BRIDGE DETERIORATION AND ITS IMPACT ON BRIDGE RATING – A PARAMETRIC STUDY

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May 2004

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INTRODUCTION

Determining the vehicular load carrying capacity of the existing highway bridges provides a challenge to the engineer. As the existing bridges age, deterioration, corrosion, fatigue, settlement of foundations, and potential scour problems pose number of challenges in computing the strength of bridge components. At the same time, the truck traffic is increasing and also the weights carried by various commercial trucks. The engineer should take into account conditions of the superstructure including the bearings in some cases, conditions of substructures units such as abutments and piers. Foundations should be evaluated, as needed, if settlements or scour problems are observed. One needs to take a look at the entire bridge and evaluate load transfer from the superstructure to foundations. This may not be needed in every case, but few situations may require evaluation of bridge superstructure and substructure when computing the load carrying capacity.

In this report only bridges with reinforced concrete deck on steel or prestressed concrete beams, reinforced concrete abutment, piers on spread or pile foundations are considered.

Bridge Rating

Bridge rating indicates ability of the bridge to carry certain level of truck loads. There are two rating levels:

A. Inventory Rating
B. Operating Rating

The inventory rating determines the load level at which a bridge can safely used for indefinite period of time.

The operating rating is higher than inventory level and is the absolute maximum permissible load level for a bridge. No load greater than operating load level should be permitted to cross the bridge.

Bridge Conditions

The biennial or periodic bridge inspection provides a good record of bridge conditions. Particular attention should be paid to the bridge components which are rated poor and some with section loss is recorded. In addition, existing plans, current photographs of bridge components provide needed information for bridge evaluation.

Truck Loads

These are the legal trucks that are allowed to be operated on the highway system. These trucks have various axle spacing, axle loads and total gross weight of the trucks. Refer to MDOT's Bridge Analysis Guide for more details.

Bridge Rating Process

The rating process involves the following main steps which are as follows:

a. Collect Data: Existing bridge plans, current inspection reports, including photographs. Use bridge deck and overlay cores to determine actual conditions and materials properties.
   Field Visit In some cases, a field visit to the bridge site will give better picture of over all structure and its condition.
   Collect any traffic study data, if available. This will give good idea of truck weights.
   Material sampling and testing – concrete deck cores, steel from beams can be tested to give better idea of material strength.
b. Analysis of Bridge Superstructure:
   Use of commercially available bridge analysis software such as AASHTO's *VIRTIS* software is a good tool for this purpose.
   There are several other bridge analysis software packages are available. The engineer should get familiar and proficient to use the software before applying it to an actual case.
   In a special case, an independent check by using other software package or using the long-hand method is suggested.
c. Analysis of Sub-structure:
   In some cases, analysis of sub-structure unit may be necessary to make sure that there is safe transfer of loads from the superstructure to the foundation.
d. Method of Analysis of Structures
   Based on the current agency policy one can use:
   1. Service Load Method (Allowable Stress Design)
   2. Load Factor Rating method (LFR), or
   3. Load and Resistance Factor Rating (LRFR)

The current AASHTO specifications for bridge design as well as Rating Manual should be used to assist the rating process.

Bridge Posting

If the inventory rating in terms of HS loading of bridge falls below the design load in terms of HS loading, then the engineer has two options, namely, (a) correct the deficiency in the bridge structure by quick emergency repairs or (b) post the bridge for allowable loadings and correct the deficiency by rehabilitation of the bridge.

Summary

The bridge analysis and rating procedure enables the engineer to estimate the load carrying capacity of a bridge. The final outcome is dependent on structural analysis model, accuracy of dead load estimates, accuracy of corrosion and deterioration assessment, engineering properties of materials in place and current bridge inspection reports. Usually the focus is on analysis of the superstructure, in few cases; the engineer may need to look at the substructure elements to assure proper load transfer to the foundation.

BRIDGE SUPERSTRUCTURE COMPONENT PROPERTIES

STEEL I SECTION

Consider typical steel I section. Due to continuous deterioration, there can be loss of thickness of I section. The following shows effect on section properties.

Consider W 36X210. Refer to AISC'S Manual of Steel Construction for dimensions of W 36x210.

Moment Capacity

Consider 5%, 10%, and 20% uniform section loss due to corrosive environment.

$$I_x \equiv 1/12(t_w)(h_w)^3 + 2\left[1/12(b_f)(t_f)^3 + (b_f)(t_f)\left(h_w + \left(\tfrac{tf}{2}\right)\right)^2\right]$$

Using the above formula, and uniform steel section loss of 5%, 10%, and 20%, provides the following results.

SUMMARY

% Uniform Section Loss	$I_x = 13609^{in4}$	
5% Uniform Section Loss	$I_x = 12466^{in4}$	8% Loss of I_x
10% Uniform Section Loss	$I_x = 11875^{in4}$	13% Loss of I_x
20% Uniform Section Loss	$I_x = 10540^{in4}$	23% Loss of I_x

Shear Capacity

Shear is resisted by the web cross-section and very little by the flanges of I section. Therefore, loss of shear capacity is proportional to the loss of uniform cross-section.

Buckling Capacity

Web Crippling Stress:

$$\frac{R}{t_w(N+2k)} \leq 0.75 \text{ Fy}$$

where R = Reaction at the support
N = Support length along the beam
t_w = web thickness

Wide flange rolled beams are proportioned in such a way that there is more than enough shear capacity at the support. No need to add bearing stiffeners as in the case of steel plate girders. Web crippling stress increases with proportional to the loss of web thickness.

In case of plate girders, bearing stiffness are provided to improve shear capacity. Pair of stiffeners provided and portion of web are acting as a column to provide bearing capacity.

Loss of moment of inertia of this column section is sensitive to the over all loss of section. Care should be taken to maintain section by preventive maintenance such as coating or by steel repairs (add steel plates for web or add stiffeners).

PRESTRESSED CONCRETE I-BEAM AND BOX BEAMS

Moment Capacity (flexural resistance) of I-beams and box beams depend on section properties, prestressed and non-prestressed provided and compressive strength of concrete.

While analyzing existing structure factors impacting the above need to be taken into account. Loss of section due to deterioration, loss of prestressing strands due to high load hits to bottom flanges and corrosion are the examples of key factors that must be taken into account. In general, PCI beams/boxes have provided excellent structural performs for many years.

Shear Capacity (resistance)

$$V_n = V_c + V_s + V_p \leq 0.25\ f'_c\ b_v\ d_v \quad [A.5.8.3.3]$$

Shear resistance is provided by concrete, vertical stirrups and vertical component of prestressing. Shear is critical near the support or beam ends. The leaky expansion joints cause rapid beam end deterioration, which results in loss of shear capacity of the beam.

Aging of the structure (beam ends) and environmental factor affecting corrosion, can reduce the shear capacity of beams. Spalling of concrete beam ends and visible diagonal shear cracks are indicators that point out that there may be some reduction in the shear capacity.

Bridge Deck Slabs (reinforced concrete decks)

The bridge deck slabs, most commonly, were designed as continuous-simply supported rectangular beams of one-foot widths. Neglecting effect of compressive reinforcement, the strength of section depends on depth of cross-section, tensile reinforcement, and strength of concrete.

The factors that impact moment and shear capacities of the deck slabs are 1) concrete delamination, 2) corrosion of steel reinforcement, and 3) deterioration of concrete.

The major factors that reduce the strength of deck section are a) corrosion of main reinforcement, b) reduction of f_c'due to environmental factors, and c) excessive delaminations, and spalling of unprotected concrete deck with no deck overlay.

Complex analytical studies have pointed out that bridge deck slab can fail due to localized shear failure caused by heavy wheel loads.

Excessive delaminations and potholes on bridge deck amplify the dynamic effect of truck traffic, and may cause localized shear failures in a badly deteriorated deck slabs.

COMPOSITE SECTIONS (BEAM AND DECK)

Bridge deck and beams provide a composite action to resist moments produced by the dead and live loads on the bridge decks.

For example, AASHTO Type IV PCI girder, spaced at 7 ft. c/c with 8 in. deck slab of 7.5", $f_c' =$ 5000 psi for grider and $f'_c = 4000$ psi for the deck following section properties are given.

Moment of Inertia, girder alone = 260,680 in^4

Moment of Inertia, slab and girder – composite = 640,039 in^4

This illustrates advantage of composite section.

Now consider due to deterioration excessive surface spalls and potholes on deck, we take reduced effective thickness of deck slab to be 6.5" (1" effective loss or 13% of depth of deck slab). The composite properties will be as follows:

Moment of Interia, slab and girder composite = 598,589 in^4
which shows loss of 6.5%

Therefore, it is vital to keep bridge deck in good condition to prevent the loss in composite section properties.

Bearings

Leaky expansion joints have caused corrosion of steel bearings as deck runoff containing deicing salts runs on the beam ends. Rocker type or pedestal type bearings subjected to excessive corrosion may need careful evaluation. Loss of bearings surface due to excessive horizontal beam movement; excessive rocker tilts should be evaluated.

Prestressed concrete beams are provided with elastomeric bearing pads. These types of bearing can dislocate as well as deteriorate due to environmental factors.

The bearing with any one of these problems need to be corrected and/or replaced, as determined by the engineer.

SUB-STRUCTURE COMPONENTS

The following are just a few examples where determining strength of structural member may be needed.

Single Column and Pier Cap (hammer head piers)

Any cracks in the pier cap as well as badly spalled column may require closer look, analysis and corrective action.

Reinforced Concrete Pier Caps

Large cantilever overhangs which support the fascia beams, need to analyzed when shear cracks and deterioration are observed.

In this case, if cap overhang is deficient, traffic over the lane close to bridge fascia can be shifted to the inner lanes on the bridge deck, during repair and strengthening of cap overhang.

Abutments

Abutment distresses such as vertical cracks, settlement and scour should be evaluated.

FOUNDATIONS

Settlements

Foundation settlement can cause structural distress, especially in continuous structures with diffential settlements. The geotechnical engineer should be consulted to remedy the settlement problem.

Scour

About 85% of structures in FHWA's National Bridge Inventory are over waterways. Scour of foundations and embankments is a major concern during and after the major flood. If scour is present, that can cause foundation settlement and unstable sub-structures, then the engineer needs to limit the use of the structure or close it to the traffic. The foundation problem should be fixed to restore structure to its original load carrying capacity.

BRIDGE LOAD TESTING

Bridge load testing is used to supplement and confirm the load carrying capacity as determined by structural analysis. The older or deteriorated bridges pose a challenge of estimating strength of bridge components. Corrosion of steel and delaminations of concrete members reduce capacity of members. In these cases, bridge load testing can help to accurately access the load carrying capacity of the bridge.

Usually the bridge load test will yield higher load carrying capacity than that determined by structural analysis. The effect of sidewalks, railings and concrete overlay is neglected in computing capacity of superstructure, but in reality these elements do contribute to the strength of overall bridge superstructure. Conservative estimation of live load factors and impact factor (dynamic load allowance) also indicate lower values of load carrying capacity V_s that determined by the load testing. Partial fixity at supports, which are idealized for design purpose as a simply support, also helps to increase load carrying capacity of the bridge.

BRIDGE POSTING

Posting

This action requires signs at the bridge indicating allowable gross weight of the trucks and axle configuration. Impact posting V_s quick corrective/preventive action of bridge repair should be investigated.

Corrective Actions

If minor deficiency has caused indication that the bridge needs to be posted, here are some quick corrective actions and their effects on the load carrying capacity of the bridge.

1. Bridge Deck – Repair delaminations, pot holes on bridge deck. Less rough surface will reduce impact of truck traffic. Thin asphalt overlay can be used, if deck is scheduled for replacement soon.
2. Beams – Repair beam ends or add temporary supports at the bearings.
3. Bearings – Add temporary support at bearings and repair or replace existing bearings.
4. Piers and Abutments –
   Pier Columns – Add concrete, steel or FRP jacket around columns, as needed.
   Pier Caps – Add intermediate support for pier cap support. Same cases of external post-tensioning can help to improve pier caps capacity. Add support under fascia overhang.
   Abutments – To correct loss of bearing surface or cracks, add temporary support under each beam.
5. Foundations –
   Scour – Add scour protection to correct scour problem.
   Loss of Bearing – Pump cement grout under spread footings to improve uniform bearing.

   In case of pile bents, additional pile bents may be added to transfer load to new pile bents.

   In all cases, the geotechnical engineer should be involved in recommending these solutions.

SUMMARY AND CONCLUSIONS

- The bridge inspection reports should be supplemented with actual testing of materials from bridge components, as needed.

- Loss of structural strength due to deterioration, of the bridge components can be input for structural analysis of the bridge system. The new programs, such as VIRTIS by AASHTO can be used to perform parametric study.

- Loss of component strength more than ten percent of its original strength, should be studied further. Preventive action such as repair or rehabilitation should be considered in a timely manner.