# APPENDIX E

# LOADING PROTOCOL
# FOR STEPWISE INCREASING CYCLIC TESTS

## Background

The choice of a testing program and associated loading history depends on the purpose of the experiment, type of test specimen, and type of anticipated failure mode (e.g., rapid strength deterioration, slow strength deterioration, member buckling, etc.).

Testing of a single specimen is adequate if the rate of strength deterioration is slow (or the level at which rapid strength deterioration occurs is well defined, e.g., member buckling), and analytical cumulative damage modeling is not part of the investigation. Testing of a single specimen provides insufficient information if the rate of strength deterioration is rapid and the level at which deterioration occurs may exhibit considerable scatter (ATC-24).

Fracture at weldments is a failure mode in which the rate of strength deterioration is rapid, and the level at which deterioration occurs exhibits considerable scatter. For such a case, ATC-24 recommends testing at least three identical specimens with identical loading histories; the performance of the specimen should be evaluated on the basis of the test with the smallest energy dissipation capacity unless a sufficient number of specimens is tested to permit a statistical evaluation of the results. Alternatively, a cumulative damage testing program (see ATC-24, Section 4.2.2) may be performed.

The basic loading history described below shall be used to evaluate performance of a beam-to-column subassembly, provided the ground motion is not of a near-field type that contains a large displacement pulse. In the latter case a near-field loading history shall be utilized (see below).

The loading history used in the Phase 2 Steel Project has been developed as a result of a series of non-linear analyses of hypothetical steel moment frame structures subjected to a range of seismic inputs. This study is presented in more detail in a SAC Background Document that is currently in preparation.

## Basic Loading History

The basic loading history for a single specimen testing program is the multiple step test, in which the loading (deformation) history consists of stepwise increasing deformation cycles as illustrated in Fig. E-1. The deformation parameter to be used to control the loading history is the interstory drift angle, $\theta$, defined as interstory displacement divided by story height. In the test specimen this angle is defined as the beam deflection divided by the beam span (to the column centerline) if the vertical beam deflection is controlled, or as the column deflection divided by the column height if the horizontal column deflection is controlled. Deformation control shall be used throughout the experiment.

In the basic loading history, the cycles shall be symmetric in peak deformations. The history is divided into steps and the peak deformation of each step *j* is given as $\theta_j$, a predetermined value of the interstory drift angle. Thus, the loading history is defined by the following parameters:

$\theta_j$ the peak deformation in load step *j*

$n_j$ the number of cycles to be performed in load step *j*

**Numerical values of $\theta_j$ and $n_j$:**

| Load Step # | peak deformation θ | number of cycles, *n* |
|---|---|---|
| 1 | 0.00375 | 6 |
| 2 | 0.005 | 6 |
| 3 | 0.0075 | 6 |
| 4 | 0.01 | 4 |
| 5 | 0.015 | 2 |
| 6 | 0.02 | 2 |
| 7 | 0.03 | 2 |
| Continue with increments in θ of 0.01, and perform two cycles at each step | | |

**MULTIPLE STEP TEST - LOADING HISTORY**

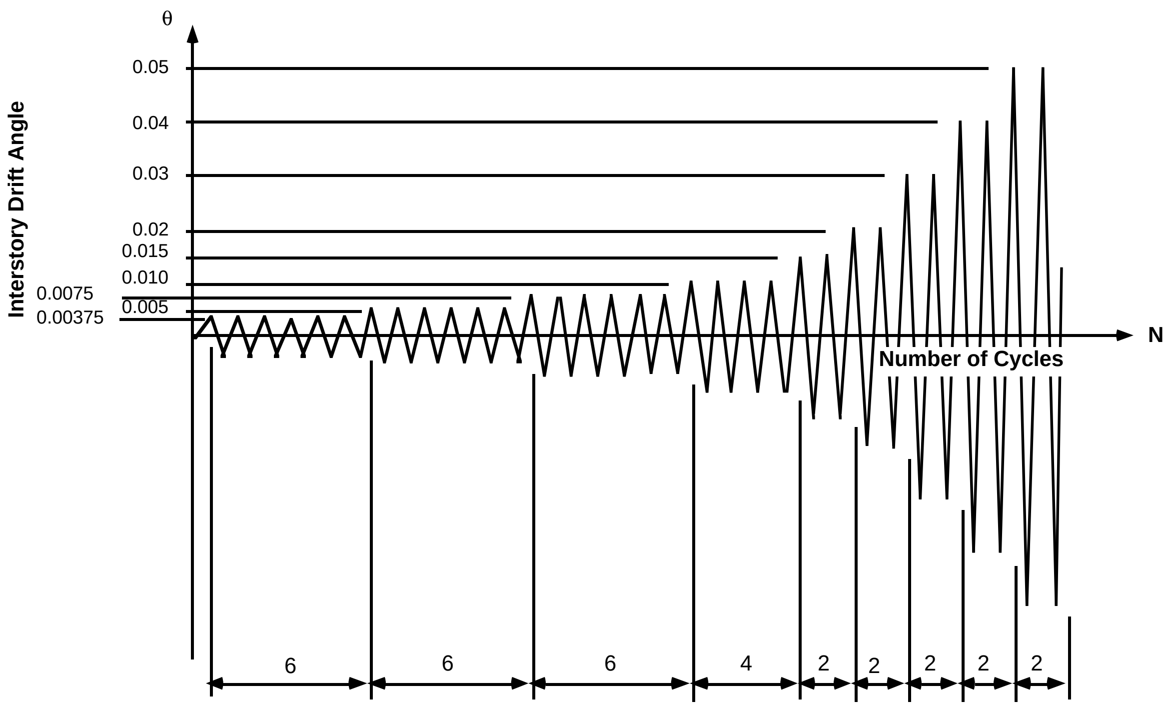


**Figure E-1. Multiple Step Test, Deformation Parameter is Interstory Drift Angle**

**Additional Considerations:**

- It is recommended to interrupt the basic loading history during the last cycle of selected large steps and carry out small cycles in order to evaluate intermittent stiffness degradation. For such stiffness evaluations the specimen is to be unloaded after reaching the peak (positive or negative) of the last cycle in the designated step, and subjected to two cycles with an amplitude of 0.005 radians, whereby the amplitude is measured with respect to the permanent deformation at the unloaded state.
- The loading history shall be continued in the established pattern until severe strength deterio-

ration is evident. If the displacement limit of the test setup is approached before severe deterioration occurs, the test specimen shall be cycled at maximum peak deformation until severe deterioration is evident. Severe deterioration may be defined as attaining a resistance at peak deformation of less than 40% of the observed peak load.

- If post-fracture behavior is to be investigated, the test program shall continue to the limit of the test facility, even after severe deterioration has occurred.

## Evaluation of Proposed Loading History in Relation to SAC Phase 1 Loading Protocol

Assumption:

Since the SAC Phase 1 loading history is based on plastic deformations (the yield displacement of the specimen), it is neccessary to make an assumption on the relation between specimen yield displacement and interstory drift angle $\theta$. In the Phase 1 testing programs the "yield interstory drift" (beam tip displacement at yielding over beam length [to column centerline]) was usually smaller than 0.01. Thus, assuming $\theta_y = \delta_y/L = 0.01$ is close to an upper bound of the reference yield "deformation", and using $\theta_y = \delta_y/L = 0.005$ is likely a lower bound of the reference yield "deformation".

The cumulative deformation ranges ($\Sigma\Delta\theta_i$) of the Phase 1 and Phase 2 loading histories are compared in Fig. E-2, using $\theta_y = 0.01$ and $\theta_y = 0.005$ for the Phase 1 history. The following observations are made:

- If $\theta_y = 0.005$ is used for the Phase 1 history, then the cumulative deformation range of the Phase 1 history exceeds that of the Phase 2 history at $\Delta\theta = 0.07$. This range corresponds to an amplitude of 0.035. Subtracting the yield rotation of 0.005, the plastic rotation amplitude is 0.03, which is the acceptability value used in Phase 1. Thus, at this acceptability value the Phase 1 history is about equally severe as the Phase 2 history, for $\theta_y = 0.005$.
- Using $\theta_y = 0.01$ for the Phase 1 history will result in cumulative deformation ranges that will always stay below those of the Phase 2 history. The main reason is that in the Phase 2 history many more small cycles are performed because the decision was made that all cycles with a range of 0.005 causes damage. The first 18 cycles are at or below yield if $\theta_y = 0.01$. With few exceptions (brittle connections that fracture very early) it is unlikely that these small cycles contribute much to cumulative damage. Disregarding these small cycles, the cumulative deformations between the Phase 1 and Phase 2 histories are comparable.

## Near-Field Loading History

Near-field ground motions present a special problem. The response to them is often characterized by one very large excursion, followed by a large number of small cycles with large mean deformation amplitude. It is expected that the cumulative damage is controlled by the first large excursion, which corresponds to monotonic loading of the test specimen. However, the subsequent smaller cycles may lead to additional deterioration that needs to be evaluated.

No specific attention has been paid to the characteristics of near-field response in the development of the basic loading history. A separate loading history that accounts for near-field effects needs to be developed. The results to be obtained from the SAC near-field response studies will be utilized to develop such a history. It is expected that the maximum deformation amplitude will

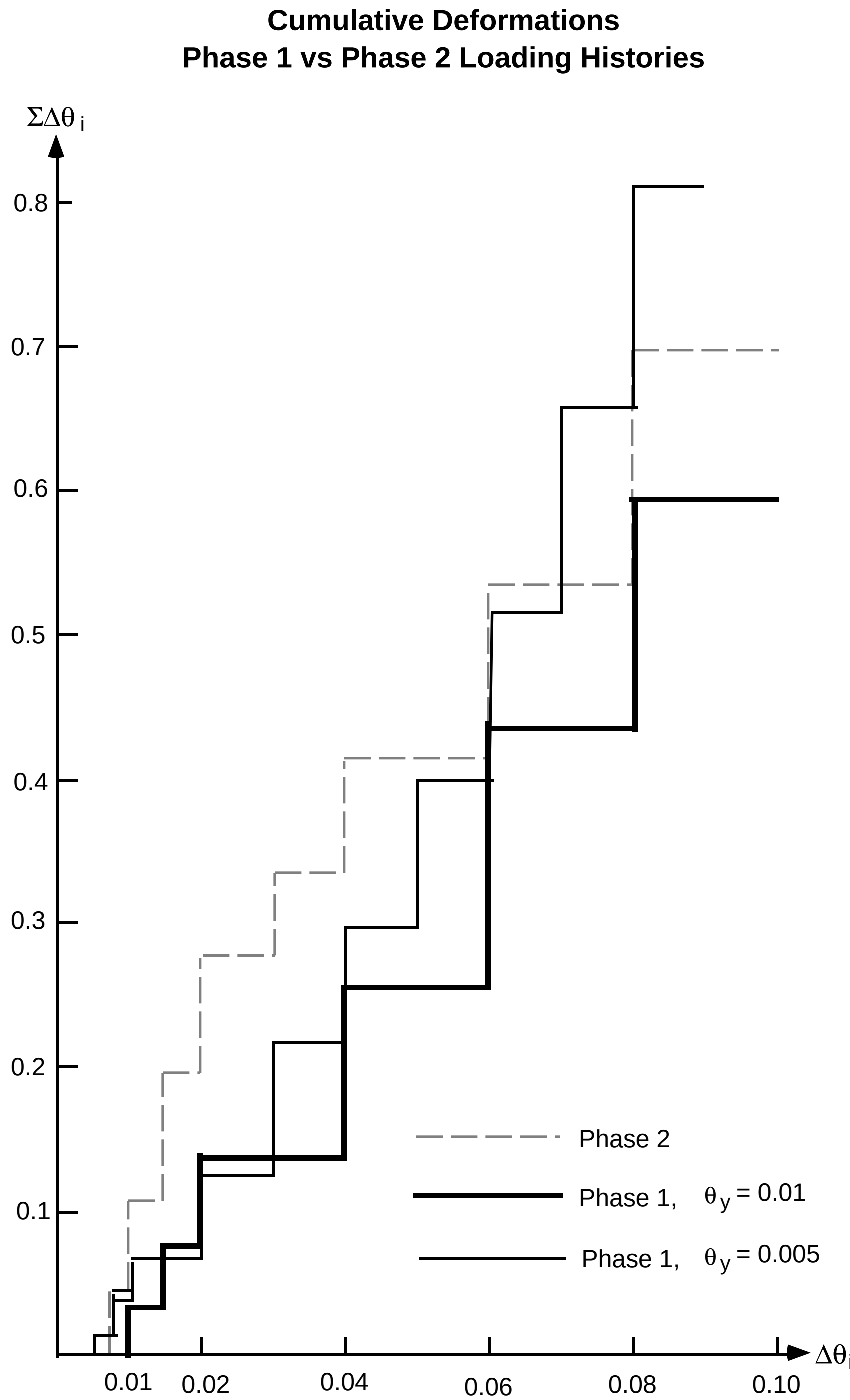


**Figure E-2. Comparison of Cumulative Deformations Between SAC Phase 1 and Phase 2 Loading Histories**

be larger than for the 2/50 ground motions, which has to be reflected in the acceptability value, but it is also expected that the additional deformation ranges due to the subsequent cycles will be smaller than for the 2/50 ground motions. The behavior under such deformation histories cannot be deduced from the basic loading history and requires a special testing program.