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CAVITATION DAMAGE SCALE EFFECTS FOR SUDDEN ENLARGEMENTS IN PIPELINES

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16. Abstracts

The initial experimental studies have been primarily concerned with the determination of incipient cavitation damage to soft aluminum specimens placed in the walls of sudden enlargements downstream from orifices in pipelines. The extent of cavitation damage was measured visually by noting the density with which pits, formed by cavitation implosions, were distributed on the test specimens. Graphs were constructed showing the density of pitting under various flow conditions using orifices of five different sizes in a 3-in. I.D. pipe. From the graphs the flow conditions for initial damage on soft aluminum were determined. An equation for the prediction of pressure scale effects was derived from the experimental data. In addition, the incipient damage on carbon steel was briefly studied to determine if the same incipient relationship existed for aluminum and steel.

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PREFACE

The initial experimental studies have been primarily concerned with the determination of incipient cavitation damage to soft aluminum specimens placed in the walls of sudden enlargements downstream from orifices in pipelines. The extent of cavitation damage was measured visually by noting the density with which pits, formed by cavitation implosions, were distributed on the test specimens. Graphs were constructed showing the density of pitting under various flow conditions using orifices of five different sizes in a 3-in. I.D. pipe. From the graphs the flow conditions for initial damage on soft aluminum were determined. An equation for the prediction of pressure scale effects was derived from the experimental data. In addition, the incipient damage on carbon steel was briefly studied to determine if the same incipient relationship existed for aluminum and steel.

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I. INTRODUCTION

The increasing number of high-head systems, such as dams, pumping plants, and municipal water systems currently being designed has developed a need for a simple economical high-head energy dissipator. Such a system must be capable of controlling pressures and flows without causing damaging cavitation, vibration, or objectionable noise. The device must be reliable and flexible as well as exhibiting economy in the face of ever increasing costs.

The use of the sudden enlargement as an energy dissipator is not new (1-11,13,15-19). It has been used successfully in a number of cases and appears to be the most logical means of answering current needs. The sudden enlargement used as an energy dissipator has a number of significant advantages. In general it is very economical and requires a relatively small structure, particularly if one of fixed geometry will give the desired performance. There is no limit as to size, as the device can vary from a fraction of an inch to many feet in diameter. The sudden enlargement permits operation with cavitation present without damage or undue vibration of the structure. The head loss in a sudden enlargement is relatively large and is efficient in dissipating head.

Successful design of sudden enlargement energy dissipators requires reliable information concerning cavitation potential and scale effects. (Scale effects are defined as parameters or combinations of parameters that cause deviation from true similarity for different geometrically sized systems using the laws of hydraulic similitude.) There is some doubt that a prototype sudden-enlargement energy dissipator structure will perform exactly in accordance with model results due to scale effects, which can be present where designs are based on model studies, particularly if the models are small. Although data on damage scale effects for sudden enlargements in pipelines are virtually nonexistent, there are definite indications from studies related specifically to cavitation (12,14,20,22,23) that scale effects are involved and that their magnitudes can be significant. Indications are that prototype values for incipient cavitation conditions are greater than obtained from model investigations; thus the model test results are nonconservative, i.e., a design based on the incipient condition, obtained from a small scale model or test facility, may actually cavitate in the prototype. It is therefore necessary to have complete data on scale effects for incipient cavitation and cavitation damage as well as the results of model tests before designers or users can adequately design sudden-enlargement energy dissipators to assure that cavitation will not occur or that there will be no cavitation damage, adverse vibrations or intolerable noise levels under specified operating conditions.

II. EXPERIMENTAL PROCEDURE

A. Test Facilities

The experimental studies related to N.S.F. Grant GK-35862 were conducted in the Hydro Machinery Laboratory of Colorado State University. The laboratory is housed in a 70' x 192' prestressed concrete building. The 3-ft thick concrete floor slab with anchors installed on 10-ft centers was designed to eliminate vibrations in the slab and building during testing. Water under heads up to 115 psi is supplied to the facilities by the nearby U.S. Bureau of Reclamation's Horsetooth Reservoir. In the tests conducted, water was taken from the reservoir and passed through the laboratory into a receiving lake; water was not recirculated during the experiments. A detailed analysis of the air content of water used in the laboratory is contained in Ref. 21.

The experiments were performed in a 3-in. I.D. test section, Fig. 1. The section was composed of a 36-in. long section of steel tubing having an 8½" x ½" slot in its wall for the insertion of a test specimen. The specimen was flush with the interior wall of the tubing and was held in position by two toggle clamps. The downstream end of the tubing was connected to 1.5 feet of 3-in. steel pipe and a transition to a 6-in. pipe. The upstream end had a flange for the

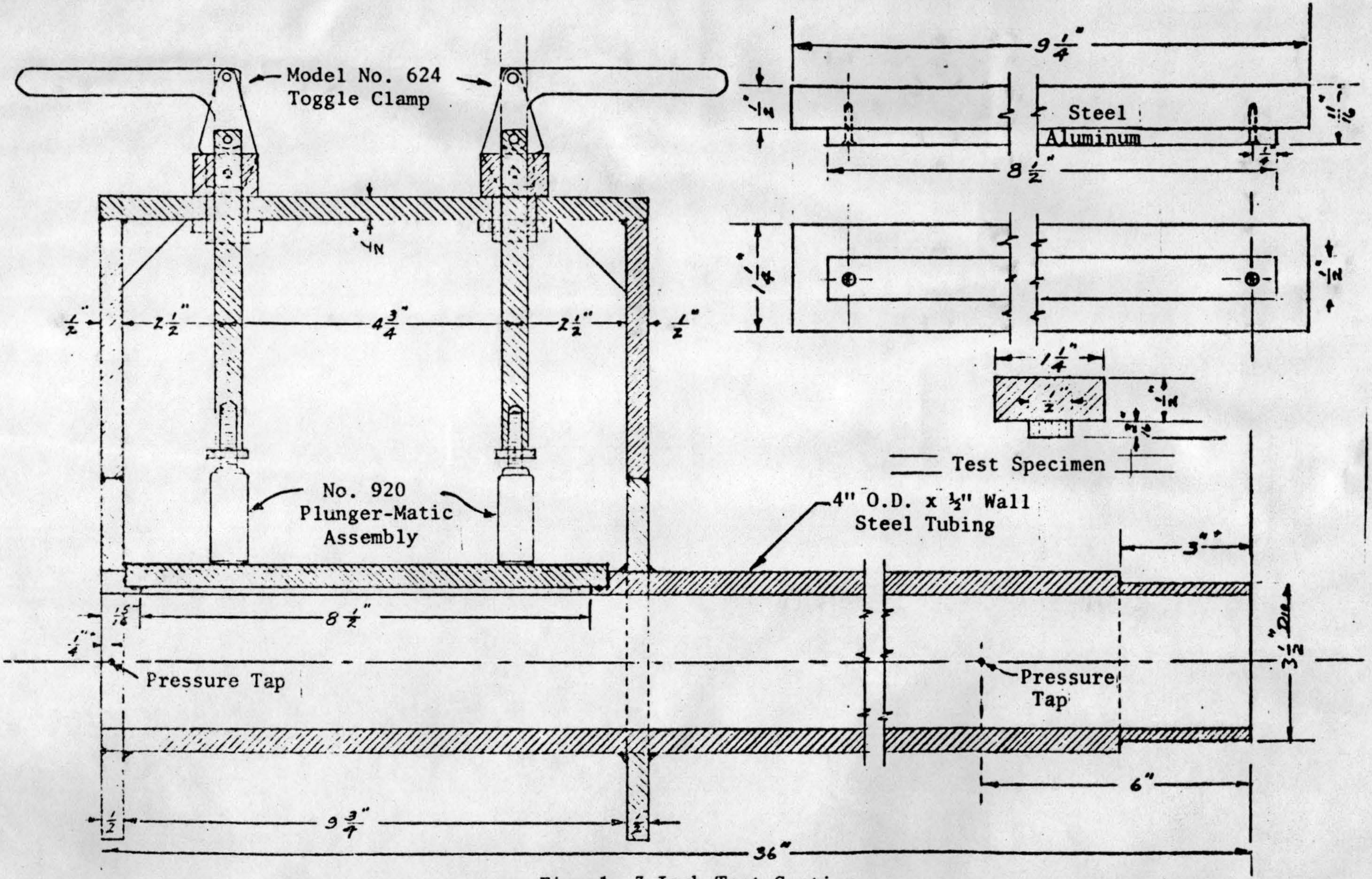


Fig. 1 3-Inch Test Section

installation of sharp-edged orifices. Upstream from the orifice was 7.5 feet of 3-in. steel pipe and a transition from 3-in. to a 6-in. steel pipe.

The 3-in. test section was placed in the larger system shown in Fig. 2. This system served the purposes of passing flow through the tests section end diversion of water around the section during insertion and removal of test specimens. A high head pump was employed to maintain certain experimental conditions.

B. Data Collection

(1) Line loss

The 3-in. test section without an orifice was first tested for friction loss by passing flow through it. Flows were monitored by an upstream orifice in the 6-in. line. The differential pressure was measured between points one pipe diameter (3 inches) upstream and ten diameters downstream of the position where orifices were to be placed. The Darcy-Weisbach friction factor was calculated for various Reynolds numbers and was used to evaluate pressure conditions for the enlargement.

(2) Cavitation damage data

Five different sized orifices (1.168, 1.333, 1.500, 2.000, and 2.400-in. diameter) were separately inserted in the test section. Flow conditions were adjusted such that each orifice had definite upstream pressures and varying cavitation intensity at each of these pressures. Pressures of 30, 50, 70, 90, 150, and 200 psi were maintained upstream from the orifices. Soft aluminum specimens (1100-0), inserted in the test section downstream from each of the five orifices, were used to evaluate the cavitation damage at the various flow conditions.

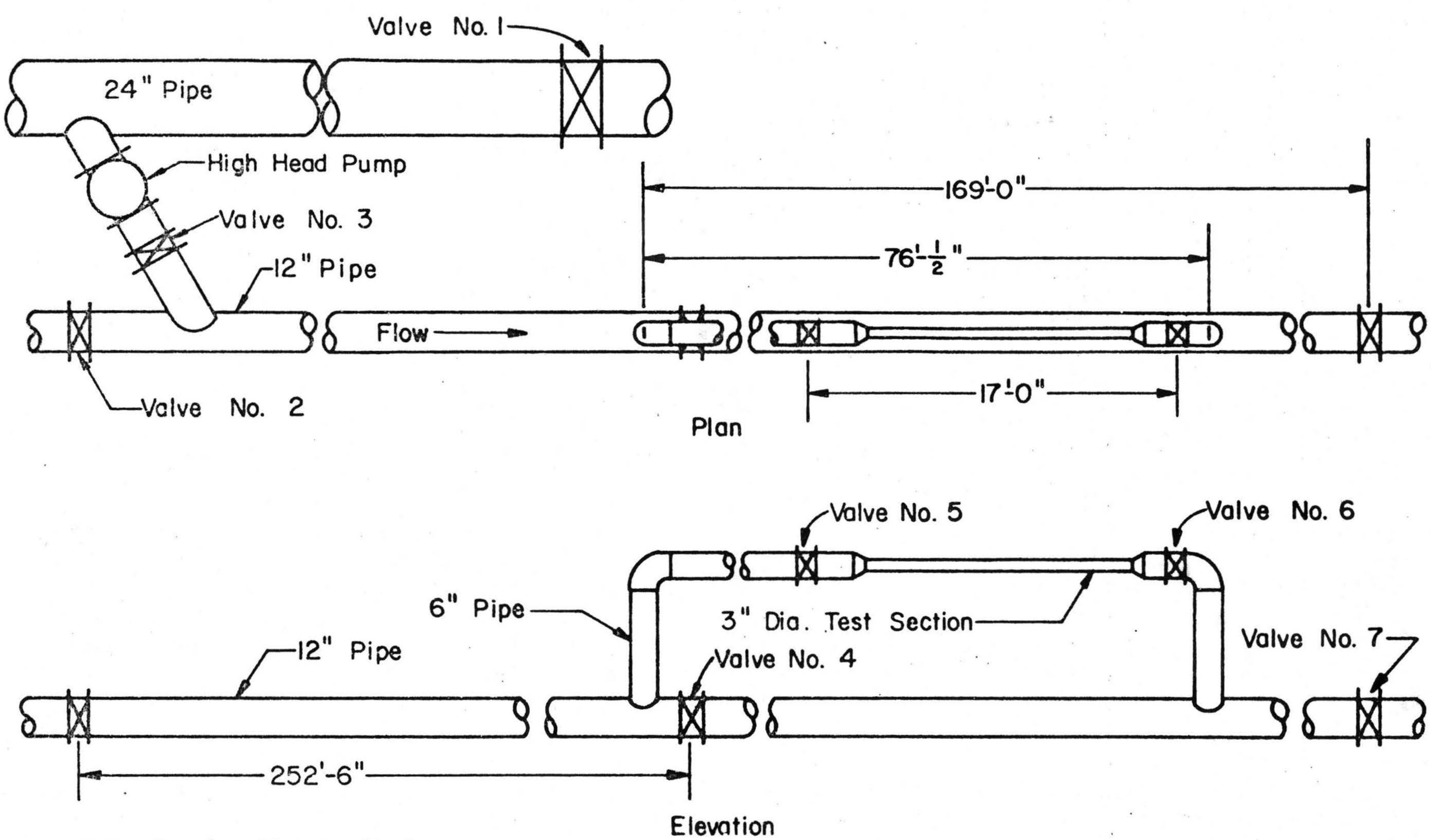
Cavitation damage tests were conducted using cold rolled steel test specimens with a Brinell hardness of 145 for comparison with aluminum. These experiments were conducted with the 2.400-in. diameter orifice and an upstream pressure of 50 psi. The tests were conducted in the same manner as the previously mentioned experiments.

The following measurements were made for each test run:

1. Mean pressures; P_u at one pipe diameter upstream from test orifice and P_d at ten pipe diameters downstream. Mercury manometers and a precise dial pressure gage were used for recording the pressures.
2. The discharge, by the use of a flow measuring orifice, located upstream from the test section, or by using the test orifice as a flowmeter. The pressure drop across the flow measuring orifice was measured by a differential manometer using mercury or Meriam.
3. Sound intensity of cavitation, observed qualitatively by ear.
4. The intensity of cavitation, measured by an accelerometer (General Radio, type 1553-A), which is a vibration meter. This meter consists of a piezoelectric-type sensing element held by a magnetic clamp placed immediately downstream of the test specimen. The meter readout was in inches per second squared. The meter was sensitive to a vibration level of from near zero to 300,000 inches per second squared over a frequency range of 2 to 2000 cycles per second.
5. The temperature of the water flowing through the test section, using a mercury thermometer.
6. The atmospheric pressure, recorded with a Precision Microbarograph.

C. Data Analysis

Each of the test specimens was visually inspected with a 3½ power magnifier for cavitation damage. The damage was indicated by the number of pits per unit area or pitting density found on the surface of the specimen. A plexiglass strip with a grid spacing of 0.2 inch was placed over the 8.5" x 0.5" specimen prior to the inspection. The number of pits between each of the grid lines were counted. The maximum density of cavitation pitting was determined by dividing the number of pits between the grid lines with the most pits by the time required to form the pits, or pits per square inch per minute.



Note: Drawing Not to Scale

Fig. 2 Laboratory Test Installation

III. RESULTS

A typical plot of maximum pitting rate versus α, the cavitation index number, for various upstream pressures is shown in Fig. 3. Similar plots were made for all aluminum specimens for the five orifices tested and for several steel specimens using the 2.4-inch diameter orifice, Fig. 4. The expression $\alpha = \frac{P_d - P_v}{P_u - P_d}$ was used to evaluate the data. P_u = mean pressure measured one diameter upstream of the orifice at the wall and projected forward to the orifice by subtracting equivalent frictional loss, P_d = mean pressure measured ten diameters downstream of the orifice at the wall and projected back to the orifice by adding equivalent frictional loss, and P_v = vapor pressure of water.

The plots were used to select the value of sigma for incipient damage where the curve for each of the values of P_u intersect the line of zero pitting. The values of sigma at incipient damage, α_{id}, for the several orifices and upstream pressures are listed in Table 1. This table was prepared using the cavitation damage results on the aluminum specimens.

The values in the table include any scale effect due to pressure. The pipe velocities for incipient damage conditions were evaluated for each orifice and upstream pressure and the data plotted versus

TABLE 1 SIGMA INCIPIENT DAMAGE FOR VARIOUS ORIFICES AND UPSTREAM PRESSURES

Pressure (psi) / Orifice (in.)	30	50	70	90	150	200
1.168	X	0.44	0.48	0.50	0.57	0.60
1.333	0.53	0.54	0.61	0.62	0.68	0.78
1.500	0.58	0.64	0.72	0.77	0.82	0.89
2.000	1.40	1.49	1.55	1.57	1.80	1.87
2.400	2.72	2.92*	3.10	3.17	3.40	X

*Aluminum and steel.

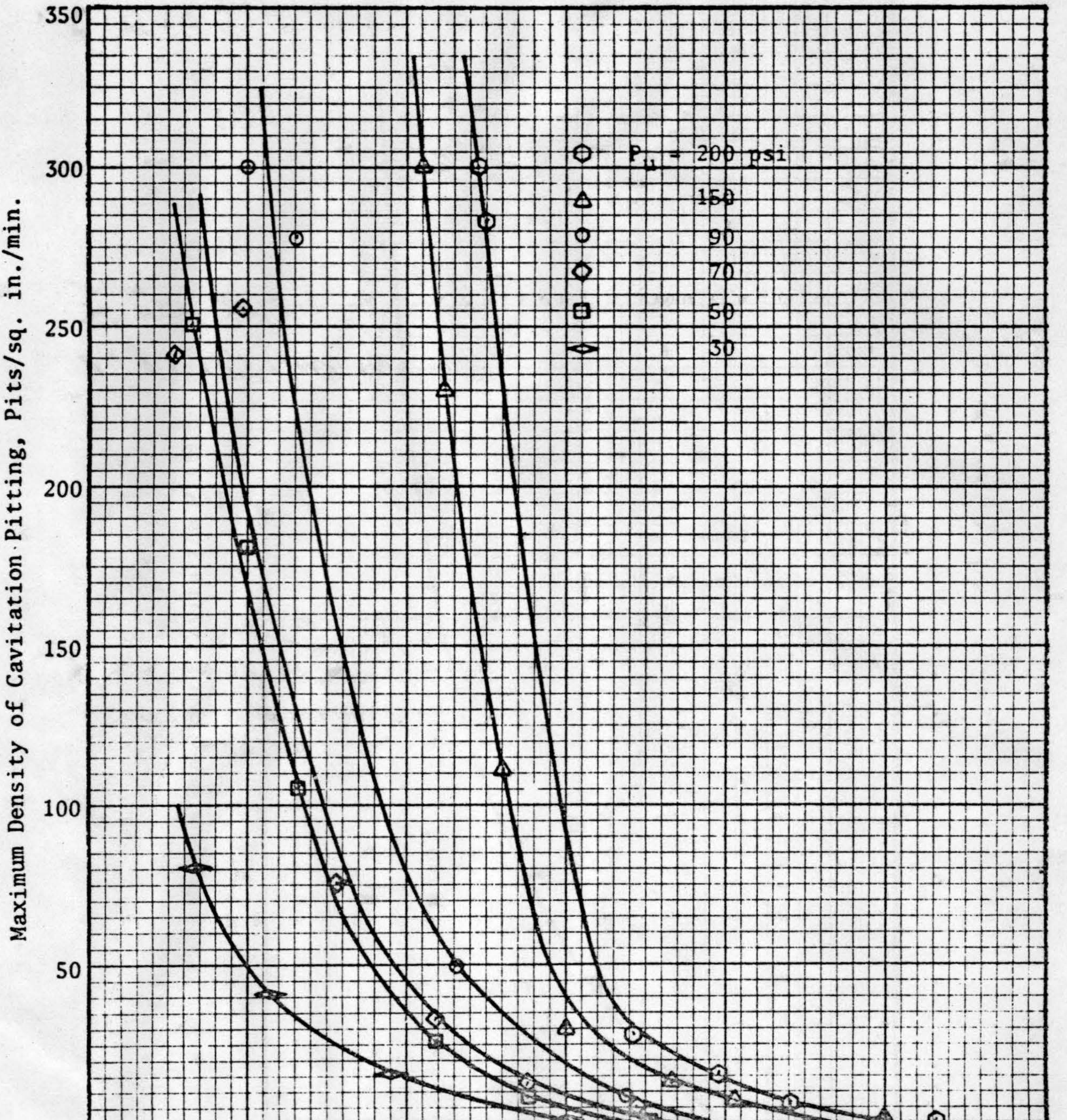


Fig. 3 Cavitation Pitting Density, Aluminum Specimen, 2.000-in. Diameter Orifice

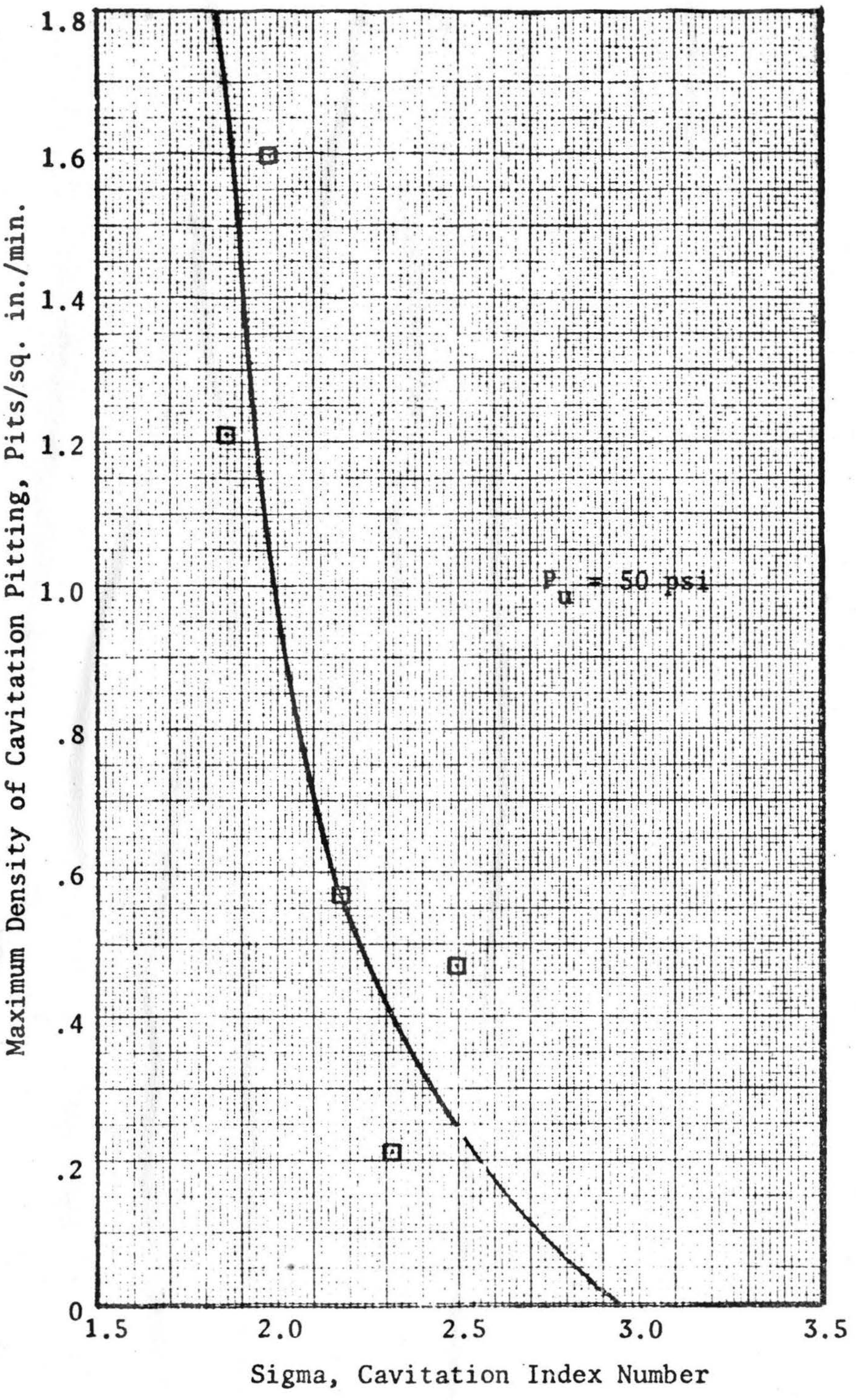


Fig. 4 Cavitation Pitting Density, Steel Specimen, 2.400-in. Diameter Orifice

P_u-P_v, Fig. 5. From tests on valves and special orifices, Refs. 20, 22 and 23, it has been determined that a slope of the lines differing from 0.5 indicates a scale effect. The slope of the lines for the tests was constant at 0.45, thus indicating a pressure scale effect for α_{id} and V_{id} for all the orifices tested.

An equation for predicting the incipient damage conditions at any given upstream pressure, velocity, and vapor pressure was developed from the test data. The equation is:

$$V_{id} = V_{idr} \left(\frac{P_u - P_v}{P_{ur} - P_{vr}} \right)^{0.45}$$

in which V_{id} is the average pipe velocity for incipient damage, P_u is the upstream pressure, P_v is the vapor pressure of the system fluid, and the r subscript denotes reference or test values.

The results of the cavitation damage tests on cold rolled steel (Brinell hardness = 145) are shown in Fig. 4. The incipient damage point for the steel with the 2.400-in. diameter orifice with an upstream pressure of 50 psi was determined to be approximately the same as for the aluminum tested under the same conditions (sigma value at incipient damage 2.92). This fact indicates that flow conditions for incipient damage may be independent of the material used in the experiment.

IV. PERSONNEL AND PAPERS IN PREPARATION

The following four people have been actively participating in the aforementioned research program; all four are associated with the Department of Civil Engineering, Colorado State University.

1. James W. Ball; Research Associate, Principal Investigator.
   Contribution: Basic Director of Project.
2. J. Paul Tullis; Associate Professor, Principal Investigator.
   Contribution: Gave advice throughout project, particularly on the detection of cavitation damage.
3. Charles E. Sweeney; Graduate Research Assistant.
   Contribution: Helped conduct experiments involved in the research.

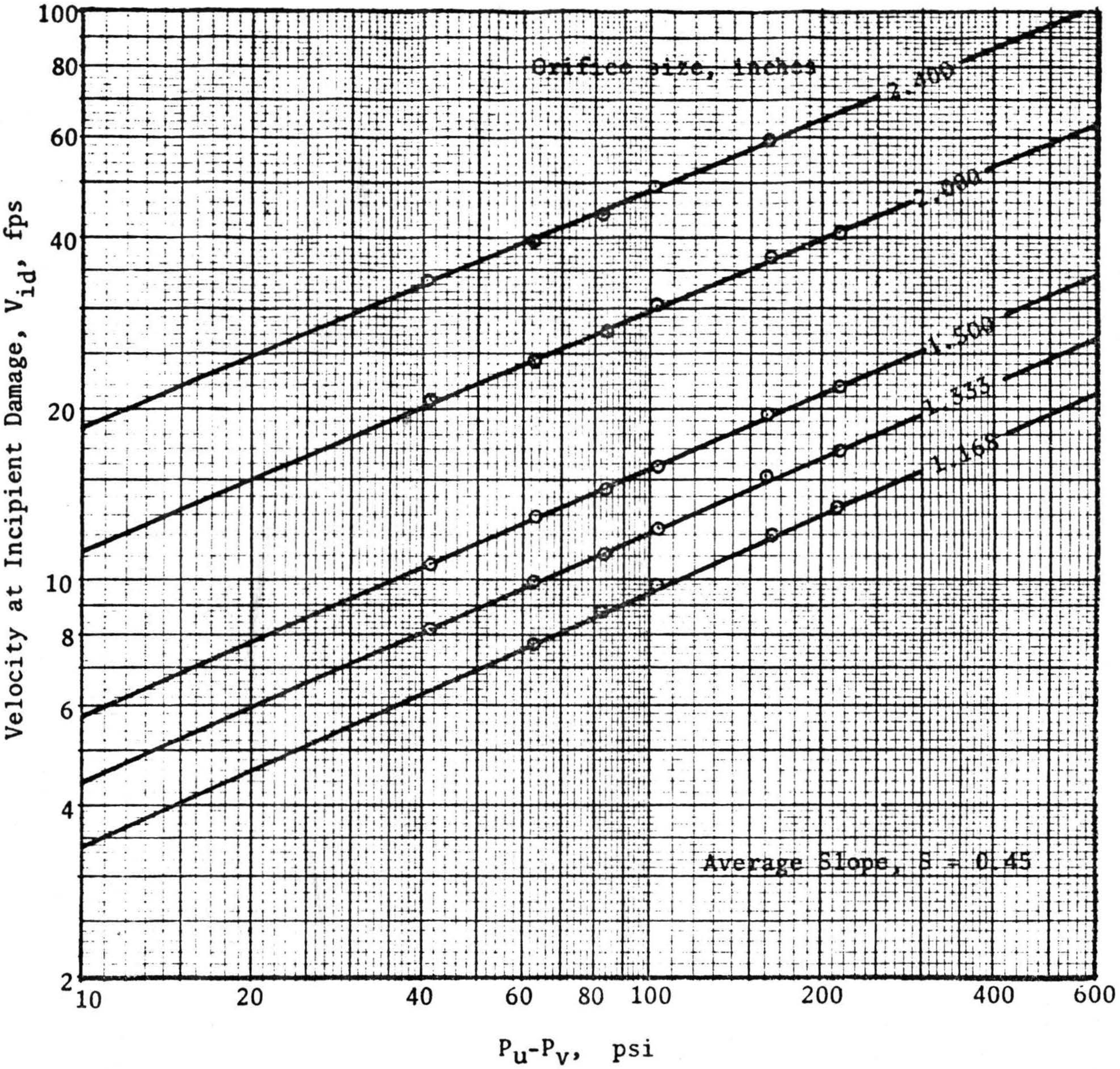


Fig. 5 Pressure Scale Effects for Incipient Cavitation Damage to Aluminum

4. Travis E. Stripling; Graduate Research Assistant.
   Contribution: Helped conduct experiments involved in the research.

Work on larger orifices in larger pipes is being actively pursued at this time. Several papers are in preparation for presentation at meetings in 1974.

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