Determination of
Fire Hose Friction Loss Characteristics

Final Report

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FOREWORD

The calculation of friction loss in fire hose is a common task for fire fighters responsible for operating fire apparatus pumps. This is required to deliver water at the proper flow rate and pressure to fire fighters controlling the fire hose nozzle. Pressures and flow rates too low will be insufficient for fire control, while pressures and flow rates too high create dangerous conditions with handling the nozzle, burst hose and other hazards.

Baseline friction loss coefficients used by today's fire fighters for calculating fire hose pressure loss were derived using hose design technology from upwards of 50 years ago. A need exists to update these coefficients for use with today's fire hose. Modern fire hose is generally perceived by fire fighting professionals as having less friction loss and different performance characteristics than the hose on which these coefficients were originally based. The focus of this study has been to develop baseline friction loss coefficients for the types of fire hose commonly used by today's fire service, and identify any additional performance characteristics that should be considered for friction loss calculations.

The Research Foundation expresses gratitude to the report authors Joseph L. Scheffey, Eric W. Forssell and Matthew Benfer, with Hughes Associates, Inc. located in Baltimore, Maryland. In addition, the in-kind donations of time and resources that have been provided to conduct this project in support of the research team have been significant. To acknowledge the extensive in-kind support for this project, the individuals and organizations that have had a principal role in this effort are recognized in the following groups: (1) Project Technical Panel; (2) Fire Hose Test Sites; and (3) Fire Hose Manufacturers.

The guidance provided by the Project Technical Panelists for this effort has been significant and beyond what is normally expected of Panel members. Over the course of the project ten Panel conference calls were held to clarify various project details, with multiple individual assignments that were addressed by certain Panel members independently. The Panel members are summarized separately on the following pages. In addition the Foundation recognizes the support provided by Larry Stewart, former Staff Liaison for the NFPA Technical Committee on Fire Hose, and the particularly noteworthy contribution of Panel Member Jim Cottrell for donating and coordinating the shipment of the measurement instrumentation used at each test site.

Three unrelated fire service facilities volunteered to participate in the experimental program and to conduct the actual field tests. This involved considerable effort over multiple days and resulted in an appreciable contribution to this study. Each site utilized multiple staff to conduct the tests, and here we acknowledge the point of contact on behalf of all their respective staff that assisted. The three organizations (in sequence of how the tests were conducted) are: Connecticut Fire Academy, Windsor Locks Connecticut (Mark P. Salafia, Program Manager); Middlesex County Fire Academy, Sayreville New Jersey (Mike Gallagher, Fire Marshal); and Texas Engineering Extension Service, Emergency Services Training Institute, College Station

Texas (Ron Peddy, Associate Division Director of the Emergency Services Training Institute, and Lee R. Hall, Private Sector Training Director).

A key part of this project was identifying, obtaining, shipping and handling of the fire hose to be tested. This was provided by six fire hose manufacturers and represents a major in-kind donation for this study. As with the test site facilities, here we acknowledge their point of contact on behalf of all their respective staff that assisted. The six fire hose manufacturers (indicated alphabetically) were: Angus-UTC (William Drake); All American/Snaptite (Bob Harcourt and Bob Dunn); Key Fire Hose (Toby Matthews); Mercedes (Duane Leonhard and Dave Pritchard); Neidner (Cliff McDaniel); and North American (Mike Aubuchon). Additional support during the project was provided by both Kochek Company and Task Force Tips for special equipment needed to conduct the tests, and they are likewise thanked for their important contribution.

The collective effort required to conduct this study has been particularly noteworthy, and it has allowed the project to address the topic far beyond the available funding resources. As such, the Fire Protection Research Foundation expresses its sincere appreciation to all involved. Special thanks are expressed to the National Fire Protection Association (NFPA) for providing the project funding through the NFPA Annual Code Fund, which was critical for this project to proceed in the first place.

The content, opinions and conclusions contained in this report are solely those of the authors.

Note: This report was issued in April 2012 and revised in October 2013. Changes other than editorial are indicated by a vertical rule beside the paragraph, table or figure in which the change occurred. These rules are included as an aid to the user in identifying changes from the previous edition. Changes have been made due to an error in the calculation of the dimensionless friction factor, ƒ. The calculations of the C factor and the C_D factor were not affected by the error. The revision effected Tables 6, 8, 9, and 10, Figure 9 in the main body of the report and Figures C.1 through C.7 in Appendix C. Equation 5a on page 6 was revised and a note was added below this equation.

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EXECUTIVE SUMMARY

Friction loss characteristics of fire hose have changed as a result of evolving hose manufacturing technology. Published friction loss characteristics may be overly conservative. While conservatism in fire protection is generally good, in this case it may lead to excessively high pump discharge pressures as the operator applies general rules-of-thumb. The resulting high nozzle pressure may make firefighting operations at the nozzle difficult or unsafe. Alternately, low pressures and flow rates based on over-optimistic friction factors will inhibit efficiency.

The overall objective of this research project was to develop friction loss characteristics for hose currently used by the fire service. The resulting updated friction loss data can potentially be used to revise published coefficients in the NFPA Fire Protection Handbook and other reference sources.

The funding for this was sufficient for the development of technical guidance only; the actual contribution of samples, equipment, and hose testing was a voluntary effort. A literature review was conducted to identify the data and physics underlying the current friction loss data. A draft test plan was developed recognizing the limitations which would be encountered in the field.

Concurrent with this effort, types, sizes, construction, and vendors of hose were identified. A list of hose was established, with 6 vendors and 82 different hoses selected for testing. Three interested fire organizations agreed to perform the tests. Hose was sent to each site and each organization conducted about 25 tests. Several sets of identical 1.75-in. diameter hose were evaluated at two locations, to potentially identify variability in test site data collection. A finalized test plan was prepared which included an outline of suggested flow and pressure measurements for each sample. This was distributed to the fire service organizations with a standardized test data sheet. Testing was performed from October, 2010 through September, 2011; data results are presented in this report. It is expected that standards-development committees and other interested parties will review the data, and perhaps perform additional analysis, to support changes in currently published friction loss constants and criteria for listing and approving hose.

A total of 86 tests were performed by three fire service organizations on 82 fire hose samples spanning 1–5 inches in diameter. Recorded hose dimensions, pressure, flow and friction loss data were used to calculate the friction factors. The data were analyzed traditionally-with respect to the nominal diameter of hose. Three friction factors were calculated: C, the factor now used in published data; and, CD and f. The traditional C factor combines hose diameter and roughness into a single constant. The C_D and f factors use the measured diameter to calculate a friction factor closely associated with hose interior roughness, thought to be associated with hose construction.

The data indicate that most C factors calculated for the tested hose fall below the currently published values. The C_D and f factors provide more insight into friction loss characteristics, since the affects of actual inside diameter are considered separately, not within the friction factor. Overall, the friction loss characteristics observed for individual tested hose sections (different manufacturers and their models) can be a factor of the inside diameter, roughness, or both. Inside diameter alone was not a predictor of the magnitude of the friction loss across all samples.

A fairly large degree of variability was observed in the data. A more thorough statistical analysis might be useful for identifying statistically significant trends.

DETERMINATION OF FIRE HOSE FRICTION LOSS CHARACTERISTICS

1.0 BACKGROUND

Friction loss characteristics of fire hose have changed as a result of evolving hose manufacturing technology. Currently published friction loss characteristics may be overly conservative. While conservatism in fire protection is generally good, in this case it may lead to excessively high pump discharge pressures as the operator applies general rules-of-thumb. The resulting high nozzle pressure may make firefighting operations at the nozzle difficult or unsafe. Alternately, low pressures and flow rates based on over-optimistic friction factors will inhibit fire fighting efficiency.

2.0 OBJECTIVES

The overall objective of this research project was to develop friction loss characteristics for hose currently used by the fire service. The resulting updated friction loss data can potentially be used to revise published coefficients in the *NFPA Fire Protection Handbook* and other reference sources. The data may be useful for standard-development technical committees such as the committees responsible for NFPA 1961 [1] and NFPA 1002 [2] associated with fire hose and driver/operators, respectively.

3.0 APPROACH

The effort was guided by a project technical panel of interested parties (see front material). The project was initiated in April of 2010. The funding for the project was sufficient for the development of technical guidance only; the actual contribution of hose samples, test equipment, and testing of hose was a voluntary effort. A literature review was conducted to identify the data and physics underlying the current friction loss data (see the References and Bibliography). With this information in hand, and parameters from precise laboratory experiments, a draft test plan was developed recognizing the limitations which would be encountered in the field. Several iterations of this plan were reviewed, with discussions related to the level of test exactness that could be expected from voluntary organizations.

Concurrent with this effort, types, sizes, construction, and vendors of hose were identified. A list of hose was established, with 6 vendors and 82 different hoses selected for testing. Fire service organizations were solicited for interest. Three organizations expressed an interest in performing the tests and agreed to participate in the project. A project technical panel member agreed to lend test equipment to each fire service organization; this reduced variability of potential different measurement equipment being used. An administrative plan was developed to send hose to each site; each organization conducted on the order of 25 individual hose tests. Several sets of identical 1.75-in. diameter hose were evaluated at two locations, to potentially identify variability in test site data collection. A finalized test plan was prepared (Appendix A) which included an outline of suggested flow and pressure measurements for each sample. Along with a standardized test data sheet (Appendix B), this guidance was distributed to the fire service organizations.

Testing was performed over the time period of October 2010 through September 2011. All of the data was collected and collated, with the results presented in this report. It is expected that standards-development committees and other interested parties will review the data, and perhaps perform additional analysis, to support changes in currently published friction loss constants and criteria for listing and approving hose.

4.0 FIRE HOSE CHARACTERISTICS AND CONSTRUCTION

4.1 General Fire Hose Description

Fire hose generally consists of one or more outer layers of woven fabric with an inner layer of rubber or similar elastomeric material. It is usually manufactured in 50 ft or 100 foot lengths with threaded metal couplings (national standard threads) on each end. Some fire department use non-threaded (Storz) couplings. Most fire hose is designed to be stored flat to minimize the storage space required. Small (1.5 in. diameter or smaller) and large (4 in. diameter and above) hose may be stored on reels.

NFPA 1961 provides the following definitions on pressure in fire hose:

- Burst Test Pressure – a pressure equal to at least three times the service test pressure.
- Operating Pressure – the highest pressure the hose should be used to in regular operation.
- Proof Test Pressure – a pressure equal to at least two times the service test pressure.
- Service Test Pressure – a pressure equal to approximately 110% of the operating pressure.

These parameters were used to establish safe testing procedures and pressure limits for flow tests.

Three uses of fire hose were of particular interest in this project: forestry hose, attack hose, and supply lines.

- Forestry hose is a flexible hose used for fighting fires in grass, brush, and trees where a lightweight hose is necessary in order to maneuver it over steep and rough terrain. It typically is 1.0 or 1.5 inches in diameter, with a standard length of 100 ft. This is the length which was used in this evaluation. Service test pressures for hose are approximately 110% of its operating pressure. Forestry hose has a normal maximum operating pressure of 275 psi.
- Attack hose is a flexible hose used to bring water from the fire pumper to a firefighting nozzle to combat municipal fires. The diameters range from 1.5 in. to 3 in. In these tests, 1.5, 1.75, and 2.5 in. diameter hoses will be evaluated. The standard length is 50 ft, which was used for this evaluation. Nozzle operating pressure is on the order of 50–125 psi. Straight tip nozzles, used in this evaluation, have a normal operating pressure of 50 psi. Attack hose is designed for use at operating pressures up to at least 275 psi.
- Supply lines are used to bring water from a distant hydrant to the fire pumper or to relay water from one pumper to another over a long distance. This hose has a diameter ranging

from 3.0 in. to 5.0 in. In these tests, 4.0 and 5.0 in. diameter hoses were evaluated. The standard length is 100 ft, which was used for this evaluation. It is designed to be used at operating pressures not exceeding 185 psi. Storz couplings are generally used with supply hose.

Because they are not commonly used, 2 in., 3 in., and 6 in. diameter hose were excluded from this series of evaluations. Hard rubber "booster line" type hose (thick rubber hose) was also excluded from consideration. Hard suction hose was not considered.

4.2 Hose Construction and Availability

The three general construction types of fire hose are:

- Single Jacket – a fabric-covered hose with one layer of woven fabric;
- Double Jacket – a fabric-covered hose with two layers of woven fabric; and
- Through-the-weave – this hose is constructed by feeding a single jacket through a rubber extruder, which coats the inside and outside of the jacket, forming an interlocking bond between jacket and liner.

Jacketed hose has an extruded liner. In the extrusion process, hot polymer or rubber is forced through a dye to create a particular cross-section shape. This liner may be rubber or thermoplastic polyurethane (TPU). The rubber category is generic, including: nitrile rubber or nitrile butadiene rubber; ethylene propylene diene monomer (EDPM); and, styrene-butadiene rubber (SBR).

Jackets are almost all synthetic, made either from nylon or synthetic polyester. Older technology hoses used cotton, which is still in use in some situations.

An initial cataloging of manufacturers (vendors) and hose types were made. A total of more than 190 combinations were identified:

<u>Single Jacket</u>

- Eleven (11) total vendor combinations (brands) – 8 vendors;
- Two (2) Jacket Types;
    - Synthetic polyester (10), Cotton/polyester (1);
- Three (3) Liner Types;
    - Polyurethane (6), TPU elastomer (4), EPDM rubber (1); and,
- 4 Diameters:
    - 0.75, 1.0, 1.5 and 1.75 in.

<u>Double Jacket</u>

- Thirty-three (33) total vendor combinations (brands) – 11 vendors;
- Three (3) Jacket Types;
    - Synthetic polyester (23), Nylon (9), High tech polymer (1);

- Six (6) Liner Types;
    - Polyurethane (5), EPDM rubber (14), TPU elastomer (10), unspecified rubber (1), nitrile rubber (1), polyester & thermoplastic (1); and,
- Nine (9) Diameters:
    - 1, 1.5, 1.75, 2, 2.5, 3, 4, 5, and 6 in.

Through-the-weave

- Eleven (11) total vendor combinations (brands) – 8 vendors; and,
- Nine (9) Diameters:
    - 1, 1.5, 1.75, 2, 2.5, 3, 4, 5, and 6 in. (most are larger diameter).

This list of potential hoses was reduced to accommodate the scope of the project as described in Section 6.1.

For evaluation purposes, all hose in this test series was categorized by exterior and interior construction:

Exterior construction – by jacketing

- Single jacket
- Double jacket
- Thru-the-weave (TTW) – not a "jacketed" hose per se, categorize as single jacket TTW

Interior construction, designated as Hose Liner Material and Forming Method in this report – by extrusion or thru-the-weave construction

- Polyurethane extruded
- Rubber extruded
- Thru-the-weave (further categorized as rubber or polyurethane TTW)

5.0 FRICTION LOSS CALCULATIONS

5.1 Theory

Fundamental friction loss equations are based on well established hydraulics for incompressible, Newtonian flow using the Hazen-Williams, Chezy, Darcy-Weisbach, Fanning-Darcy or similar loss calculation methods. As has been described in the literature [3], friction loss varies:

- Directly with the length of the hose, i.e., $FL \propto L$;
- Directly with the square of the flow velocity, i.e., $FL \propto V^2$; and,
- Inversely with the fifth power of the hose diameter, i.e., $FL \propto \frac{1}{D^5}$.

Friction loss also varies based on the internal roughness of the hose liner.

The Darcy-Weisbach, used to model the head loss of flowing fluids in hoses or pipes where high velocities might occur, was used in this analysis [4]:

$$FL = f LV^2/(2Dg) \tag{1}$$

Where:

FL = friction loss (or head loss) [ft],
V = velocity [ft/s],
L = hose length in [ft],
f = dimensionless friction coefficient,
g = acceleration due to gravity 32.2 [ft/sec^2], and
D = internal diameter [ft].

At typical fire service water flow rates (i.e., turbulent flow), the dimensionless friction factor is only dependent on the type of hose used and the diameter of the hose.

The fire service desires to have a simplified method to assess the “friction factor” of hose. When dealing with water flow through a hose, it is convenient to use the water flow rate (Q) instead of flow velocity (V), and pressure loss (ΔP_f) instead of head loss (FL). Substituting the following equations for friction loss (2a) and flow velocity (2b) into equation (1), results in an equation for the pressure loss due to friction (2c):

$$FL = \Delta P_f/\rho_w g \tag{2a}$$

$$V = (4Q)/\ \pi D^2 \tag{2b}$$

$$\Delta P_f/\rho_w g = 8 f Q^2 L/(\pi^2 g D^5) \tag{2c}$$

Where:

ΔP_f = pressure loss due to friction [lbf/ft^2],
ρ_w = density of the flowing fluid (water) [lbm/ft^3], and
Q = flow rate [ft^3/s].

Combining all of the constants in equation (2c) into a single constant, C, and converting ΔP_f, Q, and L into convenient units (Q in 100s of gpm, friction loss in psi, and hose length in 100s of feet), the modern fire-service friction loss equation results [5]:

$$\Delta P_f' = CQ'^2L' \tag{3}$$

$$C = (8 f \rho_w/(\pi^2 D^5))[((1\text{ft}^3/\text{s})/449\text{ gpm})^2(144)(100^3)]$$

Where:

$\Delta P_f'$ = pressure loss due to friction [psi],
Q' = flow rate [100 gpm],
L' = hose length [100 ft], and
C = friction loss coefficient [psi/(gpm^{2}ft)].

The *NFPA Fire Protection Handbook* provides a complete derivation of this standard fire service C value. When deriving the modern fire-service friction loss equation, Equation (3), the nominal diameter is assumed to be constant. This means that in order to compare the C of multiple hoses, one must compare hoses with the same nominal diameter (see Table 1). Hose C factors can be grouped by diameter for easy reference, as done so in the *NFPA Fire Protection Handbook* Table 13.3.8, IFSTA Appendix D [6], and other publications [7]:

Table 1. Friction Loss Coefficients by Hose Diameter

Hose Diameter [in].	Friction Loss Coefficient (for psi)
1.5	24
2.0	8
2.5	2
3.0	0.8
4.0	0.2
5.0	0.08

In order to combine the usefulness of the dimensionless friction factor (i.e., allowing for the variation of the actual inside hose diameter and the roughness of the hose lining), and the convenience of the standard fire service units used in equation (3), another friction loss factor was developed. If all constants from equation (2c) except for the hose diameter are lumped into a single constant, C_D, a modified version of equation (3) results:

$$\Delta P_f' = C_D Q'^2 L'/D^5 \tag{4}$$

$$C_D = (8 f \rho_w/\pi^2)[((1\,\text{ft}^3/\text{s})/449\ \text{gpm})^2(144)(100^3)]$$

Where:

C_D = friction loss coefficient [(ft^{4}psi)/gpm^2].

Re-arranging equations (2c), (3), and (4) one can solve for the dimensionless friction coefficient (f), and the friction loss coefficients (C and C_D), respectively:

$$f = \Delta P_f\, g\pi^2 D^5/(8\rho_w g Q^2 L) \tag{5a}$$

$$C = \Delta P_f'/(Q'^2 L') \tag{5b}$$

$$C_D = \Delta P_f' D^5/(Q'^2 L') \tag{5c}$$

Where:

f = dimensionless friction coefficient,
C = friction loss coefficient [psi/(gpm^{2}ft)], and
C_D = friction loss coefficient [(ft^{4}psi)/gpm^2].

Note, for Imperial units, the g's is equation 5a do not cancel out as the g in the denominator is utilized along with the lbm term in the denominator to cancel out the lbf term in the numerator.

These three friction factors are used with the test data described in Section 7.0 to compare the various hoses tested in this evaluation.

5.2 Limitations of the Current Friction Factor Estimates

Currently, both Underwriters Laboratories, Inc (UL) and FM Global (FM) publish test standards to which hose is tested [8, 9]. Hose tested to the FM Approval Standard uses a C factor from the Hazen-Williams Equation to establish maximum friction loss requirements:

$$FL = \left(\frac{18.73Q}{C}\right)^{1.85} \left(\frac{1}{D}\right)^{4.87} \tag{6}$$

Where

FL = friction loss [psi]
Q = flow rate [gpm]
D = hose diameter [in.]
C = Hazen-Williams constant, 135

FM limits the friction loss of nominal diameter hose to that shown in Table 2:

Table 2. FM Friction Loss Requirements per 50 ft of hose (Table 4.10.1 in FM 2111)

Hose Diameter [in.]	**Flow Rate [gpm]**	**Maximum Allowable Friction Loss [psi]**
1.5	100	18
2.0	155	10
2.5	250	8
3.0	400	8

UL limits friction loss as shown in Table 3:

Table 3. UL Friction Loss Requirements per 100 ft of hose (Table 22.1 in UL 19)

Hose Diameter [in.]	**Flow rate [gpm]**	**Maximum Allowable Friction Loss [psi]**
1.5	120	45
2.0	150	20
2.5	220	12
3.0	400	15

Neither UL nor FM establish friction loss limitations for 4 or 5 inch diameter hose.

There has been concern that the friction loss C factors published in the *NFPA Fire Protection Handbook* and other references are outdated in terms of modern hose construction. This is the basis of the current project. Potential different manufacturing techniques are not explicitly characterized in the simplified C factor. These techniques could affect the hose lining roughness, and more importantly, the actual interior diameter of the hose. As noted in Section 5.1, hose diameter affects friction loss to the fifth power.

Information provided by UL for this project supports the contention that there is wide variation of friction loss among manufacturers.

Independent tests by the Los Angeles County Fire Department showed the potential differences in hose diameters between various manufacturers for the stated nominal diameter at various pressures, Table 4.

Table 4. Potential Magnitude of Hose Diameter Difference Compared to Nominal Diameters for Various Hoses

Hose	50 psi	100 psi	150 psi	200 psi	250 psi	Total Magnitude of Measurement Difference [100ths of in.]	Total Magnitude of Measurement Difference [64ths of in.]
4-in.	**Supply – Outside hose dia. (in.)**						
Vendor A	4.6875	4.7813	4.8438	4.8750	4.9688	0.2813	18/64
Vendor A	4.6875	4.8125	4.8750	4.9375	4.9688	0.2813	18/64
Vendor A	4.5938	4.6094	4.6563	4.7031	4.7188	0.1250	8/64
Vendor B	4.5313	4.6250	4.7188	4.7813	4.8125	0.2813	18/64
Vendor C	4.5469	4.5625	4.5938	4.6094	4.6406	0.0938	6/64
2.5-in.	**Attack – Outside hose dia. (in.)**						
Vendor A	3.0000	3.0156	3.0313	3.0469	3.0625	0.0625	4/64
Vendor D	2.9688	2.9688	2.9844	3.0000	3.0000	0.0313	2/64
Vendor B	3.0313	3.0469	3.0625	3.0781	3.0938	0.0625	4/64
1.75-in.	**Attack– Outside hose dia. (in.)**						
Vendor A	2.2500	2.2500	2.2500	2.2500	2.2500	0.0000	0
Vendor A	2.2188	2.2188	2.2344	2.2500	2.2813	0.0625	4/64
Vendor E	2.1875	2.1875	2.1875	2.1875	2.2188	0.0313	2/64
Vendor E	2.1563	2.1563	2.1563	2.1875	2.2031	0.0469	3/64
Vendor D	2.1406	2.1406	2.1406	2.1406	2.1406	0.0000	0
Vendor B	2.1563	2.1563	2.1563	2.1719	2.1719	0.0156	1/64
1.5-in.	**Wildland – Outside hose dia. (in.)**						
Vendor A	1.7500	1.7656	1.7813	1.7969	1.8125	0.0625	4/64
Vendor D	1.7813	1.7813	1.7969	1.8281	1.8594	0.0781	5/64
Vendor F	1.7188	1.7344	1.7500	1.7656	1.7969	0.0781	5/64
Vendor C	1.8125	1.8438	1.8438	1.8750	1.8906	0.0781	5/64
1-in.	**Wildland – Outside hose dia. (in.)**						
Vendor A	1.1719	1.1719	1.1875	1.1875	1.2031	0.0313	2/64
Vendor D	1.2500	1.2813	1.2969	1.2969	1.3281	0.0781	5/64
Vendor F	1.2188	1.2188	1.2344	1.2344	1.2656	0.0469	3/64
Vendor C	1.2813	1.2813	1.2969	1.2969	1.3281	0.0469	3/64

6.0 EXPERIMENTAL DETERMINATION OF THE FRICTION COEFFICIENTS

6.1 Hose Manufacturers

It was clear that the number of hoses and vendors had to be reduced to a more manageable number compared to the universe of hose available. After consultation with the Technical Panel, the 0.75, 2.0 and 6.0 in. diameter hoses were eliminated. The following manufacturers were solicited to contribute hose for testing and agreed to participate:

Manufacturer	**Point of Contact**
Angus (UTC)	William Drake
Key Fire Hose	Toby Matthews
Mercedes	Duane Leonhard and Dave Pritchard
Neidner	Cliff McDaniel and Yannick Harvey
North American	Mike Aubuchon
All American/Snaptite	Bob Harcourt, Bob Dunn

These manufacturers were asked to provide representative hoses of different construction types in six different diameters: 1.0, 1.5, 1.75, 2.5, 4.0 and 5.0 inch. They selected representative hose samples from their manufacturing product line, and shipped them to the designated fire service facility. Additionally, they provided a short, uncoupled "sales sample" of each hose. This allowed the fire service facility to measure the nominal hose wall thickness without destructive measurement of the long, coupled hose sections.

Except at the fire service facility where the measurements were taken, the hose identification has remained blind. In this report, hose samples are only identified by the generic exterior construction type and liner material and forming method (method of creating the liner). These designations were established from the hose/shipping information, by the vendor directly, or from brochure information based on the model type.

Four manufacturers provided identical hose to two test sites, to obtain repeat ("round robin") measurements. Section 7.4.2 provides details on this testing.

6.2 Fire Service Organizations

Three fire service facilities volunteered to participate in the experimental program:

- Connecticut Fire Academy (CONN)
  34 Perimeter Road
  Windsor Locks, CT 06096-1069
  Point of Contact: Mark P. Salafia, Program Manager

- Middlesex County Fire Academy (MSEX)
  1001 Fire Academy Drive
  Sayreville, NJ 08872
  Point of Contact: Mike Gallagher, Fire Marshall
- Texas Engineering Extension Service, Emergency Services Training Institute (TEEX)
  200 Technology Way
  College Station, TX 77842-4006
  Points of Contact: Ron Peddy, Associate Division Director of the Emergency Services Training Institute; Lee R. Hall, Private Sector Training Director

The abbreviations used for these facilities are CONN, MSEX, and TEEX.

6.3 Test Plan and Procedure

The friction coefficients of fire hoses of different manufacture, type, and size were determined utilizing the general set-up illustrated in Figure 1. The fire service facilities were directed to conduct experiments in accordance with the finalized test plan which is provided in Appendix A. More detailed hose set-ups for different size hoses are include in the Appendix A test plan.

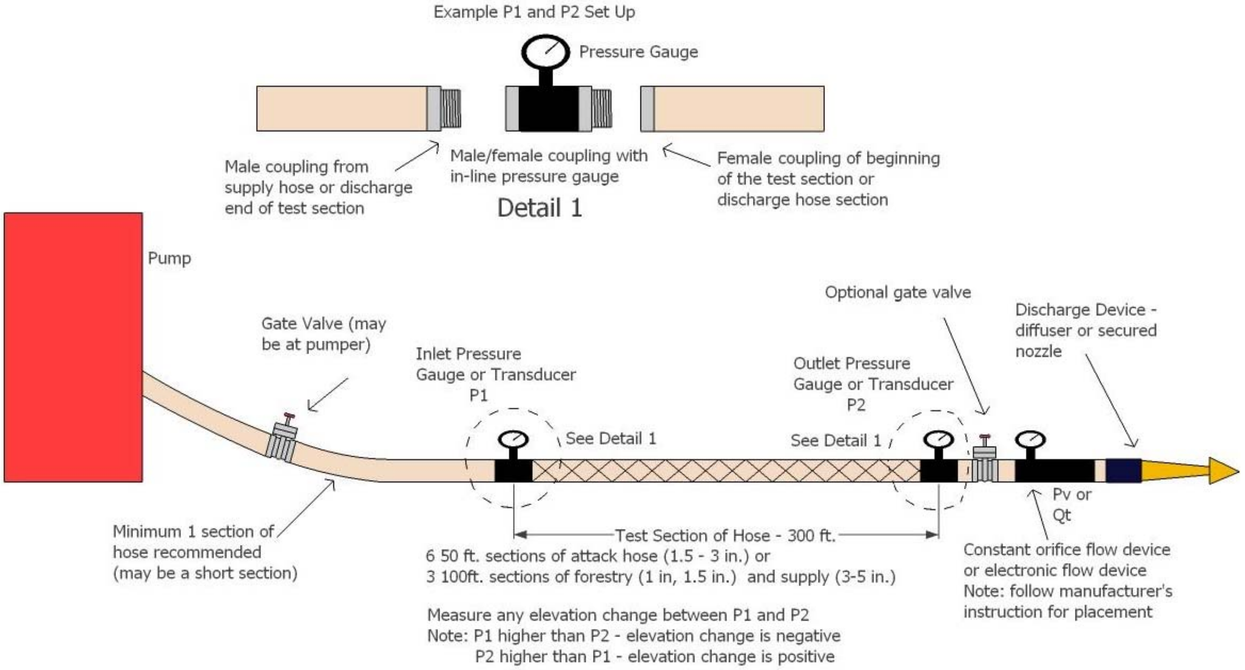

Figure 1. Setup for the determination of the hose friction coefficients

There was much debate and discussion within the technical panel regarding the exact methods and equipment to be used in measuring friction loss. The data were to be collected in a non-laboratory setting, but a high degree of care was desired so that the resulting data would be credible.

Recognizing that accuracy of the field measurements was important; the technical panel established the following parameters and guidelines:

Measurement of the loss across the couplings was not specifically assessed. The fire service organizations were requested to note the coupling material (aluminum, brass), and whether the couplings were threaded or Storz-type.

Since friction loss is highly dependent on hose diameter, it was considered important to assess this. A laboratory technique has been established to precisely measure hose diameter based on carefully controlled volumetric measurements [10]. This was considered beyond the scope of the project.

A procedure was developed for each fire service organization to determine the inside diameter of the hose:

a. Charge the hose section to 10 psi static pressure.
b. Measure the outside diameter (OD) of the hose at this pressure. “Plumbing tape,” which measures the OD of the hose directly, was used by CONN and MSEX (Figure 2). TEEX measured the outside circumference, which was then converted to outside diameter.
c. Using a sales sample of each hose supplied by the manufacturer, the wall thickness of the hose was measured at four different locations using a caliper (Figure 3). The inside diameter (ID) was then calculated by subtracting two times the average wall thickness from the OD at 10 psi.
d. Additionally, the facilities were asked to measure the OD at the hose pressures for each of the flow measurement points.

A nominal hose length section of 300 ft was considered appropriate for these measurements. The facilities were asked to charge the hose to 10 psi static pressure, straighten the hose, and measure the hose length from inside coupling to inside coupling. Fifty or one hundred foot sections were supplied. The actual and nominal hose lengths were recorded.

Elevation corrections were made, as needed, by measuring the difference observed in the static pressure on the gauges at each end of the test section of hose. The elevation difference was then added or subtracted as appropriate from the recorded friction loss.

The measured friction loss was desired over a range of flow rates for the test section. While it was desirable to have a recording flow meter, it was concluded that the use of smooth bore nozzle tips in conjunction with pitot tube pressure readings would provide reliable and accurate flow measurements. A flow meter was available in some situations as a flow check of the flow calculated from the recorded pitot readings. The flow from pitot readings was calculated using [11]:

$$Q = 29.68\ c\ D^2\ P_v^{0.5} \tag{7}$$

Where: Q = flow, gpm

c = friction loss coefficient, assumed to be 1.0 for fire department smooth bore nozzles in the NFPA *Fire Protection Handbook* Table 15.3.1
D = nozzle tip diameter, inches
P_v = velocity pressure (as measured by the pitot gage), psi

Flow as a function of the velocity pressure measured at the outlet of various sized smooth bore, straight tip nozzles is provided in the *NFPA Fire Protection Handbook* (20th Ed.), Table 15.3.1, based on this equation.

Figure2. Measurement of hose OD using a “plumbing tape” (MSEX)

Figure3. Measurement of hose wall thickness (MSEX)

As it was desirable to have a range of flows to measure friction loss through the test section, a predetermined set of flows, with associated nozzle tips, was provided to the fire service organizations, see Table 5. Each hose had a data set of between five and seven flow points. This allowed for a range of low-to-high pressure losses in the hose. The corresponding friction factors were then calculated based on the average of all of the flow points for each hose sample tested.

Table 5. Predetermined Recommended Hose Test Points

Nominal Hose Diameter	**Target Flow Rate**	**Est. Friction Loss**	**Noz./Tip Diam.**	**Pitot Reading**	**Est. Pump Press**
[in.]	[gpm]	[psi]	[in.]	[psi]	[psi]
1	20	18	0.375	23	41
	30	41	0.375	51	92
	40	72	0.500	29	101
	50	113	0.500	45	157
	60	162	0.625	26	188
1.5	50	18	0.500	45	63
	70	35	0.625	36	71
	90	58	0.625	60	118
	110	87	0.750	43	130
	130	122	0.750	60	182
	150	162	0.875	43	205
1.75	50	12	0.500	45	57
	75	26	0.625	41	68
	100	47	0.750	35	82
	125	73	0.750	55	128
	150	105	0.875	43	148
	175	142	1.000	34	177
2.5	150	14	0.875	43	57
	200	24	1.000	45	69
	250	38	1.125	44	81
	300	54	1.250	41	95
	350	74	1.250	56	130
	400	96	1.375	50	146
	450	122	1.500	45	166
4	500	15	1.500	55	70
	700	29	1.750	59	88
	900	49	2.000	57	105
	1100	73	1.750	36	109
	1300	101	2.000	30	131
5	700	12	2.000	34	46
	900	19	2.000	57	76
	1100	29	1.750	36	65
	1300	41	1.750	51	91
	1500	54	2.000	39	93
	1700	69	2.000	51	120

*For 1100, 1300, 1500 and 1700 gpm tests, two deck guns and tips of the specified size were required.

The final test plan distributed to the fire service organizations was developed based on these parameters; it is included in Appendix A. Using the parameters established in Table 5, a computer based standardized test data sheet was also provided. Inside diameter and friction loss corrected for elevation was automatically calculated by inputting data into the standardized data sheet (Appendix B). The facilities generally found that data needed to be collected by hand, and then keyed into the data sheet. The hand-collected data from TEEX was transcribed by Hughes Associates.

The final plan included a list of potential instruments that the facility might have to provide, particularly pressure gages and flow equipment. This need was greatly reduced when a technical panel member volunteered the use of his flow measurement equipment for the project. This eliminated some of the variability which might be expected with different organizations using different equipment. Several organizations also provided flow tips and measurement equipment to the fire service organizations.

Figure 4 shows equipment used at MSEX. A complete overview of the testing was provided Middlesex County, and is included as Appendix E. Figures 5 and 6 show testing at the Connecticut Fire Academy. The Connecticut Fire Academy provided a post-test set of lessons learned, attached as Appendix F, which may be useful for other organizations conducting similar tests.

Figure 4. Flow equipment used at MSEX

Figure 5. Recording data at CONN

Figure 6. Multiple nozzle flow test at CONN

7.0 RESULTS

7.1 Summary of Results

The results of the testing are summarized in Table 6. The data are grouped by the nominal diameter of the hose. A total of 86 tests were conducted on 82 hose samples. Four of the samples were tested twice as described in Section 7.4.2. All 86 tests are included in Table 6; the *f* and C factor data for all tests are graphically shown in Appendices C and D, respectively as a function of hose liner material and forming method. The following sections describe the parameters, assumptions and measurements used to summarize the results in Table 7. The term "nominal diameter categories" in the following analysis means the 1, 1.5, 1.75, 2.5, 4, and 5-inch diameter groupings.

Table 6. Friction Coefficient Determination Summary

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
											Friction Loss Coefficients				
	Test Number	Exterior Construction	Liner Material and Forming Method	Nominal Hose Diameter	Total Hose Length (unpressurized)	Measured Outside Diameter	Test Pressure Used for Outside Diameter Measurement	Wall Thickness	Inside Diameter @ Test Pressure	Total Hose Length @ 10 psi Static Pressure	*NFPA Handbook* Table 13.3.8 C	Calculated C	Calculated C_D	Calculated *f*	Coefficient of Variation
	-	-	-	[in]	[ft]	[in]	[psi]	[in]	[in]	[ft]	[psi/(gpm^{2}ft)]	[psi/(gpm^{2}ft)]	[ft^{4}psi/(gpm^2)]	-	[%]
1	CONN-7	Single Jacket	Polyurethane Extruded	1	309	1.10[C]	10	0.070	0.96	310.1	150	319	0.00104	0.0193	4.2%
2	MSEX-20	Single Jacket	Polyurethane Extruded	1	300[A]	1.24	130	0.056	1.13	300.0[A]	150	156	0.00115	0.0212	15.0%
3	TEEX-15	Single Jacket	Polyurethane Extruded	1	309	1.23	[D]	0.055	1.12	310.4	150	128	0.00092	0.0170	8.3%
4	MSEX-8	Single Jacket	Polyurethane Extruded	1	300[A]	1.24	130	0.056	1.13	300.0[A]	150	121	0.00127	0.0235	9.5%
5	TEEX-13	Single Jacket	Polyurethane Extruded	1	309	1.25	[D]	0.062	1.13	309.0	150	118	0.00053	0.0158	11.0%
6	TEEX-14	Single Jacket	Polyurethane Extruded	1	297	1.25	[D]	0.060	1.13	299.6	150	146	0.00086	0.0202	11.4%
7	CONN-8	Single Jacket	Polyurethane Extruded	1.5	307	1.73	10	0.072	1.59	307.6	24.0	33.0	0.00133	0.0245	2.8%
8	CONN-19	Double Jacket	Polyurethane Extruded	1.5	291	1.98	10	0.143	1.69	293.9	24.0	21.8	0.00122	0.0226	4.5%
9	MSEX-19	Single Jacket	Polyurethane Extruded	1.5	300[A]	1.67	150	0.056	1.56	300.0[A]	24.0	34.9	0.00129	0.0237	6.1%
10	TEEX-29	Double Jacket	Polyurethane Extruded	1.5	304	1.97	[D]	0.125	1.72	304.6	24.0	22.1	0.00135	0.0249	4.9%
11	TEEX-31	Single Jacket	Polyurethane Extruded	1.5	311	1.91[C]	[D]	0.075	1.76	311.5	24.0	27.0	0.00183	0.0338	12.9%
12	MSEX-6	Single Jacket	Polyurethane Extruded	1.5	300[A]	1.78	10	0.100	1.58	300.0[A]	24.0	14.6	0.00072	0.0132	22.3%
13	MSEX-7	Double Jacket	Polyurethane Extruded	1.5	300[A]	1.86	100	0.110	1.64	300.0[A]	24.0	16.6	0.00079	0.0146	6.4%
14	CONN-30	Single Jacket	Polyurethane Extruded	1.5	305	1.74	10	0.12C	1.50	304.2	24.0	36.6	0.00112	0.0206	2.4%
15	TEEX-10	Double Jacket	Polyurethane Extruded	1.5	305	1.95	[D]	0.130	1.69	305.9	24.0	16.0	0.00089	0.0164	6.2%
16	TEEX-8	Single Jacket	Polyurethane Extruded	1.5	296	1.71	[D]	0.064	1.58	297.4	24.0	34.5	0.00138	0.0254	4.0%
17	TEEX-9	Single Jacket	Polyurethane Extruded	1.5	305	1.79	[D]	0.068	1.65	305.8	24.0	18.0	0.00090	0.0166	9.7%
18	CONN-1	Double Jacket	Rubber Extruded	1.5	299	1.98	10	0.138	1.70	300.4	24.0	18.2	0.00105	0.0193	18.9%
19	CONN-9	Double Jacket	Rubber Extruded	1.5	304	1.93	10	0.140	1.65	305.0	24.0	18.5	0.00091	0.0168	6.4%
20	MSEX-22	Double Jacket	Rubber Extruded	1.5	300[A]	1.88	50	0.135	1.61	300.0[A]	24.0	18.7	0.00081	0.0150	4.5%
21	TEEX-28	Double Jacket	Rubber Extruded	1.5	303	1.91	[D]	0.145	1.62	305.4	24.0	16.1	0.00072	0.0133	5.6%
22	TEEX-11	Unknown[B]	Rubber Extruded	1.5	307	1.95	[D]	0.135	1.68	305.9	24.0	13.9	0.00074	0.0137	16.4%
23	CONN-20	Single Jacket (TTW)	Rubber Thru The Weave	1.5	305	1.88	10	0.116	1.65	303.8	24.0	17.8	0.00087	0.0160	9.0%
24	MSEX-18	Single Jacket (TTW)	Rubber Thru The Weave	1.5	300[A]	1.93	170	0.127	1.68	300.0[A]	24.0	13.8	0.00073	0.0135	14.3%
25	TEEX-30	Single Jacket (TTW)	Rubber Thru The Weave	1.5	306	1.91	[D]	0.110	1.69	306.8	24.0	12.4	0.00069	0.0126	4.4%
26	TEEX-12	Single Jacket (TTW)	Rubber Thru The Weave	1.5	305	1.8	[D]	0.135	1.53	305.1	24.0	20.8	0.00070	0.0129	22.2%
27	CONN-25	Double Jacket	Polyurethane Extruded	1.75	297	2.21	10	0.140	1.93	297.0	15.5	9.5	0.00102	0.0188	17.2%
28	TEEX-24	Double Jacket	Polyurethane Extruded	1.75	303	2.23	[D]	0.148	1.93	304.4	15.5	10.4	0.00113	0.0208	22.6%
29	MSEX-5	Double Jacket	Polyurethane Extruded	1.75	300[A]	2.10	112	0.105	1.89	300.0[A]	15.5	9.1	0.00088	0.0162	4.7%
30	CONN-17	Double Jacket	Polyurethane Extruded	1.75	306	2.10	10	0.130	1.84	306.9	15.5	14.0	0.00118	0.0218	5.9%
31	CONN-29	Double Jacket	Polyurethane Extruded	1.75	304	2.31	10	0.130	2.05	304.7	15.5	10.6	0.00155	0.0285	12.4%
32	MSEX-24	Double Jacket	Polyurethane Extruded	1.75	300[A]	2.10	75	0.105	1.89	300.0[A]	15.5	11.7	0.00113	0.0209	12.1%
33	TEEX-5	Double Jacket	Polyurethane Extruded	1.75	306	2.03	[D]	0.130	1.77	308.9	15.5	10.0	0.00070	0.0129	5.8%

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
											Friction Loss Coefficients				
	Test Number	Exterior Construction	Liner Material and Forming Method	Nominal Hose Diameter	Total Hose Length (unpressurized)	Measured Outside Diameter	Test Pressure Used for Outside Diameter Measurement	Wall Thickness	Inside Diameter @ Test Pressure	Total Hose Length @ 10 psi Static Pressure	*NFPA Handbook* Table 13.3.8 C	Calculated C	Calculated C_D	Calculated *f*	Coefficient of Variation
	-	-	-	[in]	[ft]	[in]	[psi]	[in]	[in]	[ft]	$[\text{psi}/(\text{gpm}^2\text{ft})]$	$[\text{psi}/(\text{gpm}^2\text{ft})]$	$[\text{ft}^4\text{psi}/(\text{gpm}^2)]$	-	[%]
34	CONN-23	Double Jacket	Polyurethane Thru The Weave	1.75	292	2.25	10	0.146	1.96	289.1	15.5	8.3	0.00096	0.0177	15.3%
35	CONN-24	Double Jacket	Rubber Extruded	1.75	293	2.12	10	0.151	1.82	296.2	15.5	9.9	0.00079	0.0146	14.8%
36	TEEX-32	Double Jacket	Rubber Extruded	1.75	294	2.25[C]	[C]	0.135	1.98	298.3	15.5	7.8	0.00095	0.0176	10.5%
37	CONN-22	Double Jacket	Rubber Extruded	1.75	300	2.14	10	0.132	1.87	302.8	15.5	10.3	0.00096	0.0177	19.0%
38	CONN-16	Double Jacket	Rubber Extruded	1.75	308	2.10	10	0.135	1.83	309.2	15.5	11.5	0.00094	0.0174	5.0%
39	MSEX-21	Double Jacket	Rubber Extruded	1.75	300[A]	2.12	75	0.135	1.85	300.0[A]	15.5	9.0	0.00079	0.0145	6.9%
40	CONN-15	Double Jacket	Rubber Extruded	1.75	298	2.13	10	0.160	1.81	300.2	15.5	14.5	0.00113	0.0209	17.2%
41	TEEX-25	Double Jacket	Rubber Extruded	1.75	304	2.23	[D]	0.152	1.93	306.8	15.5	8.40	0.00089	0.0163	12.5%
42	TEEX-6	Double Jacket	Rubber Extruded	1.75	306	2.15	[D]	0.140	1.87	305.6	15.5	8.5	0.00078	0.0144	7.8%
43	CONN-21	Single Jacket (TTW)	Rubber Thru The Weave	1.75	299	2.18	10	0.133	1.91	297.6	15.5	8.3	0.00085	0.0156	18.6%
44	MSEX-16	Single Jacket	Rubber Thru The Weave	1.75	300[A]	2.16	50	0.138	1.88	300.0[A]	15.5	7.7	0.00073	0.0135	8.2%
45	MSEX-17	Single Jacket (TTW)	Rubber Thru The Weave	1.75	300[A]	2.12	50	0.127	1.87	300.0[A]	15.5	7.0	0.00064	0.0117	30.2%
46	TEEX-26	Single Jacket (TTW)	Rubber Thru The Weave	1.75	305	2.09	[D]	0.115	1.86	305.7	15.5	7.0	0.00062	0.0115	10.2%
47	TEEX-27	Double Jacket	Rubber Thru The Weave	1.75	298	2.31	[D]	0.152	2.01	297.7	15.5	6.5	0.00085	0.0156	2.0%
48	MSEX-11	Single Jacket (TTW)	Rubber Thru The Weave	1.75	300[A]	2.10	10	0.100	1.90	300.0[A]	15.5	8.3	0.00091	0.0169	3.5%
49	TEEX-7	Single Jacket (TTW)	Rubber Thru The Weave	1.75	305	2.07	[D]	0.130	1.81	305.2	15.5	10.2	0.00079	0.0146	22.1%
50	CONN-28	Double Jacket	Polyurethane Extruded	2.5	297	3.03	10	0.148	2.73	298.6	2.00	1.69	0.00104	0.0192	9.4%
51	TEEX-23	Double Jacket	Polyurethane Extruded	2.5	303	3.10	[D]	0.148	2.80	304.6	2.00	2.22	0.00155	0.0287	6.5%
52	MSEX-3	Double Jacket	Polyurethane Extruded	2.5	300[A]	2.96	10	0.112	2.74	300.0[A]	2.00	1.43	0.00095	0.0175	3.3%
53	TEEX-4	Double Jacket	Polyurethane Extruded	2.5	310	2.98	[D]	0.140	2.70	306.4	2.00	1.46	0.00085	0.0157	6.8%
54	CONN-3	Double Jacket	Polyurethane Thru The Weave	2.5	296	2.94	10	0.170	2.60	295.9	2.00	1.74	0.00083	0.0153	9.4%
55	CONN-2	Double Jacket	Rubber Extruded	2.5	299	3.03	10	0.152	2.73	302.0	2.00	1.55	0.00094	0.0173	6.5%
56	CONN-26	Double Jacket	Rubber Extruded	2.5	309	3.00	10	0.138	2.72	308.2	2.00	1.57	0.00094	0.0174	6.0%
57	MSEX-15	Double Jacket	Rubber Extruded	2.5	300[A]	3.14	50	0.155	2.83	300.0[A]	2.00	1.28	0.00093	0.0172	13.7%
58	MSEX-23	Double Jacket	Rubber Extruded	2.5	300[A]	2.91	43	0.150	2.61	300.0[A]	2.00	1.53	0.00075	0.0137	6.6%
59	TEEX-22	Double Jacket	Rubber Extruded	2.5	305	3.10	[D]	0.164	2.77	308.4	2.00	1.20	0.00079	0.0146	4.5%
60	TEEX-3	Double Jacket	Rubber Extruded	2.5	306	3.02	[D]	0.145	2.73	306.9	2.00	1.17	0.00119	0.0132	12.3%
61	MSEX-4	Single Jacket (TTW)	Rubber Thru The Weave	2.5	300[A]	2.9	160	0.113	2.67	300.0[A]	2.00	1.15	0.00088	0.0162	8.5%
62	CONN-27	Single Jacket (TTW)	Rubber Thru The Weave	2.5	304	2.99	10	0.132	2.72	302.9	2.00	1.31	0.00079	0.0145	7.5%
63	MSEX-14	Single Jacket	Rubber Thru The Weave	2.5	300[A]	2.90	40	0.148	2.60	300.0[A]	2.00	1.51	0.00073	0.0134	10.7%
64	TEEX-20	Single Jacket (TTW)	Rubber Thru The Weave	2.5	305	2.94	[D]	0.130	2.68	304.2	2.00	1.08	0.00061	0.0112	27.1%
65	TEEX-21	Double Jacket	Rubber Thru The Weave	2.5	299	3.10	[D]	0.145	2.81	299.1	2.00	1.23	0.00087	0.0160	22.8%
66	TEEX-2	Single Jacket (TTW)	Rubber Thru The Weave	2.5	306	2.89	[D]	0.130	2.63	306.8	2.00	1.61	0.00132	0.0152	9.4%
67	CONN-6	Double Jacket	Polyurethane Extruded	4	298	4.52	10	0.157	4.20	298.1	0.20	0.21	0.00113	0.0209	3.6%

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
											Friction Loss Coefficients				
	Test Number	Exterior Construction	Liner Material and Forming Method	Nominal Hose Diameter	Total Hose Length (unpressurized)	Measured Outside Diameter	Test Pressure Used for Outside Diameter Measurement	Wall Thickness	Inside Diameter @ Test Pressure	Total Hose Length @ 10 psi Static Pressure	*NFPA Handbook* Table 13.3.8 C	Calculated C	Calculated C_D	Calculated f	Coefficient of Variation
	-	-	-	[in]	[ft]	[in]	[psi]	[in]	[in]	[ft]	[psi/(gpm^{2}ft)]	[psi/(gpm^{2}ft)]	[ft^{4}psi/(gpm^2)]	-	[%]
68	MSEX-2	Double Jacket	Polyurethane Extruded	4	300[A]	4.6	10	0.139	4.32	300.0[A]	0.20	0.13	0.00083	0.0154	6.4%
69	CONN-18	Double Jacket	Polyurethane Extruded	4	306	4.50	10	0.143	4.21	306.2	0.20	0.19	0.00099	0.0182	8.6%
70	CONN-4	Double Jacket	Rubber Extruded	4	305	4.46	10	0.144	4.17	305.8	0.20	0.19	0.00096	0.0177	2.7%
71	MSEX-13	Single Jacket (TTW)	Rubber Thru The Weave	4	300[A]	4.67	105	0.142	4.39	300.0[A]	0.20	0.14	0.00091	0.0167	6.2%
72	TEEX-18	Double Jacket	Rubber Extruded	4	310	4.62	[D]	0.155	4.31	313.8	0.20	0.15	0.00087	0.0161	4.4%
73	TEEX-1	Double Jacket	Rubber Extruded	4	301	4.60	[D]	0.180	4.24	303.9	0.20	0.10	0.00053	0.0098	20.5%
74	MSEX-10	Single Jacket (TTW)	Rubber Thru The Weave	4	300[A]	4.35	10	0.110	4.13	300.0[A]	0.20	0.18	0.00091	0.0168	2.9%
75	CONN-5	Single Jacket (TTW)	Rubber Thru The Weave	4	303	4.47	10	0.158	4.16	301.0	0.20	0.18	0.00089	0.0164	2.9%
76	TEEX-19	Single Jacket (TTW)	Rubber Thru The Weave	4	308	4.30	[D]	0.108	4.08	307.5	0.20	0.15	0.00068	0.0126	4.8%
77	CONN-12	Double Jacket	Polyurethane Extruded	5	294	5.45	10	0.170	5.11	296.4	0.08	0.082	0.00114	0.0211	6.2%
78	MSEX-1	Double Jacket	Polyurethane Extruded	5	300[A]	5.49	10	0.144	5.20	300.0[A]	0.08	0.052	0.00087	0.0160	21.5%
79	CONN-11	Double Jacket	Polyurethane Extruded	5	304	5.50	10	0.151	5.20	300.8	0.08	0.070	0.00107	0.0198	7.2%
80	CONN-13	Double Jacket	Polyurethane Thru The Weave	5	296	5.37	10	0.160	5.05	296.4	0.08	0.086	0.00113	0.0209	28.7%
81	CONN-14	Double Jacket	Rubber Extruded	5	305	5.46	10	0.139	5.18	305.0	0.08	0.059	0.00089	0.0165	9.5%
82	MSEX-12	Single Jacket (TTW)	Rubber Thru The Weave	5	300[A]	5.87	115	0.154	5.56	300.0[A]	0.08	0.041	0.00088	0.0163	8.6%
83	TEEX-17	Double Jacket	Rubber Extruded	5	303	5.59	[D]	0.176	5.24	306.3	0.08	0.053	0.00084	0.0155	7.1%
84	MSEX-9	Single Jacket (TTW)	Rubber Thru The Weave	5	300[A]	5.35	[D]	0.113	5.12	300.0[A]	0.08	0.054	0.00080	0.0147	3.6%
85	CONN-10	Single Jacket (TTW)	Rubber Thru The Weave	5	302	5.37	10	0.138	5.09	301.9	0.08	0.063	0.00087	0.0161	9.9%
86	TEEX-16	Single Jacket (TTW)	Rubber Thru The Weave	5	306	5.46	[D]	0.132	5.20	305.1	0.08	0.052	0.00079	0.0145	9.2%

A – Not measured, stated as 300 ± 1.67 ft

B – The model number listed was not found for the manufacturer; an assumption was made for the forming method.

C – Not Measured, estimated value.

D – Outside circumferences measured during flow. An average of the values was used.

TTW – Thru The Weave Construction

7.2 Results Parameters

7.2.1 Description/Construction

The outer jacket construction and the hose liner material and forming method used in the construction of the different hoses were either found in the individual test data sheets, or in manufacturers' brochures and/or data sheets for the make/model number provided. The TEEX test data did not list the hose description or construction for any hose. The description was found by checking the manufacturer's brochure information against the model number described in the test data sheets. In some cases, the manufacturer was contacted for verification of construction materials.

7.2.2 Interior and Exterior Construction

The hose liner material and forming method was determined from both the test data sheets and manufacturer's brochures or data sheets. The liner material may be described in more detail in the manufacturer's literature. In this report, "rubber" is used generically. The specific type of rubber (i.e., EPDM or nitrile rubber) was not included in the Table 6 description. The four interior construction designations are polyurethane extruded, rubber extruded, rubber thru-the-weave, or polyurethane thru-the-weave.

The exterior construction designations are single jacket, double jacket, or thru-the-weave (TTW).

7.2.3 Nominal Diameter

The nominal diameter is the listed approximate inner diameter of the hose. The nominal diameters of the hoses tested include 1.0, 1.5, 1.75, 2.5, 4.0, and 5.0 inches. It is the standard fire service designation for these hoses.

7.2.4 Total Unpressurized Hose Length

The total hose length is the length of the empty hose, measured from inside coupling to inside coupling. The MSEX test data did not list the total hose length, but reported the lengths as 300 ft ± 1.67 ft.

7.2.5 Outside Diameter (OD)

The intent was to have the fire service organizations measure OD at 10 psi static pressure, and then at each flowing pressure point. Unfortunately, this guidance was misunderstood, and there were differences in OD measurements. The outside diameters were measured at various pressures in the MSEX and CONN tests. MSEX measured outside diameter at pressures between 10 psi and 170 psi and CONN measured the outside diameter at 10 psi. The outside diameters were reported at multiple pressures for MSEX tests 1, 2, 3, 4, 6, 9, 10, and 11. With the exception of MSEX Test 4, in all cases where diameters were reported at multiple pressures, the diameter used in this analysis was that measured at 10 psi. For MSEX Test 4, the outside diameter was only measured at 50, 100, and 160 psi. The outside diameter measured at 50 psi was used in the analysis of MSEX Test 4.

The outside diameter was not reported in CONN Test 7; an estimated value of 1.10 inches was used.

TEEX measured the outside hose circumference during the tests while water was flowing. TEEX measured the outer circumference between one and eight times per hose. The average was used in the analysis of the TEEX test data. The outside circumference was not reported for TEEX tests 31 and 32. Estimated outside diameters of 1.91 and 2.25 inches were used in the analysis of TEEX tests 31 and 32, respectively. The test pressure at which the outside diameter was measured is reported in Table 6.

7.2.6 Wall Thickness

All fire service organizations were requested to measure the hose thickness of a sales sample at four locations, with the average to be used in the calculations. The wall thickness was measured by MSEX and CONN for most tests. TEEX did not measure the hose wall thickness. The wall thickness was not reported in CONN Test 30; an estimated value of 0.12 inches was used. For the TEEX tests, the wall thickness used in the calculations was based on data provided by the hose manufacturer in a follow-up call.

7.2.7 Calculated Inside Diameter

The inside diameter of each hose was calculated by subtracting two times the wall thickness from the measured outside diameter.

7.2.8 Total Hose Length at Static Pressure

The total hose length, measured from inside coupling to inside coupling, was measured at a static pressure of 10 psi for the TEEX and CONN tests. MSEX did not measure the total hose length at a static pressure of 10 psi, but reported the hose length for all hoses as 300 ft ± 1.67 ft These lengths were used in the friction factor calculations, i.e., the calculation was corrected for the actual length of hose.

7.2.9 *NFPA Fire Protection Handbook* Friction Loss Coefficient, C

The reported friction loss coefficient, C, from Table 13.3.8 of the *NFPA Fire Protection Handbook* is reported for each nominal hose diameter. The C for 1.0 in. of 150 is for hard rubber booster line.

7.3 Calculated Friction Factors from Friction Loss Data

Tables 7 and 8 provide an example of how the measured flow and pressure loss data was used to calculate friction coefficients in equations (5a), (5b), and (5c), for the hose tested during test CONN-30.

The difference between the static inlet and outlet pressure (Figure 1) was measured to account for any elevation change along the test section. In the example, the pressure was one psi greater at the nozzle end of the test section than at the pumper end under static conditions. The nozzle end was lower than the pumper end. To correct for level conditions, this 1 psi gain had to be added to the measured friction loss to provide the corrected friction loss. TEEX measured the static pressure difference for only Tests 1 and 2. TEEX tests had static pressure differences of 0.6 and 3.2 psi. In the remainder of the TEEX tests, the elevation difference was assumed to be zero. The CONN and MSEX tests had constant static pressure differences of -1.0 psi and 0.0 psi, respectively.

Table 7. Example Hose Properties (CONN-30)

Description/Construction		**TPU Liner Single Jacket, PE Extruded**
Hose Type – Liner Material and Forming Method		Polyurethane Extruded
Nominal Diameter	[in.]	1.5
Length of Each Section	[ft]	100
Coupling Type		Aluminum Threaded NST
OD (unpressurized)	[in.]	1.74
Wall Thickness	[in.]	0.12
ID (unpressurized)	[in.]	1.50
Length (unpressurized)	[ft]	305
Length (pressurized)	[ft]	304.2
OD (pressurized)	[in.]	1.74
ID (pressurized)	[in.]	1.50
Static Pressure Correction	[psig]	-1

Table 8. Example Determination of the Friction Factors from Measurements of the Flow Rate and Pressure Drop (CONN-30)

Flow Rate Measurement			**Pressure Measurements**				**Friction Loss Coefficients**		
Tip Size	**Pitot Pressure**	**Flow Rate**	**Up-Stream Pressure**	**Down Stream Pressure**	**Pressure Loss**	**Corrected Pressure Loss**	**C**	**C$_D$**	***f***
[in]	[psig]	[gpm]	[psig]	[psig]	[psig]	[psig]	[psi/(gpm^{2}ft)]	[ft^{4}psi/(gpm^2)]	-
0.5	45	50	71	43	28	29	38.07	0.00116	0.0214
0.625	36	70	89	36	53	54	36.29	0.00111	0.0204
0.625	60	90	152	61	91	92	37.10	0.00113	0.0209
0.75	43	110	179	45	134	135	36.63	0.00112	0.0206
0.75	60	130	250	63	187	188	36.56	0.00112	0.0206
0.875	43	150	286	47	239	240	35.15	0.00107	0.0198
Average							36.63	0.00112	0.0206
Standard Dev							0.874	0.0000267	0.00049
Coefficient of Variation (%)							2.4%	2.4%	2.4%

7.3.1 C Factor

Using equation (5b), the friction loss coefficient, C, was calculated for each hose at each predetermined flow rate. Testing was generally performed in accordance with the predetermined flow rates listed in Table 5. The measured pressure drop, measured pitot pressure, calculated water flow rate, and length of hose at static pressure were used in this calculation. The average friction loss coefficient, C, was calculated for each hose based on C factors for all flow rates. This provided a direct comparison to the *NFPA Fire Protection Handbook* Table 13.3.8 friction loss coefficient. The effect of couplings on the friction loss coefficient, C, was not considered.

7.3.2 C_D Factor

Using equation (5c), the friction loss coefficient, C_D, was calculated for each hose at each predetermined flow rate (Table 5). The calculated inside diameter (Sections 2.7, 7.2.5–7.2.7), measured pressure drop, measured pitot pressure, calculated water flow rate, and length of hose at static pressure (Section 7.2.8) were used in this calculation. The average friction loss coefficient, C_D, was calculated based on individual friction loss coefficients for all flow rates. The effect of couplings on the friction loss coefficient, C_D, was not considered.

7.3.3 f Factor

Using equation (5a), the average dimensionless friction loss coefficient, f, was calculated for each hose at each predetermined flow rate (Table 5). The calculated inside diameter (Sections 2.7 and 7.2.5–7.2.7), measured pressure drop, measure pitot pressure, calculated water flow rate, and length of hose at static pressure (Section 7.2.8) were used. The average dimensionless friction loss coefficient, f, was calculated based on individual factors for all flow rates. The effect of couplings on the friction loss coefficient, f, was not considered.

7.3.4 Standard Deviation and Coefficient of Variation

The standard deviation, which is the variation of the data to the mean, is expressed as:

$$\sigma = \sqrt{\frac{\sum(x-\mu)^2}{n}} \tag{8}$$

Where,

σ = Standard Deviation for a Population
μ = Average

The coefficient of variation (CV) is the ratio of the standard deviation to the mean. It is expressed in terms of a percentage as:

$$CV\,[\%] = (\sigma/\mu)*100 \tag{9}$$

7.4 Discussion

7.4.1 General Results

A summary of key data is provided in Table 9. In all nominal diameter categories except the 1 in. diameter, the average C factor established in these tests was less than the published C factor (see Appendix D). In many cases, the calculated C factors were substantially lower than the C factors published in the *NFPA Fire Protection Handbook*. For example, the lowest C factor for 1.5 in. hose was 12.4, compared to the published value of 24. For 1.75 in. hose, the lowest C was 6.5, nearly a 60% reduction compared to the published C of 15.5. None of the nineteen 1.75 in. hose samples exceeded the published C factor. This was not uniformly true across the diameter categories: 10 of the remaining 63 samples had calculated C factors exceeding the published values, with the worst case being the 1.5 in. diameter hose category where 5 of the 20 samples exceeded the published C. So, while particular hoses and the overall averages are less than the published C, a blanket statement cannot be made that all modern fire hose are "better" (have less friction loss) than the currently recommended C factors. The published C factor for 1.0 in. hose is for hard rubber (booster) type hose, so a direct comparison may be unfair. In published tables, a separate category for forestry hose in addition to booster hose is probably appropriate.

There is one apparently conclusive characteristic related to hose lining material. The highest average friction factors, both C and f, occur with hose constructed with polyurethane extruded liners (see Appendices C and D graphs). The data is inconsistent for the construction/lining material with the best friction characteristics. No conclusions were drawn related to single vs. double jacketed hose.

The NFPA published friction factor C does not correlate across the entire data set with the dimensionless friction factor f. In particular cases, it may. For the lowest calculated friction factors, the lowest C correlates with the lowest f in four of the six test nominal diameters. For the highest friction factors, C correlates with f in three of the six diameters. Associated with this observation, the lowest C correlates with the largest inside diameter in two of six diameter data sets. The lowest C correlates with the lowest f factor in five of the six diameter data sets. This suggests that, using a friction factor which directly includes the actual inside diameter (C_D or f) may not by itself be a predictor of overall friction loss. In other words, hose with an actual inside diameter greater than the nominal diameter may not necessarily result in the "best" (lowest) friction loss characteristics. This is evidenced by the observation that the rank order of C factors (lowest friction to highest) within a nominal diameter category does not directly correlate with the C_D or f rank. This is true across all nominal diameter categories. The rank order of C_D and f do correlate, as expected, since C_D is essentially a rearrangement of the flow/pressure units in Equation 2c for the f factor.

Table 9. Summary of Key Results

A	B	C	D	E	F	G
	Hose Nominal Diameter (in.)					
	1	**1.5**	**1.75**	**2.5**	**4**	**5**
1. No. of samples	6	20	19	17	10	10
2. Low friction factor						
a. C/test	118 TEEX-13	12.4 TEEX-30	6.5 TEEX-27	1.08 TEEX-20	0.10 TEEX-1	0.041 MSEX-12
b. *f*/test	0.0158 TEEX-13	0.0126 TEEX-30	0.0115 TEEX-26	0.0112 TEEX-20	0.0098 TEEX-1	0.0145 TEEX-16
3. High friction factor						
a. C/test	319 CONN-7	36.6 CONN-30	14.5 CONN-15	2.22 TEEX-23	0.21 CONN-6	0.086 CONN-13
b. *f*/test	0.0235 MSEX-8	0.0338 TEEX-31	0.0285 CONN-29	0.0287 TEEX-23	0.0209 CONN-6	0.0211 CONN-12
4. No. of samples where C > NFPA value	1	5	0	1	1	2
5. Does low C correlate with:						
a. Large ID	No	No	Yes	No	No	Yes
b. Low *f*	Yes	Yes	No	Yes	Yes	No
6. Range of % Coefficient of Variance						
a. Low/test	4.2% CONN-7	2.4% CONN-30	2.0% TEEX-27	3.3% MSEX-3	2.7% CONN-4	3.6% MSEX-9
b. High/test	15.0% MSEX-20	22.3% MSEX-6	30.2% MSEX-17	27.1% TEEX-20	20.5% TEEX-1	28.7% CONN-13
7. Average *f* factor						
a. Low/hose type	All hoses polyurethane extruded	0.0138 Rubber thru the weave	0.0142 Rubber thru the weave	0.0144 Rubber thru the weave	0.0145 Rubber extruded	0.0154 Rubber thru the weave
b. High/hose type	All hoses polyurethane extruded	0.0215 Polyurethane extruded	0.0200 Polyurethane extruded	0.0203 Polyurethane extruded	0.0182 Polyurethane extruded	0.0209 Polyurethane thru the weave
8. Rank order of C correlate with C_D and *f*?	No	No	No	No	No	No
9. Does rank order of C_D correlate with *f*?	Yes	Yes	Yes	Yes	Yes	Yes

Several examples show how the performance can differ as a function of diameter:

- In the 1.5 in. nominal diameter tests, the lowest C factor occurred in TEEX-30. This sample also had the lowest friction factor *f*. Its inside diameter was 1.69 inches. The largest diameter hose, from test TEEX-31 at 1.76 inches, had a C of 27 (exceeding the NFPA published value of 24). Its friction factor *f* was the highest. This implies the construction/internal roughness was important, since the effective inside diameter was relatively large. In reviewing the data derived in this project, one manufacturer confirmed that their own internal data indicated the importance of internal construction. Roughness of the interior lining affects friction loss.
- In the 1.75 in. nominal diameter tests, the lowest C factor occurred in TEEX-27. The inside diameter in this test was nearly the largest of the groups, 2.01 inches. The friction factor *f* was in the mid range. Diameter was important in the low C factor.

There was a wide range of variability in the data. The coefficient of variation ranged between 2.4% and 30.2%. While a detailed statistical analysis was not performed, some trends were observed. Most of the lowest friction factors within a diameter category were observed at TEEX. No such trend was observed with highest record friction factors. The lowest recorded friction factors also appeared to have higher coefficients of variation. In particular, the 2.5 in. hose with the lowest C (TEEX-20) had the highest coefficient of variation, 27.1%. Likewise, in the 4.0 in. tests, the lowest C (TEEX-1) had the highest coefficient of variation, 20.5%., and in MSEX-17, the 1.75-in. hose had the lowest *f* factor and almost the lowest C factor.

The measured upstream and downstream pressures for the MSEX tests, for most hoses less than 2.5 inches, tended to be significantly higher than what was reported for the CONN and TEEX, especially at lower flow rates. The reason for this is unclear. Since the hoses tested have a propensity to expand (i.e., their outer diameter increases) as the pressure in the hose increases, the internal diameter of a hose might be larger at theses greater pressures. The corresponding friction loss in that hose would tend to decrease. This phenomenon could explain some of the discrepancies in the friction loss data, particularly since the dimensionless friction factor and Cd were calculated using diameters measured at relatively low static pressures.

The hose lengths of the MSEX tests were stated as 300+/-1.67ft. The other test sites provided more detailed measurements of the hose length for each test. The friction loss factors are proportional to the hose length to the first power. If a nominal hose length of 300 feet is assumed, changes of 10 feet and 1 foot in the hose length would yield changes in the friction loss factors of approximately 3.3% and 0.33%, respectively.

From an experimental set up point of view, it was observed in one situation that the control valve was positioned within about two feet of the upstream pressure gauge. Turbulence near the valve made adjusting the desired pressure setting difficult. A greater separation distance between the control valve and pressure gage may have resulted in more accurate and steady readings, i.e. eliminate potential turbulence near the gage.

There was a manufacturer question regarding measurements from potential warped hose (i.e., twisted, or non-straight hose lays). Test sites were requested to straighten hose as much as possible. Appendix F describes measures to overcome kinks. Appendix E describes how no friction loss difference was observed when the 300 ft straight test section was reconfigured into a U-shaped lay. Otherwise, no other observations or problems were observed with hose lays.

The entire issue of data trends, including variability, deserves a more thorough statistical analysis, such as an analysis of variance (ANOVA), to identify statistically significant parameters related to:

- Test facility variations (see Section 7.4.2);
- Impact of hose diameter within a category and as it relates to nominal hose categories (larger diameter hose appears to have less variability, but the data sets are smaller);
- Variations in low and high end calculated friction factors;
- Impact of hose type and hose liner material, including number of jackets and extrusion vs. thru the weave. Better grouping or characterization of hose construction type might improve this analysis.

7.4.2 Round-robin Testing

The majority of hoses were tested at only one test facility. "Round-robin" testing was performed on four identical 1.75 in. models, which were tested at two facilities. The intent was to gain some insight on facility variability and test repeatability. The test facilities used identical hose models for the round-robin testing but did not necessarily use the exact same hose. The samples from four different manufacturers were identical in the sense that each hose was the same manufacturer, construction (model), length, and diameter. Whether the exact same sections were used was not identified, since the test sites and manufacturers were responsible for shipping the hose. An excerpt of the test data from Table 6 for the round-robin hose pairs is shown in Table 10.

When examining the differences between the average friction loss factors for each pair of tests, there appears to be significant variation between the fire service organizations for friction loss of the same hose. However, if the averages are taken within the context of their coefficient of variation (i.e., the average individual data set values ± the first standard deviation), the disparity in the data diminishes. Figures 7 through 9 show the average friction factors plotted by test number with the error bars shown as the first standard deviation from the average. The shaded values in Table 10 indicate for which pairs of friction loss factors the error bars overlap.

With the exception of Pair 2, the error bars for C_D and f values overlap. Only Pair 4 has C values which are in fairly good agreement. C is the friction loss factor which does not account directly for the diameter of the hose.

Recall that the same hose model was tested, but not necessarily the exact same hose sections. Perhaps there is some variability in construction, particularly if different lots were used. This was not checked. One manufacturer considered this as unlikely to contribute to such large variation.

Table 10. Test Data for Round-robin Pairs

							Friction Loss Coefficients				
Pair Number	Test Number	Measured Outside Diameter	Static Test Pressure Used for Outside Diameter Measurement	Wall Thickness	Inside Diameter @ Static Test Pressure	Total Hose Length @ 10 psi Static Pressure	*NFPA Fire Protection Handbook* Table 13.3.8	Calculated C	Calculated C_D	Calculated f	Coefficient of Variation
-	-	[in.]	[psi]	[in.]	[in.]	[ft]	[psi/(gpm^{2}ft)]	[psi/(gpm^{2}ft)]	[ft^{4}psi/(gpm^2)]	-	[%]
Pair 1	CONN-15	2.13	10	0.160	1.81	300.2	15.5	14.5	0.00113	0.0209	17.2%
	TEEX-25	2.23	[D]	0.152	1.93	306.8	15.5	8.4	0.00089	0.0163	12.5%
Pair 2	CONN-16	2.10	10	0.135	1.83	309.2	15.5	11.5	0.00094	0.0174	5.0%
	MSEX-21	2.12	75	0.135	1.85	300[A]	15.5	9.0	0.00079	0.0145	6.9%
Pair 3	CONN-17	2.10	10	0.130	1.84	306.9	15.5	14.0	0.00118	0.0218	5.9%
	MSEX-24	2.10	75	0.105	1.89	300[A]	15.5	11.7	0.00113	0.0209	12.1%
Pair 4	TEEX-32	2.25[C]	[C]	0.135	1.98	298.3	15.5	7.8	0.00095	0.0176	10.5%
	CONN-24	2.12	10	0.151	1.82	296.2	15.5	9.9	0.00079	0.0146	14.8%

A – Not measured, stated as 300 ± 1.67 ft

C – Not Measured, estimated value

D – Outside circumferences measured during flow. An average of the values was used.

Note: Shaded areas show pairs of values for which the error bars overlap (error bars consist of the average ± the first standard deviation).

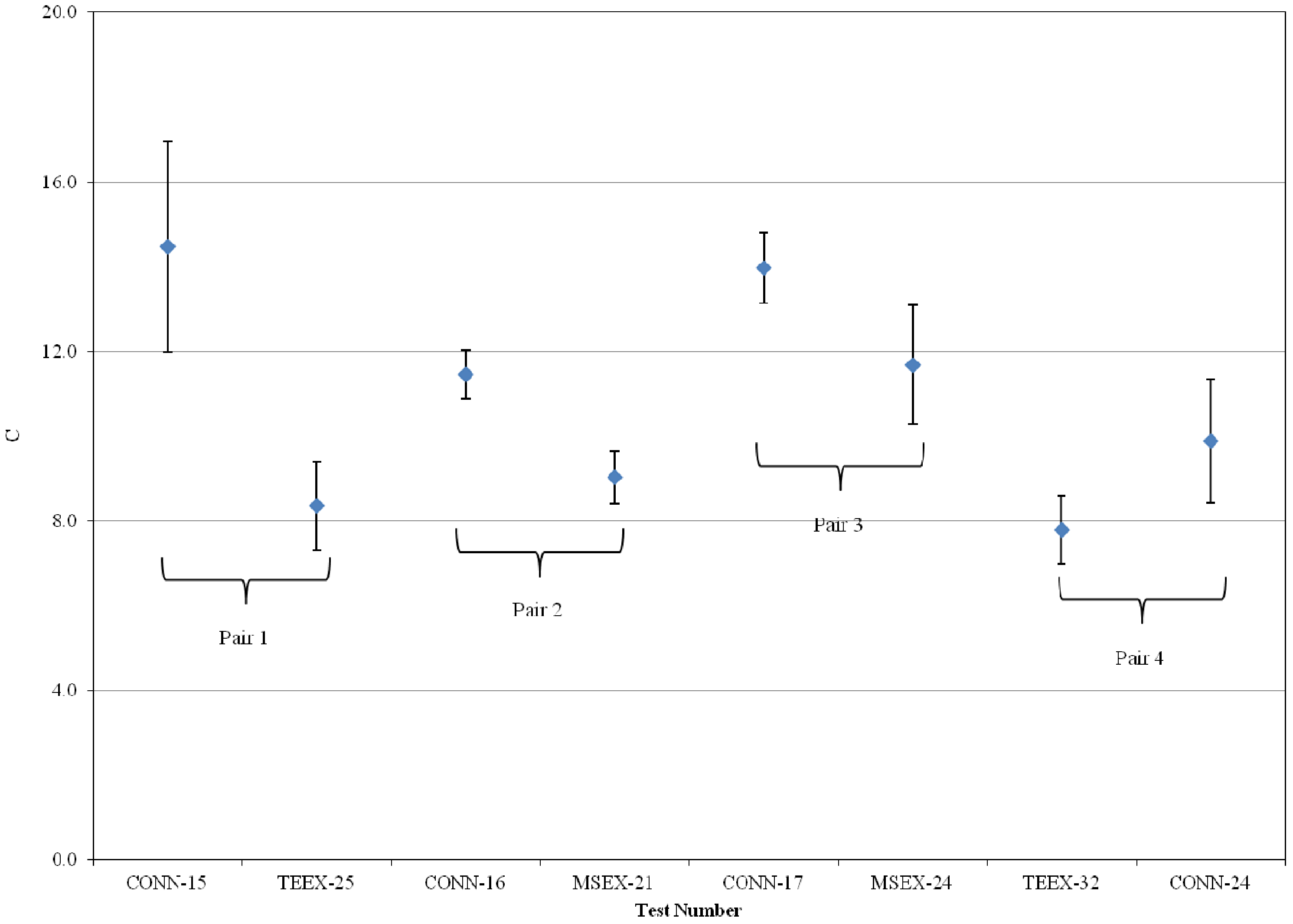

Figure 7. Plot of average Friction Loss Coefficient, C, by test number

Note: Error bars shown as the first standard deviation from the average.

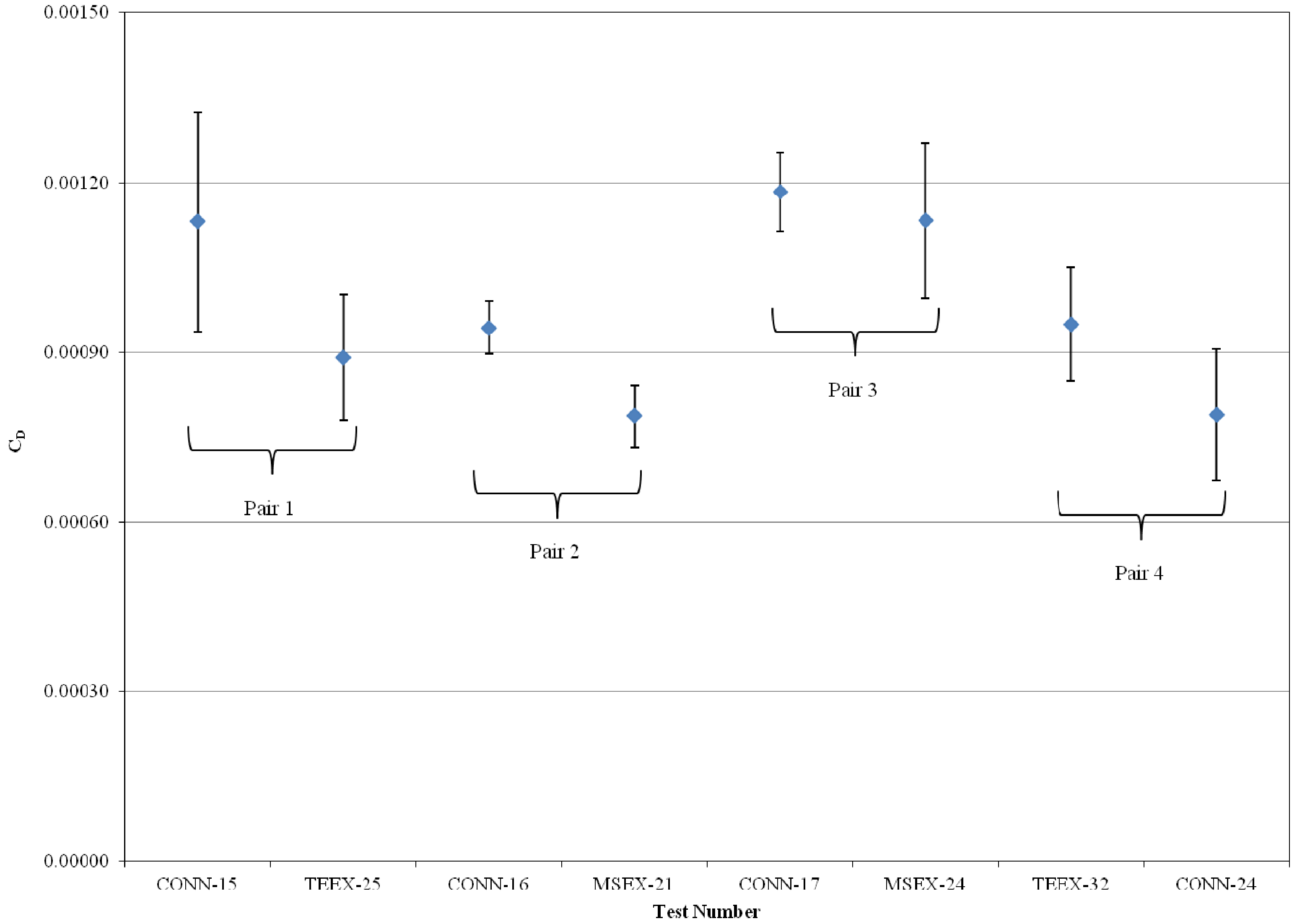

Figure 8. Plot of average Friction Loss Coefficient, C_D, by test number

Note: Error bars shown as the first standard deviation from the average.

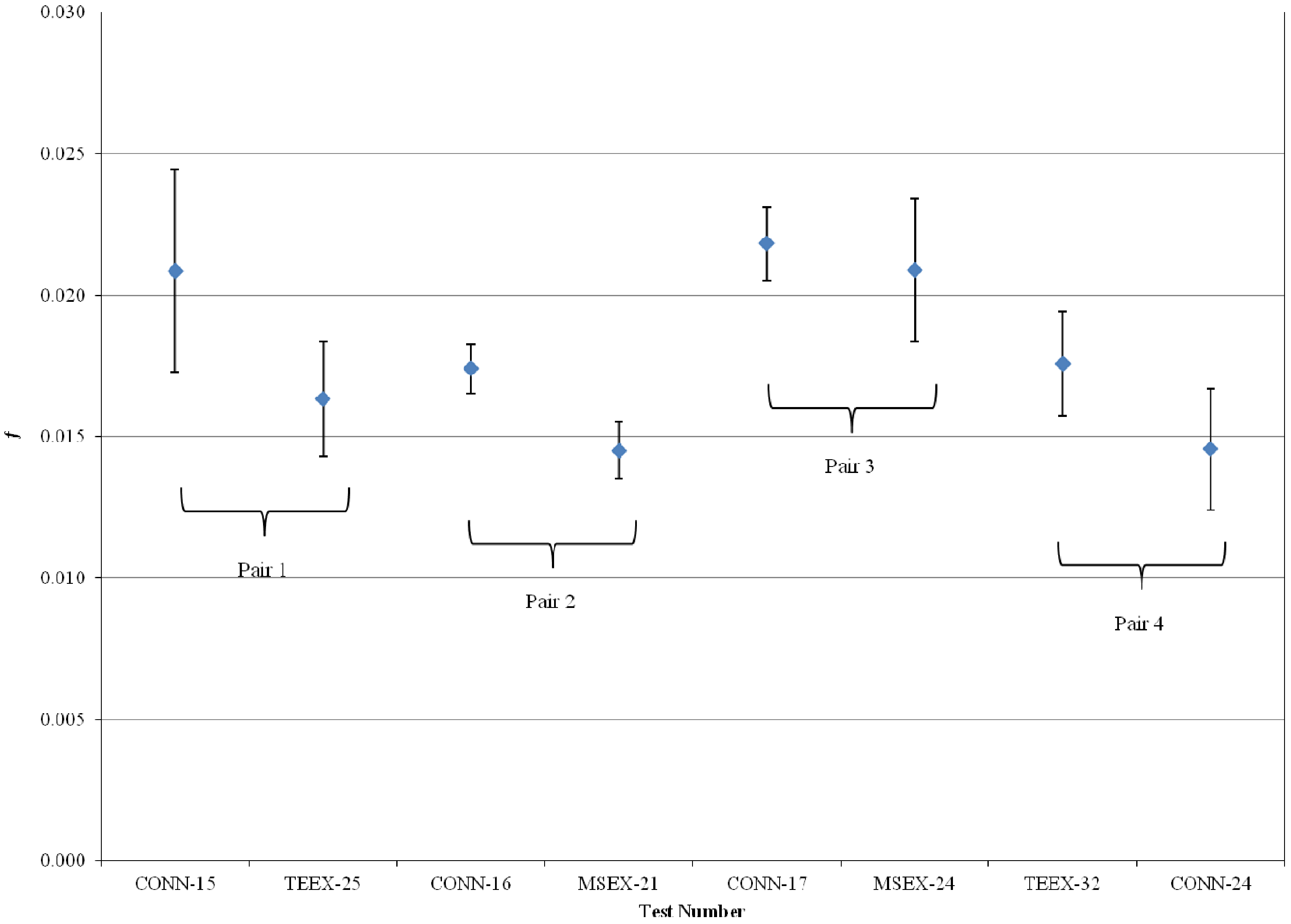

Figure 9. Plot of average Friction Loss Coefficient, *f*, by test number

Note: Error bars shown as the first standard deviation from the average.

One potential source of discrepancies in friction loss is the measured inside diameter. Hose pairs 1, 3, and 4 had differences between the wall thickness measured for the two hoses of approximately 5%, 21%, and 11%, respectively, as shown in Table 11. The wall thickness is used to calculate the internal diameter which is used to calculate both the dimensionless friction factor *f* and C_D. Because the friction loss factors are proportional to the internal diameter to the 5th power, a 20% change in the single wall thickness could impact the friction factor by up to 15%, depending on the measured outside diameter.

Table 11 – Differences in Measured Hose Wall Thickness in Round Robin Tests

Pair Number	Test Number	Wall Thickness
—	—	[in]
Pair 1	CONN-15	0.160
	TEEK-25	0.152
Pair 3	CONN-17	0.130
	MSEX-24	0.105
Pair 4	TEEK-32	0.135
	CONN-24	0.151

8.0 SUMMARY

A total of 86 tests were performed by three fire service organizations on 82 fire hose samples spanning from 1 to 5 inches in diameter. Recorded hose dimensions, pressure, flow and friction loss data were used to calculate the friction factors for each sample. The data were analyzed with respect to the nominal diameter of hose, the traditional method to assign a general friction factor.

Three friction factors were calculated: C, the factor now used in published data; and, C_D and *f*. The traditional C factor combines hose diameter and roughness into a single constant. The C_D and *f* factors use measured diameter to calculate a friction factor more closely associated with hose interior roughness. This roughness is thought to be associated with hose construction.

A simplified friction loss factor, C, is currently used by the fire service. The actual hose inside diameter and roughness characteristics are lumped into this single parameter, and portrayed in fire service standard flow, pressure and hose length terms. The data indicate that most, but not all, C factors calculated for the tested hose fall below the currently published values.

The C_D and *f* factors provide a more insight into friction loss characteristics, since the affects of actual inside diameter are considered separately, not within the friction factor. Overall, the friction loss characteristics observed for individual tested hose sections (different manufacturers and their models) can be a factor of the inside diameter, roughness, or both factors. Inside diameter alone was not a predictor of the magnitude of the friction loss across all samples.

A fairly large degree of variability was observed in the data. There were some inconsistencies in assessing interior hose diameter, based on the measurements provided by the fire service organizations. A more thorough statistical analysis might be useful for identifying statistically significant trends. Hose construction descriptions suffer from different terminology among manufacturers. An attempt to better characterize hose construction into more general categories might be useful. Individual, proprietary construction materials and techniques might make this difficult.

9.0 ACKNOWLEDGEMENTS

This project was unique within those performed by the Fire Protection Research Foundation in that testing and equipment relied solely on voluntary contributions and efforts. Five people in particular must be singled out for special recognition:

- Mark Salafia of the Connecticut Fire Academy;
- Mike Gallagher of the Middlesex County Fire Academy;
- Ron Peddy and Jim Hall of the Texas Engineering Extension Services; and
- Technical Panel Member Jim Cottrell, for donating measurement equipment and organizing the shipment of the equipment to and from the fire service facilities.

These gentlemen, along with their staff, provided hundreds of man-hours to coordinate and conduct the flow tests. Each of these people was supported by their respective organizations, and we wish to give an overall thanks to the fire service organizations.

The hose manufacturers, including All American/Snaptite, Angus/UTC, Mercedes, Key Fire Hose, Neidner, and North American contributed a total of eighty two 300-foot samples, along with the short samples in which to measure hose wall thickness. They were also responsible for shipping the hose to and from the fire academies. This project could not have been performed without their contributions.

Kochek Co., Inc and Task Force Tips also contributed equipment for the testing. Thanks are extended to them.

Finally, the project technical panel, listed in the front material, provided guidance which resulted in practical yet technically sound testing.

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APPENDIX A –
FINALIZED TEST PLAN

TEST PLAN
DETERMINATION OF FIRE HOSE FRICTION LOSS CHARACTERISTICS

Prepared by

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On behalf of the

Project Technical Panel for
Developing Friction Loss Coefficients
for Modern Fire Hose

Sponsored by

Fire Protection Research Foundation
Quincy, MA

Final

October 15, 2010
(Edited for Final Report)

TEST PLAN – DETERMINATION OF FIRE HOSE FRICTION LOSS CHARACTERISTICS

A1. BACKGROUND

Friction loss characteristics of fire hose have changed as a result of evolving hose manufacturing technology. Currently published friction loss characteristics may be overly conservative. While conservatism in fire protection is generally good, in this case it may lead to excessively high pump discharge pressures as the operator applies general rules-of-thumb. The resulting high nozzle pressure may make firefighting operations at the nozzle difficult or unsafe. Alternately, low pressures and flow rates will inhibit fire fighting efficiency.

A2. OBJECTIVES

The overall objective of this research project is to develop friction loss characteristics for hose currently used by the fire service. The output will be updated friction loss data which might be used to revise published coefficients in the *NFPA Fire Protection Handbook* and other reference sources. The data may be useful for standards-development panels such as the NFPA 1961 and 1002 standards associated with fire hose and driver/operators.

The specific objective of this test plan is to describe the procedures to be used by participating fire service organizations to measure and record friction loss in hose submitted for this project. Both the testing and provision of the hose are voluntary efforts being guided by a project technical panel.

A3. FRICTION LOSS DATA

Friction loss coefficients are derived from the diameter of the hose and friction loss over a known length of hose for a given water flow rate. This is depicted graphically in Figure A-1. The fire service organization will measure the hose, and perform pressure loss measurements on selected hose at varying increments of water flow rate. It is important that pressure and flow measurements be performed using reliable techniques, and all data be recorded accurately. This test plan describes the equipment and procedures to be used.

A4. FIRE HOSE CHARACTERISTICS AND CONSTRUCTION

A4.1 General Fire Hose Description

Fire hose generally consists of one or more outer layers of woven fabric with an inner layer of rubber or similar elastomer material. It is usually manufactured in 50 ft or 100 foot lengths with threaded metal couplings (national standard threads) on each end. Some fire department use non-threaded (Storz) couplings. Most fire hose is designed to be stored flat to minimize the space required. Small (1.5 in. diameter or smaller) and large (4 in. diameter and above) hose may be stored on reels.

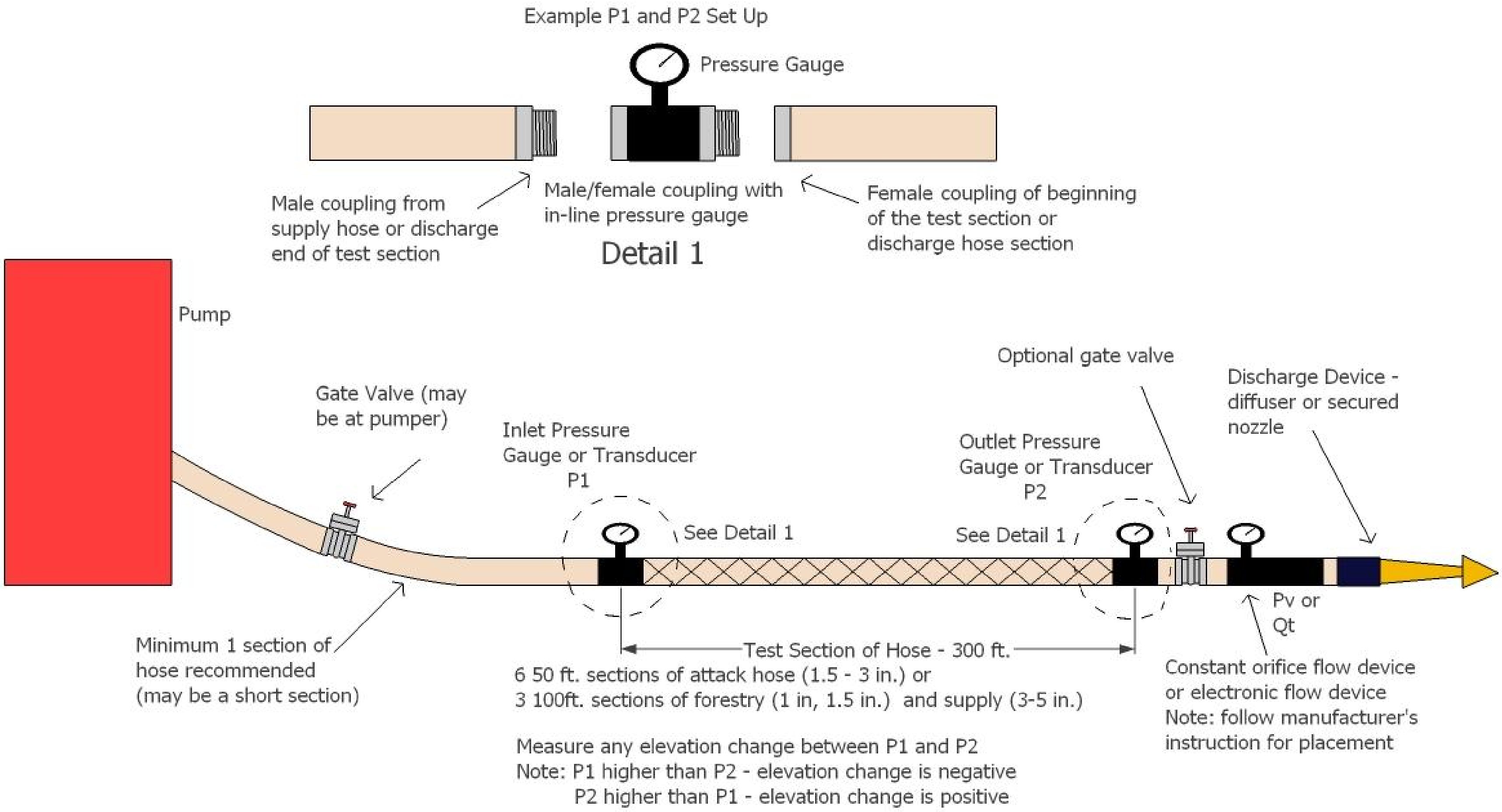


Figure A-1. Test Setup

NFPA 1961 provides the following definitions on pressure in fire hose:

- Burst Test Pressure – a pressure equal to at least three times the service test pressure.
- Operating Pressure – the highest pressure the hose should be used to in regular operation.
- Proof Test Pressure – a pressure equal to at least two times the service test pressure.
- Service Test Pressure – a pressure equal to approximately 110% of the operating pressure.

Three uses of fire hose are of particular interest in this project: forestry hose, attack hose, and supply lines.

- Forestry hose is a flexible hose used for fighting fires in grass, brush, and trees where a lightweight hose is necessary in order to maneuver it over steep and rough terrain. It typically is a 1.0 or 1.5 in. diameter, with a standard length of 100 ft. This is the length which will be used in this evaluation. Service test pressures for hose are approximately 110% of its operating pressure. Forestry hose has a normal maximum operating pressure of 275 psi.
- Attack hose is a flexible hose used to bring water from the fire pumper to nozzle to fight municipal fires. The diameters range from 1.5 in. to 3 in. In these tests, 1.5, 1.75, and 2.5 in. diameter hoses will be evaluated. The standard length is 50 ft, which will be used for this evaluation. Nozzle operating pressure is on the order of 50–125 psi. Straight tip nozzles, which will be used in this evaluation, have a normal operating pressure of 50 psi. Attack hose is designed for use at operating pressures up to at least 275 psi.
- Supply lines are used to bring water from a distant hydrant to the fire pumper or to relay water from one pumper to another over a long distance. This hose has a diameter ranging from 3.0 in. to 5.0 in. In these tests, 4.0 and 5.0 in. diameter hoses will be evaluated. The standard length is 100 ft, which will be used for this evaluation. It is designed to be used at operating pressures not exceeding 185 psi. The storz couplings will be used with supply hose.

Because they are not commonly used, 2 in., 3 in., and 6 in. diameter hose are excluded from this series of evaluations. Hard rubber “booster line” type hose (thick rubber hose) is also excluded from consideration. Also, hard suction hose is not considered.

A4.2 Hose Construction

The three general construction types of fire hose are:

- Single Jacket: A fabric-covered hose with one layer of woven fabric;
- Double Jacket: A fabric-covered hose with two layers of woven fabric; and
- Through-the-weave: This hose is constructed by feeding a single jacket through a rubber extruder, which coats the inside and outside of the jacket, forming an

interlocking bond between jacket and liner. A single fabric jacket is fed through a rubber extruder; the extruder coats the inside and outside of the fabric with rubber (or a rubber compound) to form an interlocking bond.

Three designations are used for this evaluation:

- Jacketed rubber lined hose – generally, but not always, the liner will be a nitrite rubber compound. In some cases, the liner is rubber. Ethylene Propylene Dieme Monomer (EDPM) rubber may also be used as the liner.
- Jacketed thermoplastic lined hose – the lining thermoplastic generally used in this evaluation is thermoplastic urethane, TPU.
- Extruded – There are different variations of extrusion for different sizes and makes.

Jackets are made either from nylon or synthetic polyester. Older technology hoses used cotton, which is still in use in some situations.

A5. EQUIPMENT REQUIRED

The following equipment is required to perform friction loss and hose size tests. Some of this equipment will be loaned to the fire service facility by members of the project technical panel. Other equipment is on hand or will be purchased by the fire service facility.

1. Equipment to measure hose size.
    a. Tape measure – for measuring the length of the hose of the test section.
    b. Outside diameter tape commonly referred to as a plumbers tape (accurate to 1/100th of an inch) – used to measure the outside diameter of a pressurized hose.
    c. Outside calipers – such as a digital or analog vernier caliper, to measure hose wall thickness.
2. Equipment to Measure Pressure and Flow
    a. Pressure gages – for the discharge velocity pressure, P_v in Figure A-1, a Pitot tube having a 0–150 psi range calibrated gage with increments of 1 psi will be used. For friction loss measurements, P_1 and P_2 in Figure A-1, a 0–300 psi range pressure gage (e.g., manometer) with maximum increments of 2 psi with calibration traceable to NIST, should be used. The gages should have an accuracy of ± 0.5%. The same model gages should be used for P_1 and P_2. The gages may be analog or digital.
    b. Discharge device – water will be discharged through fixed, fire department straight stream nozzle tips. Tip sizes should be 0.5 (½), 0.625 (⅝), 0.75 (¾), 0.875 (⅞), 1.0 (1), 1.125 (1 ⅛), 1.25 (1 ¼), 1.5 (1 ½), 1.75 (1 ¾), and 2.0 (2) inch diameter. The tips should be secured to a monitor nozzle of other hose control device. The 19th Edition of the *NFPA Fire Protection Handbook*, Table 10.5.1, can be used to determine flow based on velocity pressure from the pitot reading, P_v. The flow rate in the *NFPA Fire Protection Handbook* is calculated by:

- $Q = 29.68\ cd^2\ \sqrt{P_v}$, where:
  - Q = flow, gpm
  - c = friction loss coefficient, assumed to be 1.0 for fire department smooth bore nozzles in the NFPA table
  - d = nozzle tip diameter, inches
  - P_v = velocity pressure (as measured by the pitot gage), psi

3. Hose – the number and types of hose to be tested will be coordinated with each individual participating fire service organization.
4. Miscellaneous Equipment
   a. Volumetric containers (optional) – 55 gal drum, 275 gallon composite intermediate bulk containers, or portable drafting tank. This could be used to provide a rough flow check against pitot tube measurements for low flow nozzle situations (e.g., 100 gpm nozzle flow).
   b. Reducers (adapters), and couplings, and "pony" sections of hose – a number of reducers and couplings will be needed, based on the exact set-up. Figures 2-4 show the adapters which will be needed.
   c. 2.5 in. calibrated turbine flow meter – to be provided by a technical panel member for lower flow (less than 500 gpm) set-ups.
   d. Pressure relief valve (optional, to be provided by a technical panel member) – pressure relief valves may be provided as an additional safety feature for large diameter hose testing. These could be located at either the inlet or outlet side of the hose test section, or both ends. They would be set at or near the maximum operating pressure for large diameter hose, 185 psi.
   e. Gate valve – gate valves located before and after the test section could be used to isolate the test section. A gate valve after the test section could also be used to throttle flow to the nozzle tip.

Flow and test equipment, much of which may be provided on a voluntary basis, by a member of the technical panel.

A6. TEST SETUP

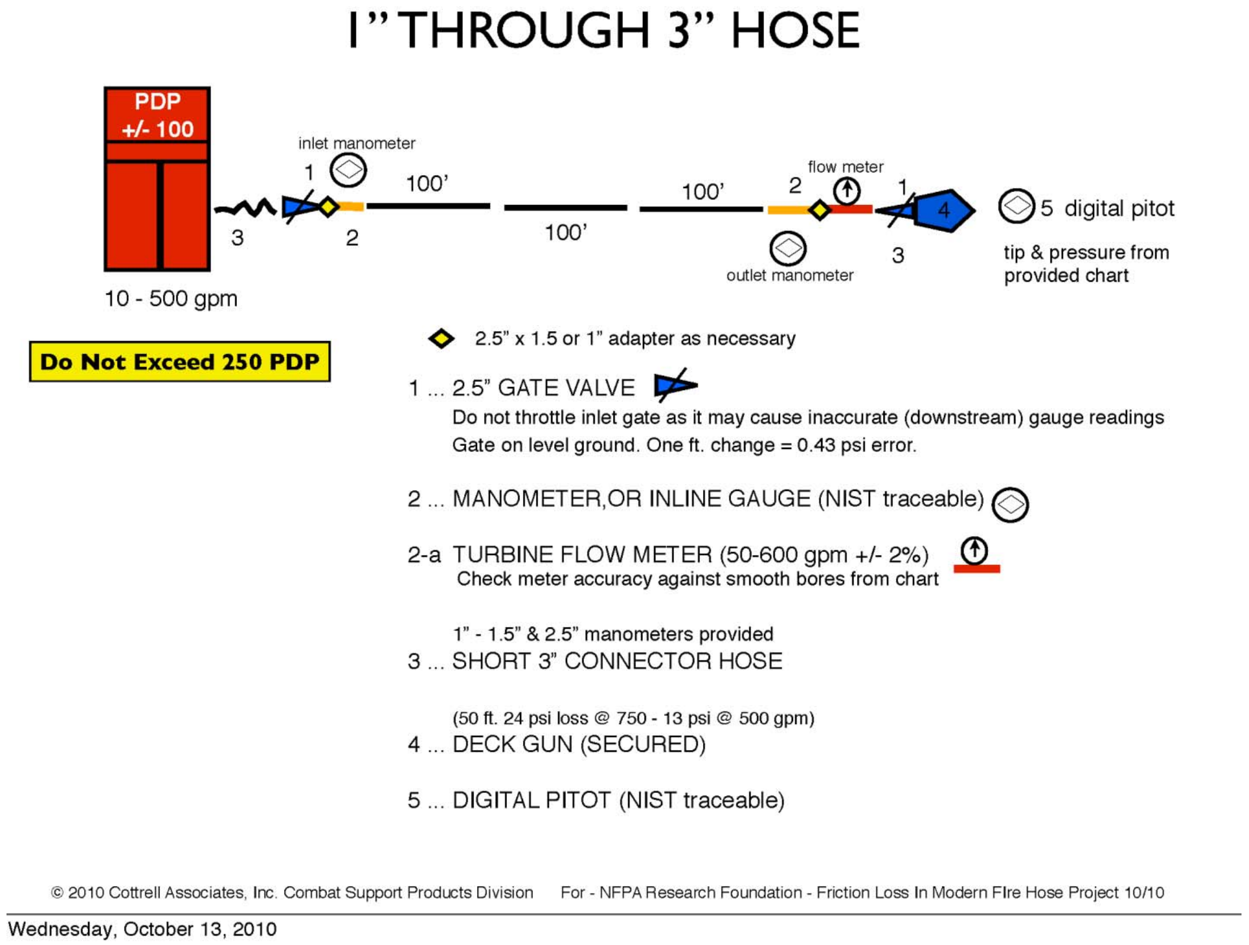
The general test setup is shown in Figure A-1. There are two basic flow set-ups:

1. Hose 1.0 in. diameter through 2.5 in. diameter with water flow points less than or equal to 500 gpm; and
2. Hose 4.0 and 5.0 in. diameter, with most flow points greater than 500 gpm. Most of the equipment for this set-up will be provided by a member of the project technical panel.

Flow diagrams for each set-up are shown in Figures 2, 3, and 4 courtesy of Technical Panel Member Jim Cottrell.

A6.1 Low Flow Setup

Figure A-2 shows a representative low flow set-up. For 2.5 in. diameter hose and less, a single discharge base nozzle can be used. The nozzle tips should be varied to achieve the desired flow and velocity pressure characteristics (see Section 7.4, Table A-1). A calibrated turbine flow meter (provided by a member of the project technical panel) may be installed between the P_2 pressure measurement and the discharge orifice. This can be used to compare the accuracy of the pitot readings. Alternatively, for lower flows (e.g., 150 gpm and less), fixed volumetric vessels can be used to perform a time/volume discharge calculation as a check against the flow established from the pitot reading.



◆ 2.5" x 1.5 or 1" adapter as necessary

1 ... 2.5" GATE VALVE
Do not throttle inlet gate as it may cause inaccurate (downstream) gauge readings
Gate on level ground. One ft. change = 0.43 psi error.

2 ... MANOMETER,OR INLINE GAUGE (NIST traceable)

2-a TURBINE FLOW METER (50-600 gpm +/- 2%)
Check meter accuracy against smooth bores from chart

1" - 1.5" & 2.5" manometers provided
3 ... SHORT 3" CONNECTOR HOSE

(50 ft. 24 psi loss @ 750 - 13 psi @ 500 gpm)
4 ... DECK GUN (SECURED)

5 ... DIGITAL PITOT (NIST traceable)

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Wednesday, October 13, 2010

Figure A-2. Representative 1 in. through 3 in. diameter hose set-up

Example Volumetric Flow Calculation

A 1.5 in. diameter handline is discharged into a 36 in. wide x 40 in. long x 50 in. high IBC. During 30 seconds of discharge, 14 in. of water are discharged into the vessel. The flow is calculated to be 175 gpm, based on:

1 gal water = 0.134 ft^3 = 231 $in.^3$

36 x 40 x 14 in. = 20,160 $in.^3$ of water discharged

$$\frac{20{,}160\ \mathrm{in}^3}{231\ \mathrm{in}^3/\mathrm{gal}} = 87.3\ \mathrm{gal}$$

$$\frac{87.3\ \mathrm{gal}}{30\ \mathrm{seconds}} \mathrm{x}\ \frac{60\ sec.}{1\ min} = 175\ \mathrm{gpm}$$

A short “pony” section of 2.5 in. diameter or larger hose should be used to connect the pumper with the test section, with the P_1 pressure gage installed just upstream of the first test section. The P_1 and P_2 pressure gages should be installed in a tapped 2.5 in female/male adapter or an equivalent assembly. For hose test sections other than 2.5 in., reducers (2.5 x 1.75, 2.5 x 1.5, 2.5, and 1.0) will be needed to connect the pony section and test hose. Likewise, at the discharge end of the test section, similar sized increases will be needed to connect to the 2.5 in. P_2 pressure coupling.

Downstream of the P_2 gage assembly, the turbine flow meter should be installed if available. It is recommended that a control value be installed after P_2 but before the nozzle assembly to throttle and control flow to the nozzle. This, along with the control value at the pump, allows test sections to be readily changed out.

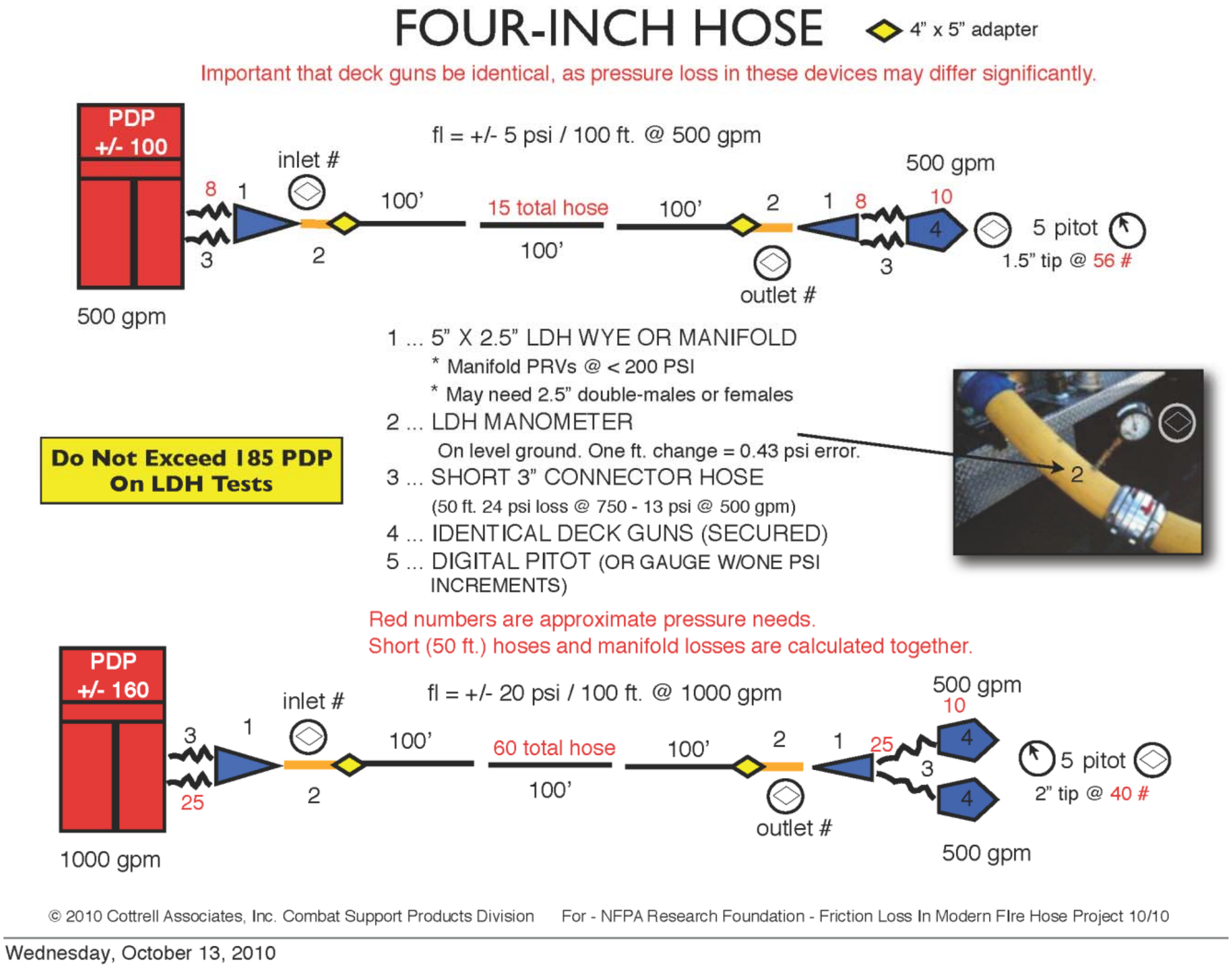
The deck nozzle assembly should be securely fastened to eliminate any movement. Pitot tube measurements are made at the nozzle tip.

A6.2 High Flow Setup

Representative high flow set-ups, much of which was provided on a voluntary basis by a member of the technical panel, are shown in Figures A-3 and A-4. They are essentially the same as the low flow set-up, except that:

1. Inline 4/5 in. pressure gages are not readily available. They will be provided by a technical panel member;
2. No additional flow calibration will be available; and
3. Two discharge nozzle assemblies/monitor nozzles are needed to achieve the higher flow rates.

Prior to initiating tests, the participating fire service organization shall submit a test schematic showing any proposed deviations from the schematics shown in Figures A-1–A-4. This should be discussed with the project coordinator before initiating any tests.


FOUR-INCH HOSE

Important that deck guns be identical, as pressure loss in these devices may differ significantly.

1 ... 5” X 2.5” LDH WYE OR MANIFOLD
* Manifold PRVs @ < 200 PSI
* May need 2.5” double-males or females
2 ... LDH MANOMETER
On level ground. One ft. change = 0.43 psi error.
3 ... SHORT 3” CONNECTOR HOSE
(50 ft. 24 psi loss @ 750 - 13 psi @ 500 gpm)
4 ... IDENTICAL DECK GUNS (SECURED)
5 ... DIGITAL PITOT (OR GAUGE W/ONE PSI INCREMENTS)

Red numbers are approximate pressure needs.
Short (50 ft.) hoses and manifold losses are calculated together.

Do Not Exceed 185 PDP On LDH Tests

For - NFPA Research Foundation - Friction Loss In Modern Fire Hose Project 10/10

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Figure A-3. Representative 4 in. diameter hose set-up

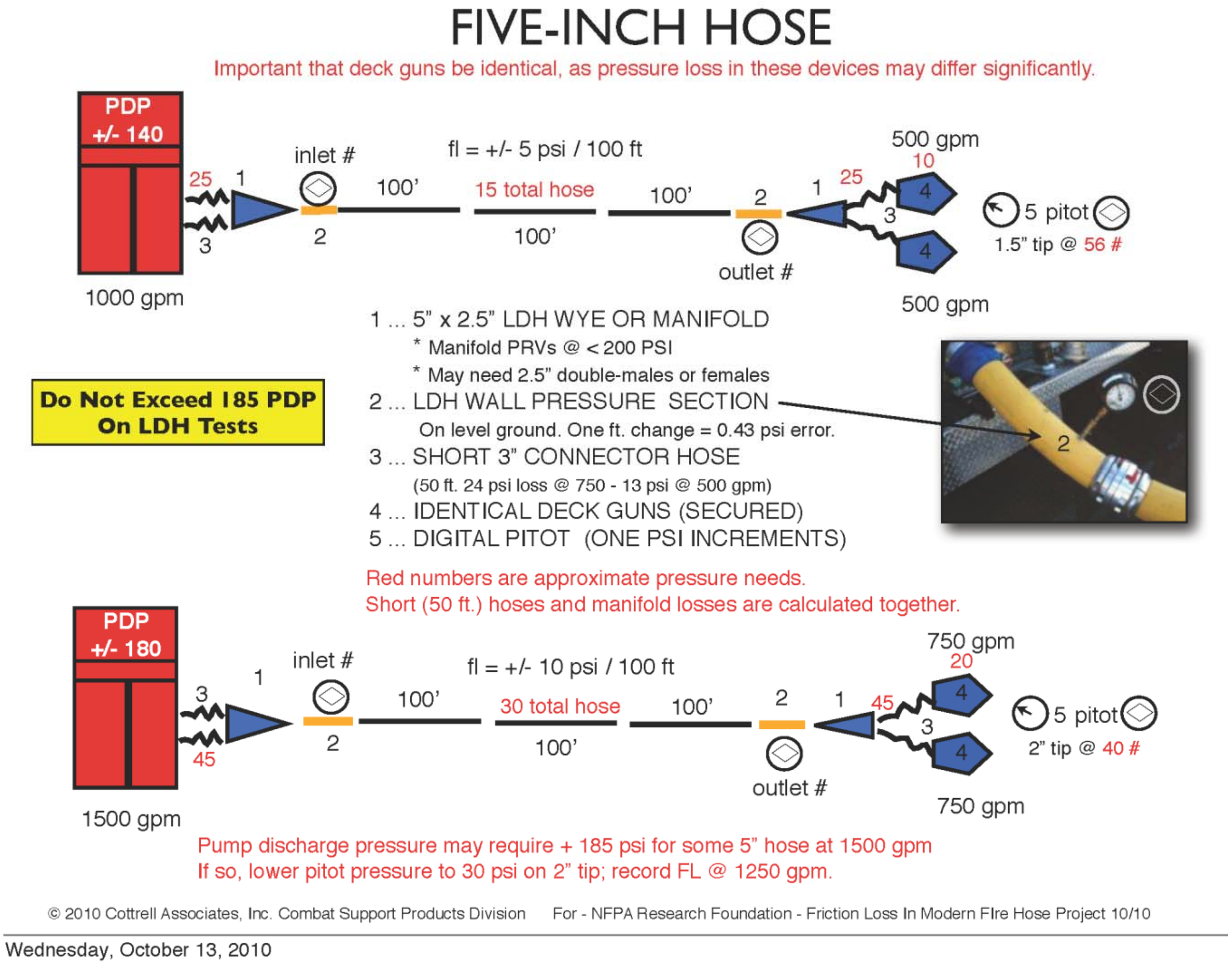

Figure A-4. Representative 5 in. diameter hose set-up

A7. TEST PROCEDURES

Six hose manufacturers have volunteered to submit products for evaluation. Three fire service facilities have agreed to perform the evaluations. The hose test sections have been identified and divided among the facilities. Each fire service facility will test a group of hoses from two manufacturers. Additionally, they will test, in a “round robin” fashion, one 1.75 in. diameter hose from two other manufacturers. This will provide a cross check of results between fire service facilities. A test data sheet has been prepared and is provided separately for use by the fire service organizations. This template can be used for each individual test. The template should be electronically stored with the facility information completed at the top. Thereafter, the template can be copied and saved with the file name of the test number. Numbering should be sequential and coded for the manufacturer, hose diameter, and construction:

- A1.0a (Manufacturer A, 1.0 inch, a, b, c designations for different construction types such as rubber lined or extruded), A1.0b, A1.5a, A1.5b, A1.75a etc… A5.0a.
- B1.0a, B1.0b,….Manufacturer B

- C1.75 (round robin test of 1.75 in. hose from Manufacturer C)
- D1.75 (round robin test of 1.75 in. hose from Manufacturer D)

Test sites can designate manufacturers however they like. The project coordinator will collate the data and report out the information blind of any manufacturer identification.

A7.1 Shakedown Tests

Prior to testing the designated hose sections, the set-up described in Section 6.1 should be constructed and water flushed through the system to remove any debris. After flushing, a nozzle tip should be attached to the nozzle assembly. A "shakedown" flow test should be conducted at a predetermined pressure/flow to check that all instruments and equipment are working properly. A flow check should be performed for the low flow set-up using the turbine flow meter or timed volume test method compared to a pitot reading and associated flow calculation (see Section 7.1). Use of a 1.5 or 1.75 in. hose in the 100–150 gpm range is recommended for this flow check. If an actual test specimen is used, the 10 psi length and diameter measurement can also be performed during this shakedown period.

If there is an elevation change between P_1 and P_2, it should be recorded as positive or negative as shown in Figure A-1. To determine if there is any elevation difference, the test section should be charged. Any difference in static pressure between P_1 and P_2, is the elevation pressure (plus or minus depending on the orientation, see the data sheet for the convention). The data sheet is designed to automatically calculate the pressure difference and correct the measured flow.

A7.2 Hose Diameter

Manufacturers will be submitting a "sales sample" of each product. These samples are uncoupled, short sections, as small as six (6) in. in length. The wall thickness should be measured for each sample and recorded to the nearest $1/100^{th}$ of an inch using calipers.

The outside hose diameter (O.D) should be measured to the nearest $1/100^{th}$ of an inch using the outside diameter tape. Additionally, this O.D will be measured as a function of hose pressure in the friction loss tests as described in Section 7.4.

A7.3 Hose Length

The total length of the test section of the hose should be measured when unpressurized. After the hose is laid out completely straight, the measurement should be taken from the inside edge of the couplings.

The hose should then be changed to 10 psi static pressure. The length of the hose should again be measured at this static pressure.

A7.4 Friction Loss and Outside Diameter Tests

After completion of the shakedown, diameter, and length tests, friction loss tests should be conducted for each hose sample at a range of flow rates. The desired flow rates for each size of hose, and flow point increments, are shown in Table A-1. Pressure should be adjusted using the pump and/or P_2 gate valve to achieve the desired flow. The actual flow does not have to be exactly the desired test flow, but should be within ± 2.5% if possible. The approximate P_v for the desired flow has been determined as shown in Table A-1, based on the *NFPA Fire Protection Handbook* data (Table 10.5.1, based on Q (gpm) = 29.68 cd $\sqrt[2]{Pv}$ where C = 1.0 d is nozzle diameter in inches, a P_v is pitot velocity pressure in psi). This table will be provided to the test facilities as a calculation spreadsheet so that tip sizes, flow, and velocity pressures can be readily assessed. Alternatively, a copy of the Table 10.5.1 can be used on-site.

For each flow increment, inlet pressure P_1 and outlet pressure P_2 should be recorded to the nearest 1.0 psi. P_v should be recorded to the nearest 0.5 psi. After a consistent stream is achieved and there is no air in the hose line, the pitot blade should be inserted into the center of water stream. The end of the blade should be held at a distance from the nozzle of one half the diameter of the nozzle opening. If the needle fluctuates, the average should be recorded. In the data spreadsheet, Q is automatically calculated for the recorded P_v. For each flow point, the outside diameter of the test hose should be measured near the beginning of the test section, i.e., just downstream of P_1.

Under no condition should the discharge pressure at the pump panel exceed the operating pressure of the hose: 275 psi for forestry and attack hose (1–2.5 in. diameter); 185 psi for supply hose (4 and 5 in. large diameter hose). The nominal flow points in Table A-1 have been established so they do not exceed this pressure, assuming a nozzle operating pressure on the order of 50 psi using the nozzle tip sizes shown in Table A-1. **Note, the friction loss in the short pony sections and the monitor nozzles have not been included in these estimates.**

A8. DATA REPORTING

The data should be recorded in the spreadsheet provided. For each nominal diameter of hose tested, copy the template and store as a new data sheet. Record the pertinent hose data. Any deviation from the test plan should be noted. Of particular importance is the size of hose couplings compared to the hose size; a notation should be made if they are different.

The spreadsheet has been set-up to automatically calculate the Q_T of the range of nozzle tips to be used.

Note any deviations to the standard test setup as shown in Figures A-1, A-2, or A-3 and described in Sections 6 and 7.

Table A-1. Hose Testing – Test Flow Points

Hose Length (x100ft)	**3**				
Hose Diameter (in.)	**Target Flow Rate (gpm)**	**Est. Friction Loss**	**Noz./Tip Diam**	**Pitot Reading**	**Est. Pump Press**
	(gpm)	(psi)	(inches)	(psi)	(psi)
1	20	18	0.375	23	41
	30	41	0.375	51	92
	40	72	0.500	29	101
	50	113	0.500	45	157
	60	162	0.625	26	188
1.5	50	18	0.500	45	63
	70	35	0.625	36	71
	90	58	0.625	60	118
	110	87	0.750	43	130
	130	122	0.750	60	182
	150	162	0.875	43	205
1.75	50	12	0.500	45	57
	75	26	0.625	41	68
	100	47	0.750	35	82
	125	73	0.750	55	128
	150	105	0.875	43	148
	175	142	1.000	34	177
2.5	150	14	0.875	43	57
	200	24	1.000	45	69
	250	38	1.125	44	81
	300	54	1.250	41	95
	350	74	1.250	56	130
	400	96	1.375	50	146
	450	122	1.500	45	166
4	500	15	1.500	55	70
	700	29	1.750	59	88
	900	49	2.000	57	105
	1100	73	1.750	36	109
	1300	101	2.000	30	131
5	700	12	2.000	34	46
	900	19	2.000	57	76
	1100	29	1.750	36	65
	1300	41	1.750	51	91
	1500	54	2.000	39	93
	1700	69	2.000	51	120

*For 1100, 1300, 1500 and 1700 gpm tests, two deck guns and tips will be required.

A9. FACILITY AND SAFETY

The performing fire service organization should check with local water and/or environmental authorities to identify any restrictions on water use and discharge. Some authorities are restrictive on the amount of water which may be used, and the discharge onto land or into sewers. Water may have to be captured and recycled.

Participating organizations will be required to sign non-disclosure agreements.

Each fire service organization is responsible for preparing and implementing a safety plan for these tests. They should be in accordance with the organization's policies and procedures.

A hazard associated with these tests is the pressurization of hoses and discharge devices. All pressures/flows proposed for testing are below the operating and service the test pressures of the hose. However, hose may rupture. To the maximum extent possible, personnel should stay clear of the hose/discharge device when charged. Personnel should have eye and head protection. The discharge device should be securely fastened. Particular care should be used when securing fire hose nozzles.

No test should be performed at or above the stated operating or service pressure. The test setup has been designed so that this should not occur. Any deviation to the test setup and procedure should be reviewed with the project technical advisor prior to testing.

APPENDIX B –
TEST DATA SHEET

Hose Coefficient Test Data Sheet

Performing Organization: ________

Principal Investigator/POC:
Name: ________ Phone: ________ Email: ________

Hose

Manufacturer: ________ Model and Model #:

Hose Description/Construction: ________

Nominal Inside Diameter (check one): ☐ 1 in. ☐ 1.5 in. ☐ 1.75 in. ☐ 2.5 in. ☐ 4 in. ☐ 5 in.

Nominal length of each hose section : ________ ft.

Hose maximum operating pressure (check one): ☐ 275 psi (1.0 - 2.5 in.) ☐ 185 psi (4 in. and 5 in.)

Coupling size, if different than nominal hose diameter: ________ inches

Couplings (check one): ☐ Threaded NST ☐ Storz

Coupling Material: ☐ Brass ☐ Aluminum

Date of Tests: ________ (e.g. 10/29/10)

Data - Physical Characteristics

Hose outside diameter (O.D.) at 10 psi static pressure: ________ inches (e.g 1.000 inches)

Average Hose Wall Thickness: ________ inches

Approximate inside diameter (I.D.) at 10 psi: ________ inches (= O.D. - 2* Average Wall Thickness)

Length of 300 ft. test section at 0 psi static pressure: ________ ft. (inside coupling to inside coupling)

Length of 300 ft. test section at 10 psi static pressure: ________ ft. (inside coupling to inside coupling)

Elevation Change Check (during 10 psi static tests):

P_1 (nearest pumper): ________ psi

P_2 (nearest nozzle): ________ psi

$\Delta P = P_1 - P_2 =$ ________ psi (if negative, elevation change from P_1 to P_2 is positive. If positive, elevation change from P_1 to P_2 is negative.)

Hose Wall Thickness:
inches (e.g. 0.125 inches)

Test #1 ________
Test #2 ________
Test #3 ________
Test #4 ________

Flow check of test setup (provide details of flowmeter or volumetric check): ________

Test Data Sheet (for 1" hose)

Test Number: ____

Deviations from test setup:

Tip Size	Desired Flow Point	Desired P_v	Measured P_v	Calculated Q	Measured P_1	Measured P_2	Friction Loss	Corrected Friction Loss	Measured O.D.	Calculated I.D.
(in.)	(gpm)	(psi)	(psi)	(gpm)	(psi)	(psi)	(psi)	(psi)	(in.)	(in.)
0.375	20	23								
0.375	30	51								
0.500	40	29								
0.500	50	45								
0.625	60	26								

Test Data Sheet (for 1.5" hose)

Test Number: ______

Deviations from test setup:

Tip Size	Desired Flow Point	Desired P_v	Measured P_v	Calculated Q	Measured P_1	Measured P_2	Friction Loss	Corrected Friction Loss	Measured O.D.	Calculated I.D.
(in.)	(gpm)	(psi)	(psi)	(gpm)	(psi)	(psi)	(psi)	(psi)	(in.)	(in.)
0.500	50	45								
0.625	70	36								
0.625	90	60								
0.750	110	43								
0.750	130	60								
0.875	150	43								

Test Data Sheet (for 1.75" hose)

Test Number: ________

Deviations from test setup:

Tip Size	Desired Flow Point	Desired P_v	Measured P_v	Calculated Q	Measured P_1	Measured P_2	Friction Loss	Corrected Friction Loss	Measured O.D.	Calculated I.D.
(in.)	(gpm)	(psi)	(psi)	(gpm)	(psi)	(psi)	(psi)	(psi)	(in.)	(in.)
0.500	50	45								
0.625	75	41								
0.750	100	35								
0.750	125	55								
0.875	150	43								
1.000	175	34								

Test Data Sheet (for 2.5" hose)

Test Number: ________

Deviations from test setup:

Tip Size	Desired Flow Point	Desired P_v	Measured P_v	Calculated Q	Measured P_1	Measured P_2	Friction Loss	Corrected Friction Loss	Measured O.D.	Calculated I.D.
(in.)	(gpm)	(psi)	(psi)	(gpm)	(psi)	(psi)	(psi)	(psi)	(in.)	(in.)
0.875	150	43								
1.000	200	45								
1.125	250	44								
1.250	300	41								
1.250	350	56								
1.375	400	50								
1.500	450	45								

Test Data Sheet (for 4" hose)

Test Number: ____________

Deviations from test setup:

Tip Size	Desired Flow Point	Desired P_v	Measured P_v	Calculated Q	Measured P_1	Measured P_2	Friction Loss	Corrected Friction Loss	Measured O.D.	Calculated I.D.
(in.)	(gpm)	(psi)	(psi)	(gpm)	(psi)	(psi)	(psi)	(psi)	(in.)	(in.)
1.500	500	55								
1.750	700	59								
2.000	900	57								
1.750	1100*	36								
2.000	1300*	30								

* - At this flow rate, two nozzle tips are required.

Test Data Sheet (for 5" hose)

Test Number: ________

Deviations from test setup:

Tip Size	Desired Flow Point	Desired P_v	Measured P_v	Calculated Q	Measured P_1	Measured P_2	Friction Loss	Corrected Friction Loss	Measured O.D.	Calculated I.D.
(in.)	(gpm)	(psi)	(psi)	(gpm)	(psi)	(psi)	(psi)	(psi)	(in.)	(in.)
2.000	700	34								
2.000	900	57								
1.750	1100*	36								
1.750	1300*	51								
2.000	1500*	39								
2.000	1700*	51								

* - At this flow rate, two nozzle tips are required.

APPENDIX C –

PLOTS OF DIMENSIONLESS FRICTION LOSS COEFFICIENT, f, BY HOSE LINER MATERIAL AND FORMING METHOD

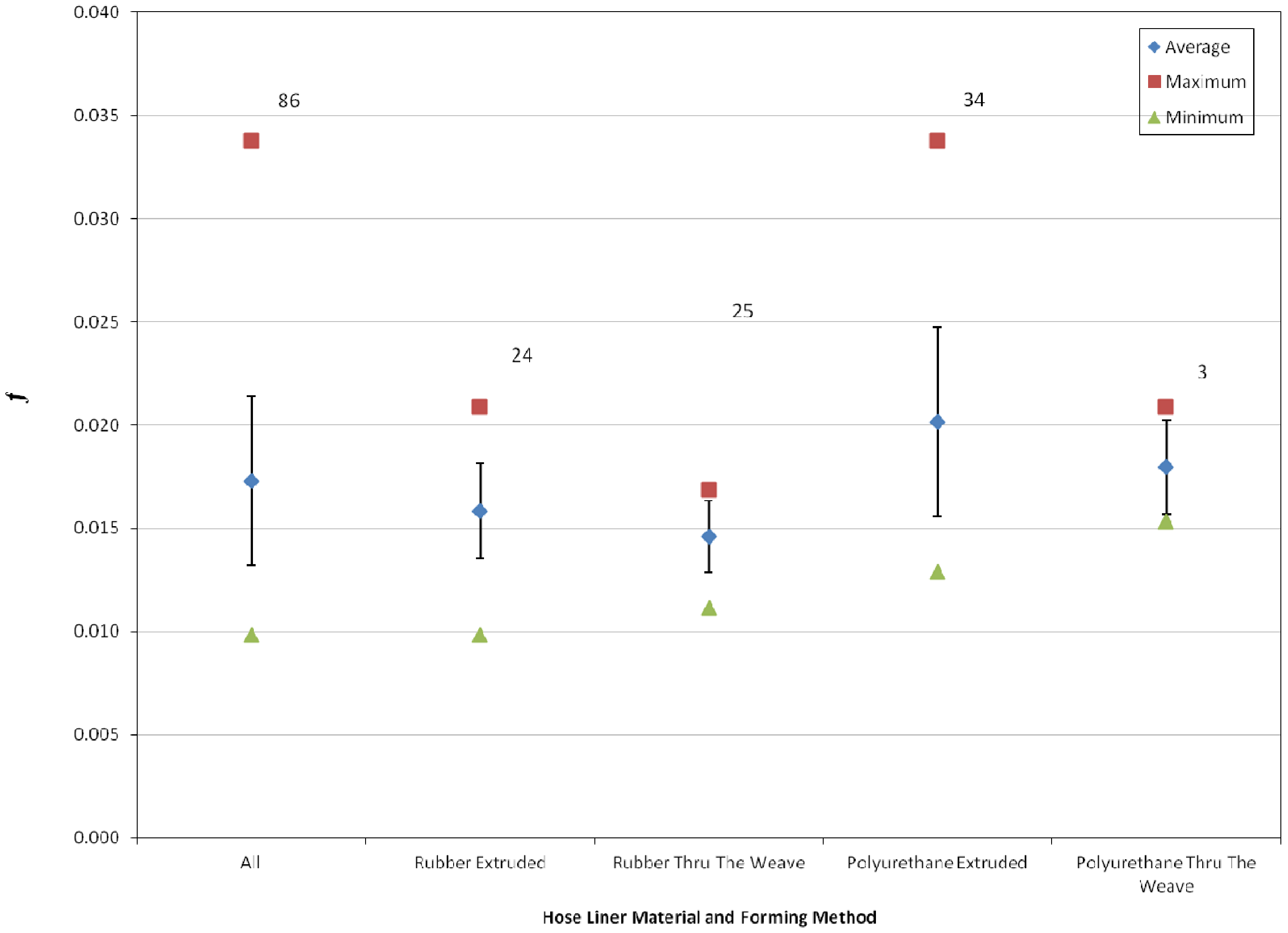

Figure C.1. Plot of Friction Loss Coefficient, *f*, by Hose Liner Material and Forming Method - All Hose Sizes.

Note: Error bars shown as the first standard deviation from the average. The number of tests is noted for each Hose Liner Material and Forming Method.

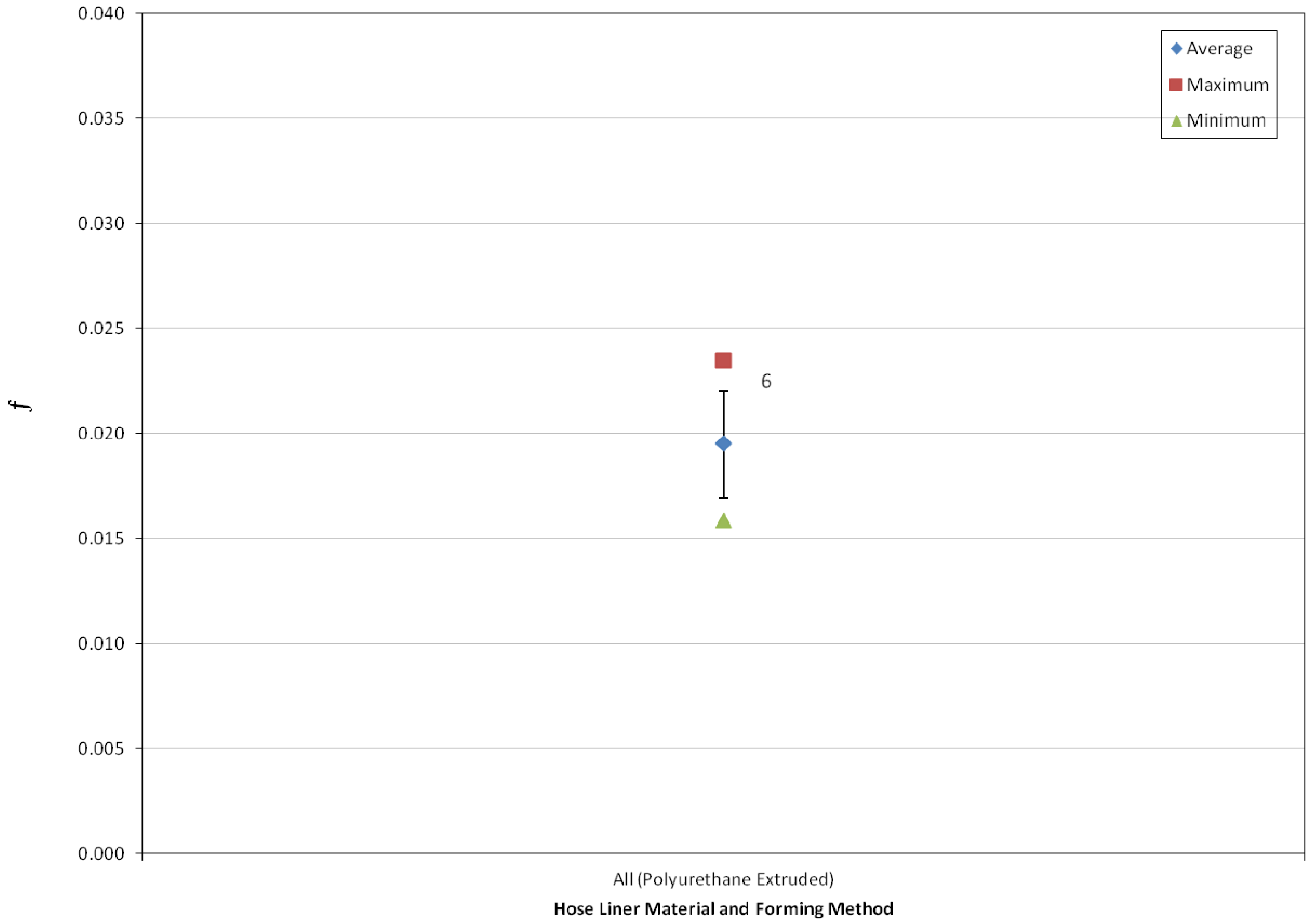

Figure C.2. Plot of Friction Loss Coefficient, *f*, by Hose Liner Material and Forming Method – 1.0 inch Hoses.

Note: Error bars shown as the first standard deviation from the average. The number of tests is noted for each Hose Liner Material and Forming Method.

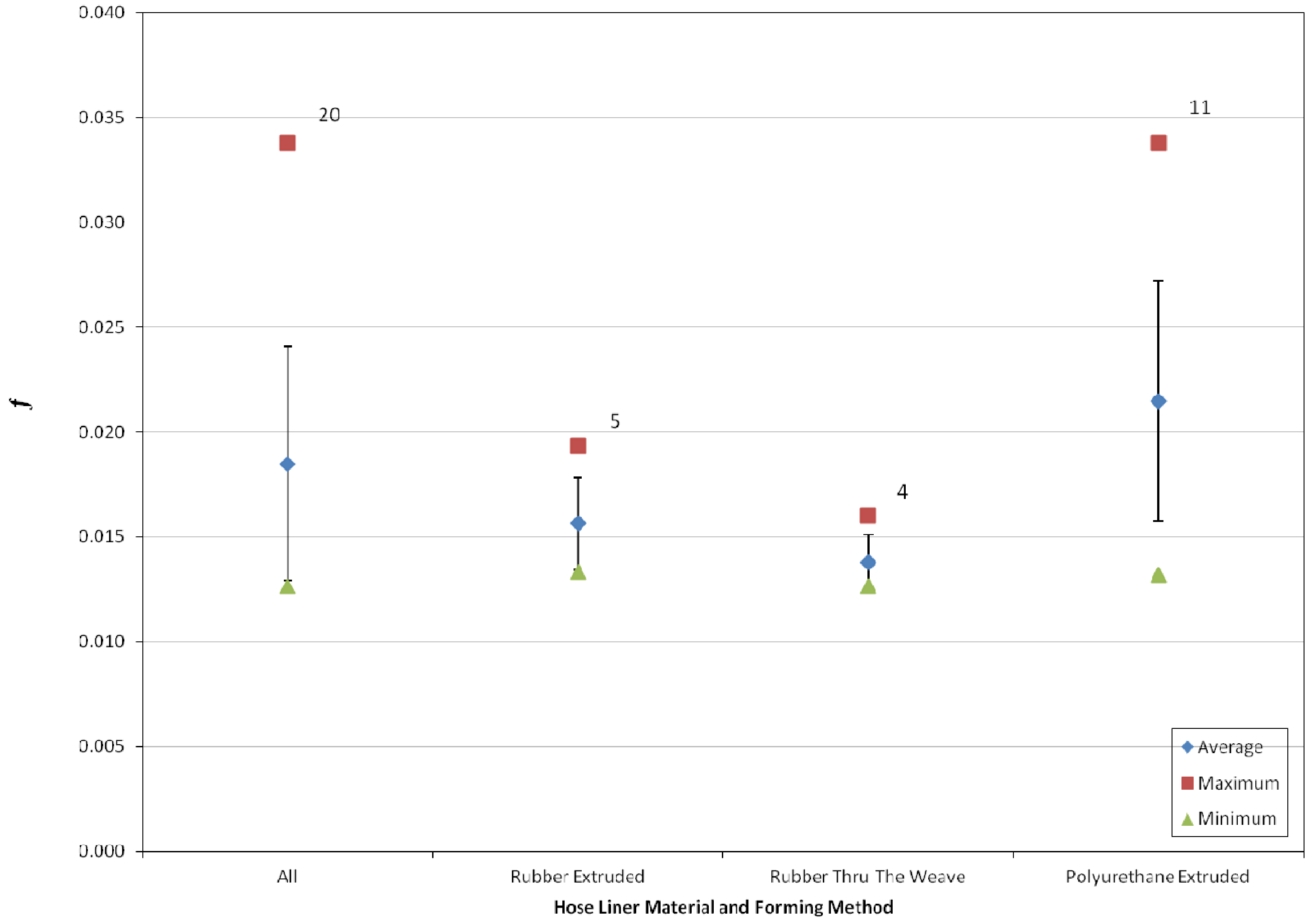

Figure C.3. Plot of Friction Loss Coefficient, *f*, by Hose Liner Material and Forming Method – 1.5 inch Hoses.

Note: Error bars shown as the first standard deviation from the average. The number of tests is noted for each Hose Liner Material and Forming Method.

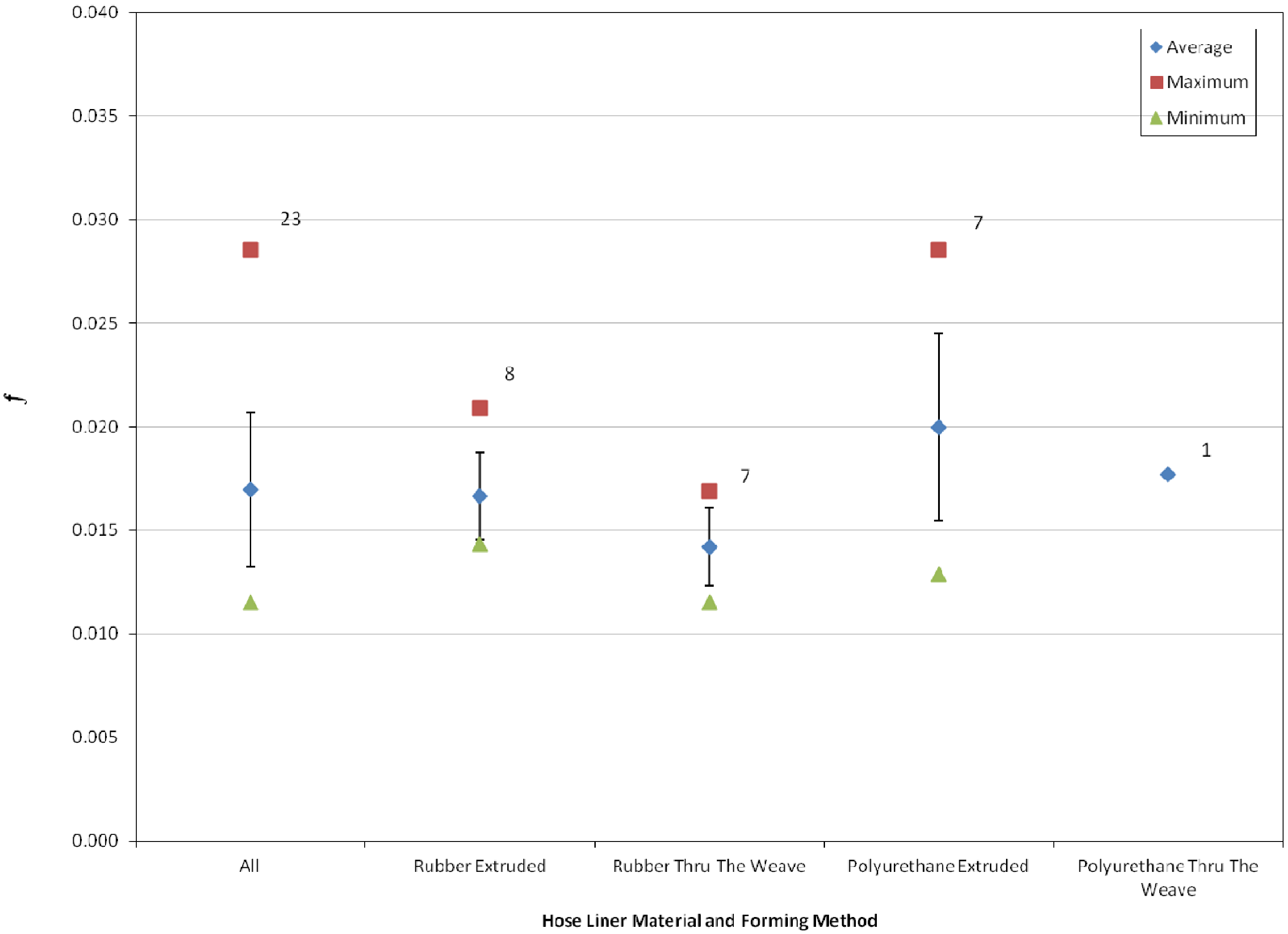

Figure C.4. Plot of Friction Loss Coefficient, *f*, by Hose Liner Material and Forming Method – 1.75 inch Hoses.

Note: Error bars shown as the first standard deviation from the average. The number of tests is noted for each Hose Liner Material and Forming Method.

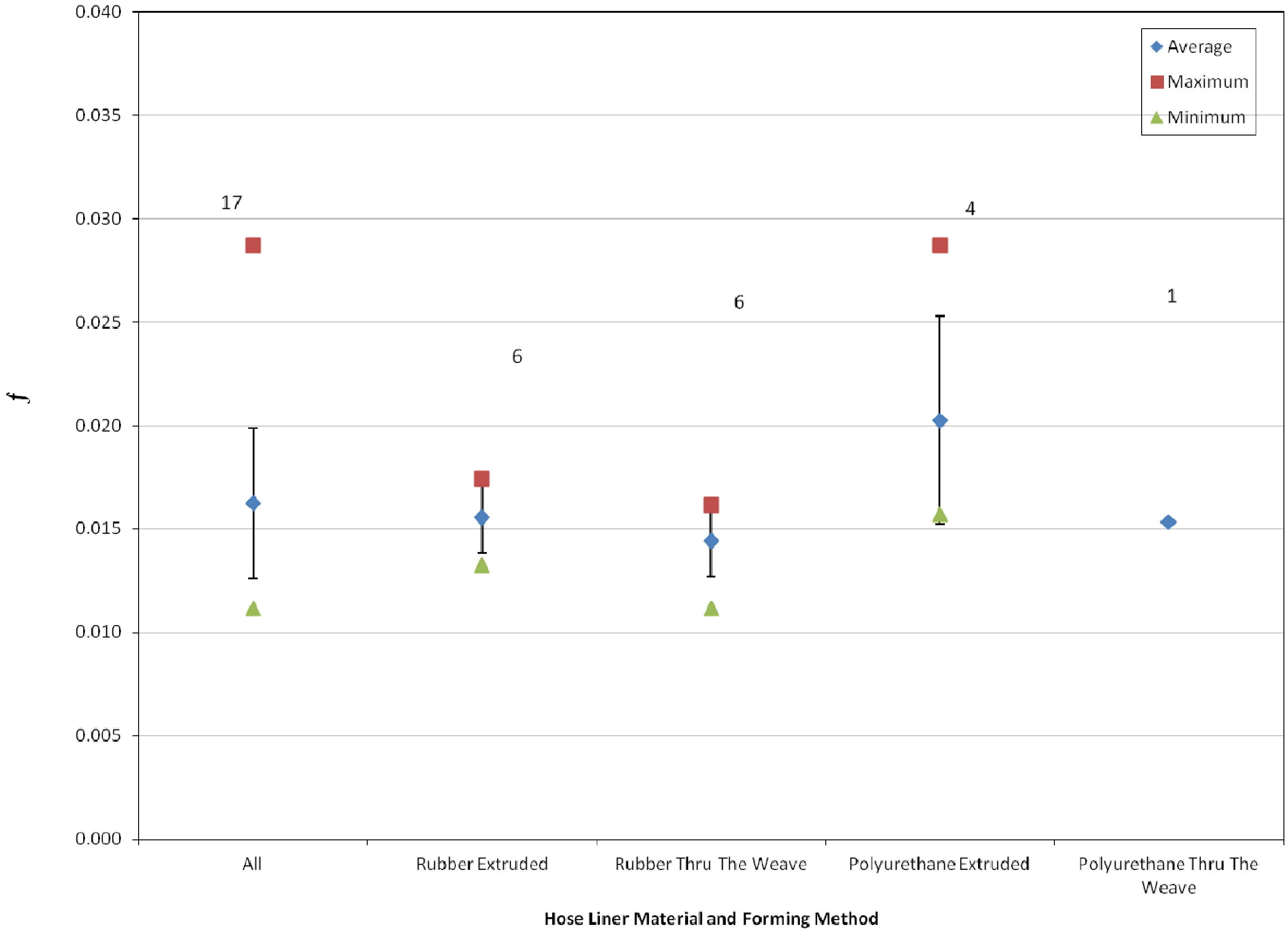

Figure C.5. Plot of Friction Loss Coefficient, *f*, by Hose Liner Material and Forming Method – 2.5 inch Hoses.

Note: Error bars shown as the first standard deviation from the average. The number of tests is noted for each Hose Liner Material and Forming Method.

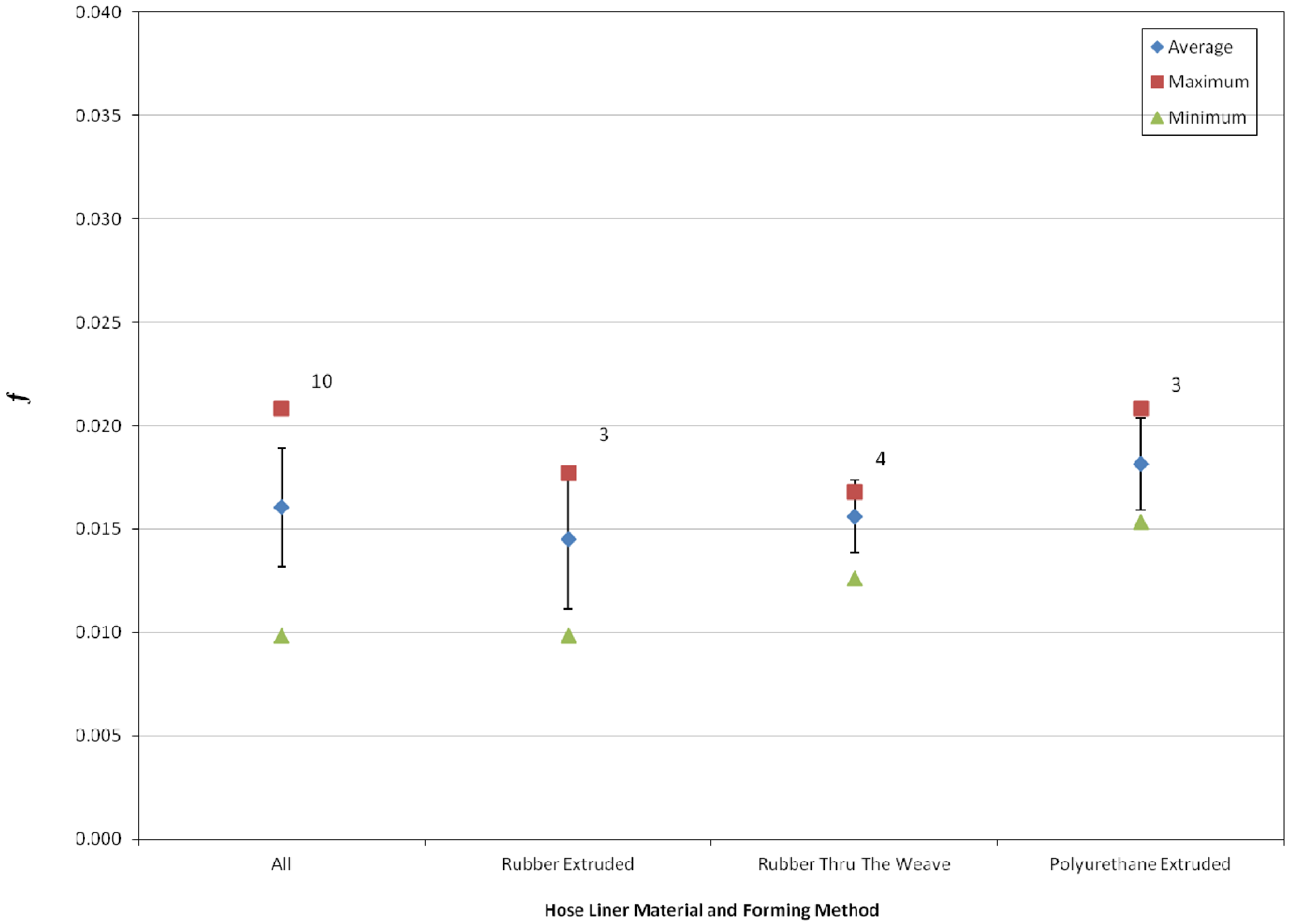

Figure C.6. Plot of Friction Loss Coefficient, *f*, by Hose Liner Material and Forming Method – 4 inch Hoses.

Note: Error bars shown as the first standard deviation from the average. The number of tests is noted for each Hose Liner Material and Forming Method.

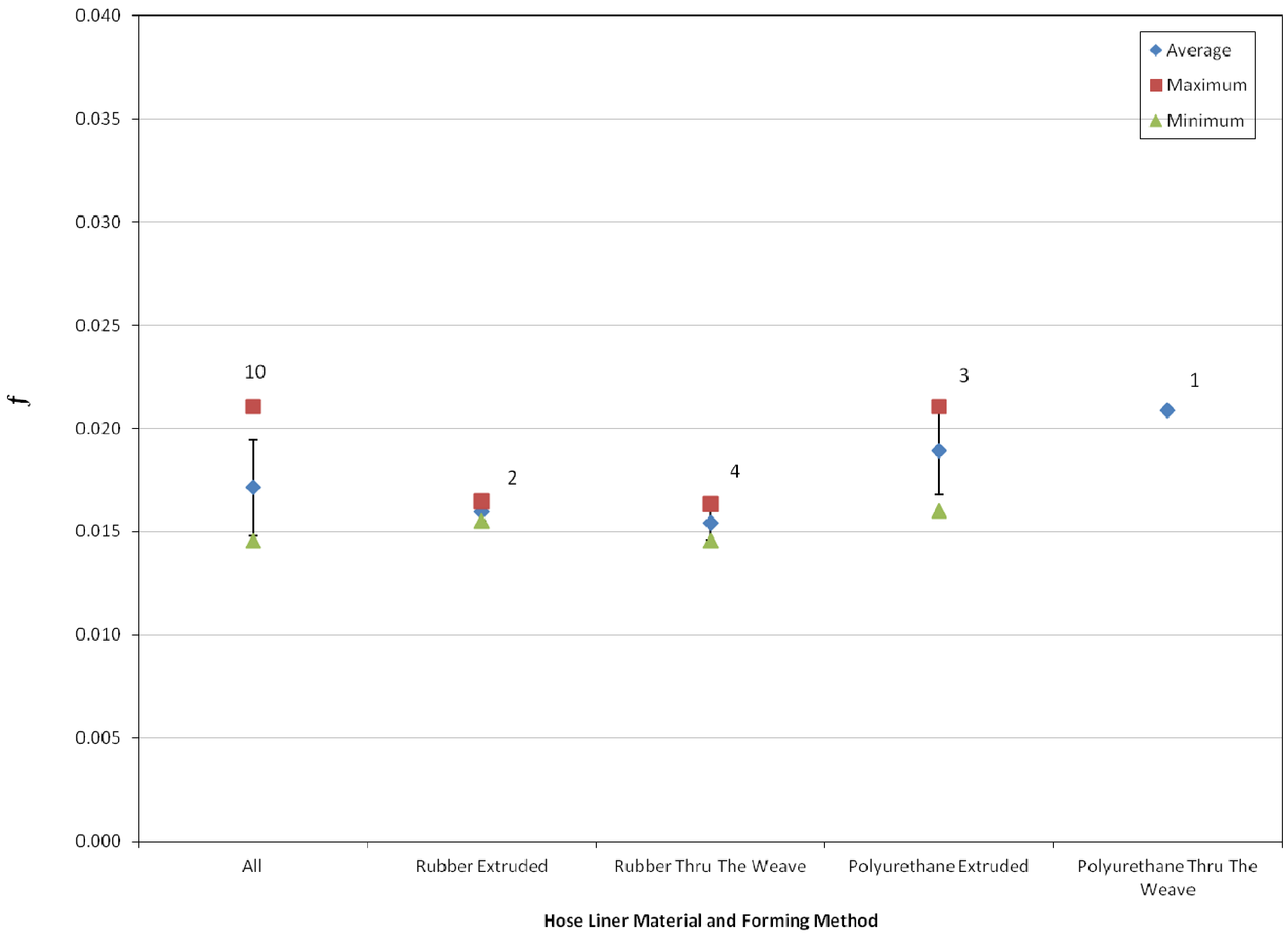

Figure C.7. Plot of Friction Loss Coefficient, *f*, by Hose Liner Material and Forming Method – 5 inch Hoses.

Note: Error bars shown as the first standard deviation from the average. The number of tests is noted for each Hose Liner Material and Forming Method.

APPENDIX D –
PLOTS OF FRICTION LOSS FACTOR, C, BY HOSE LINER MATERIAL AND FORMING METHOD

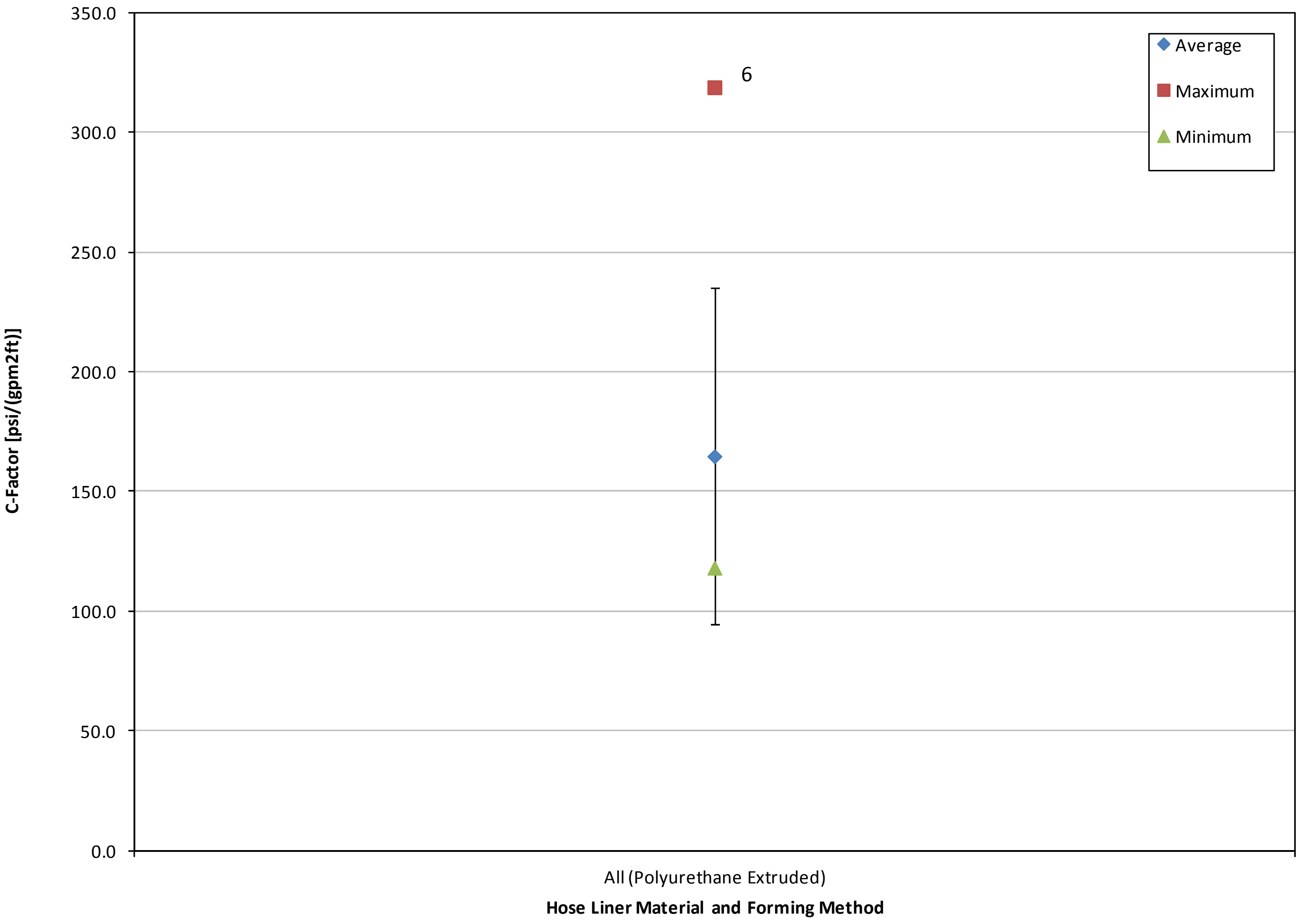

Figure D.1. Plot of Friction Loss Factor, C, by Hose Liner Material and Forming Method – 1-inch Hoses.

Note: Error bars shown as the first standard deviation from the average. The number of tests is noted for each Hose Liner Material and Forming Method.

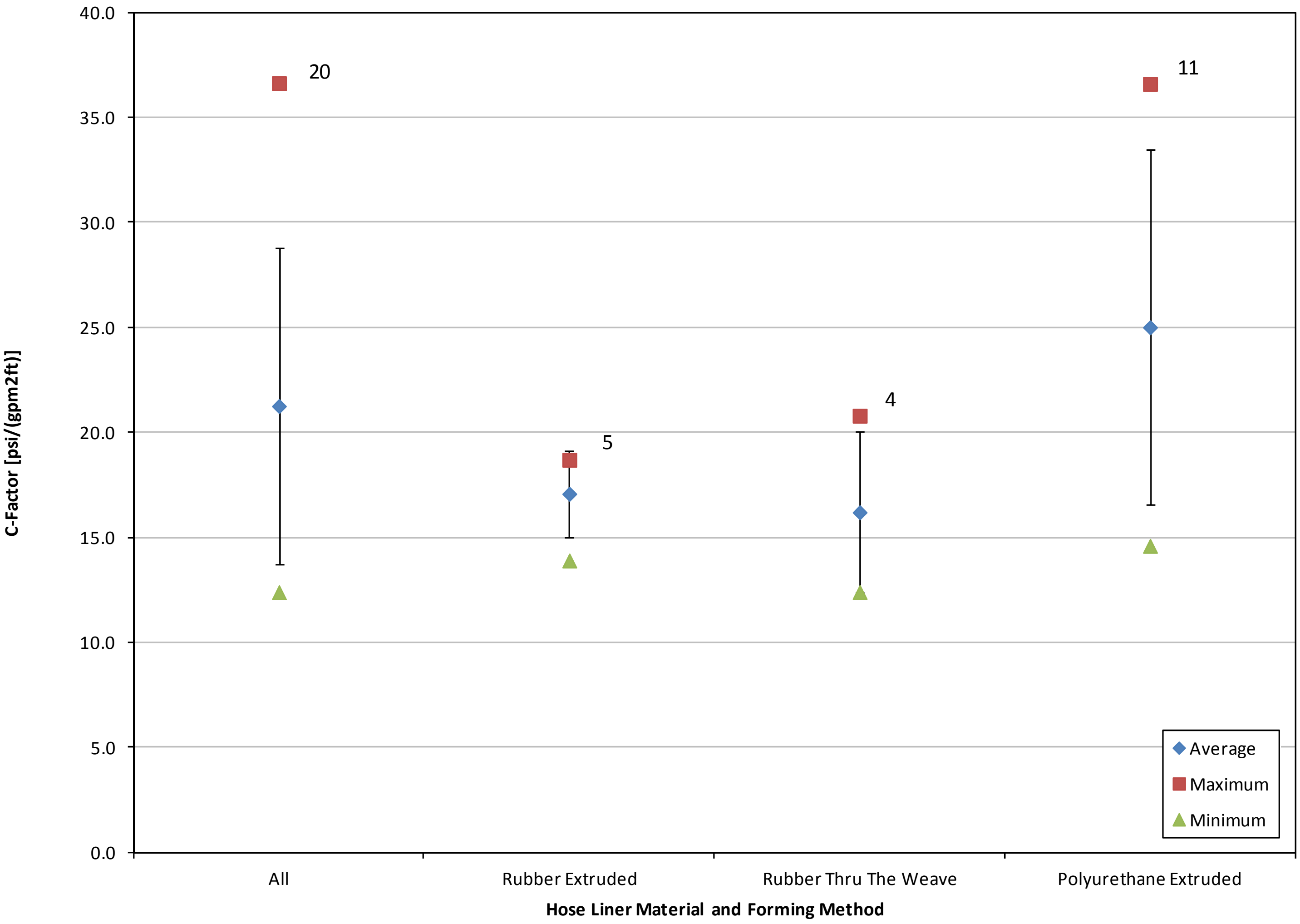

Figure D.2. Plot of Friction Loss Factor, C, by Hose Liner Material and Forming Method – 1.5-inch Hoses.

Note: Error bars shown as the first standard deviation from the average. The number of tests is noted for each Hose Liner Material and Forming Method.

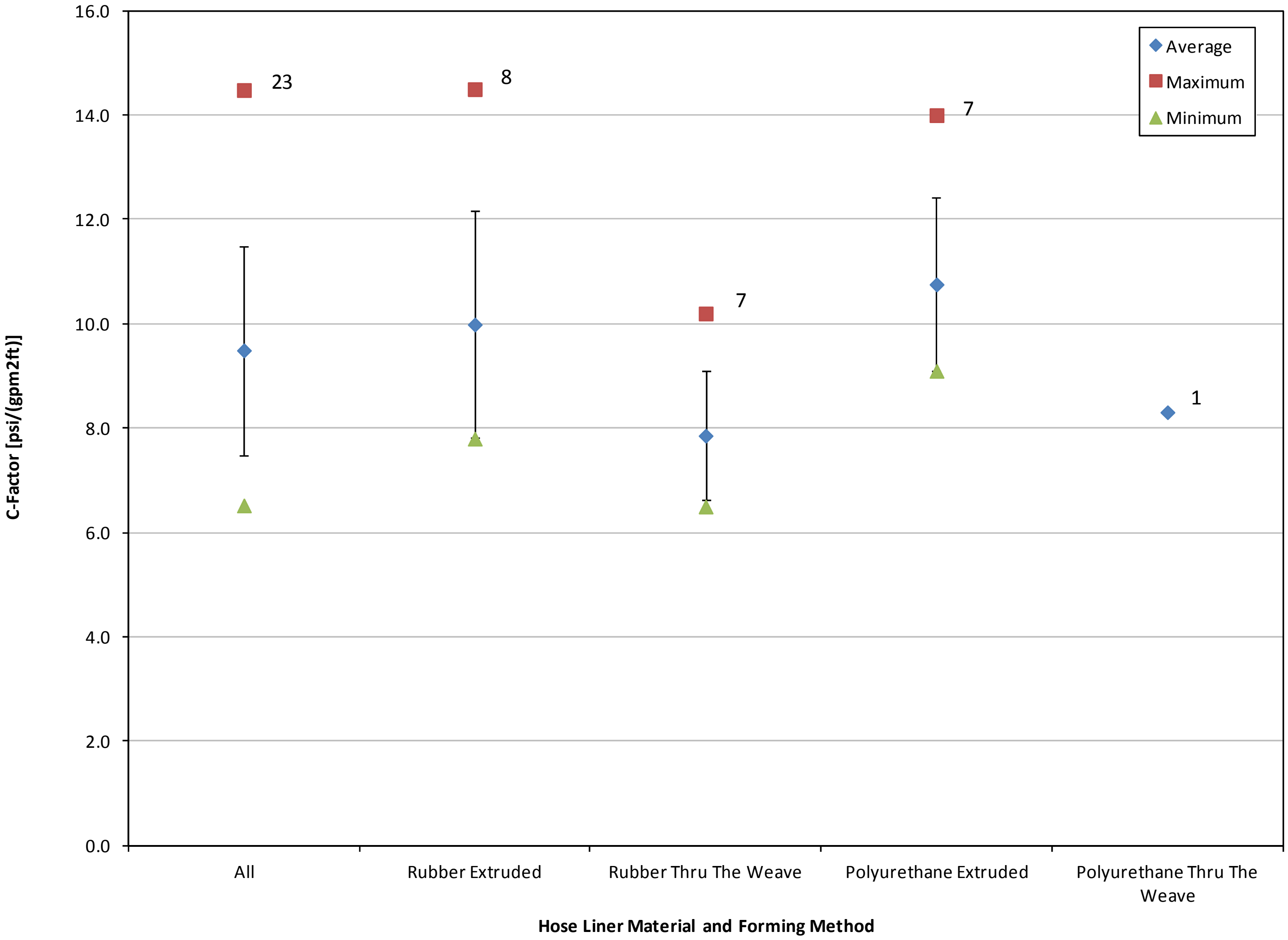

Figure D.3. Plot of Friction Loss Factor, C, by Hose Liner Material and Forming Method – 1.75-inch Hoses.

Note: Error bars shown as the first standard deviation from the average. The number of tests is noted for each Hose Liner Material and Forming Method.

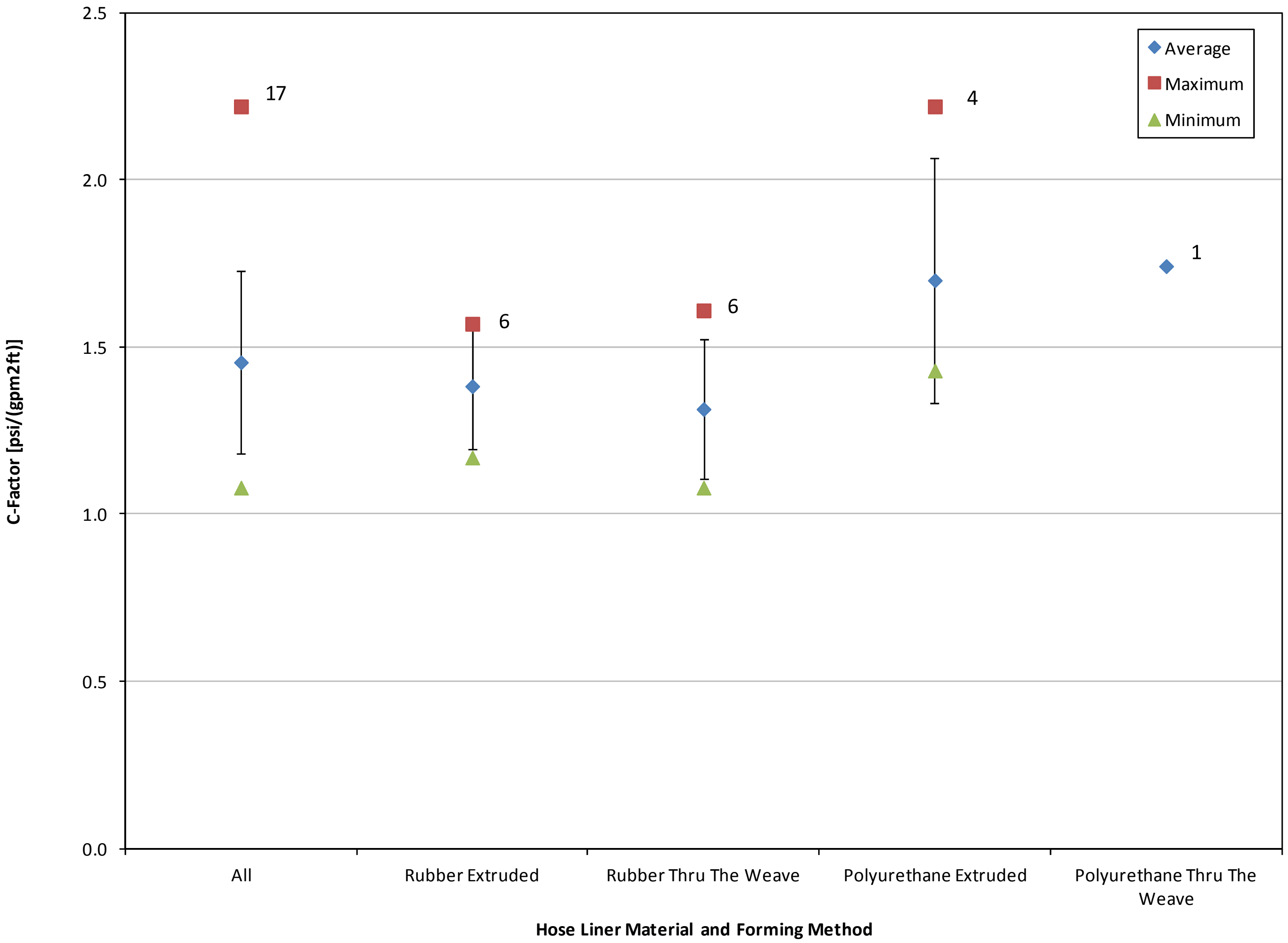

Figure D.4. Plot of Friction Loss Factor, C, by Hose Liner Material and Forming Method – 2.5-inch Hoses.

Note: Error bars shown as the first standard deviation from the average. The number of tests is noted for each Hose Liner Material and Forming Method.

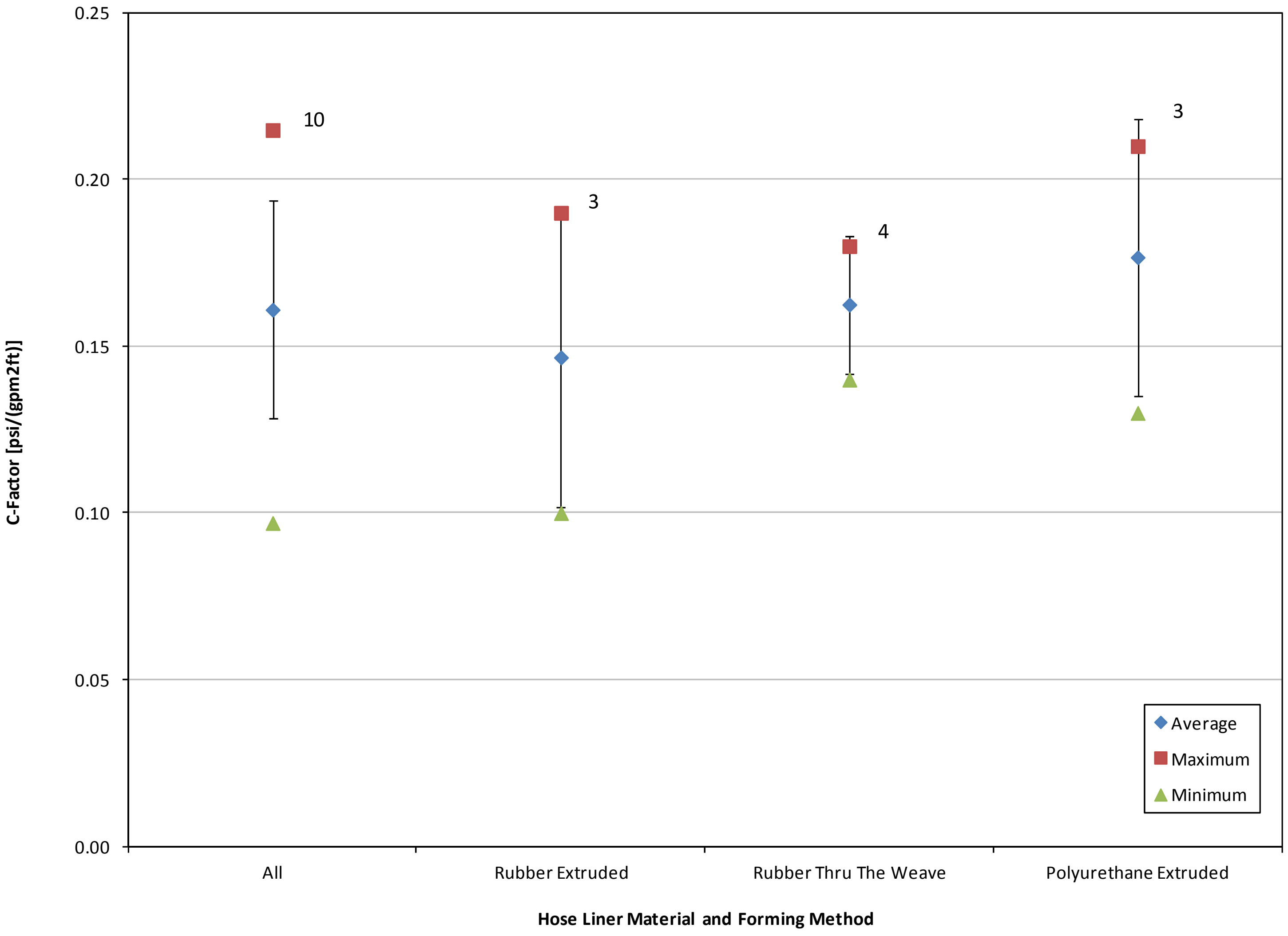

Figure D.5. Plot of Friction Loss Factor, C, by Hose Liner Material and Forming Method – 4-inch Hoses.

Note: Error bars shown as the first standard deviation from the average. The number of tests is noted for each Hose Liner Material and Forming Method.

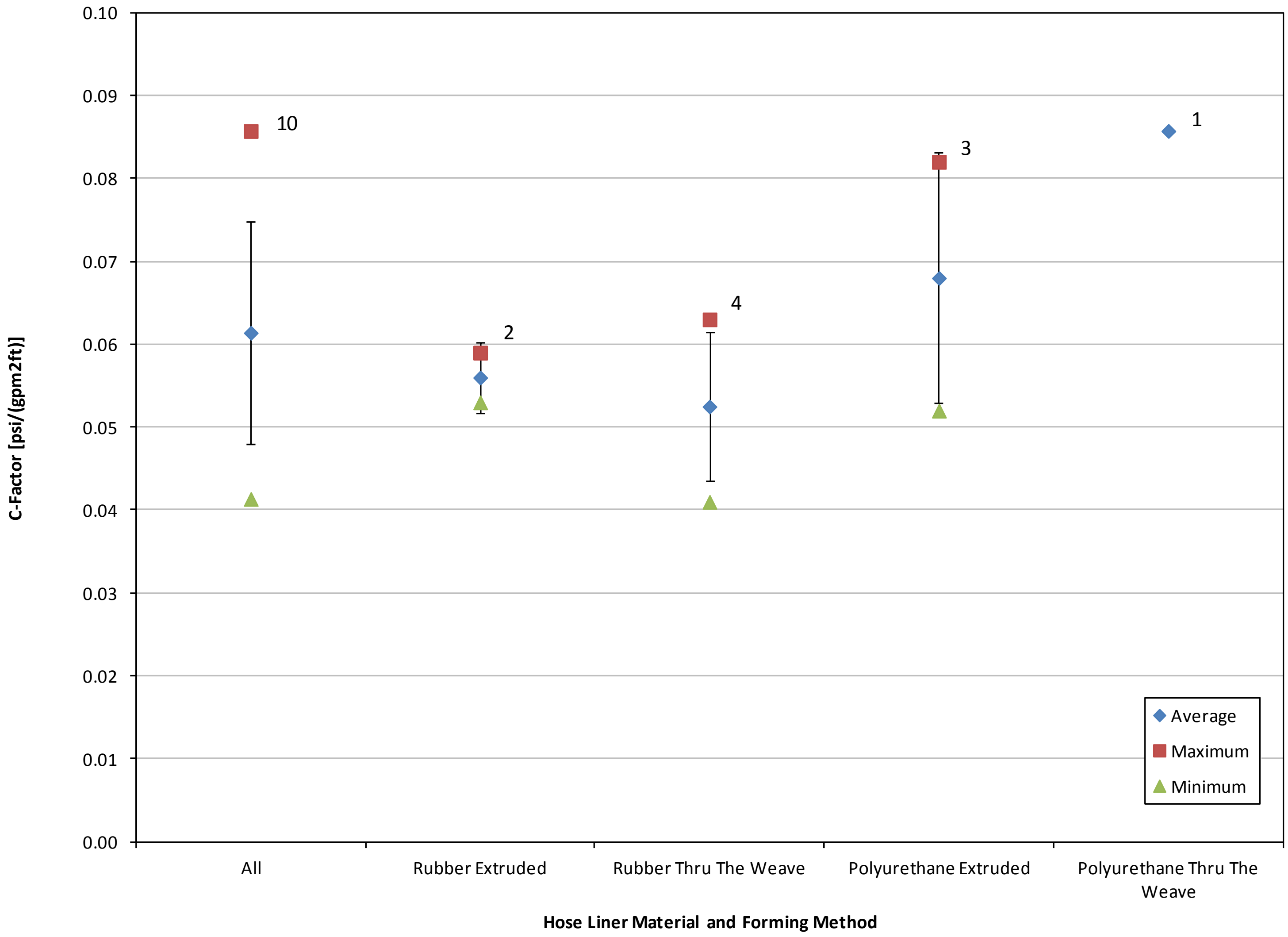

Figure D.6. Plot of Friction Loss Factor, C, by Hose Liner Material and Forming Method – 5 inch Hoses.

Note: Error bars shown as the first standard deviation from the average. The number of tests is noted for each Hose Liner Material and Forming Method.

APPENDIX E – MIDDLESEX COUNTY FIRE ACADEMY FRICTION LOSS STUDY PROCEDURES

Procedures
Middlesex County, N.J. Fire Academy Friction Loss Study
June 1–3, 2011

Project Technical Panel for Developing Friction Loss Coefficients for Modern Fire Hose

Sponsored by
Fire Protection Research Foundation
Quincy, MA

Fire Hose on Loan from Manufacturers
June 1–3, 2011

Instrumentation

Instruments Courtesy Cottrell Associates, Inc. – CombatSupportProducts.Com
Test Appliances Courtesy Task Force Tips & Kocheck Company

Procedures
Middlesex County, N.J. Friction Loss Study
June 2011

Determining Inside Diameter

Avg. wall thickness times 2

Subtract from outside diameter

Proving & Calibration – Daily

Checked against traceable instruments

Typical LDH Friction Loss Test Layout

Elevation change <1 ft. – water temp. ± 75 deg. F. recirculated from facility impoundment lagoon.

Note: two unrecorded tests conducted with hose formed in “U” – Inlet and outlet side-by-side – no change in pressure loss.

300 ft.

avg. ± 20”

Inlet Breach

Measured Flow

one psi increments

Recorded data…confidential

Diameters 2.5” through 1”

Identical instruments inlet & outlet.

Adapter 2.5” to 1.5” to 1”

Flow meter gets approximate flow, then use
pitot at test monitor for precise flow readings.

Turbine flow meter ± 10 -20 gpm.

Procedures
Middlesex County N. J. Fire Academy – Friction Loss Study
June 1–3, 2011

Approximately 144 individual FL tests of twenty-five, 300 ft. hose samples. Hose provided by hose manufacturers.

Thanks to MCFA staff from County Fire Marshal, Michael Gallagher

APPENDIX F – LESSONS LEARNED BY THE CONNECTICUT FIRE ACADEMY

Lessons Learned From Hose Testing For Fire Protection Research Foundation

In order to have continuity between the tests we chose to use the deck guns supplied by Task Force even though we have deck guns mounted on our drill ground. Secure the deck guns and then secure them again.

We did have one gun flip over before we added the pipe.

When measuring the 300' length of hose we did include the couplings on the inside section although the chart noted inside of coupling to inside of coupling. On 50' lengths 5 couplings would be included and on 100' lengths 2 couplings would be included.

Use small bleeder valves to adjust static pressure to 10 psi to make the adjustment much easier.

Have available a supply of short lengths of hose to get a more laminar flow into the manometers and flow meter.

Use a couple of folding tables to hold all the small parts and a place to write etc. Have portable radios available to communicate.

When the large diameter hose stretches it can push on the points of least resistance which in our case was the short lengths of 2 ½" hose causing kinks. Try to secure the end of the LDH with straps to limit its movement.

We only performed the outside hose measurement on the 10 psi test missed on the others which we didn't discover until inputting the final data. Had reviewed all the forms but only remembered measurement for the first test.

Use city water if available so there are no surfactants in water from other fire drill operations such as foam drills etc.

We received two new 5" manometers from Kochek after the testing was done but these should probably be incorporated in the next tests as the hose section units were weeping slightly when the testing was being performed.

The flow meter was difficult to use on most hose sizes other that the 2 ½" as low flows gave poor readings and for larger hose we would have only had a reading from as little as ¼ of the flow, so although all should be equal the final number would have been a calculation at best.

We used a fixed pitot for any configuration we could to again keep consistency versus a hand held reading.

We laminated the anticipated flow cards which are included with the materials to determine pitot readings as paper and everything else in a 100' radius will be wet at one time or another.

If anyone has questions on the mechanical side of this project give a call; we will try to help.