

VISUALIZATION OF SEISMIC BRIDGE MOTIONS

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Abstract

This paper discusses a new computer program for visualizing the animated measured response of bridge structures subjected to earthquakes. A graphical display allows the bridge to be viewed from any angle with any level of perspective and magnification to deformations. Panning and zooming are also available. Bridge behavior is measured at various locations on the structure as part to the Strong Motion Instrumentation Program. Between measured locations the bridge response is determined from spline functions consistent with structural behavior and boundary conditions. Time-history plots are also available which allow any quantity to be plotted against any other quantity, providing a powerful tool for visualizing data.

Introduction

A new computer program has been developed as part of the California Strong Motion Instrumentation Program (CSMIP) to visualize the animated response of bridge structures subjected to earthquakes. This is different from animations developed from a finite element analysis in that the results are based directly on the measured response of the structure. Between locations of measured behavior, splines are used for interpolation, allowing the entire bridge to be viewed so that the final displayed response is as smooth and realistic as possible. Of particular interest in the visualization program is that no structural modeling was used, including mass and stiffness matrices.

For this project 5 bridge structures are being investigated, including the (1) Golden Gate, (2) Vincent Thomas, (3) 5/14 Connector, (4) Painter Street Overcrossing and (5) 10/215 Connector. Since a structural model was developed and verified of the 5/14 North Connector Bridge by the PI on a prior CSMIP project [1], the development of the visualization program has centered on this structure. Two types of fundamentally different structures are being included, namely typical highway bridges with columns and spans and the more exotic suspension bridges that have 3 spans and 2 towers. For typical highway bridges the program is working properly, allowing animated views of the structure. The suspension bridge module is being finalized at the time of writing this paper.

Graphical User Interface

A graphical user interface was developed in Visual Basic [2]. The initial panel that the user sees allows the selection of one of the 5 bridges included in this study (Figure 1). If the Golden Gate Bridge button is selected, for example, then the panel shown in Figure 2 is

displayed. By further selecting the Pictures button, additional pictures of interest are provided (Figure 3).

From the initial panel the 5/14 Connector bridge is selected, as well as the pictures button, resulting in the 2 superimposed displays given in Figure 4. Figure 5 shows superimposed displays from General Plan and Instrumentation button selections, for the 5/14 Connector Bridge. Within the Instrumentation panel, the Time-History button is selected. This allows acceleration, velocity and displacement time-history results to be plotted for different time windows, as indicated by the 2 plots in Figure 6. Plotting features also allow any field to be plotted against any other field (see Figure 9). For example, displacements in the transverse and longitudinal directions can be plotted against each other providing a trace of the movement on the horizontal plane, as if watching the bridge motion traced out from above. One of traces in Figure 9 shows displacement versus velocity, as another example.

By going into 3-D plotting the bridge is displayed in full 3-D. The bridge can be rotated by typing in angles, or it can be rotated dynamically by dragging the mouse left to right and up and down. Perspective is controlled by typing in a distance that the viewer is from the bridge. The closer that the viewer is to the bridge the more exaggerated the level of perspective. In Figure 7 the perspective level is set to 2000 ft, providing the amount of distortion that would occur from viewing the structure from this distance. As the perspective distance approaches infinity the amount of distortion tends toward zero. Of course at this distance the bridge could not be seen on the screen and so the program automatically scales the size of the bridge up to the viewable area, regardless of perspective distance. A front view and a view from above the structure are provided in Figure 7. It is interesting that from above the structure, due to perspective, the columns lean in at their bases toward a common point in the distance.

All of the structure geometry is defined in the panel, with most of the information coming from the General Plan. Vertical and horizontal curve information is provided to define the alignment in 3-D space. Span lengths and column lengths are also required. While span lengths are given on the General Plan, column lengths are not and must be determined from other plan sheets. For this structure that has 2 frames, a hinge station was also provided.

Spline Techniques

In the local transverse direction the columns are assumed to act in single bending, based on a cubic curve between measured top and bottom column displacements (top of Figure 8). In the local longitudinal direction the columns act in double bending due to the restraint provided by the superstructure. However, if it were assumed that the point of inflection was at mid-height of the column, then no rotation would develop at the top of column, resulting in no rotation and, hence, no vertical displacements of the superstructure. It was assumed that the superstructure inertia is 4 times the column inertia in the longitudinal direction and that the point of inflection of the superstructure is at midspan, except for the end spans adjacent to an abutment or hinge. Based on these 2 assumptions it was found that the column point of inflection is at 55% of its height. This allowed the cubic spline to be finalized for the columns, resulting in normalized rotations at the column top as a function of relative column displacements and level of displacement magnification. An example of local longitudinal deformations is given at the

bottom of Figure 8. Here it is clear that the columns are acting in double bending and that the rotations at the top of column are the same as the superstructure rotations at the same location. This provides a realistic, smooth response to the deformations. Note that in Figure 8 the view is zoomed in near the hinge between frames, and the separation between frames is clear.

One item of interest in the level of exaggeration to deformations is that the displacements in the three global directions can be scaled to different values. For example, this allows the behavior in the transverse direction to be viewed by itself by setting magnifications in the other directions to zero.

Prior to using the splining techniques discussed above, displacement time-histories were developed in longitudinal and transverse directions at the top and bottom of each column and at the abutments. Since most of the bents had measurements for only the local transverse direction this required added splining techniques to obtain local longitudinal displacement time-histories. These splining techniques were verified in Frame 2 of the structure where local longitudinal displacements are measured at 3 bents along the frame. Local longitudinal displacements at the center bent were found by splining from the outer bents and then compared to measured results. Once local transverse and longitudinal displacements were known then these values could be rotated in to the global directions of the model for visualization purposes.

Conclusions

The initial phase of the project was to develop the Graphical User Interface (GUI) using Visual Basic (VB) for the computer program to run in Windows. The program includes 5 instrumented bridge structures to choose from as an initial database. It also permits a user to add to the database of bridges by providing geometric data such as vertical and horizontal curves found from the General Plan. The second part of the visualization program was to animate in full 3-D the measured behavior of a bridge for the duration of the chosen earthquake. Since displacements are known only at the instrument locations, and in the direction of the instrument, the remaining bridge behavior away from instrumented locations must be interpolated. The bridge superstructure and columns are represented by line elements with realistic boundary conditions and cubic splines between known results (cubic curves that are forced to obey known boundary conditions represent beam element behavior in structural analysis that are typically used for bridge design). Important boundary conditions to include are hinge locations, abutment types and pins at top and/or bottom of columns.

The program allows acceleration, velocity and displacement time-histories to be interactively viewed for all instruments on the structure. Furthermore, these quantities can be plotted against each other in any combination desired, to view behaviors or trends that are not obvious from viewing time-history data only. A good example of such a trend is the graph of superstructure acceleration at the top of a given column versus relative displacement between the top and bottom of the same column. This graph has the same shape as a force-deformation hysteresis loop for the column (vertical axis scaled by the mass) and is the best indicator of ductility demand and damage for bridge structures since nonlinear behavior is designed to occur in the columns. Such a plot also provides additional verification that the data is good, as hysteresis loops must cycle in the clockwise direction (energy is dissipated by the columns and

not created). Note that this hysteresis plot represents the force-deformation curve for the bridge column if the vertical axis is scaled by the tributary mass to the column. This is just one example of the benefit of being able to add and subtract channel results from each other and plot any quantity versus any other quantity.

The 3-D visualization requires that basic geometric information of the bridge structure be provided. Profile grade and alignment information is required, as well as the type of bridge (suspension or typical), number of spans, span lengths and footing elevations. All but the footing elevations are given on the General Plan and thus only 2 pages from the bridge plans are required to add another bridge to the database. This part of the computer program plots the structure in elevation view as distance along the bridge versus elevation of the superstructure centroid. Unit conversion is possible between ft and meters, modifying elevations, stations and distances along the bridge by a simple click of a button

Since the PI for this project was also the PI for the prior Lifeline Structure Response Project, which compares SAP [3] model responses to measured responses of the 5/14 Connector [1], it was decided that the visualization program should be initially developed for and verified against this bridge. There are two distinct advantages to using this bridge; (1) the PI is familiar with both the structure and the data as well as has the complete bridge plans available and (2) the PI has a fully developed and verified structural SAP model of the bridge, allowing comparisons outside of instrumented locations to ensure that the cubic-spline techniques realistically captures the dynamic response of the structure. By making a video of the SAP model response, direct side-by-side comparisons can be made between the (1) spline model that has no knowledge of the structure beyond its geometry and measured deformations and the (2) full structural SAP model that includes the stiffness and mass of all elements as well as the geometry.

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References

1. Dowell, R. K., *Time-History Analyses versus Measured Seismic Responses of the 5/14 Connector Bridge*, Report No. DH-04-02, Dowell-Holombo Engineering, Inc., San Diego, California, 2004.
2. Visual Basic 6, User's Manual, Microsoft Corporation, Redmond, Washington, 2000.
3. SAP2000, Version 8, User's Manuals, Computers and Structures, Inc., Berkeley, California, 2002.

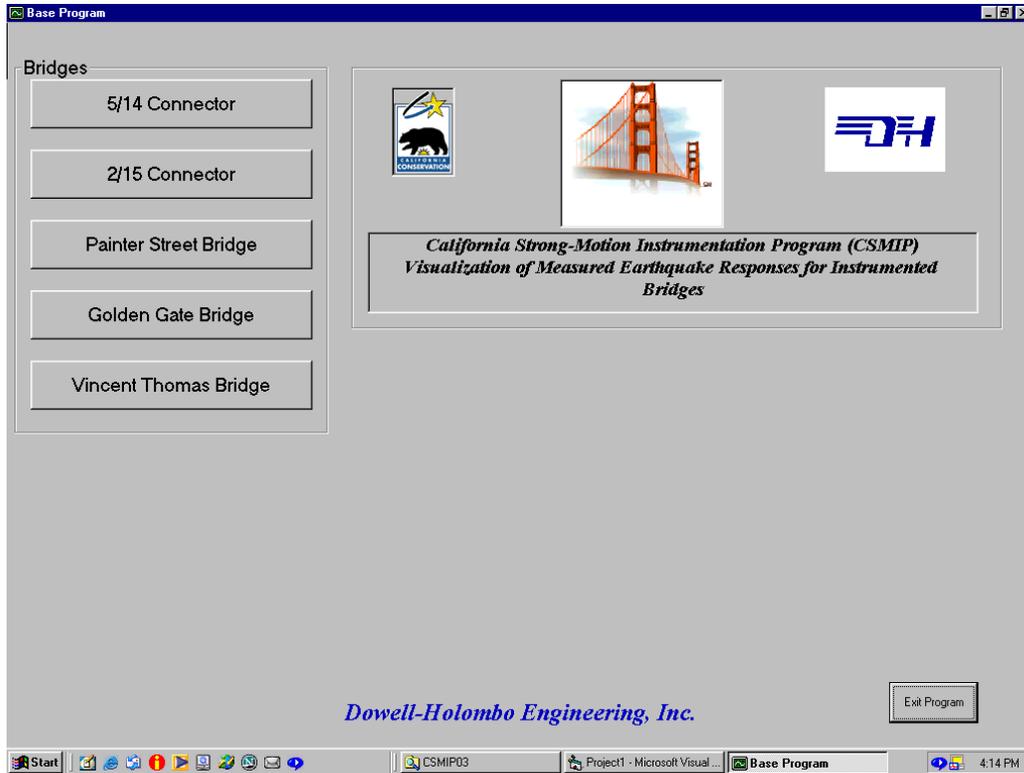


Figure 1. Graphical User Interface, Initial panel

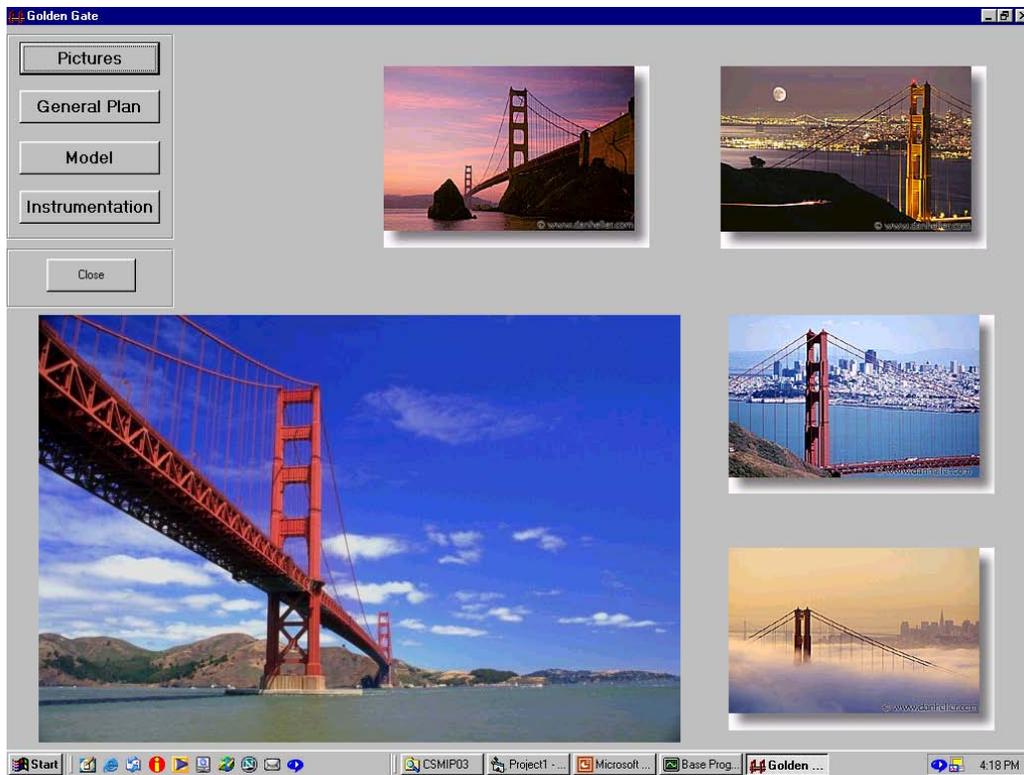


Figure 2. Golden Gate Bridge tab

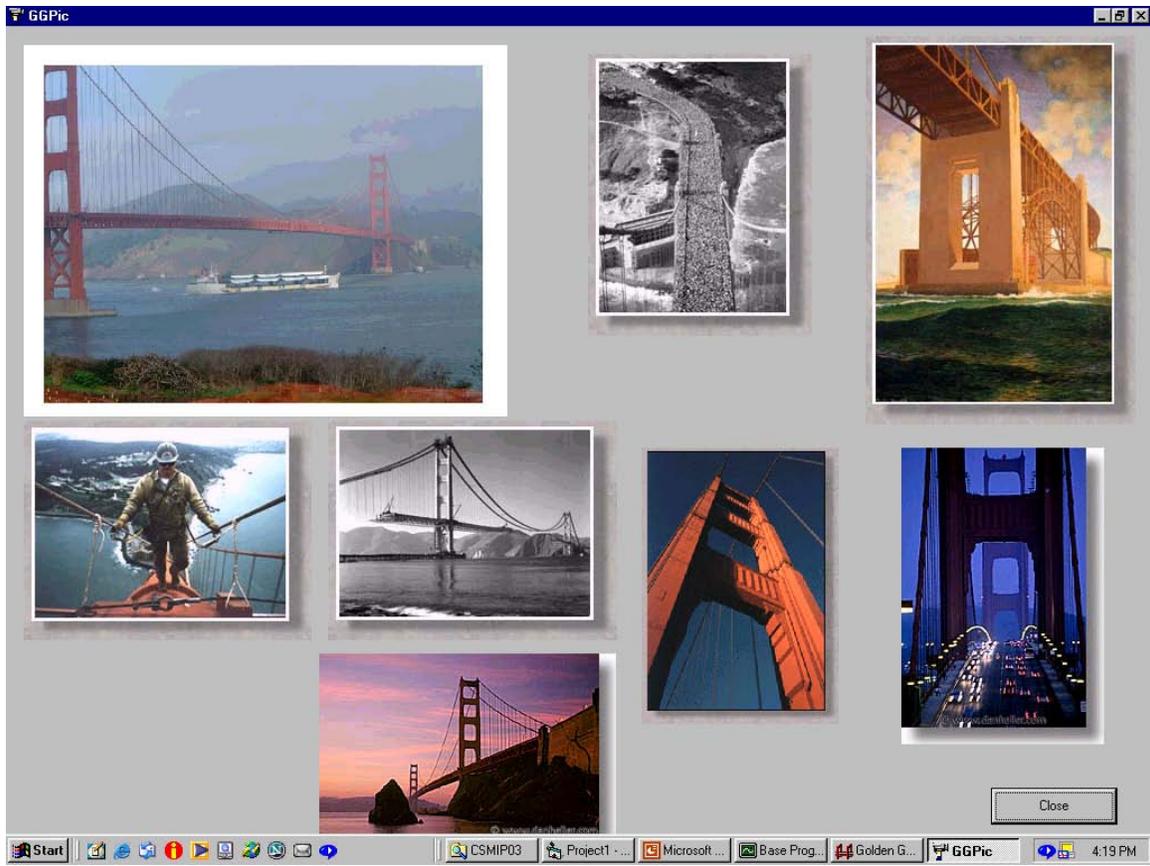


Figure 3. Pictures tab

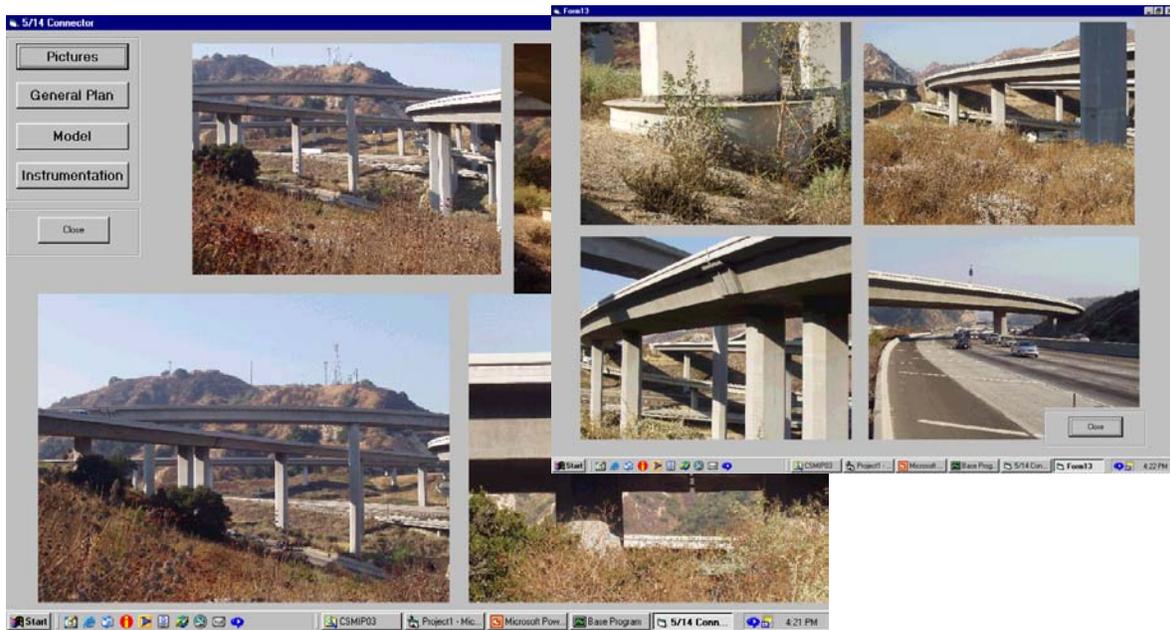


Figure 4. 5/14 Connector tab and Pictures tab

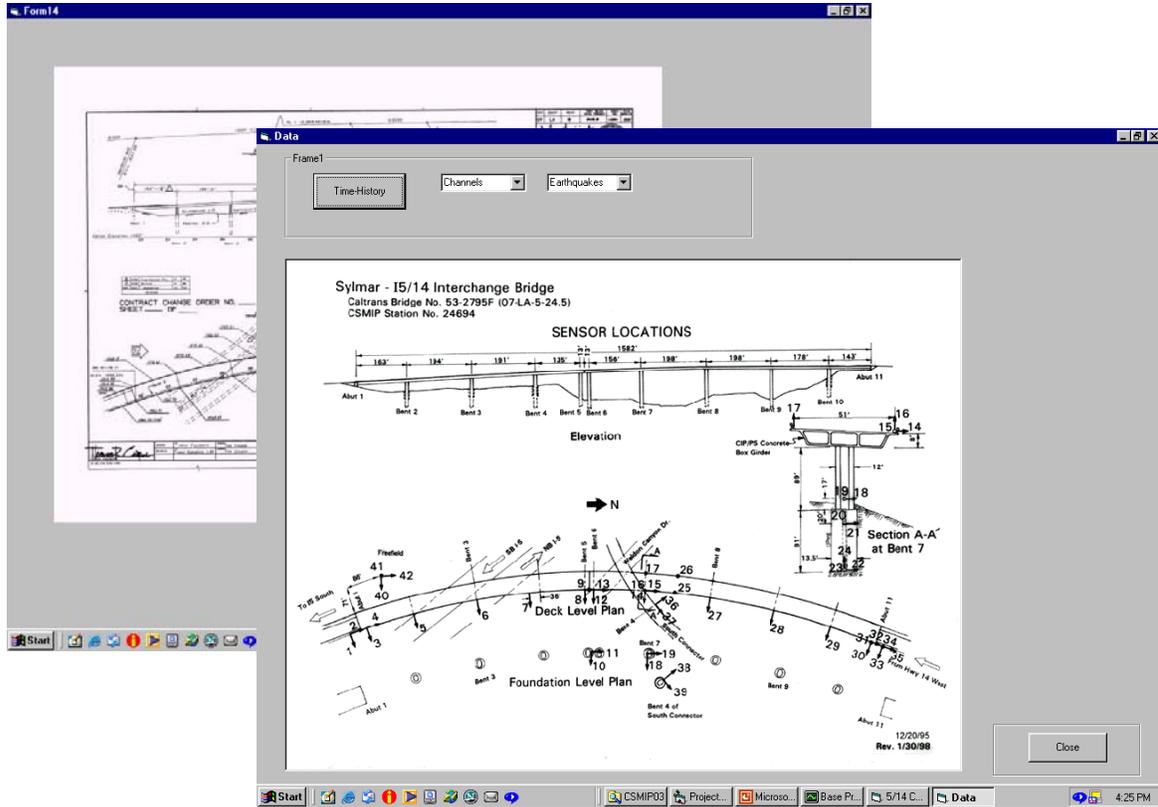


Figure 5. Instrumentation and General Plan tabs

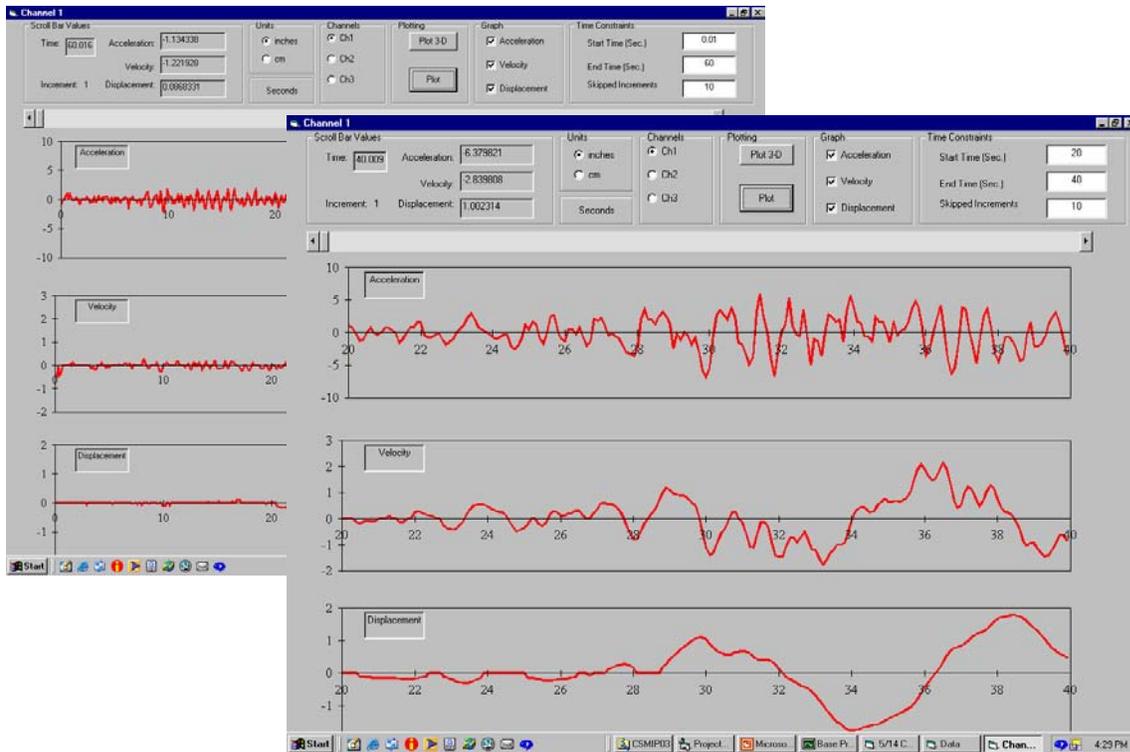


Figure 6. Acceleration, velocity and displacement time-histories with different time windows

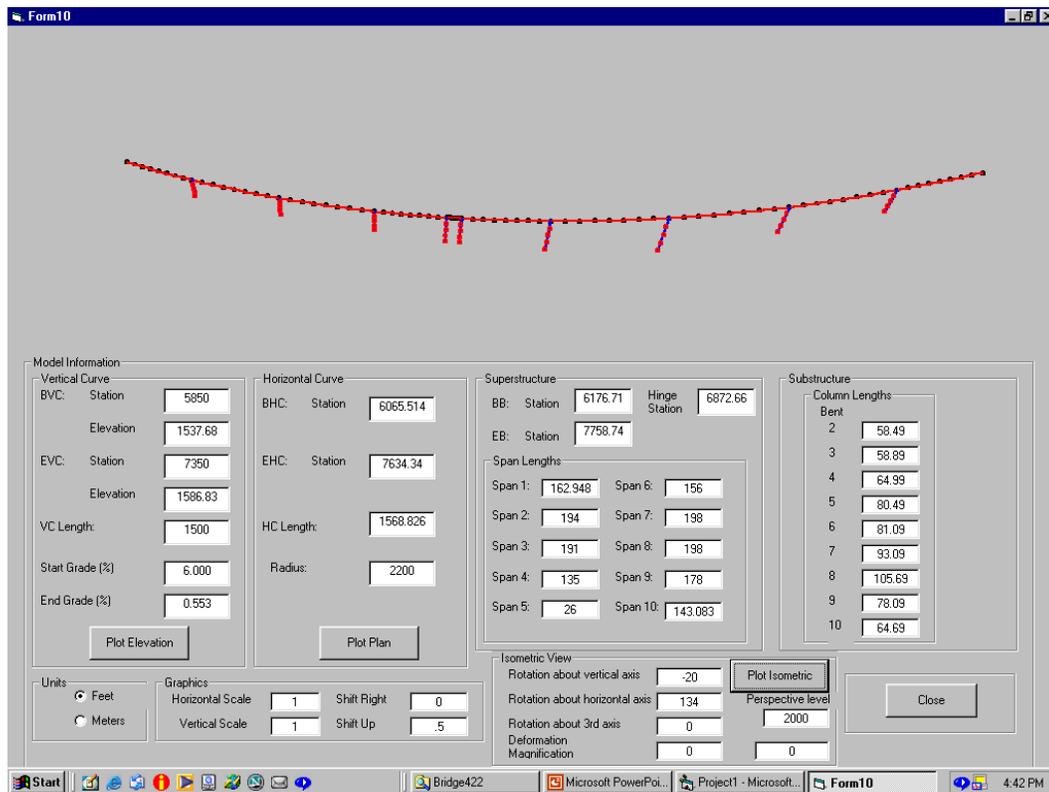
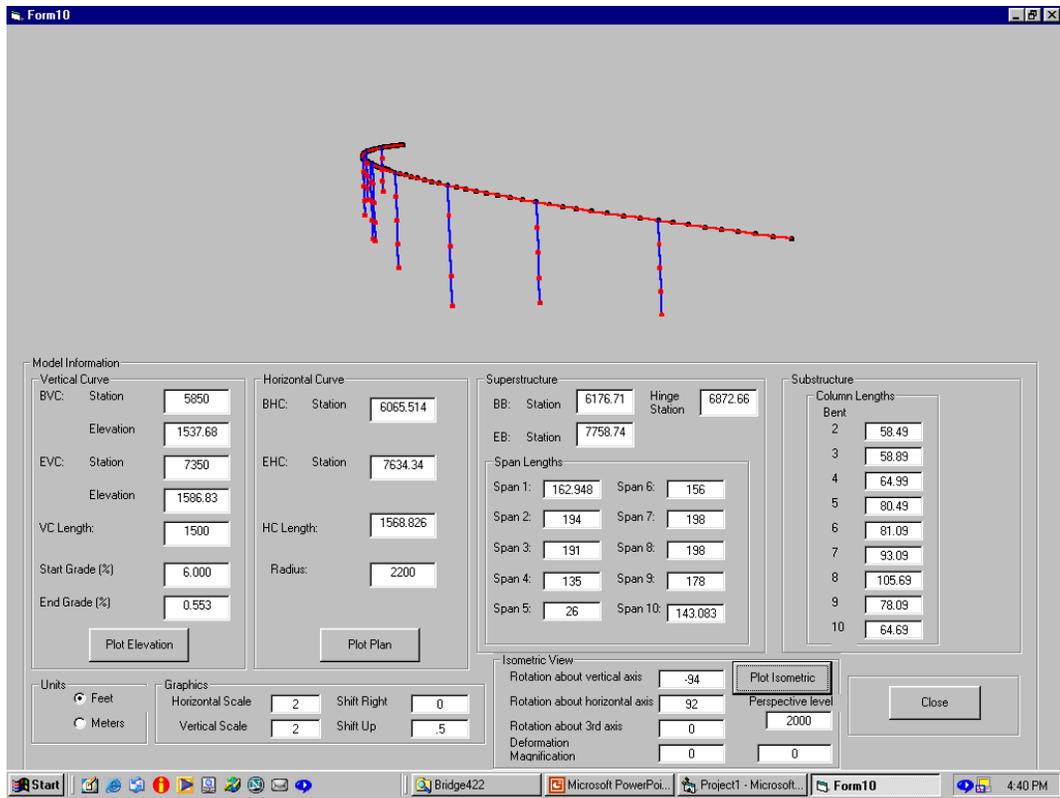


Figure 7. 3-D view of undeformed bridge from the front and from above, with perspective

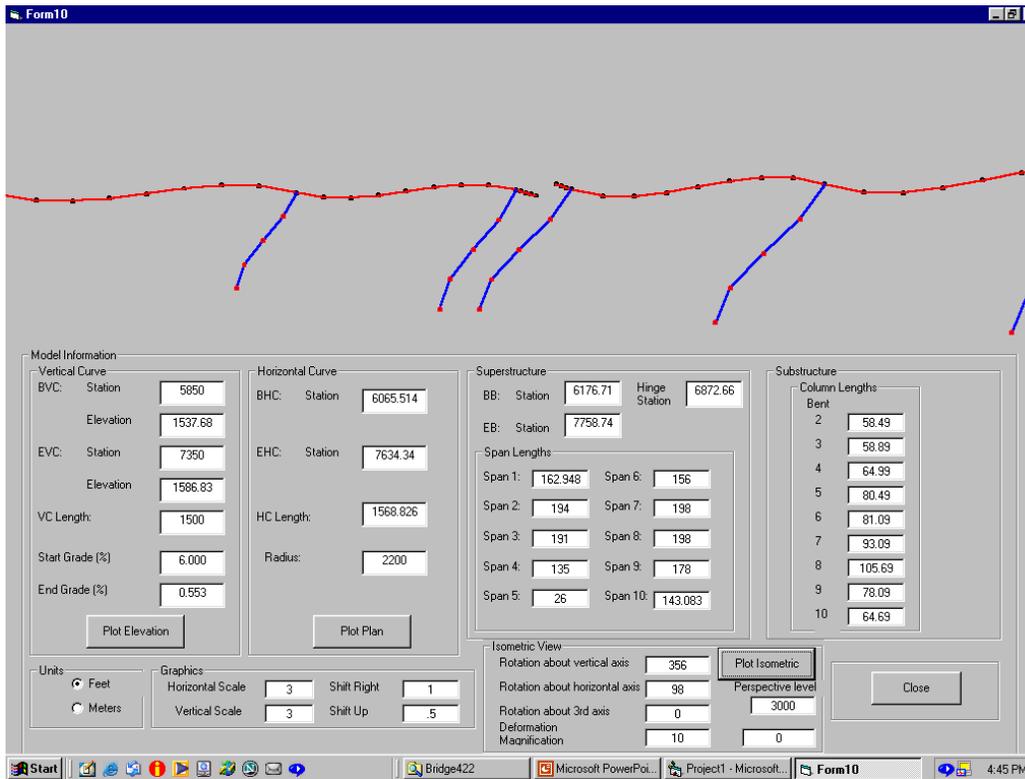
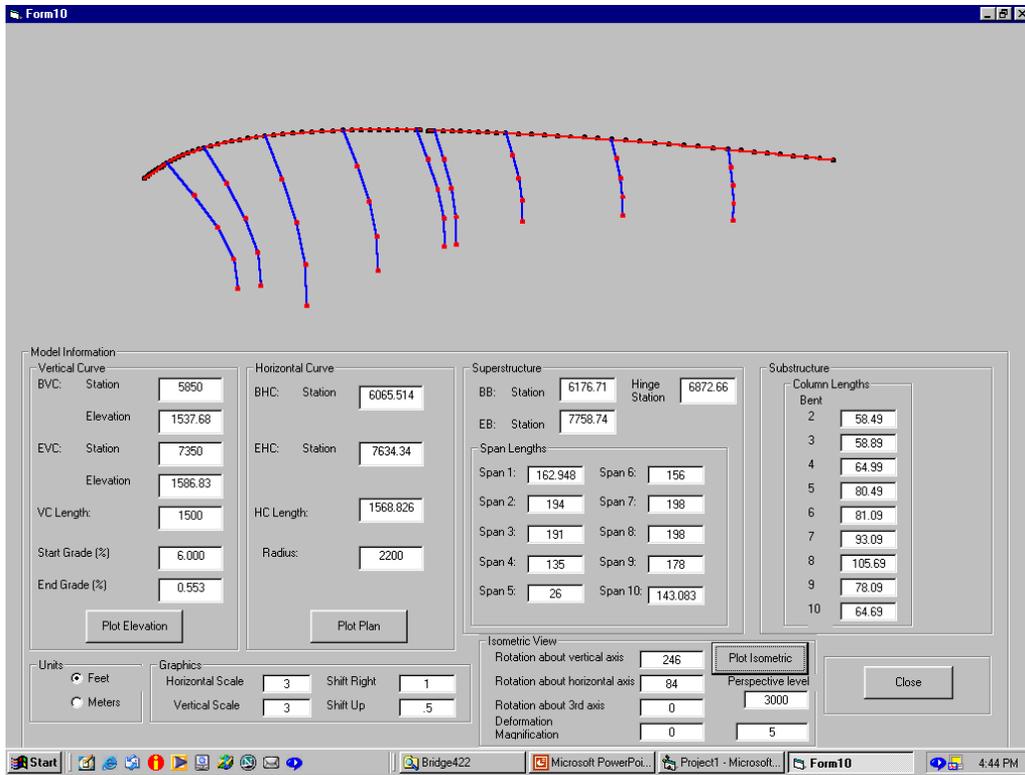


Figure 8. 3-D view of bridge, deformed in the transverse and longitudinal directions

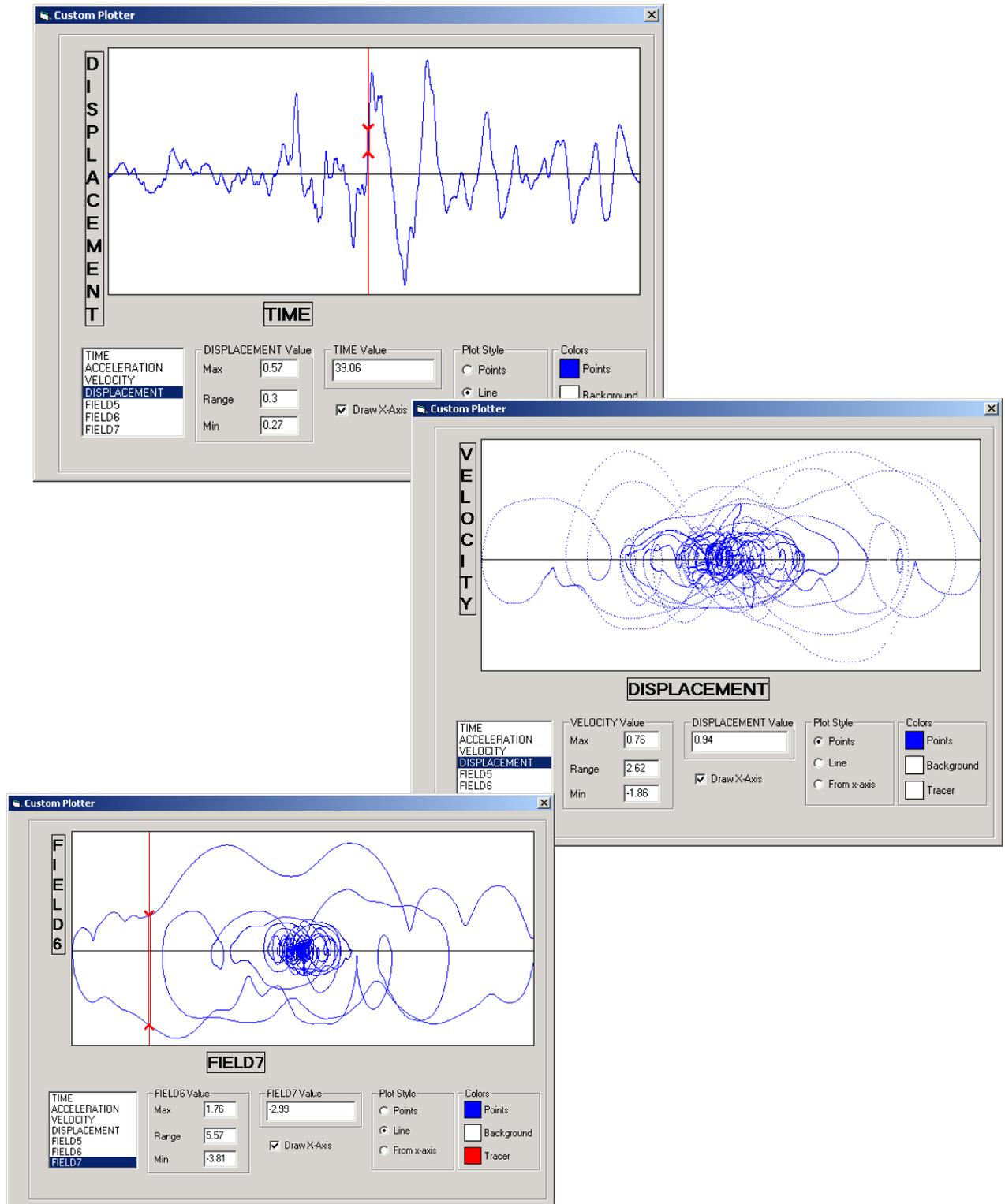


Figure 9. Examples of time-history fields plotted against other fields