APPENDIX F

SEISMIC QUALIFICATION PROCEDURE AND ACCEPTANCE CRITERIA FOR OTHER SHEAR PANEL CONFIGURATIONS

F1. SCOPE. This appendix presents the test procedure, acceptance criteria and documentation requirements needed to demonstrate the acceptability of cold-formed steel shear panel configurations different than the specific system defined in Chapter 3. Acceptable panels are limited to cold-formed steel shear panels with diagonal straps or full panel sheets as the lateral load resisting elements. The columns shall be constructed with cold-formed or hot-rolled structural steel. This is for the qualification of a prototype of the specific panel that will be used in construction. Qualification requires the testing of three specimens. All panel tests shall represent full panel system tests of all the panel components including connections, and anchors.

F2. COUPON TESTS OF ALL TEST PANEL MATERIALS. Coupon tests shall be performed on all materials that may contribute to the structural performance of the test panels. At least three coupons shall be tested from each lot of each type of material. Coupons shall be prepared and tested following the provisions of ASTM A 370. Materials that contribute to the ductility of the shear panels shall have a total elongation of at least 10% for a two-inch long gage length. All coupon test results shall be plotted in a test report, in terms of stress versus strain. All coupon test results shall also be summarized in a table in the format shown in Table F-1. The data in this table shall be the average value of the three or more coupons of the particular component.

Table F-1. Format for Tabular Coupon Test Results.

Structural Component of Coupon	Design Yield Stress (MPa or ksi)	0.2% Offset* Yield Strain (mm/mm)	0.2% Offset * Yield Stress (MPa or ksi)	Maximum Load Strain (mm/mm)	Maximum Stress (MPa or ksi)	Max Stress / 0.2% Offset Yield Stress
Component #1						
Component #2						

* See USACERL TR Chapter 4 for definitions of 0.2% offset yield strain and stress

F3. COUPON TEST OF ALL FIELD PANEL MATERIALS. Coupon tests shall be performed on all materials that contribute to the structural performance of the field panels. The field panels shall be identical to the prototype-tested panels. At least three coupons of each material shall be tested. Coupons shall be prepared and tested following the provisions of ASTM A 370. Materials that contribute to the ductility of the shear panels shall have a total elongation of at least 10% for a two-inch long gage length. All coupon test results shall be plotted in a test report, in terms of stress versus strain. All coupon test results shall also be summarized in a table in the format shown in Table F-1. The data in this table shall be the average value of the three or more coupons of the particular component. The field diagonal straps or full panel sheets shall have a coupon yield stress (0.2% offset) not greater than 5% above or not less than 10% below the test panel coupon yield stress (0.2% offset). The field material coupons for all other structural elements shall have coupon yield stress (0.2% offset) not less than the test panel coupon yield stress (0.2% offset).

F4. TEST CONFIGURATION. Full-scale test panels shall be tested with both monotonic (pushover in one direction) and cyclic loading. The panels shall be anchored to a base beam and top beam in a manner representative of the field installation. The base beam shall resist any slippage, out-of-plane movement or rotation in any direction. Vertical load shall be applied to the shear panel through the top beam, at a level representative of potential gravity loads in the field. The amount of vertical load applied should consider the worst case condition for the most vulnerable panel components. For example, the minimal vertical load may provide the most severe loading for the anchors, while the maximum vertical would provide the worst case loading for column buckling. This vertical load shall be held constant throughout each test. The top beam shall be held horizontal during all tests, as this represents the field conditions when the panel is assembled in a building. Figure F-1 shows the test configuration and instrumentation plan for shear panels tested at USACERL in order to illustrate the load configuration. In the USACERL tests, stroke control was used to keep the two vertical actuators at the same length, which held the top beam horizontal. The combined vertical force was held constant manually.

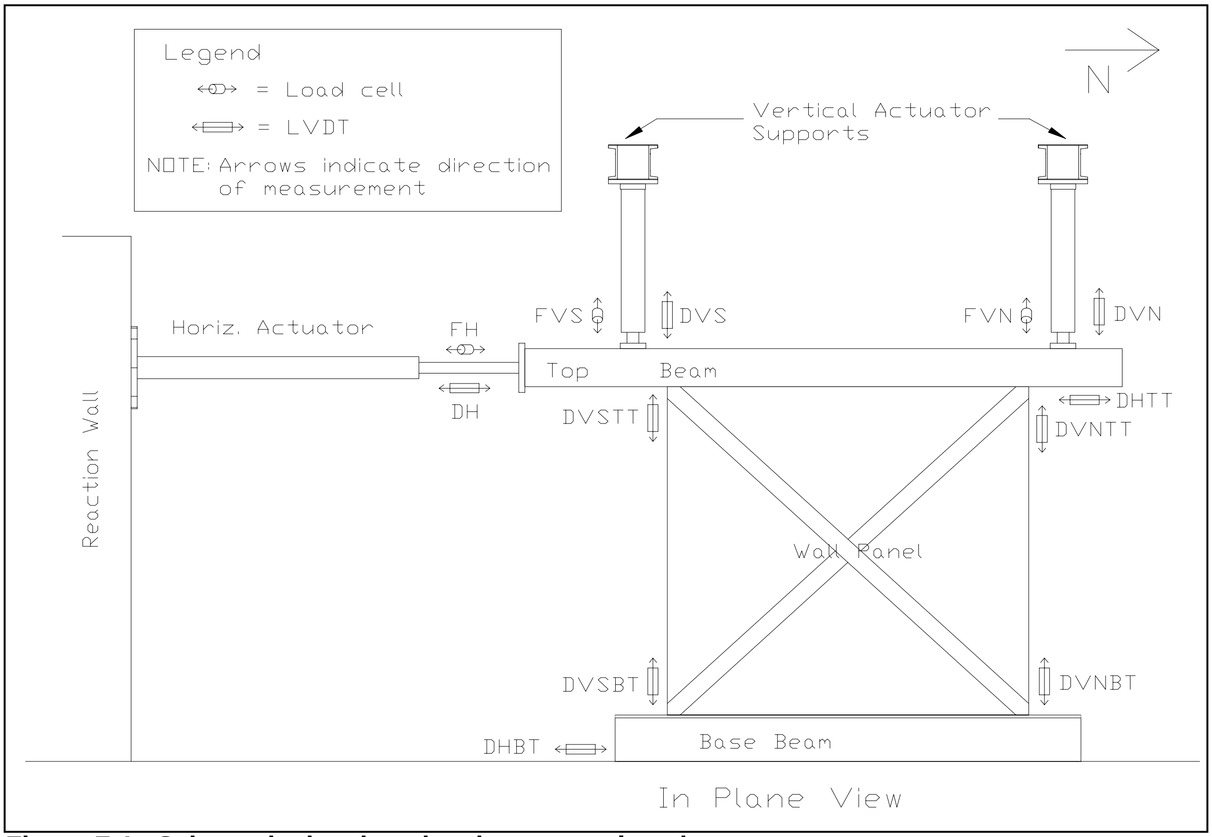

Figure F-1. Schematic drawing showing sensor locations.

F5. INSTRUMENTATION. Table F-2 defines the instrumentation required for all shear panel tests. Figure F-1 shows the location and orientation of all sensors. Table F-2 describes the purpose of each sensor. The purpose of most gages is to ensure that no unwanted motion takes place and for test control. The only data used in reporting panel performance are the 1st, 2nd, 3rd and 4th channels in Table F-2. The vertical actuator force measurements (FVS and FVN in Table F-2 and Figure F-1) are required to defined total shear force when deflections reach large amplitudes, at which point the horizontal components of these forces become significant. This total shear force, TSF is determined as follows:

$$TSF = FH - TVF\left\{\sin\left[\arctan\left(\frac{DH}{L}\right)\right]\right\} \qquad \text{(Eq F-1)}$$

Where:

FH = the measured horizontal actuator force (see Table F-2 or Figure F-1).
TVF = the total vertical actuator force, equal to FVS plus FVN (Table F-2 or Figure F-1).
DH = the measured horizontal displacement (Table F-2 or Figure F-1).
L = the length of the vertical actuators, with the vertical load applied, but not horizontal displacement.

Table F-2. Cold-Formed Steel Shear Panel Instrumentation.

Channel #	Sensor Type	Measurement, Direction, Location and Symbol	Purpose
1	Load cell	Force Horizontal, FH	Horizontal actuator load measurement
2	LVDT	Deflection Horizontal, DH	Horizontal deflection, shear panel deformation
3	Load cell	Force Vertical South, FVS	Manual vertical load control (25k total load w/#5)
4	LVDT	Deflection Vertical South, DVS	Stroke (tied to #6)
5	Load cell	Force Vertical North, FVN	Load (summed with #3, for 25k total load)
6	LVDT	Deflection Vertical North, DVN	Controlled by #4 stroke feedback
7	LVDT	Defl Horiz Bot Track, DHBT	To ensure no slippage
8	LVDT	Defl Vert South Bot Track, DVSBT	To ensure no uplift
9	LVDT	Defl Vert North Bot Track, DVNBT	To ensure no uplift
10	LRDG* (20")	Defl Horiz Top Track, DHTT	Check for shear panel deformation - same as #2
11	LRDG (10")	Defl Vert South Top Track, DVSTT	Vertical panel/column deformation & rotation check
12	LRDG (10")	Defl Vert North Top Track, DVNTT	Vertical panel/column deformation & rotation check

Note: * Linear Resistance Deflection Gauge, often called a Yo-Yo Gauge.

F6. TEST REQUIREMENTS. For each shear panel qualified, three specimens shall be fabricated and tested. This assumes only minor variation in panel performance for a given shear panel. If large variations occur more than three specimens shall be tested and a statistical evaluation of panel performance may be required. For panels with minor variation, one specimen shall be tested monotonically and two shall be tested cyclically as defined below. All tests, both monotonic and cyclic shall use stroke control, loading the panels laterally at a constant displacement per minute. The vertical load shall be held constant and the top beam shall be held horizontal throughout each test as described in Paragraph F4, Test Configuration. Both monotonic and cyclic tests shall be conducted up to deflections that cause ultimate failure of the shear panels, or reach the limits of the test equipment, but shall not be less than 10 times the lateral yield displacement of the test panel, δ_y. These are very large deflections, well beyond acceptable drift limits, but are needed to ensure that brittle failures (sudden loss of lateral or vertical load carrying capacity) do not occur near the useful deflection range of the panel.

a. Monotonic Test Protocol. A single specimen of each shear panel shall be loaded in one direction (monotonic) at a constant stroke rate that is slow enough to allow careful observation of panel performance and failure progression[1]. These observations shall include documentation of panel behavior through a log of observations with respect to displacement and photographs. Load versus deflection (TSF versus DH) shall be plotted to determine the measured lateral yield displacement δ_y. This value shall be used in defining the cyclic test protocol.

b. Cyclic Test Protocol. A minimum of two specimens of each panel configuration shall be loaded cyclically at a constant stroke rate that is slow enough to allow careful observation of panel performance and failure progression[2]. These observations shall include documentation of panel behavior through a log of observations with respect to displacement and photographs. Load versus deflection (TSF versus DH) shall be plotted to create load/deflection hysteretic envelopes. The cyclic load protocol follows a standard method, so that test results may be compared with cyclic test results of other systems. The protocol defined here is similar to SAC2[3] guidelines that have been modified to scale to the lateral yield deflection as described in ATC-24[4]. The SAC recommended loading histories call for loading with a deformation parameter based on interstory drift angle, θ defined as

[1] Monotonic tests conducted at USACERL used a stroke rate of 0.5 inches per minute.
[2] Cyclic tests conducted at USACERL used a stroke rate of 3 and 6 inches per minute. The faster stroke rate was used for panels tested cyclically beyond 10 inches (20 inches peak to peak).
[3] SAC Testing Programs and Loading Histories, unpublished guidance, 1997.
[4] Applied Technical Council (ATC) 24, Guidelines for Cyclic Seismic Testing of Components of Steel Structures, 1992.

interstory height over interstory displacement. The commentary to the SAC document explains that the interstory drift angle of 0.005 radians corresponds to a conservative estimate of the value that would cause yield deformation. Therefore, the load protocol defined by SAC in terms of drift angle are scaled to the measured lateral yield deflection, δ_y to define the cyclic test steps as defined in Table F-3. This protocol calls for a set number of cycles at each of the deformation amplitudes shown in Table F-3. This protocol is illustrated by the deformation time history shown in Figure F-2, which is based on a lateral yield deflection, δ_y of 0.4 inches and stroke rate of 6 inches per minute.

Table F-3.Cyclic Test Load Protocol.

Load Step #	SAC-2		Modified SAC Amplitude
	Number of Cycles, n	Peak Deformation, θ (radians)	
1	6	0.00375	$0.75\delta_y$
2	6	0.005	$1.0\delta_y$
3	6	0.0075	$1.5\delta_y$
4	4	0.01	$2\delta_y$
5	2	0.015	$3\delta_y$
6	2	0.02	$4\delta_y$
7	2	0.03	$6\delta_y$
8	2	0.04	$8\delta_y$
9	2	0.05	$10\delta_y$
10	2	0.06	$12\delta_y$
11	2	0.07	$14\delta_y$
12	2	0.08	$16\delta_y$
13	2	0.09	$18\delta_y$
14	2	0.10	$20\delta_y$
15	2	0.11	$22\delta_y$
16	2	0.12	$24\delta_y$
17	2	0.13	$26\delta_y$
18	2	0.14	$28\delta_y$
19	2	0.15	$30\delta_y$
20	2	0.16	$32\delta_y$

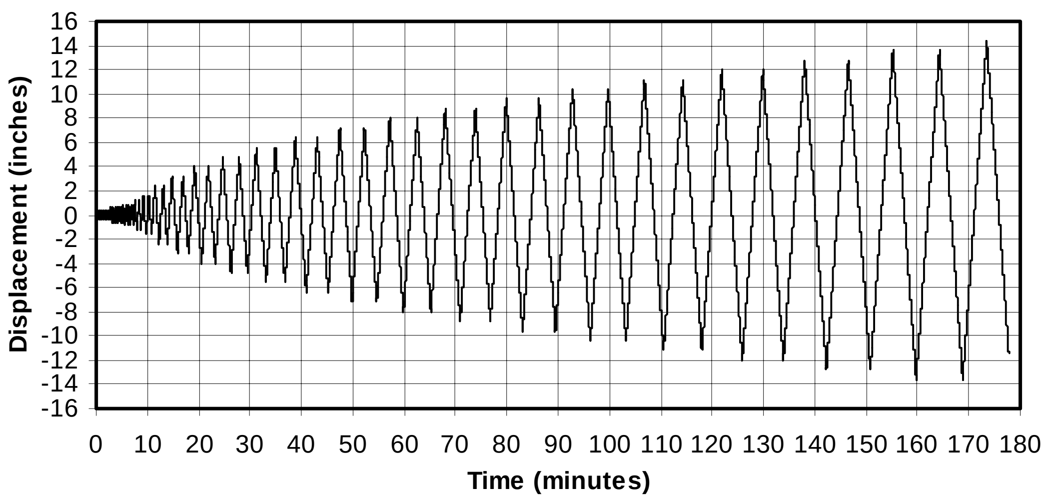

Figure F-2. Modified SAC cyclic test time history with δ_y = 0.4 in and 6 in/min stroke rate.

F7. SHEAR PANEL PERFORMANCE DOCUMENTATION. Shear panel performance from both monotonic and cyclic tests shall be documented in terms of load versus deflection plots (TSF versus DH). Cyclic tests plot load versus deflection to define load versus deflection hysteretic envelopes. Observations of panel performance and failure progression with respect to lateral displacement shall be documented in a tabular or other format. Photographs that document these observations shall be included in the test report. Test results for each specimen tested shall be summarized as indicated in Table F-4. Repeatability of panel performance of a given configuration is critical, so that if only two cyclic tests are conducted the poorest performance of the two shall form the basis for design. Therefore special consideration shall be given to large variations in panel performance, especially failure type or displacement amplitude of each type of failure. Test procedures and results shall be documented in a test report.

Table F-4. Summary of Test Panel Performance.

Test Specimen	Load Type (Monotonic or Cyclic)	Load Rate (mm/min or in/min)	Linear Shear Stiffness (kN/mm) or (kips/inch)	Shear Load at δ_y Deflection (kN or kips)	Shear Deflection at Ultimate Shear Load (mm or inches)	Ultimate Shear Load (kN or kips)

F8. DESIGN GUIDANCE. The measured load versus deflection data shall be used to define the design strength and stiffness of the shear panels. Resistance factors for each loading mechanism shall be defined that recognizes the variation of the shear panel capacity. In other words a panel shear capacity resistance factor, ϕ_v, shall reflect the variability of shear capacity of the tested panels. For example, $\phi_v = 0.9$ if the strength variability is small and mode and displacement of failures are consistent.

The following criteria shall be defined from the shear panel cyclic test data:

1. The panel ductility, μ , is the ultimate lateral deflection without loss of lateral or vertical load capacity, δ_u over yield lateral deflection, δ_y defined as follows:

$$\mu = \frac{\delta_u}{\delta_y} \qquad \text{(Eq F-2)}$$

2. The panel overstrength, Ω[5], which is the maximum measured ultimate lateral panel capacity, Q_u over the yield capacity, Q_y, defined as follows:

$$\Omega = \frac{Q_u}{Q_y} \qquad \text{(Eq F-3)}$$

3. The panel redundancy factor, ρ_1 of the individual shear panel tested[6]. This redundancy can be seen by comparing shear panel load/deflection data with coupon data, to determine if overstrength, Ω is due to strain hardening of the primary load-carrying element or due to the action of a secondary lateral load-resisting element. An example of this would be a panel with diagonal straps acting as the primary element with the columns effectively working to provide a

[5] This should not be confused with the system overstrength factor, Ω_0 defined in FEMA 302, Section 5.2.2 and Table 5.2.2 or TI 809-07, Equation C-16.
[6] This should not be confused with the reliability factor, ρ or ρ_x, which is the extent of structural redundancy in the lateral-force resisting system for an entire story of a building.

significant moment frame. In this case the moment frame would provide redundancy for the shear panel. If the diagonal straps fail, this moment frame capacity would provide lateral resistance for the moment from the P-delta effect of the gravity load. This redundancy is critical to preventing building collapse for a structure whose lateral load resisting system has failed. The panel redundancy factor, ρ_1 is calculated as follows:

$$\rho_1 = \frac{Q_u}{Q_p} = \frac{Q_p + Q_c}{Q_p} \qquad \text{(Eq F-4)}$$

Where:

Q_p = the portion of the shear panel ultimate lateral capacity carried by the primary lateral load resisting element including the effects of strain hardening. For panels with full panel sheet(s) this contribution will increase with increasing deflection due to a widening of the panel tension field. This value can only be reasonably determined by measuring Q_c (as described below) and calculating Q_p as the difference between Q_u and Q_c.

Q_c = the portion of shear panel ultimate lateral capacity carried by the columns acting as moment frames. For panels with full panel sheet(s) this value can only be obtained by testing the same exact panels with the full panel sheets removed. If these tests are not performed for full panel sheet shear panels, Q_c shall be set equal to zero.

4. The width of the cyclic test load/deflection hysteretic envelope. If the hysteretic envelope is significantly pinched (no or very little load resistance away from the peak excursions), much less energy is absorbed by the structural system so that building amplification grows. Pinched hysteretic envelopes occur when the primary lateral load-resisting element is stretched, and there is little redundant capacity from other elements to pick up load, so that little resistance is available away from the peak excursions of the load cycles. Panels with significantly pinched hysteretic envelopes, can experience high acceleration impact loading because the building will be free to sway with little resistance and then suddenly snap the lateral load-resisting element when another peak excursion is reached. This high acceleration snap can cause brittle failures. A shear panel with a great deal of redundancy within the panel, ρ_1 will tend to have a wide hysteretic envelope.

Table F-5 defines the acceptance criteria in terms of μ, Ω and ρ_1 based on data measured in the cyclic panel tests, as defined by Equations F-2 through F-4.

Table F-5. Acceptance Criteria for Shear Panels based on μ, Ω and ρ_1.

Criteria	Acceptance Requirement
Panel Ductility, μ	$\geq$ 10
Panel Overstrength, Ω	$\geq$ 1.3
Panel Redundancy factor, ρ_1	$\geq$ 1.0
Hysteretic Envelope Width	Not Required

Values for the system response modification factor, R system overstrength factor, Ω_0 and deflection amplification factor, C_d, are defined in Table F-6. These values are used in the seismic design guidance defined in TI 809-04 and FEMA 302. Exceptions to this criteria shall require Corps of Engineers Headquarters (CEMP-ET) approval.

Table F-6. Values for R, Ω_0 and C_d.

Factor	Value
System Response Modification Factor, R	4
System Overstrength Factor, Ω_0	2
Deflection Amplification Factor, C_d	3.5