APPENDIX F

INSTRUMENTATION AND DATA ACQUISITION REQUIREMENTS

Introduction

This appendix outlines requirements for instrumenting test specimens and test equipment, as well as methods for controlling tests and locations at which control forces and displacements shall be measured. It is understood that extensive instrumentation adds complexity and expense to any test program, and also requires substantial data storage and additional processing. However, it is important that sufficient data is acquired from each test specimen because the cost associated with repeating a test due to missing data is prohibitive; it is felt that the requirements outlined here will help to ensure that thorough response information will be attained at a minimum expense. In cases where acquisition hardware at a particular laboratory cannot record the number of channels specified, a reduced instrumentation plan must be negotiated with SAC.

The instrumentation configurations presented here are intended to represent a minimum channel set, and enhancements to this set will be made by individual researchers depending on the goals of their test program or interest in certain types of specimen behavior. In some cases, one or more of the basic instruments will need to be eliminated because of unusual or unique specimen designs or test arrangements. In such situations, any deviations from the basic instrumentation plan should be noted in the pre-test submittal to SAC.

A summary of instrumentation submittal requirements is provided at the end of this appendix.

General Requirements

Many different types of instruments may be used to measure the behavior of test specimens, including strain gages, load cells / pressure cells, displacement transducers, accelerometers, etc. All of these are acceptable, provided that they have sufficient resolution and accuracy for the purposes of the test. In general, an accuracy of 1% over the range of the quantity being measured (as determined from pre-test analyses) is adequate. Preliminary analyses of the specimen and loading apparatus should be used to assist in defining the instrumentation requirements and estimating the displacement/strain/force ranges to be used in selecting and calibrating instruments.

Because the installation details may have a substantial influence on the behavior of the instrumentation, it is important to select proper locations for mounting instrumentation to external reference frames as well as to the specimen itself. The installation details on the test specimen should not influence its behavior in any way, for example, by increasing the likelihood of a crack developing at a drilled screw hole. Care should be taken when attaching instruments to the specimen in a region of potential failure. Experience at some laboratories has indicated that instrument mounts may be attached securely with small, low heat-input welds without compromising the specimen.

Since both quantitative and qualitative behavior is important, every specimen should be coated with whitewash prior to testing so that the locations of most significant yielding can be identified visually. Also, the laboratory temperature should be recorded at the start of each test.

The specimen dimensions and displacement and force quantities presented in Figs. F-1 and F-2 below are referred to in the remainder of this document. When a specimen is tested by displacing the column tip horizontally, the beam ends must be restrained against vertical motions and allowed to translate horizontally. Otherwise, a rigid body rotation of the entire specimen in the direction of loading will be introduced inadvertently.

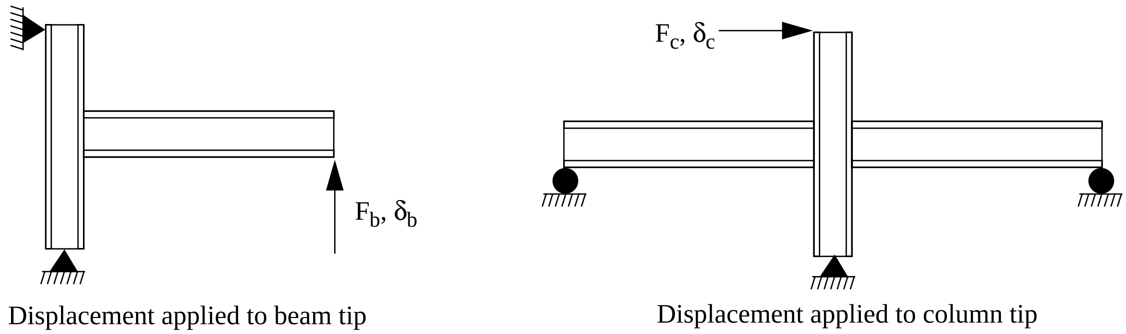

Figure F-1: Possible Approaches for Loading Beam-Column Specimens

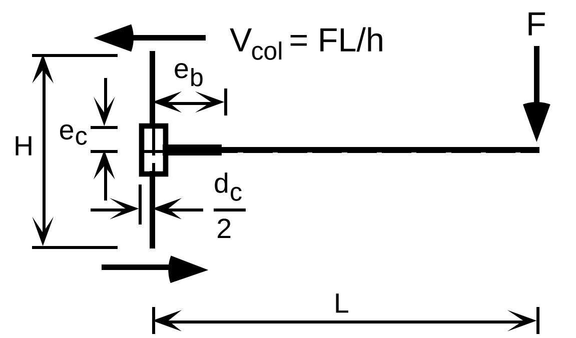

Figure F-2: Definitions for an Exterior Beam-Column Specimen

Data Acquisition

Data scanning may be either manual or computer-controlled, but in all tests, the scan rate should be frequent enough to assure that the response of the specimen is accurately recorded. The scan rate can be adjusted as a function of maximum displacement amplitude if constant-velocity loading is used. An *X-Y* plotter should be used for all tests to provide a permanent hard-copy recording of at least the control force and displacement.

Efforts should be made to include time as part of all measurement schemes, even those in which dynamic loading is not present. If a test is not run as a continuous sequence of cycles, the time elapsed between each loading sequence shall be noted. This is particularly important if the test is run over more than one day because the steel may exhibit some time-dependent healing. For dynamic tests the loading rate should be controllable, and the time must be recorded. Dynamic tests should also use an automated control system, and inertia effects should be considered when evaluating the measured loads.

Actuator Instrumentation

In general, strain-gaged load cells in line with the actuator are preferred to hydraulic pressure transducers, but in all cases the actuator loadcells must have calibration records from either the manufacturer or from the laboratory which can be traced to NIST standards. All actuators should read individual loads and displacements, and these should be recorded, even if the control scheme uses the averaged values from multiple actuators. Although the relative displacement of the actuator cylinder is required for control of the actuator, it should not be used as the control displacement for the connection assemblage (unless the clevis is preloaded as in some MTS actuators) because play in the clevis will cause the displacement of the structural element being tested to be less than that of the actuator piston. The control displacement transducer should be attached to the clevis assembly and should extend parallel to the centerline of the actuator. If the location of the control transducer is substantially shifted away from the longitudinal axis of the element, then a second transducer on the opposite side of the beam (or column) axis must be installed and the average of the two instruments used for control. This will limit the influence of twisting in the element on the measured displacement. It may be desirable in some cases to have a high-resolution displacement transducer installed perpendicular to the axis of an actuator to measure any axial deformations in the loaded member (either compression or extension) which may occur due to yielding or local buckling. This type of deformation may not be able to develop in a full frame, and the potential for this type of behavior to occur should be identified.

Beam Instrumentation

The primary displacement transducer for beams measures the displacement at the beam tip. For the Phase 2 test program, the beam tip is defined as the location at which there is zero moment, not the point at which the wide flange section is bolted to the actuator attachment hardware. The beam tip displacement will typically be measured between a reference frame and the attachment corbel at the centerline of the actuator. (It should not be the actuator piston displacement unless the actuator has pre-loaded clevises which eliminate relative displacements between the actuator piston and the clevis attachments.) This instrument must be used for all displacement control signals. As mentioned above, if the axis of the transducer differs substantially from the vertical axis of the beam, two transducers situated on either side of the beam axis should be averaged to eliminate twisting.

Additional displacement transducers may be used as desired to capture more local effects — for example, supplemental transducers between the column flange and an intermediate point on the beam to measure local hinge rotation, transducers spanning a reduced beam section (RBS, or “dogbone”) to measure local elongation or shortening due to inelastic behavior, or transducers between beam flanges and column flanges in simple connections. A typical instrumentation arrangement for measuring hinge rotations at the face of the column is shown in Fig. F-3. Note that this assumes the length of the plastic hinge region can be estimated with reasonable accuracy. If a specimen representing an interior connection is loaded at the tip of the column, the vertical displacement of the beam tip(s) should be monitored, even if rigid struts are in place to restrain the tip motion.

The three locations shown in Fig. F-4 must be strain gaged at the top and bottom of every beam section, regardless of the connection detail. In general, strain gages should also be placed in any region of the beam that is anticipated to undergo significant plastic rotations. Other installations which may be important are on the inner portions of the beam flanges (to capture curvature within the flange) and along the length of the plastic hinge region moving away from the column (using strip gages, for example). The following connection-specific guidelines should be followed:

- In RBS designs, strain gages should be installed within the reduced section and/or adjacent to it.

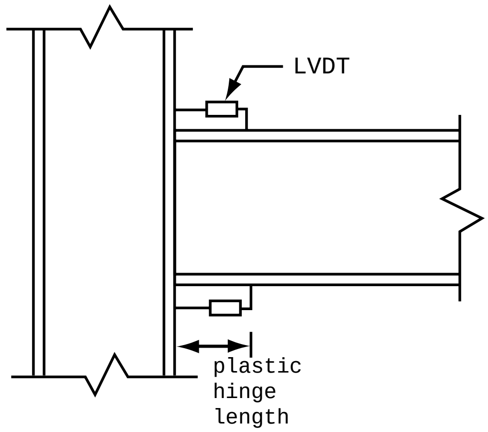

Figure F-3: Instrumentation to Capture Rotations in an Assumed Plastic Hinge

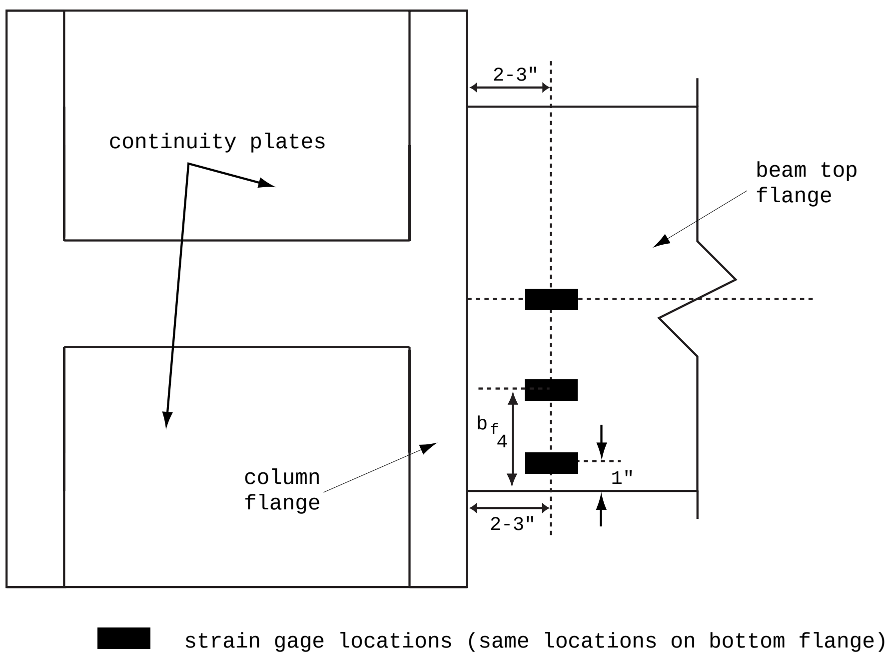

Figure F-4: Strain Gage Locations for Beam Flanges

- In strengthened designs, suitable locations on the strengthening element should be gaged (for example on cover plates or haunch flanges); the beam should also be gaged just outside of the strengthened section if a plastic hinge is anticipated to develop here.
- Unreinforced moment-resisting connections (pre-Northridge designs) may be instrumented more thoroughly in the region of the beam-column groove welds than prescribed in Figure F-4.
- Simple shear connections should be strain gaged to try to identify the mechanism of force transfer in the connection, for instance through the use of gages on the shear tab or in the web of the beam; if there is no connection between the beam and column flanges, then the gages in Figure F-4 are not required.

- Any elements in a connection that are explicitly designed to provide inelastic or other energy-dissipative behavior should be properly instrumented to determine their mechanical characteristics; examples include additional displacement transducers, thermocouples, or device-specific strain gages.
- Two beams framing into both sides of an interior column should both be instrumented as described here, unless there are differences in their design or construction which warrant separate instrumentation plans.
- Beams tested with composite slabs should have instrumentation which complements the instrumentation installed on the slab.

A separate beam instrumentation plan should be submitted to SAC for review prior to testing any other connection configurations not described here. At this time, there are no requirements to strain gage beam flange-to-column flange welds because preparation of the weld surfaces for adhering the gages may influence the weld behavior.

Column Instrumentation

In most tests the column is expected to remain elastic, and extensive instrumentation is not required. However, it is important at a minimum to determine the contribution of elastic flexural deformations in the column to the measured beam tip displacement, and at least two displacement transducers are required to measure this (Fig. F-5). Note that the locations of these instruments will differ slightly depending on whether an interior or an exterior column is being tested. Fig. F-6 shows a possible set-up for an interior beam-column connection. The displacement transducers in this case may not have sufficient resolution to differentiate between the column rotation and the overall deformation of the column due to loading at the tip. For this reason, inclinometers are also indicated in this Figure as an alternate means of extracting the column rotation from the total rotation of the connection.

Whenever it is the point of load application, the column tip displacement must be measured, consistent with the definitions and recommendations for measuring beam tip displacement given in the previous section. Further adjustments in the instrument locations will be required for tests of beams with composite slabs, with stiffeners or haunches, etc. It is desirable where channels are available that multiple transducers be used at each of the locations shown in Figs. F-6 and F-5 (for instance one on each side of the column flange along the Z-axis) to capture any column twisting that may occur. In all cases the mounts for the transducers on the column flange should be installed in such as way that there is no potential for initiating a fracture or otherwise affecting the behavior of the connection.

A minimum of four strain gages are required on the column flange opposite the beam connection in exterior beam-column specimens, as shown in Fig. F-7. These gages are intended to capture strains adjacent to the intersection between the continuity plate and the column flange, as well as any hinging which might occur in the column adjacent to the panel zone. For interior connections, these gages should be installed on both column flanges to provide symmetric recordings, although those located along the line of the continuity plate will be discarded. The precise distance from the beam flanges or continuity plates at which the gages are located may be changed if yielding is not anticipated in this region. This may be justified if haunches or triangular fin plates are installed perpendicular to the beam flange, or if a heavy web doubler plate is present.

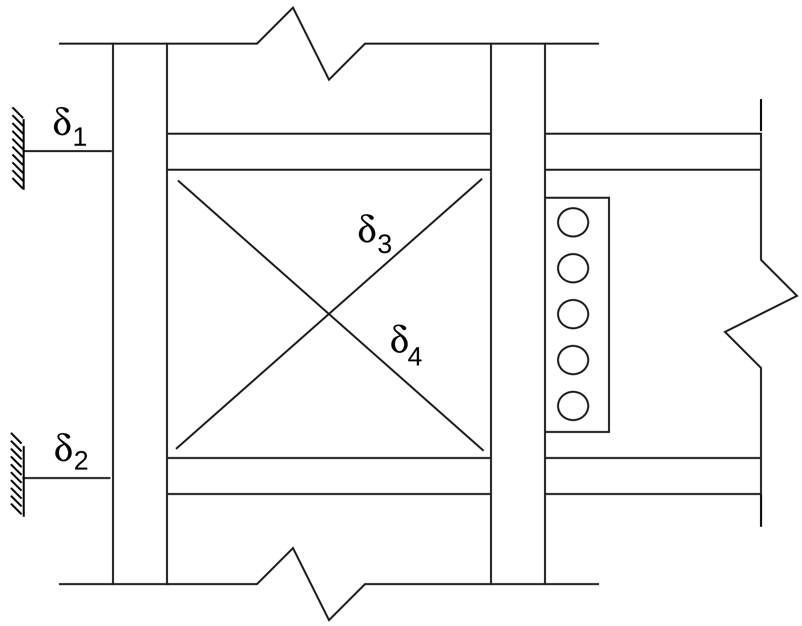

Figure F-5: Displacement Transducers for Exterior Beam-Column Connection

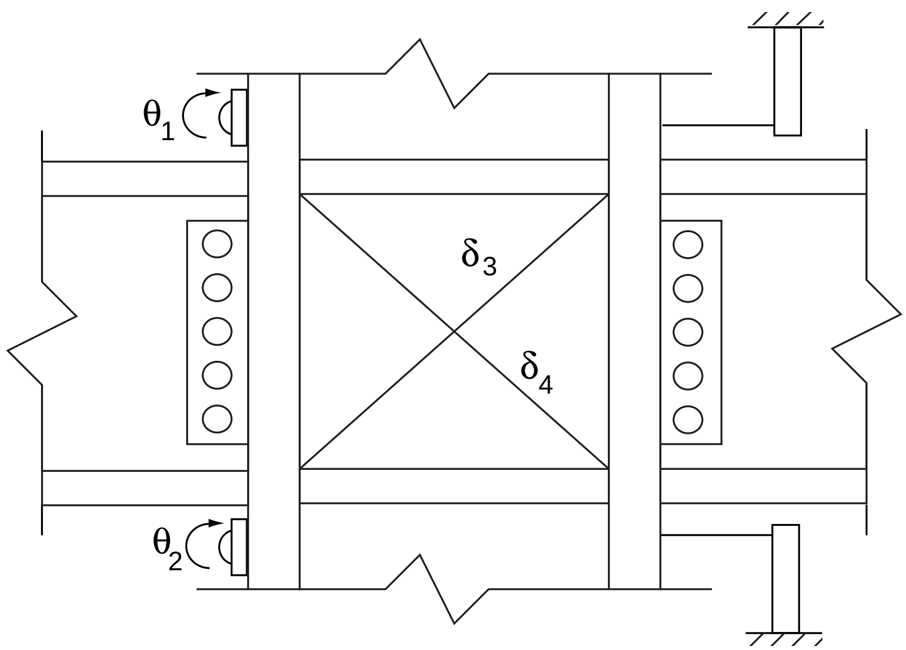

Figure F-6: Displacement Transducers for Interior Beam-Column Connection

Panel Zone Instrumentation

At least two sets of instruments are required in the panel zone of each beam-column connection test specimen. The first set is intended to measure the average shear deformation in the panel zone by means of a pair of displacement transducers running diagonally across the panel zone as shown in Fig. F-5 (transducers δ_3 and δ_4). These should not be attached to the column flanges but rather should be attached to the web adjacent to the flange-continuity plate intersection. Care must be taken in this installation detail to ensure that the behavior of the connection is not influenced by

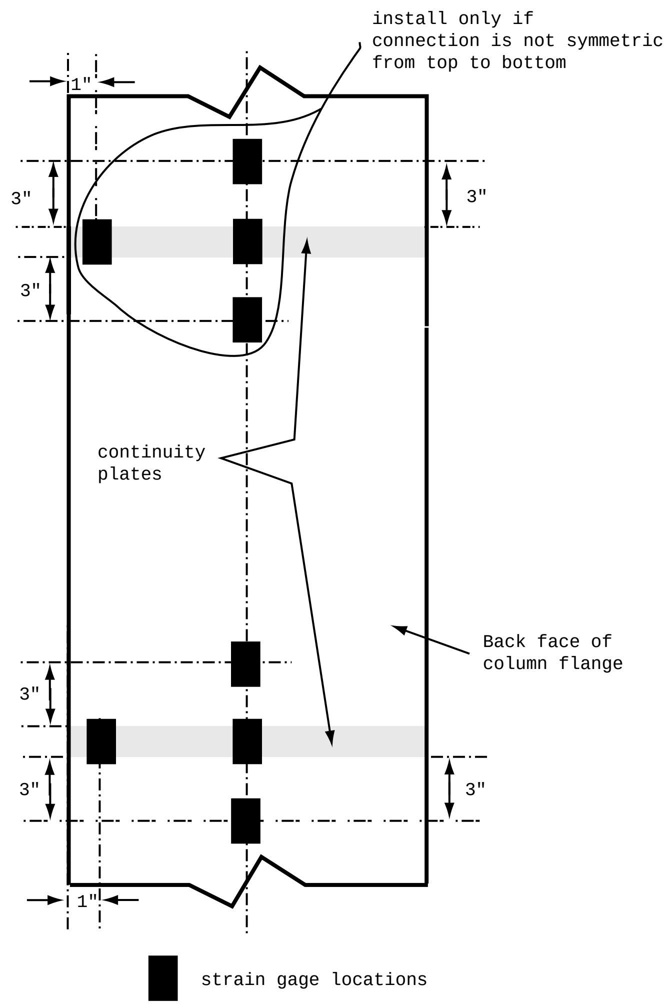

Figure F-7: Strain Gage Locations for Exterior Column Specimen

drilling into the column steel at the “k”-line of the column. Some laboratories have found that these instruments can be attached reliably using low heat-input welds on the column web.

The second set of instruments consists of a minimum of two three-element strain gage rosettes arranged on the column web in the panel zone as shown in Fig. F-8. These are intended to directly measure the shear strain at distinct locations in the web to provide more detailed information beyond the average shear deformation taken from the diagonal displacement transducers. The corner rosettes should be at least 1 in. away from the edge of the continuity plate and continuity plate weld, and at least 1 in. away from the “k”-line of the column.

Additional panel zone instrumentation shall be installed when multiple panel zones may develop in the specimen, such as specimens with haunches or vertical rib sections. This additional instrumentation should be analogous to that described above with the purpose of isolating the rotations which develop in each region of the column.

Slab Instrumentation

At this time, there are no well-defined requirements for slab instrumentation. At a minimum, displacement transducers should be installed to measure the relative displacement between the

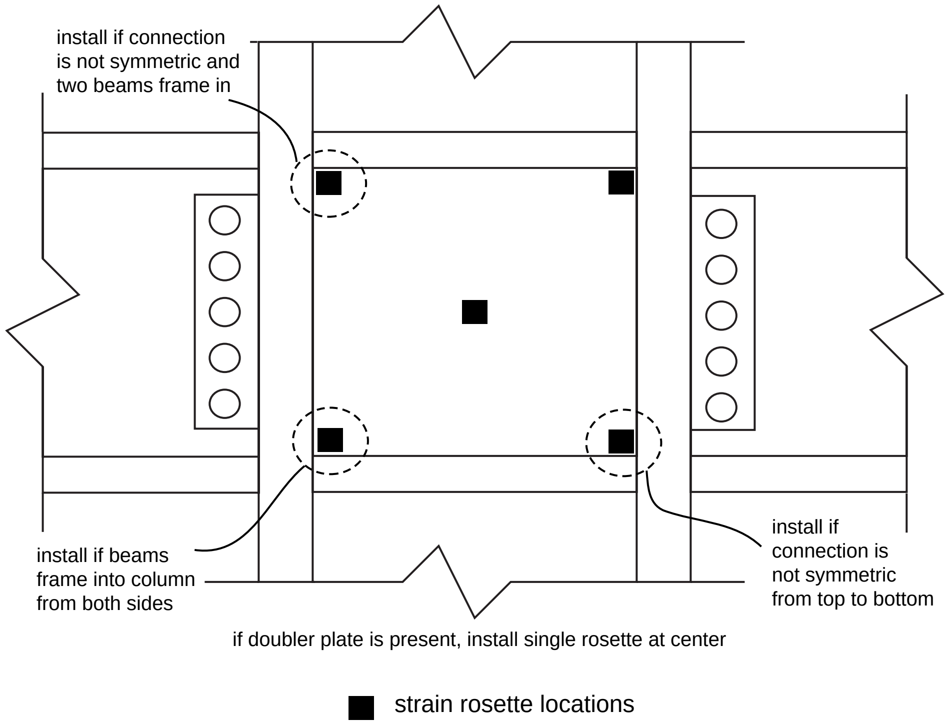

Figure F-8: Panel Zone Strain Gages

slab and the column along the axis of the beam at various locations (similar to those shown in Fig. F-3). The slab may also be whitewashed to allow cracks in the concrete to be identified easily, particularly in the region around the column.

Other Instrumentation Requirements

Specimens incorporating bolted T-stub connections should be instrumented in such a way that both the global and local behavior can be captured. This includes installing strain gages on the beam flanges near the connections to the T-stub as well as on sections of the T-stubs which will be subjected to high strains. Bolts may also be instrumented if desired. Instrumentation to measure slip between the T-stub and the beam should be used as shown in Fig. F-9.

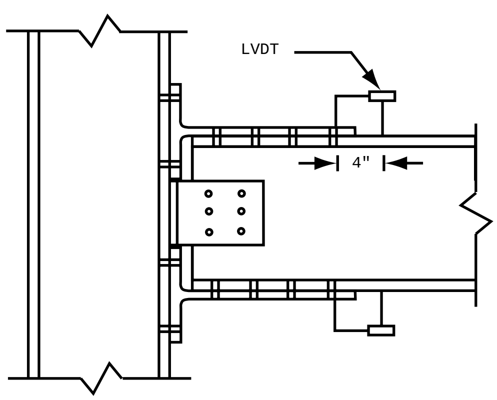

Figure F-9: Instrumentation to Measure Slip in T-Stub Connections

If connections with discrete energy-dissipating elements are tested, sufficient information should be collected on the individual devices to characterize their behavior, including strain (elongation or shear strain), strain rate, temperature, etc.

Specimens subjected to dynamic tests should have thermocouples installed in regions where yielding is expected and accelerometers installed on primary elements if inertial effects are significant.

Minimum Channel List

Table F-1 lists the minimum set of channels which must be recorded for an exterior beam-column connection test. For interior connection tests, the instrumentation associated with the beams will typically double, and there will be some modifications in the channels associated with the column. Additional channels should be recorded as noted above to trace the behavior of composite slabs and any other elements which supplement the beam-column connection.

Channel Description	Type of Transducer
Beam tip force	actuator loadcell
Beam tip displacement	displacement transducer
Beam flange strain - top, 1	strain gage
Beam flange strain - top, 2	strain gage
Beam flange strain - top, 3	strain gage
Beam flange strain - bottom, 1	strain gage
Beam flange strain - bottom, 2	strain gage
Beam flange strain - bottom, 3	strain gage
Column displacement - above beam	displacement transducer
Column displacement - below beam	displacement transducer
Column rear face strain - at continuity plate and column centerline	strain gage
Column rear face strain - at continuity plate and away from column centerline	strain gage
Column rear face strain - on column centerline above continuity plate	strain gage
Column rear face strain - on column centerline below continuity plate	strain gage
Panel zone displacement, 1	displacement transducer
Panel zone displacement, 2	displacement transducer
Panel zone strain rosette - center	strain rosette
Panel zone strain rosette - corner	strain rosette

Table F-1: Minimum Channel List for Exterior Beam-Column Connection Specimen

Submittal Requirements

A general instrumentation plan shall be submitted to SAC for review prior to commencing each series of tests. This should include the types of instruments to be used and their resolution, as well as schematic installation details and any deviations from the minimum channel set specified in this document. If this plan is followed for all of the specimens in the test series, then no further submittals are required. However, if modifications are made for subsequent specimens (e.g. adding, moving, or removing instruments), a revised instrumentation plan indicating the changes shall be submitted for each specimen in which changes are proposed. This revised plan must be submitted to SAC one week prior to testing.