after the movement to ensure that the bridge is structurally sound?

C8.8.3.3.3

If there are observed signs of distress prior to reaching the target proof load and the test must be stopped, then the actual maximum proof live load must be reduced by 12 percent by means of the factor k_O. This reduction is consistent with observations that show that nominal material properties used in calculations are typically 12 percent below observed material properties from tests.

Based on these considerations, the results of the bridge load test, whether diagnostic or proof, can be extrapolated to provide a basis for the review of requests for permit vehicles. If a diagnostic test has been performed, then test results should be used to predict the response of the bridge to the permit vehicle. The same modifications and reduced use of any enhancements in capacity observed during the test shall apply to the permit evaluation in the same way as discussed with the rating computation. Similarly, if the test is a proof load, it is necessary that the load effects of the test vehicles exceed the permit effects. A safety margin will also be needed to account for variations in weight of the permit trucks, the position of the loading, possible dynamic effects, and the possible presence of random traffic on the bridge when the permit vehicle crosses the bridge.

8.10—SERVICEABILITY CONSIDERATIONS

Load testing is primarily geared to evaluating the strength and safety of existing bridges. Load testing could also provide live-load stresses, stress ranges, and live-load deflections that could assist in the evaluation of fatigue and service limit states when these limit states may have been deemed to be of consequence by the evaluator. Careful pretest planning should be used to establish the needed response measurements for the purpose of evaluating the serviceability of an existing bridge.

8.11—REFERENCES

AASHTO. 2007. *AASHTO LRFD Bridge Design Specifications*, Fourth Edition, LRFDUS-4-M or LRFDSI-4. American Association of State Highway and Transportation Officials, Washington, DC.

NCHRP. 1998. "Manual for Bridge Rating through Load Testing," *NCHRP Research Results Digest*, Transportation Research Board, National Research Council, Washington, DC, No. 234.

APPENDIX A8—GENERAL LOAD-TESTING PROCEDURES

A8.1—GENERAL

The steps required for load rating of bridges through load testing include the following:

Step 1. Inspection and theoretical load rating
Step 2. Development of load test program
Step 3. Planning and preparation for load test
Step 4. Execution of load test
Step 5. Evaluation of load test results
Step 6. Determination of final load rating
Step 7. Reporting

A8.2—STEP 1: INSPECTION AND THEORETICAL LOAD RATING

Prior to load testing, a thorough evaluation of the physical condition of the bridge by a field inspection should be carried out, followed by a theoretical load rating (where feasible) in accordance with the procedures described in Section 6. These are necessary for use as the base condition for planning and conducting the load test and to ensure the safety of the bridge under the test load. At this stage, a determination should be made as to whether load testing is a feasible alternative to establishing the load rating of the bridge.

The analytical model developed for the theoretical rating will also be used in establishing the target test loading required, predicting the response of the bridge to the test loading, evaluating the results of the load test, and establishing the final load rating for the bridge. The procedure to interpret the test results should be determined before the tests are commenced so that the instrumentation can be arranged to provide the relevant data.

A8.3—STEP 2: DEVELOPMENT OF LOAD TEST PROGRAM

A test program should be prepared prior to commencing with a load test and should include the test objectives, the type of test(s) to be performed, and related criteria. The choice of either the diagnostic or proof load test method depends on several factors including type of bridge, availability of design and as-built details, bridge condition, results of preliminary inspection and rating, availability of equipment and funds, level of risk involved, and test objectives.

A8.4—STEP 3: PLANNING AND PREPARATION FOR LOAD TEST

Careful planning and preparation of test activities are required to ensure that the test objectives are realized. At this stage, the load effects to be measured are identified, instrumentation is selected, personnel requirements are established, and test loadings are defined, all with due regard to safety considerations. The magnitude, configuration, and position of the test loading are selected based on the type of bridge and the type of test to be conducted.

A8.5—STEP 4: EXECUTION OF LOAD TEST

The first step in the execution of a load test is to install and check the instrumentation, which could usually be done without closing the bridge to traffic. The actual load test may then be conducted, preferably with the bridge closed to all vehicular and pedestrian traffic. The loads should be applied in several increments while observing structural behavior. Measurements of strains, displacements, and rotations should be taken at the start of the bridge load test and at the end of each increment. To ensure that accurate and reliable data is obtained during the test, it is important to assess the response of the bridge to repeated load positions and to account for temperature variations during the load test. Load-deformation response and deflection recovery at critical locations should be monitored to determine the onset of nonlinear behavior. Once any nonlinearity is observed, the bridge should be unloaded immediately and the deflection recovery recorded.

A8.6—STEP 5: EVALUATION OF LOAD TEST RESULTS

At the completion of the field load test and prior to using the load test results in establishing a load rating for the bridge, the reliability of the load test results should be considered in evaluating the overall acceptability of the test results. It is important to understand any differences between measured load effects and those predicted by theory. This evaluation is generally performed in the office after the completion of the load test.

A8.7—STEP 6: DETERMINATION OF FINAL LOAD RATING

The determination of a revised load rating based on field testing should be done in accordance with Article 8.8.2 for Diagnostic Tests and Article 8.8.3 for Proof Tests. The rating established should be consistent with the structural behavior observed during the load test and good engineering judgment, and should also consider factors which cannot be determined by load testing, but are known to influence bridge safety.

A8.8—STEP 7: REPORTING

A comprehensive report should be prepared describing the results of field investigations and testing, description of test loads and testing procedures, types and location of instrumentation, theoretical rating, and final load rating calculations. The report should include the final assessment of the bridge according to the results of the load test and rating calculations, and may also contain recommendations for remedial actions.