Seismic Fragility Pipe Testing

Vincent DeVita
Rockwell International, Canoga Park, CA USA

ABSTRACT

Responding to the needs of emerging research programs, Energy Technology Engineering Center (ETEC), a Department of Energy laboratory, has designed and built a Seismic Fragility Testing System. This paper describes several fragility tests on representative piping systems recently concluded at ETEC. These tests, all resulting in piping failure, include programs sponsored by the US Nuclear Regulatory Commission (NRC) and the Electric Power Research Institute (EPRI). The results of the dynamic load testing of representative piping systems has generated valuable data which can provide the basis for ASME Code changes to current piping design criteria.

INTRODUCTION

The Energy Technology Engineering Center (ETEC), a Department of Energy (DOE) laboratory operated by Rockwell International near Los Angeles, California has designed a facility to meet seismic fragility testing needs. ETEC's Seismic Fragility Test System (SFTS) was designed and built for destructive testing of nuclear power plant components and structures. Its large displacement and high velocity capability can generate large acceleration loadings in the low frequency range generally associated with seismic events (3-10 Hz), and the multi-table support capability enables testing of large, complex, structural shapes at these same high levels.

To date, five piping systems have been tested. The first test article was a 3-in. unpressurized pipe loop. This test was sponsored by DOE to demonstrate that ETEC had an operational facility capable of producing dynamic pipe failures and to provide insight into the seismic design margins. The second, and by far the most thoroughly documented test, was a 6-in. pressurized pipe loop sponsored by the USNRC. The third test, also a 6-in. pressurized pipe loop sponsored by the USNRC and EPRI, was supported by a prototypic spring hanger and contained an actual motor operated valve, in addition to simulated valve weights. The fourth test, a 6-in. pressurized pipe loop of stainless steel also sponsored by the USNRC/EPRI was driven by three tables and a snubber. The snubber and strut were also under evaluation for this program. The last test was a re-test of the third piping system.

TEST FACILITY

ETEC's SFTS has four major subsystems: 1) shaker tables/seismic mass; 2) energy storage; 3) hydraulic power supply; and 4) digital computer control. The system is built around existing facilities and equipment, which included a 20- by 40-ft load reaction floor (seismic mass) and a gaseous nitrogen storage system.

The SFTS has four uniaxial (horizontal), independently controlled shaker tables that are mounted on a 20- by 40-ft seismic floor. Non-synchronous inputs were applied to piping to simulate required operating conditions.

The energy storage system consists of 12 30-gal piston accumulators that are manifolded to deliver hydraulic fluid to the tables, and a 3200 psi 1100 ft^3 gaseous nitrogen (GN_2) supply system to pressurize the accumulators.

The hydraulic power supply provides pressurized oil to the 24 table bearings (six pairs per table) from a 75 hp motor/pump assembly.

The microcomputer-based control system provides table control and real-time data acquisition for dynamic testing. Tables were controlled independently or synchronously with defined time history displacement functions.

The SFTS digital data acquisition system (DDAS) supplements data recorded by the digital computer control system. Up to 96 additional channels of test data can be recorded at sample rates of 400 samples/second.

TEST ARTICLES AND TEST RESULTS

3-in. Diameter Piping System Demonstration Test

The initial checkout of the test facility was performed using a 3-in. diameter, Schedule 40, unpressurized piping system.

The piping system (test article) consisted of 51 ft of 3-in. diameter (Schedule 40) carbon steel (A-106 Gr B) piping and components. Materials of construction and fabrication of the test article were in accordance with ASME Code, Section III, Class 1 requirements. Instrumentation included 8 accelerometers and 6 strain gages (3 locations).

The unpressurized pipe system was filled with oil to simulate fluid inertial effects. The test article was subjected to the following three levels of seismic input.

Low level seismic load - 5 g nominal ZPA
Intermediate level seismic load - 14 g nominal ZPA
High level seismic load - 30 g nominal ZPA

Following the successful completion of seismic test series, (no structural failure) three low-level, limited cycle (constant displacement) harmonic inputs were applied. Following the successful completion (no structural failure) of the low level input series, the following harmonic input load was applied:

6.0 Hz, ± 7.5 inches, 4-6 cycles

Failure occurred in the tee during this 6.0 Hz sine burst input. A preliminary examination of the failed component indicated a fatigue failure in the crotch area accompanied by local structural collapse. The exact sequence of events leading to failure (which came first, collapse or fatigue?) was not determined.

The test demonstrated the ability of the piping system to withstand a seismic input greater than that predicted to cause failure. ETEC pre-test analysis predicted failure would occur at 20 g - the test article did not fail at a 35 g ZPA input level. The 35 g maximum test level (30 g nominal) corresponds to 6 times the calculated elastically ASME Code Section III level D allowable value. Test results also indicated strain controlled failure rather than load controlled failure as assumed for pretest failure predictions and by ASME design criteria.

6-in. Diameter Piping System Feasibility Test

This test has been comprehensively documented in Ref. [1]. The following discussion is taken from a summary in that report.

The piping system utilized in the test (test article) consisted of some 48 ft of 6-in. diameter and 17 ft of 3-in. diameter carbon steel (A-106 Gr B) Schedule 40 piping and piping components and included a simulated valve assembly. The construction, including support locations, of the test article, was in accordance with both the NRC requirement and ASME Code Section III Class 1. Instrumentation included 6 accelerometers, 30 strain gauges at 18 locations and 1 pressure transducer and provisions to measure test article permanent set.

During testing, the test article was internally pressurized at 1000 psi and was to have been subjected to the following three levels of dynamic seismic loads:

Low level seismic Load:	5 g nominal ZPA
Intermediate level seismic load:	14 g nominal ZPA
High level seismic load:	25 g nominal ZPA

The load levels were selected on the basis of the 17.1 g ZPA level predicted by ETEC (and later corroborated by Hanford Engineering Development Laboratory (HEDL), Ref. [2], to cause failure of the test article and previous ETEC experience gained during prior similar testing of the 3-in. diameter piping system. Provisions were also made to conduct the following sequence of three sine burst tests following seismic testing if failure of the test article did not occur during the seismic tests:

Sine burst - 4 Hz: 8 cycles of $\pm$ 7 in max. displ.
Sine burst - 5 Hz: 11 cycles of $\pm$ 7 in max. displ.
Sine burst - 6 Hz: 7 cycles of $\pm$ 6 in max. displ.

The number of cycles were programmed and were designed to provide a minimum of 2 seconds of maximum displacement at 4 Hz and 5 Hz and a minimum of 1 second of maximum displacement for 6 Hz.

Three sine burst tests were to be repeated sequentially as necessary to cause failure of the test article if failure did not occur during the seismic tests.

Failure (i.e., rupture) of the test article did not occur during seismic testing. However, a 1-in. wide circumferential bulge indicative of ratchetting was observed following the high level (30 g actual ZPA) seismic test in a vertical leg of the test article. The bulge was located in a straight pipe section some 2 to 3 in above a welding neck flange at an anchor location. Subsequently, failure occurred during the second sine burst test. Rupture occurred in the previously observed circumferential bulge during the 6th of the planned 11 cycles of maximum displacement of the 5 Hz harmonic input. Failure resulted from a 300° circumferential break in the bulge; a double-ended guillotine break was avoided with prompt termination of testing. Fig. 1 shows the failure location.

Subsequent to failure of the test article, post-test examinations were conducted. These examinations included visual, metallographic and scanning electron microscope techniques.

Test Conclusions

Based on test results as presented in Ref. [1], conclusions regarding the previously stated objectives are as follows: