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The John A. Blume Earthquake Engineering Center

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WELCOME!

Welcome to all our new and returning students for the 1999-2000 school year. It is an exciting time for the Stuctural Engineering and Geomechanics Program and The John A. Blume Earthquake Engineering Center!

In June, we launched The Blume Center's redesigned web site. Its new design is exciting and easier to navigate, along with providing more information about The Blume Center and Dr. Blume. It will be updated frequently with information on seminars and special events, as well as a page devoted to our Affiliates and Donors. In February, we will begin posting student resumes and job announcements from our Affiliates. There will be more information on this in the next newsletter. Please take a look at *http://blume.stanford.edu.*

Two new faculty members are joining the Structural Engineering and Geomechanical Program this year. See the profile on **Charles Menun** on page 4, and look for a profile on **Eduardo Miranda** in the next newsletter.

Finally, we are excited to have the Geotechnical Lab sharing space with us, as well as several new and relocated students. We look forward to a fun and exciting year!

GEOTECH LAB MOVES TO BLUME CENTER

Beginning in the Fall Quarter of 1999, geotechnical lab students will be testing soils in the newly constructed Geotechnical Laboratory located in the basement of the Blume Earthquake

Engineering Center. The new lab houses a number of recently purchased equipment including two triaxial load frames and panels, a pneumatic direct/residual machine, and an automated soil compactor. A liquefaction device designed with automated drainage control also has been built for use with the shaking table facility available in the adjacent Structural Lab.

BLUME CENTER NEWS

Professors Laura Lowes, **Charles Menun** and **Eduardo Miranda** were named as 1999-2000 Frederick E. Terman Fellows. The awards are given to promising young faculty in the sciences and engineering at Stanford University.

Professor Kincho Law received the Best Paper Award from the ASCE Journal on Computing in Civil Engineering: "Client/ Server Framework for On-Line Building Code Checking", C.S. Han, J.C. Kunz and K.H. Law; Journal on Computing in Civil Engineering, ASCE 12(4): 181-194, 1998.

Six students received their Ph.D. degrees for Structural Engineering in 1998-99: **Nilesh Shome**, now working at EQE; **Hoon Sohn** now at Los Alamos National Laboratory; **Akshay Gupta,** Failure Analysis; **Ali Al-Ali**, RMS; **Abhijit Kakhandiki** now working at SAP Labs, Inc.; and **Luciana Barroso**, Assistant Professor at Texas A&M University.

On July 15-16, **Professor Anne Kiremidjian** presented a paper on Earthquake Engineering Data Issues at the CODATA workshop in Paris, France.

Professor Greg Deierlein chaired a session and presented a paper on composite RCS frame systems at the 6th JTCC Meeting of the US-Japan Cooperative Research Project on Composite and Hybrid Structures held in San Francisco on August 1-4.

Professors Helmut Krawinkler and **Allin Cornell** participated in a US-Japan Program workshop in Maui (sponsored by PEER) on Performance Based Design for Earthquakes in August.

Professors Anne Kiremidjian, Greg Deierlein and **Professor Emeritus Haresh Shah** participated in the FEMA organized NEHRP Strategic Plan Implementation Workshop held in Washington DC on September 1-2.

Professor Anne Kiremidjian presented a paper on Rehabilitation Decisions of Historical Structures at the Workshop on the Preservation of National Monuments and Treasures on September 27-28 in Rome, Italy.

RESEARCH SPOTLIGHT

Fracture Toughness Demands in Welded Beam-Column Connections

Wei-Ming Chi, Ph.D. Candidate & Gregory G. Deierlein, Associate Professor

Sponsored by FEMA through the SAC Joint Venture

Introduction

Investigations since the 1994 Northridge earthquake have established that cracking in welded steel connections resulted from a combination of factors – most notably, high strain demands coupled with large inherent flaws and stress risers, deficient field welding, and over-reliance on low-toughness materials. Strategies to improve connections consist of reducing fracture *demand* and increasing the *available* material toughness. Toughness demand can be reduced to some extent by removing weld-backing bars and minimizing defects through better quality control. More extensive measures involve reconfiguring the connection, such as with a reduced beam section (dogbone) detail, to shift regions of high stresses and strains away from the fracture critical weld. Through finite element fracture mechanics analyses, our objective is to investigate cause and effect relations between detailing parameters and fracture demands necessary for the development of fracture resistant connections.

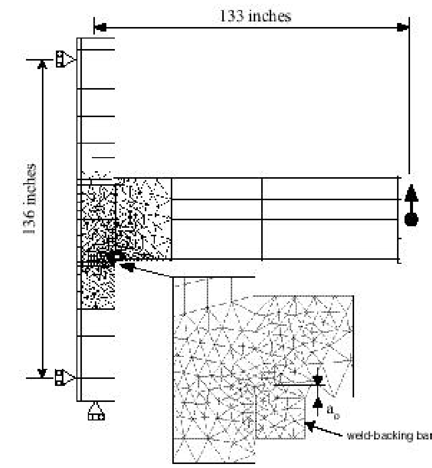

Fig. 1 - FE model of beam-column connection

Fracture Indices and Analysis Models

As shown in Figure 1, our approach utilizes detailed elastic and inelastic finite element analyses to calculate fracture demands at critical flaw locations in welded beam-column connection details. In the case shown, the initial flaw (or crack) is created by the gap behind the weld backing bar and associated weld root defect of length, a_o. Note the high mesh refinement necessary to accurately simulate the severe stress and strain gradients at the crack tip.

Toughness demand is quantified in terms of two fracture indices: stress intensity factor, K_I, and Crack Tip Opening Displacement, CTOD. The stress intensity factor describes the general magnitude of stresses surrounding the crack tip and is a valid index when elastic conditions predominate. Elastic fracture is assumed to occur when the calculated stress intensity factor exceeds a critical value, i.e., $K_I > K_{IC}$, where K_{IC} reflects the energy release rate necessary to propagate the crack. The CTOD is more indicative of inelastic behavior, and its critical value, $CTOD_c$, represents the maximum opening (or blunting) of the crack tip at incipient tearing. The indices, K_I and CTOD, are calculated via a J-integral approach, which is a convenient numerical procedure to apply in the finite element analyses.

Because ASTM tests for K_{IC} and $CTOD_c$ are relatively expensive, material toughness is more commonly measured in terms of absorbed fracture energy from impact testing of Charpy-V Notch (CVN) specimens. This is reflected in building codes, such as the 1999 AISC Seismic Specification that specifies a minimum CVN toughness of 20 ft-lbs at 70^{o}F for base metal and higher values for welding electrodes. As summarized in Table 1, CVN toughness can be roughly correlated to K_{IC} and $CTOD_c$ using empirical relationships. The lower range of CVN values in Table 1 are typical of low-toughness E70T-4 welding electrodes (commonly used before the Northridge earthquake) and the higher range is for base and weld metals that are more representative of post-Northridge building construction.

Table 1 – Typical Material Toughness Values

CVN (ft-lb)	K_{Ic} (ksi $\sqrt{in}$)	$CTOD_c$ (in)
5 to 10	40 to 60	0.0005 to 0.0012
40 to 90	105 to 160	0.0035 to 0.0082

General Behavior

Referring to Fig. 2, contrary to the distribution predicted by standard flexural theory, stresses in the vicinity of the beam flange-to-column weld are highly nonlinear and demonstrate why finite element analyses are necessary to accurately calculate fracture toughness demands. The plots in Fig. 2 are longitudinal stresses measured through the flange thickness at the three locations shown. Using linear elastic fracture analyses, the stress intensity factor K_I can be related to the weld root defect length, a_o, and nominal flange bending stress as shown in Fig. 3. To-

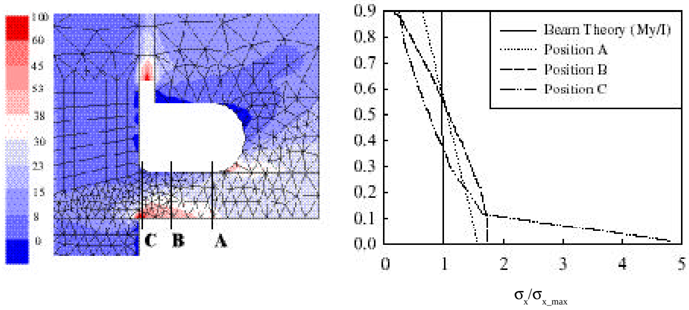

Fig. 2 - Elastic stress distribution

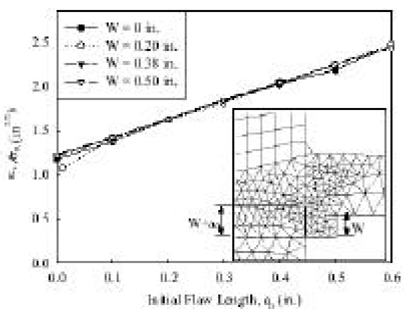

Fig. 3 - Normalized K_I versus flaw

gether with the material toughness properties in Table 1, data from Fig. 3 can be used to predict the applied stress at fracture.

Compared in Fig. 4 are toughness demands from elastic (K_I) versus inelastic analyses (CTOD) for two connections with different base and weld metal yield strengths and a flaw size of a_o = 0.1 inch. The

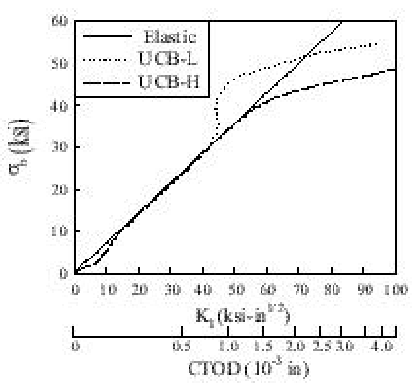

Fig. 4 - Elastic vs. inelastic response

inelastic results for connections UCB-L and UCB-H vary nonlinearly beyond a nominal bending stress of σ_b = 30 to 35 ksi due to localized yielding around the welds. The nonlinear response depends on several factors, such as the relative yield strengths of the base and weld metals, and at high stresses the fracture demands relate better to inelastic deformations than stresses. The results in Fig. 4 predict that connections with low-toughness E70T-4 weld metal (K_{IC} = 40 to 60 ksi $\sqrt{\text{in}}$) would fracture at nominal applied stress of σ_b = 30 to 50 ksi, which is consistent with investigations of damaged buildings and laboratory tests of pre-Northridge style connections.

RBS and Panel Zone Behavior

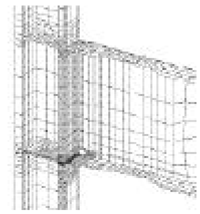

Fig. 5 - RBS Model

One of the more robust proposed connection alternatives is the Reduced Beam Section (RBS) detail in which the beam flange is trimmed down to shift the plastic hinge away from the column (see Fig. 5). Proportioning of the RBS to control toughness demand must be done relative to other deformable components of the connection, one of the primary ones being the panel zone. To examine this, we analyzed several connections with different RBS and joint panel zone strengths. Shown in Fig. 6, for example, are plots of CTOD versus inelastic plastic hinge rotation for connections with varying RBS reductions (none, 25% and 50%) and column panel zone strengths. The upper three curves in the figure are cases where large panel zone deformations and/or beam yielding in the weld region lead to large CTOD demand (CTOD > 0.01 inch) that is well in excess of available material toughness. On the other hand, where the panel zone is sufficiently strong relative to the RBS plastic hinge strength (the lowest set of curves in Fig. 6), the CTOD demand can be reliably maintained below about CTOD = 0.003 inch which is within the available toughness of most notch-toughness rated base and weld metals (Table 1).

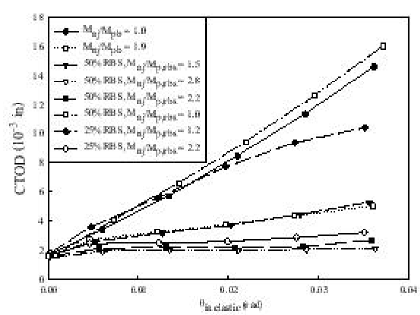

Fig. 6 - CTOD vs. inelastic connection rotation

Final Remarks

Reviewed herein are but a few of many fracture analyses we have conducted to investigate various connection design parameters. Supplemented by appropriate material, weldment, and connection tests, finite element fracture analyses contribute to our understanding of fracture behavior that is crucial for design reliable fracture resistant connections. Readers interested in more details on this study can contact Greg Deierlein at ggd@stanford.edu and look for an upcoming article in the January 2000 ASCE Journal of Structural Engineering.

NEWLY SPONSORED PROJECTS

A three-year joint project on *Probabilistic Estimation of Future Near-Source Strong Ground Motions and Probabilistic Analysis of Nonlinear Response of MDOF Structures to Such Motions*, sponsored by NSF US/Japan program in Urban Hazard Reduction. Principal Investigators: **Professors C. Allin Cornell** and **Greg Beroza**; Graduate Student: **Nicolas Luco**.

Year 2 of PEER Funding for *Probabilistic Basis for Assessment of Older Reinforced Concrete Building (Involving Cyclic Moment and Shear Degredation of MDOF Frames)*. Principal Investigator: **Professor C. Allin Cornell**; Graduate Student: **Fatemeh Jalayer**.

ALUMNI NEWS

Richard Regueiro (Ph.D. '98) is now Senior Member of Technical Staff in the Solid and Material Mechanics Department at Sandia National Laboratories in Livermore, California.

Tomohiko Hatada (Eng '97) and his wife Yasuyo had their third child and first son, Keigo, on January 29, 1999.

Lance Manuel (Ph.D. '93) recently joined the University of Texas at Austin as an Assistant Professor of Civil Engineering.

Paolo Bazzurro (Ph.D. '98) recently joined K2 Technologies, Inc. in San Jose, California.

CHARLES MENUN JOINS CEE FACULTY

The Blume Center is pleased to announce that Charles Menun joined the Stanford faculty in September as an Assistant Professor in Civil and Environmental Engineering in the Structural Engineering and Geomechanics Program. We welcome him and look forward to his active participation in the research and teaching activities at the Blume Center.

Menun received his doctoral degree from U.C. Berkeley, where he developed procedures for predicting critical seismic response combinations in linear and nonlinear structural systems. Prior to his studies at U.C. Berkeley, he worked as a design engineer for six years in Vancouver, British Columbia, specializing in residential and commercial high-rise buildings.

At Stanford, Menun intends to focus his research on the development of probabilistic methods for safety and reliability assessment in structural engineering. Of particular interest are applications of the theory of random vibrations and structural reliability to the design and analysis of structures subjected to seismic loads. Other areas of interest include applications of risk analysis and decision theory in civil engineering. Menun will teach an introductory structural engineering undergraduate course in the Winter Quarter of 2000 and a graduate level course in structural reliability in the following Spring Quarter.

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