IMPLEMENTATION OF THE ANALYTICAL CAPABILITIES REQUIRED FOR THE ASEISMIC DESIGN OF BRIDGES

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SUMMARY

This paper describes the SEISAB-I program and its capabilities for use in routine design in accordance with the latest design codes and practices. The advanced nonlinear capabilities intended for use in developing the new aeismic design methodologies to be included in SEISAB-II are also briefly described. In addition, the paper summarizes the efforts, on a national level, to implement new analysis capabilities required for the aseismic design of bridges, including some of the research currently underway at the University of California, Berkeley to enhance the nonlinear analysis capabilities of bridges.

INTRODUCTION

Both the current AASHTO (American Association of State Highway and Transportation Officials) Standard Specifications for Highway Bridges (Ref. 1), which was upgraded following the 1971 San Fernando Earthquake, and the more adopted recently AASHTO guide specification (Ref. 2), "Seismic Design Guidelines for Highway Bridges," require that a single mode or multi-mode response-spectrum analysis be conducted in the seismic design of bridges. It has been difficult to implement the new methodologies contained in these two design provisions within the United States because the analytical procedures involved are new to many bridge designers. Recognizing this problem, the National Science Foundation elected to fund a project to develop the computer program, SEISAB (SEIsmic Analysis of Bridges), which will help alleviate the implementation effort.

In addition to being used as a design tool for implementation of the new design codes, SEISAB is also being extended to include the nonlinear capabilities that were developed at the University of California, under the direction of Professor Penzien, for use by the researcher or bridge designer involved in in the following design functions.

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- Conducting parametric studies to establish procedures and design coefficients for new or improved aseismic design specifications
- Conducting detailed dynamic analyses studies on complex bridges
- Investigating newly developed aseismic design strategies that include energy dissipation
- Developing design procedures that include the complex effects of soil-structure interaction.

Extending SEISAB to include newly-developed elements unique to bridges and nonlinear analysis capabilities provides a vehicle for implementing the state-of-the-art methodologies emerging from the universities into the bridge engineering profession.

In line with the primary objective of developing a useable design tool, SEISAB-I was developed with an effective means of user communication by incorporating a problem-oriented language written specifically for the bridge engineer Ref. 1,2). The free-format SEISAB language consists of simple, easy-to-remember commands, natural to the bridge engineer in describing a bridge. Using a minimum amount of user input data, the program generates the model consistant with that required to conduct a dynamic analysis. SEISAB-I, which contains linear dynamic analysis capabilities, was well received in its first pilot workshop by a selected group of highly qualified bridge engineers from the California Department of Transportation. Three subsequent workshops that included the use of SEISAB-I for both design and retrofitting proved to be equally successful.

BACKGROUND

One of the most complicated tasks a bridge engineer is faced with in applying the latest principles of seismic design is the dynamic analysis of the structural system. This problem faces most bridge designers today, whether they use the current AASHTO design specifications (Ref. 3) or the newly adopted ATC-6 Seismic Design Guidelines for Highway Bridges (Ref. 4). The introduction of structural dynamics to the bridge design process requires that bridge designers learn both the basic principles in dynamics and how to use computer programs having dynamics analysis capabilities. This also implies introductory training in the art of mathematical modeling.

Because of the new concepts introduced in the AASHTO and ATC-6 design specifications, a major effort is required to train practicing bridge engineers in the latest principles of seismic design. This training should encourage immediate implementation of these priciples and tools. In addition, it must stimulate the interest of the profession as a whole, thus broadening the base from which even further advancements in seismic design can be made.

Although the application of structural dynamics to the bridge engineering field is somewhat in its infancy, it has become apparent that certain types of bridges may be idealized so as to be more easily analyzed mathematically. Penzien and Imbsen developed the Single Mode Spectral Method (SMSM), presented in the ATC-6 guidelines, in an effort to simplify the task of implementing structural dynamics within the field of bridge engineering (Ref. 5).

The SMSM is used to calculate the seismic design forces of a bridge that can be characterized as having its major dynamic response in a single mode of vibration. This method, although quite rigorous, reduces a complex dynamics analysis to the performance of just two statics analyses. The first static analysis is conducted to obtain the structure period, the second to apply inertial forces consistent with the displaced shape.

The SMSM, as formulated, can be applied to many types of bridges, including bridges with either continuous or discontinuous superstructures. Boundary conditions at the abutments and piers can be modeled to include the effects of the foundation. A bridge engineer can readily apply the SMSM by using hand calculations and conventional static structural analysis procedures. For the more complex bridges in the higher seismic zones, the seismic design guidelines recommend the Multimode Spectral Method (MMSM), which is a response spectrum analysis.

SEISAB-I was developed specifically to help bridge designers conduct seismic analyses. The SEISAB program has both SMSM and MMSM capabilities. In addition, elastic time-history analysis capabilities included in SEISAB-I allow the designer to conduct more detailed analyses or correlation studies in which the structure remains within the elastic range. With a minimum amount of input data, this program can generate a structural model for a dynamic analysis of almost every type of deck-girder bridge.

The SMSM will yield good approximations for the seismic design displacements and forces as long as the bridge derives most of its dynamic response from the assumed first mode shape. As noted, this requirement will be satisfied for many bridges. Bridges that receive their dynamic response from several modes of vibration must be analyzed by the MMSM or some other method that retains more than one mode. The MMSM is the most popular method used today because of practical and economic considerations. Unfortunately, most computer programs that implement the MMSM are cumbersome to use because of their input requirements.

ILLUSTRATIVE EXAMPLE

The need for a computer program with MMSM capabilities written specifically for bridge designers resulted in the development of SEISAB. A complete, lumped-parameter structural model is generated with only a few free-form input commands. The use of SEISAB will be illustrated by performing a response-spectrum analysis on a six-span, curved bridge. An ATC-6 acceleration spectrum will be used for the dynamic loading.

Description of the Bridge

The bridge is a six-span, curved box girder bridge with single column bents. The prismatic superstructure is continuous, with the exception of Span 3 which contains an intermediate hinge. The intermediate hinge is outfitted with earthquake restrainer units to provide longitudinal restraint. Shear keys at the hinge provide transverse restraint between the two superstructure sections.

The seat-type abutments are radially oriented with transverse abutment-to-superstructure shear connections and longitudinal restraint provided by restrainer units. The radially-oriented single column bents are founded on pile groups.

Modeling and Program Input Details

To perform the response spectrum analysis, the physical model of the bridge requires a mathematical representation. As is conventionally done, the SEISAB-I program models bridges by lumping properties at discrete locations along the superstructure and columns.

Initiating a Response Spectrum Analysis

The user may conduct a response spectrum analysis by specifying a single command in the SEISAB Data Block. In addition, the number of intermediate node points to be used on the superstructure and columns (i.e., the degree of accuracy of the analysis) may be specified. Because of the curved geometry of this bridge, coupling effects will be experienced and the default number of three (3) nodes on the superstructure will be increased to four (4). The input in the SEISAB Data Block is shown below:

```
SEISAB 'RESPONSE SPECTRUM ANALYSIS, 6-SPAN CURVED BRIDGE'
RESPONSE SPECTRUM
SUPERSTRUCTURE JOINTS 4
```

Describing the Horizontal Geometry

To develop the most accurate model, the location of the bridge centerline must be correct. This information is supplied to SEISAB in the ALIGNMENT Data Block. Alignment information may be taken directly from bridge plans and used as input to SEISAB. The input for the ALIGNMENT Data Block is shown below:

```
ALIGNMENT
STATION         100 + 0.0        $ INITIAL REFERENCE POINT INFORMATION
COORDINATES     N 500.0  E 250.0
BEARING         N 0 E
BC          10000.0              $ CURVE INFORMATION
RADIUS      R 600.0
BEARING     N 66 16 20 E
```

Superstructure

The stiffness and mass characteristics of the superstructure are obtained from its cross-sectional properties. The spans are prismatic, so only the properties of Span 1 are input. The torsional moment of inertia is calculated by using expressions based on thin-walled, enclosed regions. The input to SEISAB for the superstructure is shown below:

```
SPANS
LENGTHS     100.0, 143.0, 3*117.0, 100.0
AREAS        86.0             $ PROPERTY GENERATION WILL BE
I11         862.0             $ USED FOR SPANS 2-6.  ALSO,
```

```
I22      13000.0           $ PROGRAM DEFAULTS WILL BE USED
I33        360.0           $ FOR THE MODULUS AND DENSITY.
```

Defining the Structural Members

Another user input feature of SEISAB is that any structural member that can appear at more than one location in the bridge is described once in the DESCRIBE Data Block and then placed at the other appropriate locations. The structural members in the six-span bridge that need to be defined are the bent columns and the longitudinal restrainers. Because the five columns are identical in cross-section, only one need be defined. The input in the DESCRIBE Data Block is shown below:

```
DESCRIBE
COLUMN  'TYPE 1'   "TYPICAL PRISMATIC COLUMN"
AREA     33.0
I11     146.0
I22      73.0     $ PROGRAM DEFAULTS WILL BE USED FOR THE
I33     143.0     $ MODULUS AND DENSITY
RESTRAINER  'TYPE 1' "GALV. H.S. ROD"
LENGTH   5.0
AREA      3.068E-03
E         2.010E+06
RESTRAINER  'TYPE 2' "GALV. STEEL CABLE"
LENGTH  20.0      $ PROGRAM DEFAULTS WILL BE USED FOR THE
AREA      0.01    $ MODULUS
```

Abutment Information

The modeling of the two abutments is accomplished through the ABUTMENT Data Block. The connectivity between the superstructure and the abutment will be assumed to offer translation constraint in the transverse and vertical directions and rotational constraint about a horizontal axis perpendicular to the centerline of the abutment. The shear keys will provide the translational constraint and the width of the superstructure will provide the torsional constraint. The input in the ABUTMENT Data Block is shown below:

```
ABUTMENT STATION   100 + 0.0
ELEVATION          152.5  155.5
WIDTH NORMAL       35.0   $ GENERATION WILL BE USED FOR ABUT 7
RESTRAINER NORMAL LAYOUT 'TYPE 1' 8.0, 8.0 'TYPE 1' AT 1,7
```

Bent Information

The number, type and spacing of bent columns are specified in the BENT Data Block. In addition, the user may also input the type of connectivity to the superstructure, the column end conditions and the locations of restrainers. The bridge under consideration has only single-column bents, with the columns oriented radially to the superstructure. The column end conditions are fixed at both ends. Many program defaults in the BENT Data Block have been utilized for this bridge. The required input is shown below:

```
BENT
ELEVATION TOP  153.0, 153.5, 154.0, 154.5, 155.0
HEIGHT          25.0   $ HEIGHTS WILL BE GENERATED FOR OTHER BENTS
COLUMN  'TYPE 1'  AT 2 3 4 5 6
```

Foundation Information

Modeling the connection of the columns and abutments to the foundation may be accomplished either by assuming complete fixity or by allowing for a flexible support. Complete fixity is a program default and permitting movement of the column bottoms and/or abutments is done by modelling soil as uncoupled springs. The direction of the springs is normal and tangential to the centerline of the bent and the springs are input in the FOUNDATION Data Block.

The input in the FOUNDATION Data Block is shown below:

```
FOUNDATION
AT BENT  2 3 4 5 6
  KF1  4.084E+08
  KF2  4.084E+08
  KM1  2.704E+10
  KM2  1.292E+10
  KM3  2.220E+10
```

Span Hinge Information

Discontinuities in the superstructure between bents (expansion joints) are input in the HINGE Data Block. The mathematical modeling of the expansion joint or hinge is done by using a special zero-length element that has the unique property of being able to release the moment along the centerline of the hinge. Translational connectivity is specified for a horizontal axis perpendicular to the centerline of the superstructure at the location of the hinge. In addition, longitudinal restrainers may be placed across the hinge.

The expansion joint has transverse shear keys; thus the transverse force condition is input as fixed. Longitudinally, the only restraint offered is that of the restrainers. The width of the bridge is assumed to be sufficient for transmitting torsional moment across the hinge.

The input in the HINGE Data Block is shown below:

```
HINGE
AT  3  102.00      $ HINGE IS IN SPAN 3; 102 FT FROM BEGIN.
WIDTH NORMAL  33.5
TRANSVERSE FIXEDe100 ecc100
REST NORMAL LAYOUT 'TYPE 2' 4.5,4.0,4.0,4.5 'TYPE 2 AT 1
```

Earthquake Information

The last data block, the LOADINGS Data Block, specifies information about the loads applied to the bridge. The required loading for a response spectrum analysis is an acceleration spectrum. The program has the ATC-6 spectra stored away; therefore, because the default soil type does not apply here, the only input needed to define the acceleration spectrum is the soil type. Soil Type 3 (30 ft. or more of soft-to-medium-stiff clays) is present at the bridge site. Two loading cases are desired: one along an axis connecting the two abutments (in a chord or longitudinal direction), the other transverse to that axis. Because both of these loading cases are required by ATC-6, they are included in SEISAB as a program default and no input is needed. The input to the LOADINGS Data Block is shown below:

```
LOADINGS
  RESPONSE SPECTRUM
  SOIL TYPE III
```

CURRENT RESEARCH ON SEISMIC ANALYSIS OF BRIDGES

Two current projects funded by the Federal Highway Administration were initiated to improve seismic analyses of bridges: (1) Evaluation of Improvement of Energy Absorption Characteristics of Bridges Under Seismic Conditions, and (2) Improved Mathematical Idealizations to Include Foundation Effects on Seismic Response of Highway Bridges. As part of the first project, Imbsen and Penzien extended the computer program NEABS (Nonlinear Earthquake Analysis of Bridge Systems) (Ref. 6,7,8) to include the ability to model both energy-absorbing devices at intermediate expansion joints and strain-hardening effects on yielding, reinforced concrete columns. As part of the second project, Liu and Penzien continued to enhance NEABS by including the specification of a compliance function at the boundaries that includes the effects of radiation damping and the stiffness of the foundation. As a result, more detailed correlation studies can be conducted by using the NEABS capability to accurately model the dynamic characteristics of a bridge subjected to seismic excitations great enough to cause yielding of the component members. This capability is needed to assess newly-developed strategies for seismic resistance.

CONCLUSIONS

Previous efforts by Imbsen et. al., (Ref. 9) to implement seismic design of bridges indicated that there was a need to develop simplified methodologies and computer programs to assist the designer in this task. An initial pilot workshop on SEISAB was given to a group of experienced bridge engineers from the California Department of Transportation on SEISAB. The overwhelming acceptance of the proposed methodology and the computer program SEISAB by these seasoned engineers indicates that the developed methodology will assist in implementing the newly developed ATC-6 seismic design guidelines for bridges. Development of these methodologies would not be possible without the continuing research at the universities to develop new analytical procedures and to verify those developed procedures by physical testing.

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