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DESIGN CRITERIA FOR FLEXIBLE UTILITY CONNECTIONS

December 1968

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DESIGN CRITERIA FOR FLEXIBLE UTILITY CONNECTIONS

Technical Report R-608

Y-F011-05-02-304

by

D. G. True

ABSTRACT

The existing design of flexible utility connections used in naval installations incorporates a flexible bronze hose hanging freely within a corrugated metal tube so that it can move without being highly stressed at the soil-structure interface. A study was made of this design and of possible modifications to it. Theoretical predictions were formulated for flexibility and dynamic strength; the theories were tested and partially verified experimentally in the laboratory. The flexibility of a hose was related to the manufacturer's specified minimum allowable bend radius. The dynamic strength was expressed in terms of peak acceleration and hose weight and length in a semiempirical relationship suitable for use in design. It is recommended that the results of the present study be incorporated in an appropriate design manual, subject to verification by full-scale field tests, and that a summary be compiled of means to predict the relative displacements between a buried structure and the surrounding soil.

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INTRODUCTION

Statement of the Problem

Buried structures subjected to blast loading must be serviced by utilities continually during and after the blast loading. Each connection between a structure and a utility line must withstand whatever portion of the load is transmitted to it via structure, utility line, soil grains, and soil pore fluid, and must also accommodate the rapid displacement of the structure relative to the utility line. Thus, a connection, to be satisfactory, must be sufficiently flexible to accommodate a specified deflection and sufficiently strong to endure the inertial loads resulting from the rapidity of the deflection and the loads transmitted from the blast. The purpose of this study is to develop a connection design which satisfies these requirements and to establish reliable design criteria.

For purposes of this study, the displacement of a buried structure relative to a buried utility line is assumed to be the same as that of the structure relative to the free-field soil. On this basis, a connection can be designed by using available data on the behavior of buried structures. The design of the utility line is not treated in this study.

Background

A summary of the state of the art, as of December 1962, of the design of hardened structures is contained in Reference 1. Included is information on load transmission through soil and ground motion as functions of weapon yield, distance from ground zero, and soil properties. Information about displacements of footing-supported buried structures relative to free-field soil is sparse, due principally to the absence of definitive data on soil-structure interaction.

A symposium on soil-structure interaction[2] served to bring together the results of many recent and current research efforts in this field. However, these results were too general to furnish relative displacement information directly applicable in design.

In a report of preliminary NCEL work on the subject,[3] H. Tomita outlined research required to develop a reliable design of flexible utility connections. This work included studies of the type of connection design and the magnitude of relative displacement.

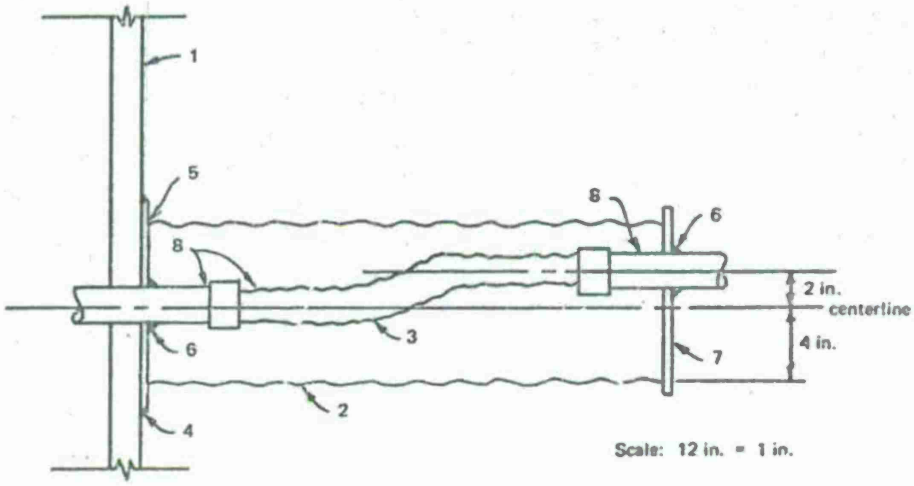
A report[4] of work done on contract for NCEL in 1965 updated the state of the art specifically related to attachments and connections for buried structures. This report outlines methods for calculating blast-induced ground motion and relative displacement between very stiff prismatic buried structures and the relatively compliant surrounding soil. It reaffirms the lack of precise data on relative displacements between footing-supported buried structures and free-field soil.

Further research into soil-structure interaction and the dynamic behavior of buried footings by NCEL and other agencies has given designers some ability to predict such relative displacements. Tests of dynamically loaded strip footings[5, 6] have indicated the nature of the load-deflection relationship of a footing buried in granular soil. For increasing load, this relationship may be approximated by an elasto-plastic idealization, wherein a very large deflection (catastrophic failure) is caused by exceeding a critical load, while smaller, more readily predictable deflections occur under loads significantly smaller than the critical load. Results of tests of buried model arch structures with footings[7, 8] give insight into the structural and footing behavior of this type of structure. Experiments in soil arching around buried model structures[9-12] show reductions in structure load that may be expected to occur simultaneously with relative deflections. These data indicate that steady-state maximum arching conditions may be established well within the subcritical footing displacement range.

An analytical method was developed at NCEL[13] to predict blast-induced body motions of buried structures with footings. This method gave very good predictions of the displacement and velocity histories of a standard metal arch Navy personnel shelter under TNT blast loading at Operation Plumbbob. The predicted peak relative displacement between structure and soil field was about 3 inches. The loading conditions at close range in this instance were approximately equivalent to nuclear blast loading at a somewhat greater range. This peak relative displacement is considered representative of values which might be expected at many field installations of this type.

The existing design of flexible utility connections in use by the Naval Facilities Engineering Command (NFEC)[14] is shown in Figure 1. This design incorporates a flexible metal hose (of the type described in Federal Specification RR-H-651b) that is enclosed in a protective corrugated metal tube. The hose contains fluid under pressure, as furnished by the utility line, and must accommodate any relative displacement between the line and the structure

wall or footing side. The protective tube provides an air space within which the hose moves. The air space is required to distribute the relative displacement evenly along the length of the deflected hose. The protective tube must be strong enough to maintain its volume of enclosed air space under soil-transmitted stresses resulting from blast loading. Details and intended use of the design are contained in Reference 14.



NOTES:

1. Shelter bulkhead.
2. Ten-inch-diameter by 36-inch-long corrugated metal pipe (CMP), 18 gage.
3. Slack flexible metallic hose 24 inches long.
4. Ten-gage plate, 14 inches square, welded all around to shelter bulkhead.
5. Butt CMP against plate. Do not weld.
6. Pipe brazed all around to plate.
7. Ten-gage plate, 14 inches square—butt against CMP. Do not weld.
8. Pipes and hose either 1 inch or 1-1/2 inches inside diameter.

Figure 1. Existing NFEC design of flexible utility connections (from Reference 14).

Alternative designs have been proposed.[3, 4] These include configurations incorporating such diverse concepts as encapsulation with a collapsible material, sliding joints, and bendable knuckles. These various conceptual designs offer varying degrees and magnitudes of freedom of motion. The resulting limited extent of applicability of each detracts from its feasibility as a standard connection design.

Approach

The decision was made to eliminate from the scope of this work the conceptual designs which were untried and for which there were no working counterparts in the field. Thus, this work includes only the existing NFEC design of a flexible utility connection, along with reasonable modifications of it, including versions incorporating alternative hose types, materials of construction, design dimensions, detailing, and installation positioning.

Flexible hose specimens were fabricated in lengths determined theoretically to give a desired deflection capability. The specimens were tested in the laboratory both statically and dynamically to determine the validity of the assumptions upon which their dimensions were based and to evaluate the stresses of flexural and inertial origin which might cause failure. The ultimate objective of these tests was to develop flexibility and dynamic strength design criteria. At the same time, working with specimens of various types enabled the project engineer to gain knowledge of their field behavior and thus to make useful recommendations concerning installation procedures and precautions.

As previously mentioned, information on relative displacement between a buried structure and the surrounding soil is indefinite quantitatively. Based upon available data, conservatively high estimates were made of maximum expected relative displacements in both directions along each of three lines of action (vertical, horizontally tangential to the side of the footing, and normal to the side of the footing). A downward footing displacement of 4 inches relative to the free-field soil, an upward relative footing displacement of 2 inches, and a horizontal displacement of 2 inches in all directions were adopted as a basis for the design and evaluation of the connections studied and reported herein. In actual experiments, these values were varied according to the length of the available experimental specimens. Rotations were not studied, due to the small amounts of rotation of connection ends anticipated in actual installations.

Experimental specimen length was determined theoretically, based on the manufacturer's specified minimum allowable bend radius. No design calculations were made involving hose stiffness or reaction forces and moments on end fittings caused by static deflections.

In addition, the theory was developed to predict the diameter of a protective metal tube enclosure required to provide sufficient deflection space to preclude damage to the hose. This geometrical aspect of design was not tested experimentally.

FLEXIBILITY OF CONNECTION HOSES

Two theories of hose deflection were developed to predict the hose dimensions required to achieve a specified deflection capability. Computer programs were written to tabulate dimensions to enable the design of test specimens.

A series of static tests was subsequently conducted to determine:

1. Bent shape of hose—to ascertain the better of the two basic assumptions used in the two respective theoretical calculation techniques
2. Amount of permanent bending incurred by hose at various portions of the design deflection
3. End forces and moments required to sustain various portions of the design deflection
4. As a result of the above, the degree to which a developed theory could satisfactorily specify design dimensions for the hose

Theory

Figure 2 shows a connection design deflected according to the displacement specifications mentioned previously (the displacement parameter, δ in the figure, equals 2 inches). The version shown is similar to that of Figure 1, but differs in the fixity of the corrugated metal tube, the installed position of the hose, and the dimensions of all parts. The location of the top of the corrugated pipe enclosure is determined by the uppermost displacement of the end fitting, while the location of the bottom is determined by the bottom of the lower arc of the hose in the compressed position. The corrugated enclosure is not attached to the structure or the incoming utility line; it can be compressed by or removed from the footing during relative displacements between the footing and the free-field soil in the direction of the hose's longitudinal axis.

An attempt was made to utilize the manufacturer's specified minimum allowable bend radius, r, of each hose in determining the length of hose needed to achieve required relative displacements between the two ends. Computer programs were written to calculate and print tables giving the required free length of hose (not restrained by end fittings) as a function of the specified displacement capability and r. One program (Appendix A) based calculations on the assumption that r was achieved along the entire length of hose, resulting

in a shape consisting of a series of circular arcs connected end to end. This shape would occur in a hose that locks at a radius of curvature equal to r and bends no farther until much larger moments are applied. The second program (Appendix B) assumed that the hose behaved elastically, taking on a sinusoidal shape, and based calculations on a radius of curvature equal to r at the location of the sharpest bend in the sine wave—the apex of the curve.

In addition, the height of protective enclosure required to allow free movement of the hose under the stated assumptions and adopted specifications was calculated, taking into account the hose's outside diameter, d_o, and the largest fitting diameter, d_f. Values of specified deflection, δ, required span (distance between end fittings, as installed), s, and required enclosure height, h, computed under the "locking" assumption for incremental deflections ranging to over 4 inches are given in Tables A-1 through A-4 for various sizes of a commercially available flexible bronze hose and in Tables A-5 and A-6 for two types of flexible rubber hose, reinforced with helically wound steel wire. Similarly, values of specified deflection, required free length, and required enclosure height computed under the "elastic" assumption are given in Tables B-1 through B-4 for the bronze hose and in Tables B-5 and B-6 for the rubber hose. The tabulated deflection is equivalent to δ in Figure 2. A value of δ = 2 inches was used to determine the dimensions of the experimental test specimens.

The design dimensions of hoses were computed differently from the outputs of the two different computer programs, because of a difference in output format arising out of efforts to simplify computer work. The basis for adjusting the output is that the free length of a hose is equal to the sum of the installed span and the deflection. This length must be computed from data given in Tables A-1 through A-6, while it appears directly in Tables B-1 through B-6. However, the installed span must be computed as the difference between free length and deflection in Tables B-1 through B-6, while it is given directly in Tables A-1 through A-6.

A comparison of the results of calculations based on the locking behavior assumption (Tables A-1 through A-6) with those based on elastic behavior (Tables B-1 through B-6) indicates a wide variation in the predictions of the span required to accommodate a specified deflection capability, especially when the deflection is a large fraction of r. In all cases the span required under the elastic assumption is larger than that required under the locking assumption. Whether or not the larger span is actually necessary, or whether the elastic or locking behavior assumption is more appropriate, should be readily evident from flexure test data.

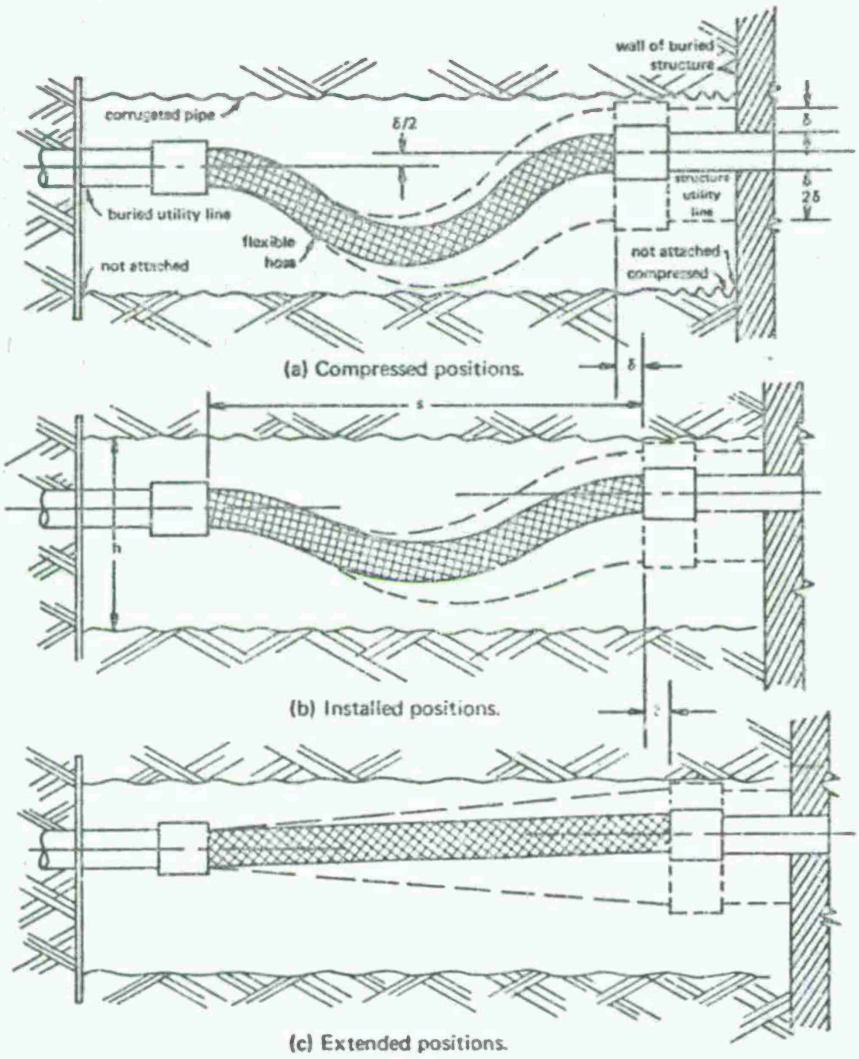


Figure 2. Theoretical assumptions of flexible utility connection movements.

Test Specimens

Flexible bronze hose specimens were procured in accordance with existing specifications[14] from available commercial products. Anaconda bronze type S-1 hose with annular corrugations and a single braided bronze wire fabric cover, hereafter referred to as hose type AB-S1, served as raw material for bronze hose test specimens. In addition, a suction-type rubber hose with stiff, helically wound reinforcing wire designed to prevent crushing and collapse was selected as a promising alternative. Rubber hose specimens were obtained from the Gates Rubber Company (GT), the B. F. Goodrich Industrial Products Company (BFG), The Goodyear Tire and Rubber Company (GY), and the United States Rubber Company (US). The free length and inside diameter of the specimens tested varied as shown in Table 1.

Hose specimens were carefully examined by the project engineer and compared on the basis of stiffness (reciprocal of flexibility). Stiffness ratings corrected for inside diameter were assigned to the available hoses on the basis of 0 to 100 (increasing for increasing stiffness).

Hoses were selected for static testing based on high resistance to distortion of cross section in bending, low subjective stiffness rating, early time of receipt of specimen, adequate length of specimen available, and variety of fittings furnished. Hoses of the US and AB designations were furnished with fittings and were tested early in the program.

Test Equipment and Measurements

The static tests were conducted by restraining hose specimens in predetermined positions of relative displacement by means of a Baldwin loading machine. The machine served both to maintain proper displacement positions and to measure total axial force on the hose specimen.

A hose specimen was placed vertically in the machine. The top hose fitting was attached to a short piece of pipe which was held in the jaws of the machine. To measure lateral forces and moments on the hose specimen and to provide a means of readily changing the restrained position, the bottom fitting of the hose was attached to an end fixture block, a piece of 2 x 6-inch (nominal size) fir wood 24 inches long. The block was supported on two rollers, spaced 9 inches on either side of its center, which rested on the platform of the loading machine, and was restrained from transverse movements by a restraining block clamped to the machine platform. Specimens in this test configuration appear in Figures 3 and 4.

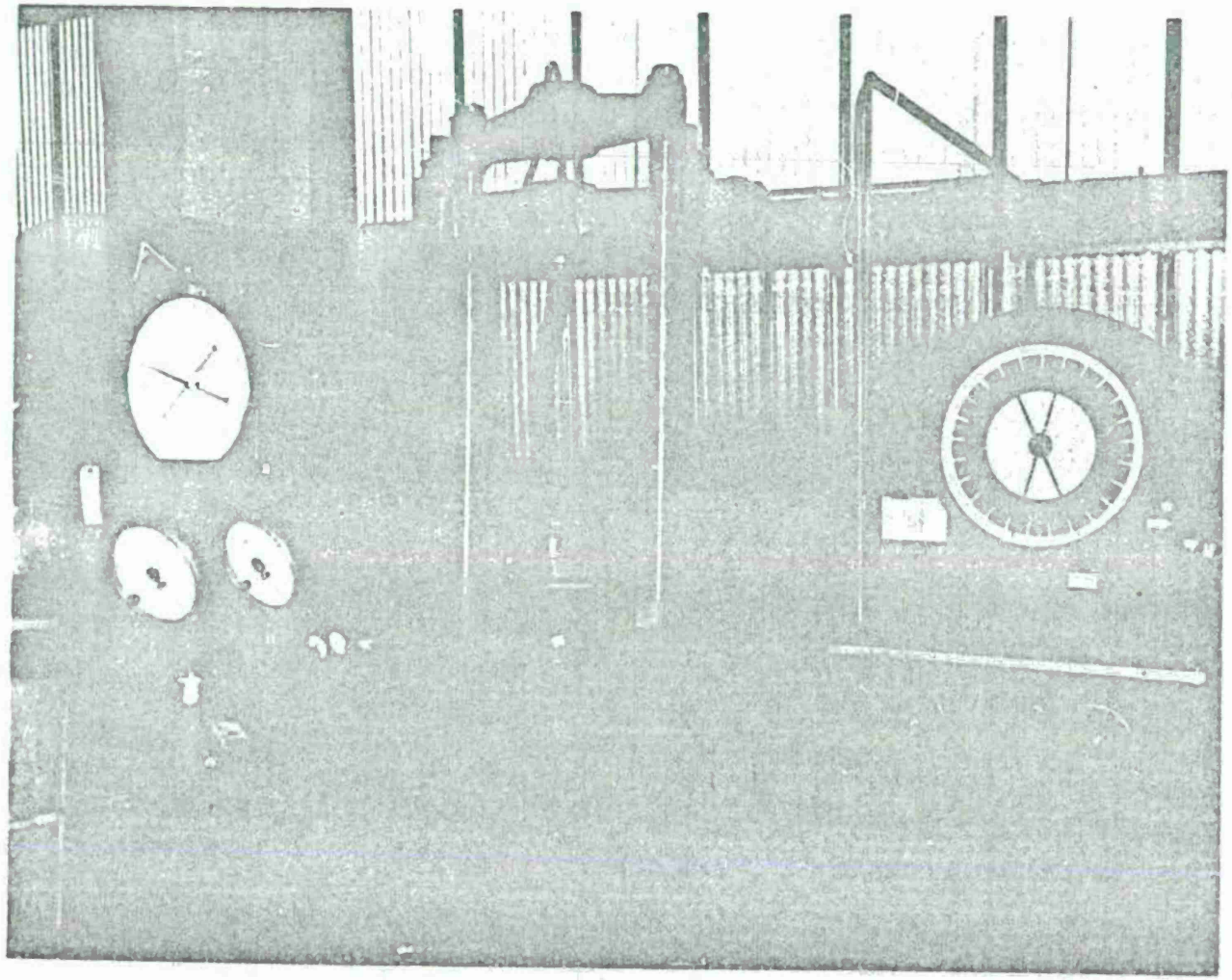


Figure 3. Static testing setup.

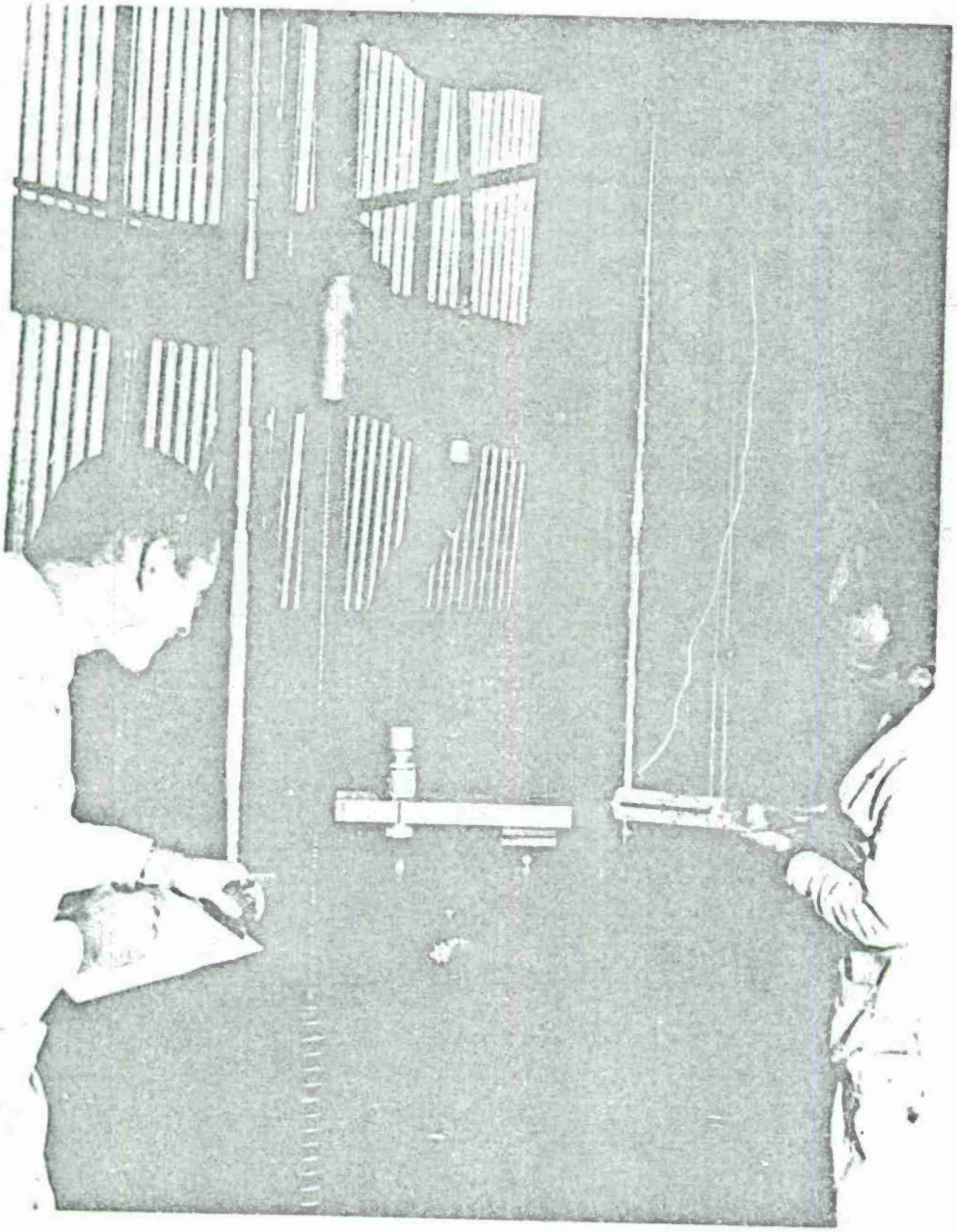


Figure 4. Static testing of flexible rubber hose with smooth wall.

Table 1. Characteristics of Hose Specimens

Designation	Wall Type*	Nominal Diameter (in.)		Weight (lb/ft)	Stiffness Rating (0-100)	Minimum Bend Radius, r (in.)	Tests Conducted†		
							Static		Dynamic
		d_i	d_o				Ambient	Pressurized	
AB-S1	C, with braided wire fabric covering reusable fittings	0.75	1.32	1.05	5	7	x	x	–
		1.00	1.58	1.21	5	8	x	x	–
		1.50	2.23	2.12	5	10	x	x	–
		2.00	2.86	3.09	5	11	x	x	x
	solder-on fittings	2.00	2.86	3.09	5	11	x	–	x
	weld-on fittings	2.00	2.86	3.09	5	11	x	x	x
BFG-82A	S	2.00	2.50	1.14	70	12	–	–	–
BFG-84H	C	2.00	2.63	1.2	20	4	–	–	–
BFG-85	S	2.00	2.63	1.4	75	12	–	–	–
BFG-89P	S	1.25	1.88	0.9	75	–	–	–	–
GT-24HW	S	2.00	2.50	1.32	50	5.8‡	x	–	–
GT-24SB	C	2.00	2.56	1.15	35	–	–	–	–
GT-200SB	C	2.00	2.63	1.36	90	–	–	–	–
GT-43HW	S	2.00	2.55	1.60	30	5.8‡	x	–	–
GT-43HW	S	2.00	2.55	1.60	30	5.8‡	x	–	x
GY-FW	S	2.00	2.55	1.33	40	5.8‡	x	–	–
US-P5120	S	2.00	2.58	1.5	80	5.8‡	x	x	–
US-P5194	C	2.00	2.50	1.1	10	4.2	x	x	–
US-P5175	S	2.00	2.59	1.3	60	5.8‡	–	–	–

* S = smooth, C = corrugated.

† Rubber hoses deemed unfeasible for the design under consideration due to excessive stiffness or corrugations were not tested.

‡ Estimated from observations of specimen.

The static test configuration permitted various displacement positions of the lower end of a specimen relative to the upper end. It prevented rotation of either end of the hose. In addition, it allowed measurements to be made of the axial and transverse forces and the end moment necessary to hold a specimen in a given deflected position. The transverse force was measured with a spring scale of 32-pound capacity (or one of 80-pound capacity when necessary) by moving the fixture block slightly away from the restraining block, as shown in Figure 4. The longitudinal force and moment were determined indirectly by computing the sum and difference of the reactions at the two rollers which supported the end fixture block. Each upward force was measured with the same spring scale by lifting each end of the fixture block slightly off its supporting roller using a hook located 9 inches from the center. A weight correction for the end fixture block was required to properly compute the axial force on the bottom of the hose. As a check, data from the loading machine were taken to provide a record of the axial force acting downward on the top end of the hose; these data were to be compared with the bottom-end axial force data after a weight correction was made for the hose.

The internal hose pressure was read from Wallace and Tiernan Bourdon-type dial pressure gages, which were an integral part of the NCEL static pressurization console used to apply pressure to water in the hose.

Relative displacements used in testing were determined from Tables A-1 through A-6, which list deflections derived theoretically from hose free length. Experimental values of δ were obtained for the lengths of available specimens by interpolation, and hoses were subjected to deflections statically to conform to the deflected positions depicted in Figure 2. Values of δ for the specimens tested are tabulated along with some test data in Table 2.

Test Data

As shown in Table 1, some connection hoses were selected for testing under varying internal pressures, while others were tested containing only atmospheric pressure. For each of the hoses tested under varying internal pressures, a set of measurements consisting of the transverse force on the end fixture block, two upward forces on 9-inch moment arms on the block, and the downward force on the top hose fitting was obtained at each of seven different relative displacement positions, as shown on the sample data sheet (Figure 5), under internal pressures of 0, 10, and 75 psig. For the remainder of the available 2-inch-diameter hose specimens, the axial force required to maintain a longitudinal deflection of $-\delta$ from the installed position, termed the buckled axial resistance, was recorded. Data of hose specimen weights and buckled axial resistances are contained in Table 2.

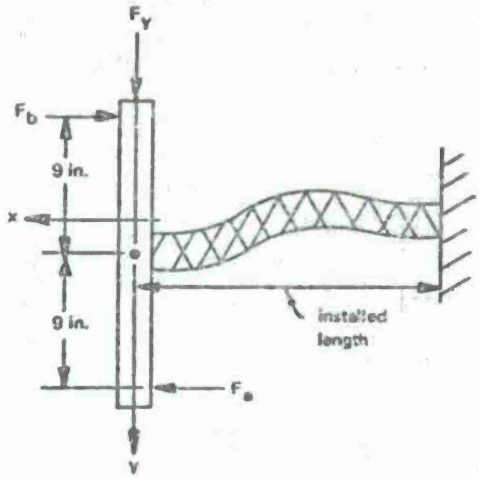
DATA SHEET

HOSE FLEXURE TESTS

Test no. 1 (1" i.d.)

Date 11-1-66 Time 1300

Personnel DT MC



Position (in.)		Int. Press., p_i (psi)	Measured Forces (lb)				Computed Loads	
x	y		Loading Machine Loads	F_a	F_b	F_Y	$F_x = F_a - F_b$ (lb)	$M = 0.75(F_a + F_b)$ (lb-ft)
0	-3.45	0	-11.6	$-7\frac{1}{2}$	11	1	$-18\frac{1}{2}$	2.81
0	0		-11.6	$-7\frac{1}{2}$	12	0	$-19\frac{1}{2}$	3.37
0	+3.45		-11.6	-7	$11\frac{1}{2}$	$-\frac{1}{2}$	$-18\frac{1}{2}$	3.19
-2.3	-3.45		-13.5	-7	13	1	-20	4.5
-2.3	0		-14.0	-7	$13\frac{1}{2}$	0	$-20\frac{1}{2}$	4.69
-2.3	+3.45		-13.5	-7	13	-1	-20	4.5
-4.6	0		-12.5	$-6\frac{1}{2}$	13	0	$-19\frac{1}{2}$	5.06

Notes: 1. Slight permanent bend after deflection of x = -2.3 in.
2. More noticeable permanent bend after deflection of x = -4.6 in.
3. Bulk of permanent set was near to fittings.
4. Hose tested was Anaconda Bronze Type S-1 with annular corrugations and one-ply braided wire covering. Size: 1 in. i.d.

Extended Length $31\frac{1}{2}$ in. Deflection, Delta 2.37 in. Weight 11.73 lb.

Figure 5. Sample static test data sheet.

Table 2. Static Test Specimen Data

Hose Designation	Inside Diameter, d_i (in.)	Free Length, ℓ (in.)	Locking Deflection Capability, δ_L (in.)	Locking Buckled* Hose Axial Resistance at 0 psig (lb)	Elastic Deflection Capability, δ_E (in.)	Elastic Buckled* Hose Axial Resistance at 0 psig (lb)
AB-S1	0.75	28.0	2.22	9	1.06	9
	1	31.3	2.37	14	1.14	13
	1.5	35.8	2.29	33	1.14	31
	2	39.5	2.60	27	1.26	19
	2	29.5	1.08	59	0.58	46
GT-24HW	2	20	1.19	125	0.60	121
GT-43HW	2	32	4.61	47	1.91	40
	2	20	1.19	106	0.60	106
GY-FW	2	22	1.58	86	0.76	76
US-P5120	2	21.9	1.53	80	0.75	44
US-P5194	2	21.8	2.44	200	1.18	129

* Buckled to assume the compressed position (2δ shorter than extended length) shown in Figure 2.

The transverse force, F_y, as entered on the data sheet, required no reduction. The longitudinal force, F_x, and the restraining moment, M, were derived as

$$F_x = F_a - F_b \quad \text{(lb)}$$

$$M = 0.75(F_a + F_b) \quad \text{(lb-ft)}$$

where F_a and F_b are static test reactions on the end fixture block, as shown in Figure 5.

The load read from the testing machine (positive in tension) was used as a check on F_x. (This load was expected to differ from F_x by a constant amount—consisting of portions of the weights of the hose, contained fluid, and end fixture block.)

Observations of the degree of permanent bending were made during the tests when the internal hose pressure was at atmospheric (0 psig), and photographs (such as shown in Figure 4) were taken to record the deflected shape. Slight permanent bends were observed in all sizes of type AB-S1 hose after longitudinal relative displacements of $-\delta$ from the installed position. Obvious permanent bending was evident after displacements of -2δ. No permanent bending was observed in rubber hose specimens subjected to longitudinal relative displacements smaller than or equal to -2δ.

Reduced test data are presented in Figures 6 through 11. Figures 6 and 7 are moment-deflection diagrams: plots of the longitudinal deflection ratio, D_x/δ, against the restraining moment M, applied at the end of the hose. The longitudinal deflection, D_x, was taken positive in tension and equal to zero at the fully extended length of the hose. Moments were computed from the upward force couple measured on the end fixture block. Figures 8 and 9 are force-deflection diagrams: plots of D_x/δ against the restraining longitudinal force, F_x. The longitudinal forces were also calculated from the upward force couple measured during the experiment. Finally, Figures 10 and 11 are plots of D_x/δ against the restraining transverse force, F_y. Points have been plotted for the three transverse deflections, $D_y = -\delta$, 0, and $+\delta$.

Discussion

The combined weight of the hose (Table 1), contained fluid, and end fixture block affects the upward force couple. This weight was highly significant, being on the same order of magnitude as the force measurements.

Permanent bending affected the linearity and hysteresis of all plots. The degree of permanent bending was deemed insignificant for $D_x \geq -2\delta$. It is significant that tests in which the internal pressure was raised above ambient were conducted after D_x had been held at -3δ to observe permanent bending.

Generally, the moment-deflection behavior shown in Figures 6 and 7 indicates an increasing bending stiffness with increasing hose size. The moment increased roughly in proportion to the longitudinal deflection. However, straight lines drawn to group the points representing various hose sizes and internal pressures do not all pass through the origin. This may be due to both the initial bends in the hose and the weight of the hose and end fixture block. Lines A and B, drawn through the two hose sizes on each plot for both zero and 10-psi internal pressures, pass closer to the origin than do lines C and D, which are drawn through data points taken when the internal pressure was 75 psi. Thus, the internal pressure also apparently influences the line's failure to pass through the origin. The data for zero and 10-psi internal pressures are essentially the same; hence they are represented by the same line.

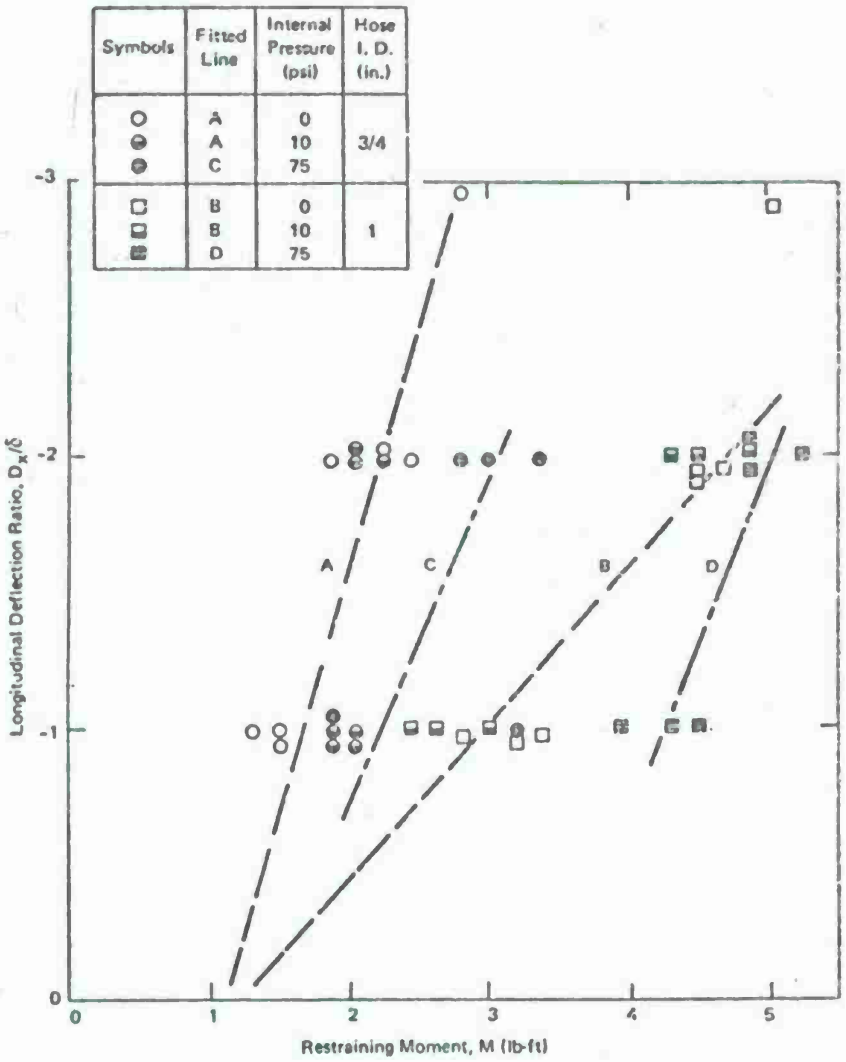


Figure 6. Static moments—smaller hoses, type AB-S1.

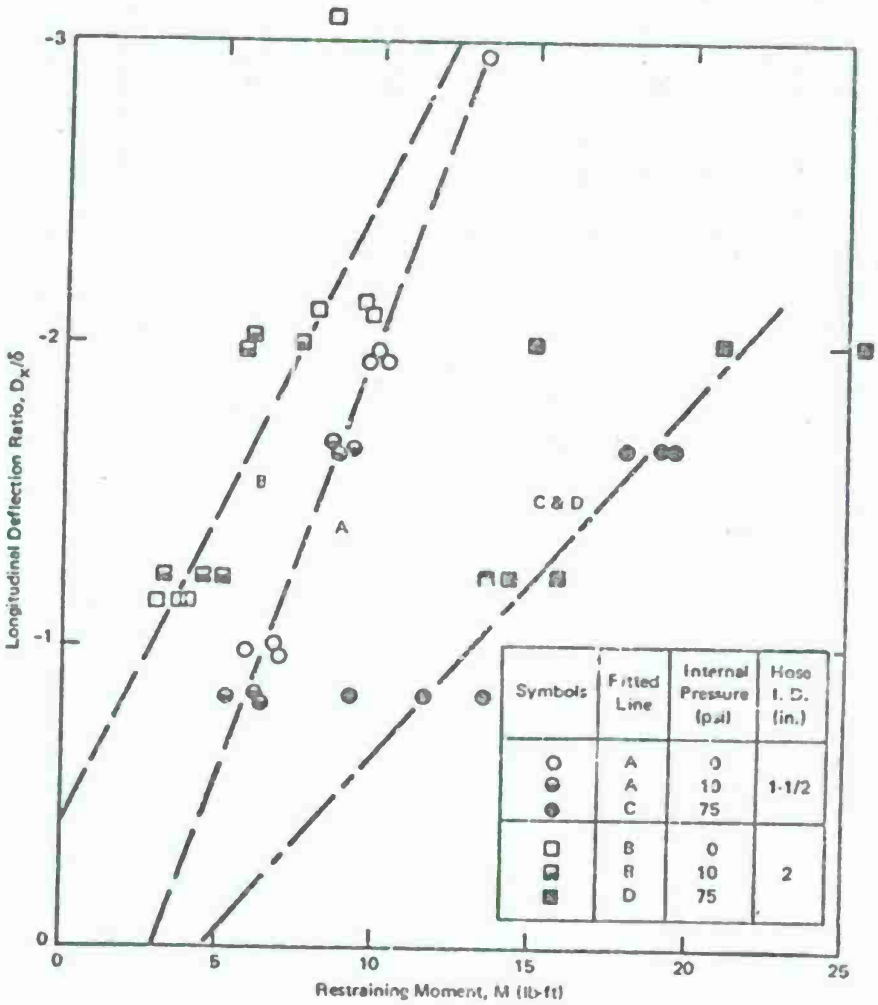


Figure 7. Static moments—larger hoses, type AB-S1.

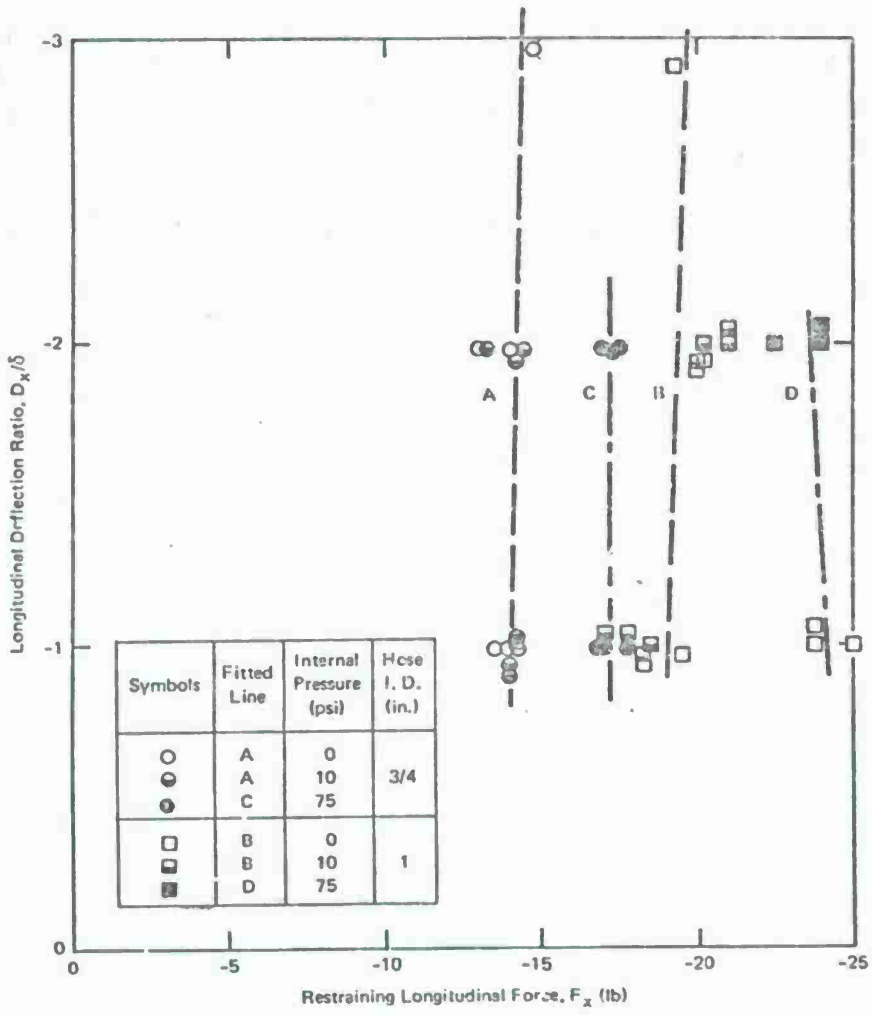


Figure 8. Static compressive forces—smaller hoses, type AB-S1.

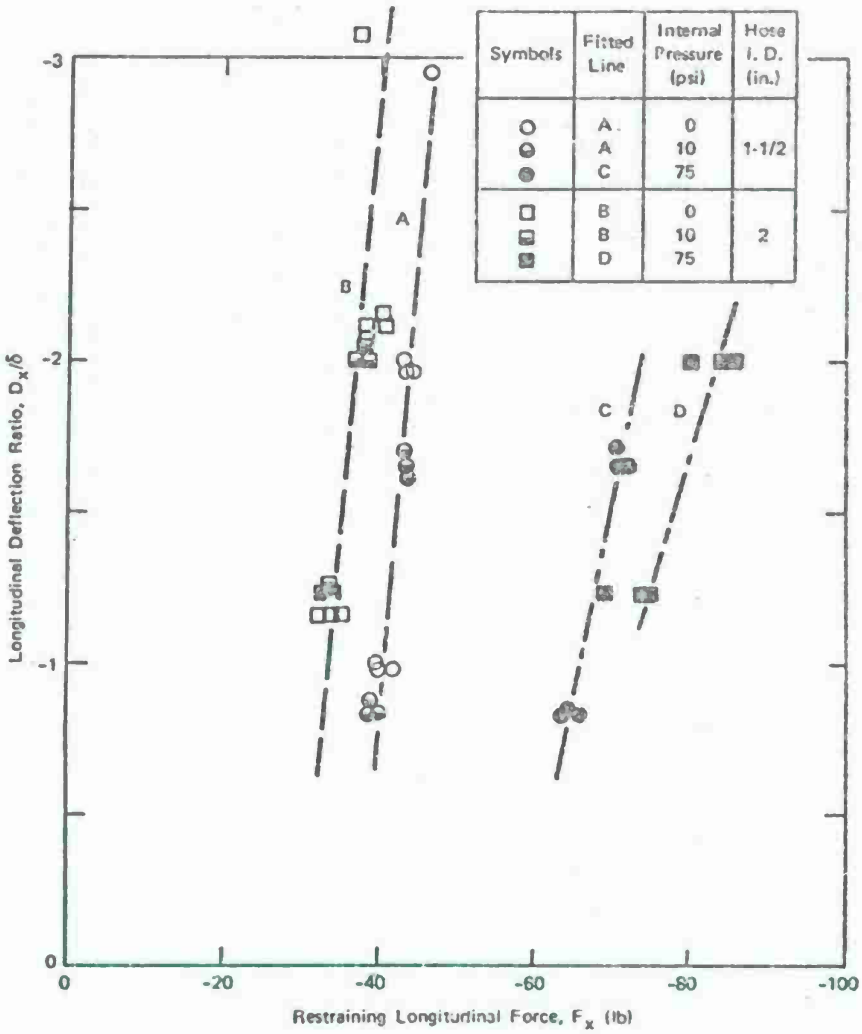


Figure 9. Static compressive forces—larger hoses, type AB-S1.

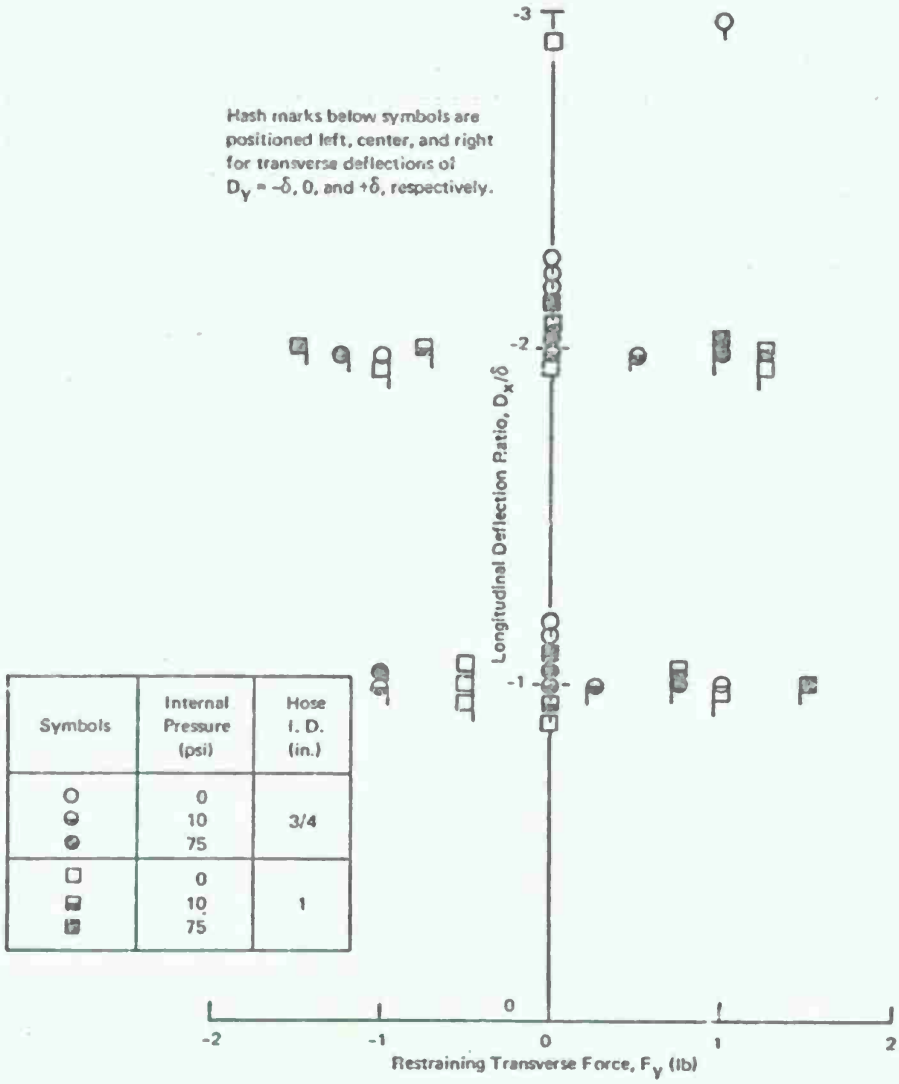


Figure 10. Static shear forces—smaller hoses, type AB-S1.

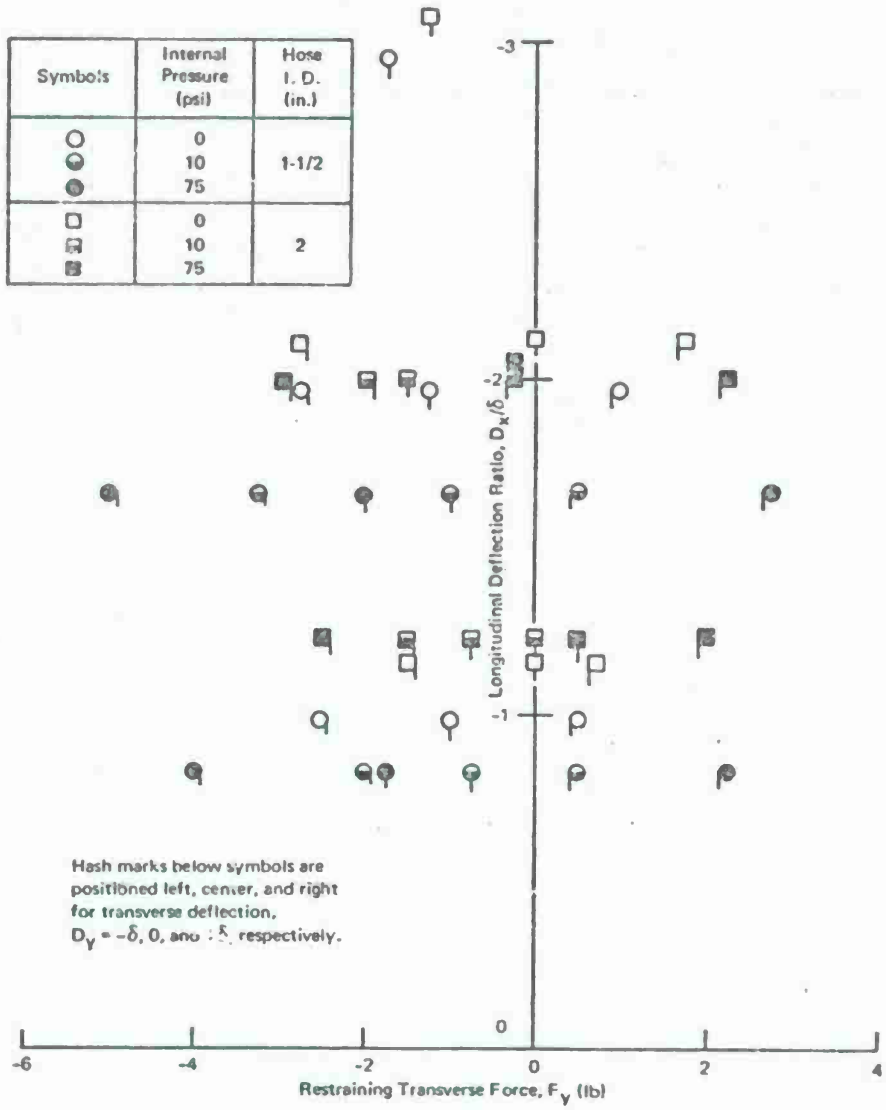


Figure 11. Static shear forces—larger hoses, type AB-S1.

The longitudinal force-deflection diagrams (Figures 8 and 9) show longitudinal force to be almost constant with varying longitudinal deflection. Some increases in force at higher deflections did occur for the larger hose tests (Figure 8); this is even more apparent at the highest internal pressure. Here again, the data for zero and 10-psi internal pressures are essentially the same and are represented by the same line.

In the plots of transverse force against longitudinal deflection (Figures 10 and 11) variations in transverse deflection have been shown by using different symbols as data points to maintain continuity of format with the preceding figures. These plots show that transverse force increased with increasing longitudinal deflection, internal pressure, and hose size. A reverse relationship is apparent between transverse force and transverse deflection; that is, they are oppositely oriented with positively correlated magnitudes. In all cases, the transverse force was very small relative to a force necessary to bend a utility line of equivalent inside diameter constructed of standard galvanized steel plumbing pipe (all transverse forces were less than 6 pounds).

The shape of the load-deflection curves (Figures 6 through 9) indicates an elasto-plastic rather than a locking behavior in the hoses tested. The apparent sinusoidal hose shape, photographed in Figure 4, sustains this hypothesis. The deflections at points of departure from linear load-deflection relationships and the deflections visually observed to cause significant permanent bending were in fair agreement, were lower than those predicted by the locking computer program, and were approximated fairly well by the elastic computer program. This, together with the sinusoidal appearance of the deflected hose, points to the elastic program as best suited to determine design information for the flexible hose.

The compressive forces required to maintain the computed longitudinal deflections for rubber hoses were much higher than for metal hoses. Also, straight-sided rubber hoses required more restraining force than corrugated rubber hoses. These large resistive forces are in agreement with subjective observations that the rubber hoses were more difficult to manually deform than bronze hoses of the same size. The higher measured forces were due, in part, to the shorter lengths of rubber hose specimens, which were based on smaller values of r.

As previously stated, computation of the lengths of hose used in the experiment was based on the assumption of locking behavior. For the metal hoses with relatively large values of r, there is only a small difference between lengths calculated by using the locking and elastic computer programs. But for the rubber hoses with relatively small values of r, the choice of a basic assumption (locking versus elastic) becomes quite important. This can be

seen by comparing the displacement parameters, δ_L and δ_E, in Tables A-6 and B-6, determined from the locking and elastic assumptions, respectively, for a section of hose with an installed span of 22 inches (1.58 inches locking versus 0.76 inches elastic). As can be derived from Table B-6, an extended free length of about 32.61 inches would be required for $\delta_E = 2$ inches. It is felt that this longer rubber hose would be satisfactory from the standpoint of ease of handling in installation and low stresses on restraining supports when the hose is deflected.

The corrugated rubber hose was seen to assume sharp internal folds when bent to any appreciable degree. Such folds are felt to cause undesirable restriction to fluid flow. The high localized long-term stresses in the rubber in these folds may cause creep and premature age-cracking of the hose wall. Such possibilities should be evaluated in more detail.

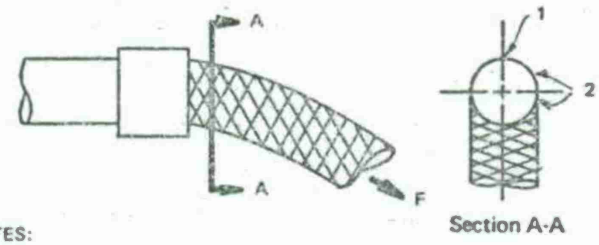
The magnitudes of load measured are not critical; the moment was sufficient to cause permanent bending, but the amount of bending can be readily controlled by limiting the deflection. The shear force was observed to be very low compared to that which could cause plastic shear deformation. However, it is possible that these forces could become critical under dynamic loading.

DYNAMIC STRENGTH OF CONNECTION HOSES

Dynamic tests were conducted on selected specimens to determine the extent of the effects of inertial loading on hose performance and reliability. Internal forces in the hose and external loads and motions were monitored. Results were compared with manufacturer-supplied data on hose strengths in an effort to establish a criterion for predicting dynamic hose performance from a manufacturer's data.

Theory

To enable the development of a theoretical relationship between inertial loading and internal forces in a hose, a load-response mechanism was assumed whereby inertial forces cause the hose to be loaded perpendicularly to the straight line drawn through both end fittings, thus causing tension to increase in the hose wall. Such tension would be maximum immediately adjacent to the end fitting undergoing rapid displacement. At this point, the tension was further assumed to be uniformly distributed (as shown in Figure 12) on the quarter-circumference of the hose situated on the side opposite from the direction of inertial load (that is, on the



NOTES:

1. This quarter-circumference assumed to carry uniformly distributed tensile stress.
2. Remainder of hose section assumed unstressed.

Figure 12. Theoretical assumption of hose stress distribution.

uppermost quarter-circumference adjacent to the end fitting when inertial forces act downward). The remainder of the section was assumed to carry no load. From the dimension of the hose section and the magnitude of the tensile force, the tensile stress in this quarter-circumference of the hose wall was calculated as*

$$\sigma = \frac{F}{\text{stressed area}} = \frac{F}{\frac{\pi t (d_i + t)}{4}}$$

or

$$\sigma = \frac{4F}{\pi t (d_i + t)} \qquad (1)$$

where F = total tensile force in hose, lb

d_i = inside diameter of hose, in.

t = thickness of hose wall, in.

The amount of hose strength available to resist inertial forces was expressed in terms of equivalent internal pressure as

$$p = p_b - p_i \qquad (2)$$

where p_b = dynamic burst pressure, psi**

p_i = internal pressure in hose, psi

* See symbols listed on foldout at end of text.

** May be supplied by the manufacturer or determined by static test.

The maximum allowable hose wall stress was then

$$\sigma_{max} = p\left(\frac{\text{internal area}}{\text{stressed area}}\right)$$

or

$$\sigma_{max} = p\,\frac{\pi d_i^2/4}{\pi t(d_i + t)} = \frac{p d_i^2}{4t(d_i + t)} \qquad (3)$$

Equating the right members of Equations 1 and 3 yielded the following expression for maximum allowable tensile force:

$$F_{max} = p\left(\frac{\pi d_i^2}{16}\right) \qquad (4)$$

The tensile force in a hose is equal in magnitude to the resultant of the reaction components at the end fitting. This resultant was computed as

$$F = \frac{F_y}{\sin\phi} \qquad (5)$$

where F_y = transverse component of hose force, lb

ϕ = angle between total tensile force and fitting axis, deg

An upper limit to the perpendicular, or shear, force, F_y, was estimated by assuming a long duration of acceleration compared to the time required for the hose to distribute inertial forces and reach an equilibrium position. The idealized hose was assumed to act as an axially rigid line offering no resistance to bending, with mass uniformly distributed along the horizontal projection. (A more accurate assumption of mass distribution in the curved hose was found to add only a negligible increment to the shear force.) The downward velocity was assumed to vary linearly with position, from the fitting velocity at the moving end to zero at the fixed end. The acceleration required to halt this motion in a given time span likewise would vary linearly with position, as shown in Figure 13. The acceleration at any point on the hose span was written as

$$a = A - \frac{Ax}{s}$$

where A = acceleration of moving end, g

x = distance measured from moving end toward fixed end, in.

s = hose span, in.

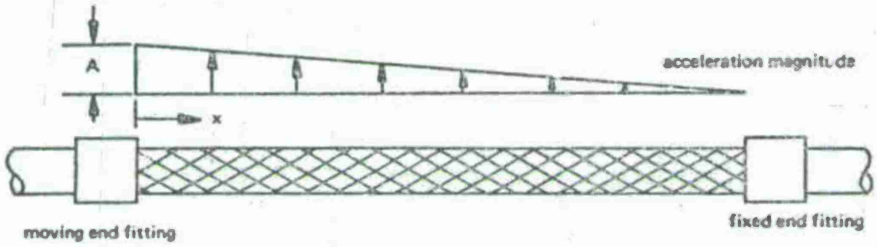


Figure 13. Theoretical assumption of hose acceleration distribution.

The force required to produce this acceleration in a mass weighing w dx would be

$$a\,w\,dx = w\left(A - \frac{A\,x}{s}\right)dx$$

where w is the weight of the hose per unit change in x, lb/in. Distributing this force to the two ends according to static moment equilibrium would give for the incremental force on the moving end

$$dF_y = a\,w\,dx\left(\frac{s - x}{s}\right) = \frac{A\,w}{s^2}(s - x)^2\,dx$$

Thus, the total force due to the end acceleration A would be

$$F_y = \int dF_y = \int_0^s \frac{A\,w}{s^2}(s - x)^2\,dx = \Big|_0^s \frac{A\,w}{s^2}\left(s^2 x - s x^2 + \frac{x^3}{3}\right)$$

or

$$F_y = A\,\frac{w\,s}{3}$$

in which ws/3 represents the effective dynamic weight of the hose. In terms of weight per unit length of hose, the force-acceleration relationship was expressed as

$$F_y = A \frac{\rho \ell}{3} \tag{6}$$

where ρ = weight per unit length of hose, lb/in.

ℓ = free length of hose in span s, in.

$\rho \ell/3$ = effective dynamic weight of hose, lb

Substituting Equation 6 into Equation 5 gave the following theoretical upper limit for experimentally measured tensile force in terms of acceleration and hose characteristics:

$$F = \frac{A}{\sin \phi} \left(\frac{\rho \ell}{3} \right) \tag{7}$$

Test Specimens

Specimens fabricated from 2-inch-inside-diameter type AB-S1 bronze hose with various fitting types and one specimen of type GT-43HW rubber hose were tested to establish their dynamic behavior characteristics. The specimens have been previously described to some extent in Table 1. Their characteristics specifically pertinent to dynamic behavior as required to evaluate parameters in Equations 4, 6, and 7 are shown in Table 3.

Test Equipment

The NCEL 10,000-pound rapid load machine, shown in Figures 14a and 14b with a specimen in test position, was utilized to provide a rapidly displacing fixture head to which nose end fittings could be attached for testing. General characteristics of the motion of the loading head, as used in testing, include:

1. Approximately 3 inches displacement within about 1/20th of a second
2. Velocity exceeding 2,000 ft/sec
3. An initial peak acceleration of about 30 to 50 g followed by a peak deceleration of 100 to 200 g

Although these parameters are not strictly equivalent to what might be expected when a footing on a buried structure is displaced under nuclear blast loading, the peak deceleration is of appropriate magnitude. Since acceleration (or deceleration), which is directly related to force, is the motion parameter having the most direct influence on internal dynamic stresses in flexible hose walls, the planned tests were expected to reveal the ability of hoses to resist peak inertial loads which might be expected to occur in actual installations under nuclear blast loading.

Test Instrumentation

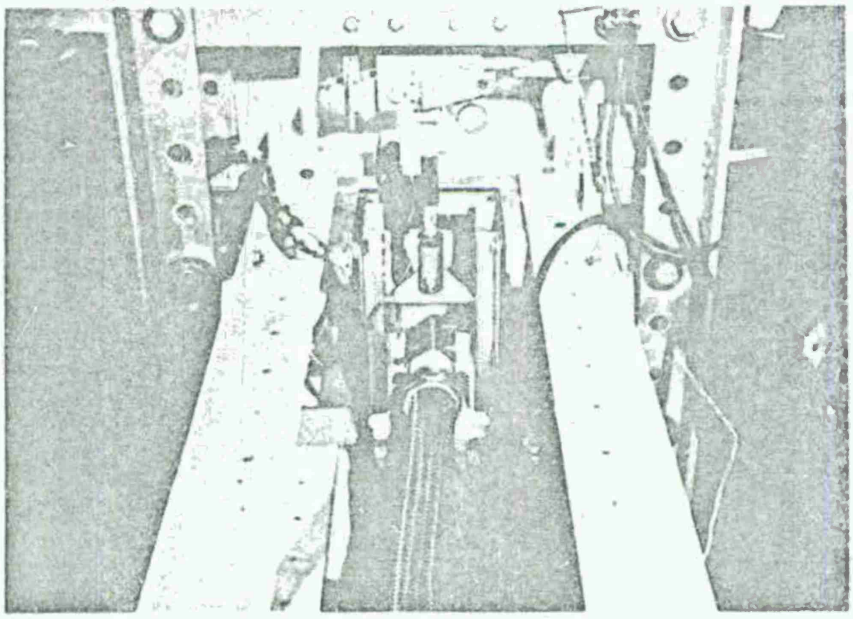
The motion of the loading head of the rapid load machine and the internal forces in the hose wall were monitored electrically. A Bourns Model 108 linear potentiometer was used to monitor head displacement, and a Statham A5-200-350 accelerometer was employed to sense acceleration. The force in the loading ram which drove the loading head was monitored with a four-arm strain gage Wheatstone bridge as a backup and check on acceleration and hose force. Hose-wall stresses were monitored indirectly with a specially designed four-way load cell capable of measuring moment, shearing force, axial force, and pressure by using four channels of electronics. The linear potentiometer, ram instrumentation, and special load cell are visible in Figure 14a, and a close-up view of the load cell appears in Figure 15.

Each gage produced data in the form of electrical unbalance in its four-arm Wheatstone bridge. Power to the bridges was supplied by a Consolidated Electrodynamics Corporation (CEC) system D type 2-105A power supply, and output signals were conditioned by type 1-113B amplifiers. The conditioned data were recorded on a CEC type 5-124 direct-writing oscillograph and CEC type 7-323 galvanometers.

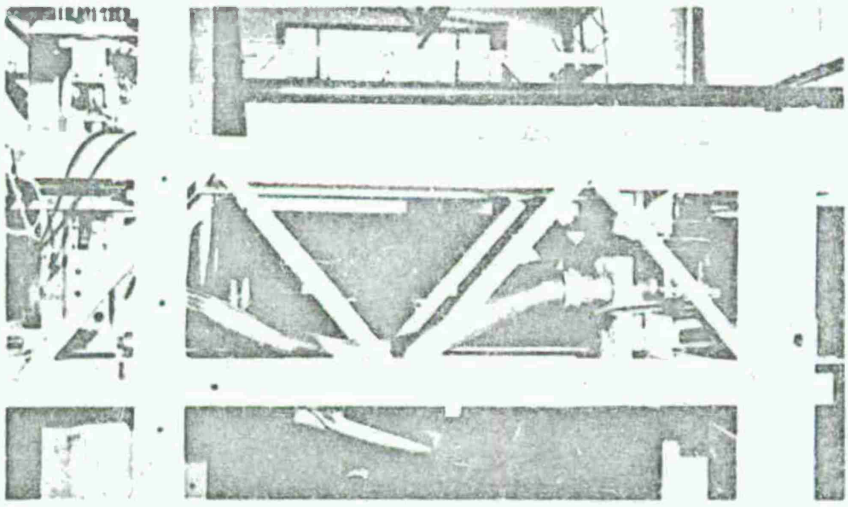
Test Data

A sample of the data in the form of an oscillogram appears as Figure 16. Data such as test number, time of day, and machine settings were noted by hand directly on the record. The calibration deflection at the beginning of each trace represents a predetermined value of the data parameter, termed the calibration equivalent. This value was determined during preliminary calibration tests. Only the peak values of the data were reduced. These were calculated by multiplying the calibration equivalent by the ratio of peak trace deflection to calibration deflection. Peak value data so obtained, together with notes of any unusual occurrences during testing, are shown in Table 4 for the entire series of dynamic tests. The displacement is positive downward, while the acceleration is positive upward. A positive ram load (tension) exerts

an upward force on the sliding end fixture head. All axial forces and strains are positive in tension. The shear force on the hose is positive upward, and the angle of action of the tensile resultant force is positive upward from the horizontal fitting axis.



(a) Showing loading ram, sliding end fixture block, and instrumentation.



(b) Showing fixed end support frame.

Figure 14. NCEL 10,000-lb rapid load machine with specimen in test position.

Table 3. Dynamic Test Specimens Characteristics

Hose Designation	Fittings	Free Length, ℓ (in.)	Weight-Per-Unit-Length			Effective Dynamic Weight, $\rho\ell/3$ (lb)	Burst Pressure, p_b* (psi)	Maximum Inside Diameter, d_i (in.)	Allowable Tensile Force, $F_{max} = \frac{\pi d_i^2}{16}(p_b - p_i)$† (lb)
			Hose, ρ_h (lb/in.)	Water, ρ_w (lb/in.)	Total $\rho = \rho_h + \rho_w$ (lb/in.)				
AB-S1	reusable	39.5	0.258	0.144	0.402	5.29	650	2.6	765
AB-S1	solder-on	29.5	0.258	0.144	0.402	3.95	1,200	2.6	1,497
AB-S1	weld-on	29.5	0.258	0.144	0.402	3.95	800	2.6	965
GT-43HW	shank	32.0	0.133	0.114	0.247	2.63	625‡	2.0	432

* Taken from manufacturer's ratings.

† p_i taken as 75 psi.

‡ Taken as five times the manufacturer's rated working pressure.

Table 4. Dynamic Test Results, Peak Values

Test No.	Hose	Displacement, D_y (in.)	Acceleration, A (g)	Ram Load, L (lb)	Load Cell Strain (μin./in.)				Axial Force, F_x (lb)	Shear Force, F_y (lb)	Resultant Tensile Force, F (lb)	Angle of Action, ϕ (rad)	Internal Pressure, p_i (psi)	Contained Fluid*	
					S1	S2	S3	S4							
D-1		–	95.8	–	-541	-329	515	411	-94.75	-589.96	597.52	1.41	0	A	
D-2		–	99.5	-877	-671	-403	588	491	-302.49	-950.87	997.83	1.26	0	A	
D-3		3.84	186	-2,250	-710	-442	715	530	18.22	-585.36	585.64	-1.53	0	A	
D-4		3.86	180	-2,270	-685	-434	721	565	131.20	-837.92	848.13	-1.41	10	A	
D-5		3.84	180	-2,640	-676	-426	714	558	138.49	-825.59	837.12	-1.40	10	A	
D-6		3.88	179	-2,370	-608	-376	735	544	462.85	-1,052.80	1,150.05	-1.15	75	A	rapid loading m
D-7	AB-S1	3.86	–	-1,453	–	–	–	–	0.00	0.00	0.00	1.57	0	A	
D-8	(reusable	3.94	–	-1,540	-737	-408	768	428	112.97	-69.97	132.89	-0.55	0	A	
D-9	fittings)	3.98	151	-1,430	-685	-376	708	378	83.82	25.50	87.61	0.29	0	A	
D-10		3.68	147	-1,430	-726	-410	748	424	80.17	-87.16	118.43	-0.82	0	W	
D-11		3.73	138	-1,350	-805	-360	910	428	382.67	204.69	433.97	0.49	75	W	hose—fitting s
D-12		3.66	128	-1,460	-826	-327	1,018	458	699.74	117.29	709.50	0.16	75	W	
D-13		3.48	110	-1,170	-924	-357	1,110	457	677.87	409.39	791.91	0.54	75	W	
D-14		3.56	97	-1,170	-936	-368	985	477	178.58	631.49	656.26	1.29	75	W	
D-15		3.67	134	-1,530	-1,000	-448	1,135	562	492.00	138.62	511.16	0.27	75	W	hose—fitting s
D-16		3.62	132	-1,370	-760	-269	830	280	255.11	206.12	327.98	0.67	75	W	
D-17		3.62	110	-1,170	-673	-250	731	351	211.38	-50.72	217.38	-0.23	75	W	
D-18		3.28	98	-1,320	-624	-246	700	296	276.98	-31.60	278.77	-0.11	75	W	
D-19		3.42	142	-1,860	-840	-300	930	317	328.00	197.78	383.02	0.54	75	W	
D-20	GT-43HW	3.49	146	-1,880	-867	-300	982	324	419.11	214.70	470.91	0.47	75	W	
D-21	(shank	3.50	142	-1,840	-891	-312	984	317	338.93	263.90	429.56	0.66	75	W	
D-22	fittings)	3.46	152	-1,960	-904	-315	1,022	349	430.05	197.74	473.33	0.43	75	W	
D-23		3.46	149	-1,830	-904	-308	1,011	365	389.96	187.11	432.52	0.44	75	W	tested after 7 h
D-24		3.53	154	-1,850	-949	-346	1,055	361	386.31	199.93	434.98	0.47	75	W	tested after 1 d
D-25		3.50	155	-1,830	-932	-327	1,043	361	404.54	204.43	453.26	0.46	75	W	tested after 2 d
D-26		3.48	151	-1,780	-916	-311	1,011	351	346.22	240.18	421.38	0.60	75	W	tested after 5 d
D-27		3.09	28	-748	-348	-115	414	143	240.53	255.98	351.26	0.81	75	W	
D-28		3.40	103	-1,372	-886	-306	1,067	429	659.65	451.38	799.30	0.60	75	W	
D-29		3.18	78	–	-794	-260	961	386	608.63	426.99	743.47	0.61	75	W	
D-30	AB-S1	3.40	179	–	-1,511	-472	1,480	600	-112.97	1,510.22	1,514.44	-1.49	75	W	rapid loading m
D-31	(solder-on	3.58	189	-2,405	-1,062	-520	1,306	605	889.25	-65.02	891.63	-0.07	75	W	
D-32	fittings)	3.50	190	-2,490	-1,150	-531	1,200	635	182.22	362.24	405.49	1.10	75	W	
D-33		3.52	196	-2,720	-1,250	-583	1,277	681	98.40	441.37	452.20	1.35	75	W	
D-34		3.43	230	-2,813	-1,290	-588	1,270	659	-72.89	545.70	550.54	-1.43	75	W	
D-35		3.48	235	-2,890	-1,271	-588	1,732	670	1,680.11	-118.09	1,684.26	-0.07	75	W	rapid loading m
D-36		3.48	213	-2,340	-1,430	-459	935	471	-1,804.03	-21.88	1,804.16	0.01	75	W	
D-37		3.58	240	-2,903	-1,019	-508	1,130	541	404.54	439.64	597.44	0.82	75	W	
D-38	AB-S1	3.64	242	-3,080	-1,075	-519	1,166	565	331.65	533.76	628.40	1.01	75	W	
D-39	(weld-on	3.49	227	-2,456	-905	-427	1,039	530	488.36	304.56	575.54	0.55	75	W	
D-40	fittings)	3.58	244	-3,035	-1,075	-506	1,189	588	415.47	488.86	641.56	0.86	75	W	
D-41		3.62	240	-3,170	-1,087	-518	1,189	600	371.73	490.69	615.60	0.92	75	W	
D-42		3.62	240	-3,170	-1,088	-406	1,166	588	284.27	579.48	645.45	1.11	75	W	
D-43		3.64	2[illegible]	-3,260	-845	-506	946	612	368.09	-63.72	373.57	-0.17	75	W	rapid loading m

* A = air, W = water.

Table 4. Dynamic Test Results, Peak Values

	Strain (μin./in.)			Axial Force, F_x (lb)	Shear Force, F_y (lb)	Resultant Tensile Force, F (lb)	Angle of Action, ϕ (rad)	Internal Pressure, p_i (psi)	Contained Fluid*	Remarks
	S2	S3	S4							
	329	515	411	-94.75	-589.96	597.52	1.41	0	A	–
	403	588	491	-302.49	-950.87	997.83	1.26	0	A	–
	442	715	530	18.22	-585.36	585.64	-1.53	0	A	–
	434	721	565	131.20	-837.92	848.13	-1.41	10	A	–
	426	714	558	138.49	-825.59	837.12	-1.40	10	A	–
pid loading m	376	735	544	462.85	-1,052.80	1,150.05	-1.15	75	A	rapid loading machine—load cell separation
	–	–	–	0.00	0.00	0.00	1.57	0	A	–
	408	768	428	112.97	-69.97	132.89	-0.55	0	A	–
	376	708	378	83.82	25.50	87.61	0.29	0	A	–
	410	748	424	80.17	-87.16	118.43	-0.82	0	W	–
ose—fitting s	360	910	428	382.67	204.69	433.97	0.49	75	W	hose—fitting separation
	327	1,018	458	699.74	117.29	709.50	0.16	75	W	–
	357	1,110	457	677.87	409.39	791.91	0.54	75	W	–
	368	985	477	178.58	631.49	656.26	1.29	75	W	–
ose—fitting s	448	1,135	562	492.00	138.62	511.16	0.27	75	W	hose—fitting separation
	269	830	280	255.11	206.12	327.98	0.67	75	W	–
	250	731	351	211.38	-50.72	217.38	-0.23	75	W	–
	246	700	296	276.98	-31.60	278.77	-0.11	75	W	–
	300	930	317	328.00	197.78	383.02	0.54	75	W	–
	300	982	324	419.11	214.70	470.91	0.47	75	W	–
	312	984	317	338.93	263.90	429.56	0.66	75	W	–
	315	1,022	349	430.05	197.74	473.33	0.43	75	W	–
sted after 7 h	308	1,011	365	389.96	187.11	432.52	0.44	75	W	tested after 7 hours at constant p_i
sted after 1 d	346	1,055	361	386.31	199.93	434.98	0.47	75	W	tested after 1 day at constant p_i
sted after 2 d	327	1,043	361	404.54	204.43	453.26	0.46	75	W	tested after 2 days at constant p_i
sted after 5 d	311	1,011	351	346.22	240.18	421.38	0.60	75	W	tested after 5 days at constant p_i
	115	414	143	240.53	255.98	351.26	0.81	75	W	–
	306	1,067	429	659.65	451.38	799.30	0.60	75	W	–
	260	961	386	608.63	426.99	743.47	0.61	75	W	–
pid loading m	172	1,480	600	-112.97	1,510.22	1,514.44	-1.49	75	W	rapid loading machine—load cell separation
	520	1,306	605	889.25	-65.02	891.63	-0.07	75	W	–
	531	1,200	635	182.22	362.24	405.49	1.10	75	W	–
	583	1,277	681	98.40	441.37	452.20	1.35	75	W	–
	588	1,270	659	-72.89	545.70	550.54	-1.43	75	W	–
pid loading m	688	1,732	670	1,680.11	-118.09	1,684.26	-0.07	75	W	rapid loading machine—load cell separation
	459	935	471	1,804.03	-21.88	1,804.16	0.01	75	W	–
	508	1,130	541	404.54	439.64	597.44	0.82	75	W	–
	519	1,166	565	331.65	533.76	628.40	1.01	75	W	–
	527	1,039	530	488.36	304.56	575.54	0.55	75	W	–
	506	1,189	588	415.47	488.86	641.56	0.86	75	W	–
	518	1,189	600	371.73	490.69	615.60	0.92	75	W	–
	496	1,166	588	284.27	579.48	645.45	1.11	75	W	–
pid loading m	506	946	612	368.09	-63.72	373.57	-0.17	75	W	rapid loading machine—load cell separation

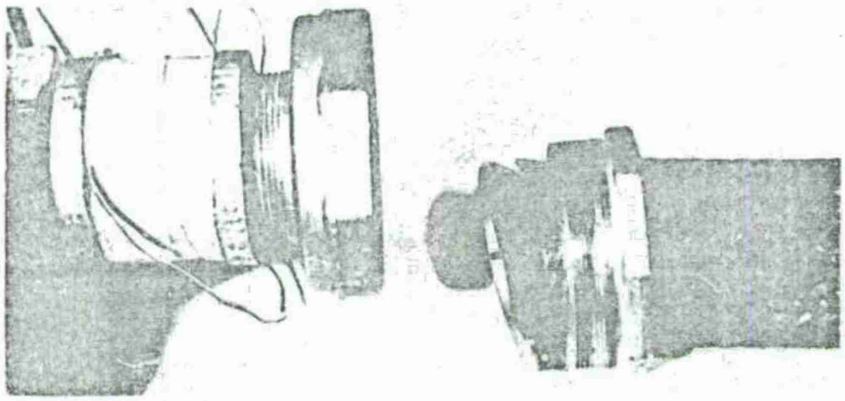


Figure 15. Type AB-S1 hose with disassembled reusable-type end fitting and special load cell.

To obtain the magnitude and direction of the peak tensile force acting on the hose section immediately adjacent to the instrumented end fitting, it was necessary to linearly combine the strain data from the four strain gages of the special load cell attached to that fitting. The coefficients for this linear combination were determined theoretically by using the dimensions of the load cell, fitting, and hose, and the modulus of elasticity of the load cell material (steel). The flexibility coefficients for strains in the cell walls in terms of imposed forces were arranged in a matrix, which was inverted to give stiffness coefficients for the external forces (axial force, moment, and shear force) in terms of measured strains. These forces acting on the load cell were then combined to give the horizontal and vertical forces acting on the hose at the end of the hose fitting. Then, the magnitude and direction of the resultant tensile force in the hose were computed. Application of this transformation to the strain gage data of Table 4 resulted in the computed hose forces, which are also shown in Table 4.

Discussion

The peak transverse force measured during each dynamic test, as given in Table 4, has been plotted versus peak acceleration in Figure 17. Data so erratic as to lie off of the plot have been omitted. The data show a definite dependence on hose type and length. Also, the straight lines representing Equation 6 have been plotted on Figure 17 for comparison with experimental data. Inspection reveals that the theoretical values (upper limits) of F_y have, in fact, exceeded essentially all of the experimental data.

The few data points not bounded by the limit lines can be attributed to the large observed experimental error. The theoretical upper limit lines are apparently valid, subject to modification by an appropriate factor of safety, for use in obtaining the design shear force.

The measurements of axial force on the fitting, F_x, taken during the experiment were erratic, preventing meaningful comparison between the resultant force F and the allowable force F_{max} (shown in Table 3). However, a definite trend is apparent whereby F_x is highly correlated with the span-to-length ratio. This trend will be discussed later.

DEVELOPMENT OF DESIGN CRITERIA

The major discrepancy between actual accelerations in blast-loaded field installations and the decelerations imposed in this test series lies in the longer duration of actual field accelerations. For a given peak magnitude of acceleration, the impulse imparted to a specimen is proportionate to duration. The strain in a dynamic system is, in turn, proportionate to impulse. Thus, a specimen would be more likely to fail under a longer duration of acceleration. Hence, failure of a hose specimen in these tests is felt to be a very positive indication that failure would occur in field installations experiencing equal peak accelerations, whereas success during laboratory tests, although believed a good indication, does not necessarily prove the durability of a hose in the field. For this reason, hose reliability must be certified by theoretical considerations based on experimental evidence until tests incorporating loading more nearly equivalent to field loading are completed. A high-explosive field test of connections attached to a prototype buried structure would allow such loading. Another alternative is the attachment of connections to a footing supported on soil and loaded by a nuclear-blast-type dynamic force. Such tests are beyond the scope of this study. Nevertheless, the semiempirical dynamic strength specifications developed below constitute a good working basis for the design of elastic hose flexible connections intended for field installations subject to any type of nuclear blast loading which produces peak accelerations up to 200 g. The static flexibility specifications developed below are felt to be valid for any elastic hose installed in accordance with the basic developmental assumptions.

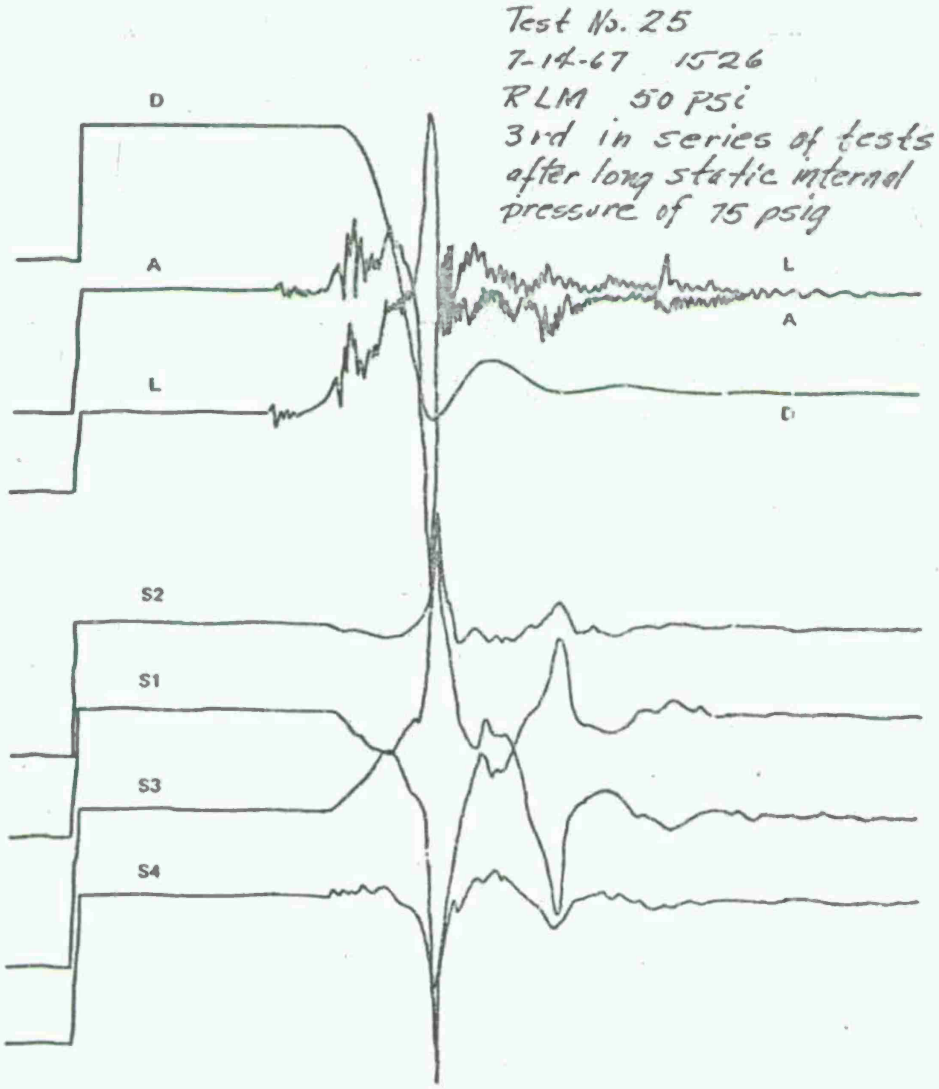


Figure 16. Sample dynamic test data oscillogram.

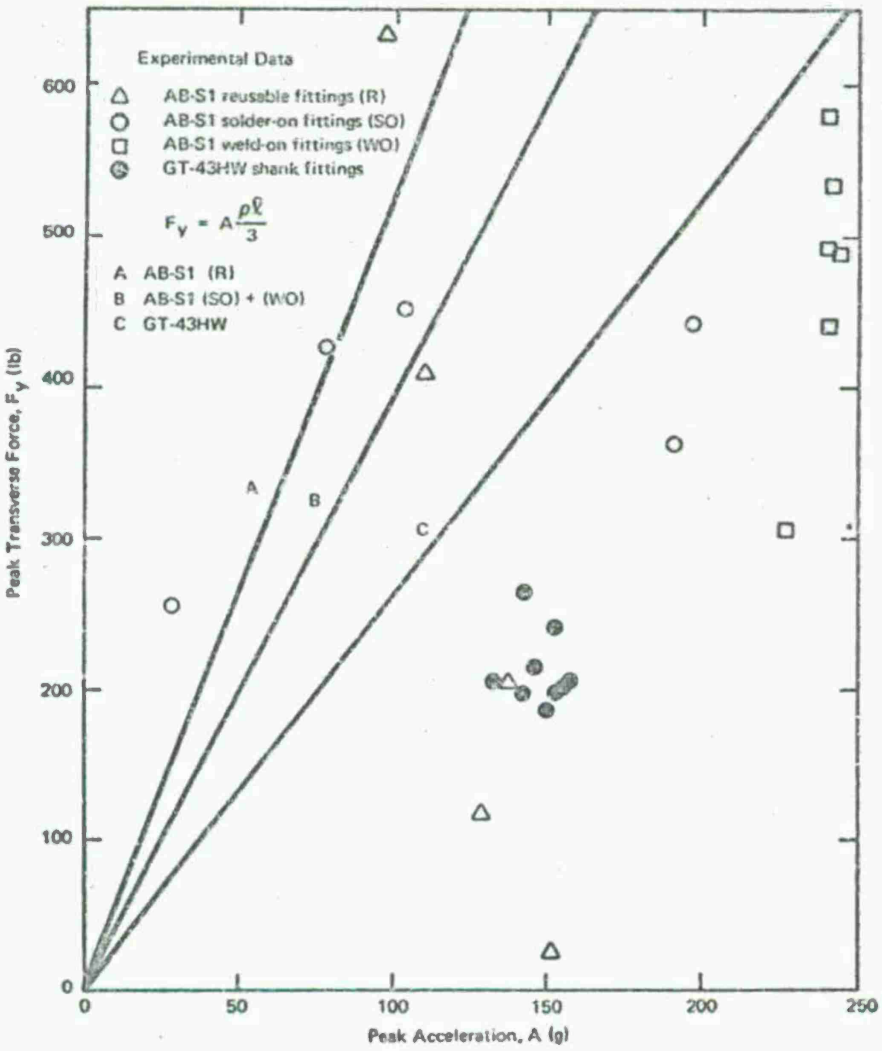


Figure 17. Peak dynamic shearing force.

Effect of Geometry on Inertial Loading

The axial inertial fitting force, F_x, has exhibited a good correlation with the span-to-length ratio of the hose. As this ratio approaches 1, the angle of force resultant, ϕ, approaches zero, causing both F_x and F to increase indefinitely. To circumvent such a dangerous situation in field installations, the hose should be installed so as to prevent ϕ from getting close to zero under any anticipated movement. The minimum allowable angle was arbitrarily chosen as

$$\phi > 30 \text{ degrees} \tag{8}$$

This is equivalent to restricting the maximum horizontal force to

$$F_x < \frac{F_y}{\tan\phi} = 1.732\, F_y$$

and equivalently restricting the maximum resultant tensile force to

$$F_{max} = 2\, F_y \tag{9}$$

The resultant force angle at the fitting, ϕ, may be restricted to values greater than 30 degrees by installing the hose so that the sum of the span and the maximum extensional deflection (equal to δ) is less than or equal to a maximum allowable span, which is defined by

$$\ell' = s + \delta \tag{10}$$

To calculate ℓ', the idealized hose was further assumed to take on a parabolic shape. Since the idealized hose cannot sustain moments, the hose angle and the resultant force angle at the fitting are identical. The length of the parabola, ℓ, was then related to the slope at any point, ϕ', by

$$\ell = \int d\ell = 2 \int_0^{\ell'/2} \sqrt{1 + \tan^2\phi'}\, dx$$

Integrating

$$\ell = \frac{\ell'}{2}\left[\sqrt{\tan^2\phi' + 1} + \frac{\ln\left(\tan\phi' + \sqrt{\tan^2\phi' + 1}\right)}{\tan\phi'}\right] \tag{11}$$

Substituting $\phi' = \phi = 30$ degrees gives

$$\ell = 1.05\,\ell'$$

or

$$\ell' = 0.95\,\ell \tag{12}$$

When the right-hand members of Equations 10 and 12 are equated the relationship between free length and installed span becomes

$$s = 0.95\,\ell - \delta \tag{13}$$

This relationship effectively limits the maximum tensile force according to Equation 9.

Flexibility Criteria

To enable designers to utilize the elastic flexibility design method of Appendix B, a set of data with $r = 1$ inch, $d_i = 0$, and $d_o = 0$ was processed by a version of the elastic computer program to give an output which includes an account of Equation 13, is normalized on the basis of r, and takes no account of fitting diameter or hose outside diameter in computing the basic enclosure height, h'. This output is converted to any real hose by multiplying by r and adding the effects of d_i, d_o, and Equation 13. This is summarized in the following transformation:

$$\left.\begin{aligned} \delta &= (\delta/r)\,r \\ \ell &= (\ell/r)\,r \\ s &= 0.95\,\ell - \delta \\ h &= (h'/r)\,r + [(d_i + d_o)/2] \end{aligned}\right\} \tag{14}$$

The normalized parameters δ/r, ℓ/r, and h'/r appear in Table 5.

Dynamic Strength Criteria

The required dynamic strength of a hose of a given weight and length installed in accordance with the static elastic flexibility design specifications may be determined from the expected field acceleration. When Equations 2,

4, 6, and 9 are combined, the dynamic burst pressure required with a factor of safety of 1.0 may be calculated as

$$p_b = p_i + \frac{32}{\pi d_i^2}\left(\frac{\rho \ell}{3}\right)A \qquad (15)$$

A safety factor somewhat greater than 1.0 should be applied as determined by engineering judgment.

TABLE 5. DESIGN DIMENSIONS NORMALIZED ON THE MINIMUM ALLOWABLE BEND RADIUS --FLEXIBLE UTILITY CONNECTION ELASTIC HOSE LENGTH AND ENCLOSURE HEIGHT NEEDED FOR A SPECIFIED DEFLECTION CAPABILITY

I.D. = 0.00 IN., O.D. = 0.00 IN.,
FTG. D. = 0.00 IN., BEND RAD. = 1.0 IN.

DEFLECTION δ/r	LENGTH ℓ/r	ENCLOSURE HEIGHT h'/r
0.000	0.000	0.000
.006	3.239	.488
.023	3.565	.612
.045	3.913	.756
.072	4.285	.925
.106	4.685	1.122
.148	5.118	1.353
.200	5.588	1.621
.263	6.103	1.934
.340	6.671	2.301
.433	7.299	2.732
.547	8.000	3.239
.685	8.788	3.838
.854	9.681	4.550
1.062	10.702	5.401
1.317	11.877	6.424
1.635	13.247	7.666
2.030	14.859	9.183
2.520	16.781	11.059
3.164	19.100	13.403
3.984	21.948	16.376
5.056	25.500	20.203

The burst pressure required under the dynamic strength design method is a dynamic pressure in that dynamic hose stresses are applied for a short time only (usually not more than 1 second). The manufacturer's rated burst pressure is generally somewhat lower than a dynamic burst pressure because it is static and may include the effects of hose distress due to creep. The discrepancy may be especially high for hoses made of rubber or other noncrystalline materials. For this reason, a design based on the manufacturer's ratings may be overly conservative. Increased economy in design may be realized by pressure-testing hoses being considered for use for dynamically flexible utility connections in such a way that the pressure is maintained for a short duration, perhaps about a second. A system of electrically timed solenoid valves, together with a pressure reservoir, could accomplish such testing at small expense.

It should be mentioned here that the type of reusable fittings attached to the bronze hose (shown in Figure 15) are particularly susceptible to the mechanism of failure observed in the experiment—that is, the oblique face of the conical compression flange is oriented roughly parallel (45 degrees) to the direction of tensile force F. Thus, the fitting-hose juncture is maintained by friction alone, with no angular restrictions such as are imposed when the hose is stressed under pressure at an angle $\phi = 0$. Such a fitting might be expected to fail at a lower load than that predicted from the burst pressure, and should therefore be designed with a higher factor of safety.

Example of Design Problem

The results of this study as embodied in Equations 14 and 15, Table 5, and Figure 18 have been applied to a typical hose as an example. The deflection mechanism as specified by Equation 14 and Appendix B is shown in Figure 18. The following are available design data:

p_i = 75 psi (water)	δ = 2.0 inch	d_f = 3.0 inch
A = 100 g	d_i = 2.0 inch	d_o = 2.6 inch

Various strengths of hose with r = 6.0 inches and ρ = 1.60 lb/ft are available.

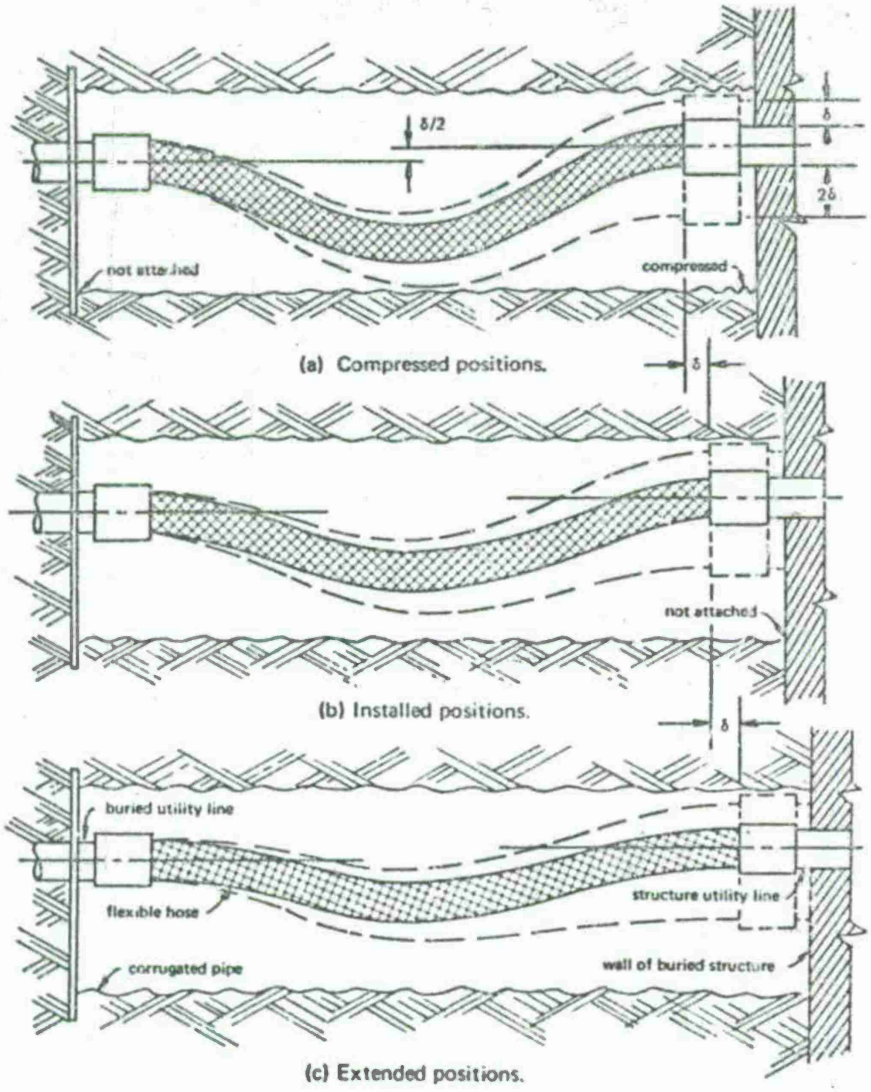


Figure 18. Recommended assumptions of movements for design of flexible utility connections.

Flexibility design is begun by normalizing the displacement parameter on the basis of the minimum bending radius:

$$\frac{\delta}{r} = \frac{2}{6} = 0.33$$

From Table 5, $\ell/r = 6.62$ and $h'/r = 2.27$. Substituting into Equation 14

$$\ell = 6.62(6.0) = 39.7 \text{ inches}$$

$$s = 0.95(39.7) - 2.0 = 35.7 \text{ inches}$$

$$h = 2.27(6.0) + 1/2\ (3.0 + 2.6) = 16.4 \text{ inches}$$

Dynamic strength design is based on the hose weight. The total weight per unit length of hose, ρ, is equal to the dry weight plus the weight of contained fluid. The weight of contained water is

$$\rho_w = 62.4 \frac{\text{lb}}{\text{ft}^3} \left[\frac{\pi (1^2)}{144} \text{ ft}^2 \right] = 1.36 \text{ lb/ft}$$

The total weight per unit length is

$$\rho = (1.36 + 1.60) \text{ lb/ft} = 2.96 \text{ lb/ft} = 0.247 \text{ lb/in.}$$

Substituting into Equation 15

$$p_b = 75 + \frac{32}{\pi (2.0)^2} \left[\frac{0.247(39.7)}{3} \right] 100 = 908 \text{ psi}$$

RELATED WORK

Prototype flexible utility connections were included in the Operation PRAIRIE FLAT high-explosive field test in the summer of 1968 to corroborate the semiempirical criteria developed in this study and to evaluate connection behavior in the field in order to assess what modifications in design criteria, if any, are appropriate. Specimens for the field test were chosen based on results of the present study. Findings of the field test will be reported after detailed data reduction and analysis have been completed.

CONCLUSIONS

1. The assumption of elastic hose behavior was found to be more appropriate than the assumption of locking hose behavior. Flexible metal hose designed by using the minimum allowable bend radius and the assumption of elastic hose behavior should serve satisfactorily under static deflections (Figure 18), as also should smooth-walled rubber hose designed in the same way. The required free length of hose, the hose span, and the enclosure height can be determined by using the flexibility criteria of Equation 14 and Table 5.

2. The dynamic strength of hose must be adequate to withstand inertial forces arising from rapid deflection. A semiempirical relationship between required hose strength and acceleration magnitude was developed to incorporate the effects of hose weight and length. The resulting required hose strength in terms of dynamic burst pressure may be computed from Equation 15.

3. The flexibility and dynamic strength criteria developed in this study are suitable for incorporation in a standard design manual, and are felt to be valid for nuclear blast loading that produces peak accelerations within the range achieved during the reported experiment (up to 200 g).

RECOMMENDATIONS

1. Work should be undertaken to update and augment the existing manual NAVDOCKS P-81, "Personnel Shelters and Protective Construction," dated September 1961, by adding an appendix on flexible connections of all types. Results of this study and of the field tests mentioned above should be included as well as pertinent information on air ducts and other types of connections.

2. A summary should be compiled of means to predict the magnitude of "specified deflection capability" (equal to the relative displacement between a buried structure and the surrounding soil) for various structural configurations, soils, and loadings.

Appendix A

DIGITAL COMPUTER PROGRAM: LOCKING HOSE DESIGN FOR A FLEXIBLE UTILITY CONNECTION

The required span, s, and protective enclosure height, h, shown in Figure 2, are computed as functions of the specified connection deflection capability, δ. These computations are based on the assumption that the hose exhibits locking behavior. Such a hose bends under an applied moment, but upon reaching the curvature defined by the manufacturer's specified minimum allowable bend radius, r, it locks at that curvature and will bend no farther until a much larger applied moment causes some kind of failure. The moment-curvature diagram for such a hose is shown in Figure A-1. In compression, such a hose buckles into a shape like that shown in Figure A-2—a series of circular arcs connected end-to-end.

The buckled shape is assumed to span a distance 2δ shorter than the straight extended shape. The four parameters δ, s, h, and r are related according to the above assumptions by

$$\sin\left(\frac{s+\delta}{4r}\right) = \frac{s-\delta}{4r} \qquad \text{(A-1)}$$

and the larger of

$$h = 2r\left[1 - \cos\left(\frac{s+\delta}{4r}\right)\right] + 2\delta + \frac{d_i + d_o}{2} \qquad \text{(A-2)}$$

or

$$h = 3\delta + d_i \qquad \text{(A-3)}$$

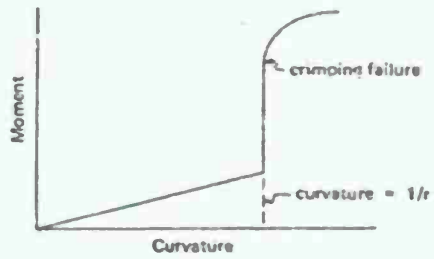


Figure A-1. Moment-curvature diagram for locking hose.

(Equation A-3 yields a larger value of h than Equation A-2 for large values of δ/r; however, Equation A-2 is applicable to all values tabulated in this report.)

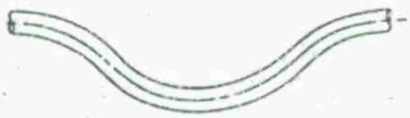


Figure A-2. Buckled shape of locking hose.

The computer program written in FORTRAN II to compute and tabulate design dimensions on the above basis appears in Figure A-3. Also, at the bottom of this figure are listed the numbers on the input data cards which resulted in the output shown in Tables A-1 through A-6. The numbers on the data cards are, respectively, the hose's inside and outside diameters, the largest fitting diameter, and the minimum bend radius. Output consists of tabulated values of specified deflection capability, δ, installed span, s, and enclosure height, h. The free length of a hose is equal to $\delta + s$.

```
C       FLEXIBLE UTILITY CONNECTION **LOCKING** HOSE DESIGN
      8 READ 1,DI,DE,DF,R
        PUNCH 11
     11 FORMAT(53HFLEXIBLE UTILITY CONNECTION **LOCKING** HOSE SPAN AND)
        PUNCH 12
     12 FORMAT(49HENCLOSURE HEIGHT NEEDED FOR A SPECIFIED DEFLECTIO12HN CA
       1PABILITY)
        PUNCH 13,DI,DE,DF,R
     13 FORMAT(6HI.D. ,F5.2,12H IN.. O.D. ,F5.2,15H IN.. FTG. D. ,F5.2,17H
       1 IN.. BEND RAD. ,F5.1,4H IN./)
        PUNCH 14
     14 FORMAT(36HDEFLECTION    SPAN    ENCLOSURE HEIGHT)
        PUNCH 15
     15 FORMAT(3X6HIINI6X6HIINI9X6HIINI/)
        DO 2 I=1,48
        D=I-1
        P=D*.1
        D=P/R/4.
        A=D.
        X=.1
      3 S=SINF(A+D)
        IF(S-A+D)4,4,5
      5 A=A+X
        GO TO 3
      4 IF(S-A+D-.0000136)6,6,7
      6 A=A-.9*X
        X=.1*X
        GO TO 3
      7 Y=2.*R*(1.-COSF(A+D))+2.*P+DF/2.+DF/2.
        A=A*R*4.
        Z=3.*P+DF
        IF(Z-Y)2,2,10
     10 Y=Z
      2 PUNCH 1,P,A,Y
      1 FORMAT(4F10.2)
        IF(SENSE SWITCH 2)8,9
      9 CALL EXIT
        END
.75         1.32        2.156       7.
1.          1.575       2.625       6.
1.5         2.23        3.562       10.
2.          2.855       4.188       11.
2.          2.5         3.12        4.25
2.          2.58        3.22        5.8
```

Figure A-3. Locking computer program.

TABLE A-1. DESIGN DIMENSIONS--BRONZE LIMITED BENDING HOSE--3/4 IN.

FLEXIBLE UTILITY CONNECTION "LOCKING" HOSE SPAN AND
ENCLOSURE HEIGHT NEEDED FOR A SPECIFIED DEFLECTION CAPABILITY
I.D. = .75 IN., O.D. = 1.32 IN., FTG. D. = 2.15 IN., BEND RAD. = 7.0 IN.

DEFLECTION (IN)	SPAN (IN)	ENCLOSURE HEIGHT (IN)
0.00	0.00	2.15
.10	9.71	2.79
.20	12.18	3.48
.30	13.89	4.09
.40	15.23	4.66
.50	16.35	5.19
.60	17.32	5.71
.70	18.18	6.20
.80	18.96	6.68
.90	19.66	7.14
1.00	20.31	7.60
1.10	20.91	8.04
1.20	21.48	8.46
1.30	22.00	8.91
1.40	22.50	9.33
1.50	22.97	9.75
1.60	23.42	10.16
1.70	23.84	10.57
1.80	24.25	10.97
1.90	24.64	11.37
2.00	25.01	11.76
2.10	25.37	12.15
2.20	25.71	12.53
2.30	26.04	12.92
2.40	26.36	13.29
2.50	26.67	13.67
2.60	26.97	14.04
2.70	27.26	14.41
2.80	27.54	14.78
2.90	27.81	15.15
3.00	28.07	15.51
3.10	28.33	15.87
3.20	28.58	16.23
3.30	28.82	16.58
3.40	29.06	16.94
3.50	29.29	17.29
3.60	29.51	17.64
3.70	29.73	17.98
3.80	29.95	18.33
3.90	30.16	18.68
4.00	30.36	19.02
4.10	30.56	19.35
4.20	30.75	19.70
4.30	30.94	20.04
4.40	31.13	20.37
4.50	31.31	20.71

TABLE A-2. DESIGN DIMENSIONS--BRONZE LIMITED BENDING HOSE--1 IN.

FLEXIBLE UTILITY CONNECTION "LOCKING" HOSE SPAN AND
ENCLOSURE HEIGHT NEEDED FOR A SPECIFIED DEFLECTION CAPABILITY
I.D. = 1.00 IN., O.D. = 1.57 IN., FTG. D. = 2.62 IN., BEND RAD. = 8.0 IN.

DEFLECTION (IN)	SPAN (IN)	ENCLOSURE HEIGHT (IN)
0.00	0.00	2.62
.10	10.63	3.19
.20	13.33	3.91
.30	15.20	4.54
.40	16.68	5.12
.50	17.91	5.67
.60	18.98	6.20
.70	19.93	6.71
.80	20.78	7.20
.90	21.56	7.68
1.00	22.28	8.15
1.10	22.94	8.60
1.20	23.56	9.05
1.30	24.15	9.49
1.40	24.70	9.93
1.50	25.22	10.36
1.60	25.72	10.78
1.70	26.19	11.20
1.80	26.64	11.61
1.90	27.07	12.02
2.00	27.48	12.42
2.10	27.88	12.82
2.20	28.27	13.22
2.30	28.64	13.61
2.40	28.99	14.00
2.50	29.34	14.38
2.60	29.67	14.77
2.70	29.99	15.15
2.80	30.31	15.52
2.90	30.61	15.90
3.00	30.91	16.27
3.10	31.19	16.64
3.20	31.47	17.01
3.30	31.75	17.37
3.40	32.01	17.73
3.50	32.27	18.09
3.60	32.52	18.45
3.70	32.77	18.81
3.80	33.01	19.17
3.90	33.24	19.52
4.00	33.47	19.87
4.10	33.70	20.22
4.20	33.92	20.57
4.30	34.13	20.92
4.40	34.35	21.26
4.50	34.55	21.60

TABLE A-3. DESIGN DIMENSIONS--BRONZE LIMITED BENDING HOSE--1 1/2 IN.

FLEXIBLE UTILITY CONNECTION ''LOCKING'' HOSE SPAN AND
ENCLOSURE HEIGHT NEEDED FOR A SPECIFIED DEFLECTION CAPABILITY
I.D. = 1.50 IN., O.D. = 2.23 IN., FTG. D. = 3.56 IN., BEND RAD. = 10.0 IN.

DEFLECTION (IN)	SPAN (IN)	ENCLOSURE HEIGHT (IN)
0.00	0.00	3.56
.10	12.35	4.05
.20	15.50	4.81
.30	17.68	5.48
.40	19.41	6.09
.50	20.85	6.67
.60	22.10	7.23
.70	23.22	7.76
.80	24.22	8.28
.90	25.13	8.78
1.00	25.98	9.27
1.10	26.76	9.75
1.20	27.50	10.22
1.30	28.19	10.69
1.40	28.84	11.14
1.50	29.46	11.59
1.60	30.04	12.03
1.70	30.60	12.47
1.80	31.14	12.90
1.90	31.65	13.33
2.00	32.15	13.75
2.10	32.62	14.17
2.20	33.08	14.58
2.30	33.52	14.99
2.40	33.94	15.40
2.50	34.36	15.80
2.60	34.76	16.20
2.70	35.14	16.60
2.80	35.52	16.99
2.90	35.88	17.38
3.00	36.24	17.77
3.10	36.59	18.16
3.20	36.92	18.54
3.30	37.25	18.92
3.40	37.57	19.30
3.50	37.88	19.68
3.60	38.19	20.05
3.70	38.49	20.42
3.80	38.78	20.79
3.90	39.06	21.16
4.00	39.34	21.53
4.10	39.62	21.89
4.20	39.88	22.26
4.30	40.15	22.62
4.40	40.40	22.98
4.50	40.65	23.34

TABLE A-4. DESIGN DIMENSIONS--BRONZE LIMITED BENDING HOSE--2 IN.

FLEXIBLE UTILITY CONNECTION "LOCKING" HOSE SPAN AND
ENCLOSURE HEIGHT NEEDED FOR A SPECIFIED DEFLECTION CAPABILITY
I.D. = 2.00 IN., O.D. = 2.85 IN., FTG. D. = 4.18 IN., BEND RAD. = 11.0 IN.

DEFLECTION (IN)	SPAN (IN)	ENCLOSURE HEIGHT (IN)
0.00	0.00	4.18
.10	13.16	4.71
.20	16.53	5.49
.30	18.86	6.17
.40	20.70	6.80
.50	22.25	7.39
.60	23.58	7.96
.70	24.77	8.50
.80	25.85	9.03
.90	26.83	9.54
1.00	27.73	10.04
1.10	28.57	10.53
1.20	29.36	11.02
1.30	30.10	11.49
1.40	30.80	11.95
1.50	31.47	12.41
1.60	32.10	12.86
1.70	32.70	13.31
1.80	33.27	13.75
1.90	33.83	14.18
2.00	34.36	14.61
2.10	34.87	15.04
2.20	35.36	15.46
2.30	35.84	15.88
2.40	36.30	16.29
2.50	36.74	16.70
2.60	37.17	17.11
2.70	37.59	17.51
2.80	37.99	17.92
2.90	38.39	18.31
3.00	38.77	18.71
3.10	39.15	19.10
3.20	39.51	19.49
3.30	39.86	19.88
3.40	40.21	20.27
3.50	40.55	20.65
3.60	40.88	21.03
3.70	41.20	21.41
3.80	41.52	21.79
3.90	41.83	22.17
4.00	42.13	22.54
4.10	42.42	22.91
4.20	42.71	23.28
4.30	43.00	23.65
4.40	43.28	24.02
4.50	43.55	24.38

TABLE A-5. DESIGN DIMENSIONS--CORRUGATED RUBBER LIMITED-BENDING HOSE--2 IN.

FLEXIBLE UTILITY CONNECTION "LOCKING" HOSE SPAN AND
ENCLOSURE HEIGHT NEEDED FOR A SPECIFIED DEFLECTION CAPABILITY
I.D. = 2.00 IN., O.D. = 2.50 IN., FTG. D. = 3.12 IN., BEND RAD. = 4.2 IN.

DEFLECTION (IN)	SPAN (IN)	ENCLOSURE HEIGHT (IN)
0.00	0.00	3.12
.10	6.84	3.72
.20	8.69	4.34
.30	9.89	4.89
.40	10.83	5.39
.50	11.61	5.87
.60	12.28	6.33
.70	12.88	6.78
.80	13.41	7.21
.90	13.90	7.63
1.00	14.34	8.04
1.10	14.75	8.44
1.20	15.13	8.84
1.30	15.49	9.22
1.40	15.82	9.61
1.50	16.14	9.99
1.60	16.43	10.36
1.70	16.72	10.73
1.80	16.99	11.09
1.90	17.24	11.45
2.00	17.49	11.81
2.10	17.72	12.16
2.20	17.95	12.51
2.30	18.16	12.86
2.40	18.37	13.20
2.50	18.57	13.54
2.60	18.77	13.88
2.70	18.95	14.22
2.80	19.13	14.55
2.90	19.30	14.88
3.00	19.47	15.21
3.10	19.64	15.54
3.20	19.79	15.87
3.30	19.95	16.19
3.40	20.09	16.51
3.50	20.24	16.83
3.60	20.38	17.15
3.70	20.51	17.47
3.80	20.65	17.78
3.90	20.77	18.10
4.00	20.90	18.41
4.10	21.02	18.72
4.20	21.14	19.03
4.30	21.26	19.33
4.40	21.37	19.64
4.50	21.48	19.95

TABLE A-6. DESIGN DIMENSIONS--SMOOTH RUBBER LIMITED-BENDING HOSE--2 IN.

FLEXIBLE UTILITY CONNECTION "LOCKING" HOSE SPAN AND
ENCLOSURE HEIGHT NEEDED FOR A SPECIFIED DEFLECTION CAPABILITY
I.D. = 2.00 IN., O.D. = 2.56 IN., FTG. D. = 3.22 IN., BEND RAD. = 5.8 IN.

DEFLECTION (IN)	SPAN (IN)	ENCLOSURE HEIGHT (IN)
0.00	0.00	3.22
.10	8.56	3.89
.20	10.73	4.56
.30	12.22	5.15
.40	13.40	5.69
.50	14.38	6.20
.60	15.23	6.69
.70	15.97	7.17
.80	16.65	7.63
.90	17.26	8.07
1.00	17.82	8.51
1.10	18.35	8.94
1.20	18.83	9.36
1.30	19.29	9.77
1.40	19.72	10.18
1.50	20.12	10.58
1.60	20.51	10.98
1.70	20.88	11.37
1.80	21.22	11.76
1.90	21.56	12.14
2.00	21.88	12.52
2.10	22.18	12.89
2.20	22.48	13.26
2.30	22.76	13.63
2.40	23.03	14.00
2.50	23.30	14.36
2.60	23.55	14.72
2.70	23.80	15.08
2.80	24.04	15.43
2.90	24.27	15.78
3.00	24.49	16.13
3.10	24.71	16.48
3.20	24.92	16.82
3.30	25.13	17.17
3.40	25.32	17.51
3.50	25.52	17.85
3.60	25.71	18.19
3.70	25.89	18.52
3.80	26.07	18.86
3.90	26.25	19.19
4.00	26.42	19.52
4.10	26.59	19.85
4.20	26.75	20.18
4.30	26.91	20.50
4.40	27.06	20.83
4.50	27.22	21.15

Appendix B

DIGITAL COMPUTER PROGRAM: ELASTIC HOSE DESIGN FOR A FLEXIBLE UTILITY CONNECTION

The required free length, ℓ, and protective enclosure height, h, shown in Figure 2, are computed as functions of the specified connection deflection capability, δ, and the manufacturer's specified minimum allowable bend radius, r. These computations are based on the assumption that the hose exhibits elastic behavior in buckling, assuming an approximately sinusoidal shape. The greatest curvature in the hose—at the apex of the sine wave—is limited by r. Any hose with an elastic (straight-line) moment-curvature diagram is expected to buckle into this approximately sinusoidal shape and thus to be reasonably well represented by this assumption.

The buckled shape is assumed to span a distance 2δ shorter than the straight extended shape. The four parameters, δ, ℓ, h, and r are related according to the above assumptions by

$$\ell = \int_0^{2\pi/b} \sqrt{1 + \frac{1}{b^2 r^2} \cos^2 bx}\, dx \qquad \text{(B-1)}$$

$$\ell_o = \frac{2\pi}{b} \qquad \text{(B-2)}$$

$$\delta = \frac{\ell - \ell_o}{2} \qquad \text{(B-3)}$$

and the larger of

$$h = \frac{2}{r b^2} + 2\delta + \frac{d_i + d_o}{2} \qquad \text{(B-4)}$$

or

$$h = 3\delta + d_i \qquad \text{(B-5)}$$

where ℓ = extended length

ℓ_o = span of buckled hose

d_f = largest fitting diameter

d_o = outside hose diameter

b = additional parameter used for convenience

(Equation B-5 yields a larger value of h than Equation B-4 for large values of δ/r.)

A computer program was written in FORTRAN II to compute values of design dimensions on the above basis. The integral in Equation B-1 was reduced to elliptic form for computations. Values from a table of elliptic integrals were read into the computer program as data. The computer program appears in Figure B-1, followed first by the elliptic integral data and then by the input data which resulted in the output shown in Tables B-1 through B-6. The numbers on the data card are, respectively, the hose's inside and outside diameters, the largest fitting diameter, and the minimum bend radius. Output consists of tabulated values of specified deflection capability, δ, free length, ℓ, and enclosure height, h. The installed span, s, of the hose may be computed as $\ell - \delta$.

The original computer program was revised to account for a reduced maximum allowable span defined by

$$\ell' = s + \delta = 0.95\,\ell$$

A run was made with $r = 1.0$ and $d_i = d_f = d_o = 0$ to give output data normalized on the basis of r and independent of fitting diameter and hose diameter. The revised program and input data appear in Figure B-2. Resulting computer output is given in Table 5.

```
C       FLEXIBLE UTILITY CONNECTION ELASTIC HOSE DESIGN
        DIMENSION E(46)
        READ 1,E
      1 FORMAT(8F10.3)
      8 READ 1,DI,DE,DF,R
        PUNCH 11
     11 FORMAT(51HFLEXIBLE UTILITY CONNECTION ELASTIC HOSE LENTGH AND)
        PUNCH 12
     12 FORMAT(49HENCLOSURE HEIGHT NEEDED FOR A SPECIFIED DEFLECT1012HN CA
       1PABILITY)
        PUNCH 13,DI,DE,DF,R
     13 FORMAT(6HI.D. =F5.2,12H IN., O.D. =F5.2,15H IN., FIG. D. =F5.2,17H
       1 IN., BEND RAD. =F5.1,4H IN./)
        PUNCH 14
     14 FORMAT(26HDEFLECTION  LENGTH  ENCLOSURE HEIGHT)
        PUNCH 15
     15 FORMAT(13X4H(IN)16X4H(IN)19X4H(IN)/)
        DO 2 I=1,45
        X=I-1
        C=SINF(X*.034906586)
        B=(SQRTF(1.-C*C))/(C*R)
        RB=R*B*B
        A=E(I)*SQRTF(1.+R*RB)*4./RB
        P=A*.5-3.1415927/B
        Y=DF*.5+DE*.5+P*2.+2./RB
        Z=3.*P+DF
        IF(Z-Y)2,2,10
     10 Y=Z
      2 PUNCH 1,P,A,Y
        PUNCH 7
      7 FORMAT(///)
        IF(SENSE SWITCH 3)5,6
      5 PAUSE
      6 IF(SENSE SWITCH 2)8,9
      9 CALL EXIT
        END
1.5709    1.5703    1.5689    1.5665    1.5632    1.5589    1.5537    1.5476
1.5405    1.5326    1.5238    1.5141    1.5037    1.4924    1.4803    1.4675
1.4539    1.4397    1.4248    1.4092    1.3931    1.3765    1.3594    1.3418
1.3238    1.3055    1.2870    1.2681    1.2492    1.2301    1.2111    1.1920
1.1732    1.1545    1.1362    1.1184    1.1011    1.0844    1.0686    1.0538
1.0401    1.0278    1.0172    1.0086    1.0026    1.0000
.75       1.32      2.156     7.
1.        1.575     2.625     8.
1.5       2.23      3.562     10.
2.        2.855     4.188     11.
2.        2.5       3.12      4.25
2.        2.58      3.22      5.8
```

Figure B-1. Elastic computer program.

```
C       FLEXIBLE UTILITY CONNECTION ELASTIC HOSE DESIGN
        DIMENSION E(46)
        READ 1,E
      1 FORMAT(8F10.3)
      8 READ 1,DI,DE,DF,R
        PUNCH 11
     11 FORMAT(51HFLEXIBLE UTILITY CONNECTION ELASTIC HOSE LENTGH AND)
        PUNCH 12
     12 FORMAT(49HENCLOSURE HEIGHT NEEDED FOR A SPECIFIED DEFLECTIO12HN CA
       1PABILITY)
        PUNCH 13,DI,DE,DF,R
     13 FORMAT(6HI.D. =F5.2,12H IN., O.D. =F5.2,15H IN., FTG. D. =F5.2,17H
       1 IN., BEND RAD. =F5.1,4H IN./)
        PUNCH 14
     14 FORMAT(36HDEFLECTION  LENGTH  ENCLOSURE HEIGHT)
        PUNCH 15
     15 FORMAT(3X4H(IN)6X4H(IN)9X4H(IN)/)
        DO 2 I=1,45
        X=I-1
        C=SINF(X*.0349065886)
        B=(SORTF(1.-C*C))/(C*R)
        RB=R*B*B
        A=E(I)*SORTF(1.+R*RB)*4./RB
        P=A*.475-3.1415927/B
        Y=DF*.5+CE*.5+P*2.+2./RB
        Z=3.*P+DF
        IF(Z-Y)2,2,10
     10 Y=Z
      2 PUNCH 1,P,A,Y
        PUNCH 7
      7 FORMAT(//)
        IF(SENSE SWITCH 3)5,6
      5 PAUSE
      6 IF(SENSE SWITCH 2)8,9
      9 CALL EXIT
        END
1.5708    1.5703    1.5689    1.5665    1.5632    1.5589    1.5537    1.5476
1.5405    1.5326    1.5238    1.5141    1.5037    1.4926    1.4803    1.4675
1.4539    1.4397    1.4248    1.4092    1.3931    1.3765    1.3594    1.3418
1.3238    1.3055    1.2870    1.2681    1.2492    1.2301    1.2111    1.1920
1.1732    1.1545    1.1362    1.1184    1.1011    1.0844    1.0686    1.0538
1.0401    1.0278    1.0172    1.0086    1.0026    1.0000
                                1.
```

Figure B-2. Revised elastic computer program.

TABLE B-1. DESIGN DIMENSIONS--BRONZE ELASTIC HOSE--3/4 IN.

FLEXIBLE UTILITY CONNECTION ELASTIC HOSE LENGTH AND
ENCLOSURE HEIGHT NEEDED FOR A SPECIFIED DEFLECTION CAPABILITY
I.D. = .75 IN., O.D. = 1.32 IN., FTG. D. = 2.15 IN., BEND RAD. = 7.0 IN.

DEFLECTION (IN)	LENGTH (IN)	ENCLOSURE HEIGHT (IN)
0.00	0.00	2.15
0.00	1.53	2.15
0.00	3.07	2.16
0.00	4.63	2.17
.01	6.21	2.20
.02	7.81	2.24
.05	9.45	2.47
.08	11.13	2.77
.12	12.86	3.14
.18	14.66	3.58
.25	16.52	4.11
.35	18.47	4.72
.46	20.51	5.45
.61	22.67	6.29
.78	24.96	7.27
1.00	27.39	8.40
1.25	29.99	9.71
1.56	32.79	11.23
1.93	35.82	13.00
2.37	39.12	15.04
2.91	42.72	17.41
3.54	46.69	20.18
4.31	51.09	23.41
5.23	56.00	27.21
6.33	61.52	31.68
7.67	67.77	36.97
9.31	74.91	43.29
11.30	83.14	50.86
13.76	92.73	60.03

TABLE B-2. DESIGN DIMENSIONS--BRONZE ELASTIC HOSE--1 IN.

FLEXIBLE UTILITY CONNECTION ELASTIC HOSE LENGTH AND
ENCLOSURE HEIGHT NEEDED FOR A SPECIFIED DEFLECTION CAPABILITY
I.D. = 1.00 IN., O.D. = 1.57 IN., FTG. D. = 2.62 IN., BEND RAD. = 8.0 IN.

DEFLECTION (IN)	LENGTH (IN)	ENCLOSURE HEIGHT (IN)
0.00	0.00	2.62
0.00	1.75	2.62
0.00	3.51	2.63
0.00	5.29	2.64
.01	7.09	2.67
.03	8.93	2.72
.05	10.80	2.94
.09	12.72	3.28
.14	14.70	3.70
.21	16.75	4.21
.29	18.88	4.81
.40	21.11	5.51
.53	23.45	6.34
.69	25.91	7.30
.89	28.52	8.42
1.14	31.30	9.71
1.43	34.28	11.21
1.78	37.48	12.95
2.21	40.94	14.97
2.71	44.70	17.30
3.32	48.83	20.01
4.05	53.36	23.18
4.92	58.39	26.87
5.97	64.00	31.21
7.24	70.31	36.32
8.77	77.45	42.37
10.64	85.62	49.59
12.91	95.02	58.24

TABLE B-3. DESIGN DIMENSIONS--BRONZE ELASTIC HOSE--. /2 IN.

FLEXIBLE UTILITY CONNECTION ELASTIC HOSE LENGTH AND
ENCLOSURE HEIGHT NEEDED FOR A SPECIFIED DEFLECTION CAPABILITY
I.D. = 1.50 IN., O.D. = 2.23 IN., FTG. D. = 3.56 IN., BEND RAD. = 10.0 IN.

DEFLECTION (IN)	LENGTH (IN)	ENCLOSURE HEIGHT (IN)
0.00	0.00	3.56
0.00	2.19	3.56
0.00	4.39	3.57
0.00	6.62	3.58
.02	8.87	3.62
.04	11.16	3.69
.07	13.50	3.94
.12	15.90	4.38
.18	18.38	4.90
.26	20.94	5.53
.36	23.60	6.28
.50	26.39	7.16
.66	29.31	8.19
.87	32.39	9.40
1.12	35.65	10.79
1.42	39.13	12.42
1.79	42.85	14.29
2.23	46.85	16.46
2.76	51.18	18.98
3.39	55.80	21.90
4.15	61.03	25.29
5.06	66.71	29.24
6.16	72.99	33.86
7.47	80.00	39.28
9.05	87.88	45.67
10.96	96.81	53.23
13.30	107.02	62.26

TABLE B-4. DESIGN DIMENSIONS--BRONZE ELASTIC HOSE--2 IN.

FLEXIBLE UTILITY CONNECTION ELASTIC HOSE LENGTH AND
ENCLOSURE HEIGHT NEEDED FOR A SPECIFIED DEFLECTION CAPABILITY
I.D. = 2.00 IN., O.D. = 2.85 IN., FTG. D. = 4.18 IN., BEND RAD. = 11.0 IN.

DEFLECTION (IN)	LENGTH (IN)	ENCLOSURE HEIGHT (IN)
0.00	0.00	4.18
0.00	2.41	4.18
0.00	4.83	4.19
.01	7.28	4.21
.02	9.76	4.26
.04	12.28	4.32
.08	14.85	4.68
.13	17.49	5.15
.20	20.21	5.73
.29	23.03	6.42
.40	25.96	7.24
.55	29.03	8.21
.73	32.24	9.35
.96	35.63	10.67
1.23	39.22	12.21
1.57	43.04	13.99
1.97	47.13	16.06
2.46	51.53	18.45
3.04	56.30	21.21
3.73	61.47	24.42
4.57	67.14	28.15
5.57	73.38	32.50
6.77	80.29	37.59
8.21	88.00	43.55
9.95	96.67	50.57
12.06	106.49	58.89

TABLE B-5. DESIGN DIMENSIONS--CORRUGATED RUBBER ELASTIC HOSE--2 IN.

FLEXIBLE UTILITY CONNECTION ELASTIC HOSE LENGTH AND
ENCLOSURE HEIGHT NEEDED FOR A SPECIFIED DEFLECTION CAPABILITY
I.D. = 2.00 IN., O.D. = 2.50 IN., FTG. D. = 3.12 IN., BEND RAD. = 4.2 IN.

DEFLECTION (IN)	LENGTH (IN)	ENCLOSURE HEIGHT (IN)
0.00	0.00	3.12
0.00	.93	3.12
0.00	1.86	3.12
0.00	2.81	3.13
0.00	3.77	3.14
.01	4.74	3.17
.03	5.73	3.25
.05	6.76	3.44
.07	7.81	3.66
.11	8.90	3.93
.15	10.03	4.25
.21	11.21	4.62
.28	12.45	5.06
.37	13.76	5.57
.47	15.15	6.16
.60	16.63	6.85
.76	18.21	7.65
.95	19.91	8.57
1.17	21.75	9.64
1.44	23.75	10.38
1.76	25.94	12.32
2.15	28.35	14.00
2.61	31.02	15.97
3.17	34.00	18.27
3.84	37.35	20.98
4.66	41.14	24.20
5.65	45.40	28.04
6.86	50.48	32.63
8.35	56.30	38.20
10.20	63.15	44.99
12.53	71.32	53.37

TABLE B-6. DESIGN DIMENSIONS--SMOOTH RUBBER ELASTIC HOSE--2 IN.

FLEXIBLE UTILITY CONNECTION ELASTIC HOSE LENGTH AND
ENCLOSURE HEIGHT NEEDED FOR A SPECIFIED DEFLECTION CAPABILITY
I.D. = 2.00 IN., O.D. = 2.58 IN., FTG. D. = 3.22 IN., BEND RAD. = 5.0 IN.

DEFLECTION (IN)	LENGTH (IN)	ENCLOSURE HEIGHT (IN)
0.00	0.00	3.22
0.00	1.27	3.22
0.00	2.55	3.22
0.00	3.84	3.23
.01	5.14	3.25
.02	6.47	3.31
.04	7.83	3.51
.06	9.22	3.76
.10	10.66	4.06
.15	12.14	4.43
.21	13.69	4.86
.29	15.30	5.37
.38	17.00	5.97
.50	18.78	6.67
.65	20.68	7.48
.82	22.69	8.42
1.04	24.85	9.51
1.29	27.17	10.77
1.60	29.68	12.23
1.97	32.41	13.92
2.41	35.40	15.89
2.93	38.69	18.18
3.57	42.33	20.86
4.33	46.40	24.00
5.25	50.97	27.71
6.36	56.15	32.09
7.71	62.07	37.33
9.36	68.89	43.60
11.40	76.83	51.20
13.93	86.18	60.47

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LIST OF SYMBOLS

A	Transverse acceleration at moving end fitting (g)
a	Transverse acceleration at point x on the hose (g)
b	Theoretical parameter used for convenience
D_x	Longitudinal component of hose displacement at moving end fitting, positive for extension of hose (L)
D_y	Transverse component of hose displacement at moving end fitting, positive toward concave side of curved hose (L)
d_f	Diameter of largest part of end fitting (L)
d_i	Inside diameter of hose (L)
d_o	Outside diameter of hose (L)
F	Force on hose at moving end fitting (F)
F_a, F_b	Static test reactions on end fixture block as shown in Figure 5 (F)
F_x	Longitudinal component of force on hose at moving end fitting, positive in tension (F)
F_y	Transverse component of force on hose at moving end fitting, positive toward concave side of curved hose (F)
h	Required height (diameter) of protective corrugated metal tube enclosure (L)
h'	Basic enclosure height (excludes effects of hose and fitting diameters) (L)
L	Rapid load machine ram load (F)
ℓ	Free length of hose (L)
ℓ'	Maximum allowable span (L)
ℓ_o	Span of buckled hose (L)
M	Restraining moment on hose at fitting (FL)
p	Amount of hose pressure strength available to resist forces (F/L^2)
p_i	Internal hydrostatic pressure (F/L^2)
p_b	Dynamic bursting pressure (F/L^2)
r	Manufacturer's specified minimum allowable bend radius (L)
s	Installed span of hose between fittings (L)
t	effective thickness of hose wall (L)
w	Weight of hose per unit change in x (F/L)
x	Position coordinate of point on hose, measured from moving end toward fixed end (L)
δ	Displacement parameter—specified deflection capability (L)
δ_E	Displacement parameter computed by assuming elastic hose behavior (L)
δ_L	Displacement parameter computed by assuming locking hose behavior (L)
ρ	Combined weight per unit length of hose and contained fluid (F/L)
ρ_h	Weight per unit length of empty hose (F/L)
ρ_w	Weight per unit length of water in hose (F/L)
σ	Tensile stress in hose wall (F/L^2)
ϕ	Angle between direction of action of hose force F and fitting axis
ϕ'	Slope of hose at any point along its length

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13. ABSTRACT

The existing design of flexible utility connections used in naval installations incorporates a flexible bronze hose hanging freely within a corrugated metal tube so that it can move without being highly stressed at the soil-structure interface. A study was made of this design and of possible modifications to it. Theoretical predictions were formulated for flexibility and dynamic strength; the theories were tested and partially verified experimentally in the laboratory. The flexibility of a hose was related to the manufacturer's specified minimum allowable bend radius. The dynamic strength was expressed in terms of peak acceleration and hose weight and length in a semiempirical relationship suitable for use in design. It is recommended that the results of the present study be incorporated in an appropriate design manual, subject to verification by full-scale field tests, and that a summary be compiled of means to predict the relative displacements between a buried structure and the surrounding soil.

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