I. PROJECT TITLE

Analysis/Design Software for Assessment of the Performance and Capacity of Reinforced Concrete Bridge Piers (KSU_RC): Phase I Upgrade

II. INTRODUCTION

Bridges are pillars of the transportation infrastructure in rural or urban areas. Realistic simulation of the performance; as well as evaluation of the strength and displacement capacity of reinforced concrete bridge piers are basic needs for design and/or decision on retrofitting/replacing existing deficient bridges. It is well known that the values calculated based on the code using conventional analytical methods **are not realistic and in most cases very conservative**. The PI tested a reinforced concrete beam under a simple monotonic lateral load, and the nominal capacity calculated based on the ACI code, was less than 50% of the real capacity. On the other hand, experimental facts have shown the significant effects of loading pattern on the performance and real capacity of reinforced concrete structural elements, especially bridge piers. There are cases where the **actual capacity under a certain load pattern is much less than the predicted capacity in design**[1]. So the **design is unsafe** and un-conservative.

The **loading scenarios** experienced by **bridge piers are not** always of a **conventional type**. Axial load can be proportional or non-proportional to the lateral force or displacement. The lateral forces and displacements may not be monotonic especially for dynamic excitations.

Prediction of the **real performance** of a column under the aforesaid loading scenarios, is **beyond a monotonic linear or even non-linear push-over analysis** and requires analysis of the **hysteresis (cyclic) moment-curvature and force-deflection response** of the section and member, which in turn, requires realistic monotonic non-linear material models as well as **hysteresis rules** for the material, including plain and confined concrete, and longitudinal and lateral steel. Some of the existing professional, educational or commercial software do at most a push over non-linear analysis and do not have the capability of a cyclic analysis under independently-variable axial load, hence, their prediction does not include realistic load effects which may be very significant and un-conservative in some cases.

III. BRIEF HISTORY OF KSU_RC

To address the aforesaid analytical needs required for an intensive experimental and analytical research program on performance of bridge piers under various loading conditions[2], the PI has developed a windows-based computer application[3] that can be used for a more accurate and realistic assessment of performance and capacity under any load/displacement condition using

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[1] Esmaeily A., Xiao Y., "Behavior of Reinforced Concrete Columns under Variable Axial Loads: Analysis", American Concrete Institute, ACI Structural Journal, Vol. 102, No. 5, Pp. 736-744, September-October 2005

[2] Esmaeily A., Xiao, Y., "Behavior of Reinforced Concrete Columns under Variable Axial Loads", American Concrete Institute, ACI Structural Journal, Vol.101, No.1, pp.124-132, January-February 2004

[3] http://www.ce.ksu.edu/faculty/esmaeily/KSU_RC.htm

the most recent analytical methods and models at the time[4] (1997-2001). The program **was benchmarked** against experimental data from a number of reinforced concrete bridge columns tested under a wide range of loading patterns, including non-proportional axial load and cyclic lateral displacement.

The first version of the program, named USC_RC, was based on a console application written in FORTRAN by the PI, which was later converted to a dynamic link library when the graphical interface was added to the application. USC_RC as well as USC_Viewer as a "by product" of USC_RC, are available on the University of Southern California, Structural Laboratories website (to where I do not have any access)[5]. KSU_RC was the next generation of USC_RC with more analytical models and options. This transformation was possible by using a part of my startup to provide necessary resources, including my first graduate student who graduated early 2004. KSU_RC is used by private and public professional and educational institutes, including KSU, for the PI's "advanced reinforced concrete" course. Considering the demanded web traffic, in 2005, College of Engineering dedicated enough space on the engineering servers to host this application. However, KSU_RC, while currently used by various educational as well as professional private and public Institutes and agencies, **including a number of DOTs**[6], needs an upgrade for compatibility with Windows Vista and the upcoming Windows 7, and can be further developed to revise the interface and expand the analytical options.

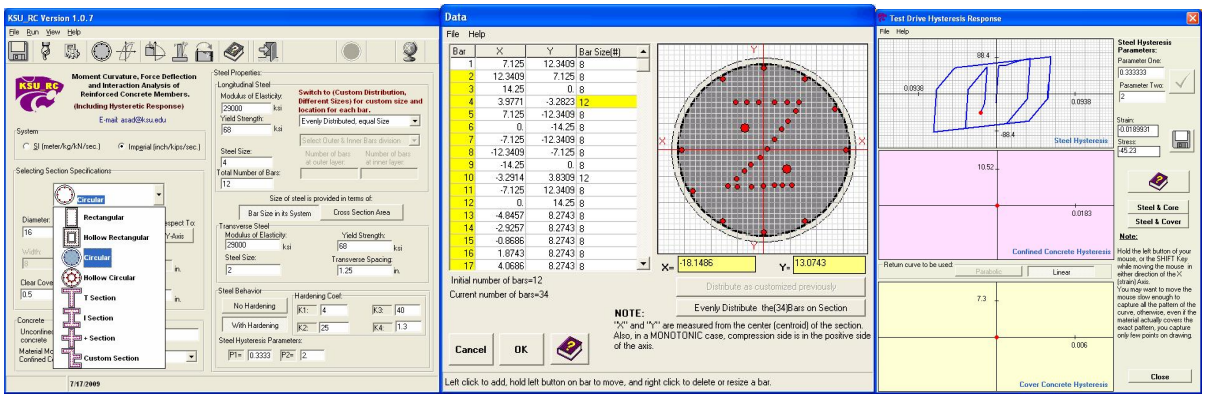

Figure 1: Snapshots of the existing KSU_RC main window, Section Customization and Material Exploring Windows

IV. OVERALL LONG-TERM OBJECTIVES

Following, is a list of overall long-term objectives that will upgrade the program to its next level of functionality:

1) Upgrading the program for compatibility with Windows Vista and the upcoming Windows 7, and revising the programming language towards a more object-oriented

[4] "Performance Analysis Tool for Reinforced Concrete Members", Journal of Computers & Concrete, October 2007, Vol.4, No. 5, Pp 331-346

[5] http://www.usc.edu/dept/civil_eng/structural_lab/asad/index.htm

[6] A list of some private companies, public agencies (such as DOTs), schools and graduate students who have used KSU_RC as their professional/educational/research analytical tool is available upon request

algorithm. Addition of web-based functionality to KSU_RC is considered as a future step, when needed.

2) Revision of the program interface, and increasing the efficiency of saving and retrieving data. An Active-X control has already been developed by the PI to visualize 2-D data in any format which will be implemented into the pertinent interface.
3) Revision to accommodate more analytical options as an object-oriented application, and more analytical models such as:
   a. more recent material models, including a custom model
   b. more hysteresis rules for the material cyclic response
   c. more sections including a custom section
4) In addition to the existing Fiber Model based Moment-Curvature, Force-Deflection and Axial force-Bending Moment Interaction analysis, add code-based methods with and without confinement effects (used for "real" and "code" capacity assessment) for:
   a. monotonic moment-curvature and force-deflection under constant or proportional axial load
   b. capacity assessment based on the code (AASHTO, ACI)
5) Expansion of the existing Axial Force-Bending Moment Interaction to include an option for which each point is the maximum capacity achieved from a moment-curvature analysis for the given load history and axial load. This will give a realistic interaction curve, which is not based on a pre-assumed strain distribution
6) Adding a "Virtual Laboratory" component (making a virtual test possible by a click and move of the pointer) that can serve not only for performance assessment but also research activities related to:
   a. Parametric study on material models and analytical methods, as well as hysteresis rules
   b. Calibration of analytical models and methods against experimental data
   c. Performance of various confinement (material, application method and location, etc)
7) Expanding the capability of both "displacement controlled" and "force controlled" analysis

V. PROPOSED OBJECTIVES FOR THIS PHASE OF UPGRADE:

As the first phase, it is proposed to revise and develop the KSU_RC application further with the following objectives:

1) Upgrading the program for compatibility with Windows Vista and the upcoming Windows 7, and revising the programming language towards a more object-oriented algorithm
2) Revision of the program interface, and increasing the efficiency of saving and retrieving data
3) Accommodate more options for the existing Moment-Curvature, Force-deflection and Axial Force-Bending Moment Interaction analysis. In this phase, based on the budget limitation as discussed on October 1st 2009 with Dr. Stokes, the PI will be his best to include addition of code-based methods with and without confinement effects, if possible, for:
   a. Moment-Curvature response (monotonic)
   b. Interaction curve

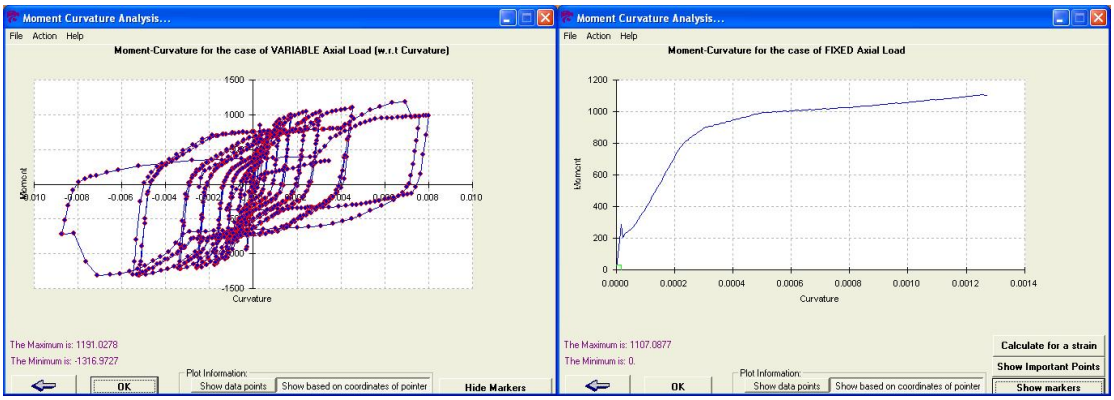

Figure 2: Two sample analysis results for a cyclic (under constant axial load) and a monotonic (under proportional axial load) moment-curvature for a rectangular section reinforced based on ACI 318-08 code

VI. ESTIMATE OF FUNDING AND RESEARCH PERIOD FOR PHASE I:

The budget needed for this research program is estimated as $20,000 over a time period of "one year".

KSU_RC can be provided by UTC (via the UTC website) to be used by public and private institutes. KSU_RC and its further development in terms of analytical models, methods, options, and user interface can potentially be used as a valuable analytical tool for research on **sustainability of reinforced concrete bridge piers**, aligned with the **UTC mission**. The budget will include payments for a graduate student.

VII. URGENCY, PAY-OFF POTENTIAL AND AGREEMENT WITH THE UTC GOALS:

The proposed work should have a high priority for UTC. KSU_RC will serve as a detailed analysis tool that accounts for the actual capacity; and the effects of material and loading pattern on columns having various sections. It can also be used as an analytical research tool as mentioned. In general, KSU_RC will be a **valuable contribution** to the transportation community and can serve the **sustainability of transportation infrastructure** by providing realistic assessment of the performance and existing capacity of bridge piers.

VIII. IMPLEMENTATION STRATEGY:

The results of the proposed program, which will be the next version of KSU_RC, compatible with Windows Vista and Windows 7 with an upgraded graphical interface and more functionality, will provide UTC and other agencies in the field of rural and/or urban transportation, with a valuable tool to assess the actual capacity and real performance of reinforced concrete structural members, especially bridge piers with different geometry and material properties, under various types of realistic loading conditions. The application can also be used for parametric studies or experimental validation of material models and related analytical methods. Some **policy can be published for downloading and using the program.**

IX. PROJECT PERSONNEL:

The Principal Investigator for this research program will be Dr. **Asad Esmaeily**, to whom KSU_RC is copy righted. He is a registered Professional Engineer and holds a Ph.D. in Civil/ Structural Engineering and two MS's in Earthquake and Electrical Engineering from University of Southern California. He has more than 15 years of experience in the experimental and analytical studies on structures, including experimental and analytical work on bridges in general and bridge piers in particular, material modeling, prestressed concrete, etc. He has also conducted research on cost-effectiveness of bridge types, as well as, analytical and experimental research on signal based damage detection using limited input/output signals, sensor networks, and remote sensing projects. He has developed a number of computer applications in different areas of civil engineering, especially structures and reinforced concrete structural members. In addition, a qualified graduate student will be involved in this research program.

X. SUBMISSION INFORMATION:

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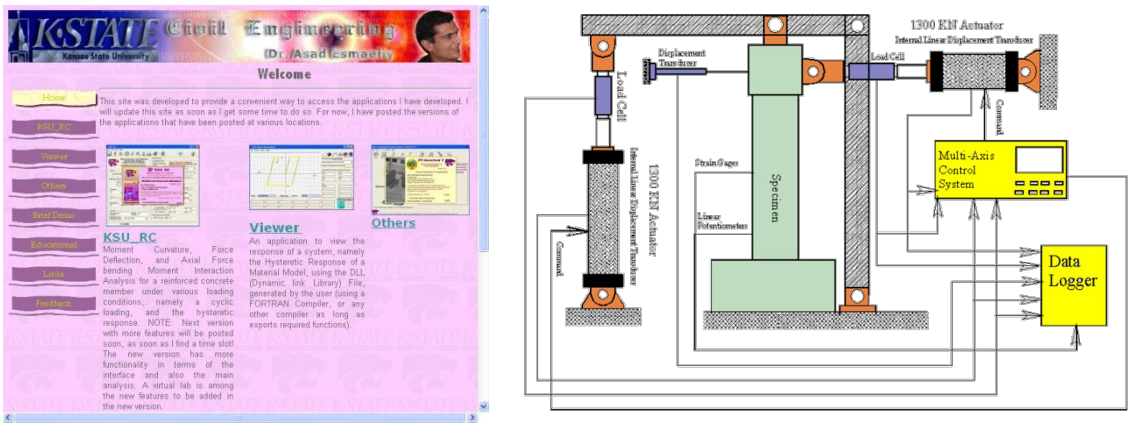

Figure 3: A snapshot of the PI's site developed to host KSU_RC and other applications; and the test setup for 12 RC columns, results of which were used as a benchmark to validate analytical results of KSU_RC