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USE OF FIELD TESTING IN STRUCTURAL MODELLING OF STEEL BRIDGES

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ABSTRACT:

The assessment of the load-carrying capacity of bridges is an important part of any bridge management system. Current methods for calculating load effects and load ratings are based on applying the principles of structural analysis and mechanics to a structural model of the bridge. The assumptions involved in this process do not, generally, represent the real bridge behavior. Examples of these assumptions are related to load distribution among different bridge components, actual end restraints, degree of composite action in the case of bridges with composite floors, and effect of specific bridge details at connections. Basing the assessment on the results obtained from such models usually yields conservative results.

In order to make the structural model more representative of the actual bridge behavior, field testing of the bridge can be used to better define the real characteristics affecting bridge behavior. Data collected from field testing can then be used to calibrate the structural model so that it can be used to determine a realistic bridge response to actual loads and arrive at a more realistic bridge rating.

The paper discusses the application of this procedure to two common types of steel bridges: slab-on-girder bridges and truss bridges. In both cases, the factors affecting the real bridge behavior are identified. Methods used to incorporate these factors into the structural model are presented.

KEY WORDS:

Bridge assessment, structural modeling, field testing.

INTRODUCTION:

Current methods used for calculating the effect of loads on bridges are based on using the principles of structural analysis and mechanics applied to either a simple structural model or a more sophisticated finite element model. The assumptions used in this process do not, in general, represent the real behavior of the bridge accurately and usually yields conservative results. Examples of these are the assumptions related to the following items:

1- The distribution of loads among different bridge components.
2- The end restraints at supports.
3- The degree of composite action in bridges with composite floors.
4- The effect of specific details used in bridge connections.

In addition, the values used for material properties are usually based on nominal values that may differ from one bridge to another. Furthermore, the provisions of design codes are usually very conservative at predicting the behavior of the bridge.

In order to make the structural model more representative of the actual bridge behavior, field testing of the bridge can be used to better define the real characteristics affecting bridge behavior by using data collected from field testing to calibrate the structural model so that it can be used to determine a realistic bridge response to actual loads and arrive at a more realistic assessment of the bridge behavior.

This paper discusses the application of this procedure to two common types of steel bridges: slab-on-girder bridges and truss bridges. In both cases, the factors affecting the real bridge behavior are identified. Methods used to incorporate these factors into the structural model are presented.

TYPES OF FIELD TESTS [1]:

1- Material testing:
   a) using extracted samples or non-destructive tests to identify the actual material properties such as density, elastic modulus, ultimate strength and yield strength.
   b) using ultrasonic or radiographic examination to identify defect or section deterioration.
2- Geometric monitoring of the bridge using surveying techniques, GPS, and remote sensing.
3- Long term monitoring of the structural behavior of the bridge to identify strain or displacement values under actual loadings.
4- Static load testing to identify strain responses to trucks or train loading.
5- Dynamic testing to identify acceleration responses to moving loads or forced excitations.

CALIBRATION PROCEDURE [4]:

The calibration procedure used to make the structural model more representative of the actual bridge behavior consists of the following steps [4], see Fig. 1:

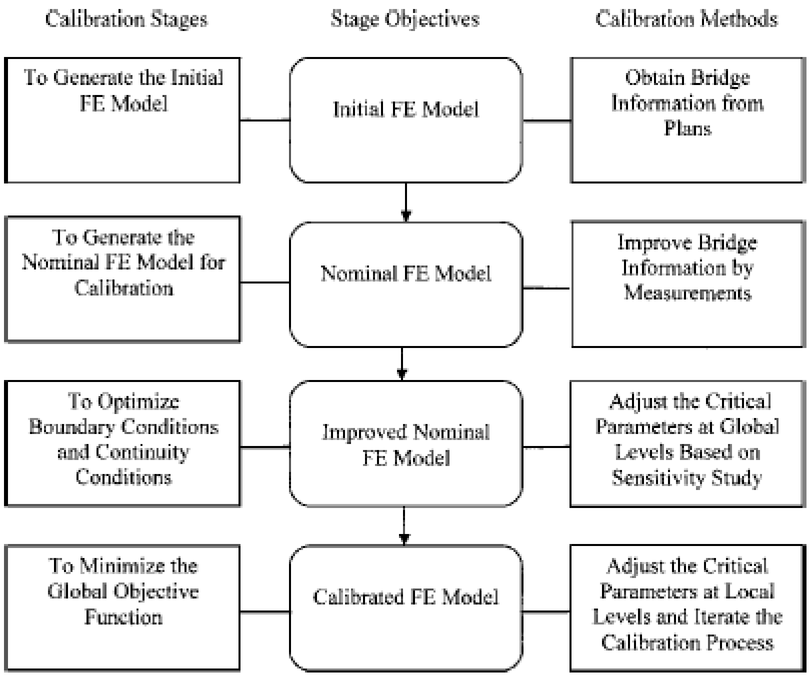


Figure 1: Flow Chart of Calibration Procedure [4]

Step 1: Preliminary inspection of the bridge:

This inspection includes:
   a) review of bridge plans.
   b) visual inspection to record any defects
   c) review of previous maintenance and inspection reports

Based on information collected during this inspection:
1) The data needed to construct a preliminary structural model is collected
2) An instrumentation plan is developed for the load test so that it provides a better understanding of the bridge behavior (e.g.: end restraint, edge stiffening, composite action, load distribution, etc)

Step 2: Structural Modeling:

A preliminary structural model is created at the beginning of the process to represent the best knowledge about the bridge members, connections, supports conditions,… etc. Any of the available analysis software such as STAAD, SAP, etc. can be used to construct the model. The results of the preliminary inspection related to section and material properties, section deterioration, support conditions…etc are used in the model input data. The live loading of the model should resemble the field test load. Appropriate critical load paths to induce maximum live load effects are defined. The model must be capable of simulating true behavior of the bridge while being adaptable to the optimization procedure used in parameter estimation.
After the model is set, analysis is carried out to produce the analytical results. These results are compared to the loading test results.

Step 3: Load Test:

Test Design [1]:

1) Establish purpose /objections of the test application.
2) Determine form and duration of the testing.
3) Identify the types and quantities of variables to be measured and their measurement locations.
4) Select sensors and data acquisitions components.
5) Validate /calibrate the measurement systems.
6) Design load cases for controlled tests.
7) Develop procedures for evaluating data quality, data processing and analysis and archival.
8) Create presentation and decision criteria.

The load and sensor locations and data acquisition systems are selected to obtain a set of data meeting the optimality criteria considering both required bounds of confidence for parameter estimation and test feasibility. Error sensitivity analyses are required to determine the required confidence bounds for the structural parameter estimates.

The data obtained from the experiment must be processed for use in the parameter estimation module such that the quality of the data is maintained.

Issues that need to be considered are:
1) Data must be validated to ensure that it originated from a reliable sensor
2) Channels should be separated so that parameters estimation and verification can be performed in clear checks and balances system; and
3) To ensure consistent conclusions, the results of different tests must be comparable.

Quality assessment of measurements is an extremely important factor in the data processing step. Confidence factors for each sensor or data channel can be calculated using probabilistic methods, physical behavior, structural principles, and engineering judgments.

Step 5: Model Calibration [4]:

Basic Theory

The preliminary structural model represents the actual structure with limited accuracy because of possible damage and/or deterioration of the bridge. Thus the nominal model needs to be calibrated to more accurately simulate the experimental results. The critical parameters of the model are adjusted in a step-by-step process so that the analysis results match the experimentally measured static and/or dynamic responses. The comparisons of the analytical and experimental responses give an indication of the accuracy of the model during calibration. From the results of the comparisons, the separate or combined effects of critical model parameters on the responses can be distinguished. Conversely, the results will be used in deciding which of the parameters should be adjusted and how they should be changed. These forward and reverse processes will be iterated until the responses between the analytical model and experimental measurements converge.

Adjustments of the Geometry, Material, and Section Properties:

The adjustments of the critical parameters are typically separated into those that will most directly affect the static responses and those that will most directly affect the dynamic responses.
The strain responses are considered to be static responses while the modes shapes and frequencies are considered to be dynamic responses. Within these divisions, the stiffnesses of springs over supports and moments of inertia of rigid links affect only the stiffness matrix of the bridge model. Adjustments of unit weight of concrete and nodal mass over piers affect only the mass matrix of the bridge model. Variations of thickness of deck, modulus of elasticity of concrete, and modulus of elasticity of steel affect both stiffness and mass matrices of the bridge model. The order in which the parameters are varied is determined with this in mind.

In order to minimize the differences between the model and test results, the effect of changing these parameters within defined boundaries is investigated. Analytical accuracy is reported in terms of error between the calibrated model and the field testing results. The error is considered as the objective function of the optimization problem [4]:

$$E = f(E_1, E_2, E_3, E_4, \ldots.., E_n)$$

where E = total error function, Ei = error function for i’th parameter, n = number of parameters.

Model calibration method:

Model calibration is done by performing multiple iterations including statistical analysis of the model where analytical results are compared to measured results. Each iteration consists of n sub-iterations where n is the number of parameters. Basically, one parameter per sub-iteration is changed within the defined boundaries to establish the model accuracy sensitivity for that particular parameter. After all sub-iterations are completed and the model accuracy is established, all parameters are optimized accordingly, and a new iteration begins with updated parameters.
These iterations-loops (i.e. iterations and sub-iterations) continue until the error cannot be improved, and the optimization process is terminated within the percent error from the final iteration as the "lowest" error. The parameters from this last iteration represent the calibrated model. A "good" model will generally have a correlation coefficient greater than 0.9 and a percent error less than 10%.

Step 6: Utilization of the calibrated model

This step includes obtaining interpretations in a form that is useful to other applications within the bridge management system. The calibrated bridge model may be used as a base line to study the effect of defects and/or deterioration on the real bride behavior.

Application to Slab-on-Girder Bridges [3]:

The following example illustrates the application of the calibration procedure to a slab-on-girder bridge [3]. The bridge was tested by both modal test and truckload test. The bridge has five girders, three spans (60’-75’-60’), zero skew.

Basic Information

The bridge consists of three spans measuring 60’, 75’, and 60’. The bridge has no skew, it is 36’ wide, and consists of 5 (W33 x 141 and W36 x 194) girders spaced at 8’-4”.

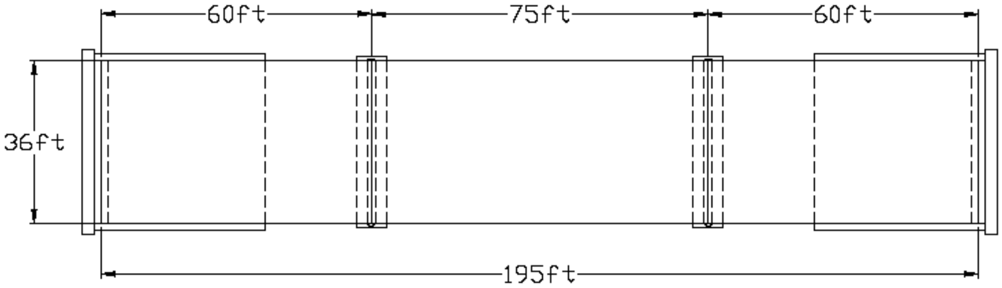


Figure 6.1 Plainview of BUT-732-1043

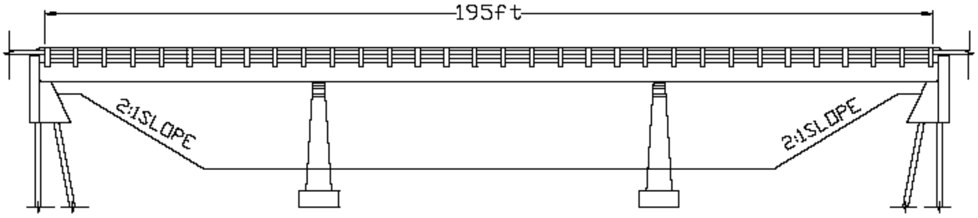
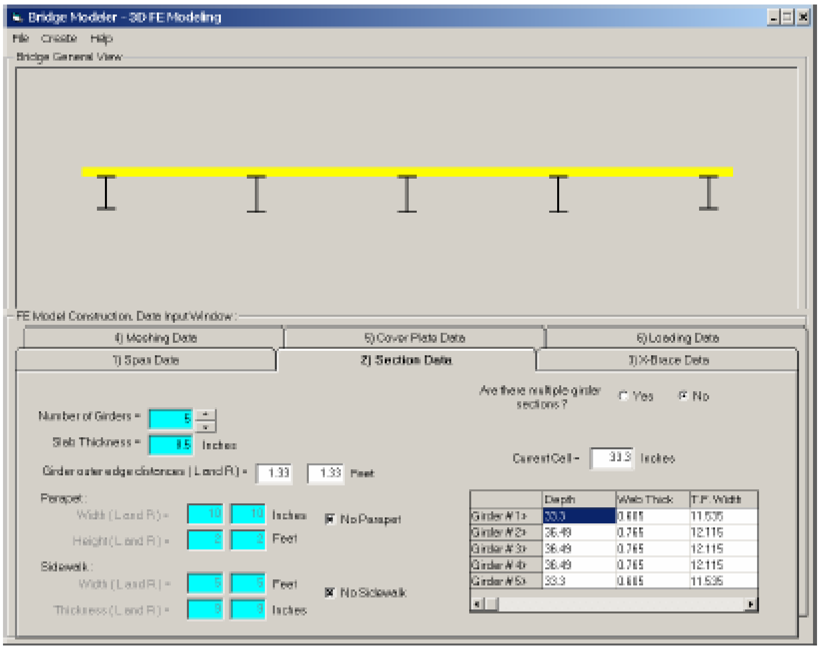


Figure 6.2 General Elevation of BUT-732-1043

Structural Model:



Number of Girders = 5
Slab Thickness = 8.5 Inches
Girder outer edge distances (L and R) = 1.33 1.33 Feet
Parapet:
Width (L and R) = 10 10 Inches
Height (L and R) = 2 2 Feet
☒ No Parapet
Sidewalk:
Width (L and R) = 5 5 Feet
Thickness (L and R) = 9 9 Inches
☒ No Sidewalk
Are there multiple girder sections? ○ Yes ● No
Current Cell = 33.3 Inches

	Depth	Web Thick	T.F. Width
Girder # 1>	33.3	0.685	11.535
Girder # 2>	36.49	0.765	12.115
Girder # 3>	36.49	0.765	12.115
Girder # 4>	36.49	0.765	12.115
Girder # 5>	33.3	0.685	11.535

Figure 6.5 GUI of the Bridge Modeler Software

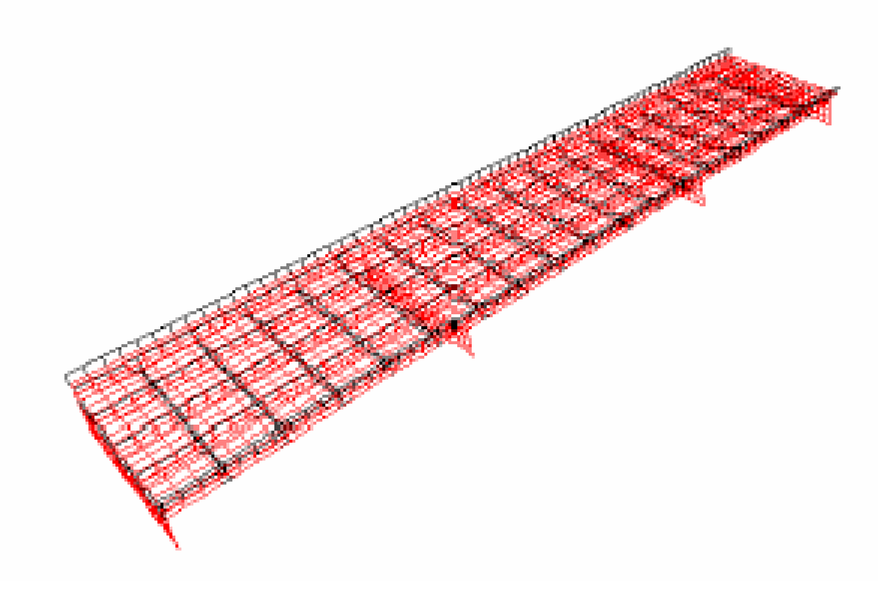


Figure 6.6 BUT-732-1043 Nominal Model

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Optimization Process:

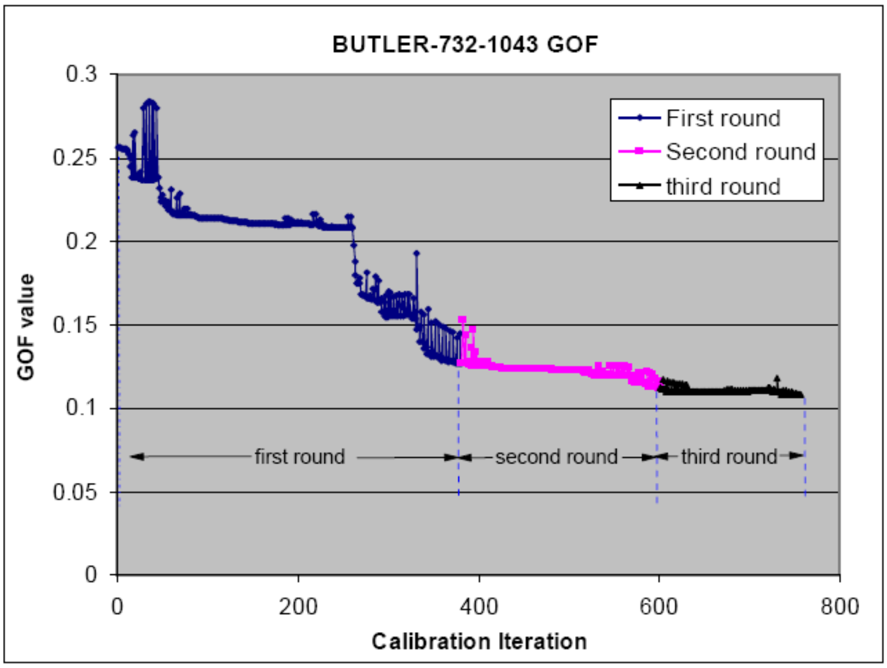

Figure 6.8 BUT-732-1043 GOF Curve in Calibration Process

Results of Calibration:

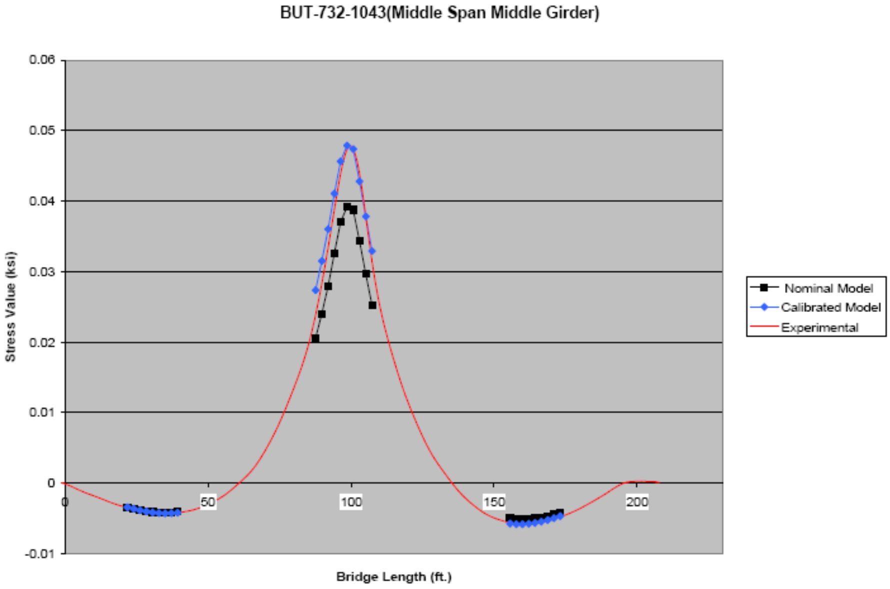

Figure 6.16 Example of BUT-732-1043 UIL Calibration Result

Example of Parameter Calibration:

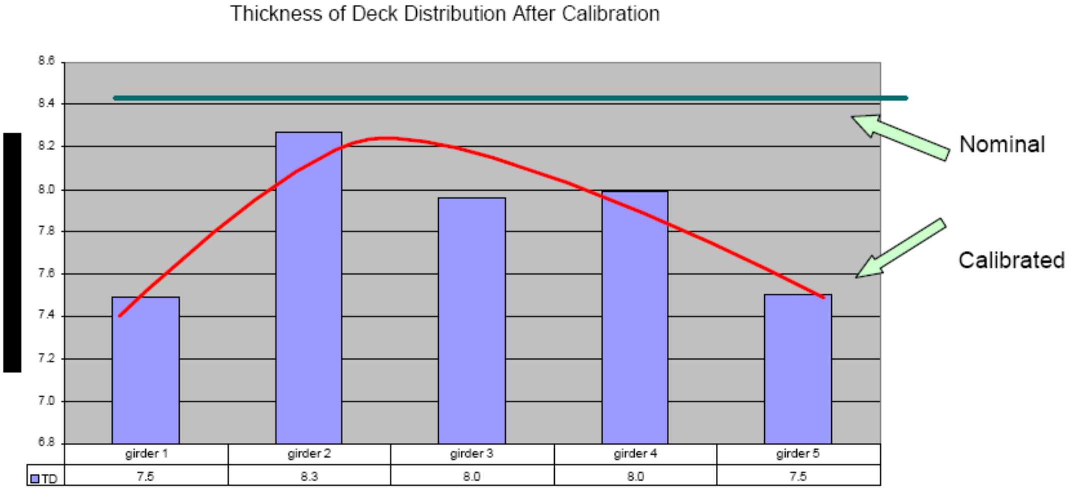

Figure 6.17 T_D Calibration Result

Application to Truss Bridges [2]:

Steel Through-Truss Bridge

Bridge Description:

Structure Type: Open deck thru-truss with pinned connections.
Span Length(s): 155 feet, Skew Right
Member Types:
Bottom Chord: Eyebars and built-up sections (riveted).
Top Chord: Built-up sections (riveted)
End Posts: Built-up sections (riveted)
Diagonals: Eyebars
Floor Beams: Built-up sections (riveted)
Stringers: Built-up sections (riveted)
Structural Steel Fy = 36 ksi, E=29,000 ksi (from material test results)

Structural Model:

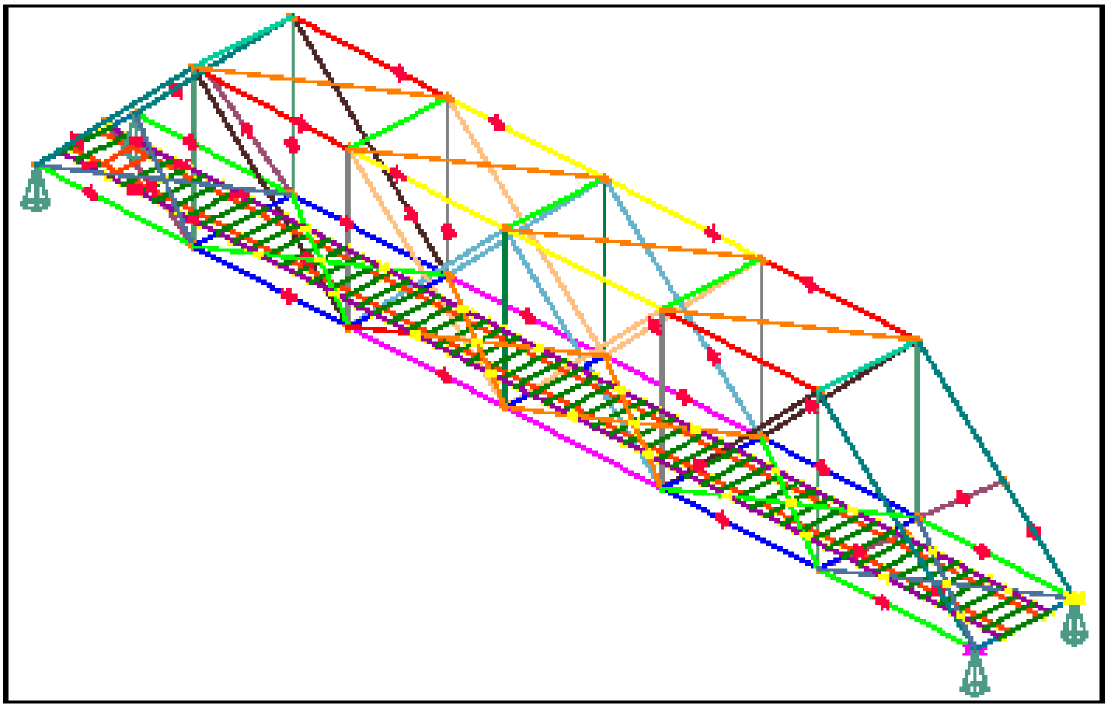

Figure 14 Computer generated display of bridge model

Test Measurements

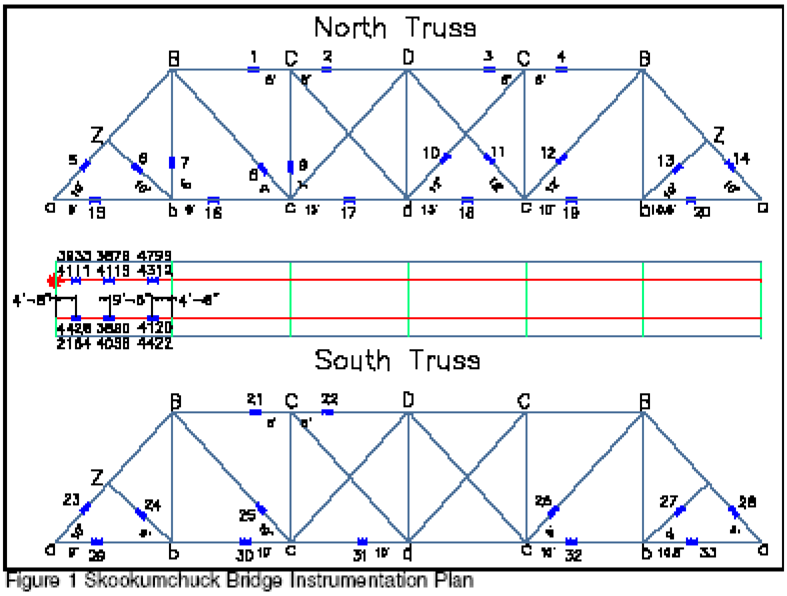

Figure 1 Skookumchuck Bridge Instrumentation Plan

Test Results:

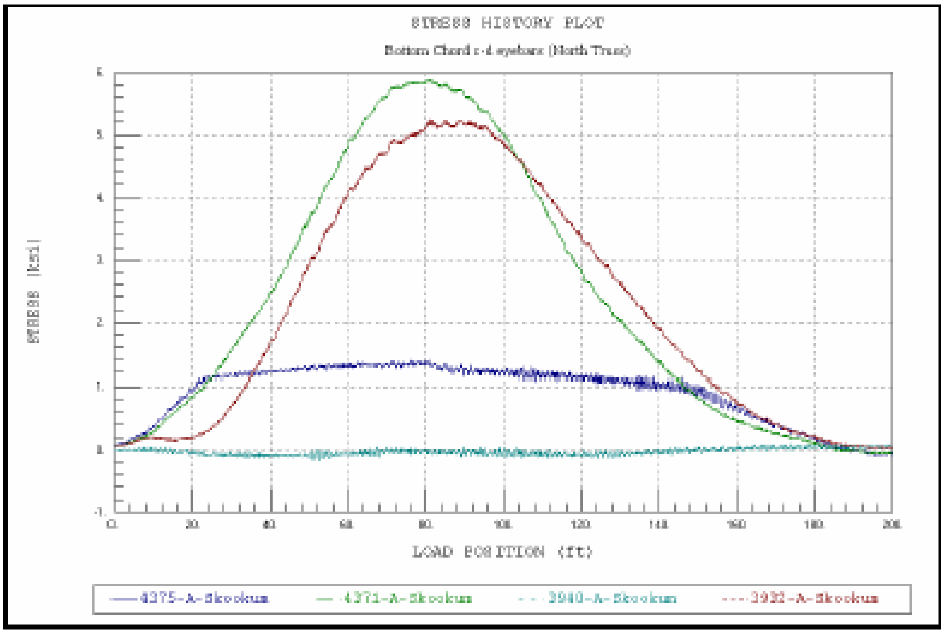

Figure 9 Bottom Chord Eyebars c-d of North Truss (load variations).

Calibration Results:

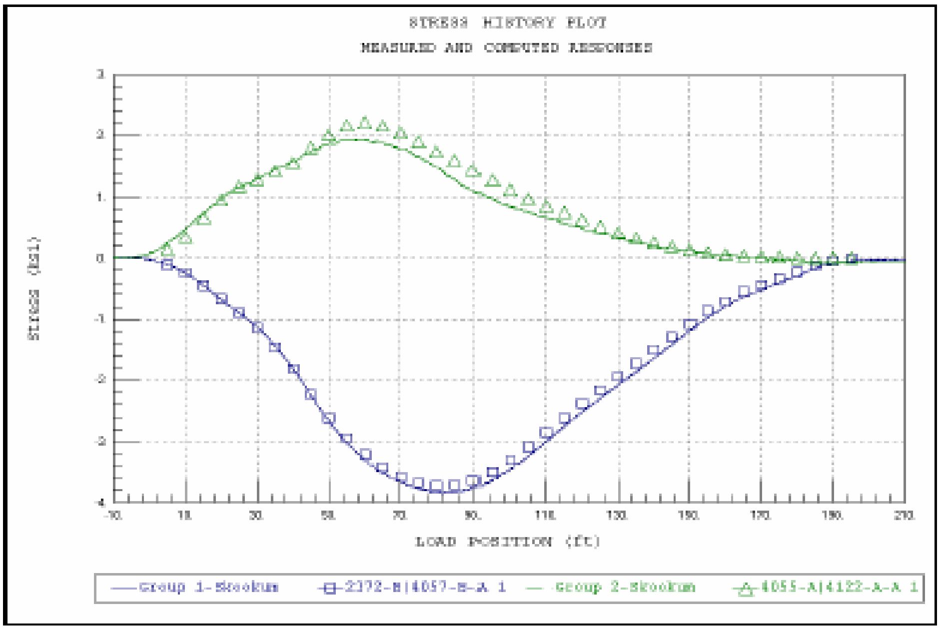

Figure 15 Comparison of axial force stress @ Sections 1 & 16.

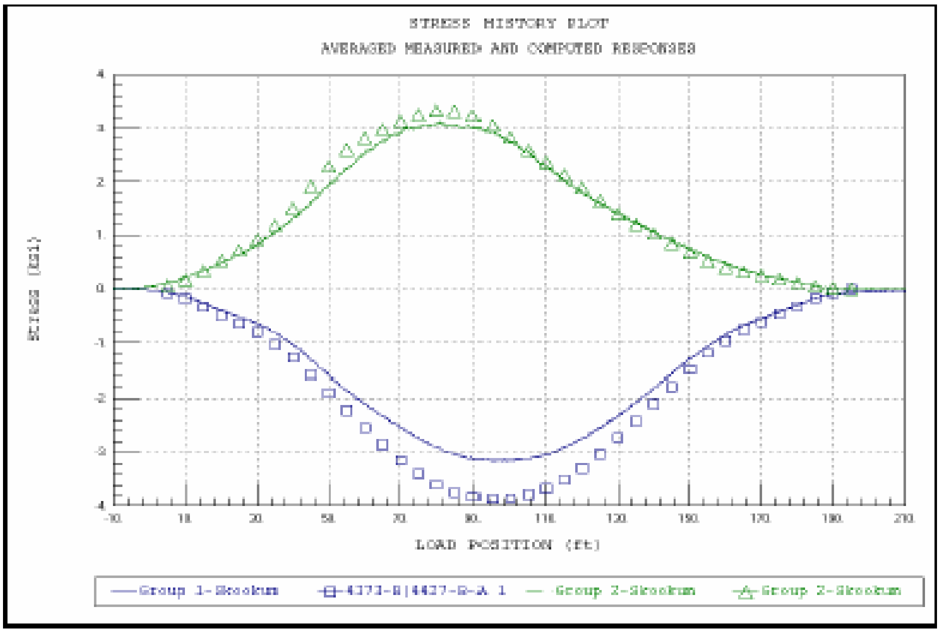

Figure 16 Comparison of axial force stress @ Sections 2 & 17.

Calibration Results (Contd.)

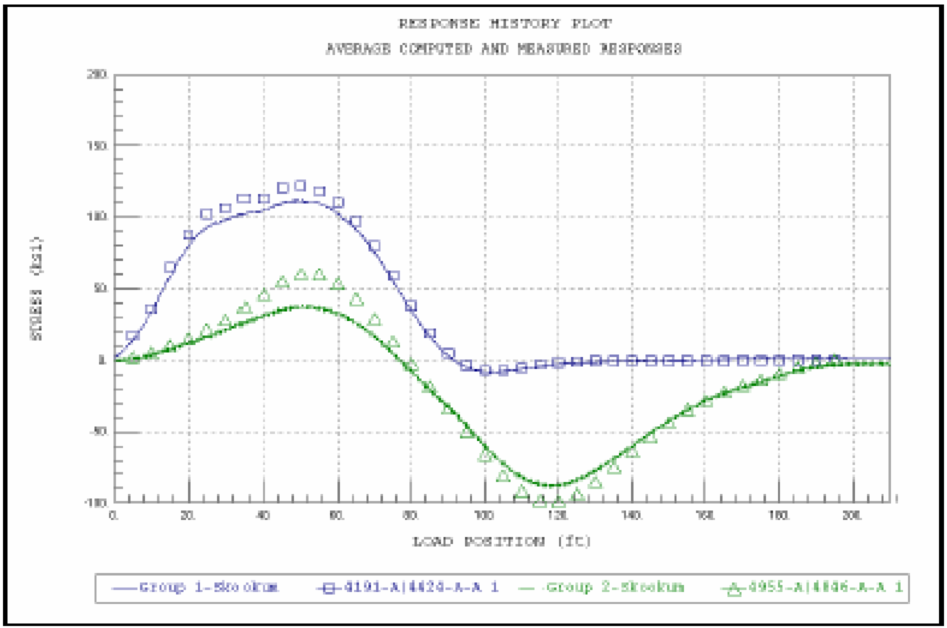

Figure 21 Comparison of axial force stress @ verticals - Sections 7 & 9.

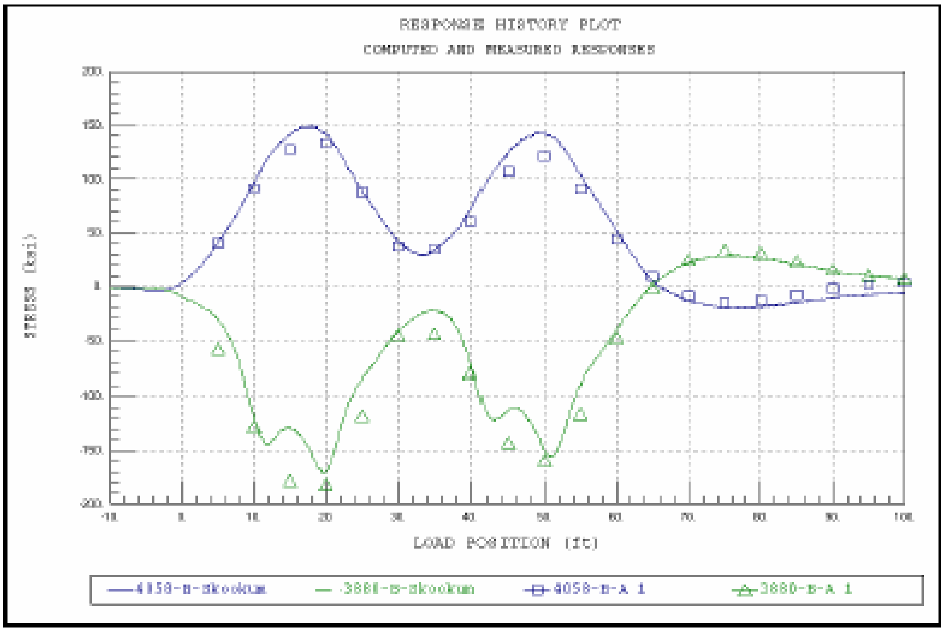

Figure 22 Comparison of stresses @ stringer midspan.

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