Presented at the 11th SMiRT Conference, Tokyo, Japan, August 17-31, 1991

PIPING COMPONENT PERFORMANCE UNDER SIMULATED WATER HAMMER LOADING

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1 INTRODUCTION

The occurrence of a water hammer event can cause severe damage to a piping system and its supports. It is generally accepted that total elimination of water hammer occurrence in power plants is not possible and most research on the subject tends to focus on the prevention of water hammer by system design and operation/maintenance precautions. However, damage to piping, including pipe rupture, continues to occur in power plants at an approximate constant low rate. Experimental research on the behavior of piping components during a water hammer transient has been rather limited. This is in contrast to the extensive research on piping component response due to seismic events where actual damage of piping caused by real earthquakes is almost nonexistent. Most piping code rules for stress limits are based on assumed failure modes that are appropriate for short duration impulsive loading, such as caused by a water hammer event, but are not appropriate for reversed cycle loading, such as caused by a seismic event. Yet, for design, the rules are applied for seismic inputs and ignored for water hammer. For this reason, several experiments with simulated water hammer loading have been conducted as part of the Piping Dynamic Reliability Programs sponsored by the Electric Power Research Institute (EPRI). Both virgin and eroded/corroded (removed from actual service) piping components have been subjected to hydraulic transient loading which simulates the two common water hammer effects of an overpressure transient in a "solid" line or a slug momentum loading in a voided line. This paper summarizes the results of these experiments and provides recommendations for distinguishing between the effects of water hammer and cyclic loading in power plant piping.

2 WATER HAMMER TESTING PROGRAM

As part of the Piping Dynamic Reliability Programs sponsored by the Electric Power Research Institute, several full scale pipe water hammer simulations were conducted on both virgin and eroded/corroded pipe components. The purpose of these tests were to demonstrate the difference in component margins and behavior during impulsive water hammer hydraulic transients, as opposed to reverse cyclic loading such as during a seismic event. Concerns with water hammer have recently increased due to the fact that water hammers do occur, and regularly, while seismic events are infrequent.

The goal was to provide data illustrating the fundamental difference between impulsive and cyclic loading. Current ASME code requirements are based on a definition of failure involving pipe component static collapse. Tests have shown that component collapse is not the failure mode for cyclic loading (but rather "fatigue ratcheting" is). It is, however, known that impulsive loads can and do achieve component collapse. A second goal was to investigate the amount of reduced capacity of carbon steel components thinned by the erosion/corrosion phenomena.

3 TESTING FACILITY AND SET-UPS

Two types of testing were performed in the laboratories of ANCO Engineers. The first kind, called a "slug test", uses an isolated segment of water in a pipe, accelerated through a voided test loop, which causes inertial loads at bends, water hammer loads at sealed ends, and jet forces at open ends. In the second type of test, called "solid test", a filled pipe was suddenly pressurized to produce a traveling transient shock wave through the test loop.

Fig. 1 shows the gas/water gun used to achieve these tests. Pressurized nitrogen tanks were separated from the test loop with a double rupture diaphragm. Rupture of the diaphragm (in less than .01 second) produced the accelerated slug or shock wave. Initial pressures up to 3,000 psi (resulting in transient pressures to 6,000 psi) were used. Slug velocities up to 300 feet/sec were achieved.

Figs. 2 through 5 show the plan view of the four pipe loop configurations tested. In Fig. 2, an 8 inch Sch. 100 open ended pipe was used with two bends. Two separate tests were conducted with virgin and eroded/corroded elbows (removed from service with 30% wall thickness reduction). Only slug tests were performed. Note that this loop, as well as all others, was firmly anchored to a 500 ton concrete reaction mass. Instrumentation included, typically, 2-6 pressure transducers, 5-10 channels of strain gages, and 3-6 channels of accelerometers.

Fig. 3 shows a 6 inch Sch. 40 pipe segment, with both open and closed ends, which was tested both with and without a single pipe restraint. Both slug and solid tests were performed.

Fig. 4 shows a 3 inch Sch. 40 pipe system, with total length of 180 feet, restrained by several pipe struts, and closed at its end with a simulated open tank condition. Both solid and slug tests were performed.

Finally, Fig. 5 shows a 6 to 8 inch Sch. 40 closed pipe system with a thinned eroded/corroded elbow removed from actual service with 80% wall thickness reduction. Solid tests only were performed.

4 RESULTS

The test conducted using the test setup of Fig. 2 (8 inch) produced elbow collapse from the force generated by the resultant change of momentum as the accelerated slug passed through the second elbow. The behavior of the virgin and eroded/corroded elbows was quite similar, but the eroded/corroded elbow experienced about 50% greater collapse deformation.

The test conducted using the test setup of Fig. 3 (6 inch) was able to fail a "weak" single support under both high level slug and solid tests. Nominal supports, typical of what is usually found on such a pipe, did not fail during testing. In cases without support, it was clear that the inertial loads produced as the slug passed through the second bend, were sufficient to collapse the first elbow. Total collapse was only prevented by collision with the concrete protective wall. Collision with the wall produced only a minor denting of the second elbow.

The tests of the 3 inch loop shown in Fig. 4 were are able to fail weak, but not nominal, supports. In this configuration, neither slug nor solid tests produced any significant component collapse.

The 6-8 inch system shown in Fig. 5 concentrated on the performance of the first elbow, which was eroded/corroded with only 20% wall thickness remaining. Solid testing resulted in a blow-out failure of the elbow involving approximately 50% of its circumference. Failure occurred at code ultimate hoop tensile strength.

5 CONCLUSIONS AND RECOMMENDATIONS

These tests support the following observations:

A. In contrast to cyclic loads (where non-collapse failures can only be induced at great margins above code design levels), there are situations involving hydrodynamic impulsive loads where collapse failures can occur at close to ASME code values.

B. For eroded/corroded piping, failure mechanisms and levels are probably not significantly affected if thinning does not exceed 50% of the nominal wall thickness. Greater thinning, however, does markedly reduce capacity.

C. In considering changes to existing code requirements, care must be exercised to distinguish between the behavior of piping systems to impulsive as opposed to cyclic loads.

D. Testing provides clear and valuable insight to this decision process by identifying the differences in component behavior under dynamic loading.

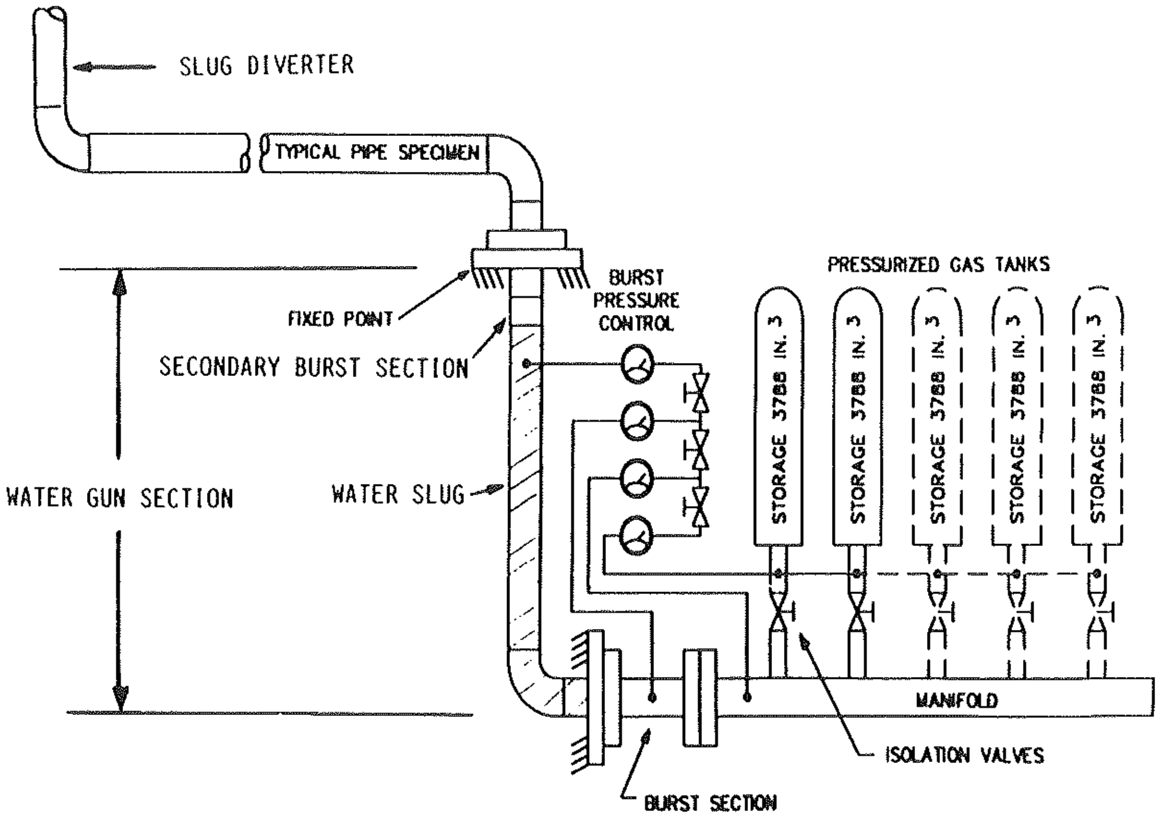

Fig. 1: Hydraulic Pipe Transient Testing System

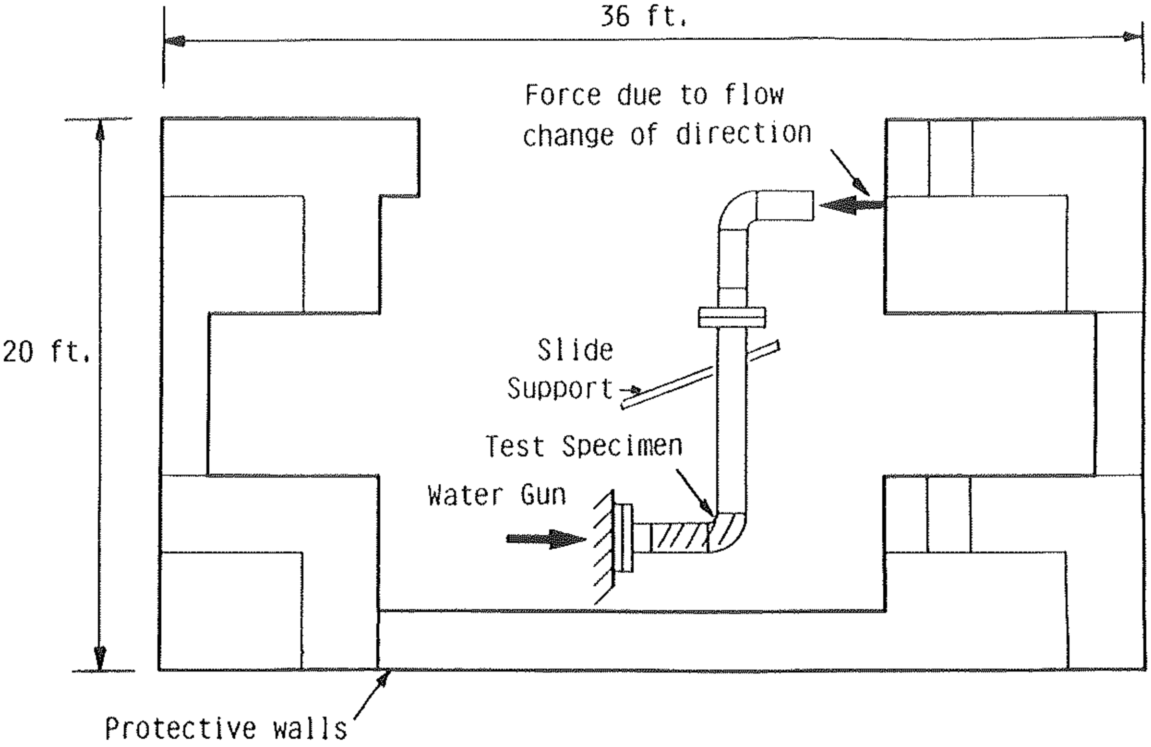

Fig. 2: Slug Test Setup - 8" Sch. 100 Elbows

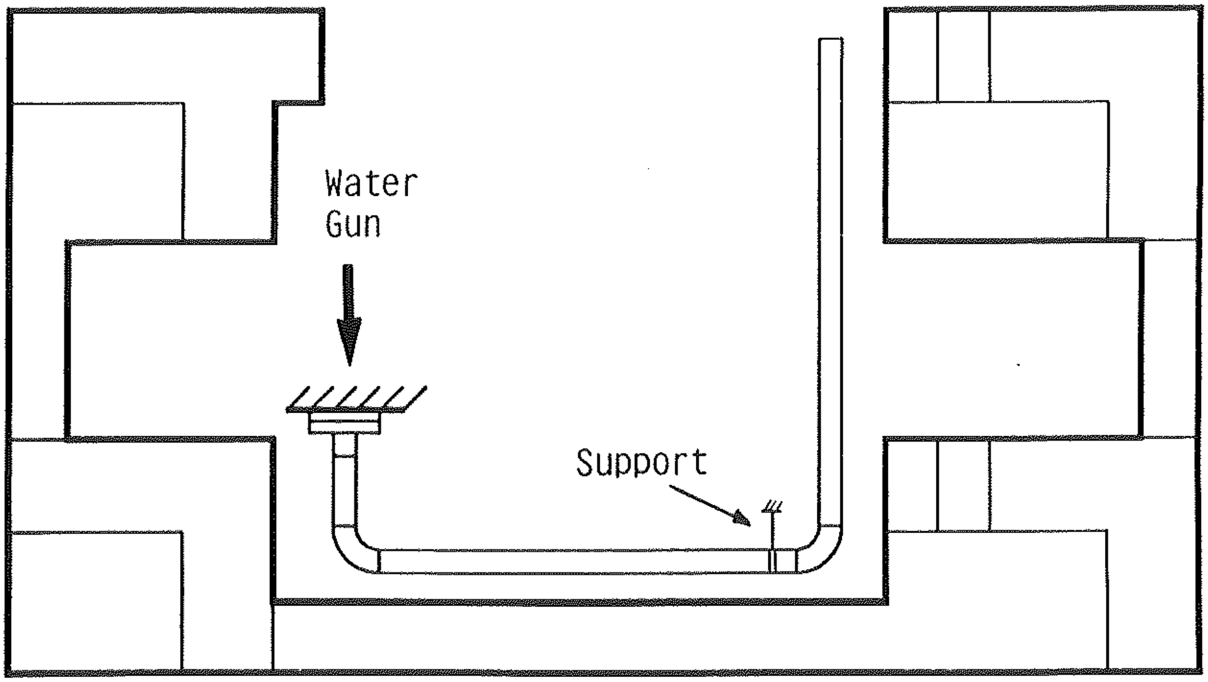

Fig. 3: Slug and Solid Test Setup - 6" Sch. 40 Pipe Components

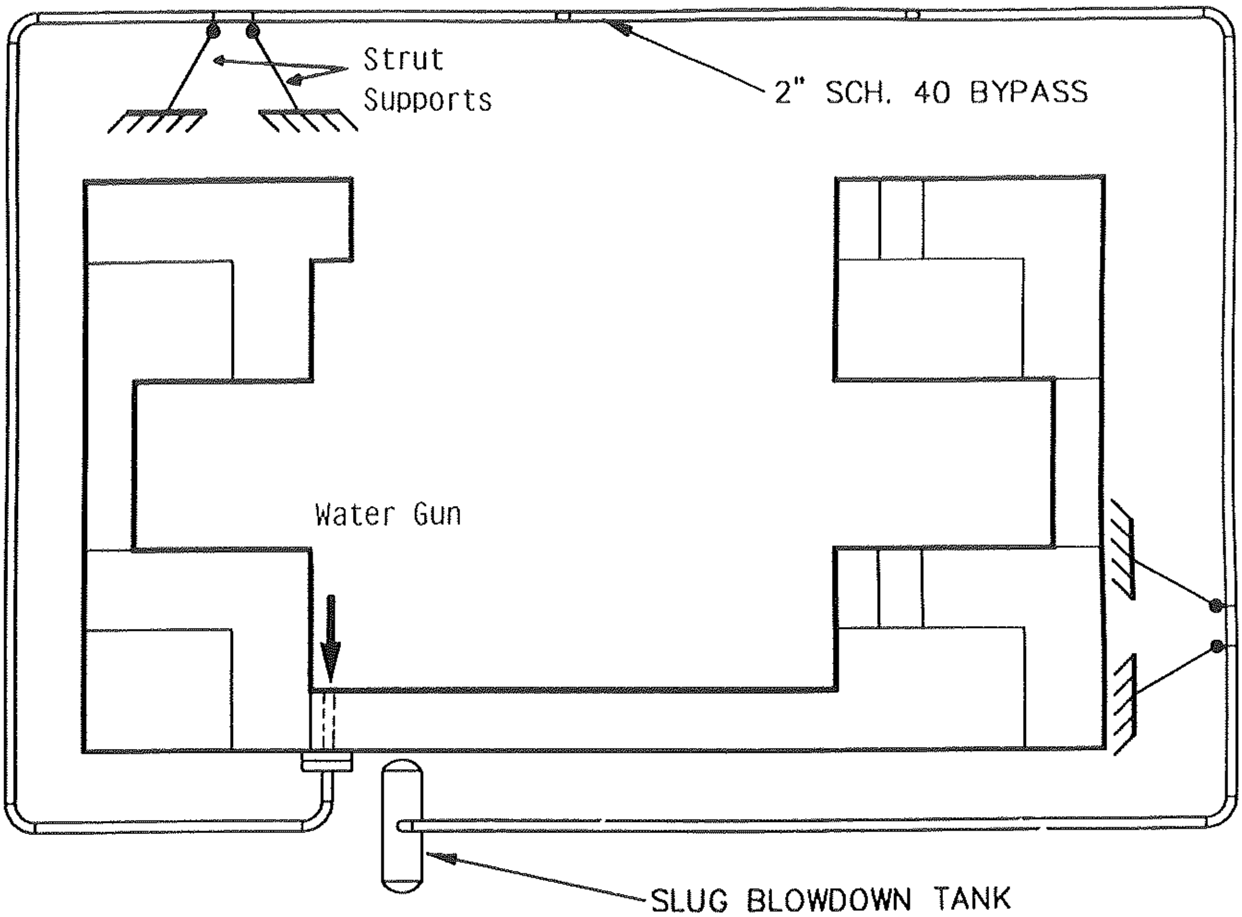

Fig. 4: Slug and Solid Test Setup - 3" Sch. 40 Pipe System

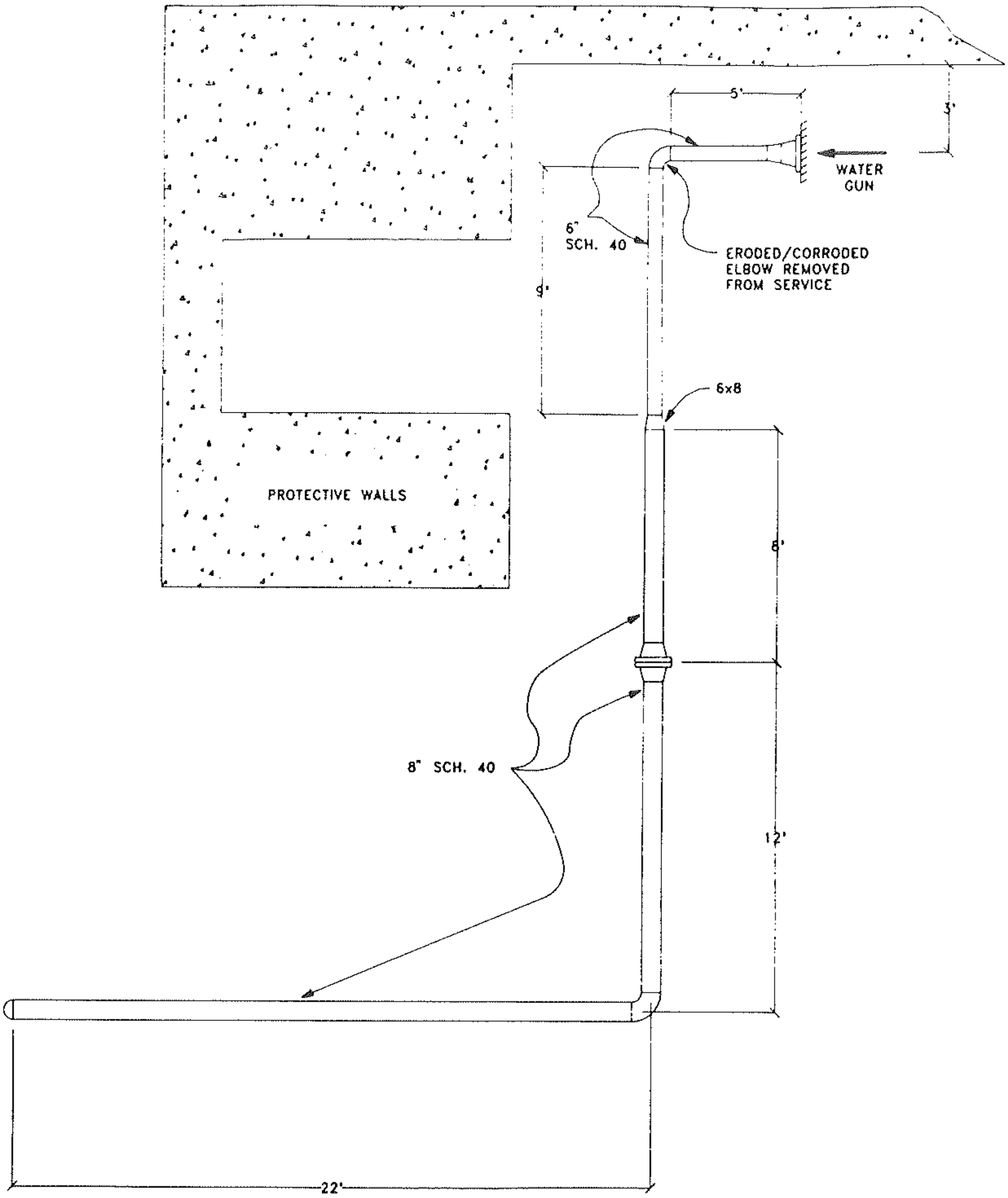

Fig. 5: Solid Test Setup - 6" and 8" Sch. 40 Piping System With Thinned Eroded/Corroded Elbow