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Reliability Verification for Virtual Design Analysis

Ehsan Mirnateghi[1, 2+] and Joe Satkunananthan[2]

[1] Department of Civil Engineering, University of California, Irvine, 92697, USA
[2] MSC.Software Corporations, Santa Ana, California, 92707, USA

Abstract. This paper verifies the reliability of virtual design analysis in structural applications. To this end, we obtained the experimental data from the original experiment that was tested in the C. L. Powell Structural Research Laboratories at University of California, San Diego. We performed a finite element analysis (FEM) to reconstruct the quasi-static standard SAC/multi-step loading history on a cantilever steel beam (W30x99) using MSC Marc. Upon completion of this FEM analysis, we verified the comparability of our results with the original experiment. This study simulated the original experiment reaction force with an error of 3.6%, and the maximum reaction moment with an error of 0.62%. As a result, a costly full scale experiment that only could have been done in a few laboratories around the world was simulated and studied to minimize the cost expenditure of resources.

Keywords: Finite Element, Virtual Design, RBS, Green Experiment, Model Verification

1. Introduction

The FEM was first developed by Richard Courant in 1943 to obtain approximate solutions for vibration systems. Later, in the 1950s, major studies were performed on the stiffness and deflection of complex structures using FEM and numerical analysis [2]. Currently, with the invention of fast computers, which can undertake numerical analyses with an incredible precision, the role of FEM has evolved in engineering applications. For example, industries are now using FEM for design verification and testing prior to manufacturing or construction.

The objective of this paper is to compare the observation and results from a costly full-scale testing of a steel beam in a laboratory to the FEM virtual analysis completed using MSC Marc. The full-scale test was done in C. L. Powell Structural Research Laboratories at University of California, San Diego (UCSD) in 1998 [1]. During this experiment, the standard SAC/multi-step loading history was used for the quasi-static testing of a steel beam, W30x99 [3]. The 3-dimensional (3D) Computer Aided Design (CAD) model of the experiment was developed using SolidWorks (SolidWorks Corp. Wolthham, MA, USA) and the simulation and analysis was conducted using MSC Marc 2012 (MSC Software, Santa Ana, CA, USA)

2. Methodology

The 3D CAD model of the 150” steel beam (W30x99) was modelled (Fig 1) using a reduced beam section (RBS), as specified in the lab report of the original experiment (Fig 2). The CAD model was imported into Patran (MSC Software) as a parasolid file for pre-processing. Using Patran, the model was meshed into approximately 4” elements in a hybrid pattern (Fig 3).

+ Corresponding author.
E-mail address: emirnate@uci.edu

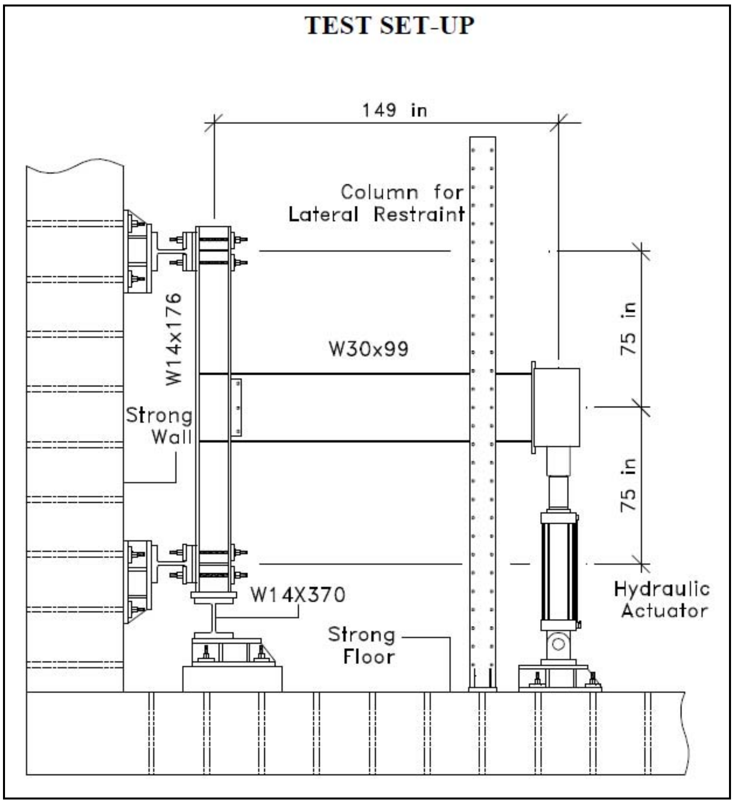

Fig. 1: Test setup in the original experiment in the UCSD Lab from Uang et. al [1] [4].

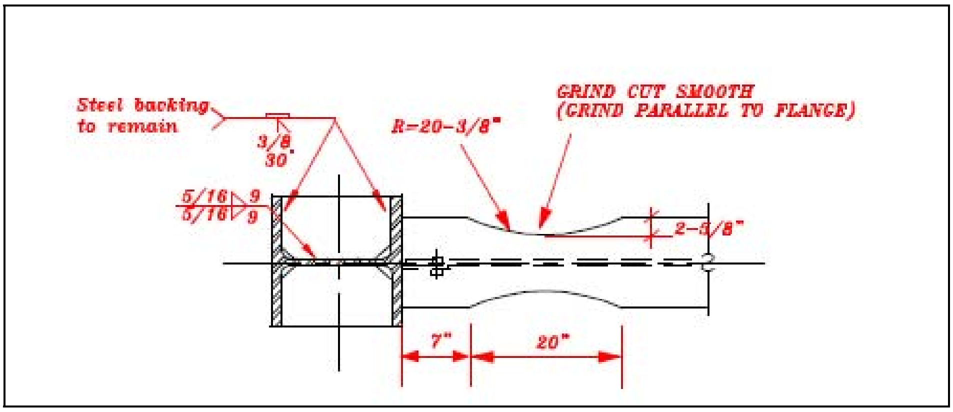

Fig. 2: RBS details at the face of the column from the UCSD Lab report by Uang et. al [1] [4].

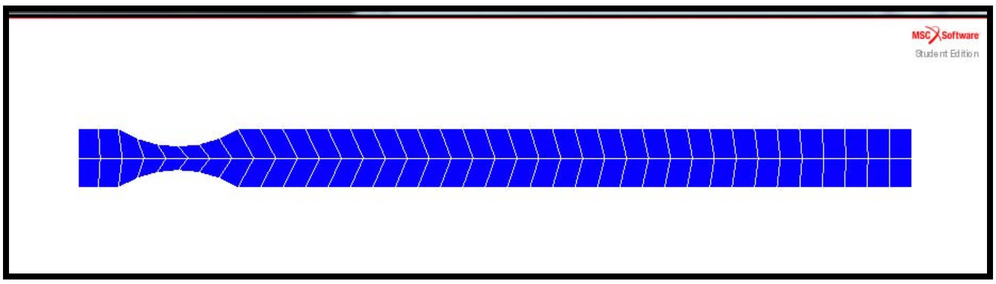

Fig. 3: Steel beam imported and meshed in Patran (top View).

In accordance with the original test setup, the following boundary conditions were added. Instead of adding the boundary conditions to the individual nodes at the ends of the beam, two rigid plates were added to control the deformation of the nodes (see Fig 4). By adding these plates to the face of the column and the loading plate, the simulation and its accuracy were improved.

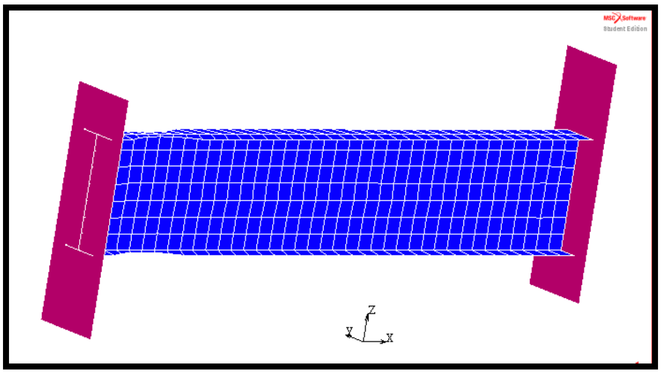

Fig. 4: Added rigid plates used to control the support and loading on sides of the beam.

We defined a controlling node to provide a rotational degree of freedom on the y-axis of the loading plate. The standard SAC/multi-step loading history was defined (Fig 5) and applied to the tip of the cantilever beam. The inter-story drift angle was converted to displacement using the length of the beam (e.g. 0.05 rad x 150" = -7.45").

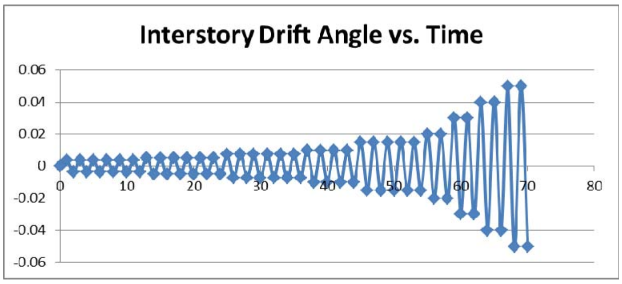

Fig. 5: SAC/multi-step loading history.

Consistent with the original lab report, ASTM A992 steel was used in the simulation. For this test, hardening was the main issue due to repetitive loading. Isotropic and kinematic hardening were both used and then compared to the result from the original experiment (see Fig 7). Finally, the model was submitted to MSC Marc for nonlinear analysis.

3. Simulation and Verification

The result of the model was post-processed by Marc Mentat (MSC Software), where different fringe plots and graphs were obtained (see Fig 6). The fringe of the deformed beam is shown below in its last step at the 7.45" tip deformation.

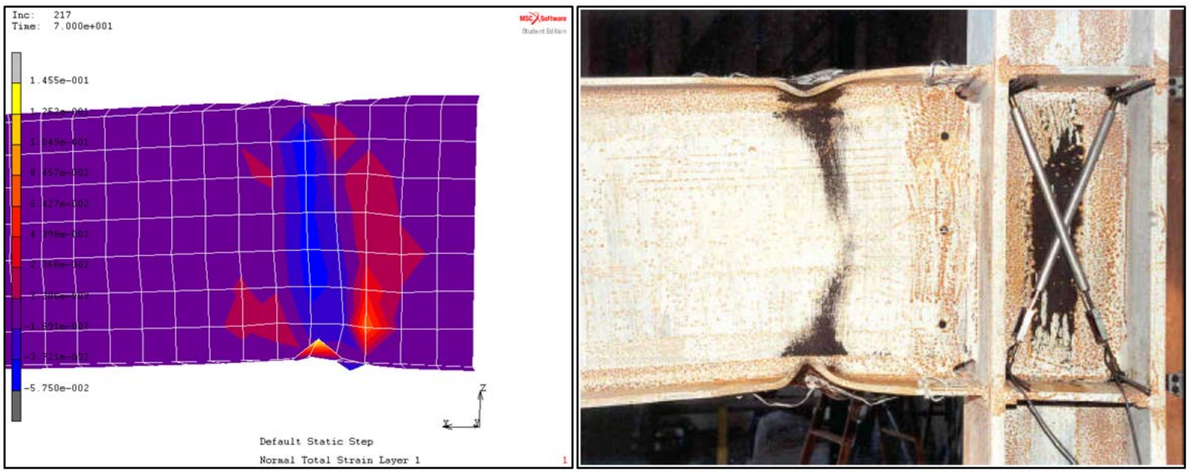

Fig. 6: Comparison of the model vs. the experiment at 5% drift.

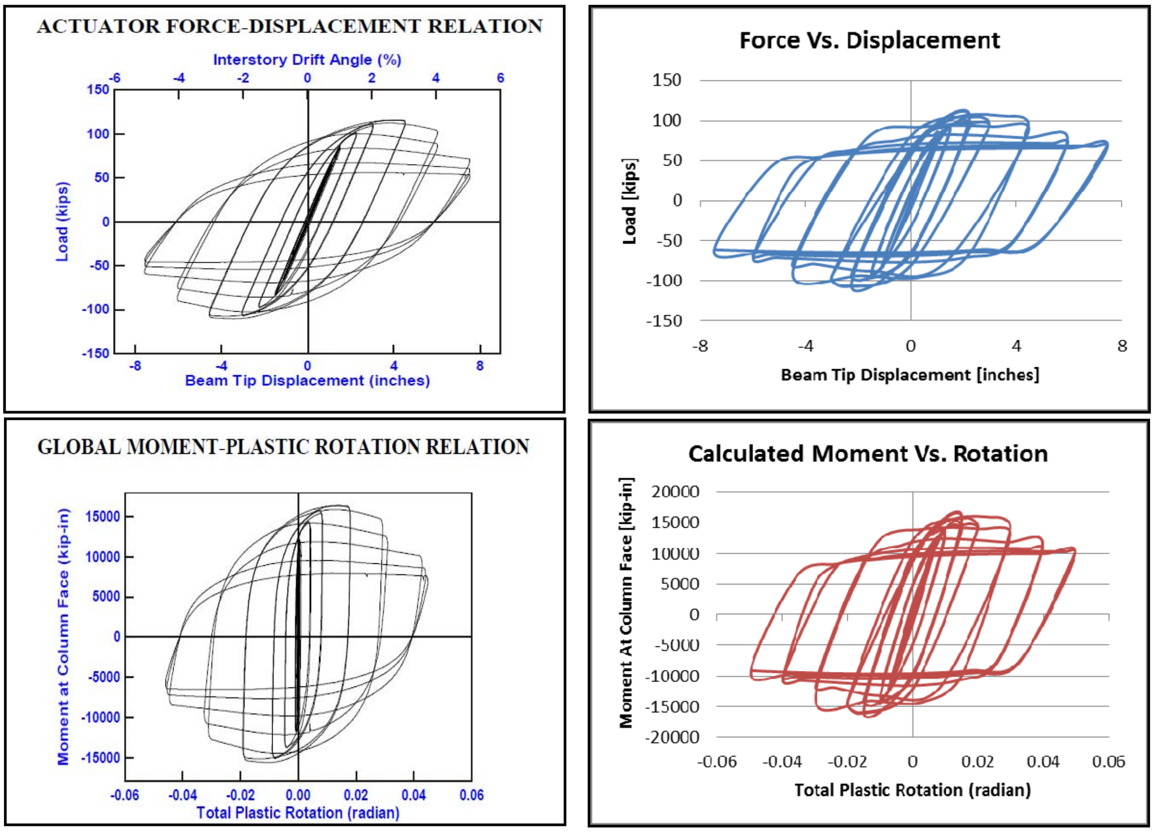

Fig. 7: Comparison between experimental (right) vs. virtual analysis by MSC Marc (left).

4. Conclusion

The reaction forces that I obtained from MSC Marc are very close to the results of the experiment as seen in Fig 7. The kinematic hardening better simulated the original experiment. The maximum reaction force in the original experiment was 106kips, whereas the simulation's maximum reaction force was 110kips. At the same time, the maximum reaction moment in the experiment was 16000kip-in, whereas the maximum reaction moment in simulation was 15900kip-in for simulations with kinematic hardening. This study simulated the original experiment reaction force with an error of 3.6% and the maximum reaction moment with an error of 0.62%. In terms of buckling of the web during the loading, the result of the experiment and simulation are comparable with respect to the deformation at the tip of the beam in that moment. These results verify the value and accuracy of virtual analysis for designing and testing in various engineering fields while optimizing resources. In the future, these analyses can be supplemented with additional simulations for numerical evaluation of the eigenvalues for a beam's buckling analysis.

5. References

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