# Cold-Formed Steel Framed Shear Wall Test Database

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## Abstract

The main objective of this paper is to introduce a recently compiled cold-formed steel framed shear wall test database, to reveal the database structure, and to present the method to access and present data. Many monotonic and cyclic tests have been conducted on cold-formed steel framed shear walls in the last 20 years. Cold-formed steel framed shear wall provisions in AISI S240, AISI S400, and ASCE 41 are supported by these tests. Recently the database has been standardized and expanded to include additional tests, complete cyclic information from tests, limit states, and code prediction information. The database structure incorporates ordered plain text files for each individual test; custom MATLAB codes, which can read, process, and plot designated database subsets; and a central Excel spreadsheet that includes most descriptive information. The database structure and basic information are summarized herein and are aimed to advance the understanding and modeling of cold-formed steel framed shear walls.

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**KEYWORDS**

Earthquake engineering, Cold-formed Steel, Shear walls, Test information, Test Strength, Database

# INTRODUCTION

Various systems contribute to the lateral resistance of buildings framed from cold-formed steel (CFS). The overall behavior, design, and performance of cold-formed steel lateral force-resisting systems are summarized in Madsen et al. 2016. Predicting the lateral response of CFS-framed shear walls can be complex as considerable nonlinearity may be generated at connections, in any sheathing materials, or in the framing steel itself. As a result, experimental testing has taken a central role in studying the behavior of cold-formed steel framed lateral force-resisting systems, as well as providing strength and drift guidance for these systems.

Design provisions for lateral force resisting systems in the North American Standard for CFS Structural Framing (AISI S240-20), the North American Standard for Seismic Design of CFS Structural Systems (AISI S400-20), and the Seismic Evaluation and Retrofit of Existing Buildings standard (ASCE41-17, ASCE, 2017) are constructed based on available CFS-framed shear wall test data. Therefore, the integration of tested cold-formed steel framed shear walls into a comprehensive database is expected to provide a necessary means for improving the understanding and design of cold-formed steel framed systems.

Currently, 700 individual tests drawn from 29 different primary sources (Al-Kharat and Rogers, 2005; Al-Kharat and Rogers, 2006; Balh and Rogers, 2010; Blais, 2006; Boudreault, 2005; Branston, 2004; Briere and Rogers, 2018; Chen, 2004; Comeau, 2008; DaBreo, 2012; Elhajj, 2005; Hikita, 2006; Kochkine and Hill, 2006; Liu et al., 2012; Lu, 2015; Morello, 2009; Morgan et al., 2002; Nguyen et al., 1996; Ong-Tone, 2009; Rizk and Rogers, 2018; Rokas, 2006; Salenikovich AJ and Dolan JD, 1999; Santos and Rogers, 2018; Serrette et al., 1997; UCI, 2004; Velchev, 2008; Yu and Chen, 2009; Yu et al., 2007; Yu et al., 2007) are incorporated into the CFS framed shear wall test database introduced herein. These collected tests include all CFS framed shear wall testing that underpins AISI S240-20 and AISI S400-20. An initial version of this database supported the recent revision to ASCE41-17 (ASCE, 2017) for cold-formed steel framing (Ayhan et al. 2016; Ayhan et al. 2018). Seismic overstrength and seismic fragility function research efforts were also conducted based on the database (Schafer et al. 2020; Haghpanah and Schafer 2020). It is worth noting that recent testing exploring higher capacity steel sheet sheathed shear walls providing up to 145939 N/m (10,000 lbf/ft) capacity at McGill University (Santos and Rogers, 2018; Briere and Rogers, 2018; Rizk and Rogers, 2018) have been incorporated into the database.

## DATABASE STRUCTURE AND DETAIL

The database has a specific folder structure, a central Excel spreadsheet database, and an analysis engine driven by custom MATLAB (R2018b) codes. There are three subfolders within the database home folder, including “Data”, “Reference”, and “Analysis”. The “Data” subfolder contains seven folders named with affiliations where the shear wall tests were conducted. Within every affiliation folder, there is a “main” folder containing a series of ordered plain text files, each corresponding to a shear wall test data. A “Reference” subfolder under the home folder stores source literature (mainly test reports and degree theses) corresponding to each test data group. Another “Analysis” subfolder accommodates all the custom MATLAB codes and generates figure files after running the codes.

In the central database Excel spreadsheet, the fields are designed to capture all salient features of shear wall test specimens and results that can be read into and utilized by custom MATLAB codes. Some of the key field information are listed in Table 1, while the detailed database field dictionary corresponding to the central database Excel spreadsheet is summarized in the Appendix. English customary units have been adopted within the database. The paths of the raw test data text files are also stored inside the central Excel spreadsheet, which can be accessed by the custom MATLAB codes to read the exact raw plain text test data files. The link information between a certain source and its corresponding reference is saved in a separate sheet within the central Excel spreadsheet. It is worth noting that the Excel spreadsheet is intended as input to the analysis engine. Parameters selected from the test data response, such as the peak strength, are handled in the analysis engine but not stored in the spreadsheet. This is an intentional decision to require the analyst to utilize the data files, not just the input spreadsheet.

**Table 1.** Data fields for the CFS-framed shear wall database

| Information type | Field category | Selected parameters within the field |
|---|---|---|
| Overall shear wall test information | Basic identification | id, source, test_no, loading_detail |
| | Wall overall | loading, width, height, thickness, Designation1, sides |
| | Opening details | opening_id, sheathing area ratio, window_num, window_dim |
| Tested shear wall configuration | Strap bracing details | strap_detail, strap_width, strap_thickness, strap_grade |
| | Sheathing details | she_details, she_thickness, she_strength, she_spacing_perimeter |
| | Chord stud details | chord_web, chord_flange, chord_lip, chord_t, chord_nom_Fy |
| | Field stud details | field_web, field_flange, field_lip, field_t, field_nom_Fy |
| | Track details | track_web, track_flange, track_t, track_nom_Fy, track_actual_Fu |
| | Fastener stud track | fastener_stud_track_no, fastener_stud_track_len |
| | Gusset plate details | gusset_id, gusset_width, gusset_t, gusset_nom_Fy |
| | Bridging details | bridging_loc, bridging_web, bridging_flange, bridging_t |
| | Hold down details | holddown_id, holddown_no, holddown_offset |
| | Ledger details | ledger_id |
| Strength and limit states | Limit state | est_primary_failure, listed_failure_mode, notes_on_failure |
| | AISI S400-15 prediction | S400_USA_applicable, S400_CAN_applicable, S400_vn_USA |
| Data files | Data files | data_units, data_dir, data_main, data_raw_txt, data_raw_image |
| | Processed data files | proc_dxf, proc_cyclic, proc_mono, proc_backb, proc_backb_ave |

The analysis engine is composed of a few custom MATLAB scripts reading in both the central spreadsheet and raw text test data files following the accurate file path for deeper manipulation of the data. These custom scripts are able to process test data, visualize specific test or designated database subset results, and further explore the database. The four largest groups of tested shear walls can be classified by sheathing type. The force-deformation response of all the shear wall tests with wood structural panels, steel sheet sheathing, strap bracing, and gypsum sheathing are presented in Fig. 1, which presents an overview of the available data and overall hysteretic shape of CFS framed shear wall test with different sheathing types.

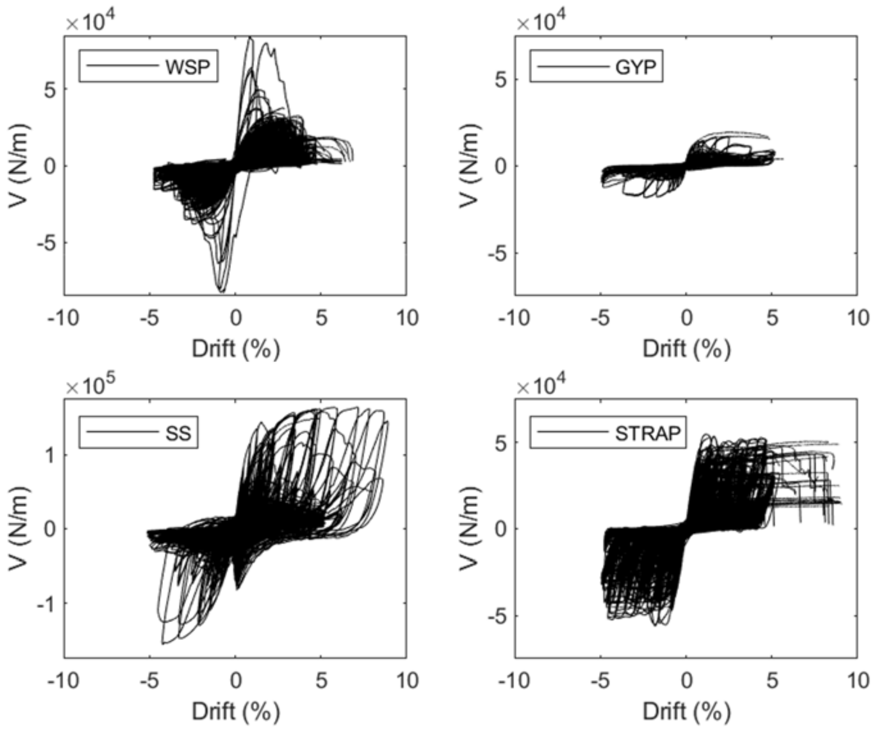


**Figure 1.** Normalized drift vs. strength for all data in the shear wall database.

## DATABASE USAGE SAMPLE CODE AND OUTPUTS

There are three sample codes available in the CFS framed shear wall dataset. The first sample code deals with the situation where we would like to find a specific test, plot the test force-deformation curve, and obtain the peak force and corresponding drift ratio when we already know the unique test ID (which can be found in the summary spreadsheet).

The second sample code addresses the situation in which we need to find all the tests whose configuration match each cell in the strength tables for CFS framed shear walls sheathed with Wood Structural Panel (WSP) or Steel Sheet (SS) in AISI S400-20, further plotting these force-deformation curves and obtaining the average peak force and corresponding average drift ratio.

It is important to note that many of the tests in the shear wall database are not compliant with detailing requirements in the design specifications – it is up to the analyst to ensure that the selected data is appropriate for their analysis – the analysis code and spreadsheet provide necessary information to make this determination, and a field exists in the spreadsheet as to whether or not the test is judged to be compliant with AISI S400-15. The third sample code is able to help us filter out all the tests with a particular type of sheathing, load protocol (monotonic or cyclic), and valid detailing per AISI S400-20 as well as to plot the force-deformation curves and generate various histogram plots of peak forces or peak force per unit wall width.

In the first sample code, “Database_Usage_Example1.m”, there are three input parameters including “ID_Input”, “write_switch”, and “units_output”. The “ID_Input” should be a unique test ID from the first column of the database center spreadsheet, while the parameter “write_switch” determines whether the code outputs the force and drift ratio values and generates the force-deformation curve. If we set the “ID_Input” as 682 and the “write_switch” as 1, then it is expected that the MATLAB command window outputs the force and drift ratio values, and a figure shown in Fig. 2 is plotted. The last parameter of “units_output” controls the unit system for the output data and figure. Either “N-m” or “lbf-inch” can be input as “units_output” resulting in two different unit systems.

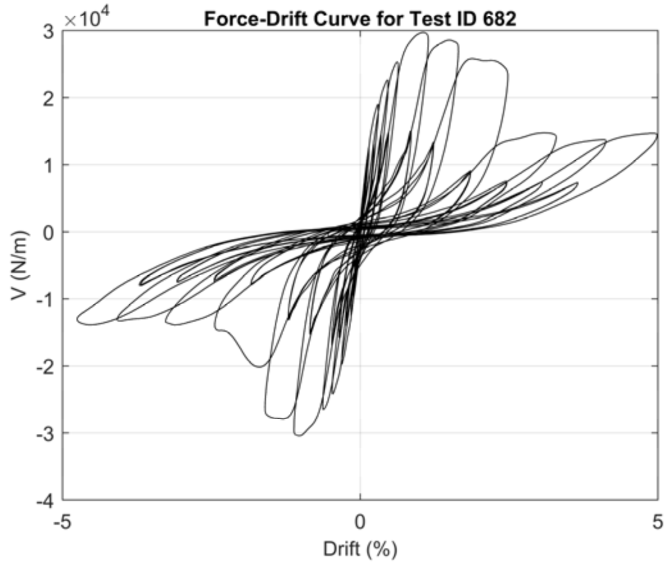


**Figure 2.** The output of sample analysis code 1: force-displacement curve for test ID 682.

The second sample code, "Database_Usage_Example2.m" shows how we can determine all the tests under cyclic loading whose configurations match with each cell in Table E1.3-1 for CFS framed shear walls sheathed with Wood Structural Panel (WSP) in AISI S400-20. The code reads in all the test data of shear wall test configurations with Oriented Strand Board (OSB) sheathing and outputs a series of mean peak forces and corresponding mean drift ratios (both positive and negative loading directions) of tests matching each cell with OSB sheathing configuration in Table E1.3-1 of AISI S400-20 in the command window. In addition, the sample code generates a force-deformation curve plot, as shown in Fig. 3, covering all the shear wall configurations with OSB sheathing in Table E1.3-1 of AISI S400-20 when parameter "write_switch" is set as 1. This last parameter of "units_output" plays a similar role to the first sample code.

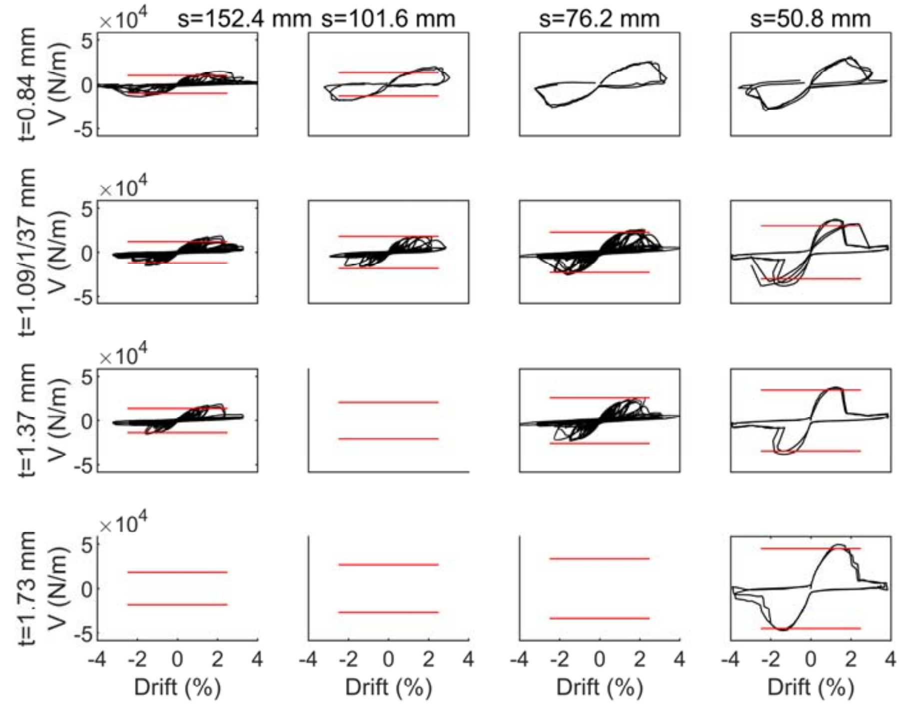


**Figure 3.** The output of sample analysis code 2: force-displacement curves of all the cyclic tests matching CFS framed OSB sheathed shear wall configurations in Table E1.3-1 of AISI S400-20.

The third sample code, “Database_Usage_Example3.m” aims to filter out and process all the tests demonstrating a valid detailing per AISI S400-20, such as a particular type of sheathing (Gypsum Board sheathing adopted herein as an example) or load protocol (cyclic loading chosen in the sample code), and further plot the test force-deformation curves with a certain detailing feature in the same figure. Within the database, 348 tests employ a cyclic loading protocol, while 352 tests adopt a monotonic one. With regard to sheathing type, 279 tests utilize wood structural panels; 241, steel sheet sheathing; 117, strap bracing; 40, gypsum sheathing; and, finally, the remaining 23 tests use other configurations. The third sample code also generates two histogram plots based on absolute peak force per unit length to help understand the shear wall strength value distribution.

In the third sample code, four input parameters, “Sheathing_Input”, “Loading_Input”, “write_switch”, and “units_output”, need to be defined. The default values are taken as “GYP”, “cyclic”, “1”, and “N-m”. This code filters out all the test data with CFS framed shear wall sheathed with Gypsum Board and plots the force-displacement cures in the same figure, as presented in Fig. 4. In addition, the third sample code also plots all the cyclic testing data in the same figure, as shown in Fig. 5. The parameters, “write_switch” and “units_output”, are similar to the usage method in the first and second sample codes. Furthermore, this code also generates a histogram for the absolute peak force per unit length of all the tests within this database, as presented in Fig. 6. To better understand the shear wall strength distribution for tests with different sheathing materials, the third sample code also generates a stacked histogram for absolute peak force per unit length of all the tests, as shown in Fig. 7.

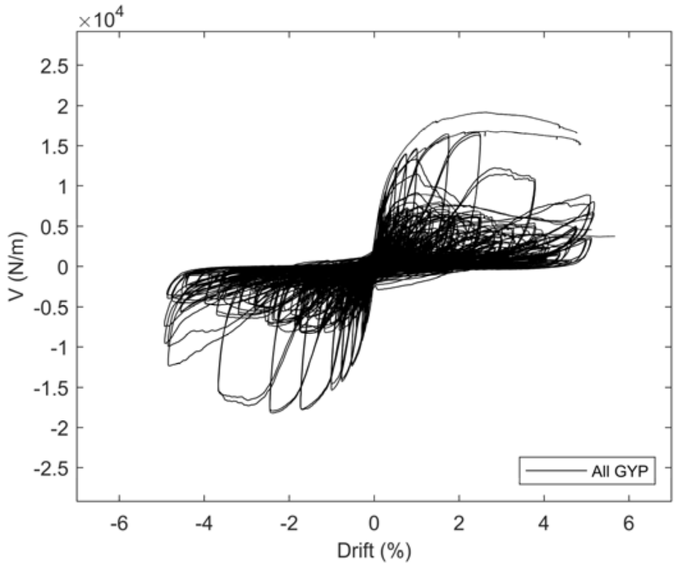


**Figure 4.** The output of sample analysis code 3: Force-displacement curves of all the CFS framed shear wall tests with Gypsum Board sheathing.

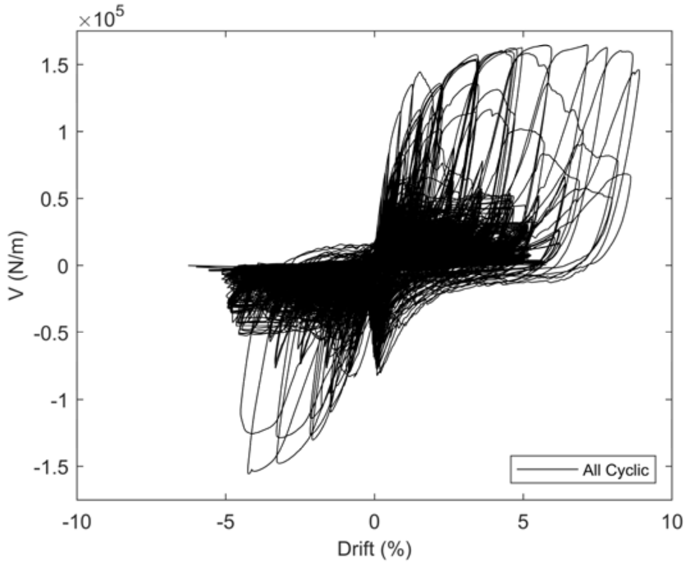


**Figure 5.** The output of sample analysis code 3: force-displacement curves of all the CFS framed shear wall tests under cyclic loading.

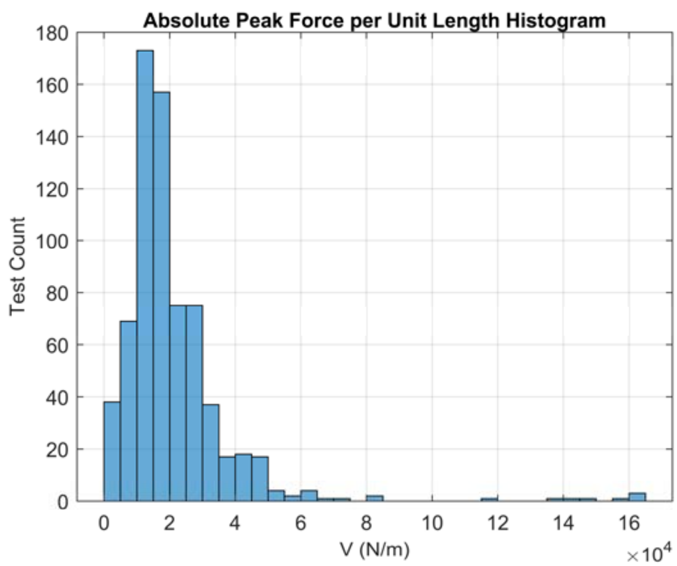


**Figure 6.** The output of sample analysis code 3: histogram of absolute peak force per unit length for all the tests.

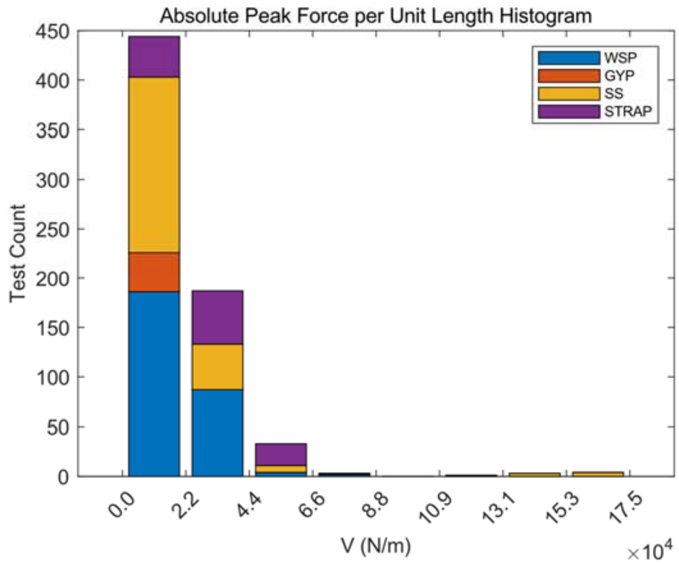


**Figure 7.** The output of sample analysis code 3: tacked histogram of absolute peak force per unit length for all the tests.

## DATABASE APPLICATION DISCUSSION

The cold-formed steel framed shear wall database has numerous potential uses. For design specifications, the data may be used to refine strength and drift requirements. In addition, the data provides a direct means to assess the overstrength and ductility of shear walls. As one contemplates a more analysis-based path for predicting lateral performance, the data provides a direct means to incorporate tested shear walls in models. Or the tests can provide benchmarks for high-fidelity models or semi-analytical/phenomenological model approaches. It is also possible to use the database to assess specific aspects of the nonlinear response – for example, cyclic degradation, post-peak slope, and ultimate drift. etc. Further, the database is large enough to assess statistics of response and directly explore component and subsystem reliability. In addition, the database is large enough in size to be used as a training set for modern machine learning methods to predict strength or full shear-deformation response. The authors are aware of recent additional tests that could also be used to further expand the database, particularly on new sheathing materials, etc.

## SUMMARY AND CONCLUSIONS

A database composed of 700 tested cold-formed steel framed shear walls has been assembled. Complete descriptive information and lateral force-deformation response are included in the database. The database consists of cold-formed steel framed walls, sheathed with the wood structural panel, sheathed with steel sheet, braced by straps, with and without gypsum board finish, and a small number of additional miscellaneous configurations. The database incorporates all necessary information and data, including test configuration information, complete test response, limit states, and American Iron and Steel Institute code prediction information. The basic database structure is introduced, and three example MATLAB codes for presenting how the database can be utilized are provided. The database provides important and useful information to advance the understanding and modeling of lateral force-resisting systems in cold-formed steel framing.

## ACKNOWLEDGMENTS

Building this database has included generosity and help from a large number of people. Postdoctoral researcher Dr. Deniz Ayhan Moen initiated the first version of the database and participated in the ASCE 41 analysis using the first version. Master's student Sam Baer contributed to the expansion of the main database, and doctoral student Dr. Fardad Haghpanah provided significant error-checking when he was utilizing the database. Professor Cheng Yu provided source data not publicly available to improve the database information. Professors Tara Hutchinson and Kara Peterman in the CFS-NHERI effort provided feedback on the database and its application along with their doctoral students Amanpreet Singh, Hernan Casteneda and Fani Derveni. In addition, several members of the Lateral Committee at the American Iron and Steel Institute have provided feedback on the database and its application. This work is in part, part of the research project, Seismic Resiliency of Repetitively Framed Mid-Rise Cold-Formed Steel Building (CFS-NHERI) which is supported by the National Science Foundation under Grant No.1663348 and No.1663569. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation or others acknowledged. The authors would like to express gratitude for the generosity of the original researchers of all these shear wall tests.

## DECLARATION OF CONFLICTING INTERESTS

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/ or publication of this article.

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Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the sponsors and employers.

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## APPENDIX

**Table 1.** Detailed data field dictionary for the CFS-framed shear wall database

| Data field | Column | Units | Variable |
|---|---|---|---|
| basic_identification | A | N/A | id |
| | B | N/A | source |
| | C | N/A | test_no |
| | D | N/A | loading_detail |
| wall_overall | E | N/A | loading |
| | F | ft | width |
| | G | ft | height |
| | H | N/A | h_on_w |
| | I | in. | thickness |
| | J | N/A | Designation1 |
| | K | N/A | Designation2 |
| | L | N/A | sides |
| | M | N/A | notes |
| strap_bracing_details | N | N/A | strap_detail |
| | O | in. | strap_width |
| | P | in. | strap_thickness |
| | Q | ksi | strap_grade |
| | R | ksi | strap_actual_Fu |
| | S | ksi | strap_actual_Fy |
| | T | N/A | strap_Ry |
| sheathing_details | U | N/A | she_details |
| | V | N/A | she_sides |
| | W | in. | she_thickness |
| | X | ksi | she_strength |
| | Y | ksi | she_Fu |
| | Z | ksi | she_Fy_actual |
| | AA | N/A | she_fastener_diam |
| | AB | N/A | she_fastener_pitch |
| | AC | in. | she_fastener_len |
| | AD | in. | she_spacing_perimeter |
| | AE | in. | she_spacing_field |
| chord_stud_details | AF | N/A | chord_config |
| | AG | N/A | chord_fastener_qty |
| | AH | N/A | chord_fastener_dia |
| | AI | N/A | chord_fastener_pitch |
| | AJ | in. | chord_fastener_length |
| | AK | in. | chord_fast_spacing |
| | AL | in. | chord_web |
| | AM | in. | chord_flange |
| | AN | in. | chord_lip |
| | AO | in. | chord_t |
| | AP | ksi | chord_nom_Fy |
| | AQ | ksi | chord_act_Fu |
| | AR | ksi | chord_actual_Fy |

| | | | |
|---|---|---|---|
| field_stud_details | AS | in. | field_spacing |
| | AT | in. | field_web |
| | AU | in. | field_flange |
| | AV | in. | field_lip |
| | AW | in. | field_t |
| | AX | ksi | field_nom_Fy |
| | AY | ksi | field_actual_Fu |
| | AZ | ksi | field_actual_Fy |
| track_details | BA | in. | track_web |
| | BB | in. | track_flange |
| | BC | in. | track_t |
| | BD | ksi | track_nom_Fy |
| | BE | ksi | track_actual_Fu |
| | BF | ksi | track_actual_Fy |
| fastener_stud_track | BG | N/A | fastener_stud_track_no |
| | BH | in. | fastener_stud_track_len |
| gusset_plate_details | BI | in. | gusset_id |
| | BJ | in. | gusset_width |
| | BK | in | gusset_t |
| | BL | ksi | gusset_nom_Fy |
| | BM | ksi | gusset_actual_Fu |
| | BN | ksi | gusset_actual_Fy |
| bridging_details | BO | N/A | bridging_loc |
| | BP | in. | bridging_web |
| | BQ | in. | bridging_flange |
| | BR | in. | bridging_t |
| holddown_details | BS | N/A | holddown_id |
| | BT | N/A | holddown_no |
| | BU | in. | holddown_offset |
| opening_details | BV | N/A | opening_id |
| | BW | N/A | sheathing area ratio |
| | BX | N/A | door_num |
| | BY | ft | door_dim |
| | BZ | N/A | window_num |
| | CA | ft | window_dim |
| ledger_details | CB | N/A | ledger_id |
| limit_state | CC | N/A | est_primary_failure |
| | CD | N/A | listed_failure_mode |
| | CE | N/A | notes_on_failure |
| AISI S400-15 prediction | CF | N/A | S400_USA_applicable |
| | CG | N/A | S400_CAN_applicable |
| | CH | kN/m | S400_vn_CAN |
| | CI | lbf/ft | S400_vn_USA |
| | CJ | kN | S400_Vn_CAN |
| | CK | lbf | S400_Vn_USA |
| | CL | N/A | S400_notes |
| data_files | CM | N/A | data_units |
| | CN | N/A | data_note |
| | CO | N/A | data_dir |
| | CP | N/A | data_main |

| | | | |
|---|---|---|---|
| | CQ | N/A | data_raw_txt |
| | CR | N/A | data_raw_xls |
| | CS | N/A | data_raw_image |
| processed_data_files | CT | N/A | proc_dxf |
| | CU | N/A | proc_cyclic |
| | CV | N/A | proc_mono |
| | CW | N/A | proc_backb |
| | CX | N/A | proc_backb_ave |