Environmental Protection Technology Series

A Portable Device for Measuring Wastewater Flow in Sewers

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A PORTABLE DEVICE FOR MEASURING WASTEWATER FLOW IN SEWERS

By

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Contract No. 14-12-909
Project 11024EVF

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ABSTRACT

A research and development program to develop a portable device which is capable of measuring wastewater flow in sewers was undertaken by Hittman Associates, Inc. for the Environmental Protection Agency under Contract No. 14-12-909. This work consisted of an investigation of the theoretical approach to be used, laboratory investigations and experiments to develop design criteria, design and fabrication of two prototype units, and field testing and evaluation of these units.

Measurement of the cross-sectional area of flow was done by the use of capacitor plates to sense the change in water level in the sewer pipe. The method selected to measure the velocity of the flow involved the timing of a heat pulse as it traveled down the pipe. Theoretical evaluations and laboratory experiments were performed to prove the mode of operation of the proposed gage.

Two prototype gages were fabricated. The overall accuracy of the final prototype was, at best, ± 15 percent. Separately, cross-sectional area of flow measurements were generally accurate to within five percent. Velocity measurements were accurate to within 10 percent under ideal conditions. The accuracy of the separate cross-sectional area measurements were not affected by contaminants in the sewer. Scum deposits on the walls of the gage significantly and adversely affected the accuracy of the velocity readings.

This report was submitted in fulfillment of Contract Number 14-12-909 by Hittman Associates, Inc. under the sponsorship of the Environmental Protection Agency. Work was completed as of April 1973.

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ACKNOWLEDGMENTS

The support and technical guidance received from Mr. Harry C. Torno, serving as project officer for the Environmental Protection Agency, is greatly appreciated. The guidance received from Dr. H. R. Thacker of the Environmental Protection Agency is also appreciated.

Major contributions to the design and field testing of the prototype gages were made by Charles W. Mallory of Hittman Associates, Inc.

The cooperation of the Howard Research and Development Corporation in providing field test sites for the prototype gages is gratefully appreciated.

SECTION I
CONCLUSIONS

Based upon the designs used for the second prototype gage developed under this project, a sewer gage can be constructed which is capable of measuring flow in partially filled sewers to within 15 percent accuracy. This gage would use the principle of capacitance for measuring the cross-sectional area of the flow and the timing of a heat pulse between an upstream and a downstream thermistor to measure velocity. Further refinement of some portions of the gage might produce accuracies of within 10 percent.

Separately, the cross-sectional area measurements yield readings within five percent of actual. Velocity measurements yield readings within 10 percent of actual under optimum conditions.

The cross-sectional area measurements are not affected by contaminants in the sewer. Scum deposits on the walls of the gage significantly and adversely affect the accuracy of the velocity readings. These scum deposits posed problems even though the prototype gages were tested only in storm sewers. Thus, it is probable that gage fouling would be an even more serious problem when the gage is used in sanitary sewers.

High flows are difficult to detect in the velocity measuring portion of the gage. Also, the accuracy of the cross-sectional area measurements deteriorates to 15 percent under high flows.

Further refinements in the shape of the capacitor plates will help to increase the accuracy of the cross-sectional area readings at high flows. The steam pulsing set up never functioned as planned. The proper functioning of this mechanism would enable a more accurate determination to be made of the capabilities of the velocity measuring portion at high flows.

Low flows cannot be measured by this gage due to the requirements for placing the heat sensing thermistors a minimum distance from the bottom of the pipe.

An instrument which fits into a 24-inch pipe can be fabricated for approximately $5000 on a one-time basis. This includes all the peripheral equipment except the steam boiler and its heat source. A complete gage which fits in an eight-inch sewer can be constructed for approximately $4000 on a one-time basis. The steam supply for either gage would cost an additional $620. On a limited production basis, these costs might be expected to be reduced by up to 30 percent.

SECTION II

RECOMMENDATIONS

Further work is not recommended on the use of heat pulses to measure flow velocity because of the maintenance problems associated with keeping the detectors clean. Recent information indicates that sonic methods of velocity measurement may be a better approach than heat pulse measurements. If this is not the case, several approaches could be tried to improve the heat pulse measurement technique. These would include greater temperature increases to overcome the thermal resistance of coatings in the detectors, use of specially designed valves to give shorter and higher magnitude heat pulses, use of single detectors with timing initiated upon the injection of the heat pulse, use of retractable self-cleaning detectors injected into the stream by the pressure of the steam pulse, development of steam boilers suited for unattended field use and use of heat pulse measurements only for the calibration of test sections, and using capacitance for flow measurement as discussed above.

SECTION III

INTRODUCTION

Accurate and reliable measurement of the flow of water in sanitary, storm, and combined sewers is essential to virtually every water pollution control and water resource program. A wide range of methods of measurement currently exist (Ref. 1). Unfortunately, existing, commonly-used instruments are usually severely limited in the range of flows which can be accurately measured and are subject to fouling, resulting in substantial missing data (Ref. 2). Consequently, Hittman Associates was under contract to the U.S. Environmental Protection Agency (EPA), Office of Research and Development, to develop a portable device for accurately and reliably measuring the flow of wastewater in sewers. This flow measuring device was to require little electric current, place a minimal obstruction in the sewer pipe, and be readily installed thorugh an ordinary manhole without special preparation. The work on this project was divided into two phases.

In Phase I, the proposed gage was theoretically conceptualized and laboratory tested under both static (still water) and dynamic (moving water) conditions. A preliminary technical design and cost estimate, based on the laboratory findings, was also prepared under Phase I.

In Phase II, two prototype gages were designed, fabricated, laboratory tested and calibrated, and installed in a sewer outlet for a period of field testing and evaluation. One prototype gage was constructed to fit in a nominal eight-inch diameter sewer line while the other was constructed to fit in a 24-inch diameter line. The field tests were conducted at a sewer outfall where a well-calibrated weir existed immediately downstream. The weir measurements of discharge were supplemented by cross-sectional area and velocity meter readings within the outfall itself.

This report constitutes the final and summary report for the entire project. Included herein are the results of the Phase I analyses and tests as well as the final findings of the field trials conducted under Phase II.

SECTION IV

PHASE I: THEORETICAL ANALYSIS AND LABORATORY TESTS

The volume rate of flow in a sewer is defined by the relationship:

$$Q = A\overline{V} \tag{1}$$

where:

Q = volume rate of flow, cfs

A = cross-sectional area of flow, ft^2

V = average or effective velocity, fps

Therefore, in order to determine the complete range of flows in a pipe, from partly full, to full flow, to full flow under pressure, both the velocity of the flow and its cross-sectional area must be measured.

THEORETICAL BACKGROUND FOR CROSS-SECTIONAL AREA MEASUREMENT

The method utilized to measure the cross-sectional area of the flow within a sewer pipe depends upon the unique properties of the electrical capacitance of a sewer cross section, with the wastewater forming a portion of the dielectric. If capacitor plates are incorporated in the walls of a sewer pipe, the measured capacitance will increase as the height, and thus the cross-sectional area, of the wastewater in the sewer increases. This is made possible due to the difference between the dielectric constant of air as compared to that of water. The ratio of the dielectric constant of air to water is approximately 1:80 under normal conditions.

Ideally, referring to Figure 1, the normalized first order theoretical capacitance function is:

$$C_{norm} = \text{capacitance relative to maximum capacitance} = \frac{\ln\left(\frac{\sin\theta}{\sin\theta_o} \times \frac{1+\cos\theta_o}{1+\cos\theta}\right)}{\ln\frac{1+\cos\theta_o}{1-\cos\theta_o}} \tag{2}$$

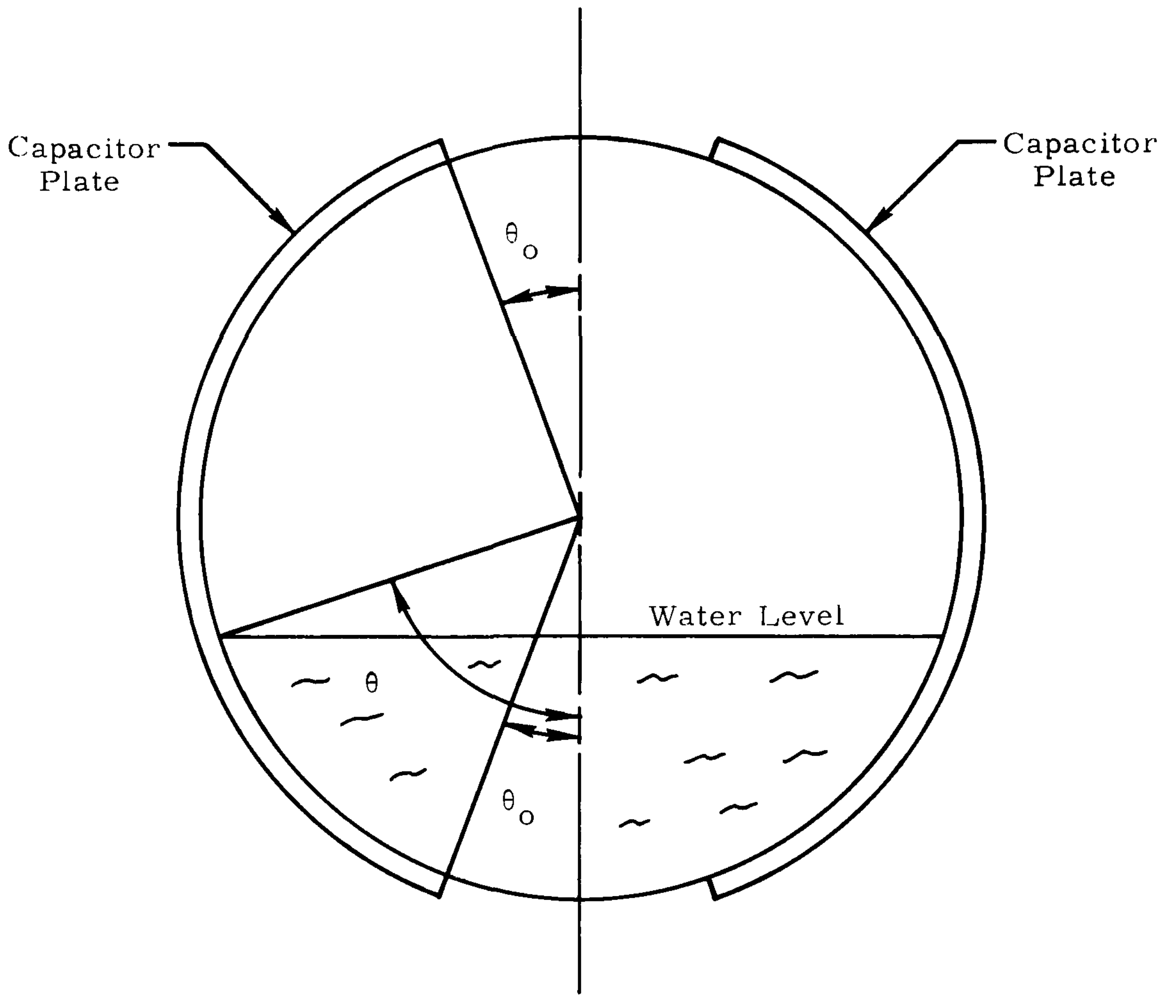


Figure 1. Geometry of the Capacitance-Cross-Sectional Area Measuring Section

Equation (2) does not take field fringing into account and considers the dielectric constant of air to be negligible compared to that of water.

For some values of θ_o in Equation (2), the response of the capacitance readings to the filled area of the pipe is nearly linear. The effects of field fringing will tend to increase the linear range of the response and additional linearization can be accomplished by modifying the shape of the capacitor plates near their edges. Thus, capacitance can be used to determine the filled cross section of the pipe due to the difference between the dielectric constants of air and water. Further, the relationship between filled cross section and capacitance can be linearized for maximum sensitivity over the entire range of flows by optimum sizing and shaping of the capacitor plates.

STATIC TESTS: CAPACITANCE VERSUS CROSS-SECTIONAL AREA MEASUREMENTS

In order to verify the theoretical predictions and arrive at an optimum size and edge shape of the capacitor plates, an extensive laboratory test program was conducted. This initial test program on the capacitance-cross-sectional area test section was performed on an eight-inch diameter, static, that is, stationary water, test section. Figure 2 shows one of the initial static test modules, with the capacitance measuring bridge, used during this phase of the laboratory test program.

The first aspect of the capacitance versus cross-sectional area measuring portion of the gage to be investigated was the optimum size and shape of the capacitor plates. Referring back to Figure 1, angle θ_o was varied from 10 to 50 degrees in increments of 10 degrees. At each setting, the capacitance versus filled cross section response was measured for the entire range of water heights, from empty pipe to completely full.

Results of these experiments indicated that a θ_o of 30 degrees produced the most linear function of normalized capacitance; that is, capacitance

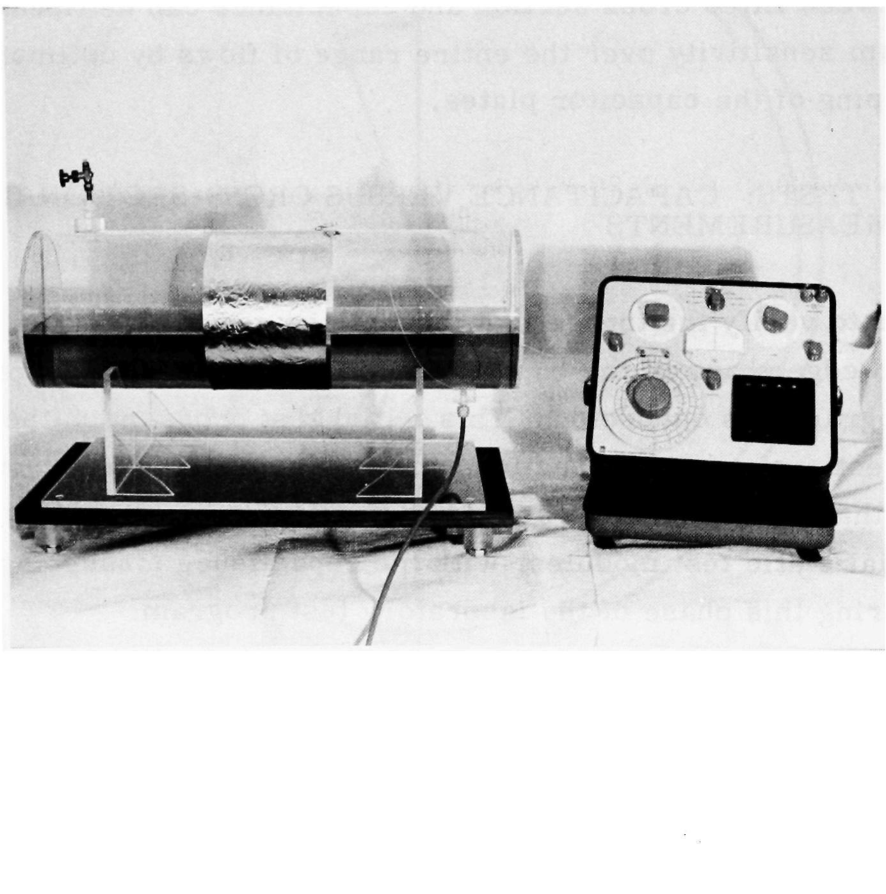


Figure 2. Typical Static Test Section with Capacitance Bridge

relative to maximum capacitance, versus percent of area filled. Figure 3 shows this function for the 30-degree plates. Note the nearly linear response of normalized capacitance versus percent area filled function, except in the upper range.

In an effort to more nearly linearize this upper portion of the curve, and thus provide for greater sensitivity in this range, experiments were conducted on capacitor plates with tapered edges. The effect of the tapers is dramatic, as is seen in Figure 4. Notice that the linear portion of the curve has now been extended over the entire range. This insures a maximum and consistent degree of sensitivity throughout the range of filled pipe conditions.

The second aspect of the capacitance versus cross-sectional area measuring portion of the gage which was investigated involved the optimization of the materials to be used on constructing a prototype gage. The original static test section was fabricated from Plexiglas because of some of the inherent advantages of this material. Included among these are its transparency, workability, and adequate strength for its proposed application. However, unexpected difficulties with certain tests were found to be caused by water absorption by the Plexiglas test section.

Consequently, a review was made of the physical properties of commercially available materials which might be considered in the design of the prototype sewer gage. This review concentrated on water absorption characteristics. Certain materials, such as glass, exhibit negligible water absorption but have undesirable mechanical properties. The best material reviewed was a tetrafluoroethylene thermoplastic, commonly known as Teflon. A new test section was designed and constructed using this material instead of Plexiglas, which is a methyl methacrylate thermoplastic. Further laboratory tests using the Teflon test section confirmed its application for a sewer gage and completely solved the water absorption problem.

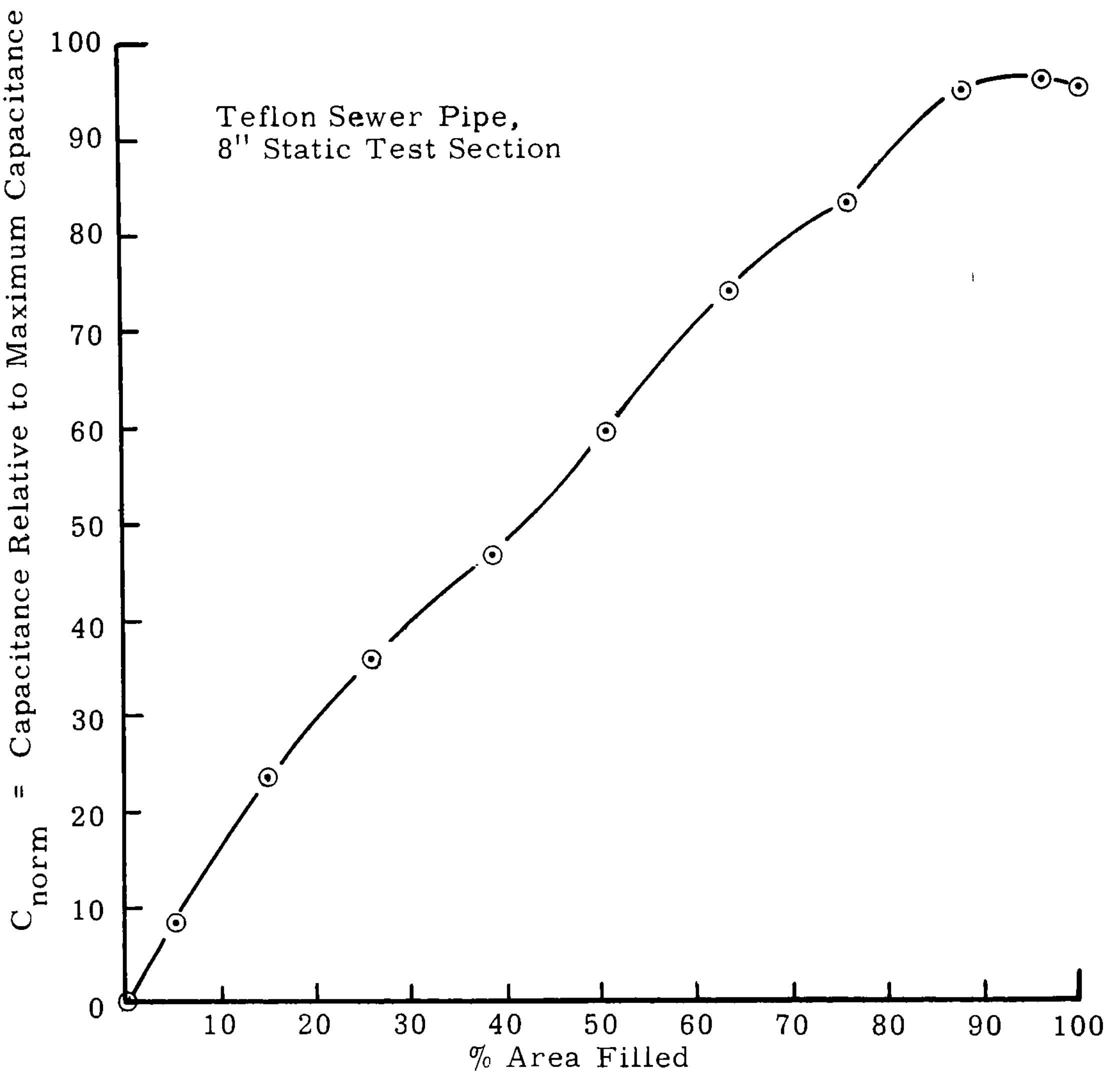


Figure 3. Normalized Capacitance vs Percent Area Filled for $\theta_o = 30^\circ$ Plates

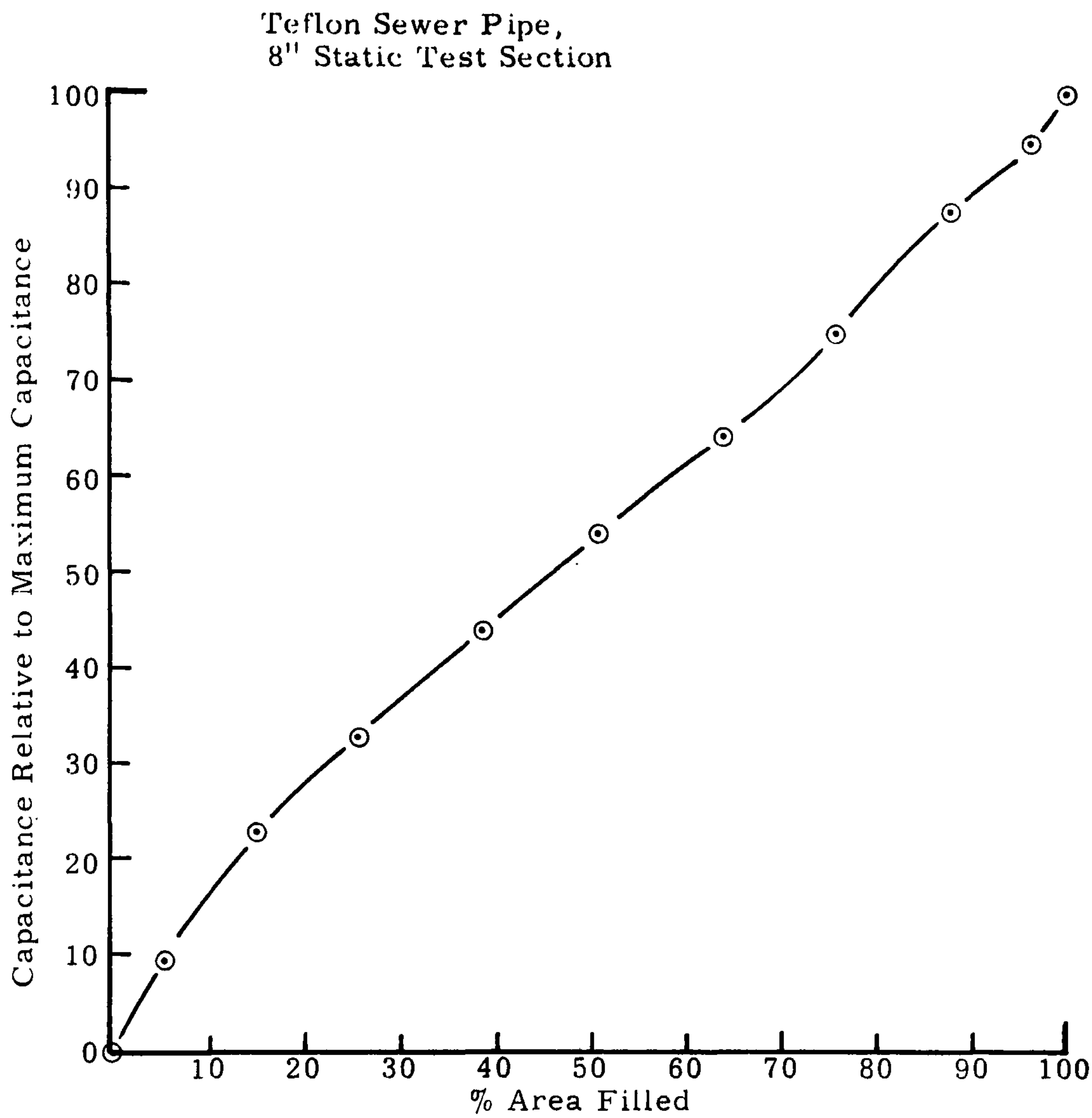


Figure 4. Normalized Capacitance vs Percent Area Filled for Plates With Tapered Tops

The capacitor plates themselves are fabricated from 0.004-inch thick brass plates. Some difficulty was experienced while taking capacitance readings due to extraneous signals from nearby objects. This problem was overcome by adequate electronic shielding of the device and lead wires to the capacitance bridge, and by precise calibration of the test section within exactly the same surroundings during each test. Therefore, an adequate degree of shielding was determined to be a mandatory requirement for the prototype instruments.

Following optimization of the size, geometry, and materials for the capacitance-cross-sectional area measuring portion of the sewer gage in pure water, a number of major contaminants in sewers were identified as likely to affect the dielectric constant. Theoretically, the dielectric constant of pure water varies from 88 to 73.28 over the range of temperature from 32° to 104°F (Ref. 3). Sand, rocks, and soil have dielectric constants in the range of 10 to 15 (Ref. 4). The contaminants listed in Table 1 were consequently investigated with respect to their effect on the dielectric constant.

TABLE 1. MAJOR VARIABLES INVESTIGATED FOR THEIR EFFECTS ON THE DIELECTRIC CONSTANT

Variable	Probable Range
Temperature	1° to 35°C
Dissolved solids	
$NaCl$	10 to 10,000 mg/ℓ
$NaHCO_3$	10 to 10,000 mg/ℓ
$MgSO_4 \cdot 7H_2O$	10 to 10,000 mg/ℓ
$C_{12}H_{22}O_{11}$	10 to 10,000 mg/ℓ
Some mixture of the above	10 to 10,000 mg/ℓ
Suspended solids	
Inorganic (clays)	10 to 10,000 mg/ℓ
Organic (starch)	10 to 10,000 mg/ℓ
Some mixture of the above	10 to 10,000 mg/ℓ
Selected mixture of dissolved and suspended solids	10 to 10,000 mg/ℓ

The dissolved and suspended contaminants tests had no significant effect on the cross-sectional area measurement up to 10,000 mg/l concentration. Temperature did have a noticeable effect upon the cross-sectional area measurements. However, the effect of temperature was substantially smaller than expected and was sufficiently small so that the observed effect would not require temperature compensation in the prototype instrument design, as originally contemplated. Tests were also conducted upon the effects of combinations of all of the contaminants listed in Table 1 on the dielectric constant. Results of these experiments also showed no significant effect.

DYNAMIC TESTS: DEVELOPMENT OF VELOCITY MEASURING SECTION

After verification, development, and testing of the capacitance versus cross-sectional area measuring section on the static test stand, a specially designed dynamic test stand for flowing water experiments was constructed. This test stand provided a constant head tank from which flows up to 350 gallons per minute could be obtained in a four-inch test segment. The water from the test section and overflow from the head tank were constantly recirculated by a centrifugal pump. Flow to the test section was controlled by two valves, one of the quick shut-off type and one gate valve, the latter used for precise flow control. The four-inch sewer gage test section itself could be mounted horizontally or at any slope up to 10 degrees. This permitted experiments to be conducted at any flow depth and at velocities ranging from 0 to 12 feet per second. True flow was measured via a calibrated sump into which the sewer gage test section discharged.

Initially, the cross-sectional area measuring section was mounted on the test stand and a series of tests were run to determine its response in moving water. After its performance under dynamic conditions was proved, plans were formulated for the development of a velocity measuring section. Five different methods for measuring velocity were proposed, analyzed, tested, and evaluated. These are summarized in the following subsections.

Capacitance-Air Bubble Method

This method was the one that was originally conceived as being the most promising for velocity measurement. Basically, the method again depends upon the capacitance of the wastewater flow cross section and the effect on this capacitance of the displacement of air bubble tracers. Air bubbles can be detected due to the aforementioned difference between the dielectric constants of air and water, and the consequent effect of air bubbles on the dielectric of a capacitor. Theoretically, because of this difference in dielectric constants, a bubble could be detected as it rose and was swept downstream past a capacitor plate.

Static test stands were set up in which air could be bubbled past pairs of capacitor plates. Three separate plate configurations, as shown in Figure 5, were evaluated. Each configuration was evaluated in terms of optimum size, location of the plates with respect to the top and/or bottom of the pipe, and spacing between a number of parallel capacitor plates.

Type (a), the "upright" configuration as shown in Figure 5, was found to be the most sensitive in detecting air bubbles. Consequently, these type (a) plates were mounted on the dynamic test stand with an air sparger located upstream from the plates.

Great difficulty was experienced in detecting the air bubbles as they crossed or surfaced at the capacitor plates in moving water. Flows from approximately one-quarter full to full flow were tested with little success. The distance of the air sparger from the nearest capacitor plate, as well as the size of the bubbles, i. e., the volume of the air pulse, was varied over the widest possible range. At low flows, up to 30 percent of the flow volume passing the capacitor plates was composed of injected air, with little success in timing the speed of the air pulse as it was swept downstream by the flowing water.

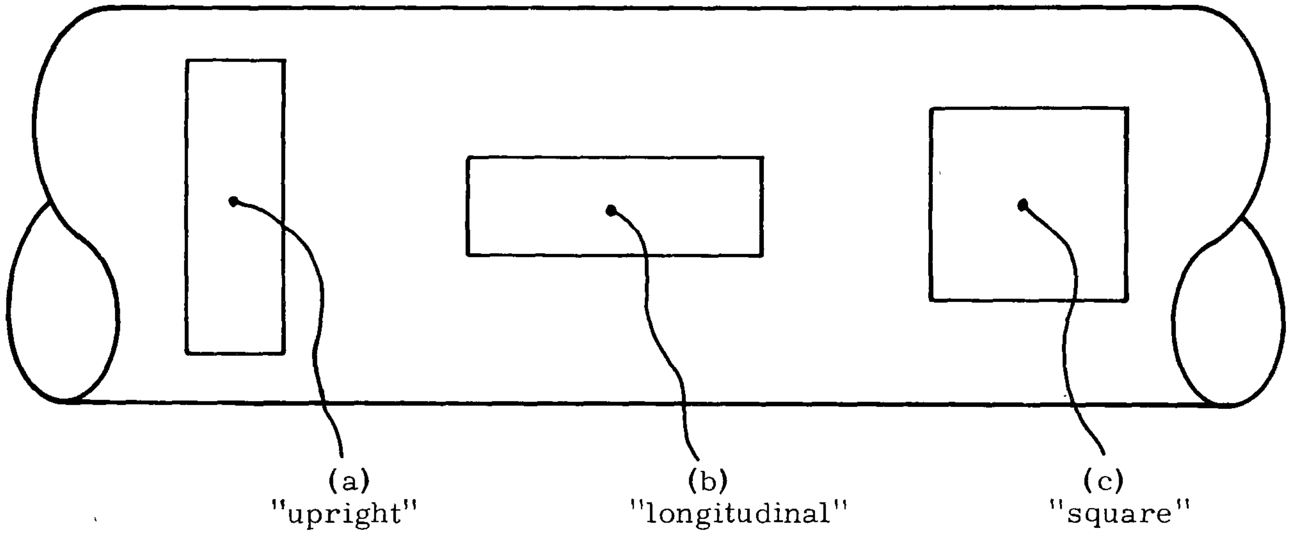


Figure 5. Three Capacitor Plate Configurations Which Were Evaluated for Use with Air Bubbles in Measuring Velocity

Failure of this approach was found to be due to the following:

(1) At other than full flows, surface perturbations of the water accounted for a significant change in the capacitance readings. This "background noise" masked the effect which a passing air bubble had on the capacitance readings.

(2) At high flows, the large amount of entrained air in the flowing water produced a two-phase flow situation (Refs. 5, 6, and 7). This entrained air made it difficult to distinguish between this source of air and that air introduced in order to measure velocity via capacitance reading.

(3) At low flows, the bubbles rose to the surface of the water faster than they were swept downstream by the water flowing past the capacitor plates. This rapid rise velocity thus precluded their being detected downstream by the capacitor plates before breaking the surface.

Inductive Method

Basically, this method utilizes a drive coil external to the pipe to create an audio frequency magnetic field. The magnetic field, in turn, induces an eddy current in any nearby conductor, such as the water in the pipe. This eddy current can then be detected by sensitive pickup coils located near the pipe invert. If the water is moving, the signal detected will be out of phase with the stronger signal resulting from direct coupling of the drive and pickup coils, the amount of this phase shift being correlated with effective velocity.

For the four-inch dynamic test section, the drive coil was fabricated from 100 turns of No. 24 gage enameled magnet wire, and the two pick-up coils were each of 100 turns of No. 30 gage plastic insulated wire. Optimization of this setup was achieved in the form of the location, spacing, and shielding of the coils and other electronic equipment.

Experiments performed on the four-inch dynamic test section failed to demonstrate a detectable phase shift. When a number of subsequent runs with all the factors optimized also failed, this velocity measuring approach was abandoned. Failure of this approach was attributed to the extreme smallness of the signal to be detected. Initial trouble was also experienced with background "noise" and the extreme sensitivity of the electronic equipment, but these problems did not, in themselves, account for the failure of this approach.

Success could probably have been achieved by using larger coils and a greater drive current. This approach was undesirable, however, due to the requirement for minimum flow obstruction. The larger coils would place too large an obstruction to the smooth flow of water through the measuring section.

Magnetic Flow Meter Approach

The second approach for measuring velocity involved use of a large coil to induce a DC field. Electrodes in contact with the water would then, theoretically, detect a change in voltage which would be proportional to a change in velocity.

Up to 50 volts at 1.5 amperes of current were used to induce the field in the drive coil. An additional refinement was added after the initial tests in the form of a massive iron ring in order to further concentrate the field. Results were negative.

The identical setup was used in subsequent experiments, except that alternating current was used. An AC signal of 1 KHz at 2 amperes was used as a drive. It was hoped that either an amplitude change or a phase shift of the AC signal could be detected; however, none materialized.

A number of inherent advantages of an AC signal over a DC signal warranted its investigation in this connection. The greatest of these is the absence of "drift" of an AC signal and its noncorrosive or plating effect on the exposed electrodes.

The magnetic flow meter approach will certainly work in a full pipe condition if a large enough piece of suitable conductive material is used to concentrate the field. Such instruments have, in fact, been used successfully in a large number of applications (Ref. 8). The materials used to concentrate the field could be an iron ring in the case of DC or a laminated ring in the case of AC. However, the bulkiness of this item again precludes its use where a portable, easily installed instrument with a minimum of restriction in a sewer pipe is required.

Electric Current Method

A fourth attempt at velocity measurement involved applying a voltage across the dynamic test section, between two electrodes in direct contact with the water. Again, both direct and alternating current were evaluated.

The use of alternating current produced negative results in that no change in the amplitude, or a phase shift of the signal, could be detected. The range of experiments performed using AC ran from use of normal, 60 cycle frequency to a very low frequency of 0.01 cycles per second. Also, additional tests were made using alternating current in the form of square waves, with similar negative results.

Experiments using DC were run with a voltage of up to 50 volts at two milliamperes. The change in DC voltage, as measured across a one ohm resistor, was then observed as velocity changed. Here, an increase in current was observed as velocity decreased, with the filled cross-sectional area remaining the same. Figure 6 is a photograph of a typical oscilloscope trace of the DC signal across a fully flowing pipe as the velocity is gradually reduced. A DC signal between electrodes placed along the length of the pipe showed a similar reaction, but of a lesser magnitude.

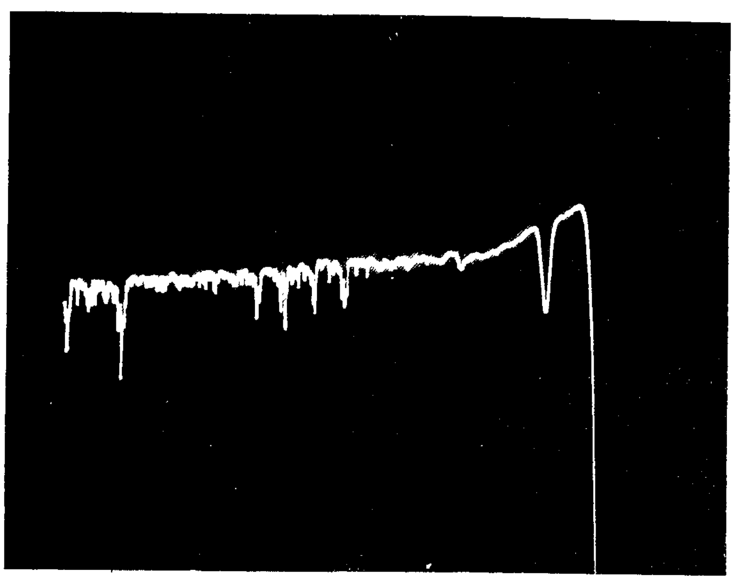


Figure 6. Oscilloscope Trace of DC Signal Across Two Exposed Electrodes as Velocity is Decreased

Although initially promising, further tests on this velocity measuring technique pinpointed a number of developmental problems in using this method in a practical instrument. One of these problems was the inability to separate changes in the signal due to true velocity changes, as opposed to random changes due to DC signal "drift." A second problem was the previously mentioned one of the plating phenomenon of the direct current on the exposed electrodes. This, in itself, will tend to degrade the DC signal over a period of time, especially in a sewage medium, causing a loss of precision and erratic readings.

Heat Pulse Method

This method for velocity measurement proved to be the best of the ones tried and was subsequently developed as the one for integration with the cross-sectional area measuring section to make a complete sewer gage. Basically, this method involves the tracing of a heat pulse as it is swept down the pipe by the flowing water. The time of flight, as measured between strategically located thermocouples, would then give an indication of the average velocity in the sewer.

Initial experiments were carried out in a still-water basin to determine the heat conduction characteristics of water. A hot water pulse was introduced at one corner of a water basin and thermocouple readings were taken at a number of points throughout the basin for a half-hour period. It was concluded that the heat dissipation through the water by conduction was negligible when compared to the propagation of the pulse down the sewer due to the velocity of the water. Thus, the velocity of the heat pulse, and consequently the velocity of the water, could be determined very accurately by timing the pulse as it passed between two points.

Subsequently, a test section utilizing this concept of velocity measurement was fabricated and installed on the dynamic test stand. The first tests on this section were performed injecting hot water as the carrier of the heat pulse. Hot water was found to be a poor medium via which to rapidly inject a high temperature heat pulse into the sewer because of the relatively large volume of hot water required in order to produce a noticeable temperature rise. This large mass of water being injected into the pipe produces a localized increase in flow. The increased velocity associated with this flow is sensed by the thermocouple probes, giving erroneously high velocity values for the sewage flow. Consequently, it was decided to use steam as the injection medium, the advantage of steam being that a large amount of heat can be injected using a small volume of steam, thus minimizing the localized flow variation effects.

The standard pressure cooker used during the laboratory experiments provided steam at pressures between 16 and 18 psi. Iron-constantan thermocouples were utilized to detect the steam pulse because of their sensitivity in detecting low temperatures.

Table 2 is a summary of the heat pulse-velocity test section experiments, ranked from lowest to highest velocity. The development of the heat pulse method of velocity measurement can be traced through an analysis of Table 2. During the first series of experiments, it was discovered that the factor most affecting the accuracy of the velocity measuring section was the length of time during which the steam pulse was injected, i. e., the steam pulse duration. Tests 2, 3, and 4 in Table 2 dramatically illustrate this point. In this series of tests, the only variable was the length of time of steam injection. As the duration of the steam pulse was reduced, the error in the velocity readings was also seen to decrease. The high velocity readings with a larger steam pulse were found to be caused by the momentum imparted to the flow in the sewer by the injected steam. This increased flow rate, although smaller than that caused by hot water injection, is nevertheless significant, especially in the four-inch diameter pipe that was used for the laboratory experiments. As the length of time of the steam pulse was reduced, the error in velocity readings was accordingly decreased.

Notice that steam pulses on the order of one-half of a second or shorter in length produced significantly more accurate velocity measurements than those of a longer duration. Pulses of a duration less than one-quarter of a second were unobtainable in the laboratory dynamic test program due to the use of a hand-operated steam injection valve. The greater expense required to mechanize the steam injection and thus obtain pulses of a shorter duration was not justified in the laboratory test phase since the thrust of the laboratory experiments was to demonstrate the basic concept and this could be done quite nicely with the manual setup.

TABLE 2. SUMMARY OF VELOCITY MEASUREMENT TESTS USING HEAT PULSE METHOD

Test No.	Number of Readings	Actual Velocity (fps)	Mean Measured Velocity (fps)	Deviation From Actual (%)	Steam Pulse Duration (sec)
1	7	0.332	0.360	+ 8.4	$\frac{1}{4}$
2	5	0.430	0.595	+38.4	2
3	1	0.430	0.543	+26.3	$1\frac{1}{2}$
4	1	0.430	0.528	+22.8	1
5	4	0.553	0.614	+11.0	$\frac{1}{2}$
6	5	0.553	0.584	+ 5.6	$\frac{1}{2}$
7	8	0.963	0.936	- 2.9	$\frac{1}{2}$
8	5	3.23	3.97	+22.9	$\frac{1}{2}$
9	9	6.89	7.51	+ 9.0	$\frac{1}{4}$
10	6	6.89	7.14	+ 3.6	$\frac{1}{4}$
11	11	7.12	8.28	+16.3	$\frac{1}{2}$

A second factor which was isolated as affecting the accuracy of the velocity measuring section was the degree to which the thermocouples protrude into the sewer pipe. Tests 5, 6, and 11 of Table 2 illustrate the degree of refinement in the velocity readings which is possible by having the thermocouples at the optimum height. In Test 5, the pipe was flowing at approximately one-quarter full and the thermocouples were at the surface of the water. Test 6 was performed under exactly the same flow conditions, but with the electrodes halfway between the bottom of the pipe and the surface of the water. The effects of thermocouple placement are apparent. In Test 11, the thermocouples were again at the surface of the water, with the pipe approximately one-quarter full. The larger error in velocity measurement is again apparent.

The high velocity readings obtained when the heat sensors were placed too close to the surface of the water were due, in part, to the larger than required steam pulses injected into the pipe. If the steam pulse was too large, it was observed that waves were set up on the surface of the water. These waves propagated downstream faster than the mean flow velocity. The thermocouples sensed these waves, thus giving erroneous (too high) velocity readings.

There is a trade-off between having the thermocouples protrude too high into the pipe and thus be vulnerable to large objects flowing down the sewer,and having them too close to the wall of the pipe and thus erroneously read what would perhaps be the slowest portion of the velocity profile. The optimum height and location of the thermocouples in terms of these two considerations were determined by experiment to be as shown in Figure 7. Two thermocouples are used per cross section in order to obtain a more accurate picture of the velocity profile across the pipe or to easily switch from one thermocouple to another in case of damage. They are placed 15 degrees off the bottom of the pipe to inhibit interference with them by solids which may accumulate in the bottom of the pipe.

To summarize the results of the laboratory tests on the heat pulse method: When all the experimental factors affecting the velocity measuring device were optimized, the resultant error in the velocity measuring section of the sewer gage was found to be less than 10 percent. This is illustrated by Tests 2, 4, and 10 in Table 2. With mechanically controlled steam pulses, it was postulated that this erorr could probably be reduced even more and the majority of the remaining error could be

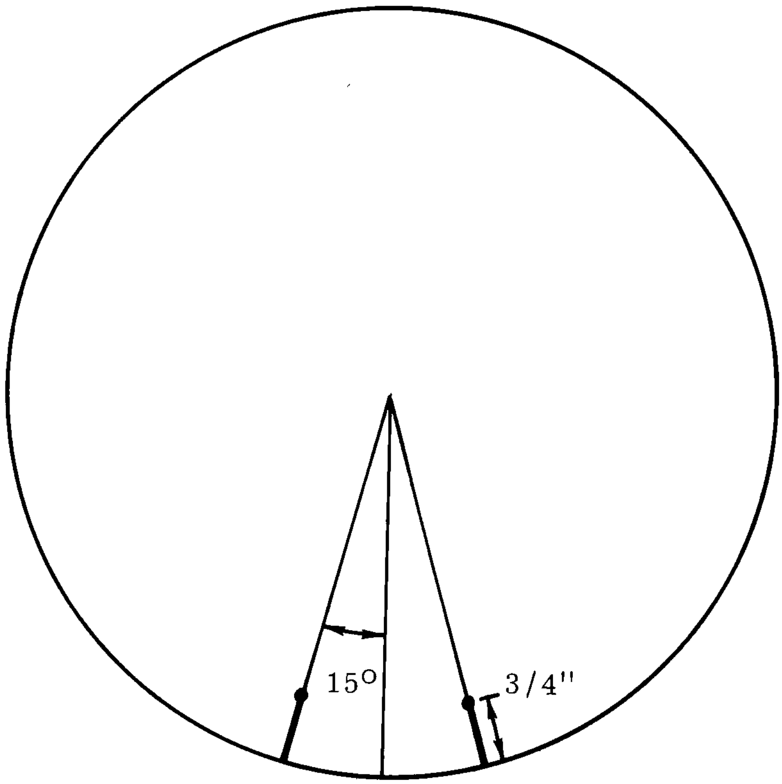


Figure 7. Optimum Placing of Thermocouples

either electronically, physically, or mathematically calibrated out of the gage to reduce the overall error in the velocity measurements to within five percent.

DYNAMIC TESTS: COMPLETE SEWER GAGE

With the separate development of the cross-sectional area (capacitance) and velocity (heat pulse) measuring portions of the sewer gage, the combined sections were ready for testing on the four-inch diameter dynamic test stand. First, the cross-sectional area measuring section was tested and calibrated on the dynamic test stand in both the still and moving water conditions. Then, experiments were performed on the complete sewer gage, combining the capacitance readings and the velocity measurements to arrive at a total flow. Results of these tests are summarized in Table 3, listed from lowest to highest tested flow.

TABLE 3. SUMMARY OF COMPLETE SEWER GAGE TESTS

Test No.	Number of Readings	Actual Flow (gpm)	Mean Measured Flow (gpm)	Deviation From Actual (%)	Steam Pulse Duration (sec)
1	11	3.08	4.46	+44.8	$1\frac{1}{2}$
2	3	8.30	8.78	+ 5.8	$\frac{1}{4}$
3	5	8.45	10.10	+19.5	2
4	2	13.3	12.4	- 8.3	$\frac{1}{4}$
5	2	24.5	35.2	+43.6	$1\frac{1}{2}$
6	3	24.5	30.3	+23.7	1
7	1	24.5	26.3	+ 7.4	$\frac{1}{2}$
8	2	36.1	34.6	- 4.2	$\frac{1}{4}$
9	4	63.5	82.8	+30.4	$\frac{1}{2}$
10	4	63.5	63.3	- 0.3	$\frac{1}{4}$
11	4	108	123	+13.9	$\frac{1}{4}$
12	9	270	294	+ 8.9	$\frac{1}{4}$
13	6	270	280	+ 3.7	$\frac{1}{4}$

As with just the velocity measuring section, experiments were again performed on the variance of the flow measurements with the duration of the steam pulse. Tests in series 5, 6, and 7 and series 9 and 10 in Table 3 again illustrate the sensitivity of the measurements to the amount of steam injected.

For all the complete sewer gage tests, the thermocouples were placed near their optimum location; that is, approximately three-quarters of an inch from the wall of the pipe.

After completion of the laboratory test program, is was concluded that a portable sewer gage could be designed which would measure flow in sewers to within an accuracy of approximately 10 percent, as Tests 2, 4, 8, 10, 11, 12, and 13 in Table 3 point out. Three factors would have to be optimized in order to achieve this projected accuracy. These factors are:

(1) Injection of a short, intense steam pulse

(2) Optimum location of the thermocouples with respect to the periphery of the pipe

(3) Achievement of complete mixing of the steam pulse

SECTION V

PHASE II: PROTOTYPE DESIGN

GENERAL DESIGN PARAMETERS

The principal objective of the first phase of this project was the proof of the principal of operation and the development of design criteria for a prototype sewer gage. This sewer gage was fabricated and field tested in Phase II of the project. The gage was designed with the following requirements in mind:

(1) Capable of functioning under all conditions of flow, from partially full, open channel type flow to full flow under varying surcharge pressures

(2) Readily installed in existing pipes

(3) Minimum interference with pipeline hydraulics

(4) Neither influence nor be influenced by any contaminants in the liquid

(5) Operate with satisfactory accuracy under all flow conditions

(6) Applicable to a wide range of conduit sizes

(7) Rapidly installed through a standard manhole or in other locations where the sewer is accessible

(8) Capable of being instrumented for remote readout

(9) Minimum of moving parts for easy maintenance

(10) Minimum power requirements

(11) Capable of being manufactured at a reasonable cost

Figure 8 is a schematic diagram of the major components of the prototype sewer gages. It was decided to construct two prototype gages — one which would fit in a nominal eight-inch diameter sewer and the other

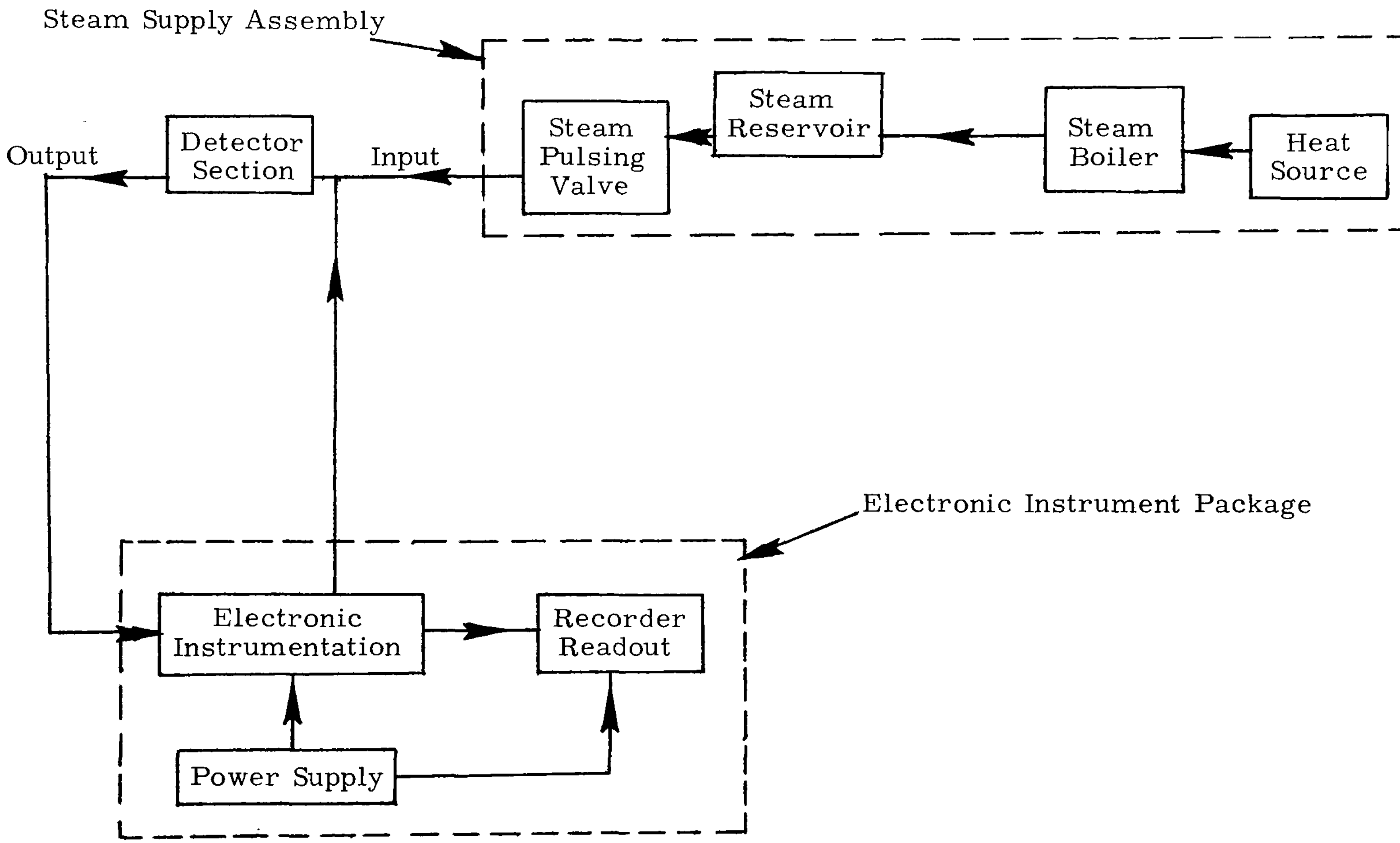


Figure 8. Schematic of Prototype Sewer Gages

to fit in a nominal 24-inch diameter sewer. This would allow not only a comparison of the accuracy and sensitivity of the gage in both small and relatively large diameter sewers, but would also enable an accurate cost determination to be made for various size sewer installations.

The detector section is the only component of the sewer gage which must be located within the sewer line to be measured. It was designed as a hollow tube with an outside diameter slightly smaller than the internal diameter of the sewer. It incorporates both the capacitor plates for cross-sectional area measurement and the steam inlet ports and heat sensors for velocity measurement. All the other components of the gage are mounted external to the sewer; either within the manhole itself, as in the case of the steam reservoir and pulsing valve which are bolted to the top of the outfall end of the detector section, or outside the manhole completely, as is the case of the steam boiler and heat source. The electronic instrumentation package is enclosed in a waterproof container and is sufficiently small so that it can be located anywhere that is most convenient. This arrangement of the components provided that the detector section was the only component which had to be fabricated separately for the 8- and 24-inch sewer lines. All the other components were designed and used for both prototype installations.

STEAM SUPPLY ASSEMBLY

The steam supply assembly was designed to deliver a pulse of steam every minute to the steam exit ports located in the detector section. The steam boiler used was a small, standard item with a maximum working pressure of 100 pounds per square inch (psi). It delivers steam at a constant pressure (pressures between 35 and 40 psi were used for both the eight and 24 inch prototypes) to a steam reservoir. This steam reservoir is no more than an insulated cylinder, 3.3 inches in diameter and 46.8 inches long, mounted on top of the detector section. The reservoir was designed to release its entire contents of steam to the detector section in pulses through a steam pulsing valve. The volume of the steam reservoir was calculated as adequate to heat one-half of the cross section of a 24-inch sewer 1^{o}F. These heating requirements were determined during the laboratory dynamic test program.

Automatic pulsing of the steam at one minute intervals was to be provided by the steam pulsing valve located between the steam reservoir and the detector section. No commercially available, automatically resetting, steam pulsing valve could be located. Therefore, pulsing was accomplished through use of a modified pilot-operated valve. Complete success at automatic steam pulsing was not achieved with this valve. However, the steam inlet pulses to the detector section were adequate for field testing of the prototype sewer gages. Complete design and fabrication of an exactly suited steam pulsing valve was not felt to be justified during preliminary prototype development.

ELECTRONIC INSTRUMENTATION PACKAGE

The signals from the capacitor plates and heat sensing probes in the detector section are fed into an electronic instrumentation package. This package contains the electronic circuitry, power supply, and recorder. Figure 9 is a schematic of the major components of the package.

As shown in Figure 10, the area signal is obtained from a counter whose count is proportional to the reading obtained by the capacitor which measures the filled cross section. Concurrently, the "time of flight" or velocity signal is obtained from a counter whose count is proportional to the time of travel of the heat pulse between the upstream and downstream heat sensors. The signals from the heat sensors are picked up by two high gain amplifiers and fed to a start-stop circuit. The output from the start-stop circuit gates the time counter.

The inputs to both the time and area counters are from a master oscillator. The oscillator provides a scale of 256 counts to full scale area and also scales the time oscillator for a 256 to 1 count for time of flight.

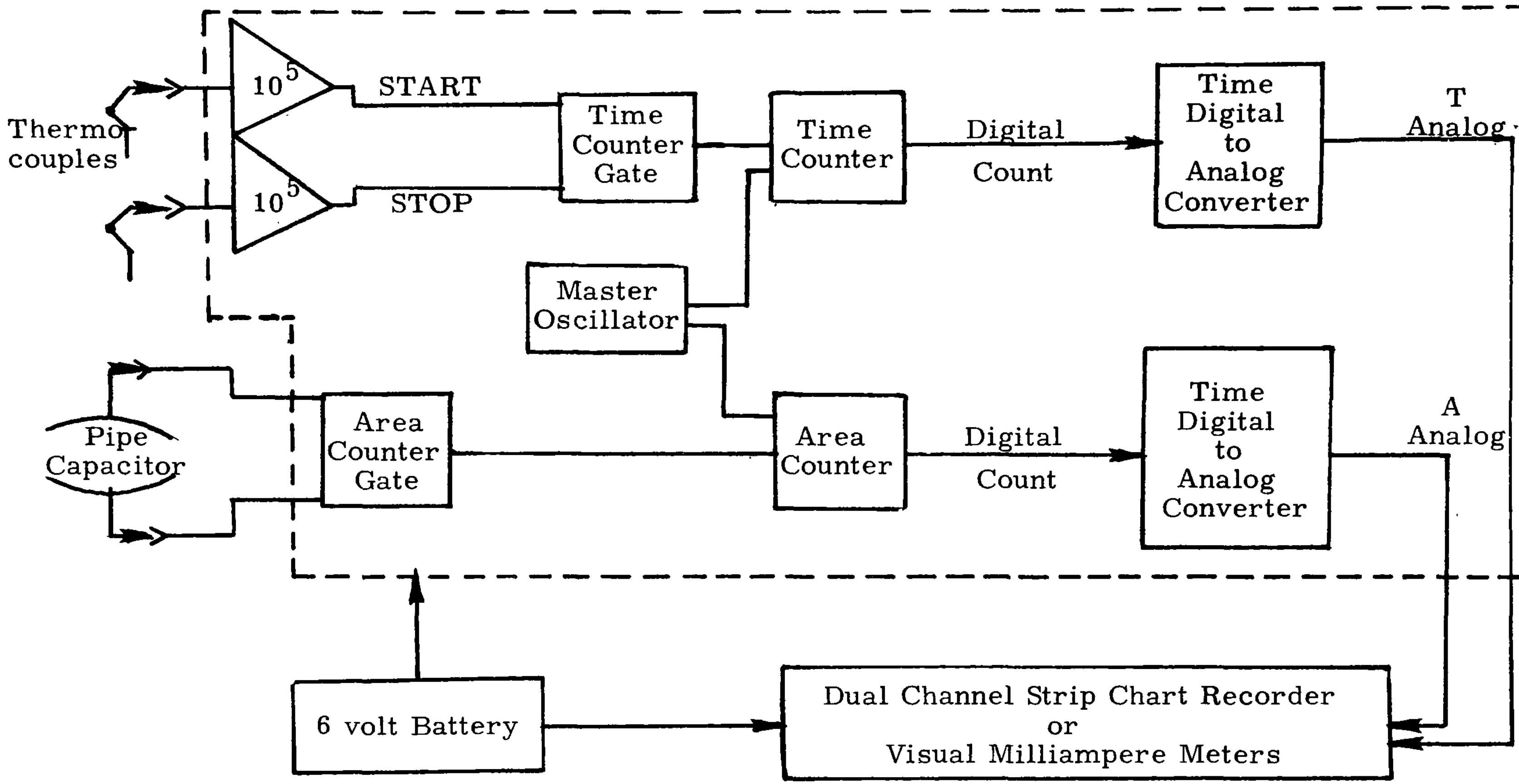


Figure 9. Electronic Instrumentation Package

Outputs from both counters are converted to analog signals using a digital to analog ladder network before being presented to the strip chart, recorder, or visual meters. Both the visual meters and strip chart recorder were used during the course of the field trials.

A divider circuit which would convert the area and velocity signals directly to a flow volume was originally designed into the electronics package. However, the output from the divider circuit was found to be less reliable than the individual inputs of area and velocity. Thus, this circuit was removed early in the field test program.

The entire electronic instrumentation package, including circuitry, recorder, and six-volt battery, is contained in a 12 inch by 10 inch by 7 inch waterproof box. Its total weight is somewhat less than 30 pounds.

DETECTOR SECTION: EIGHT-INCH PROTOTYPE

Figure 10 shows the basic body shell of the detector section used for the eight-inch prototype. A Teflon liner with the shaped capacitor plates bonded to it is inserted inside the body. The Teflon then acts as a shield between the capacitor plates and the wastewater flowing through the detector section. The access holes near the bottom of the section are for insertion of the heat sensors and knife-edge guards.

Fabrication of the completed eight-inch prototype was followed by a period of laboratory checkout. The completed gage was installed on the dynamic test stand and the steam and electrical lines were installed. During this laboratory checkout, a number of varieties and ratings of heat sensors were evaluated in terms of their sensitivity to the input stream pulse and their stability against the experienced and expected background temperatures. Thermistors with a 10,000 ohm at 25°C rating were selected as being the most suitable heat sensors for both the upstream and downstream positions. After this was determined, final calibration was performed on the electronics prior to installation at the field test site.

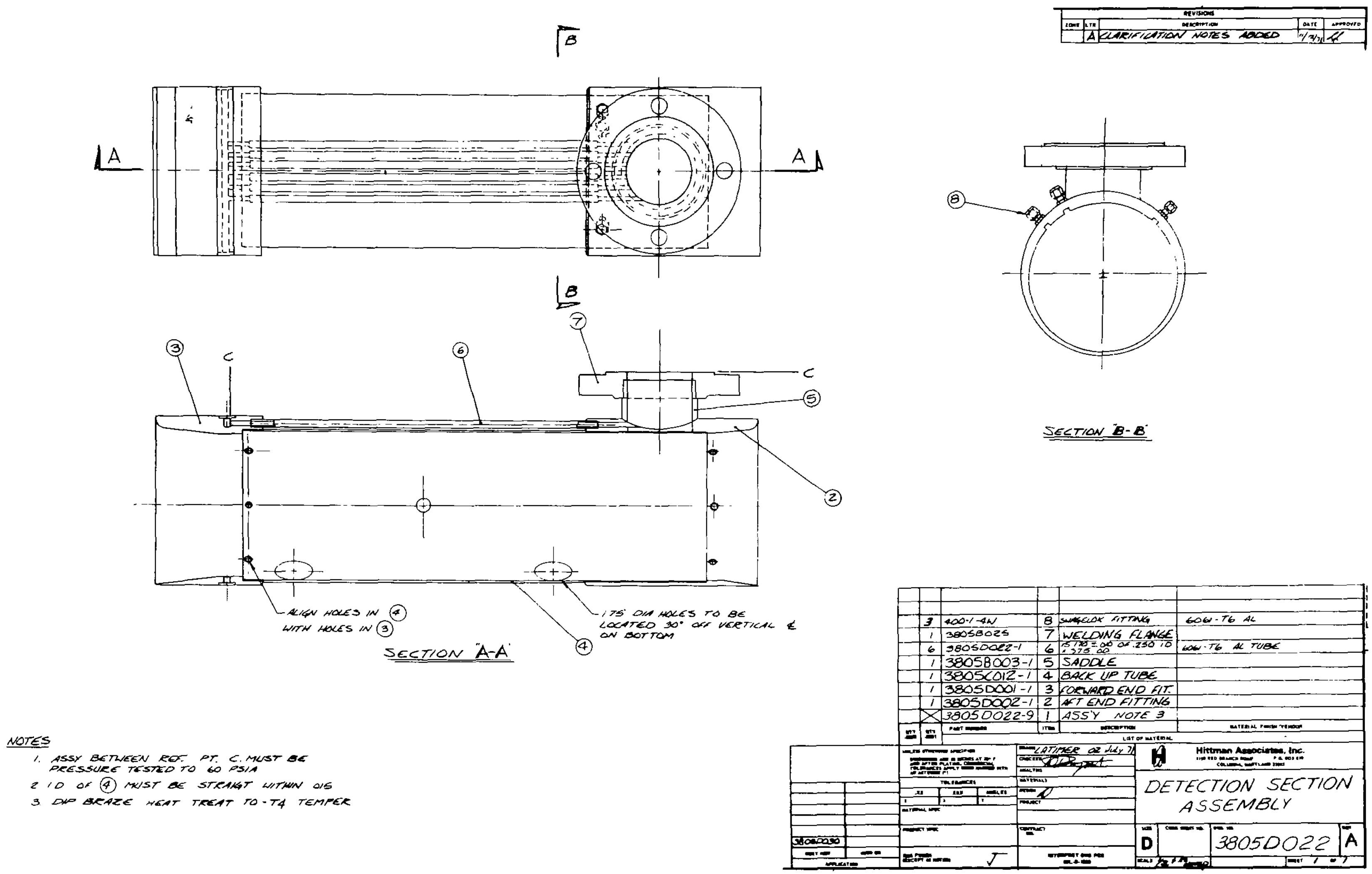


Figure 10. Basic Body of Detector Section, Eight-Inch Prototype

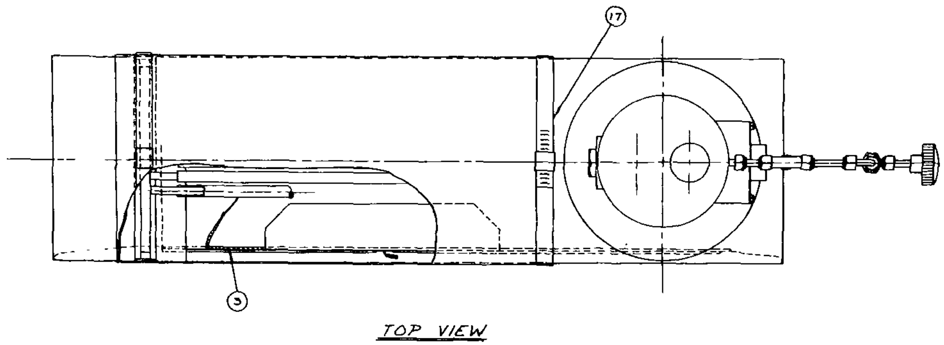
Figures 11 and 12 show the fully assembled eight-inch detector section with the steam reservoir and pulsing valve attached. A rubber boot protects the electronic lead wires and also provides, via an air blowup valve, a means of sealing the gage securely against the inner wall of the sewer. The detector section is normally inserted into the sewer line via a manhole or outfall structure as far as the upright reservoir flange will permit. The steam pulsing valve and reservoir sits atop the detector section within the manhole or outside the sewer if it is installed at an outfall. Figure 13 shows how the major components of the entire sewer gage system would be assembled for flow measurement.

DETECTOR SECTION: 24-INCH PROTOTYPE

Basically, the 24-inch detector section is a scaled-up version of the eight-inch section with a number of important modifications which resulted from the field testing of the eight-inch prototype. These modifications increased the sensitivity of the instrument and bettered its operational capabilities.

Within the eight-inch section, as shown in Figures 11 and 12, the Teflon liner extended almost the entire length of the detector section. The thermistors protruded through the shield and provided a one-foot distance between themselves for velocity measuring purposes. During the laboratory checkout and field evaluation of the eight-inch section, it was discovered that the direct coupling of the Teflon shield to the thermistors produced considerable electronic background noise when the capacitor plates were energized. The one-foot distance between the upstream and downstream thermistors was also found to be at the limit of detection of the heat pulse by the downstream thermistor, especially at high flows.

Consequently, as shown in Figure 14, the capacitor plates and Teflon liner are physically separated in the 24-inch prototype detector section. The distance between the upstream and downstream thermistors has also been reduced to eight inches to increase the detection probability by



QTY	QTY	PART NUMBER	ITEM	DESCRIPTION	MATERIAL/FINISH/VENDOR
2		1¼ x 3LG	33	PIPE NIPPLE	
1		1¼ x 3THD	32	REDUCING FLANGE	316 S'STL RAISED FACE 125 RMS AW
	4	#2-56 x 3/16 UNC	31	FLAT HD C'SK SCREW	S'STL.
	8	5/8	30	FLAT WASHER	STL. CAD PL.
	4	5/8-11-UNC	29	NUT, HEX FINISHED	STL CAD PL
	4	5/8-11 x 3LG UNC	28	BOLT, HEX HD CAD. PL	STL. CAD PL.
	1	3-CGP-11-304	27	FLEXATIC GASKET	FLEXATALIC
1		SS-6R-4M-50	26	SAFETY RELIEF VALVE	NUPRO
X		3805D030-25	25	STEAM RESERVOIR & VALVE ASSY	
1		UP-2-1250-6-NC-U	24	VALVE	AIRMATIC
1		3805D023-9	23	STEAM RESERVOIR SUB ASSY	
	AR		22	EPOXY	
	4	GB41J1	21	THERMISTER	FENWAL ELECTRONICS
	AR	BTR-30-3BT	20	WIRE	BERT-TEK INC.
	16	10-32 x 3/8	19	FLATHEAD CSK SCREW	S STL
	5FT.	M206-5	18	.005 TEFLON TAPE x 1"	DODGE INDUSTRIES, HOOSICK FALLS, NY
	1	H-116-SS SIZE 116	17	CLAMP	MURRY
	2		16	SWAGELOK FITTING	SWAGELOK
	1	#0-32	15	CLAMP	PUNCH-LOK
AR		¼ O.D x .035 WALL	14	TUBE	COPPER ASTM-B-75 TYPE DHP
1		B-6C-25	13	SERIES CHECK VALVE	NUPRO
1		400-3-4TMT	12	MALE RUN TEE	SWAGELOK
1		B-6C-1	11	SERIES CHECK VALVE	NUPRO
1		400-3	10	TEE	SWAGELOK
1		1RS4	9	VALVE	WHITEY
4		400R-6	8	REDUCER	SWAGELOK
2		400-9	7	ELBOW	SWAGELOK
	1	3805A026-1	6	HEADER COVER	
	2	3805A017-1	5	SPARGE	
	1	3805B011-1.	4	BOOT	
	1	3805C016-9	3	LINER	
	1	3805D022-9	2	DETECTION SECT ASSY	
	X	3805D030-1	1	ASSEMBLY	

LIST OF MATERIAL

DRAWN LATIMER 30 Jun 7?

Hittman Associates, Inc.

SEWER GAGE ASS'Y

SIZE D | DWG NO. 3805D030 | SCALE 1/2 | SHEET 1 OF 2

Figure 11. Top View of Fully Assembled Detector Section and Steam Reservoir and Pulsing Valve of Eight-Inch Prototype

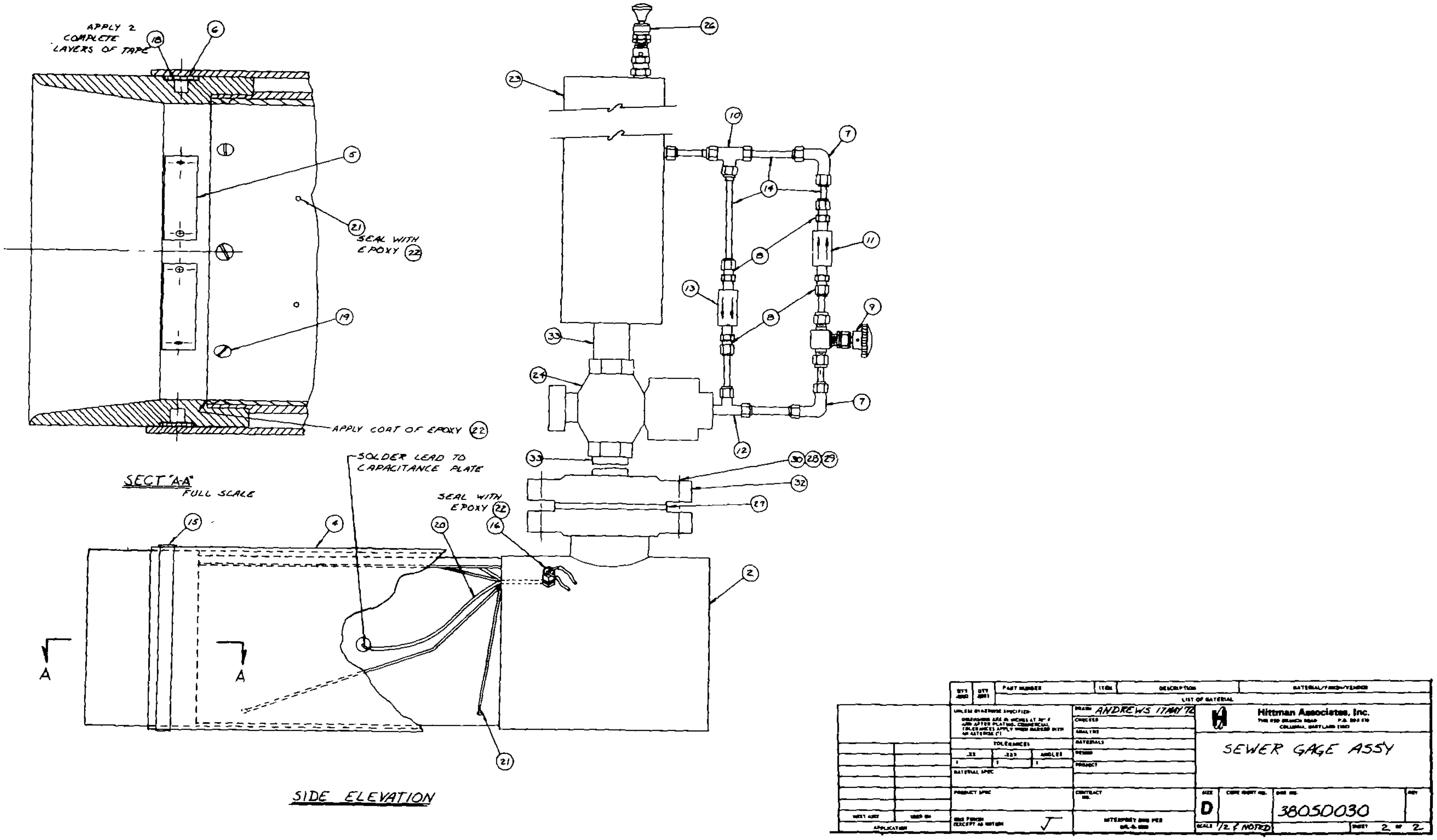


Figure 12. Side View of Fully Assembled Detector Section and Steam Reservoir and Pulsing Valve of Eight-Inch Prototype

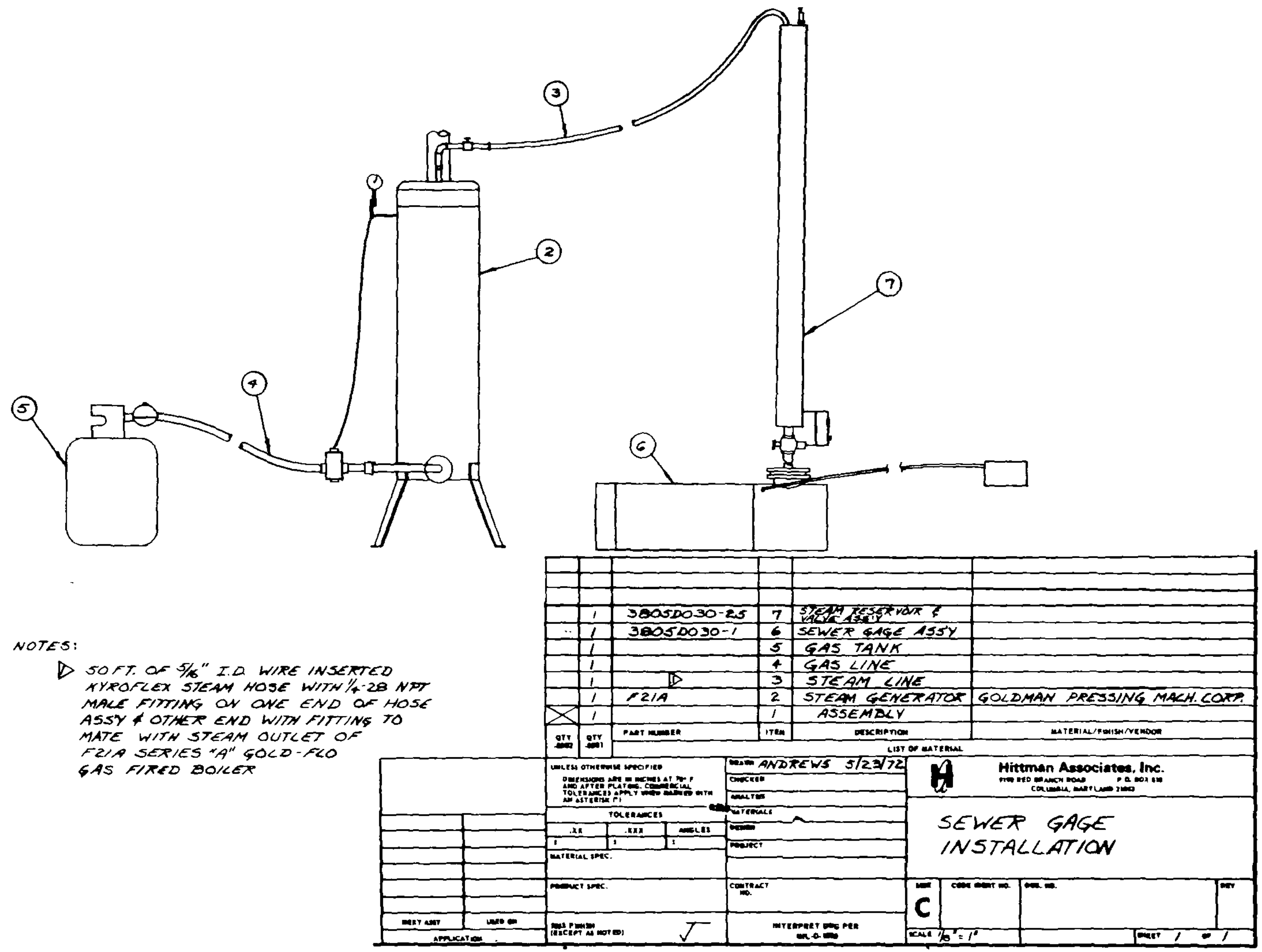


Figure 13. Sewer Gage Installation

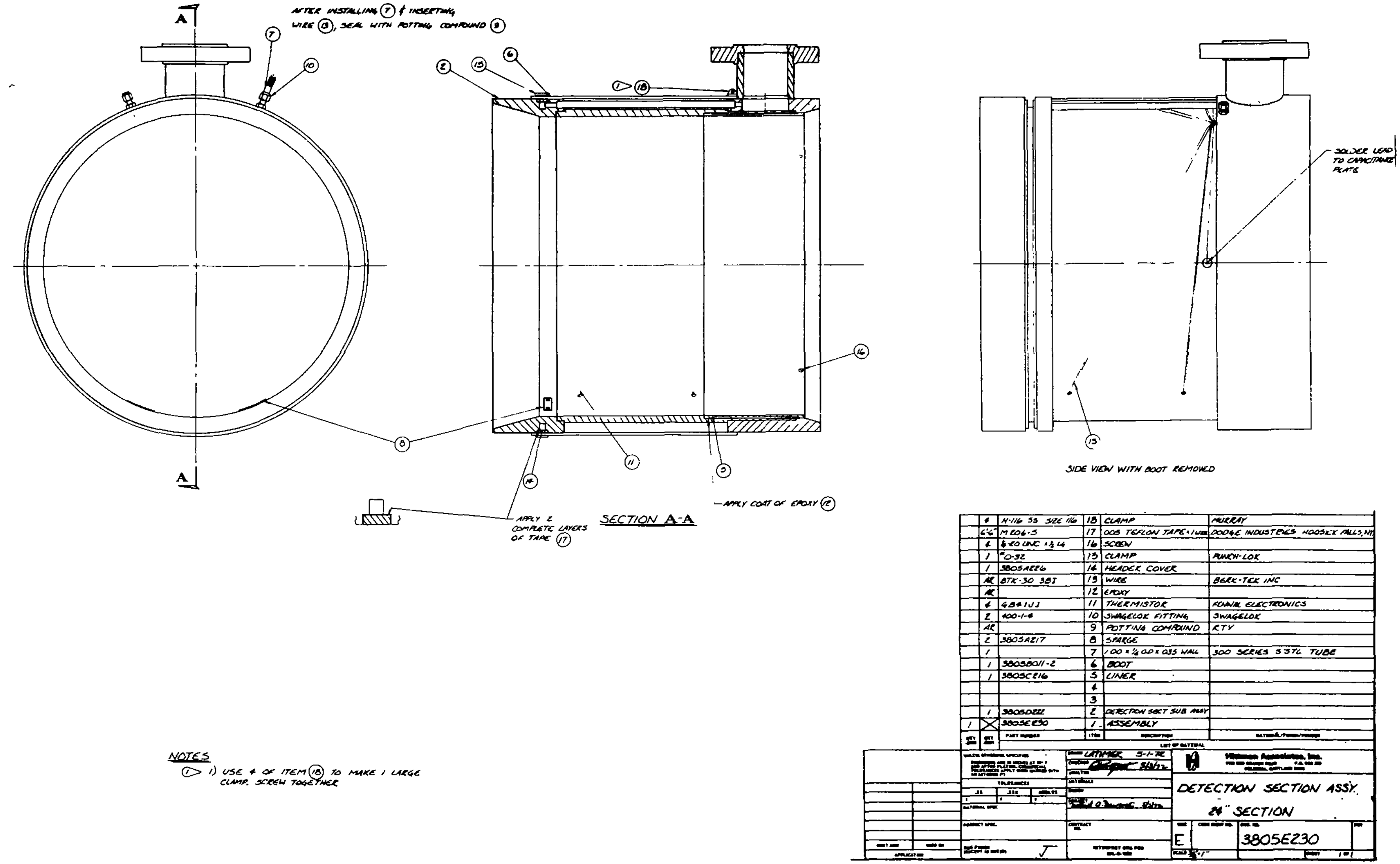


Figure 14. Detector Section Assembly, 24-Inch Prototype

the downstream thermistor. A more powerful mainspring in the steam pulsing valve and a simpler and finer-adjusted pilot valve pulsing system bettered the operating characteristics of the gage during the field evaluations in the 24-inch sewer.

COSTS

Costs of fabricating the eight- and 24-inch prototype detector sections are given in Table 4. Table 5 shows the fabrication costs for the steam reservoir and pulsing valve assembly and the electronic instrumentation package which were common for both the eight- and 24-inch prototypes. These costs do not reflect, of course, any costs of design. The cost of the steam boiler and its related fuel supply are not included since the unit used for this development work is not ideally suited for the application. If commercial sewer gages are to be made available, this component would have to be redesigned and scaled down.

The cost of the 24-inch detector section shown in Table 4 also reflects the redesign of this section in the larger size. In effect, this produced some cost savings since the overall length of the detector section, and also the amount of Teflon needed for shielding the capacitor plates, was reduced. Thus, a redesigned eight-inch detector section should cost less than the $1625 cost of the initial prototype of this unit.

A complete sewer gage, say for a 24-inch line, would cost approximately $5000, on a prototype basis, exclusive of steam boiler and heat supply. On a semiproduction basis, this cost might be expected to be reduced by up to 30 percent.

TABLE 4. FABRICATION COSTS FOR 8-INCH AND 24-INCH PROTOTYPE DETECTOR SECTIONS

Item	8-Inch Section Cost ($)	24-Inch Section Cost ($)
Aluminum body	645	1272
Teflon shield	120	275
Thermistors	11	11
Rubber boot	20	45
Thermistor shields	96	96
Lead wire	10	10
Steam inlet diffusers	100	100
Capacitor plates	1	2
Miscellaneous screws, bolts, clamps, fittings, and sealants	75	100
Dip brazing, hardcoating, and sealing	140	185
Assembly	407	407
TOTAL	$1625	$2503

TABLE 5. FABRICATION COSTS FOR PROTOTYPE STEAM DELIVERY ASSEMBLY, ELECTRONIC INSTRUMENTATION, AND STEAM SUPPLY

Item	Cost ($)
Steam Reservoir and Pulsing Valve Assembly	
End caps	45
Reservoir cylinder	42
Insulation jacket	61
Welding	36
Flange	18
Main pilot valve	75
Pilot valve spring	2
Miscellaneous piping, fittings, and valves	20
SUBTOTAL	$299
Electronic Instrumentation Package	
Circuit board and wiring	277
Electronic components	171
Dual channel recorder	171
Waterproof enclosure	75
Power supply	4
Fabrication and checkout	1465
SUBTOTAL	$2163
Steam Supply	
Steam boiler	490
Non-electric gas regulator for boiler	85
50 feet of steam supply hose	45
SUBTOTAL	$620
TOTAL	$3082

SECTION VI
PHASE II: FIELD EVALUATION RESULTS

EIGHT-INCH GAGE

The outfall culvert from a small, approximately four-acre lake served as as the field test site for the eight-inch prototype sewer gage. The culvert is a nominal 24 inches in diameter. Therefore, a simple adapter was constructed for this culvert in order that the eight-inch prototype could be inserted.

A well-calibrated, compound V-notch and rectangular sharp-crested weir is located immediately downstream of this outfall culvert. Measurements from this weir were supplemented with measurements of filled cross section, velocity, and total flow at the gage itself.

The gage was tested for flows which ranged from near zero to up to 56.1 gallons per minute (0.125 ft^3/sec). Overall, the cross-sectional area measurements via capacitance readings were found to be accurate to within 10 percent of the actual filled cross section, although some less accurate, scattered readings did occur. The cross-sectional area measurements were also found to be more reproducible and trouble-free than the velocity measurements. The velocity measuring portion of the gage was generally troublesome and less accurate during the field trials. This resulted in total flow measurements, i.e., the combined cross-sectional area and velocity measurements, to be usually within 20 percent of the actual measured flow. Figures 15 and 16 show two of the tests which produced some of the most trouble-free results during the field trials, one at a relatively low flow (0.0102 cfs), and one at the maximum flow tested (0.125 cfs).

The eight-inch prototype did not function as smoothly as was hoped for due to a number of development problems. Consequently, extensive field test data could not be collected to substantiate the continued

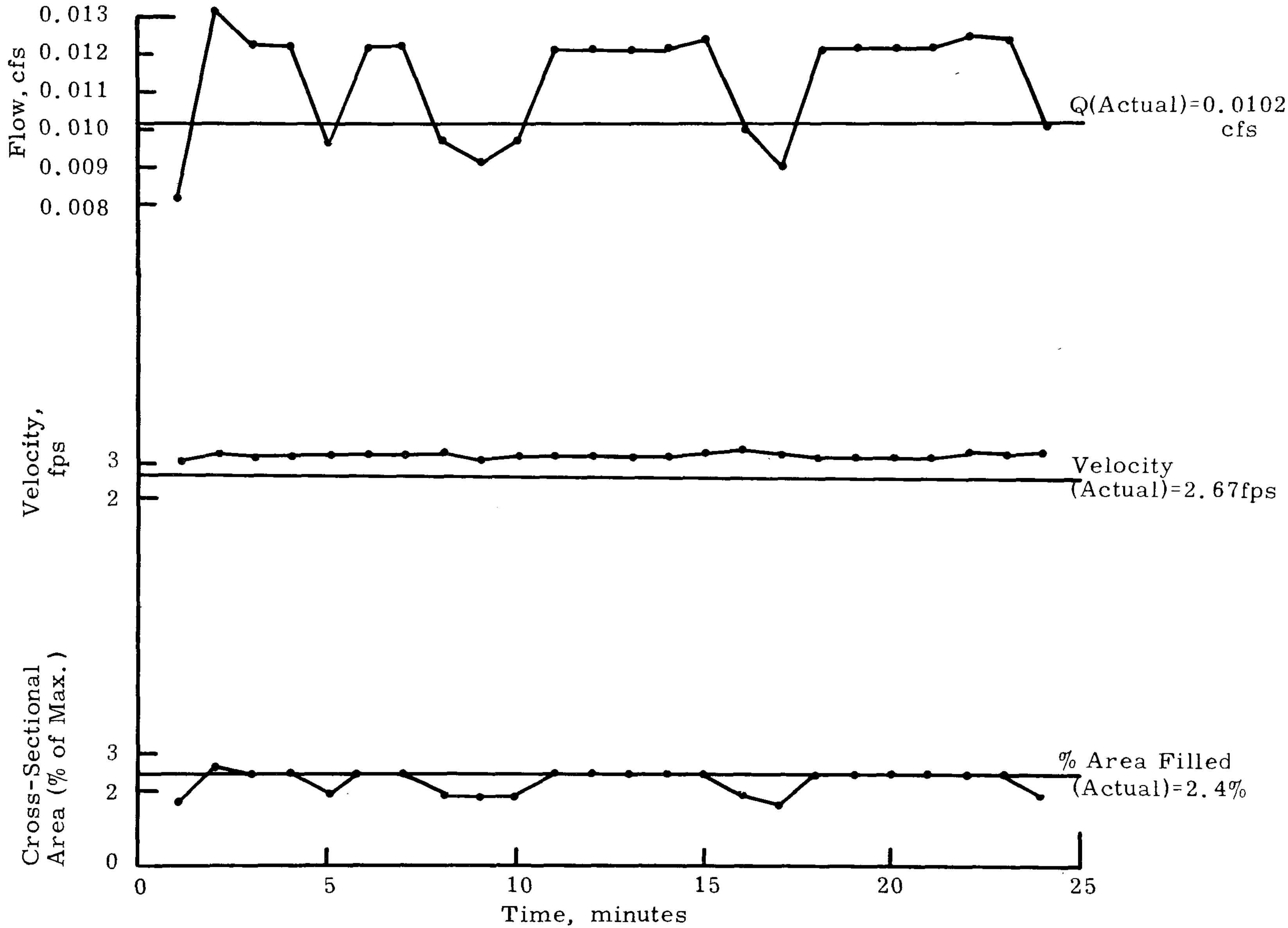


Figure 15. Eight-Inch Prototype Test, Q = 4.57 gpm

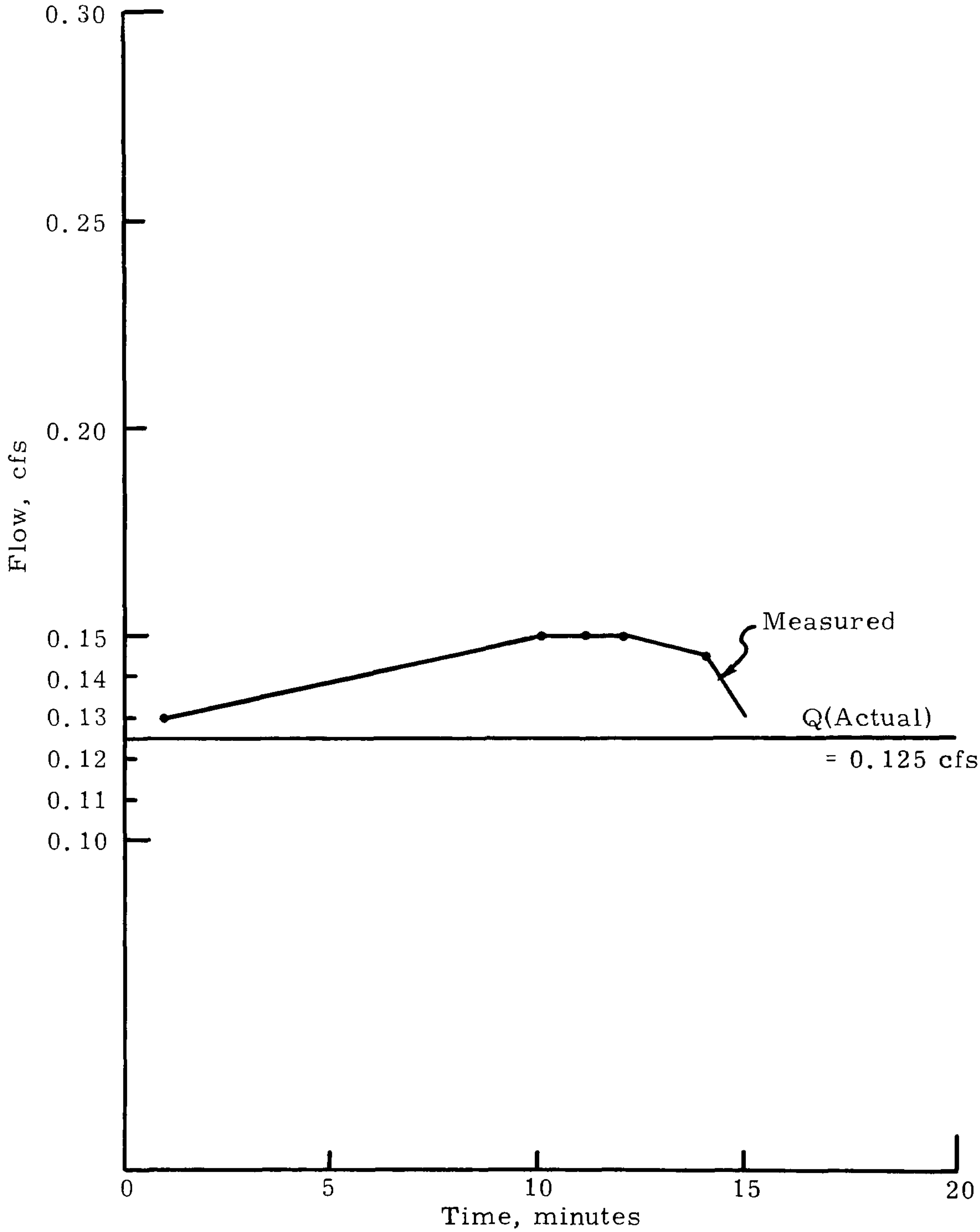


Figure 16. Eight-Inch Prototype Test, Q = 51.6 gpm

reproducibility of the total flow readings. Most of these problems were solved by the subsequent redesign for the 24-inch prototype. These problems were:

(1) Coupling of the capacitor to the thermistor circuit via the Teflon liner, as discussed in Section V, resulted in a large electronic background noise which was superimposed on any signal which the steam pulse might generate on the thermistors. The sensitivity of the velocity measuring portion of the gage was consequently reduced. This accounted for a fairly large portion of the trouble experienced with the velocity measurements. The problem was completely eliminated by physically removing the thermistors from their Teflon shield portion of the gage in the 24-inch prototype.

(2) Water leaking underneath the edge of the rubber boot to the inner parts of the detector section caused short circuits between the capacitor plates and the aluminum body of the detector section, and between the thermistor lead wires. The shorting of the capacitor plates to the metal detector body, in effect, caused the entire detector section to act as the cross-sectional area measuring capacitor. The relatively small range of capacitance change with water level within a generally high background capacitance reading caused by this situation decreased the sensitivity of the cross-sectional area measurements enormously. Short circuiting of the thermistor lead wires also caused loss of sensitivity in the velocity readings. The heat pulse signal was often "lost" when water leakage occurred. This problem was also completely solved in the 24-inch prototype by use of more extensive potting of all electric leads in the detector section, better insulation between the capacitor plates and the metal body of the detector section, and use of a tighter clamping and sealing mechanism between the rubber boot and the detector body.

(3) Erratic operation of the steam pulsing mechanism necessitated the use of manual steam pulses throughout the field trials of the eight-inch prototype. This caused variations in the steam pulse duration and pressure, thus causing erratic velocity readings. The functioning of this mechanism was improved, although not rendered completely automatic during the field trials of the 24-inch prototype.

These three problems all contributed to the low degree of accuracy of the velocity measurements in the eight-inch gage. Complete elimination of the first two problems and partial fixing of the third in the 24-inch prototype greatly improved the accuracy of the velocity readings.

A source of built-in loss of sensitivity which bears mentioning is the complete loss of velocity readings at very low flow. This is due to the placement of the heat-sensing thermistors at 15^{o} of the bottom centerline of the pipe, as shown in Figure 7, to avoid interference by any bed load which may be present. At very low flows, the thermistors are thus totally removed from the wastewater. Placement of the thermistor tips with less than a three-quarter inch protrusion from the detector section wall was tried in order to measure lower flows. No apparent deleterious effect was noticed, so placement of the thermistors closer to the wall was also done in the 24-inch prototype.

24-INCH GAGE

The necessary refinements which were identified during the field evaluation of the eight-inch prototype were incorporated into the 24-inch detector section described in Section V. Refinements were also made in the steam pulsing mechanisms as described above. The 24-inch prototype was field tested in the same culvert as the eight-inch prototype. Since the culvert diameter is a nominal 24 inches, no special adapter was necessary. Flows up to 7.12 cfs were measured during the field evaluation period.

The cross-sectional area measuring portion of the gage was found to be accurate to within five percent of actual flow area for flows up to approximately three-quarters of full pipe flow. At the upper limits of flow, the 24-inch prototype was found to measure cross-sectional area to within 15 percent of actual area. Figure 17 shows this deterioration in accuracy of the cross-sectional area measurements during a quick response test.

This decrease in accuracy near the top range of flow is probably due to the normal flattening of the capacitance versus filled cross-section curve at the upper limits of filled cross section which was investigated during the laboratory experiments in Phase I of the project. This flattening reduced the sensitivity of capacitance readings to changes in filled cross section in this range. Nominal 45^{o} tapers were included on the corners of the capacitor plates for the 24-inch prototype. These tapers, however, which were adequate for the eight-inch prototype, are probably insufficient for significantly linearizing the upper portion of the response curve. Larger tapers might thus improve the accuracy of the 24-inch cross-sectional area measuring portion in the upper flow ranges.

The velocity measuring portion of the 24-inch prototype yielded better results than its eight-inch predecessor. It was found to read within ten percent of true velocity for flows up to half-full pipe flow. Over half-full flow, the accuracy of the velocity measurements deteriorated slightly. At flows at which the pipe was over 70 percent full, the steam pulses could usually not be detected by the thermistors. Figure 18 is an example of one of the short duration, steady state flow tests conducted on the gage. The pipe was slightly more than half-full during the test. The surprisingly good results obtained illustrate the accuracy of the gage when most of its important physical parameters are optimized.

The only external parameter which was found to affect the accuracy of the sewer gage was scum buildup on its walls where they are constantly

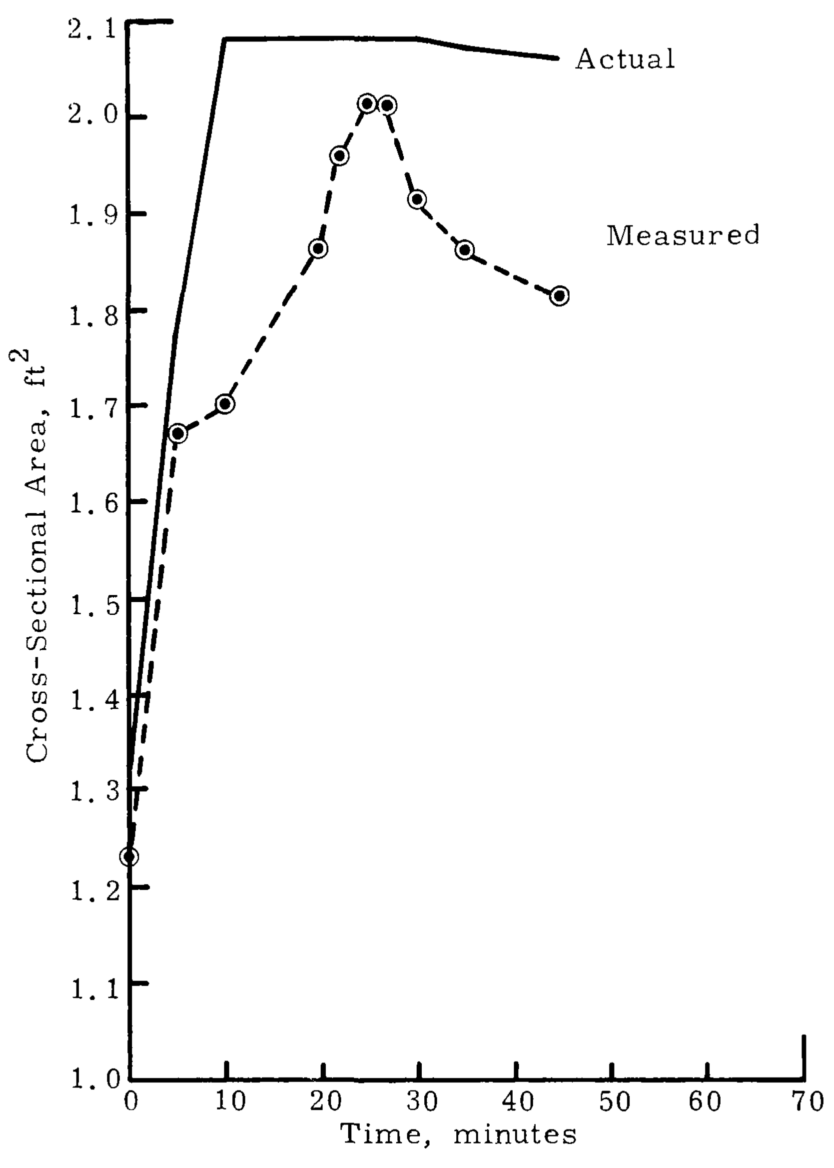


Figure 17. 24-Inch Prototype Cross-Sectional Area Measurement at High Flows, Quick Response Test

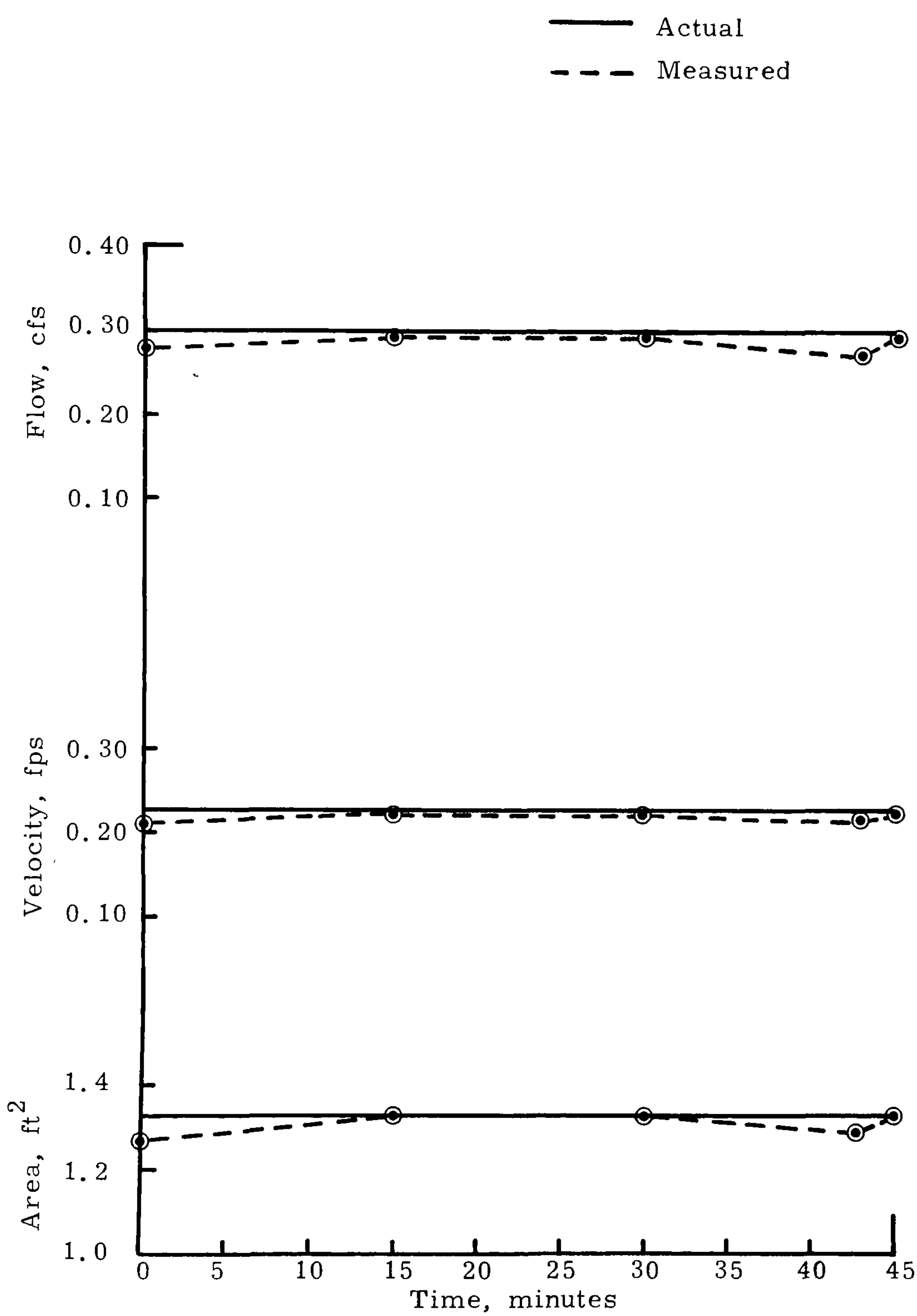


Figure 18. 24-Inch Prototype Field Test of March 29, 1973

in contact with the base flow. During the field trials, the 24-inch prototype was left in the sewer continually for a long duration operation and maintenance test. This extended test lasted over one and one-half months. About midway through the period, a loss in the accuracy of the velocity measurements became apparent. The velocities measured by the gage were consistently lower than the actual velocities. Inspection of the interior wall of the detector section revealed a buildup of scum on the wall of the section which was continually immersed in the base flow. This scum was measured to be at least one-quarter of an inch thick and was composed primarily of algae and sediment. Figure 19 illustrates the dramatic effect this scum buildup had upon the accuracy of the velocity measurements. Once this scum was cleared from the wall of the detector section, the velocity reading returned to within an acceptable range of accuracy. The scum had no apparent effect upon the cross-sectional area measurements.

DISCUSSION

Optimization of the design of the 24-inch detector section resulted in a gage which is capable of measuring flows in partially filled sewers to within an accuracy of 15 percent. Further optimization of the steam reservoir/heat pulsing mechanism might further increase the accuracy of the velocity measuring portion of the gage. The accuracy of the total flow measurements might then be expected to approach 10 percent.

The use of capacitance to measure cross-sectional area was found to be more accurate and trouble-free than the heat pulse sensing concept used to measure velocity. Further refinement of the shape of the capacitor plates should further increase the sensitivity of this method of cross-sectional area measurement in the upper and lower ranges of flow.

The problems caused by the accumulation of wastes on the thermistor probes of the velocity measuring mechanism may be a major problem in the further development of this type of gage. Buildup of this scum

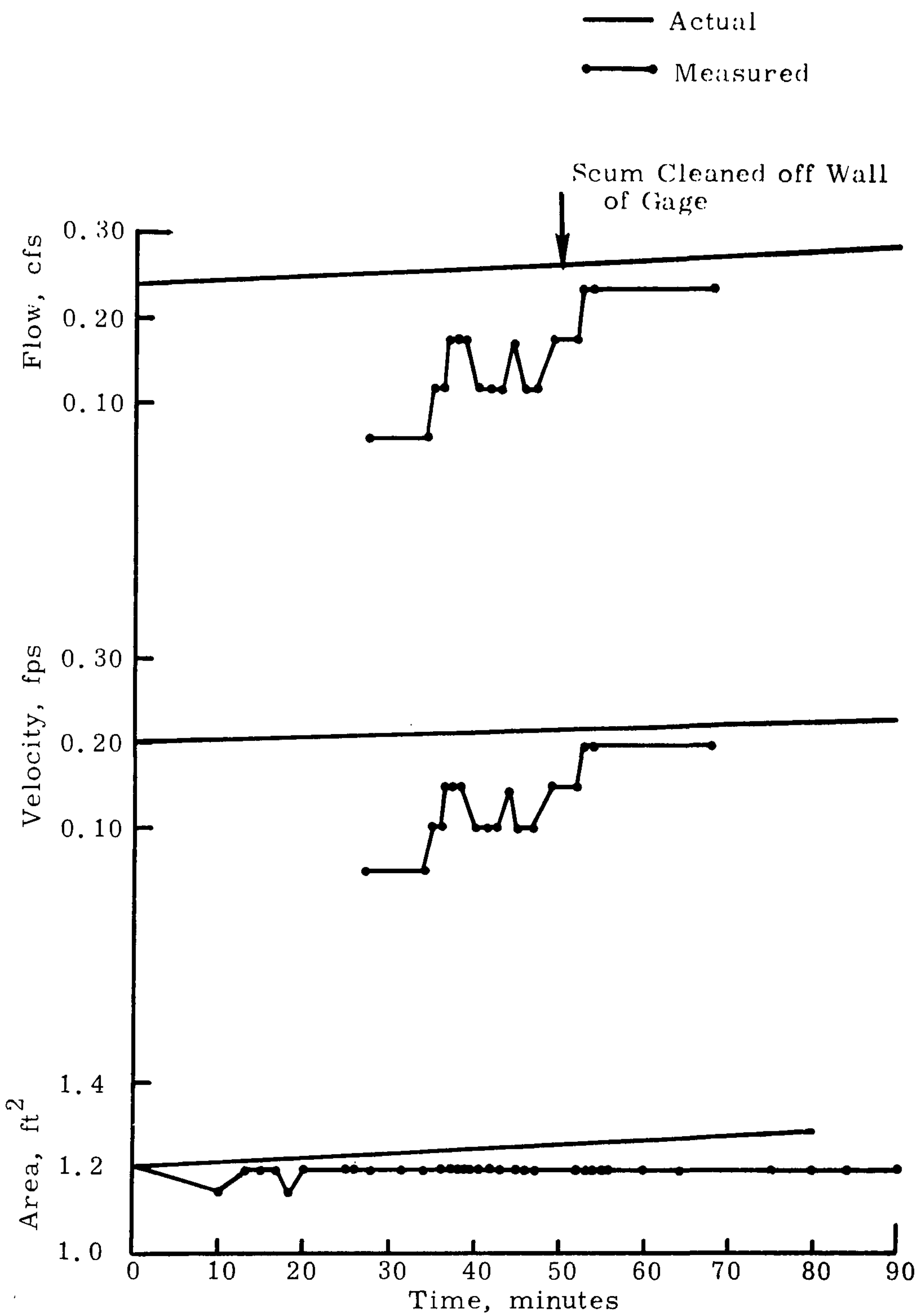


Figure 19. 24-Inch Prototype Field Evaluation, March 16, 1973

was found to be a problem, even in the relatively "clean" stormwater culvert in which the prototype gages were tested. Use of such gages in sanitary or combined sewers thus require almost daily maintenance to ensure accurate velocity readings.

A 24-inch sewer is probably the maximum diameter in which the present prototype design will work to an acceptable degree of accuracy. The large amount of metal in the vicinity of the capacitor plates, i.e., in the body of the detector section itself, masks the capacitance readings to some degree. If larger diameter sewer flow measurement is contemplated, it is recommended that consideration be given to redesigning the body of the detector section out of some nonconductive material, yet one which will not absorb significant amounts of water.

SECTION VII

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SELECTED WATER RESOURCES ABSTRACTS

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5. Report Date
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8. Performing Organization Report No.

7. Author(s)
Nawrocki, Michael A.

10. Project No.

9. Organization
Hittman Associates, Inc.
9190 Red Branch Road
Columbia, Maryland

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14-12-909

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Environmental Protection Agency report number, EPA-600/2-73-002, January 1974.

16. Abstract
A research and development program to develop a portable device which is capable of measuring wastewater flow in sewers was undertaken by Hittman Associates, Inc. for the Environmental Protection Agency under Contract No. 14-12-909. This work consisted of an investigation of the theoretical approach to be used, laboratory investigations and experiments to develop design criteria, design and fabrication of two prototype units, and field testing and evaluation of these units.

Measurement of the cross-sectional area of flow was done by the use of capacitor plates to sense the change in water level in the sewer pipe. The method selected to measure the velocity of the flow involved the timing of a heat pulse as it traveled down the pipe. Theoretical evaluations and laboratory experiments were performed to prove the mode of operation of the proposed gage.

Two prototype gages were fabricated. The overall accuracy of the final prototype was ±15 percent. The accuracy of the separate cross-sectional area measurements was within five percent. Cross-sectional area measurements were not affected by contaminants in the sewer. Scum deposits on the walls of the gage significantly and adversely affected the accuracy of the velocity readings.

17a. Descriptors
*Flow Measurement, *Sewers, *Research and Development, Gages

17b. Identifiers
*Capacitance, *Heat Pulse Velocity, Prototype Development

17c. COWRR Field & Group 07B

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