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to: Jay Larson
Director, Construction Standards Development
American Iron and Steel Institute
3810 Sydna Street
Bethlehem, PA 18017-1048

re: Addendum to "Sheathing Braced Design of Wall Studs" proposal

Jay:

This letter serves to clarify certain specifics in my proposal on "Sheathing Braced Design of Wall Studs" that require additional discussion. The items discussed herein do not change the budget provided to you in the initial proposal. In your emails to me on 4 August, 2006 and 28 August, 2006 you detailed the additional needed information:

> "On the Sheathing Braced Design of Wall Studs project we could accept a revised proposal or your suggested approach of an addendum. Either would need to provide more specificity regarding certain elements of the RFP (e.g., no mention of out-of-plane lateral load cycling and no explanation of how results would be applicable to wall heights of 12 feet when the maximum wall height to be tested is 10 feet). Also, the revised proposal or addendum should (1) address the objective to define the minimum length of wall for which the provisions would be applicable, (2) demonstrate that the use of eccentrically applied axial loads rather than lateral loads will produce suitable results for all failure modes of interest, (3) clarify that the issue of conditioning some specimens under lateral load is included, (4) clarify that both strength and stiffness limit states will be considered, and (5) provide more description of the personnel, including student researchers and technicians, that will be needed to perform the testing outlined. We talked about several, but not all, of these issues with Tom Trestain earlier this week." *4 Aug. 2006 email*

> "*Dr. Schafer states that the testing rig will not be ready until Sept. 2007. However, in his Table 1 "Work plan and schedule", he proposes that Phase 1 testing will commence in the spring of 2007. A clarification is needed on this point. * For both suggested Phase 1 and Phase 2 testing, it is not clear to me how the suggested number of tests will be divided to cover the 3 desired loading conditions; axial compression only, bending only and combined axial and bending. I feel that additional tests are needed to be able to cover all wall variables and loading conditions. The other option is to repeat tests only once (2 identical tests only) to be able to consider more variables. * In Table 3, the

bending only loading was not listed as a loading condition." *28 Aug. 2006 email*

The following sections outline my response to the issues raised.

Wall Height

The testing rig developed for this project, due to practical space limitations in my lab, will have a maximum specimen height somewhere between 10 and 12 ft. Final clearance depends on the depth of the load beams selected and clearance between the load beam and reaction frame. Therefore, my proposal conservatively states that 10 ft. will be the maximum wall height to be tested. The RFP requests that wall heights up to 12 ft. be covered in the results. I agree that tests at 12 ft. would be desirable, but they are by no means necessary. An outcome of this research is the validation of a fundamental mechanics-based design methodology, one in which wall height would certainly be a variable. The testing will provide validation of this design methodology, and an extrapolation of the results to walls 1 or 2 ft. higher will be both reasonable and reliable. The mechanics-based design method will be simplified to an efficient and simplified method for the COFS standard in the bounds prescribed in the RFP. The fundamental mechanics-based design methodology that will form the basis for the simplified method will be applicable well outside the bounds as well. (For further discussion see the final paragraph of Section 2 of the original proposal). Wall height up to 12 ft. will be covered in the design method. A prescriptive solution for selected geometry and details can also be made available for those design situations that are the most common.

Minimum Wall Length

The RFP requests that the minimum wall length for which the provisions are applicable be addressed in the research. This item was not addressed in the original proposal. The request assumes that a minimum wall length is an appropriate limitation; however, properly formulated wall length should be a variable. As wall length is decreased the available shear rigidity decreases and thus the sheathing resistance decreases, finally to zero. It may be appropriate and even desirable in some cases to rely on the small amount of resistance available from a narrow wall. Insofar as sheathing shear rigidity is important, wall aspect ratio, rather than length, is the more likely key variable.

As discussed above if we employ a fundamental mechanics-based design approach the role of wall length (aspect ratio) will be a direct one. Now, for practical reasons in the simplification to this method we (COFS committee members) may decide to place a limit on wall length, but this will be a practical decision as to when typical resistance is too low to be useful, rather than a fundamental limitation. Enough flexibility is built into the Phase 2 testing in the proposal (see Section 2 "Development of the full Phase 2 testing matrix" in the proposal) that validation tests exploring the role of wall aspect ratio may be performed. The final Phase 2 testing matrix will developed in consultation with a COFS task group. Finally, the computational work detailed in the proposal can, and will, examine this issue. The role of wall length (aspect ratio) in the behavior and design of sheathed walls will be provided, and minimum wall length provisions developed, as appropriate, for the simplified design method.

Eccentric axial load instead of lateral load

The testing envisioned in this proposal uses eccentrically applied axial loads (end moments), rather than lateral loads to induce bending in the walls. A directly applied lateral pressure, such as in the case of a wind load, would typically be expected to follow the stiffest path as it loads the studs – this path is not in-line with the shear center and thus creates a tendency for the studs to roll that must be mitigated by the fasteners attached to the sheathing. As a result, applying end moments may not place as high a demand on the fasteners as directly applied lateral load. However, directly applying lateral loads in the laboratory has its own drawbacks. Most prominently, the members used to load the wall laterally introduce a frictional resistance between the load and the wall that can act as additional bracing for the studs. Directly applied end moments as envisioned in this testing plan ensures that the only bracing provided to the studs against translation and twist is from the sheathing. Further, with directly applied end moments the moment demand on the studs is more conservative than a uniform or point lateral load.

This detailed issue of load application is an excellent example of why we need the "Computational Modeling" outlined in Section 2 of the proposal in addition to the testing. With a finite element model of the sheathed wall we can, early on in the project, study the influence of this loading detail on the fastener demands. Thus, we can have a specific prediction of the difference in the fastener demands in a wall with end moments vs. lateral loads. If the fastener failure is the controlling limit state then we can develop a correction to the tested results to account for this reduction. Further, if modeling reveals that twisting due to lateral loads is critical to understanding the behavior of the stud in general, or the fastener in specific, we can propose additional testing in Phase 2 of the project to address this issue in detail. Possible testing envisioned includes a bending-only wall test with direct lateral loads, as well as fastener-only tests if the fastener limit state is dominant. If these tests are needed to achieve the goals of the project they will be proposed to the COFS task group and we can decide together what is best required to address this issue.

Testing of the walls under axial load and with end moments provides an ideally controlled way to study the behavior of sheathed walls. With the testing setup, any combination of axial load + bending can be explored and the true beam-column behavior of the sheathed wall system understood. Testing in the laboratory is always an idealization of reality, but I feel that this setup is the best for exploring the complicated member behavior of sheathed walls.

Pre-conditioning of some specimens (Out-of-plane lateral load cycling)
The influence of out-of-plane lateral load cycling on the ultimate capacity of the walls, particularly those with gypsum board, will be explored. It is possible that service-level deformations cause important degradation in the panel-fastener stiffness. Degradation that influences the ultimate strength. The testing rig developed for this proposal will be used to apply small magnitude (service-level) end moments (rotations) that will flex the wall and thus exercise the panel-fastener configuration prior to application of axial load. This influence will be specifically explored in the Phase 1 testing. The results from recent work on rotational restraint between joists and sheathing (also sponsored by the COFS) will be used, in part, to develop a protocol for these service-level deformations and to provide initial guidance on when significant degradation in the stiffness is anticipated. Pre-conditioning of specimens will be performed in the testing.

Strength and stiffness limit states
It is requested that the research and resulting design method address both strength and stiffness limit states for the sheathing. In particular, if one consider the sheathing as a bracing member then current engineering guidance (e.g., AISC's provisions) is that the bracing must meet

minimum stiffness and minimum strength requirements. Further, the extent to which strength and stiffness requirements are additive (or not) is not fully understood. A final design methodology has not yet been determined; however, the potential for both strength and stiffness of the sheathing to govern its behavior as a bracing member will be considered.

Further, the original proposal does not address stiffness limit states for the sheathed wall as a system. To my knowledge, it has not been the practice of the standards to place prescriptive stiffness limit states, however stiffness (deflections) will be measured in the testing and the developed design methods will consider methods necessary to predict the stiffness of wall systems for comparison to engineer-specified deflection tolerances. Further, the nature of the stiffness degradation as the wall reaches ultimate limit states will be examined to understand the fragility of the different sheathed-wall systems and to provide engineers with guidance on the expected performance of walls sheathed with different materials as they reach loads near their ultimate capacity.

Personnel

Technician: The Department of Civil Engineering has one full-time technician for laboratory support: Jack Spangler. Mr. Spangler has worked for the Department for over 15 years and specializes in developing and maintaining sensor networks. Mr. Spangler previously worked for the Physics Department and has provided laboratory support in a University setting for over 40 years. Mr. Spangler will be available to help in this research.

Machinist: The Department of Civil Engineering part-time machinist recently passed away. The Department has contracted with Eric Harden, Sr. Machinist, in the Mechanical Engineering Department at this time. Eric will be available on an hourly-basis, covered by the Department, to help with the machining needs in this research. The machine shop is located in the same building as the Structural Engineering Laboratory.

Rachel Sangree, Post-doctoral Researcher, Department of Civil Engineering, Johns Hopkins University will also be working on this project. She received her Ph.D. in 2006 from Professor Schafer studying the behavior of covered wooden bridges through laboratory and field experimental testing supplemented with finite element analysis. She has a P.E. license and served as a bridge engineer before initiating her graduate studies at Johns Hopkins. Rachel has significant laboratory experience. Rachel is developing the testing rig that will be used in this project for the related National Science Foundation project, as such no salary is requested for her in this budget. However, her work will have direct bearing on this project so she is listed here.

A Ph.D. graduate student will be assigned to the project. As the project funding has not yet been secured it is not definite whom the student will be. The most likely candidate is Lindsey Smith. Lindsey is a new Ph.D. student in our Department this Fall. Lindsey received her B.S. in Engineering Mechanics from Columbia University. Subsequently she has worked as a geotechnical field engineer, and as a project engineer designing climbing walls and ropes courses. Lindsey is keenly interested in academia, and fundamental mechanics as they are applied in design, and would be an excellent student investigator for this project. Two other students are possible, as is a new student next year. All of our students are of the highest caliber and I am confident we can secure a quality young researcher for this project.

In addition we will engage undergraduate student researchers for this project as needed.

Testing Rig Startup Discrepancy
A reviewer has an inquiry about the testing rig stating: "*Dr. Schafer states that the testing rig will not be ready until Sept. 2007. However, in his Table 1 "Work plan and schedule", he proposes that Phase 1 testing will commence in the spring of 2007. A clarification is needed on this point." The testing rig will be ready in Spring 2007 as stated in the proposal and as shown in Table 1 of the proposal. Page 5 of the proposal states:

"Money has been secured for the envisioned testing rig, the hydraulic actuators have been donated to the University, and a post-doctoral student is beginning in September 2006 to complete the design and bring the testing rig online. Nonetheless, the rig is a relatively time consuming endeavor, what with 12 actuators to control. Given the work left to complete in design, fabrication, and control software testing cannot commence until Spring 2007, as indicated on the schedule given in Table 1."

Design of the rig is currently underway with a post-doctoral student working in my laboratory already. We are still on schedule for being online with testing in Spring 2007.

Mode of Loading for Testing
A reviewer has an inquiry about the mode of loading, stating: "* For both suggested Phase 1 and Phase 2 testing, it is not clear to me how the suggested number of tests will be divided to cover the 3 desired loading conditions; axial compression only, bending only and combined axial and bending. I feel that additional tests are needed to be able to cover all wall variables and loading conditions. The other option is to repeat tests only once (2 identical tests only) to be able to consider more variables. * In Table 3, the bending only loading was not listed as a loading condition."

It is envisioned that the Phase 1 testing will focus primarily on compression loading with the exception of "pre-conditioning" discussed above. The limit states explored by the compressive loading are anticipated to be the most critical; particularly in the case of dis-similar sheathing (see, e.g., the paper attached to the proposal). The lack of symmetry in the bracing can potentially lead to unusual failure modes that are of interest and concern. We want to explore these limit states as early as possible in the experimental research.

Further, in Phase 1 bending-only loading will be explored computationally as discussed above in the section "Eccentric axial load instead of lateral load". In addition, a great deal of new information exists on the bending response of sheathed studs. Including newly sponsored COFS testing on the rotational restraint between studs (and joists) attached to a variety of sheathing materials. In the case of bending-only loading the sheathing on the compressive side is known to dominate the response. This existing research supplemented with computational work will be used to provide a clear design method and understanding for the bending-only response.

Prior to any Phase 1 testing the proposed matrix of tests will be brought to an AISI-COFS task group. My bias in the Phase 1 testing is primarily towards compressive testing; however with our testing rig – bending or compression + bending tests can be performed with equal ease. Therefore, based on the task group's recommendation we will finalize the testing matrix and the mode of loading before conducting the tests. As the reviewer states, in some instances it may be possible to do only 2 tests on a wall configuration and use the additional testing, in Phase 1, for exploring the other loading modes.

For the Phase 2 testing the final details are not yet settled. The Phase 2 testing will be significantly informed by the Phase 1 testing and complementary computational research. Final testing details will be developed in consort with an AISI-COFS task group. Direct investigation of axial + bending load is of significant interest in the Phase 2 testing because existing beam-column provisions are known to be excessively conservative in many situations. In addition to exploring mode of loading the testing seeks to explore other key design variables: fastener spacing, stud depth, stud thickness, stud grade and stud spacing, around the Phase 1 control configuration.

The case for a wider battery of tests is almost always a strong one, whether it be more modes of loading, different fasteners, etc. However, the goal of the testing is not just to fill out a matrix of different design variables, but rather to explore the key limit states that the wall will experience. By understanding how the wall fails the appropriate mechanical models for its prediction can be both developed (as needed) and validated for use in design. Once the Phase 1 testing is complete and the computational work underway, we should be able to provide some good feedback to the AISI-COFS task group on the Phase 2 testing plan and thus be able to make an informed decision on the second phase of tests.

If you have any additional questions regarding my proposal I would be happy to speak with you and further clarify the issues. I look forward to working together on this work.

Sincerely,

Ben Schafer

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