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THE SWIRL CONCENTRATOR AS A GRIT SEPARATOR DEVICE

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment—air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

As part of these activities, the study described here investigated the applicability of a swirl concentrator chamber to perform the functions of a grit separation and removal facility.

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ABSTRACT

A study was conducted by the American Public Works Association to determine the applicability of a swirl concentrator chamber to perform the functions of a grit separation and removal facility. The swirl concentrator principle was originally developed in Bristol, England, and subsequently modified and applied by the APWA to act as a combined sewer overflow regulator.

The ability of the swirl flow pattern to effectively remove solids of particular sizes or specific gravities was noted during the first study. This hydraulic flow configuration was developed and adapted to effectively remove grit from either the underflow from the combined sewer overflow regulator or from domestic sanitary sewage.

Hydraulic model studies were used to develop optimum design configurations. For an average flow of 0.084 m^3/sec (3 cfs), the diameter of the unit would be 2.19 m (7.2 ft) and 1.1 m (3.6 ft) deep. The efficiency of removing grit particles of 2.65 sg and size greater than 0.2 mm will be equal to that of conventional grit removal devices. The unit has no moving parts. Conventional grit washers and lifts can be employed.

The complete report on studies carried out on a swirl grit removal model by the LaSalle Hydraulic Laboratory Ltd. is included as an appendix.

The report was submitted in fulfillment of the agreement between the City of Lancaster, Pennsylvania, and the American Public Works Association, under the partial sponsorship of the Office of Research and Development, U. S. Environmental Protection Agency, in conjunction with Research and Demonstration Project 11023 GSC (S-802219.)

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FIGURES (Continued)

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The American Public Works Association is deeply indebted to the following persons and their organizations for the services they have rendered to the APWA Research Foundation in carrying out this study for the City of Lancaster, Pennsylvania, and the U. S. Environmental Protection Agency.

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SECTION I
CONCLUSIONS, RECOMMENDATIONS AND OVERVIEW

CONCLUSIONS

1. Hydraulic model tests indicate that the swirl concentrator principle can be utilized to provide the same high degree of performance in settling and removing grit particles as conventional devices.

2. The dynamic action of the swirl concentrator appears to wash the grit and may result in a minimum of organic materials settled and entrapped with the inorganic grit particles.

3. The design of the swirl concentrator as a grit chamber has been developed for rapid calculation of the size of the different elements, allowing ready sizing of units for various quantities of flow.

4. The small size, high efficiency, and absence of mechanical equipment in a swirl grit chamber facility appear to offer advantages over conventional devices. In conjunction with a swirl concentrator serving as a combined sewer overflow regulator, it can provide an efficient means of removing the extremely large concentrations of grit which can be anticipated, in the foul sewer wastes removed from the clarified wastewaters which are to be discharged to receiving streams or to overflow treatment or storage facilities.

5. The device could be used to provide removal of relatively large quantities of grit and larger organic material from flows which may require emergency bypassing or wasting at overtaxed sewage treatment plants.

RECOMMENDATIONS

Demonstration facilities should be constructed to evaluate the swirl concentrator in actual field service, for: (1) Removal of grit from the underflow from the swirl concentrator as a combined sewer overflow regulator; (2) grit removal from combined sewer overflow and storm water; and (3) grit removal from sanitary sewage, or industrial wastes as a pre-treatment stage of conventional wastewater treatment.

OVERVIEW

Previous studies by the American Public Works Association indicated that the swirl concentrator principle was very effective at removing particles of specific grain sizes and specific gravity combinations from flows. The City of Lancaster has prepared plans for the construction of a swirl concentrator as a combined sewer overflow regulator. The site requires that flow to the interceptor be pumped. Project consultants recommended that the pumps and wet well should be protected from the anticipated high (up to 13,000 mg/l) concentration of grit in the foul flow.

The current study was authorized to determine if, by means of hydraulic modeling techniques, a design could be evolved for a grit chamber using the swirl concentrator technique.

The swirl concentrator principle involves the development of a flow chamber utilizing circular, long-path kinetic energy to produce separation of solids from liquid and settling of the particles. The settling is achieved by the development of optimum hydraulic conditions to accomplish settling and removal of solids without the use of mechanical accessories.

A limited number of tests were conducted to determine the relationship between the chamber diameter and the height of the clear water discharge weir above the floor. Although the usual parameters of design will establish a chamber diameter that will reduce the depth to the bottom of the conical hopper, variations as desired may be made.

Figure 1, Swirl Concentrator As a Grit Separator, Final Form, portrays the model in its final form. The device should be effective in removing grit from the underflow foul liquid to the interceptor sewer from the swirl concentrator combined sewer overflow regulator; from sanitary sewage, and from certain industrial wastes.

A complete report of the hydraulic laboratory studies is attached as Appendix A. A translation of a German article concerning the Geiger grit chamber is included as Appendix B. Although the configuration for the Geiger device is somewhat similar to the swirl concentrator, the device is reported to be efficient only when the flow is relatively constant. Experimental testing of the swirl concentrator has shown that a wide variation of flow rate can be accommodated without a loss of efficiency through normal diurnal variations.

Although the study was performed for the City of Lancaster, Pennsylvania, with a specific application defined, all work was accomplished in a manner which allows ready application of the resultant design parameters to conditions which might be found at other installations and for other purposes.

The Metropolitan Denver Sanitary District No. 1 constructed a swirl concentrator/grit separator based upon the flow requirements of the City of Lancaster. The unit cost was approximately $4,500, without necessary valve and grit washing mechanism -- both of which were available to the District. The cost and size of the unit is less than for a conventional unit. Preliminary evaluation has indicated satisfactory operation. Full-scale evaluation is planned and will be reported separately.

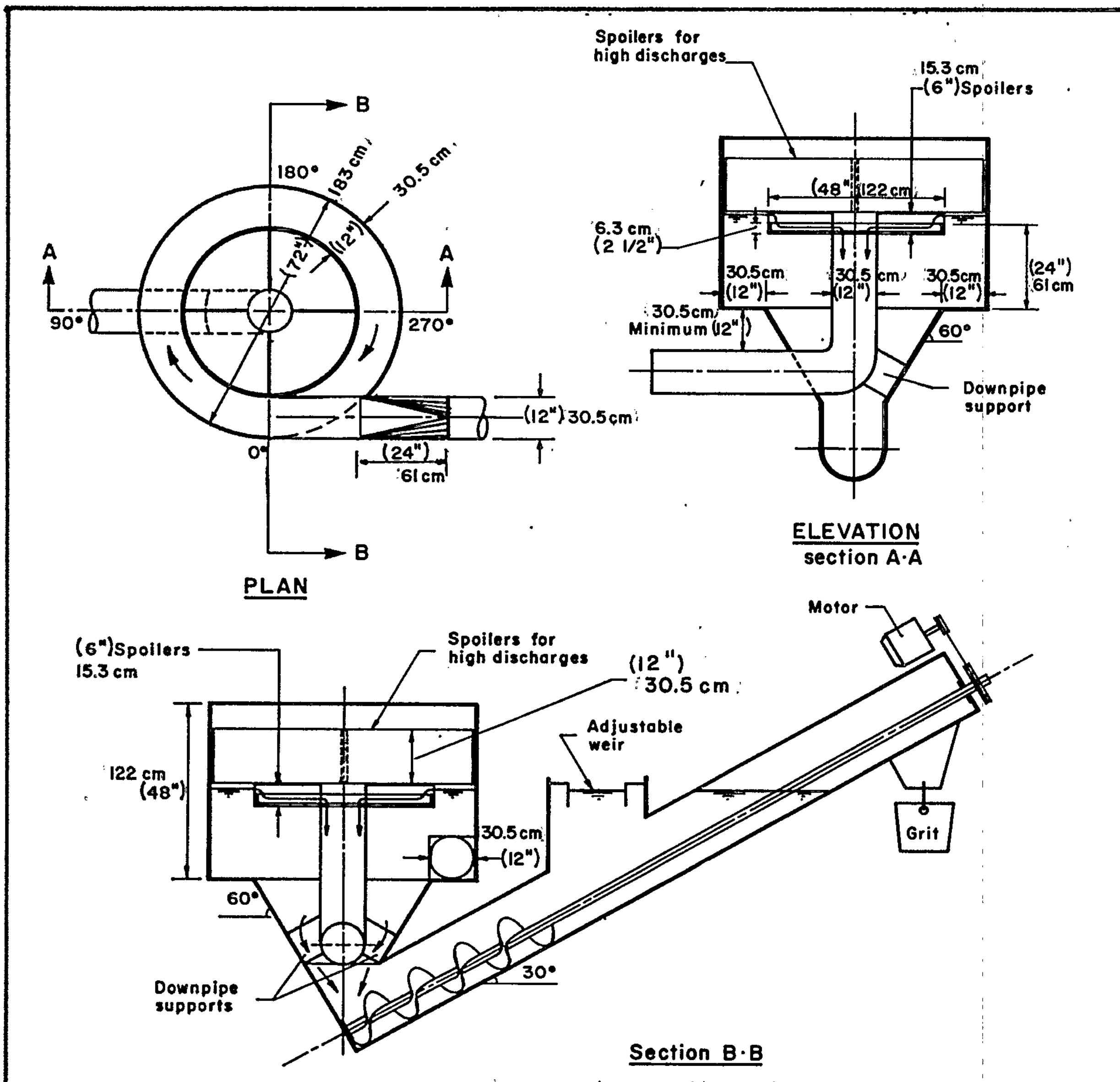


FIGURE 1 SWIRL CONCENTRATOR AS A GRIT SEPARATOR, FINAL FORM

SECTION II
THE STUDY

The ability of a swirl concentrator to remove solids from a liquid flow field by means of hydraulic separation, led to the rational suggestion that an extension of this principle to other liquid-solids separation phases of wastewater treatment should be investigated. Among the proposals for second-generation study in the report on the "Swirl Concentrator as a Combined Sewer Overflow Regulator Facility" – EPA-R2-72-008. September 1972, was one of direct relationship to the Lancaster, Pennsylvania overflow storage-pump back-partial treatment installation: namely, the study of the applicability of the swirl concentrator principle to the problem of separating grit from combined wastewater flows and the removal of this inorganic component of pollution wastes from the organic portions which could then be diverted to interceptor-treatment facilities.

The current study, covered by this Report "The Swirl Concentrator as a Grit Separator Device" resulted from this recommendation.

Grit Removal:
Basic Principles and Practices

The degritting of wastewater is common practice. It is one of the conventional pretreatment stages in sewage and/or industrial wastes treatment plants. The removal of inorganic grit is provided to prevent excessive wear on subsequent handling operations such as pumping, comminuting and screening of sewage and pumping of sludge. Elimination of inert solids prevents deposition of such material in settling tanks, sludge hoppers, sludge digestion chambers, aeration chambers, pipelines and other locations.

The removal of grit material is normally carried out by hydraulic classification – a procedure for separating inorganic and heavier solids from lighter organic materials contained in wastewater flows. The principle involves separation or classification by means of flow-rate control, thus utilizing the difference in settling rates, or buoyancy, between the different specific gravities of these two types of wastes solids.

Design of sewers is based on the principle that average sewage solids – organic and inorganic in character – can be held in suspension in a so-called self-scouring sewer line at flow velocities over 0.61 m (2 ft) per second. Similarly, grit chamber design is based on the principle that heavier grit will settle at velocities of flow of 0.3 m (1 ft) per second, while lighter organics will be held in suspension under these hydraulic conditions until they reach settling chambers where flow velocities are reduced to rates in the general range of 0.3 m (1 ft) per minute more or less. This, then, is the basic criterion for the separation of solids-from-solids in grit units, and the separation of solids-from-liquid in clarification or settling chambers.

No grit chamber is a perfect solids classification device. Some grit may pass through the chamber, regardless of its configuration and hydraulics, and some organics may settle and be intermingled with the inorganic grit. Grit washers or other auxiliary solids separation facilities are often used to remove organics from deposited grit to make it possible to dispose of innocuous inorganics by such means as dumping, use as fill, application of coarse material to sludge drying beds, dressing of pathways and other means.

The flow configurations used for grit removal are varied. They may provide rectangular channels or various combinations of flow-through chambers; they may be circular or square in shape; they may be equipped with various types of mechanical collection and removal devices to free chambers of such deposits. Grit chambers may be aerated to provide the agitation needed for washing the deposited solids and to move depositions to designated points of concentration and removal.

Grit may be removed from wastewater flows by mechanical means, such as screens, but the effectiveness of solids classification is diluted by such devices because they depend on solids size, rather than solids gravimetrics for removal. It is obvious that gravity separation or classification is more positive and more effective.

The application of the swirl concentrator phenomenon to the task of grit removal is dependent on the ability to provide flow velocity conditions and internal hydraulic patterns which will separate heavier, larger solid particles from lighter, smaller materials and to allow the two separated classifications to be collected and removed at separate points. In this respect, this application is different from the successful use of the swirl concentrator as a total solids separator of combined wastewater flows, as developed in the research project which led to the finding that swirl concentration could be applied to the task of removing grit materials only.

The APWA Study

The proposal by the APWA Research Foundation to carry out a study of the application of the swirl concentration principle to the function of grit removal was based on the background data outlined above and on known principles of grit chamber design, also as outlined above. Continuity of purpose with the previous study of swirl applications for combined wastewater overflow clarification was proposed. The study's objective was to achieve a workable, effective grit removal device for the Lancaster, Pennsylvania regulator-treatment installation, and a grit separator design which would have a broader and more universal application in the treatment of storm, combined, domestic and industrial wastewaters.

A realistic appraisal of the proposal led to the conclusion that a mere substitute for conventional grit removal facilities by means of a swirl concentrator should not be the proper and ultimate goal of the study. Any application of the swirl principle, as intended by the proposal, should be judged on its ability to perform the grit separation and removal process more efficiently, more rapidly by *flash* classification, and therefore more expeditiously and economically than other means of performing this function. This would apply not only to the specific configuration and dimensions of a swirl concentrator-separator for the Lancaster project but, in addition, to any necessary conformations required to make this method of grit handling amenable to other uses in other locations.

The proposal provided for initiation of studies of the action of simulated mixtures of solids — synthesized to approximate in model size the admixture of non-organic grit and non-grit organics that would actually be contained in the Lancaster four sewer flows, following handling in the swirl concentrator overflow regulator previously studied. This combined sewer regulator device, it was estimated, could divert as much as a ton of concentrated solids to the foul sewer out of the combined sewer overflow within a few hours. Removal of the grit portion of this solids loading would protect downstream pumps against wear and abrasion and benefit the sewage treatment processes tributary to the Lancaster interceptor sewer system.

To perform the outlined studies, it was planned that the basic configurations of the original regulator overflow swirl concentrator chamber be examined and such modifications as would enhance the ability of this hydraulic facility be made to: (1) separate grit from non-grit solids; (2) concentrate and remove these heavier solids from the cahmber via a bottom foul sewer connection and/or mechanical-physical means; and (3) allow the organic wastes to overflow over a central weir and discharge assembly into the Lancaster interceptor sewer and treatment plant.

The particle flow model established for the overflow concentrator study is substantially applicable to the separation of grit from organic solids. The assumption of discrete non-interacting particles would be valid throughout the body of the flow chamber, except near the bottom where increased solids concentrations may occur and where these deposits might not continuously gravitate to the bottom foul sewer outlet. Inlet configurations were developed to provide proper velocities and directional injection of solids into the forced swirl pattern, under flow variations affected by normal diurnal and abnormal storm conditions. Other hydraulic factors affecting model configurations and internal baffles, dampeners, and other appurtenant parts of a workable swirl chamber were studied in the model having a scale of 1:2 with the ultimate Lancaster installation. The Froude relations were particularly attractive at such a large scale for all the hydraulic parameters.

Swirl concentrator modifications were made to meet changes in inflow characteristics from former non-uniform flows to constant flows that will produce full-sewer conditions in the inlet line at all times. Modifications of the *bottom shape of* the chamber, the point of grit outlet and the foul sewer size were also necessary.

No mathematical modeling studies were proposed for the grit research project. The basis for solids and liquid behaviors was adequately determined in the previous studies to permit their interpretation in connection with the solids classification patterns anticipated in the grit swirl hydraulic investigation.

SECTION III
GENERAL FEATURES AND DESIGN

The general features of the hydraulic model are identified in Figure 2, Isometric View, Swirl Concentrator as a Grit Separator.

(a) Inlet. – The inlet dimension is normally designed to allow an inlet velocity of 0.61 m (2 ft) per second. On this basis the inlet diameter becomes the controlling dimension for sizing the unit. A set of curves has been developed to express the relationship between flow, inlet dimension, chamber width and depth. The flow is directed tangentially so that a "long path" pattern, maximizing solid separation in the chamber, may be developed.

(b) Covered Inlet. – The Covered inlet is a square extension of the inlet which is the straight line extension of the interior wall of the inlet extending to its point of tangency. Its location is important, as flow which is completing its first revolution in the chamber strikes, and is deflected inwards, forming an interior water mass which makes a second revolution in the chamber, thus creating the "long path" flow pattern.

Without the deflector, the rotational forces would quickly create a free vortex within the chamber, destroying the solid separations efficiency. The height of the deflector is the height of the inlet port, insuring a head above the elevation of the inlet, a feature which tends to rapidly direct solids down towards the floor.

(c) Overflow Weir and Weir Plate. – The diameter of the weir is a function of the diameter of the chamber, and of the inlet dimension. Under normal conditions, the weir diameter is equal to the chamber diameter minus twice the inlet dimension. The depth, or vertical distance from the weir to the flat floor, is normally twice the inlet dimension. The height, or rise, of the weir plate is normally 0.25 x the inlet diameter.

The weir plate connects the overflow weir to a central column, carrying the clear overflow to the interceptor and primary treatment. The horizontal leg of the downshaft should leave the chamber parallel to the inlet.

(d) Spoilers. – Spoilers are radial flow guides, vertically mounted on the weir plate, extending from the center shaft to the edge of the weir. They are required to break up the rotational flow of the liquid above the weir plate, thus increasing the efficiency of the weir and the downshaft.

The height of the spoilers is the same as the inlet diameter. This proportionately large size, as compared to the combined sewer overflow regulator, is required because of the possible large variations in diurnal flow which may be anticipated.

(e) Floor. – The floor of the unit is level and is in effect a shelf, the width of the inlet.

(f) Central Hopper. – The central hopper is used to direct the settling grit particles to a single delivery point where they may be removed to a conveyor for washing and removal from the system.

The hopper is at an angle of 60 degrees to the floor. If the angle is less than 45 degrees, particles will build up at the lip. As the angle is increased, the problem decreases to an optimum condition at 60 degrees.

The downshaft elbow must be sufficiently below the floor to prevent formation of eddy currents. This depth appears to be the inlet diameter. Structural supports for the elbow and actual pipe connections must be designed to prevent rags from being caught on a protruding bolt head, flange or strut. The downshaft should exit parallel to the inlet to assure a minimum hydraulic interference for settling particles.

Figure 3, General Design Dimensions, lists the various important dimensions, which are given as a function of the inlet diameter, D_1.

A supplemental study was made to determine how the ratio of depth to width, or diameter, of the swirl chamber might be varied to allow flexibility of design.

Basic Criteria of Grit and Organic Constituents of Inflow

Grit Size. – The character of the grit reaching any plant will depend on many factors. Chief among these are the nature of

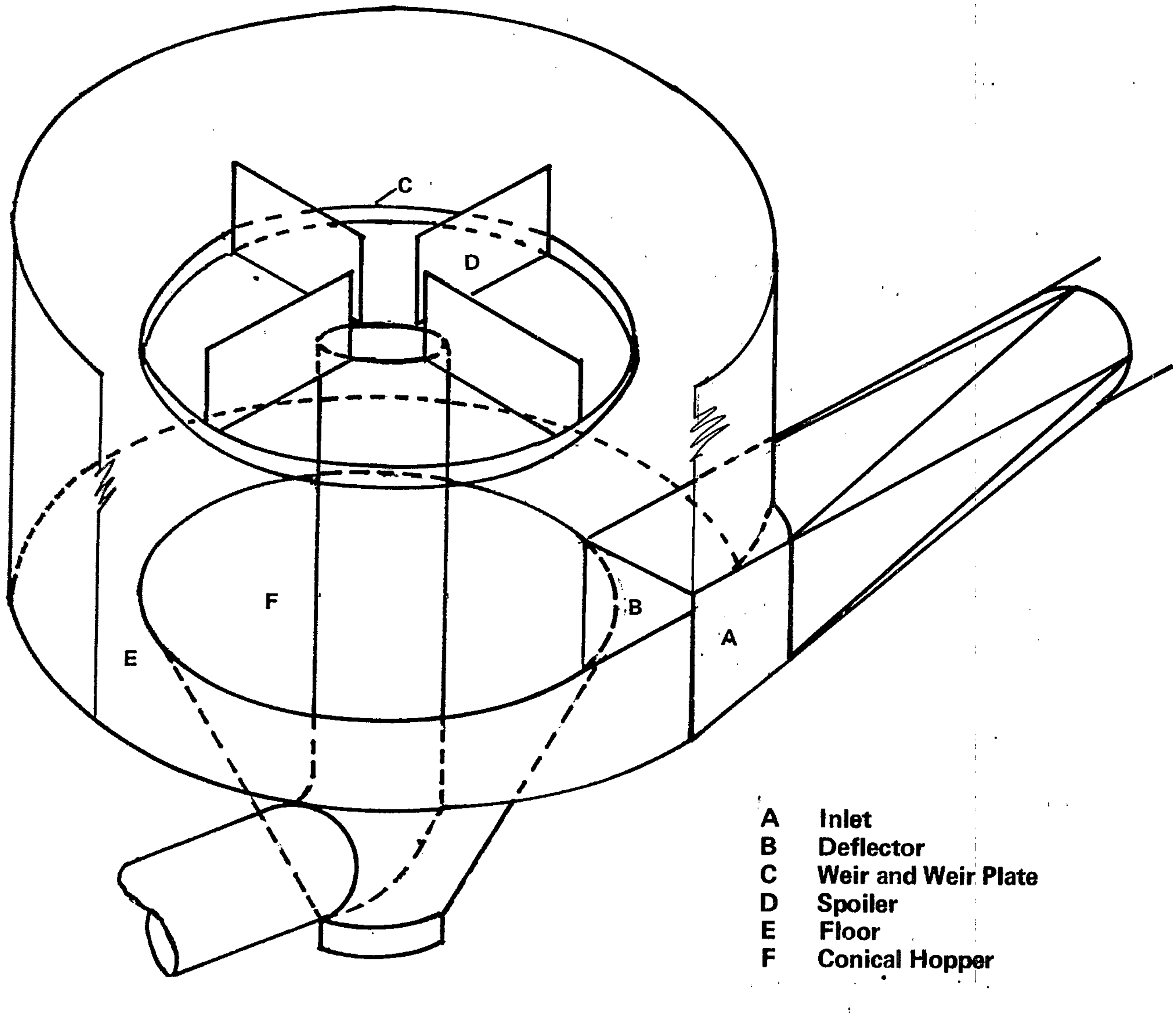
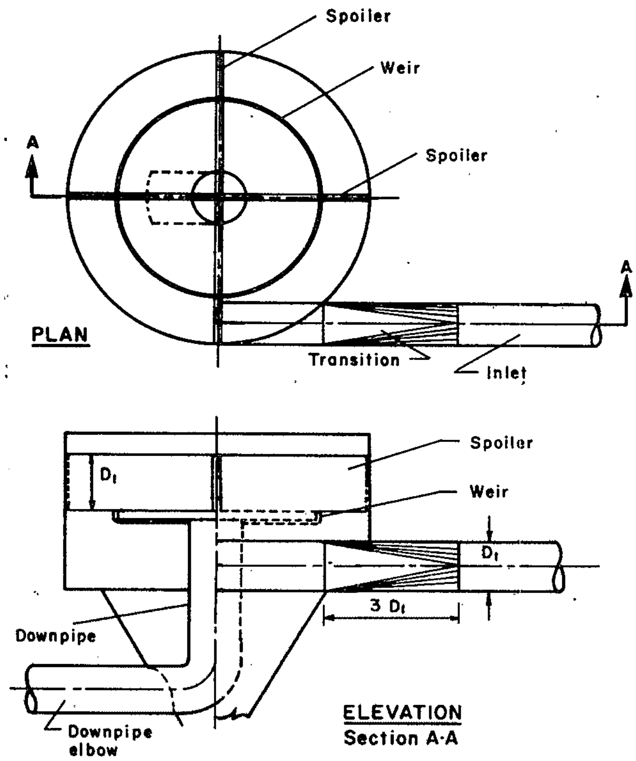


FIGURE 2 ISOMETRIC VIEW, SWIRL CONCENTRATOR AS A GRIT SEPARATOR



NOTE: Inlet and foul outlet should be parallel for optimum hydraulic conditions within conical hopper.

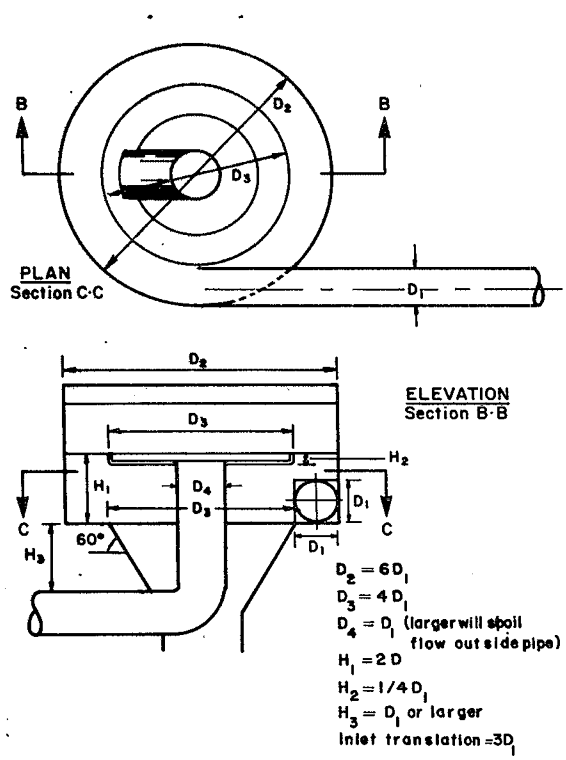


FIGURE 3 GENERAL DESIGN DIMENSIONS

the soil, the age and condition of the sewer pipe and its joints, pipe slope, catch basin and street cleaning practices, the type of ground cover in the tributary area, urban street conditions, and whether the collection system consists of separate or combined sewers.

Available data on the mechanical analysis of grit removed from representative wastewater treatment plants were compared to establish criteria for grit sizes for this study.

Data from eight existing plants located in the United States and Canada are tabulated in Table 1, Sieve Analyses of Samples from Grit Chambers. The original data were adjusted to correspond with the U.S. sieve numbers and to indicate percent of weight finer than given sieve sizes. These sieve analyses are shown graphically in Figure 4, Gradation Curves of Samples from Grit Chamber in Model. Most of the grit particles in the samples are larger than 0.2 mm. This may be explained by the fact that most grit chambers are designed to remove only grit greater than 0.2 mm size. A notable exception is the sample from Tampa where 65 percent of the sample is finer than 0.2 mm.

New York City performed an extensive study in 1962 and 1963 on the character of grit collected in aerated grit chambers and in other plant structures downstream of the grit chambers. Samples were taken at several locations in grit chambers at three plants. The analyses of samples taken closest and farthest from the grit chamber inlet at these plants are given in Table 2, Sieve Analysis of Samples from Aerated Grit Chamber, New York City Plants, and plotted in Figure 5, Gradation Curves of Samples from Aerated Grit Chambers, New York City Plants. Samples near the inlet have less than 10 percent of the sample finer than 0.2 mm while samples near the end of the chamber show 15 to 25 percent finer than 0.2 mm. Over 90 percent of all the samples are finer than 2.0 mm. Samples were also taken in aeration tanks, final settling tanks and digestion tanks at these three plants. Data on the coarsest

Table 1. SIEVE ANALYSIS OF SAMPLES FROM GRIT CHAMBERS

Sieve Designation mm	U. S. Sieve No.	Percentage Finer by Weight (1) Green Bay Wis. 1/	(2) Kenosha Wis. 1/	(3) Tampa Fla. 1/	(4) St. Paul Minn. 1/	(5) St. Paul Minn. 1/	(6) Winnipeg Manitoba 2/	(7) Winnipeg Manitoba 2/	(8) Denver Colo. 2/
6.3	1/2 in.								94.9
4.75	4				99.0	93.0		77.1	
3.35	6								89.2
2.36	8				95.0	80.0		46.3	
2.00	10	96.3	88.0				96.9	38.9	75.2
0.850	20	90.9			88.0	47.0	83.2	14.7	
0.600	30								6.7
0.425	40	80.2	30.0				44.3	6.3	
0.300	50	70.4		97.7	80.0	33.0	19.2	3.5	
0.212	70	48.3					4.4	1.3	
0.180	80		5.0						
0.150	100	21.8		40.7	3.0	0.1			0.7
0.075	200	3.9		0.5					

Notes:

1/ Adapted from data in ASCE Manual No. 36, 1959 edition
2/ All data adapted from correspondence, 1973
(4) Lower range
(5) Upper range
(6) Inlet end
(7) Outlet end

samples from these structures are shown in Table 3, Sieve Analysis of Samples from Structures Downstream of Aerated Grit Chambers, New York City Plants, and Figure 6, *Gradation Curves of Samples from* Structures Downstream of Aerated Grit Chambers, New York City Plants. The grit at these downstream points is much finer than

Table 2. SIEVE ANALYSES OF SAMPLES FROM AERATED GRIT CHAMBERS NEW YORK CITY PLANTS

Sieve Designation		Percentage Finer by Weight					
		(9)	(10)	(11)	(12)	(13)	(14)
mm	U.S. Sieve No.	Rockaway	Rockaway	Coney Island	Coney Island	Jamaica Bay	Jamaica Bay
4.75	4	99	100	99	100	98	100
1.18	16	90	100	94	99	87	99
0.850	20	83	99	86	98	80	98
0.600	30	74	98	65	94	68	96
0.425	40					40	88
0.300	50	26	62	13	45	15	55
0.212	70	7	18	5	16	4	26
0.150	100	2	4	1	4	2	10
0.075	200					1	2

Notes: All data adapted from correspondence
(9) 10 feet from inlet, Feb., 1963
(10) 46 feet from inlet, Feb., 1963
(11) Chamber No. 3, May, 1962
(12) Chamber No. 4, May, 1962
(13) Bay No. 1, Dec., 1963
(14) Bay No. 3, Dec., 1963

Table 3. SIEVE ANALYSES OF SAMPLES FROM STRUCTURES DOWNSTREAM OF AERATED GRIT CHAMBERS NEW YORK CITY PLANTS

Sieve Designation		Percentage Finer by Weight		
		(15)	(16)	(17)
mm	U.S. Sieve No.	Rockaway	Coney Island	Rockaway
4.75	4			100
1.18	16			96
0.850	20		100	91
0.600	30	99	99	86
0.300	50	68	60	68
0.212	70	29	20	42
0.150	100	8	8	22

Notes: All data adapted from correspondence

(15) Aeration tank, Mar., 1963
(16) Final settling tank, Jan., 1963
(17) Digestion tank

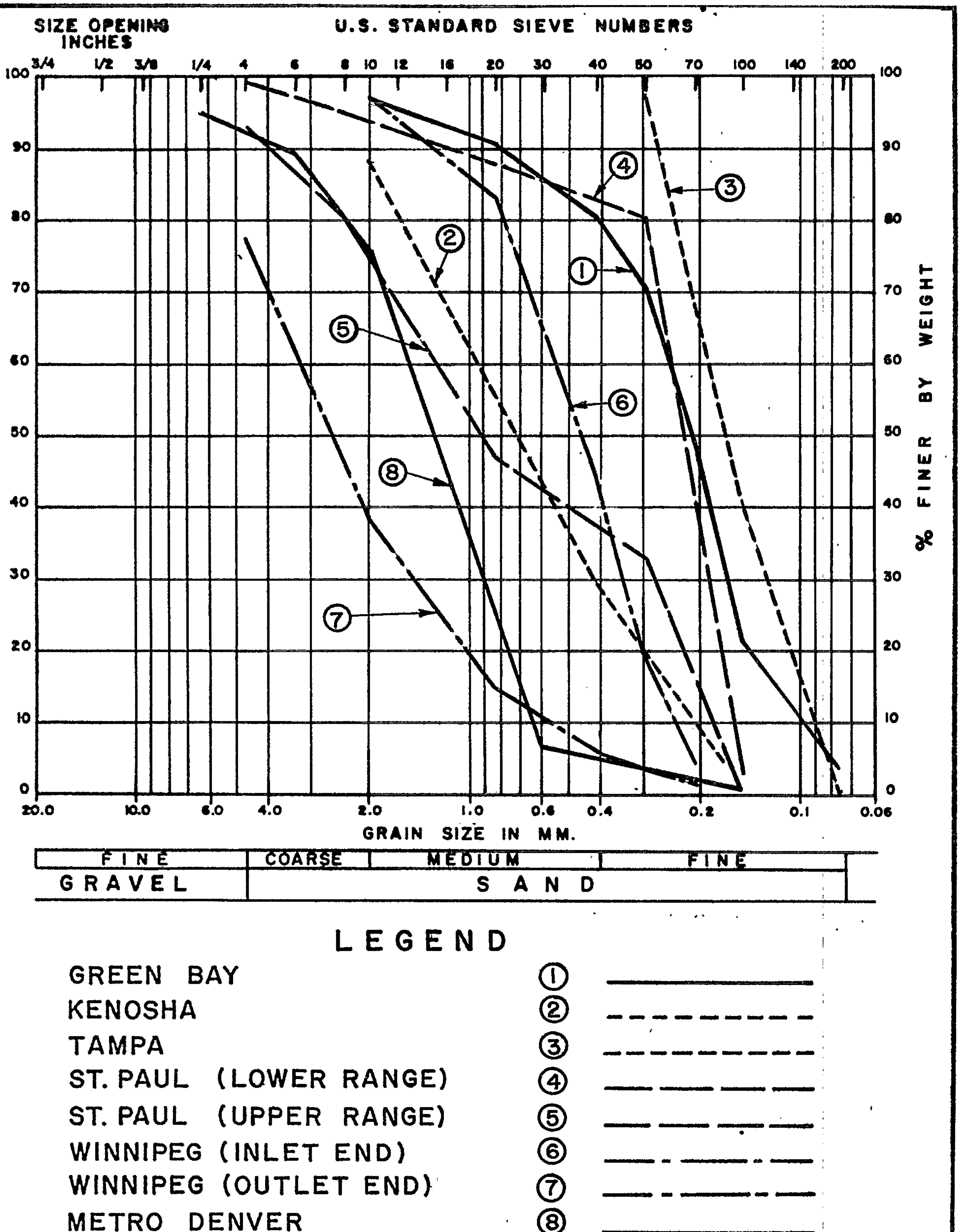
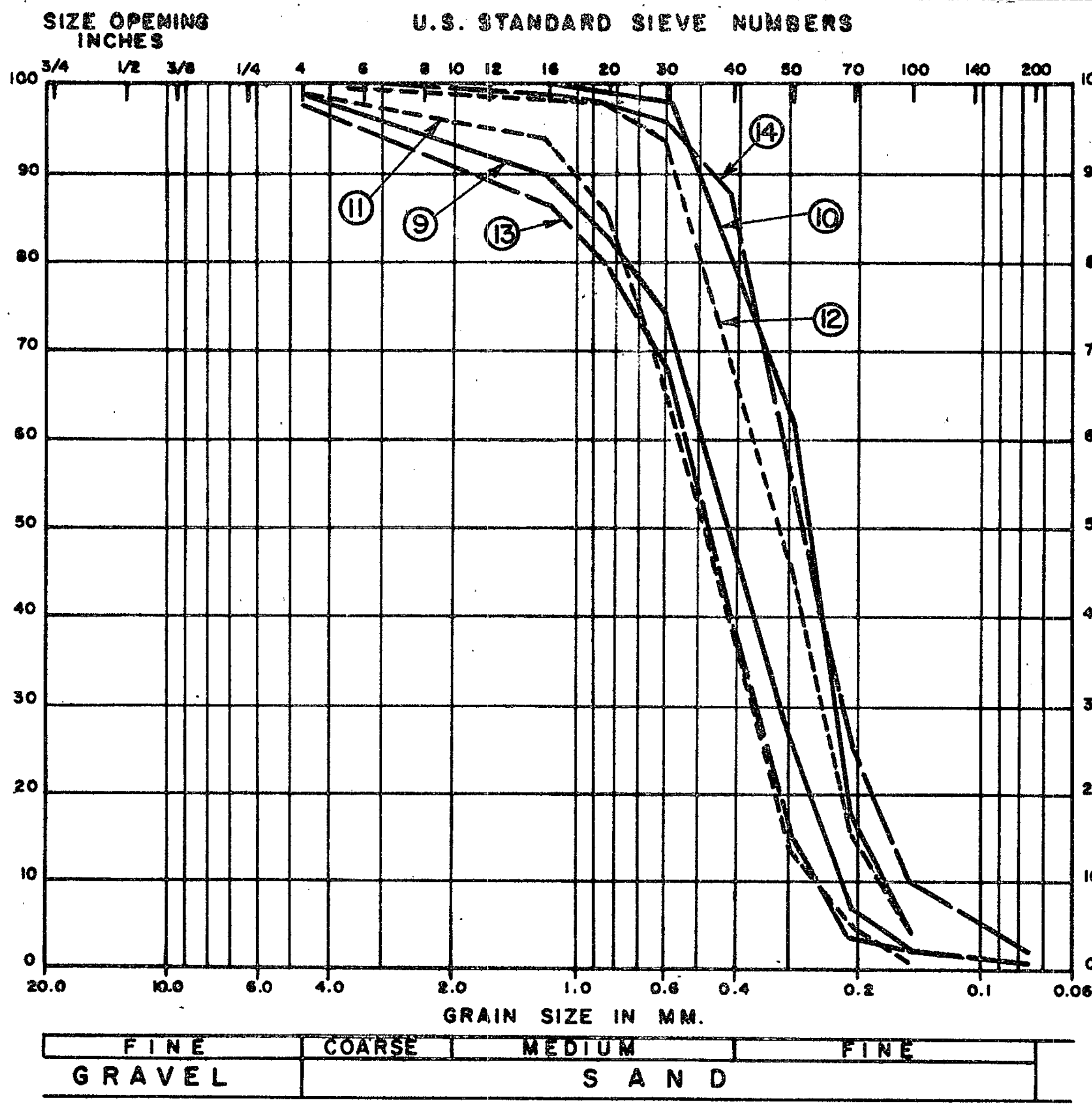


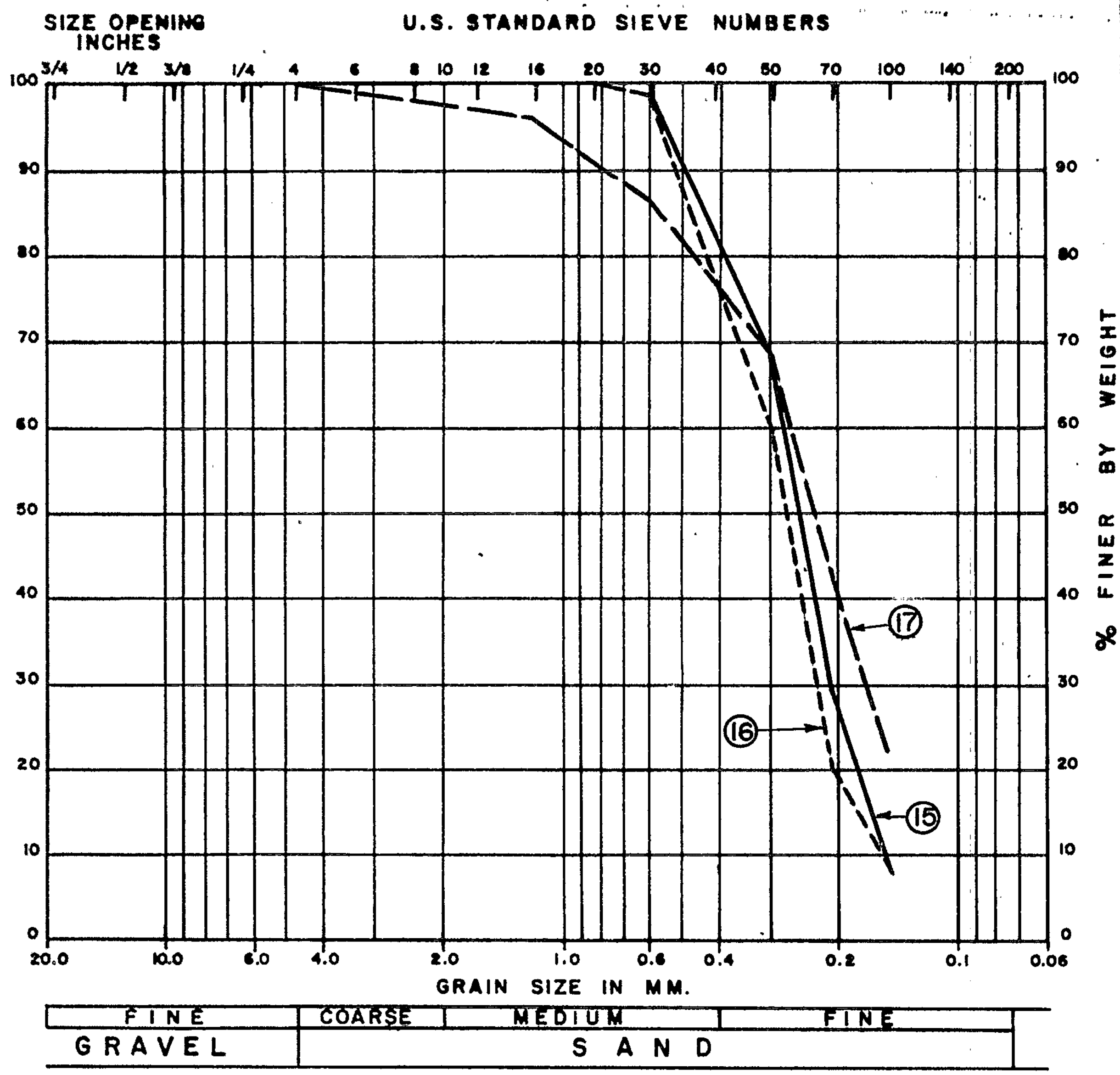
FIGURE 4 GRADATION CURVES OF SAMPLES FROM GRIT CHAMBER



LEGEND

ROCKAWAY, N.Y. WPCP	(10 FEET FROM INLET)	⑨	————
ROCKAWAY, N.Y WPCP	(46 FEET FROM INLET)	⑩	————
CONEY ISLAND, N.Y. WPCP	(CHAMBER NO. 3)	⑪	------------
CONEY ISLAND, N.Y. WPCP	(CHAMBER NO. 4)	⑫	- - - - - -
JAMAICA BAY, N.Y. WPCP	(BAY 1)	⑬	—— —— ——
JAMAICA BAY, N.Y. WPCP	(BAY 3)	⑭	—— —— ——

FIGURE 5 GRADATION CURVES OF SAMPLES FROM AERATED GRIT CHAMBERS



LEGEND

ROCKAWAY, N.Y. WPCP (AERATION TANK) ⑮ ————

CONEY ISLAND, N.Y. WPCP (FINAL SETTLING TANK) ⑯ - - - - - -

ROCKAWAY, N.Y. WPCP (DIGESTION TANK) ⑰ — — — —

FIGURE 6 GRADATION CURVES OF SAMPLES FROM STRUCTURES DOWNSTREAM OF AERATED GRATE CHAMBERS, NEW YORK CITY PLANT that captured in the grit chamber, with about one-third finer than 0.2 mm and all finer than 1.0 mm, except for grit deposited in the Rockaway digestion tank.

Based on the foregoing, a "typical grit" for purposes of this study was assumed to range in size from 0.2 mm to 2.0 mm, with a gradation corresponding to a straight line on a mechanical analysis graph.

The assumed gradation is given in Table 4, Typical Grit Gradation, and shown graphically in Figure 7, Gradation Curve of Typical Grit.

Table 4

TYPICAL GRIT GRADATION

Size mm	U. S. Sieve No.	% Finer by weight
2.00	10	100
0.850	20	63
0.425	40	31
0.300	50	18
0.212	70	0

Specific gravity of the typical grit is assumed to be 2.65.

Based on the Unified Soil Classification System, the typical grit consists of fine sand with size from 0.212 mm (U.S. Sieve No. 70) to 0.425 mm (U.S. Sieve No. 40), and medium sand with size from the latter value to 2.00 mm (U.S. Sieve No. 10).

Grit Quantity. – A comparison of the quantity of grit collected in separate and combined sewer systems, as reported in ASCE Manual No. 36[1], was made, based on 11 cities with combined sewers, and 15 cities with separate sewers.

This comparison indicated the following range in the maximum quantities of grit collected in grit chambers.

	Combined Sewers 11 Cities	Separate Sewers 15 Cities
Miligrams/liter		
Low	32	11
High	290	170
Cubic feet/million gallons		
Low	2.7	0.9
High	24.1	14.1
Pounds/million gallons (assuming 100 lbs/cf)		
Low	270	90
High	2410	1410

It should be noted that two cities, Battle Creek and Cleveland, in ASCE Manual No. 36, reported grit quantities in storm periods which on the above basis would be equivalent to 2,000 mg/l and 6,500 mg/l, respectively.

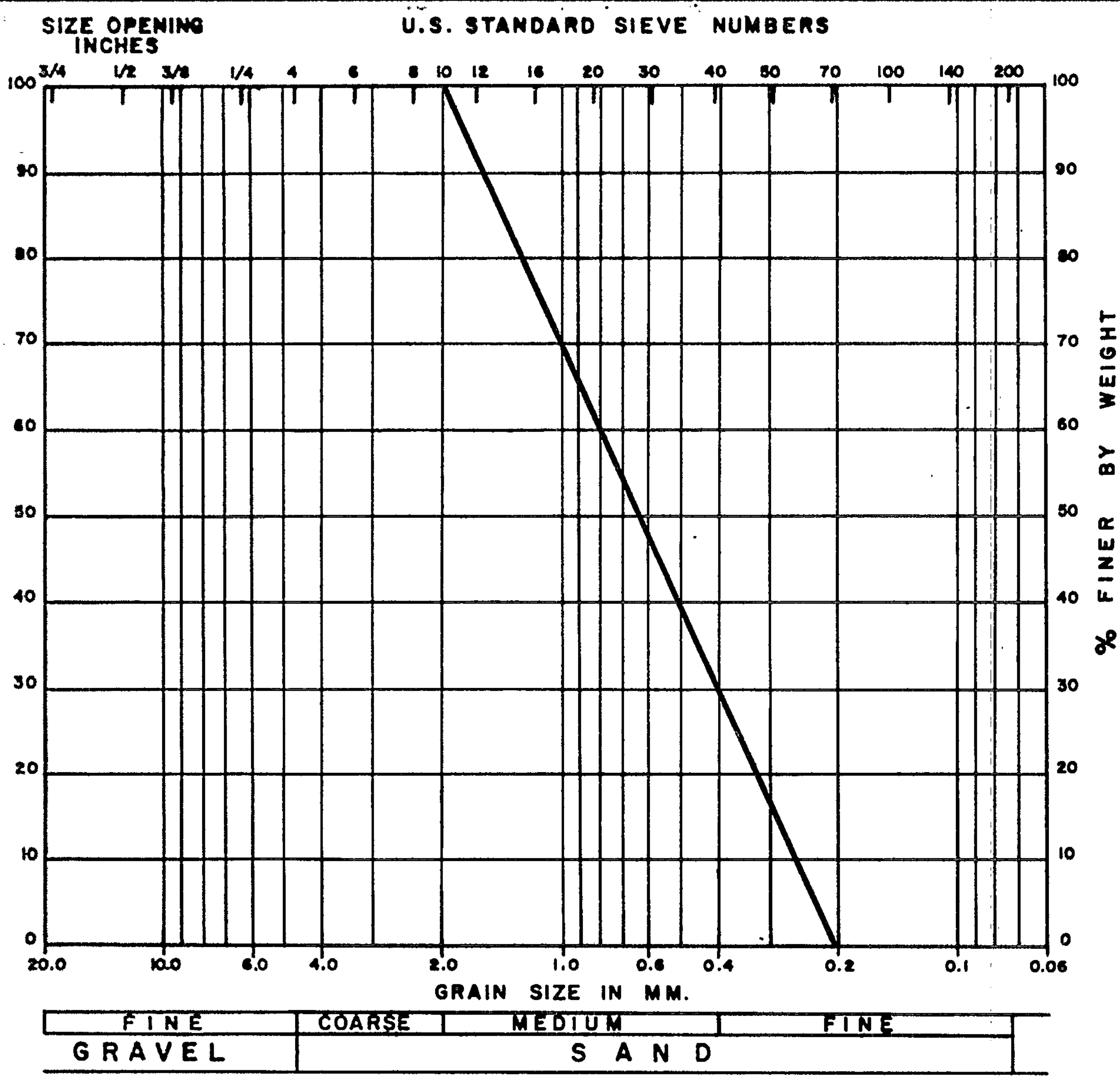
While data are available on the quantity of grit removed from grit chambers, no information is available either on total grit arriving at a plant or on the percent of total grit recovered in the grit chambers. Experimental work by Chasick and Burger in New York City in 1964[2] indicated that a cyclone grit separator would remove practically all sand of 0.1 mm size and greater. Subsequent work by Neighbor and Cooper in 1965[3] indicated that the proper installation of baffles in aerated grit chambers could raise the recovery rate of grit of 0.2 mm size and greater, from 70 to 90 percent. Later work by Albrecht published in 1967[4] indicated that with proper design an aerated grit chamber could remove 95 percent of grit 0.25 mm in size and greater. The last conclusion is consistent with the removal of 90 percent of grit of 0.2 mm size and larger.

From the foregoing, it appears reasonable to conclude that the maximum quantities of grit 0.2 mm in size and larger will range from 40 to 360 mg/l in combined sewers and from 20 to 200 mg/l in separate sewers and that the grit recovered in the grit chamber will be 90 percent of the foregoing and will range from 36 to 324 mg/l in a combined sewer system and from 18 to 180 mg/l in a separate sewer system.

In a previous EPA report on the swirl concentrator[5] it was also assumed that the maximum concentration of grit in combined sewers would be 360 mg/l.

The summary of grit characteristics used for this report is given in Table 5, Specific Gravity, Size and Concentration of Settleable Solids.

Organic Constituents. – The character of settleable solids, excluding grit and floatable solids, is considered to be the same in sanitary sewers as in combined sewers except for the concentration. Based on conclusions reached in the previous EPA report on the swirl concentrator[5] the quantity and quality of the settleable solids in both sanitary and combined sewers are given in Table 5. Non-settleable and dissolved solids are not



GRADATION

SIZE MM	U.S. SIEVE NO.	% FINER BY WEIGHT
2.00	10	100
0.850	20	63
0.425	40	31
0.300	50	18
0.212	70	0

FIGURE 7 GRADATION CURVE OF TYPICAL GRIT

Table 5. SPECIFIC GRAVITY, SIZE AND CONCENTRATION OF SETTLEABLE SOLIDS

Material	Specific Gravity	Concentration mg/l	Particle Size mm
Combined Sanitary and Storm Sewage			
(1) Settleable Solids Excluding Grit	1.05–1.2	200–1550	0.2–5
(2) Grit	2.65	40–360	0.2-2.0
(3) Floatable Solids	0.9–.998	10–80	5–25

Particle Size Distribution

Material						
(1) Settleable Solids Excluding Grit	Size (mm)	0.2	0.5	1.0	2.5	5.0
	% by weight	10	10	15	25	40
(2) Grit (see Table 4)						
(3) Floatable Solids	Size (mm)	5	10	15	20	25

Sanitary Sewage
Same as above except for concentration

Material	Concentration mg/l
(1) Settleable Solids Excluding Grit	200–500
(2) Grit	20–200
(3) Floatable Solids	10– 80

considered herein because it is assumed that the swirl concentrator will not affect their removal.

Flow Rate, and Overflow and Foul Discharge Rates

The primary purpose of this study was to design a grit removal device capable of performing the functions of a conventional grit chamber, to accommodate the high solid flow from a combined sewer overflow regulation with a flow of from 0.028 m^3/sec (1 cfs) to 0.146 m^3/sec (5 cfs). This would conform with the following **design criteria**:

Peak flow	0.140 m^3/sec	(5 cfs)
Average flow	0.084 m^3/sec	(3 cfs)
Minimum flow	0.028 m^3/sec	(1 cfs)

When the use of a swirl concentration grit chamber is considered for sanitary sewage flow the flow hydrograph will vary from one location to another but it will generally follow a diurnal pattern of maximum flows in the daylight hours and minimum flows in the late night hours.

Investigations by others have indicated that the variation in concentration of suspended matter is greater than the variation in the flow. The concentration of suspended matter can be expected to be less than 40 percent of the average at low flows and to be greater than 150 percent of average during peak flows. During periods of low flow grit would be expected to settle out in the sewers and subsequently to be flushed out when the flows exceed the average rate. Assuming periodic flows with a greater concentration of grit than the average concentration, it might be possible for 70 to 80 percent of the suspended matter to be discharged during the period of peak flow. Hence, the grit chamber must be designed to remove grit at maximum efficiency during daily peak flow periods.

It is also necessary to operate at reasonable efficiency during low flow periods. Grit chambers designed on the basis of velocity control accomplish this by controlling the velocity through the chamber between 0.229 m/sec (0.75 fps) and 0.366

m/sec (1.2 fps). In addition, removal of grit may not be achieved during low flow periods but postponed until peak flow periods when the higher velocities will keep the organics in suspension. Aerated grit chambers are designed to provide a continuous velocity of flow with a transverse velocity between 0.458 m/sec (1.5 fps) and 0.61 m/sec (2.0 fps) to keep the organics in suspension.

In the swirl concentrator it is hoped that the rotational flow pattern induced by the entrance velocity will be sufficient at all times to keep the organic matter in suspension while permitting the settling of the grit. Since this may not always occur, it is considered necessary to use a grit washer to remove organic materials which settle out with the grit.

Therefore, one of the initial concepts in the use of the swirl concentrator as a grit chamber involved the use of the grit washer with an inclined screw conveyor. This concept is shown in Figure 8, Grit Chamber Above Ground with Inclined Screw Conveyor. The determination of the grit quantity to be removed is given in Table 6, Grit in Sanitary Sewage. With a grit concentration range of 20 to 200 mg/l in sanitary sewage, the range of grit removal for an average daily flow of 0.084 m^3 sec (3 cfs) would be from 0.002 to 0.0424 m^3/hr (0.1 to 1.2 cuft/hr).

Using data from one manufacturer of this type of grit washer, this grit quantity would require a washer with a screw diameter of 22.9 cm (9 in.) with capacity of 0.56 m^3/hr (20 cuft/hr) and would require a wash water rate of 0.171 m^3/min (45 gpm). The wash water in this case would be the quantity of sewage allowed to flow up the screw casing from the swirl chamber with the grit. This would keep the organics in suspension and be returned to the effluent pipe from the grit chamber after flowing over the adjustable weir.

Table 6. GRIT IN SANITARY SEWAGE

			Min	Max
1.	Sanitary Sewage flow	m^3/sec	0.084	0.084
2.		cfs	3	3
3.	Grit concentrations	mg/l	20	200
4.	Grit removal	mg/l	18	180
5.	Weight of grit	kg/hr	5.5	55
6.		lbs/hr	12	120
7.	Volume of grit	m^3/hr	0.002	0.024
8.		cuft/hr	0.1	1.2

Notes:

Line 4 = 90% x Line 3

Line 6 = $\frac{3}{11.55}$ x Line 4 x $\frac{8.345}{24}$

The secondary purpose of this study was to determine the feasibility of using the swirl concentrator for further concentrating the grit contained in the foul outlet from a swirl concentrator used as a combined sewer overflow regulator at Lancaster, Pennsylvania. The design flow for the regulator in Lancaster is 4.62 m^3/sec (165 cfs). The flow in the foul outlet is expected to range from 0.042 m^3/sec (1.5 cfs) to 0.140 m^3/sec (5.0 cfs). Thus, the influent to the swirl grit chamber will be the effluent from the foul outlet of the regulator. The determination of the settleable solids in the foul outlet from the swirl regulator, based on the concentrations shown in Table 5, is given in Table 7, Settleable Solids in Swirl Concentrator Used as a Combined Sewer Overflow Regulator at Lancaster.

The derivation of 68 percent in line 7 of Table 7 is based on data in EPA Report EPA-R2-72-008. Figure 22 of that report indicates that the swirl concentrator will remove 90 percent of grit larger than 0.35 mm. Figure 7 of this grit swirl concentrater report indicates that 76 percent of the typical grit is larger than 0.35 mm. Therefore, the swirl concentrator will remove 68 percent (90% x 76) of the total grit entering the storm water regulator. If the grit chamber is sized on the basis of the design curves which are based on removal of 90 percent of grit over the 0.2 mm size, then it is reasonable to assume that the chamber will remove 100 percent of the grit over 0.35 mm in size. Thus, the grit to be removed is from 0.28 to 2.52 m^3/hr (10 to 90 cuft/hr). According to data of one manufacturer, this will require a screw with diameter of 50.8 cm (20 in.) with capacity of 3.5 m^3/hr (124 cuft/hr), having a wash water rate of 0.36 m^3/min (95 gpm).

The settleable solids, excluding grit, in the foul outlet flow from the combined sewer overflow regulator will vary from 12,700 to 29,600 mg/l, as shown in Table 7. This is

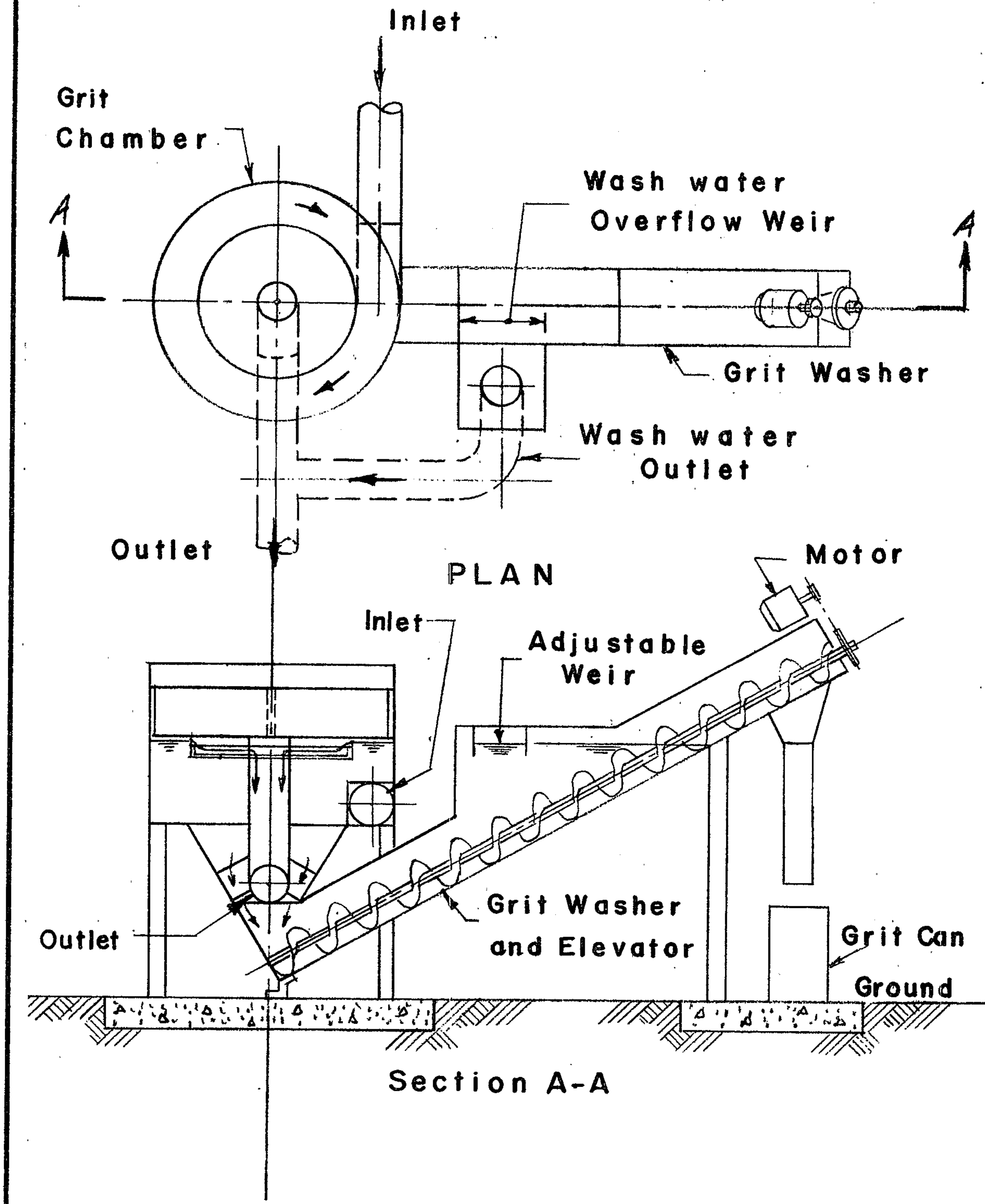


FIGURE 8 GRIT CHAMBER ABOVE GROUND WITH INCLINED SCREW CONVEYOR

based on the design curves in EPA Report EPA-R2-72-008[5]. Figure 22 of that report indicates that the regulator will remove 90 percent of settleable solids, excluding grit larger than 1.0 mm. Figure 3 of that report indicates that 65 percent of settleable solids, excluding grit, are larger than 1.0 mm. Hence 58 percent (90% x 65) of the settleable solids, excluding grit, will be removed through the foul inlet.

Table 7. SETTLEABLE SOLIDS IN SWIRL CONCENTRATOR USED AS COMBINED SEWER REGULATOR AT LANCASTER

		Min	Max
	Flow		
1.	Combined flow m^3/sec	4.62	4.62
2.	(cfs)	(165)	(165)
3.	Flow in foul outlet m^3/sec	0.042	0.14
4.	(cfs)	(1.5)	(5.0)
5.	Ratio combined to foul outlet flow	110	33
	Grit		
6.	Concentration in inflow mg/l	40	360
7.	Percentage of total grit in foul outlet	68	68
8.	Concentration in foul outlet mg/l	3000	8100
9.	Kilogram/hour	457	4100
10.	(Lbs/hr)	(1010)	(9060)
11.	m^3/hr	0.28	2.52
12.	(cuft/hr)	(10)	(90)
13.	Grit percentage by weight	0.3	0.8
	Settleable solids excluding grit		
14.	Concentration mg/l	200	1550
15.	Percentage in foul outlet	58	58
16.	Concentration in foul outlet mg/l	12,700	29,600
17.	Percentage by weight in foul outlet	1.3	3.0
	Total settleable solids		
18.	Percentage by weight in foul outlet	1.6	3.8

Notes:

Line 7 = 90% x 76
Line 8 = (line 6 x line 5 x line 7) ÷ 100
Line 10 = (line 8 x 8.345 x line 4 x 0.646) ÷ 24
Line 11 Assuming grit weighs 1640 Kg/m^3 (100 lb/cuft)
Line 13 = line 8 ÷ 10,000
Line 15 = 90% x 65
Line 16 = (line 14 x line 5 x line 15) ÷ 100
Line 17 = line 16 ÷ 10,000
Line 18 = line 13 + line 17

As shown in Table 7, the inflow to the grit chamber at Lancaster may have concentrations of 1.3 to 3.0 percent settleable solids, excluding grit, 0.3 to 0.8 percent grit, and 1.6 to 3.8 percent total settleable solids. Of this material, it is assumed that the grit chamber will remove all the grit which may range from 0.28 to 2.52 m^3/hr (10 to 90 cuft/hr).

In practice, because of the highly variable rate of grit discharge from the combined sewer overflow regulator, it may be desirable to eliminate the washing of the grit because of the difficulty in adjusting the wash water flow rate to the varying concentrations of grit.

Design Features

Grit Removal. – The first concept for removing the grit involved the use of an inclined screw and grit washer. If the chamber is located above ground with an inclined screw conveyor discharging above ground, the proportions of the structure would be as shown in Figure 8. The most suitable material for construction would be structural steel shapes and carbon steel plates.

If both the grit chamber and the inclined screw conveyor are located below ground the layout may be as shown in Figure 9, Grit Chamber Below Ground with Inclined Screw Conveyor. Access must be provided to the lower part of the screw for lubrication and maintenance purposes. The simplest construction would be to make the chamber of steel, as in the previous case, and construct a concrete rectangular chamber to provide access. the inclined screw must be lengthened for the previous case in order to get the delivery point sufficiently high above ground level to discharge the grit into a storage container. From the proportions shown in Figure 9, the length of the screw conveyor is 3-1/3 times the diameter. This length may become excessive for larger diameter chambers and other methods of removing the grit may have to be considered, such as a depressed ramp.

Another method of removing the grit, which is sometimes used in aerated grit chambers, is a horizontal screw to convey the grit to a manhole with a bucket elevator to lift the grit to the grit washer located above ground level. This is shown in Figure 10, Grit Chamber Below Ground with Horizontal Screw Conveyor. Access must be provided to the horizontal screw for lubrication and maintenance; therefore, it would appear most feasible to construct the grit chamber of steel and install it in a concrete box as shown. This structure is similar to that of an aerated grit chamber except that the steel grit chamber supplants the aeration equipment and baffles.

A comparison of dimensions seems in order. For a design flow of 0.056 m^3/sec (2 cfs) and 95 percent efficiency, and an inlet diameter of 0.305m (1 ft) Figure 14 gives a D_2 of 1.8 meters (6 ft). On Figure 13, the intersection of 0.056m^3/sec (2 cfs) and 0.305m (1 ft) lies between the upper and lower limits and is therefore satisfactory. From Figures 10 and 15 it appears the concrete structure would be about 1.8m (6 ft) deep and 1.8m (6 ft)-wide and 2.4m (8 ft) long excluding the bucket elevator chamber.

Aerated grit chambers are usually designed on the basis of 2 to 3 minutes detention time at peak design flow. If a 2.4 minute detention time were selected the chamber would be the same size as indicated above. Therefore, the concrete structures would be similar in size for the two types.

Another device that might be used to elevate the grit is a tubular conveyor. In this case, the outer structure of the chamber could be of poured concrete. The tubular conveyor could be installed in a chase or recess in the concrete structure. The recess should be provided with a removable cover so that all sections of the conveyor could be reached for maintenance purposes. The layout of the chamber using a tubular conveyor is shown in Figure 11, Grit Chamber Below Ground with Tubular Conveyor. Grit dropped into the grit washer would be relatively dry and it would be necessary to provide a water supply to the grit washer.

Another method of removing the grit is by use of an air lift. This would require the addition of equipment to provide compressed air unless such air was also provided for other purposes at the site. This would require the installation of two vertical pipes in the chamber which might interfere with the rotational flow in the chamber.

Wash Water. – The wash water required for the grit washer can be supplied from

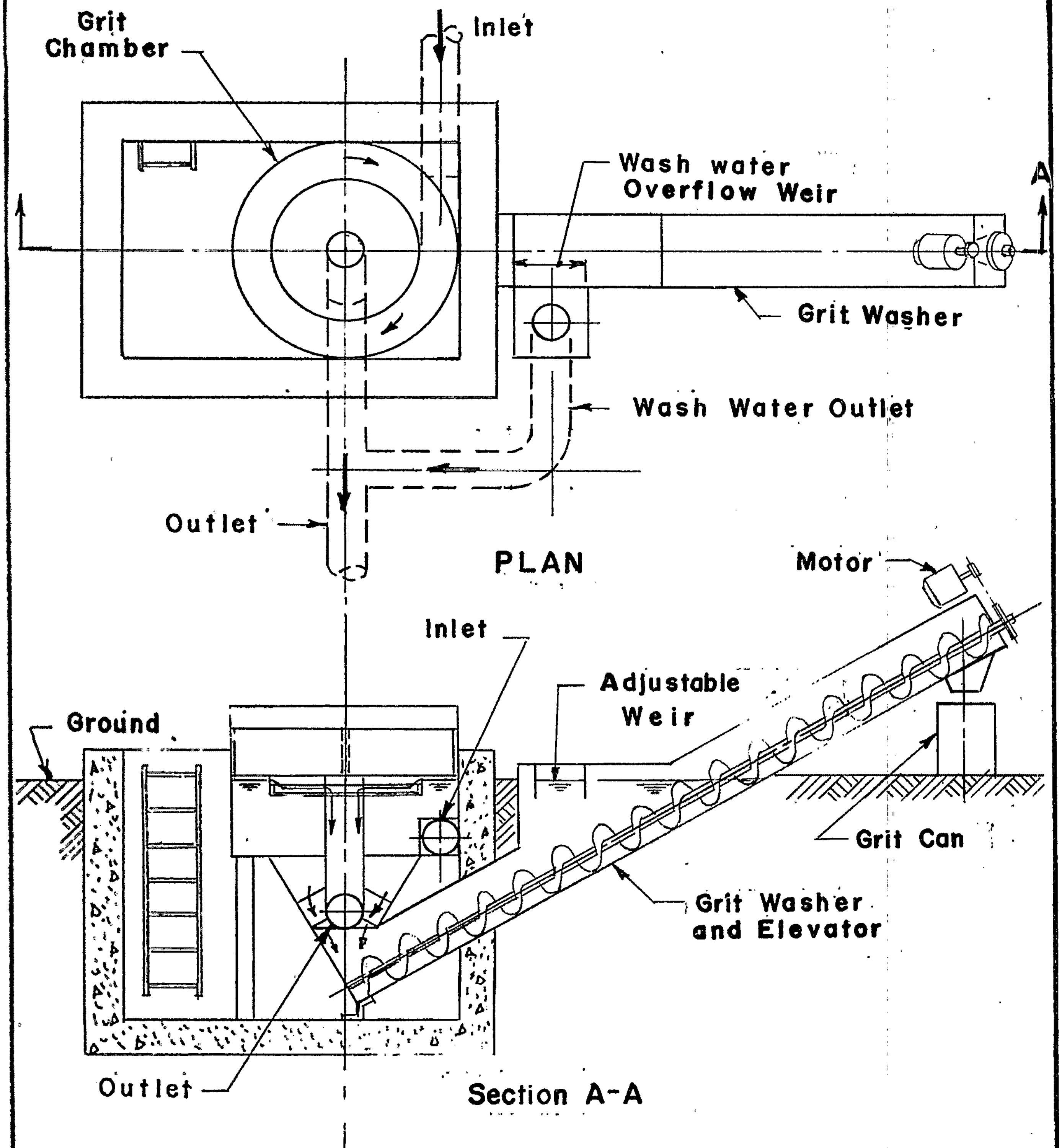


FIGURE 9 GRIT CHAMBER BELOW GROUND WITH INCLINED SCREW CHAMBER

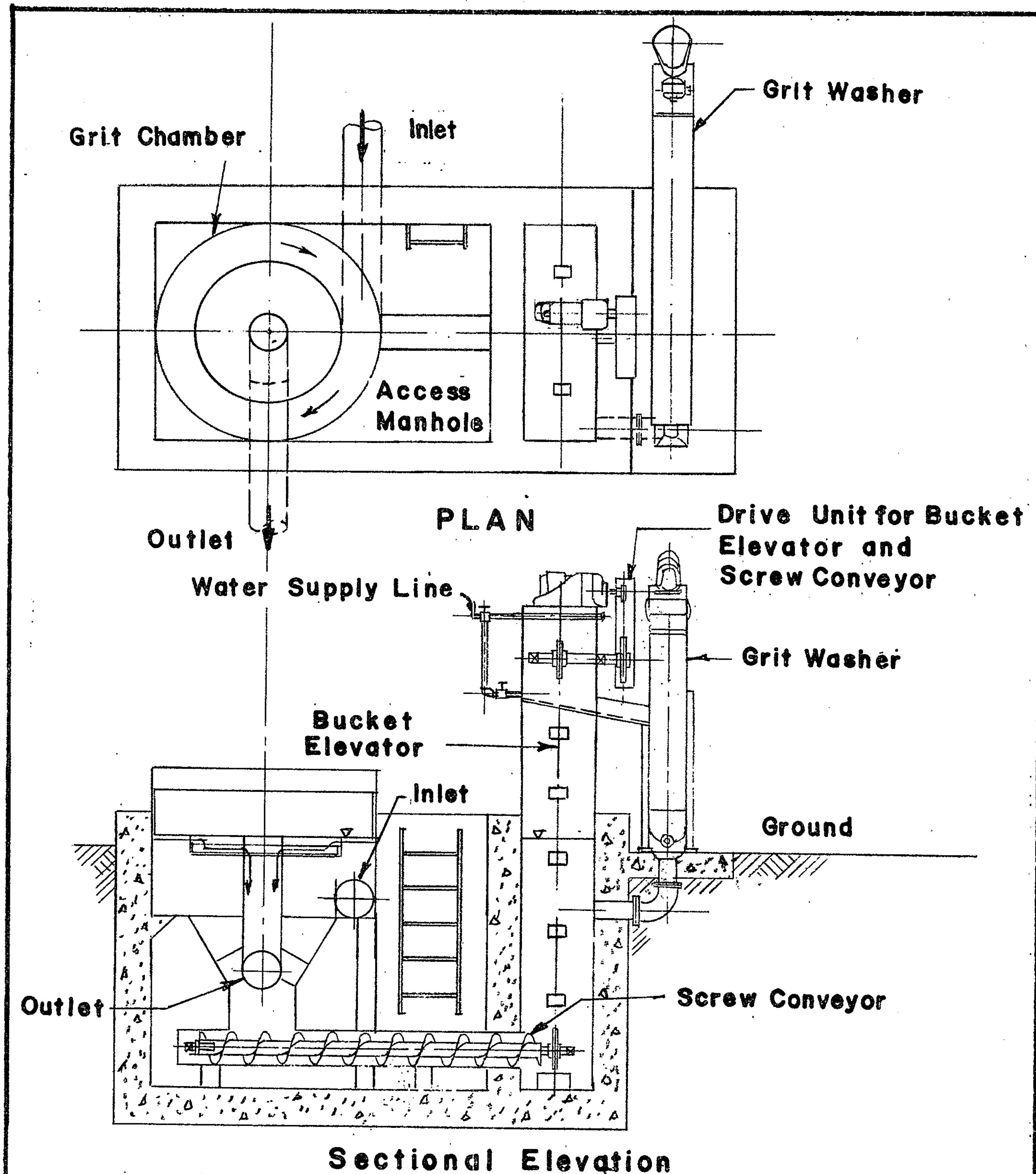


FIGURE 10 GRIT CHAMBER BELOW GROUND WITH HORIZONTAL SCREW CONVEYOR

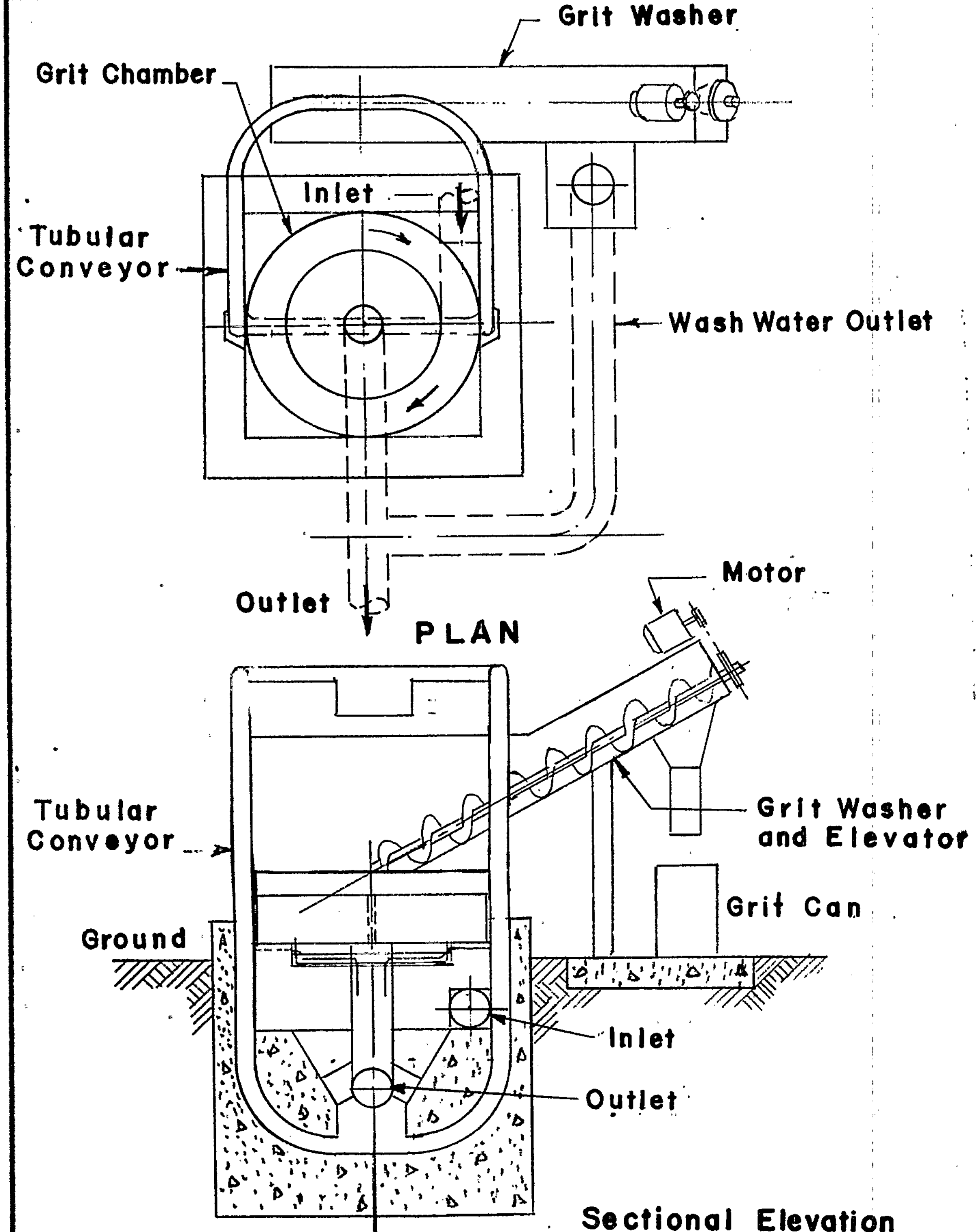


FIGURE 11 GRIT CHAMBER BELOW GROUND WITH TUBULAR CONVEYOR

sewage discharged out of the foul outlet with the grit. The area of the space above the screw should be designed so that the velocity of the wash water flowing upward will be between 0.042 to 0.070 m/sec (1.5 to 2.5 fps). Velocities lower than this may permit organic matter to settle out and velocities above this may produce an upward movement and loss of the grit. The adjustable weir must be set so that the required flow of wash water is obtained. If the weir is set high so that the wash water rate is lower than the design rate, the grit will contain a larger amount of organic matter. The area of the water surface upstream of the adjustable weir must be such that the surface loading of the wash water rate shall be at least 0.55 $m^3/min/m^2$ (13.5 gpm/sq. ft).

Other Facility Factors

Before using the swirl concentrator as a grit chamber, designers should make a comparison of the various alternatives. For large flows the swirl concentrator with a cone-shaped hopper may require a depth greater than the more conventional grit chambers. The presence of high ground water or bed rock may affect cost estimates appreciably if the deeper structure is used.

Another major factor is the head available and the effect of the grit chamber on the hydraulic flow line of the plant. If a particular type of grit chamber requires the addition of pumping facilities it is doubtful if its use can be justified on an economic basis.

The maintenance of the swirl concentrator grit chamber should not be materially different from the maintenance of conventional grit chambers. In line with the usual practice, at least two units – one for standby – should be constructed so that the removal of grit can be continued when one unit is taken out of service.

The mechanical equipment should be provided with electrical devices so that the equipment can be operated either continuously, or intermittently as regulated by a time clock, or manually. It is not certain to what extent organic matter will settle out in the conical hopper during low flow periods. For this reason, it may be necessary to operate the grit washer intermittently at such times to prevent such accumulations of organic matter in the hopper.

Design

The following sequence is recommended for the design of the swirl concentrator as a grit separator.

1. Select Design Discharge. The design engineer must select the design discharge appropriate to each project based on the design criteria for the project.

The normal application of the swirl concentrator as a grit chamber would be its use in a wastewater treatment plant. In such an application the grit chamber should be designed for the maximum design flow.

Another application of the swirl concentrator considered in connection with this study was as a grit removal device for the foul flow from a swirl concentrator used as a regulator. In that case the design flow for the grit chamber should be based on the foul flow discharge from the overflow regulator. It is proposed to use the grit chamber for this purpose in Lancaster to remove grit from the foul flow prior to pumping the foul flow to the treatment plant. At Lancaster it is also proposed to regulate the foul flow discharge from the overflow regulator. A third application would be as a combined sewer overflow or stormwater treatment plant unit process. Where grit is a problem prior to syphons or pumping stations within the collector system, the swirl unit can also be used. Therefore, the designer must select the design flow based on these considerations.

2. Select the Operating Efficiency. With a discharge determined as above, 90 percent recovery is suggested as an acceptable operation. However, if there is the possibility for any future but undefined increase in the discharge, using 95 percent recovery would provide some extra capacity.

3. Find the Square Inlet Dimension – D_1. Having selected the desired recovery rate and the design discharge, the corresponding figure in the series of Figures 12, Chamber Diameters for 95 Percent Recovery and $H_1/D_1 = 2$; 13, Chamber Diameters for 90 Percent Recovery and $H_1/D_1 = 2$; and 14, Chamber Diameters for 80 Percent Recovery and $H_1/D_1 = 2$, would be used. Enter the

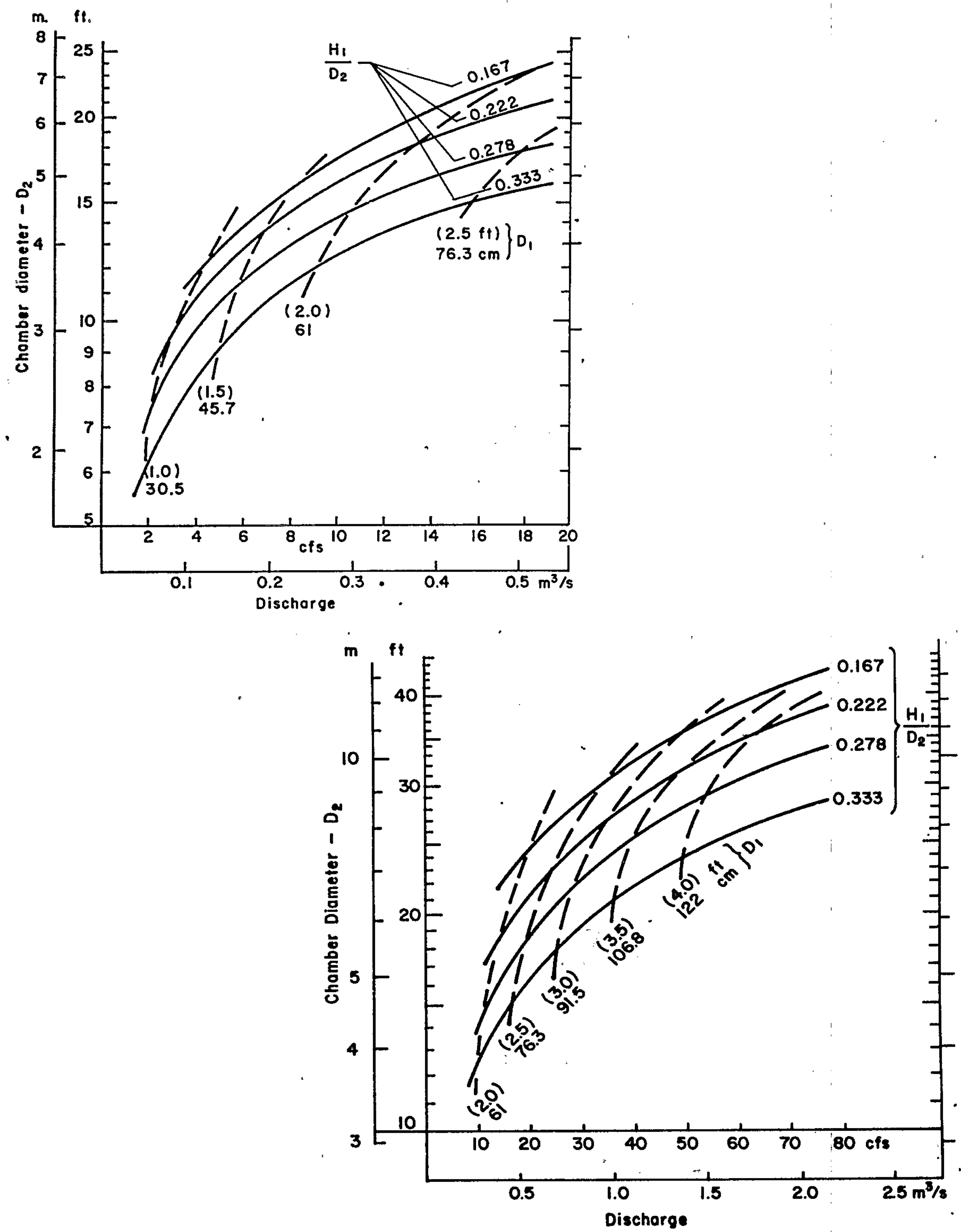


FIGURE 12 CHAMBER DIAMETERS FOR 95 PERCENT RECOVERY AND $H_1/D_1 = 2$

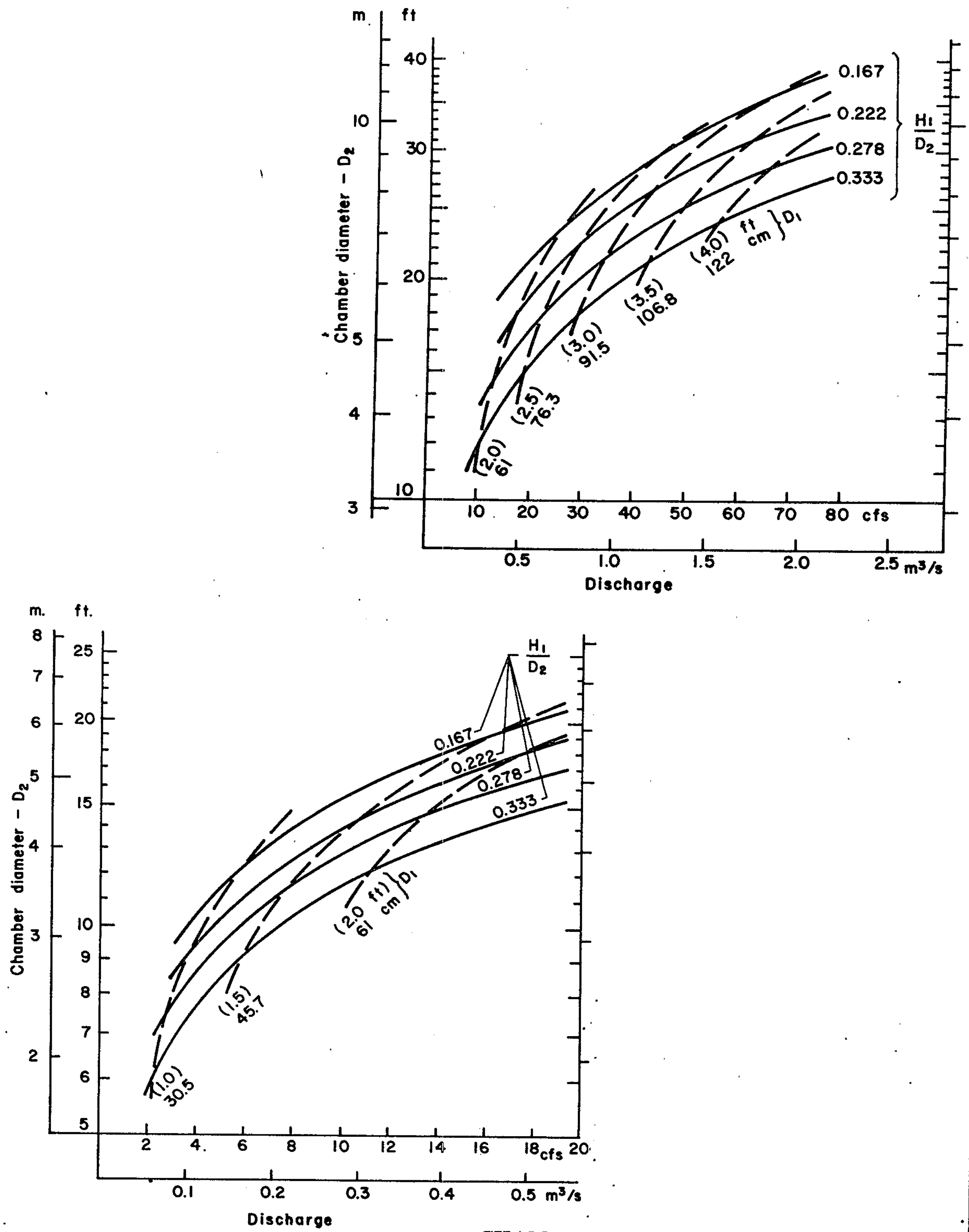


FIGURE 13 CHAMBER DIAMETERS FOR 90 PERCENT RECOVERY AND $H_1/D_1 = 2$

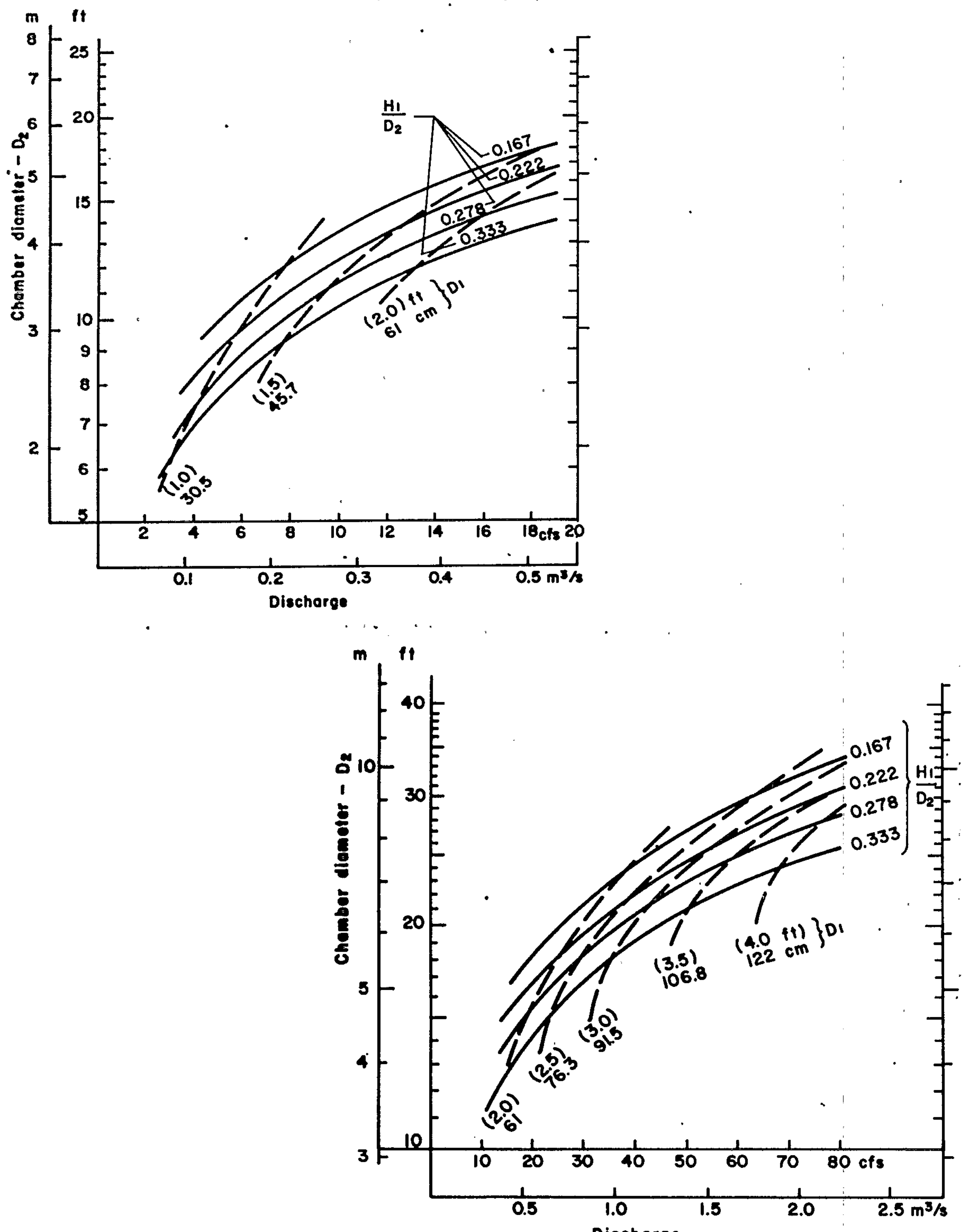


FIGURE 14 CHAMBER DIAMETERS FOR 80 PERCENT RECOVERY AND $H_1/D_1 = 2$

figure with the design discharge, and follow this vertically upward to the broken D_1 line which most nearly corresponds to the supply sewer diameter. It might be advantageous to select a larger or smaller D_1 to coincide exactly with the supply sewer size. In the model tests, the square inlet dimension was the same as the supply sewer diameter, so these are the ideal operating conditions for this unit.

In cases where the square inlet dimension cannot conveniently be made the same as the supply sewer, a reducing or expanding transition would be necessary. If the supply sewer is concentrically aligned with the inlet, the transition should have a length of at least three times D_1 ($3D_1$). Another possibility would be to have the supply sewer discharge into an inspection manhole. Leaving the manhole would be the square inlet cross section leading into the grit chamber. The distance from this manhole offtake to the square inlet discharge in the chamber should also be a minimum of 3 times D_1 ($3D_1$). This arrangement could be used to provide the transition in directions, levels or sizes between the supply sewer and the square inlet.

4. Find Grit Chamber Diameter — D_2. The intersection point found in 3 above defines the chamber diameter, D_2 on the ordinate scale at left. In the considerations for choosing D_1 it might be a valuable aid to check the D_2 size as well. Taking a smaller D_1 means a larger D_2 is necessary; there could well be an economical or practical optimum relation between the two dimensions.

5. Select Design Discharge. As stated previously, another purpose of this study was to provide criteria for designing a grit chamber for a daily sanitary sewage flow varying between 85 and 425 l/s (3 and 15 cfs) with an inlet pipe diameter of 61 cm (2 ft).

Assume the designer decides to remove 90 percent of the grit over 0.2 mm size with discharge at the maximum rate.

Enter Figure 12 with 426 l/s (15 cfs). Read D_2 = 4.88 m (16 ft). Also interpolate H_1/D_2 = 0.25. Therefore H_1 = 1.22m (4.0 ft). On Figure 15 the intersection of 0.43m ^{3}/s (15 cfs) and 61 cm (2 ft) lies between the upper and lower limits and is therefore satisfactory. From Figure 15, Approximate Stage — Discharge Curves Over Weir, the head on the weir is about 24 cm (0.78 ft).

6. Find Depth-Width Ratio — H_1/D_2. The same discharge — D_1 — D_2 intersection point on the pertinent figure in the Figures 12,13 and 14 series also defines the H_1/D_2 ratio with respect to the solid lines on the figure. Interpolation between lines can be done without extreme care as slight changes in the ratio are not critical to the structure's operation. With the ratio determined, multiplication by the chamber diameter found in 5 above gives the weir height.

7. Find Dimensions of Complete Unit Using D_1 D_2 and H_1 as found above, go into Figure 3 to compute dimensions of all pertinent elements of the structure.

8. Find Water Level in Chamber. With the unit completely dimensioned, it would then have to be set with respect to the level of the incoming sewer. Figure 15 gives the approximate levels of the water in the chamber as a function of the flow over the weir lip.

Height to Width Relationships

To increase the flexibility for design, the variations of required chamber diameter and height or depth were determined for various inlet dimensions, at various levels of efficiency. Thus, for design flows of 0.2m^3/sec (7 cfs), and 95 percent recovery, the following relationships of design dimensions from Figure 12 can be used.

Inlet Dimension D_1	0.55m (1.8 ft)	0.52m (1.7 ft)	0.48m (1.55 ft)	0.43m (1.4 ft)
Ratio of Height to Width H_1/D_2	0.33	0.278	0.222	0.167
Chamber Diameter D_2	3.3m (10.8 ft)	3.8m (12.5 ft)	4.3m (14.1 ft)	4.6m (15 ft)
Chamber Height H_1	1.1m (3.6 ft)	1.05m (3.5 ft)	0.95 (3.1 ft)	0.76m (2.5 ft)

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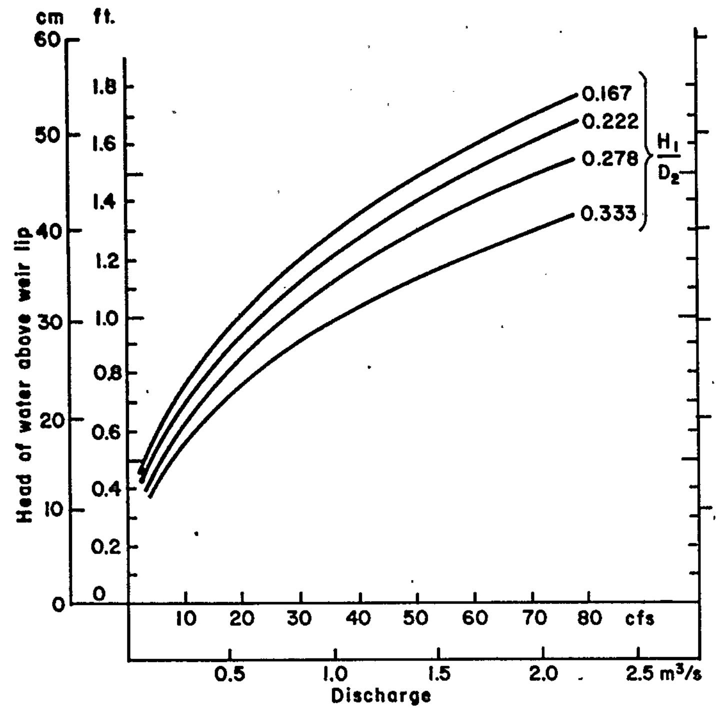


FIGURE 15 APPROXIMATE STAGE – DISCHARGE CURVES OVER WEIR

SECTION IV
IMPLEMENTATION

Consideration of the use of a swirl concentrator as a grit separator device requires an evaluation of many factors which include:

1. elevation at which the flow will enter the facility;
2. the size of the facility based upon anticipated flow; and
3. an economic comparison with other types of grit separation devices.

The operation of the device is predicated upon the relationship between the inlet dimension, the chamber diameter, the depth and the expected operating efficiency. If the flow is under pressure, then the inlet must be enlarged to reduce the inlet velocity. The size of the inlet is the key to determining the geometric design of the unit.

The rapid increase in depth required with larger flows suggests that a number of smaller units operated in parallel would be less costly to construct and operate as compared to the costs of units with inlet sizes of three feet or larger.

The choice of a conventional grit washer and conveyor is predicated upon the anticipated volume of grit which must be removed, and the depth of the bottom of the cone.

As there are no mechanical parts within the swirl concentrator, maintenance requirements will be minimal. However, the grit washer-conveyor system will require maintenance and points of access in construction details.

In order to evaluate the efficiency of the unit, it will be necessary to analyze samples of the grit collected and of the solids from the downstream source to determine the size and amount of grit particles carried through the unit. In addition, grit from the swirl concentrator and the grit wash water should be sampled to learn if an excessive amount of organic material is being entrained with the grit. From the survey which was undertaken by the APWA, it was learned that most operators interviewed preferred to achieve high grit removal of small particles, even though this is generally accompanied by the removal of an organic loading that may be equal to the grit loading.

Laboratory studies indicated that a washing action induced within the swirl concentrator may minimize organic solid concentrations in the collected grit.

Cost of Facility. – A prototype unit, 1.83 m (6 ft) in diameter with a 0.305 m (1 ft) inlet has been constructed by the Metropolitan Sanitary District of Denver. The unit is the same size as that required for the City of Lancaster. The unit was fabricated of steel and mounted above ground. Construction cost, exclusive of the grit conveyor-washer, was approximately $4,500 in 1973.

Figure 16, Prototype Unit, Denver Colorado, is a photograph of the demonstration unit constructed by the Denver Metropolitan Sewage Disposal District No. 1.

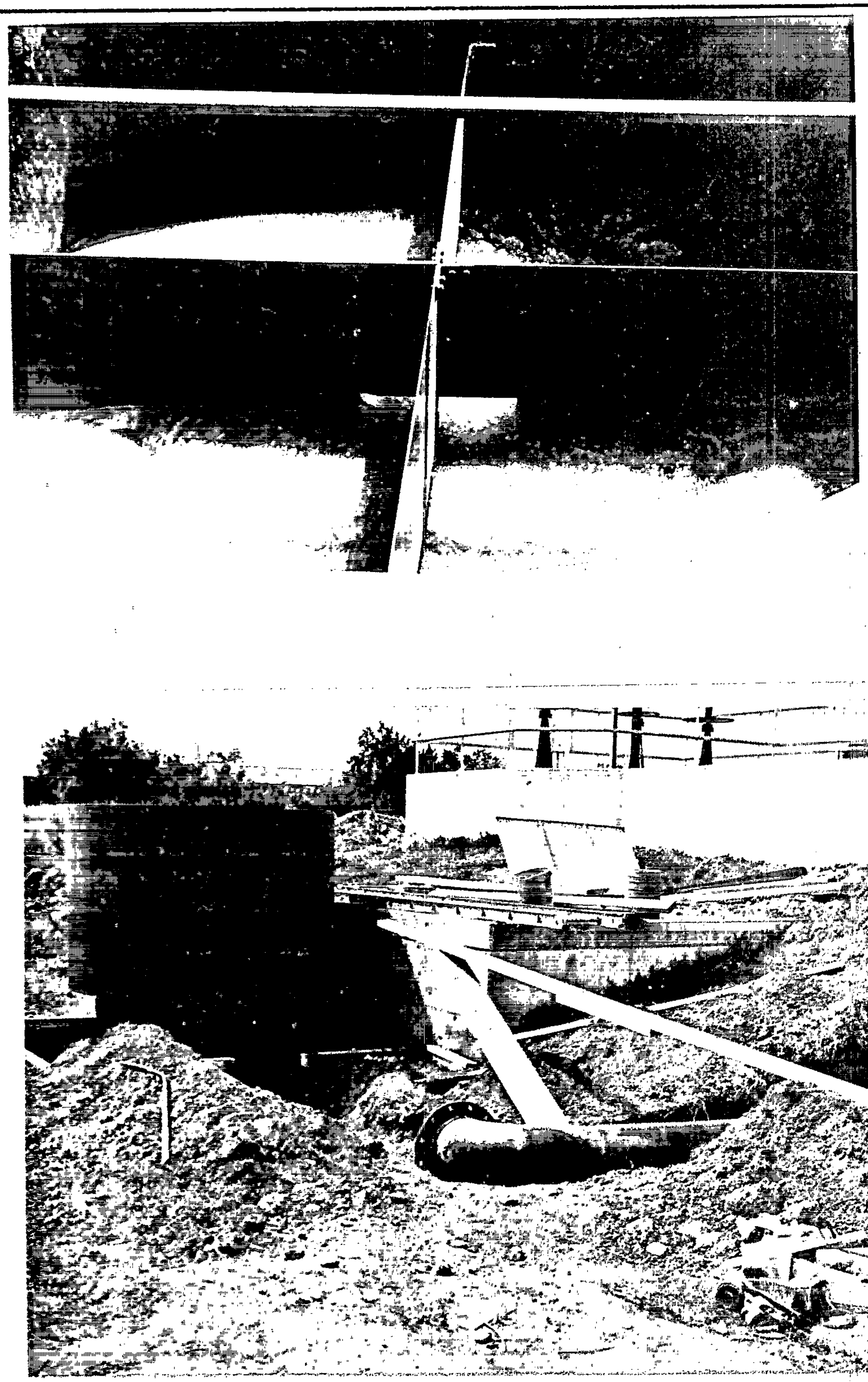


FIGURE 16 PROTOTYPE UNIT, DENVER, COLORADO

SECTION V
GLOSSARY OF PERTINENT TERMS
(as applied to this report on the swirl concentrator)

Foul Sewer – The sewer carrying the mixture of combined sewage and concentrated settleable solids to the grit chamber or interceptor sewer from a combined sewer concentrator overflow regulator facility.

Grit – Heavier and larger solids which, because of their size and specific gravity, settle more readily to the floor of the swirl concentrator chamber by the phenomenon of gravity classification.

Overflow Weir – The structural member of the swirl concentrator, which is built as a central circular wall, with a proper form of overflow edge or crest over which the clarified wastewater can discharge to the downdraft outlet leading to predetermined points of discharge or subsequent holding or treatment plants.

Regulator – A device or apparatus for controlling the quantity and quality of admixtures of sewage and storm water admitted from a combined sewer collector sewer into an interceptor sewer or pumping or treatment facility, thereby determining the amount and quality of the flows discharged through an overflow device to receiving waters, or to combined sewer overflow retention or treatment facilities.

Scaling – The principle of ascertaining dimensions and capacities of hydraulic test units to evaluate the performance of swirl concentrator chambers, and to up-scale such sizes to provide actual field design and construction criteria or parameters.

SECTION VI

APPENDIX A
REPORT OF HYDRAULIC LABORATORY STUDIES

Previous laboratory work, performed in developing the swirl concentrator principle, was directed to its use as a combined sewer overflow regulator. Studies completed by the LaSalle Hydraulic Laboratory in February, 1972, made up part of the APWA Report titled "The Swirl Concentrator as a Combined Sewer Overflow Regulator Facility," EPA-R2-72-008, September 1972.

This earlier work indicated that the concentrator should be capable of operating more efficiently on narrower grain-size bands. The present study was therefore directed to separating and removing only the grit from the sewage.

The model used in the earlier study was modified to suit the new parameters. Additions to and modifications of the study plan were incorporated into the study program as test results became available and were analyzed by the committee of consultants.

Principles and Scope of the Study

The swirl concentrator principle, as first used by Mr. Bernard Smisson in Bristol, England, and then later modified and developed by the LaSalle Hydraulic Laboratory, showed great effectiveness as a solids separator for storm flows in combined sewer applications. The present investigation was carried out to apply the knowledge gained in these earlier projects to the use of the swirl concentrator as a grit separation chamber.

The basic swirl concentrator geometry resulting from the previous study of the combined sewer overflow regulator was taken as the starting point for the present investigation. Two sets of conditions were provided to guide the research:

- The first precept was to accept the bottom foul outlet discharge from the swirl concentrator overflow regulator at Lancaster, Pennsylvania. The discharge was to be about 42.5 l/s (1.5 cfs) under normal conditions, and could rise to 141 l/s (5cfs). The inlet pipe to the grit chamber would be 30.5 cm (1 ft) diameter.
- The second set of conditions was to investigate a 61 cm (2 ft) inlet pipe diameter, assuming a daily sanitary sewage flow varying between 85 and 425 l/s (3 and 15 cfs). The first case was conceived to comply with the particular characteristics of the overall demonstration project being built at Lancaster, which would provide a pilot plant swirl concentrator to serve as a grit chamber. The second case was to cover the application of the swirl grit separation principle to any municipal treatment plant application, allowing a general scale-up of the dimensions over a wide range of different prototype sizes.

Model Description

The main feature of the model was the separation chamber which took the form of a vertical cylinder 91.5 cm (36 in.) in diameter and 102 cm (40 in.) high, made of 13-mm (1/2-in.) plexiglas as shown in Figure 17, Model Layout. Inflow to the chamber was through a polyvinyl chloride (PVC) pipe which could be 7.6, 10.2, 12.7 or 15.2-cm (3, 4, 5 or 6-in.) diameter, set at a slope of 1:1,000. A vibrating solids injection system was placed on this supply pipe, 2.14 m (9 ft) upstream of the chamber. Water supply to the model through the pipe was taken directly from the constant level tank in one of the laboratory's permanent pumping stations.

A flexible 5.1-cm (2-in.) diameter tube was placed inside the cylinder, beneath the floor of the test chamber to pick up the foul flow. The tube was outletted from the bottom of the cylinder, and led to a solids settling tower fitted with an adjustable level outlet pipe which could be raised or lowered at will to control the discharge drawn off through the foul outlet.

The clear water outlet came up from the base on the centerline of the cylinder in the form of a 15.2-cm (6-in.) diameter PVC pipe. Its level could be modified either by adding or removing sections of the same diameter pipe.

Outflow from this pipe, which in operation represents the major part of the total discharge through the structure, was delivered to a large settling basin equipped with a calibrated V-notch weir. The basin allowed sufficient time for most of the solids contained in the clearer overflow to settle

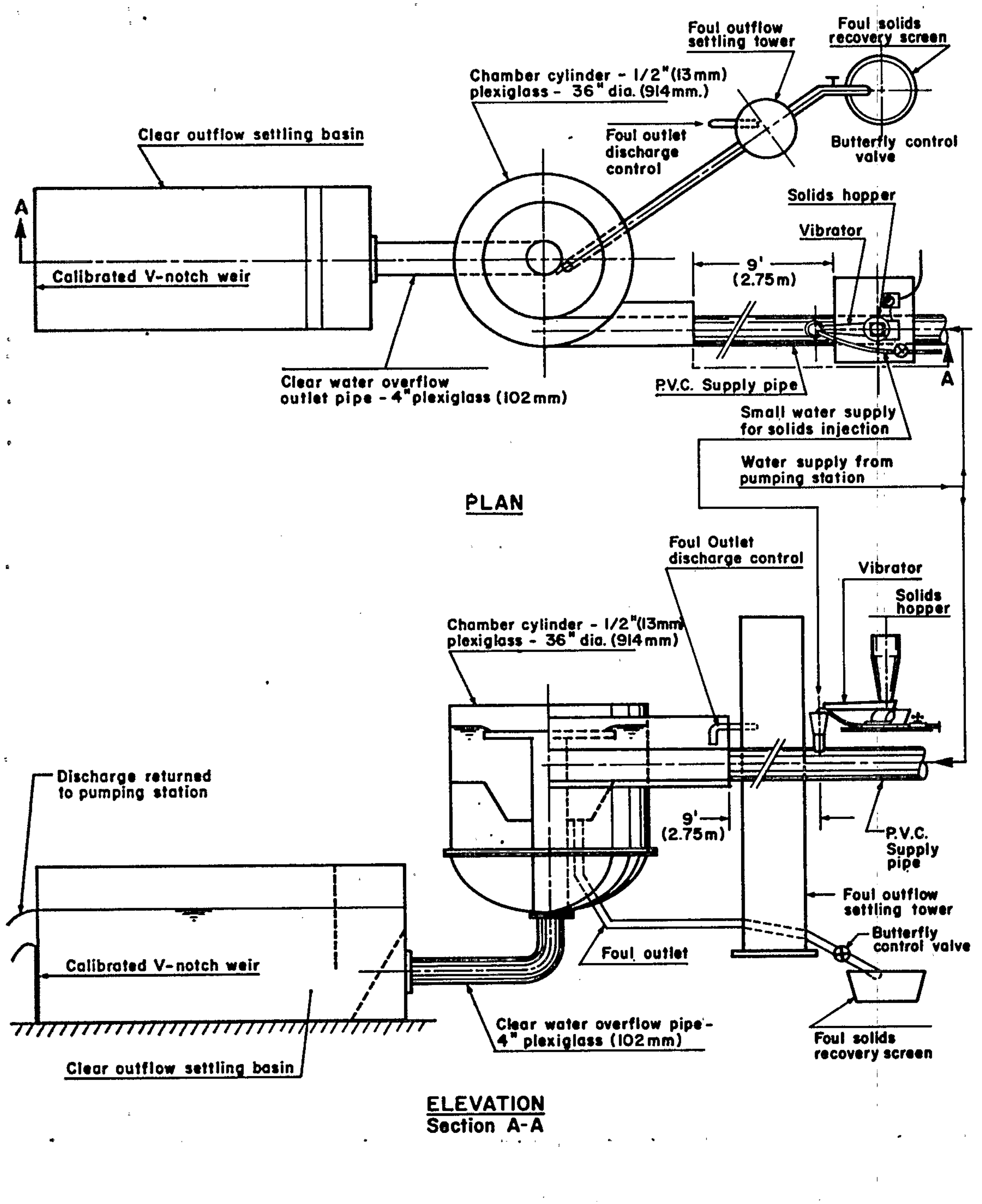


FIGURE 17 MODEL LAYOUT

out. A point gauge on a manometer pot indicated the level within the basin, determining the discharge going over the V-notch weir, hence the clear discharge over the circular weir in the chamber.

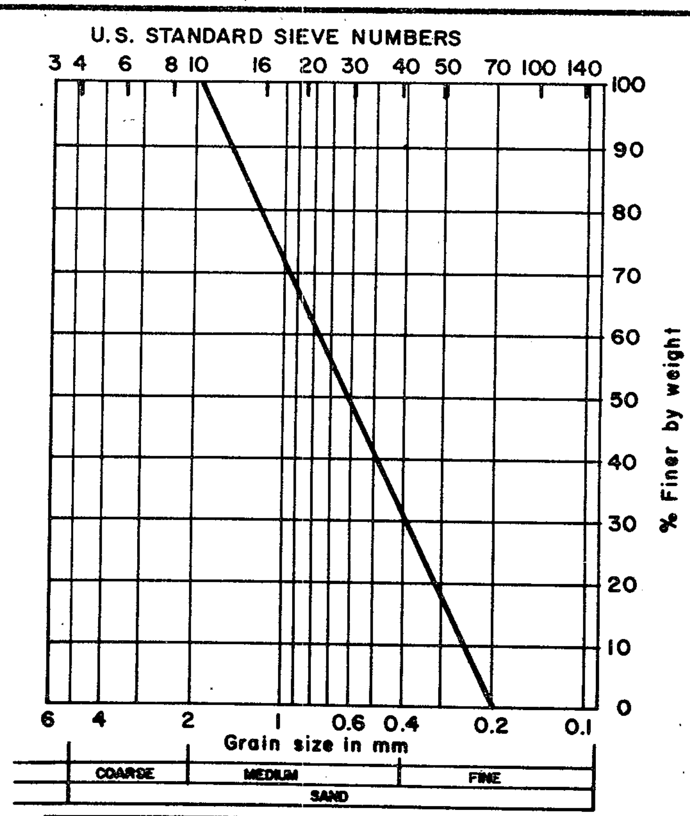
As the model existed at the beginning of this study, the inlet pipe with its round cross-section entered on an enlarged rectangular plexiglas enclosure fixed to the cylindrical chamber wall in which variations to the entrance form could be fitted and tested, as shown in Figure 17.

The floor of the chamber was formed of a thin cement mortar crust, supported on a gravel base which filled the lower portion of the chamber. This crust could be very easily broken out and modified either with new mortar or plasticine. Plasticine was used due to its speed and simplicity of application.

Solids Simulation

The grit material in sewage to be removed in the test swirl structure was established, as shown in Figure 18, Typical Grit Gradation. The outside grain size limits of 0.2 and 2.0 mm (No. 70 and No. 10 sieve) correspond to the standard soil mechanics definition of medium and coarse sand, respectively. The specific gravity of grit was assumed to be 2.65, and the straight-line grain size distribution was selected as a representative of samples taken from existing grit chambers in sewage treatment plants.

Particle sizes larger than about 1 mm (No. 18 sieve) are known to move along in flowing water according to equations of the type propounded by Meyer-Peter and Muller[1] or H.A. Einstein.[2] Between 1 mm and 0.2 mm (No. 18 sieve and No. 70 sieve) the particles



U.S. SIEVE No.	SIEVE OPENING mm	% FINER BY WEIGHT
10	2.000	100
20	0.850	63
40	0.425	31
50	0.300	18
70	0.212	0

FIGURE 18 TYPICAL GRIT GRADATION

Source: Alexander Potter and Associates
Memorandum of April 24, 1973

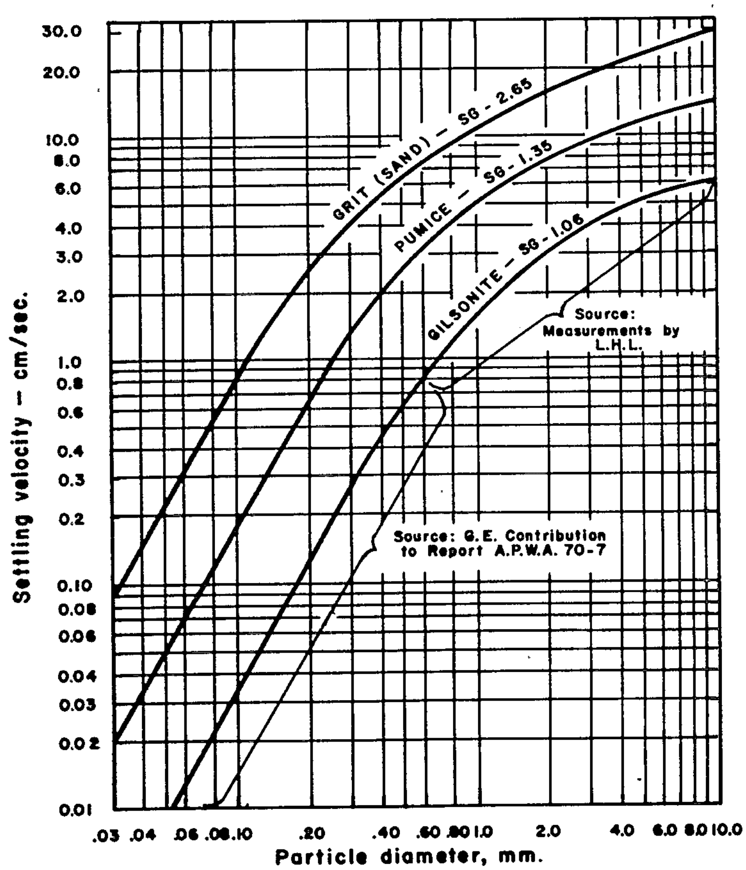


FIGURE 19 PARTICLE SETTLING VELOCITIES FOR GRIT, PUMICE AND GILSONITE

are in the transition zone between the above case and the Stokes relation. Since the particles involved in both prototype and model extended into both ranges, across the transition zone, the above equations could not adequately describe the scale relations.

It was therefore necessary to use curves of particle settling velocities as shown in Figure 19, Particle Settling Velocities for Grit, Pumice and Gilsonite. For a given grit size with S.G. 2.65 in the prototype, the settling velocity was determined from Figure 19. Based on Froude's law of similitude, this was divided by the square root of the scale being considered to find the required model settling velocity. Referring to Figure 19 with this model settling velocity, the model particle sizes were found for each of the simulating materials – Gilsonite, pumice and fine sand.

The physical relations used here can be expressed as follows:

Model scale = $\lambda = L_p / L_m$

where L_p and L_m are corresponding dimensions in the prototype and the model respectively.

From Froudes Law, the velocity simulation is given by:

$$\frac{V_p}{V_m} = \frac{L_p}{L_m} = \lambda$$

and

$$V_m = \frac{V_p}{\lambda}$$

The initial tests were conducted where

the scale ratio of prototype to model was 4. For a ratio of 4 the settling velocity in the prototype should be divided by the square root of 4 or 2. From Figure 19 the settling velocity of grit of 0.2 mm size is 2.6 cm/sec. The model settling velocity is then 1.3 cm/sec. Thus in the model the grit of 0.2 mm size can be simulated by use of 0.12 mm grit and 0.30 mm pumice or 0.80 Gilsonite.

Figure 20, Prototype Grit Sizes Simulated by Pumice, shows the prototype grit sizes simulated by the pumice used on the model. The range of pumice particle sizes shown are those which were used on the model as indicated by the gradation curves in Figure 21, Gradation Curves for Pumice, Gilsonite and Sand Used in Model. From this, it can be seen that the pumice adequately covered all the required prototype sizes up to, say, scale 4, and only down to 0.4 mm (No. 40 sieve) at scale 16.

Gilsonite, with a specific gravity of 1.06, was used to fill in this lower area of finer particles; its corresponding simulation curves are shown in Figure 22, Prototype Grit Sizes Simulated by Gilsonite in Model. The grain size distribution curve for the material used on the model is shown in Figure 21.

Sand was used for some of the tests, as a means of providing a check on the behavior of the lighter specific gravity particles; i.e., gilsonite and pumice. The grain size distribution curve of the sand used is shown in Figure 21. The model simulation characteristics are shown in Figure 23, Prototype Grit Sizes Simulated by Sand in Model. It can be seen that the sand sizes used on the model covered the prototype grit sizes fairly well.

The reasons that sand was not used more extensively in the testing were, first, it moved more slowly in the model, and secondly,

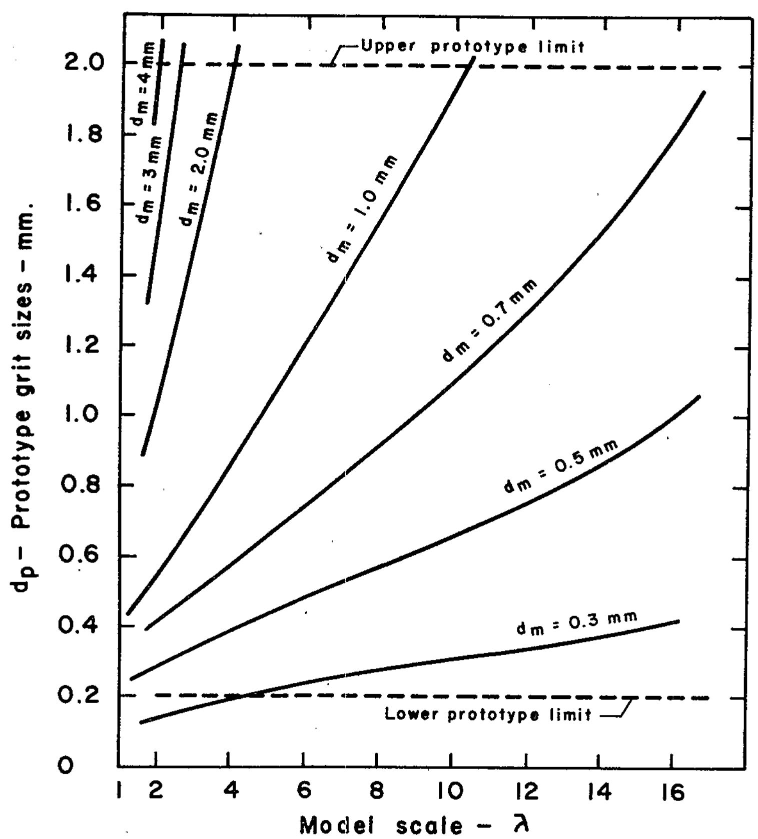


FIGURE 20 PROTOTYPE GRIT SIZES SIMULATED BY PUMICE

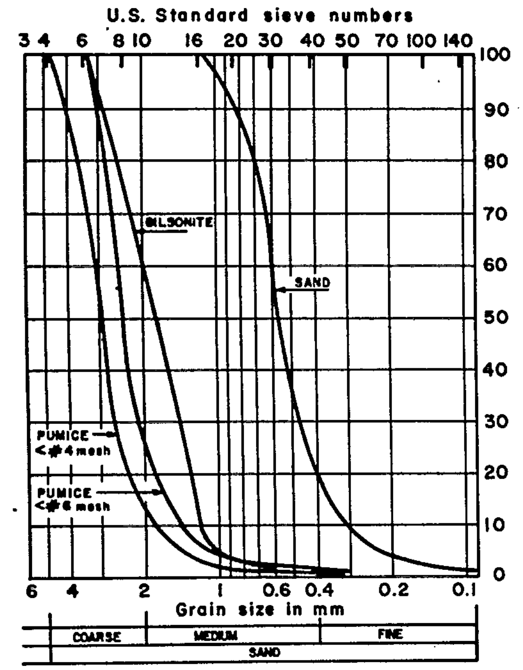


FIGURE 21 GRADATION CURVES FOR PUMICE, GILSONITE AND SAND USED IN MODEL

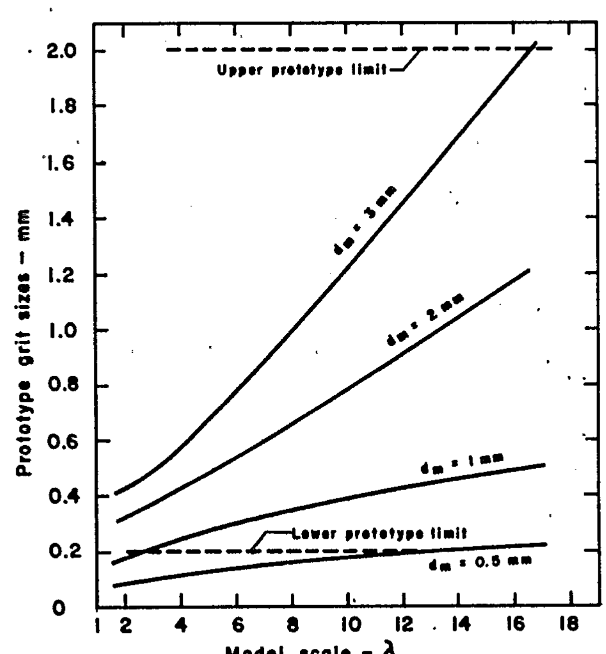


FIGURE 22 PROTOTYPE GRIT SIZES SIMULATED BY GILSONITE IN MODEL

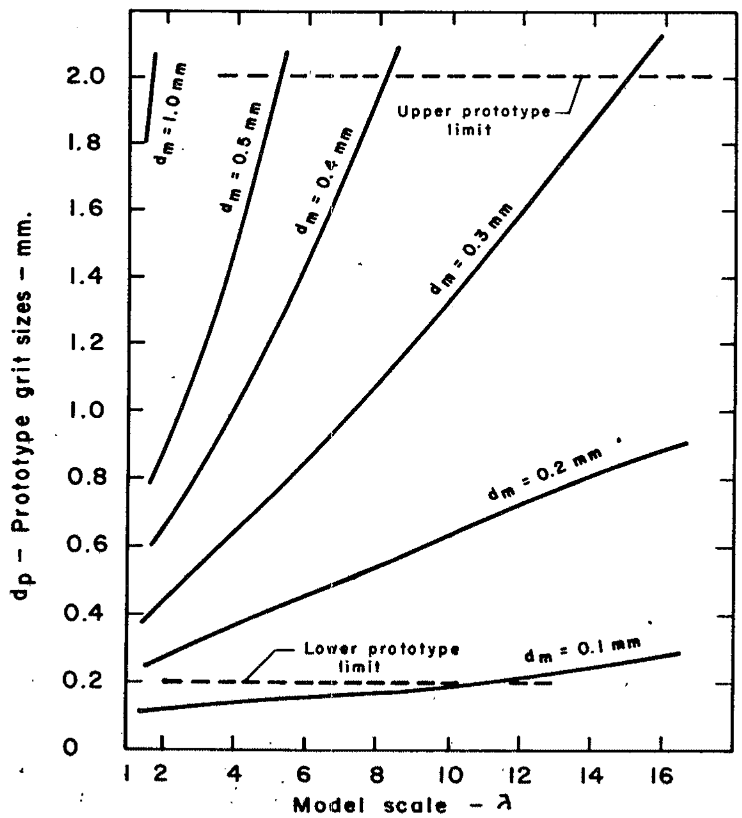


FIGURE 23 PROTOTYPE GRIT SIZES SIMULATED BY SAND IN MODEL

being so fine, it was difficult to recover it conveniently after each test of the existing model set-up. Both factors would have tended to lengthen the testing program considerably.

Normal grit concentrations in sewage were defined as lying between 20 mg/l and 360 mg/l (0.00125 and 0.0225 lbs/cu ft). In this range, there are few enough particles in the flow to permit each one to react individually. Therefore, concentrations used in the model were kept near the upper limit of the given range, where the individual particles still moved with practically no collision effect with adjacent particles.

An additional particular concentration case was considered for the Lancaster Project where the inflow to the grit chamber will come from the foul outflow from the Swirl Concentrator Overflow Regulator. A suggested concentration for this case in prototype was 750 to 13,500 mg/l. It was not possible to reproduce this rate of solids flow in the model, as it involved the mechanics of slurry flow in the pipe, and detailed consideration of this was beyond the scope of the present study.

However, solids injection rates in the order of 2000 mg/l were tested. These consisted of introducing the solids fast enough for dunes to form on the pipe invert. As these concentrated solids masses arrived in the chamber, the characteristics of their behavior could be followed.

The general model testing procedure for each case consisted of establishing steady-flow conditions, then injecting into the water coming through the inlet pipe one full liter of the solid material under test. The rate of injection was controllable within the limits set forth above. After each test, the solid material was collected either in the desired location in the chamber, on the chamber floor, or in the stilling basin for the V-notch weir used to measure the flow over the circular weir in the chamber. The volume of solids recovered in the desired location in the chamber floor (hopper, cone or bottom outlet) was expressed as a percentage of the original liter injected, and is referred to as the grit removal efficiency of the test.

Preliminary Tests with Foul Discharge

At the outset of this test series, the model configuration was in the form shown in Figure 24, Original Layout, which was the layout developed for the earlier tests of the Swirl Concentrator as an Overflow Regulator. First tests were run using a 1:4 scale ratio, giving a 61-cm (2-ft) diameter inlet pipe. Results with this arrangement were not acceptable over the range of discharges, between 85 and 425 l/s (3 and 15 cfs). Efficiencies were as low as 75 percent, even though as much as 10 percent of the inflow water discharge volume was drawn off through the foul outlet.

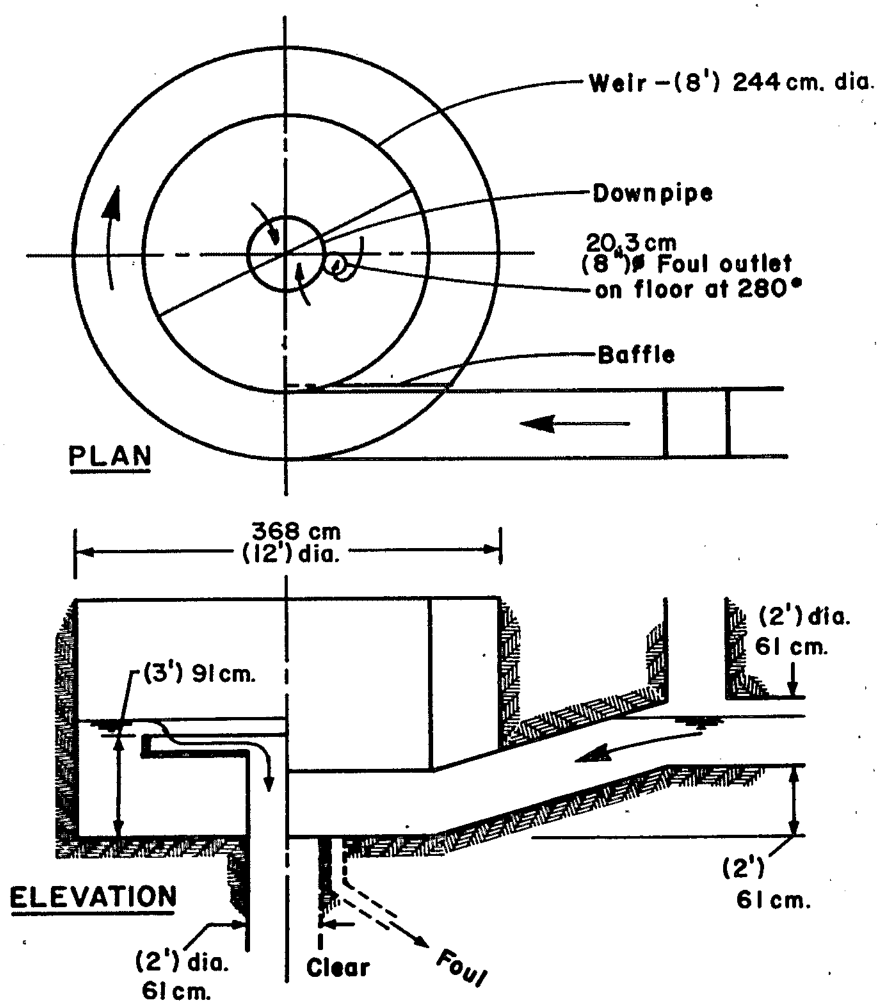


FIGURE 24 ORIGINAL LAYOUT

Following discussion of these results with the study's group of consultants, the configuration shown in Figure 25, Preliminary Layout for Lancaster Study, was provided in the model. The Lancaster Project requirements were undertaken first, so the 30.5-cm (1-ft) diameter inlet pipe was simulated at scale 1:2.4. Foul discharge volumes of up to 10 percent of the inflow were drawn off. Inflows between 42.5 and 141.6 l/s (1.5 and 5 cfs) were tested.

Efficiencies were *distinctly higher under* these new configuration conditions, reaching as high as 95 percent. However, appreciable portions of the deposited grit remained as accumulations on the chamber floor. The annular gutter around the central downpipe was not particularly advantageous, since deposits accumulated at various points in the gutter, and could not be drawn to any single collection point.

Returning to the use of just a flat floor in

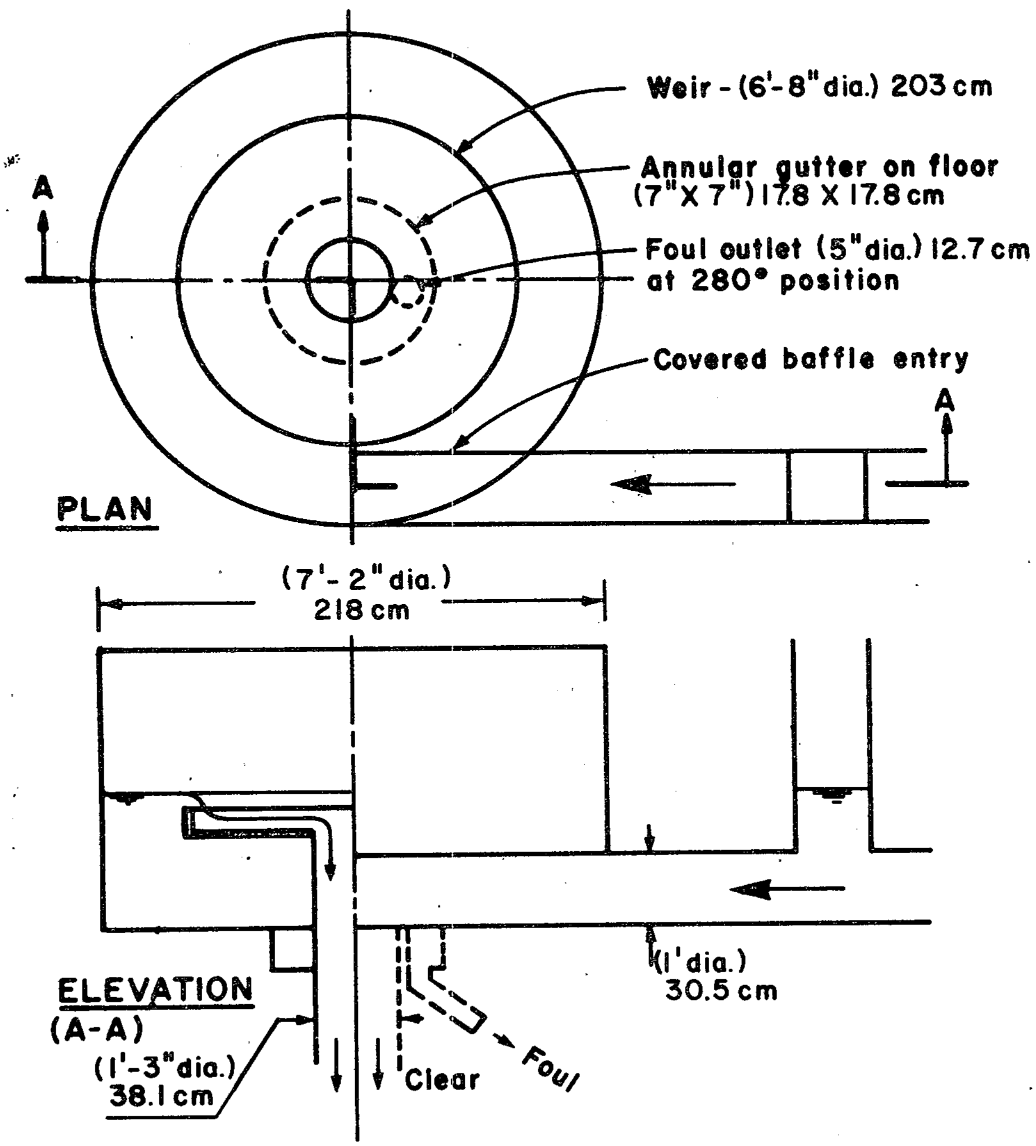


FIGURE 25 PRELIMINARY LAYOUT FOR LANCASTER STUDY

the chamber, the layout shown in Figure 26, Single Gutter—Small Outlet Scheme, resulted from a series of cut-and-try development tests. It showed promise by giving consistently higher solids recoveries out through the foul outlet. The foul discharge volumes were taken as 10, 15 and 20 percent of the inflow.

It became evident at this stage of the studies that foul discharges as high as these would be difficult to handle through the proposed mechanical grit removal equipment. Also, the bottom outlet at 12.7 cm (6 in.) diameter was too small to handle such volumes.

On the other hand, the use of the floor gutter seemed to be an efficient way of directing the solids toward the center of the chamber. As the flow passed over the gutter, it generated a rolling current with the longitudinal axis along the gutter. Solid particles, moving along on the chamber floor, fell into this rolling current and were entrained in it.

If the gutter was placed radially, so the flow in the chamber passed over it at right angles, the roller and particles would stay at about the same relative position out from the downpipe. However, when the gutter was placed at about a 20° angle from a radial line, as shown in Figure 26, the rolling current developed a longitudinal current along the gutter. All solids particles caught in the rolling current were therefore entrained toward the center of the chamber where they could be captured by some suitable means.

Flat Floor Concept

Experience gained in the preceding tests had provided definition of the particles' trajectories in the chamber and along the floor over the range of discharges being considered. However, this had been accomplished with appreciable amounts of the inflow water discharge being withdrawn through the foul outlet.

The present series of tests was therefore planned to study the characteristics based on using a flat floor in the chamber, no foul discharge, and a large hopper into which the grit would be directed.

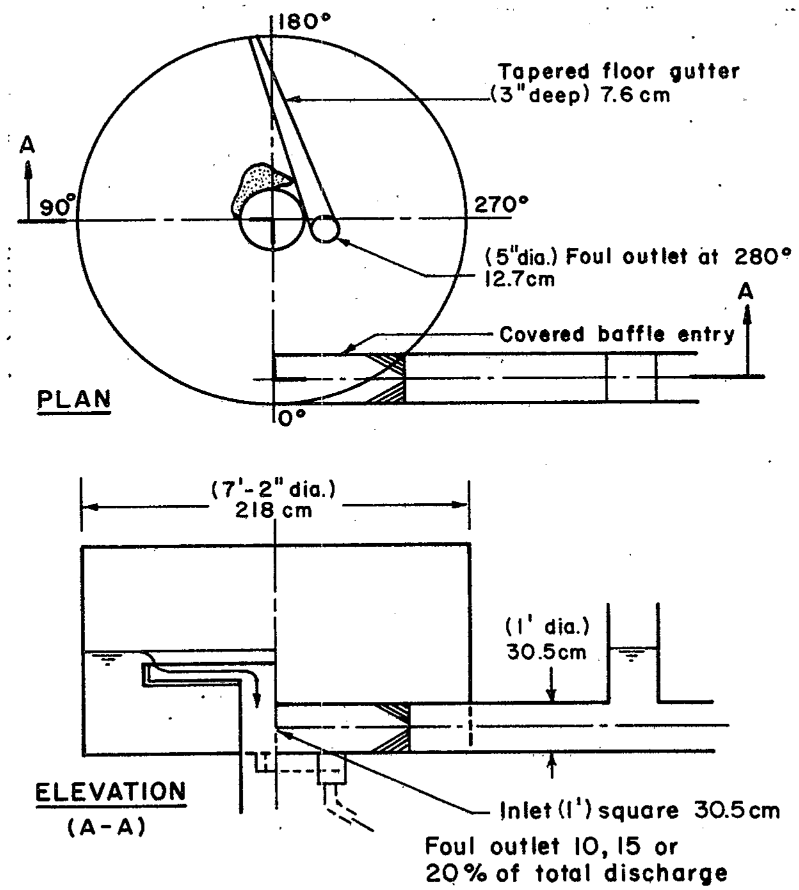
The three gutter arrangement shown in Figure 27, Three Gutter-Large Hopper Scheme, was typical of layouts tested following the findings of the previous tests. Results were encouraging, although there was significant turbulence generated in the hopper. The gutter location at 270° did not contribute much to the operation, and the one at the 90° location intercepted the flow at right angles, so the particles tended to remain out from the hopper, turning in the roller generated in the gutter as shown in Figure 27.

At this stage, it was decided to adapt the grit chamber to a definite dimensioned vertical-sided hopper that would feed a screw conveyor. The first position tried with this 30.5 x 45.7-cm (12 x 18-in.) hopper was 270°, as shown in Figure 28, Scheme with Hopper at 270°. Results were disappointing in tests either with or without as much as 20 percent foul outlet discharge. Although most of the solids were retained in the chamber, heavy deposits remained on the floor as shown in Figure 28. This was an unexpected finding, since previous work had clearly demonstrated that 270° was the best position for collecting deposited solids.

The hopper was then moved to the 180° position as shown in Figure 29, Vertical-Sided Hopper at 180°. The solids deposition pattern was typical of the discharges of 85 and 141.6 l/s (3 and 5 cfs) tested. Although this floor accumulation pattern covered a greater area than the previous configuration, the deposits were not so deep, and represented much less volume. At this stage it appeared that this was the best position for the hopper, but that it would require guides or vanes of some kind to carry the solids into it.

A series of tests were performed to evaluate floor baffles or vanes located at various positions on the chamber floor. The arrangement shown in Figure 30, Hopper at 180° with Three Floor Baffles, was the most efficient in this series. The baffles, 6.5 cm (2.5 in.) (prototype) high, worked relatively well in guiding the solids to the hopper, but in so doing, they created additional turbulence in the flow so that much of the material was being thrown back up into suspension continuously. It appeared that baffles, at least at the 90° and 180° positions where the flow velocities were higher, caused too much disturbance in the chamber.

Figure 31, Hopper at 180° with Two Gutters, shows the developed locations of two



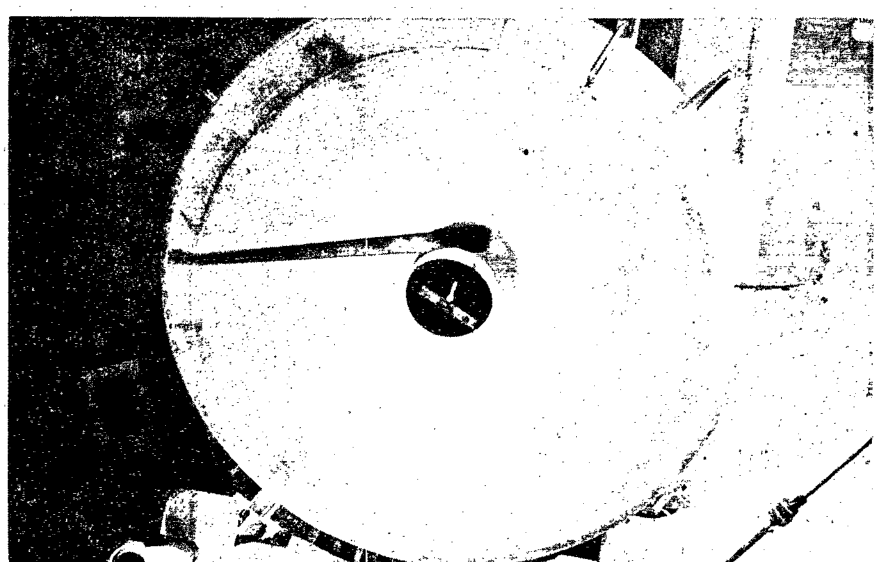
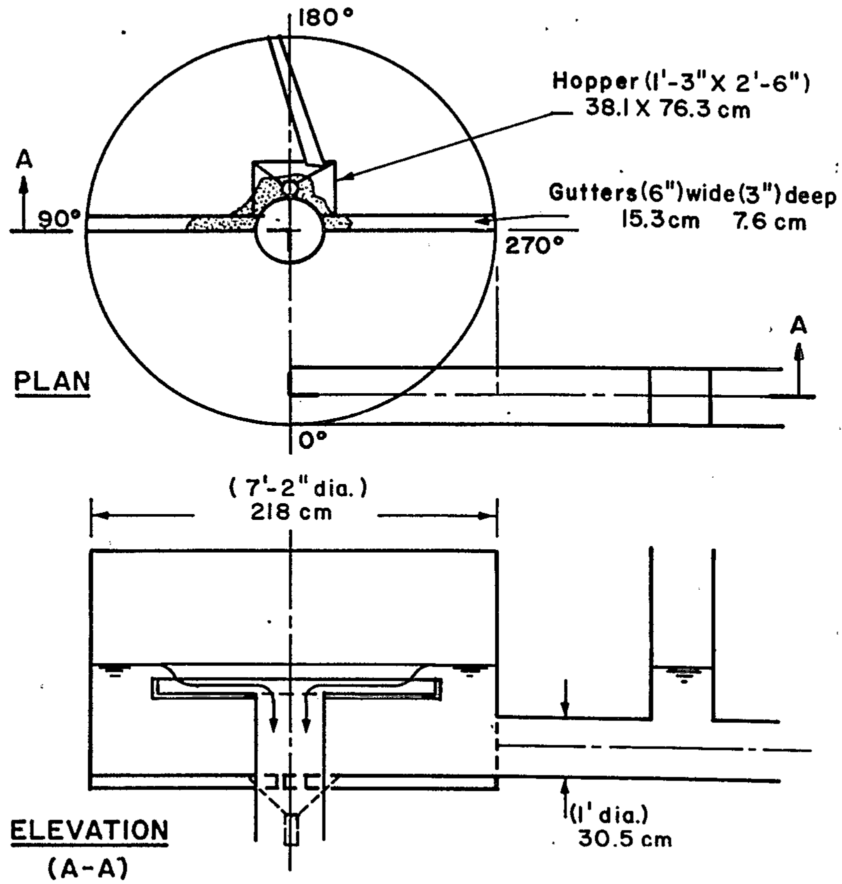


FIGURE 26 SINGLE GUTTER – SMALL OUTLET SCHEME



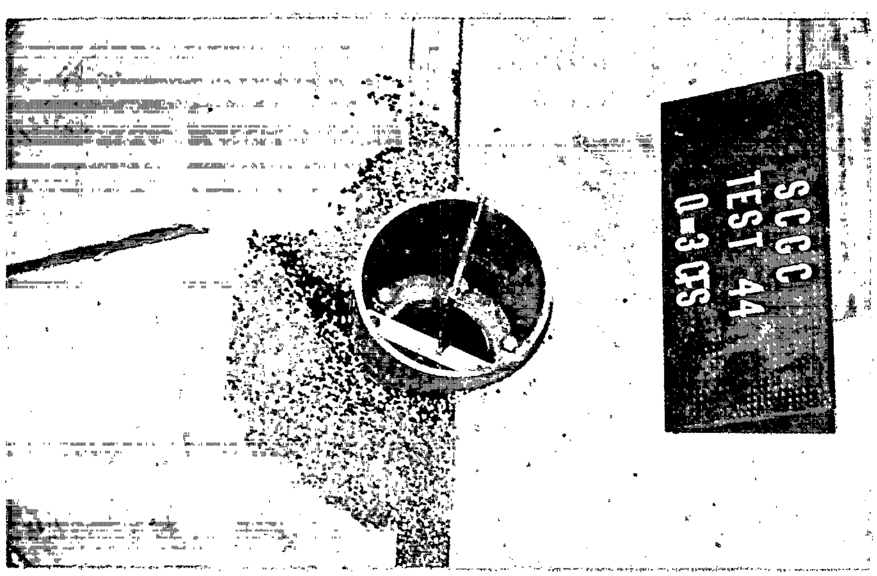


FIGURE 27 THREE GUTTER – LARGE HOPPER SCHEME

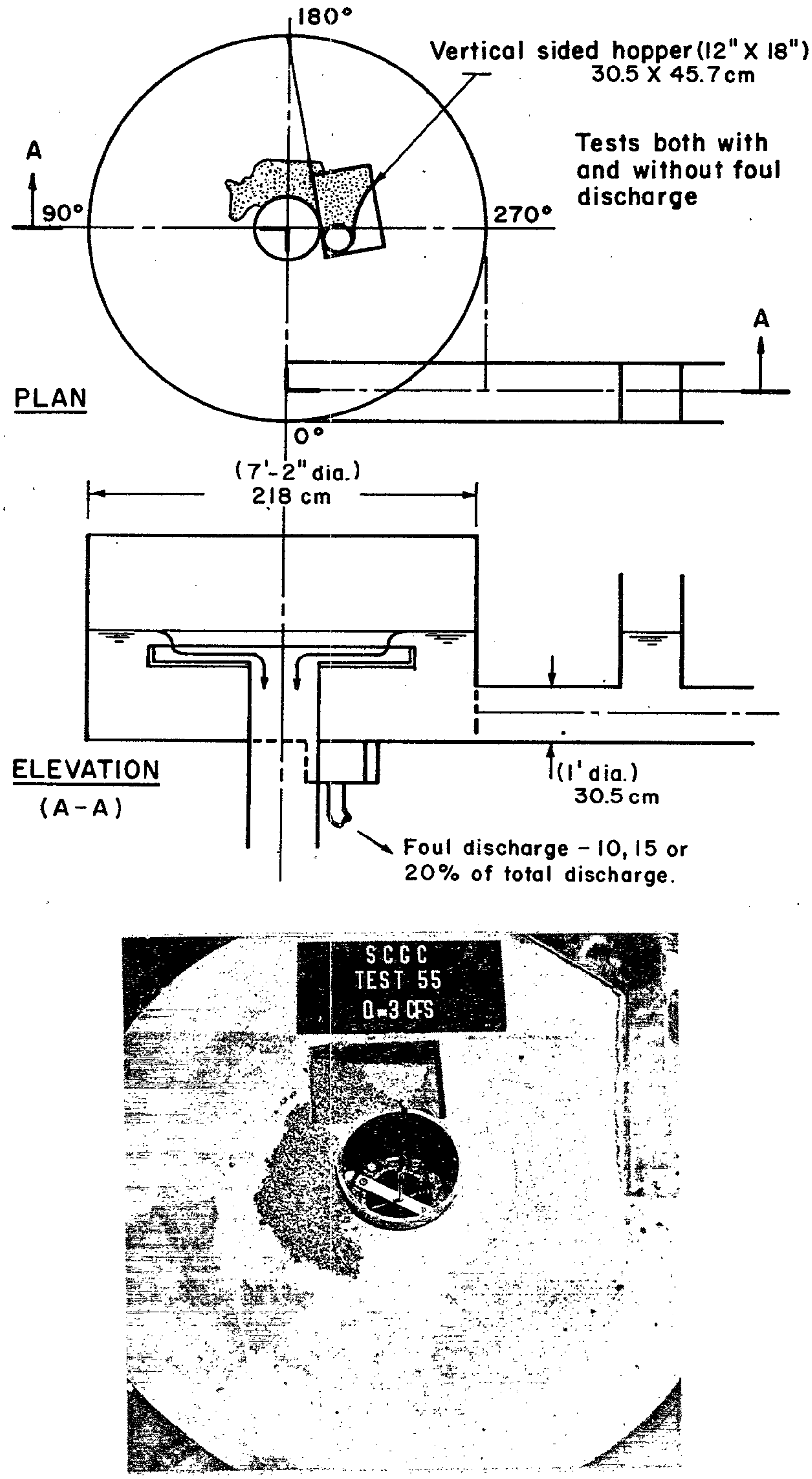
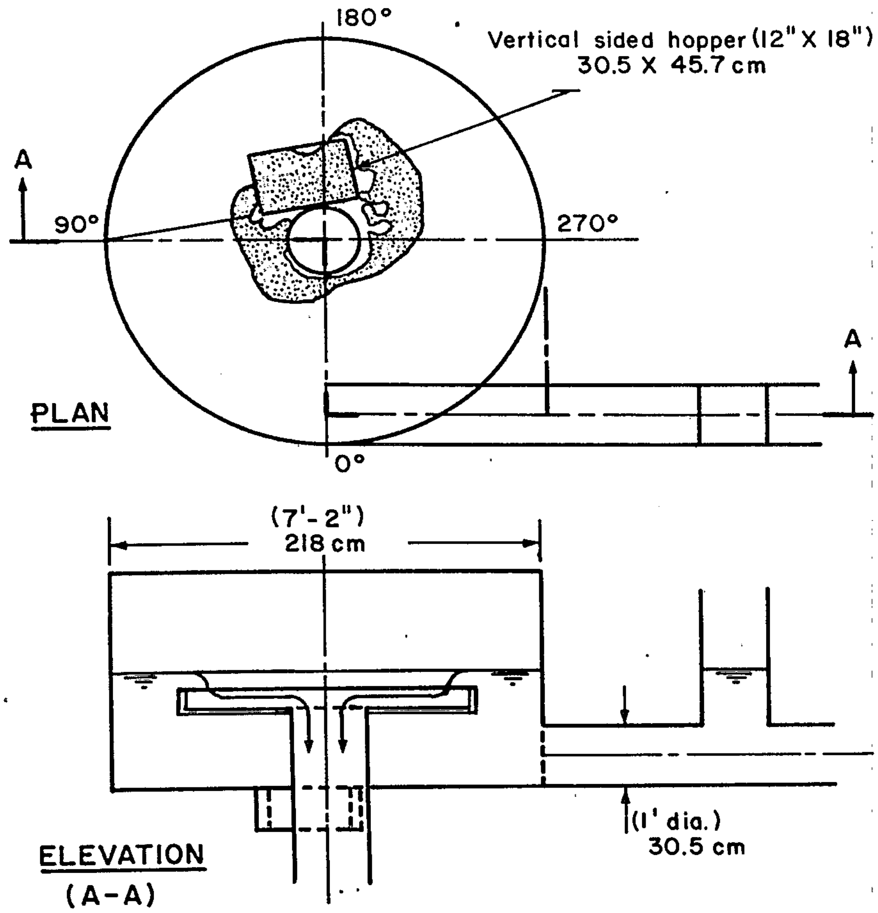


FIGURE 28 SCHEME WITH HOPPER AT 270°



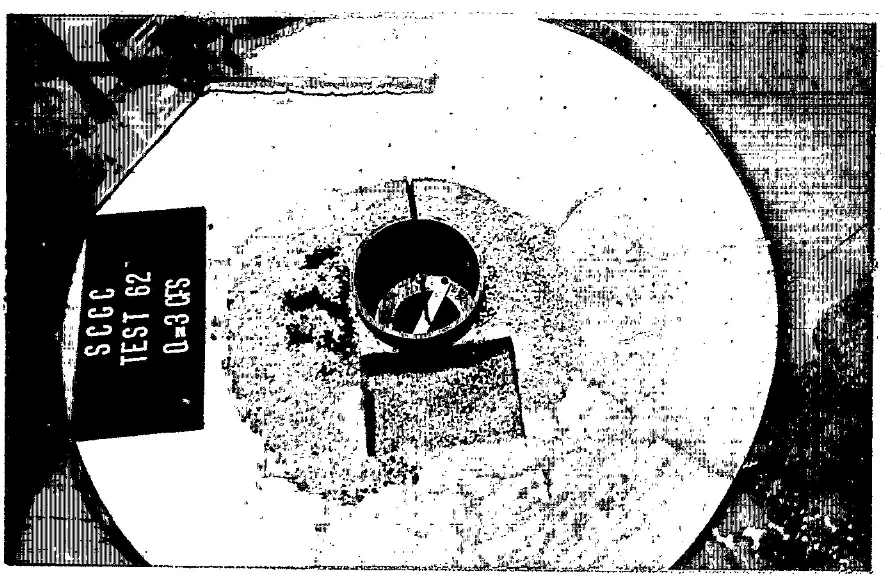


FIGURE 29 VERTICAL-SIDED HOPPER AT 180°

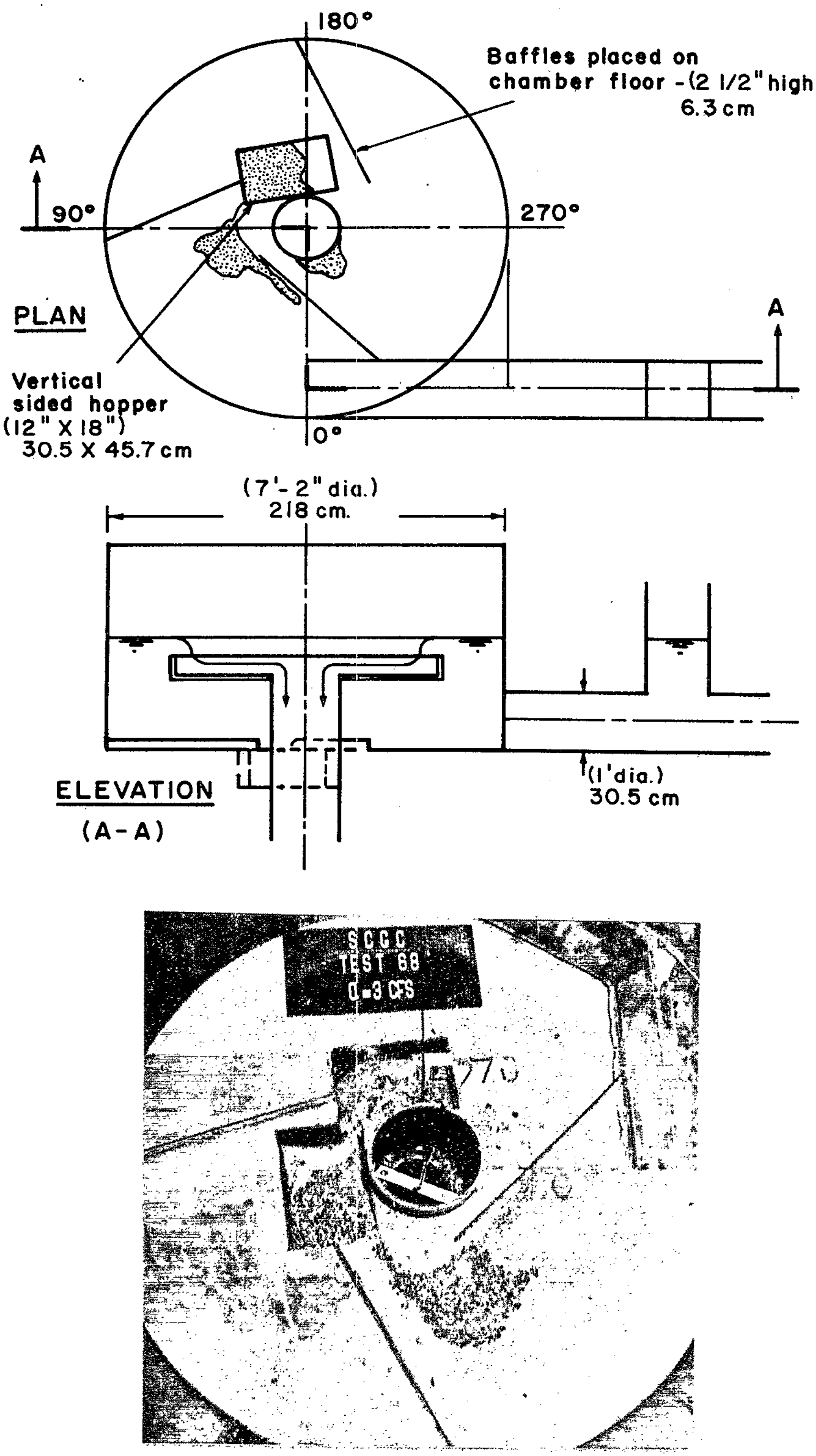


FIGURE 30 HOPPER AT 180° WITH THREE FLOOR BAFFLES

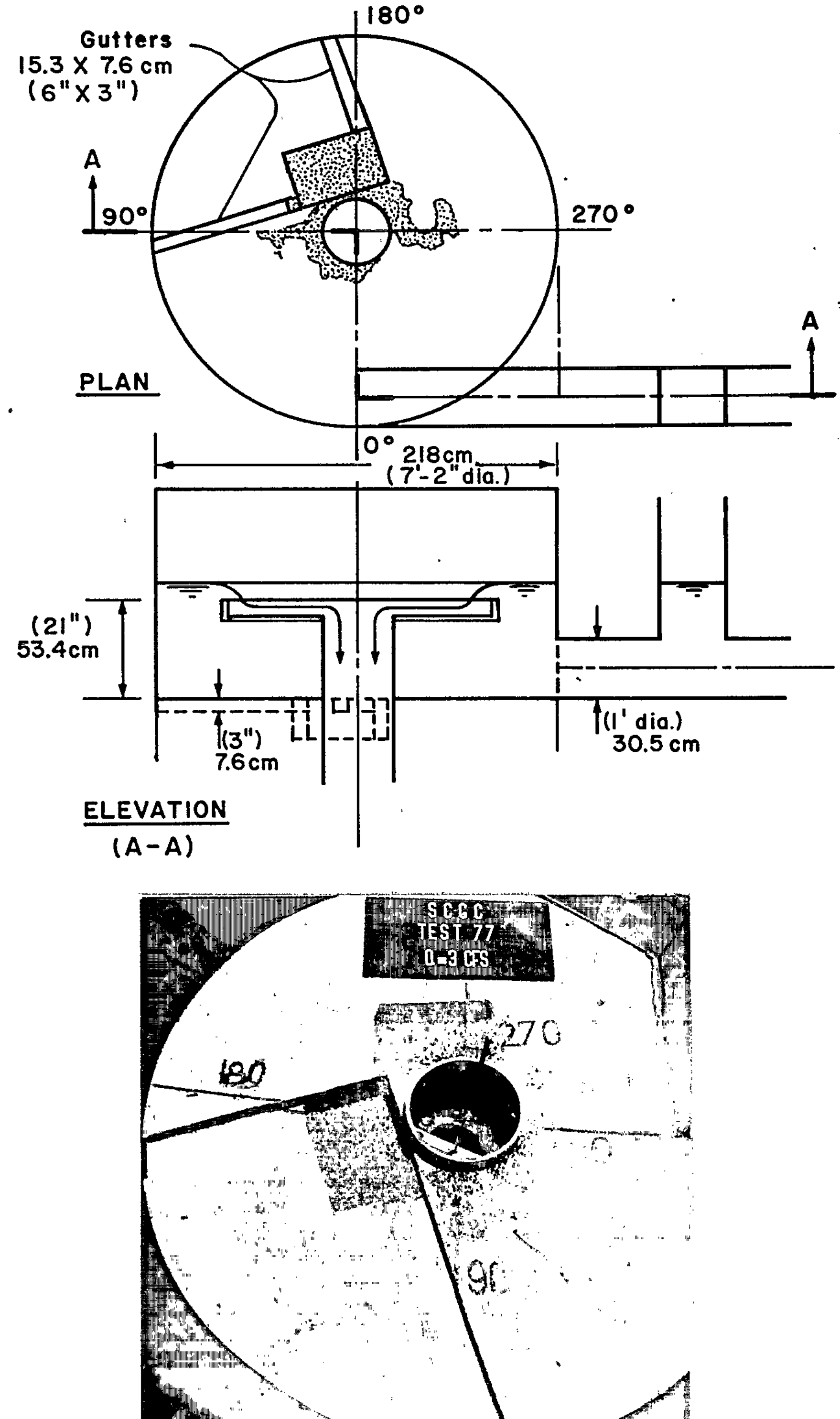


FIGURE 31 HOPPER AT 180° WITH TWO GUTTERS AND THREE FLOOR BAFFLES

floor gutters which were very efficient in directing material to the hopper, even without any foul outflow. However, the gutter at 180° was drawing so much water that it caused high turbulence in the hopper and ejection of some of the accumulated solids. This material continued around the central downpipe, and was deposited on the chamber floor.

Final Flat Floor Configuration

Following a detailed series of tests intended to reduce to a minimum the deposits on the chamber floor, the layout shown in Figure 32, Hopper at 180° with Two Gutters and One Floor Baffle, was selected as the most advanced form of this concept. Also included in these tests was the procedure of drawing off a constant discharge of 2.8 l/s (0.1 cfs) (prototype) through the foul outlet in the hopper bottom to simulate the flow through the grit removal screw conveyor.

During these tests, the gutter at 180° was reduced to a 7.6 x 7.6-cm (3 in. x 3 in.) cross section from its original 15.2-cm (6-in.) width. This effectively reduced the discharge which it directed into the hopper, inhibiting the turbulence which had been ejecting too many solids back into the swirl chamber. There were, however, still some solids escaping from the hopper and migrating around the central downpipe. The floor baffle located at the 0° position, in a relatively calm water zone, served the purpose of redirecting these particles back into the hopper.

The deposit shown in Figure 32 was typical of tests run at 85 and 141.6 l/s (3 and 5 cfs). The volumes on the floor were very small; once the approximate pattern shown was formed, it remained in equilibrium over a wide range of the higher discharges. However, at the 42.5 l/s (1.5 cfs) discharge the deposit on the floor was substantial. With a discharge of 56.5 l/s (2 cfs) running during solids injection, no large deposit was formed.

Having settled on the configuration shown in Figure 32, as the optimum for the flat floor concept, detailed tests were carried out to determine the effects of different overflow weir levels. Weir heights of 53.3, 61.0, and 68.5 cm (21 and 27 in.) above the chamber floor were tested for the three prototype discharges of 42.5, 85 and 141.6 l/s (1.5, 3 and 5 cfs). The pumice samples smaller than 3 mm (passing No. 6 mesh) shown in Figures 4 and 5 were all recovered either on the chamber floor for 42.5 l/s (1.5 cfs), or in the hopper for discharges above 56.5 l/s (2 cfs). Therefore, a complete series was carried out using only the Gilsonite, see Figures 17 and 18, to evaluate the chamber's performance for the fine end of the grit scale. The results are shown in Figure 29, Solids Separation for Flat Floor Concept.

The first point noted was that for the small discharge of 42.5 l/s (1.5 cfs) the deposit on the chamber floor was significant; as the discharge increased, the deposit no longer formed, and/or the existing solids accumulation was swept out. The quantity of solids recovered in the hopper increased as the weir height was raised except at 42.5 l/s (1.5 cfs). Similarly, the solids carried out the overflow increased as the weir level dropped and the inflow discharge increased.

Remarks

This model configuration operated very well in the middle and higher discharge ranges. It was particularly encouraging to find that even with the 141.6 l/s (5 cfs) rate the chamber still recovered nearly 25 percent of the finest materials, between 0.1 and 0.4 mm (No. 140 and No. 40 sieve).

On the other hand, at the lowest discharge, 42.5 l/s (1.5 cfs), deposits on the chamber floor always remained. The energy arriving in the flow at this discharge was not sufficient to move the material the distance necessary across the chamber floor to the gutters or hopper.

At this stage, it was concluded that this design would be valid if installed on a sanitary sewage system with a daily flow variation between the 42.5 and 141.6 l/s (1.5 and 5 cfs) tested. At the lower discharges, deposits would be built up in the chamber, but as the discharge subsequently increased, the deposits would be swept into the hopper. Another acceptable mode of operation would be with relatively constant discharges, always greater than 56.5 l/s (2 cfs).

These limitations were considered too restrictive in view of the goals set for the project, so a new line of research was established as described in the following sections.

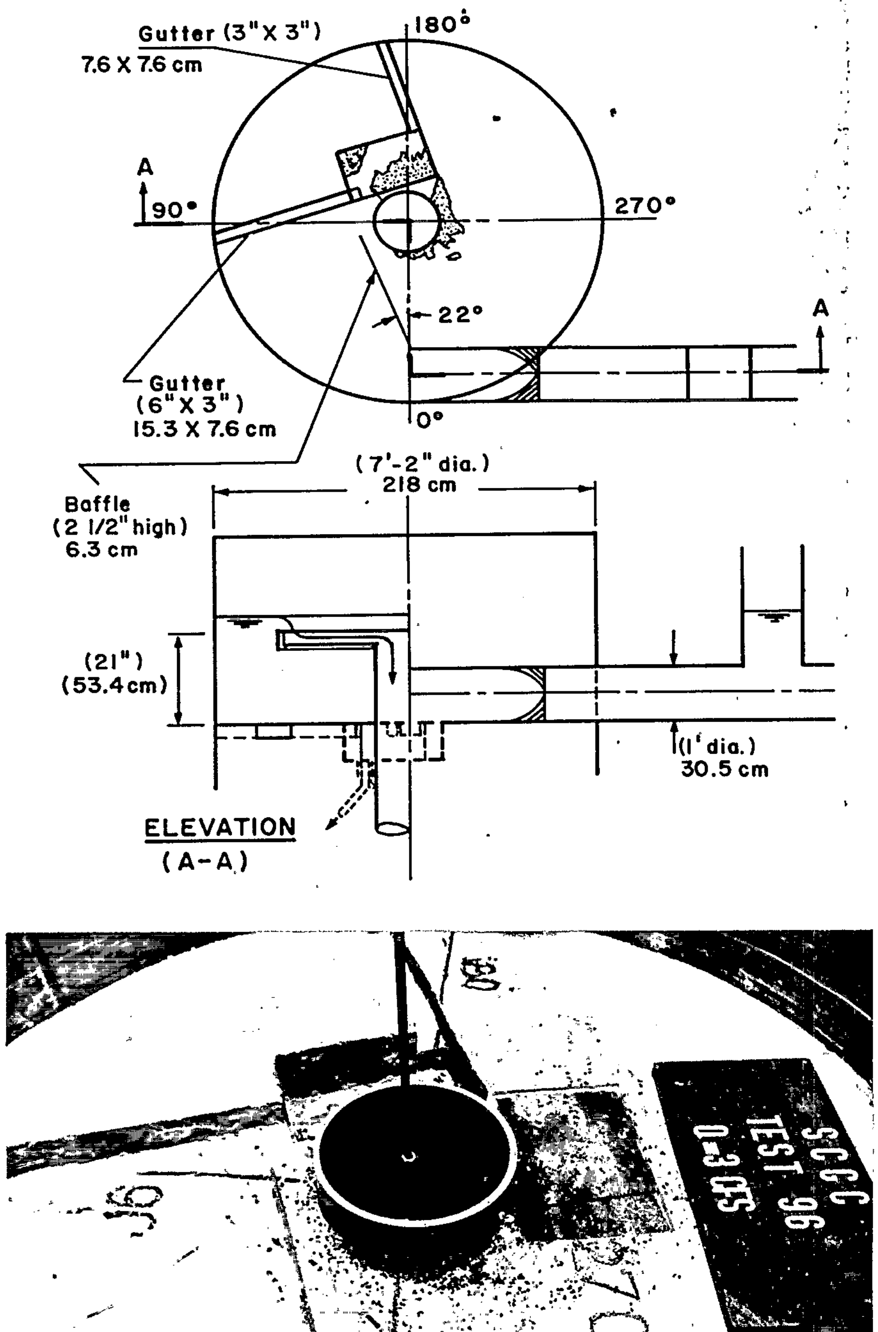
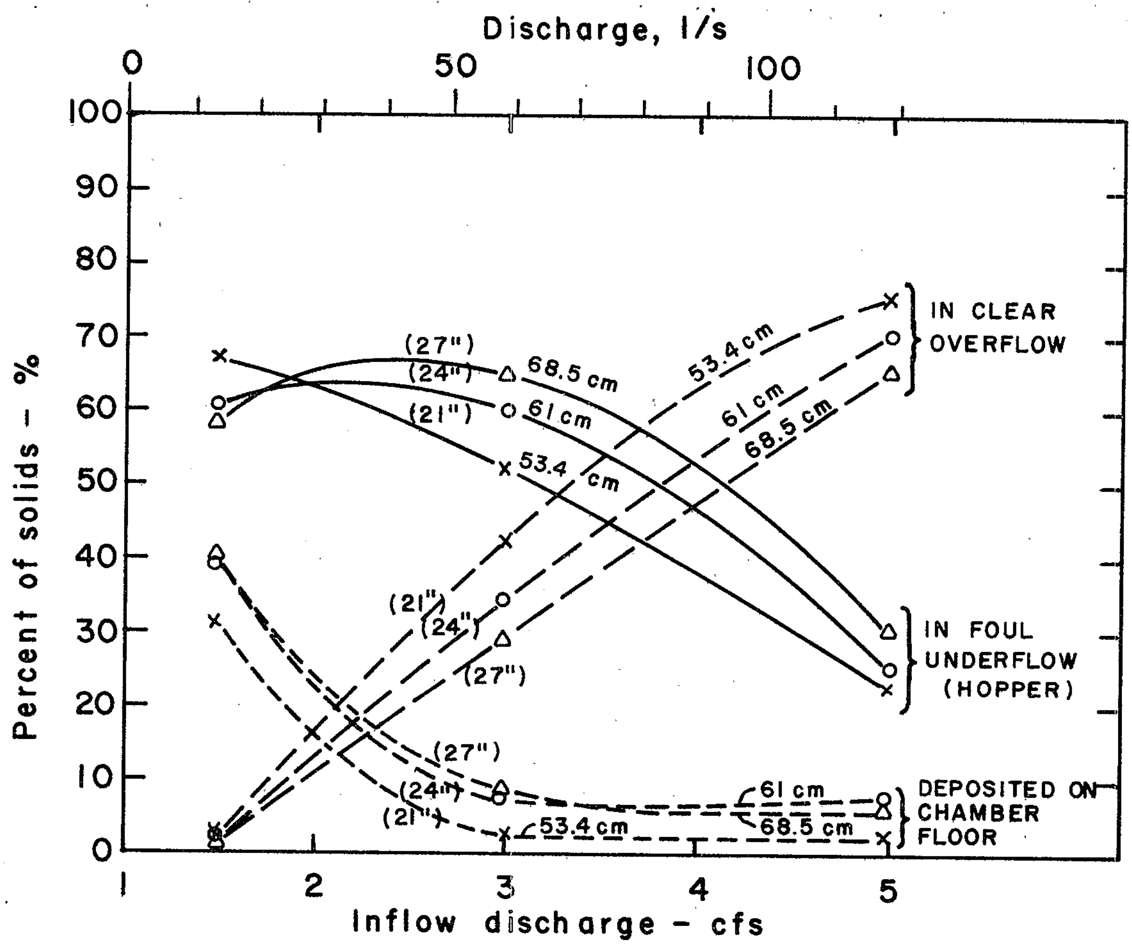


FIGURE 32 HOPPER AT 180° WITH TWO GUTTERS AND ONE FLOOR BAFFLE



NOTE :

- Solids represented were: on model, Gilsonite: 1-3 mm prototype grit, 0.1 - 0.26 mm
- Foul outflow through hopper = 0.1 cfs (prototype) = 2.83 ℓ/s
- Chamber layout as on FIG. 16
- 21", 24" and 27" indications on graph correspond to weir heights above chamber floor

FIGURE 33 SOLIDS SEPARATION FOR FLAT FLOOR CONCEPT

Conical Floor Concept

Discussions with the project group of consultants resulted in the proposal to return to a symmetrical floor arrangement, with a cone dropping around the central downpipe. This approach included the use of an elbow in the downpipe, at some selected level just below the chamber floor level, so the clear flow would be taken off horizontally. At the same time, it introduced the possibility of continuing the sloping sides of the cone down to a single collection point below the downpipe, on the chamber's central axis, as shown in Figure 34, Conical Floor Principle.

The use of an annular gutter had been tried and abandoned in the earliest tests as shown by Figure 25. The problem at that time was that the central downpipe was considered as extending down deeper, and that the grit had to be concentrated at one point beside the downpipe to be drawn off. The grit showed marked tendencies to deposit in the annular gutter, but it was distributed irregularly around it, so that it was not possible to draw it off effectively. However, in the new concept, the grit could drop anywhere in the cone and it would migrate downward under the downpipe where it could all be picked up mechanically by some form of elevator.

At this time it had also been decided that the chamber at Lancaster must operate without inlet deposition problems at the minimum steady discharge of 42.5 l/s (1.5 cfs). This required the model scale to be 1:2, giving a prototype 183-cm (6-ft) diameter chamber for the 30.5-cm (1-ft) diameter inlet pipe.

The first configuration tried following this principle is shown in Figure 35, Small Cone, Elbow Flush with Floor. The upper edge of the conical floor basin was 101.5 cm (40 in.) in diameter, and the downpipe was considered as having its elbow located with the top of the horizontal section at the 90° position just flush with the flat outer chamber floor level.

It was immediately evident that the downpipe elbow was so high that turbulence occurred in the chamber. Flow tended to build up in the cone, rotating around the vertical section of the downpipe; when it reached the elbow, it was pushed upward again, ejecting the solids material into the upper zone. This resulted in a significant deposit on the flat floor around the 180° position.

The next step was to lower the downpipe elbow so that it was below the existing cone bottom on the model; i.e., 15.2 cm (6 in.) prototype below the flat floor, as shown in Figure 36, Small Cone, Elbow 6 in. (15.2 cm) Below Flat Floor. This arrangement removed all obstruction from the flow circulating in the cone, and there was no longer any re-entrainment of particles that had dropped onto the bottom. At higher discharges the deposit on the flat floor at 180° was reduced to a very small volume which quickly reached an equilibrium state and did not increase in size. However, for discharges around 42.5 l/s (1.5 cfs) significant deposits remained at the inlet.

Observations of the solid particles' trajectories during the tests with the layout shown in Figure 36 demonstrated that, once inside the chamber, the particles tended to work their way to the right of the jet, (i.e., toward the center of the chamber). However, the edge of the cone was too far to reach for these particles with the amount of energy available in the smallest discharges. This indicated the need to widen the cone so its upper edge extended out to the side of the square inlet opening.

Final Conical Floor Configuration

Figure 37, Final Conical Floor Configuration, shows the basic layout of the widened conical floor which was accepted as the most efficient configuration of this principle. The upper edge of the cone can be seen extended to a point just outside of the square baffle-inlet. Preliminary tests with various levels and orientations of the downpipe elbow indicated that it should be taken out along the 90° line, and should be at least 30.5 cm (1 ft) below the flat floor level.

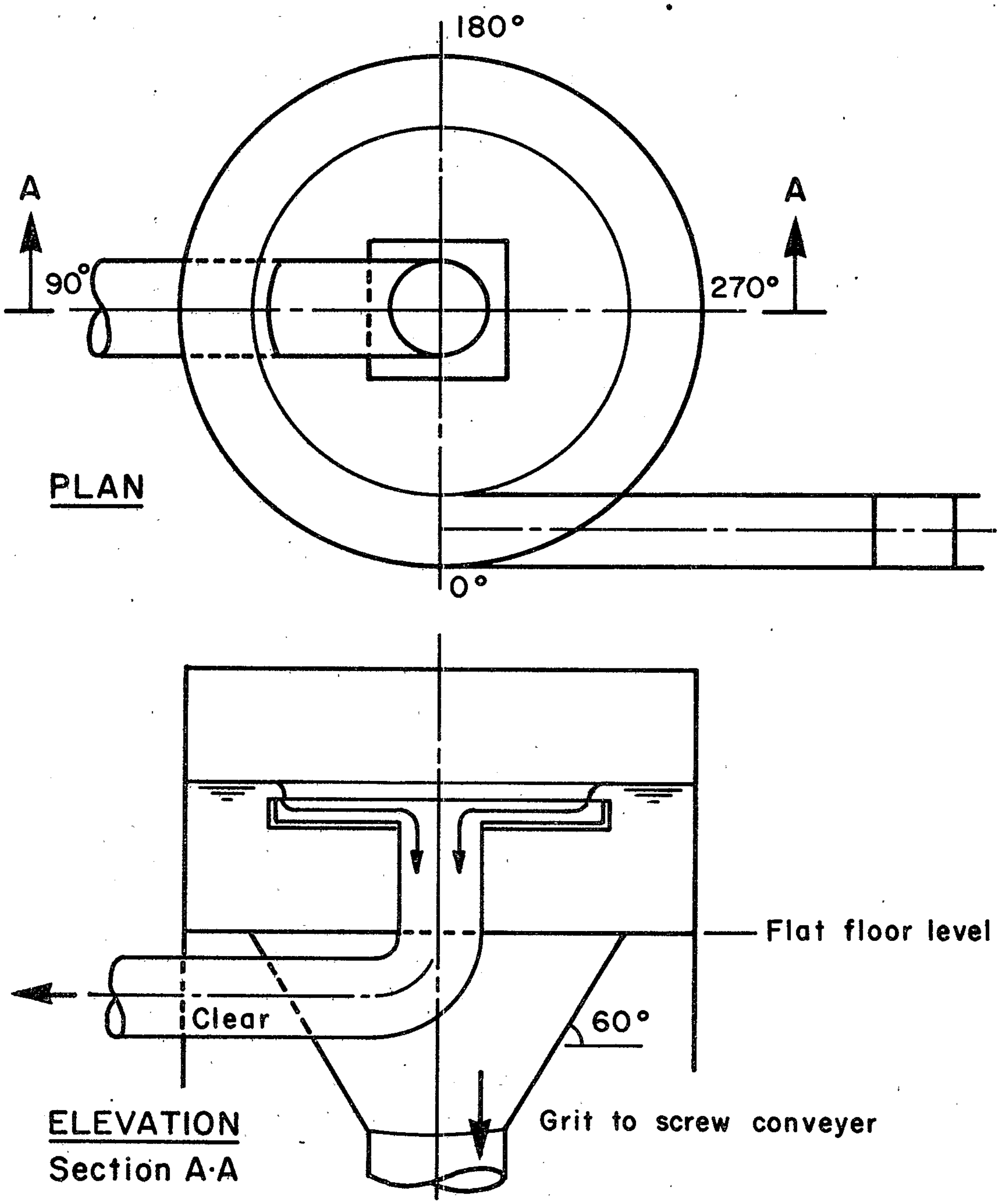
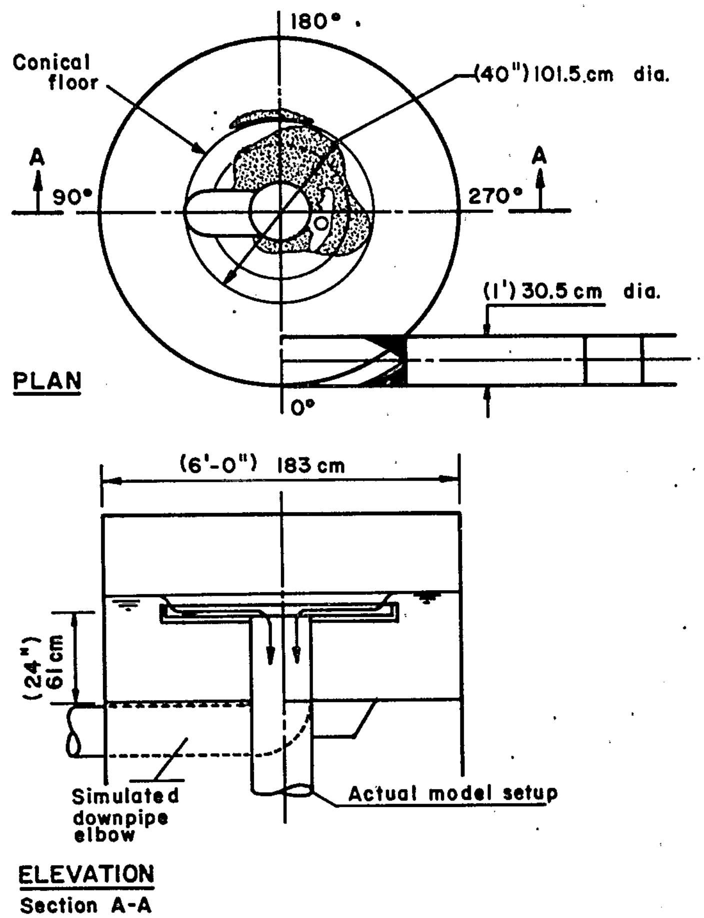


FIGURE 34 CONICAL FLOOR PRINCIPLE



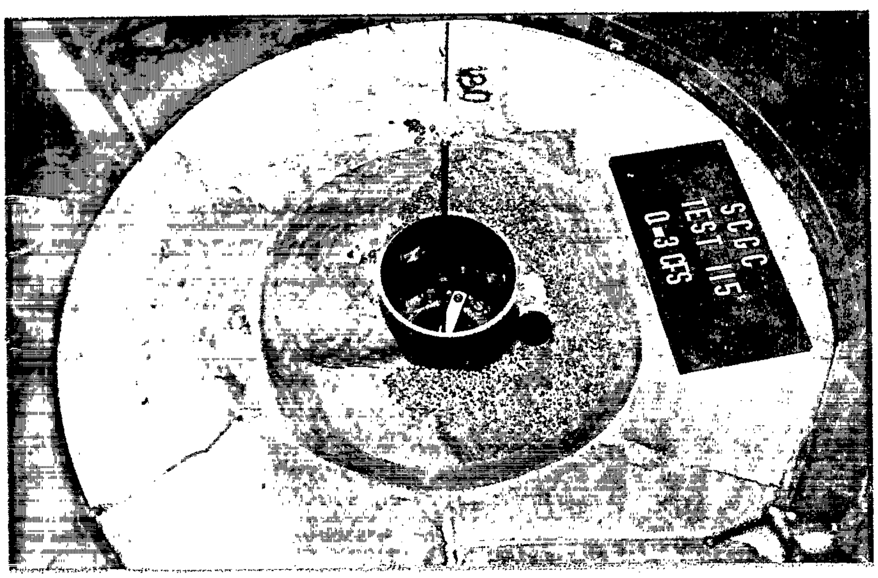


FIGURE 35 SMALL CONE, ELBOW FLUSH WITH FLOOR

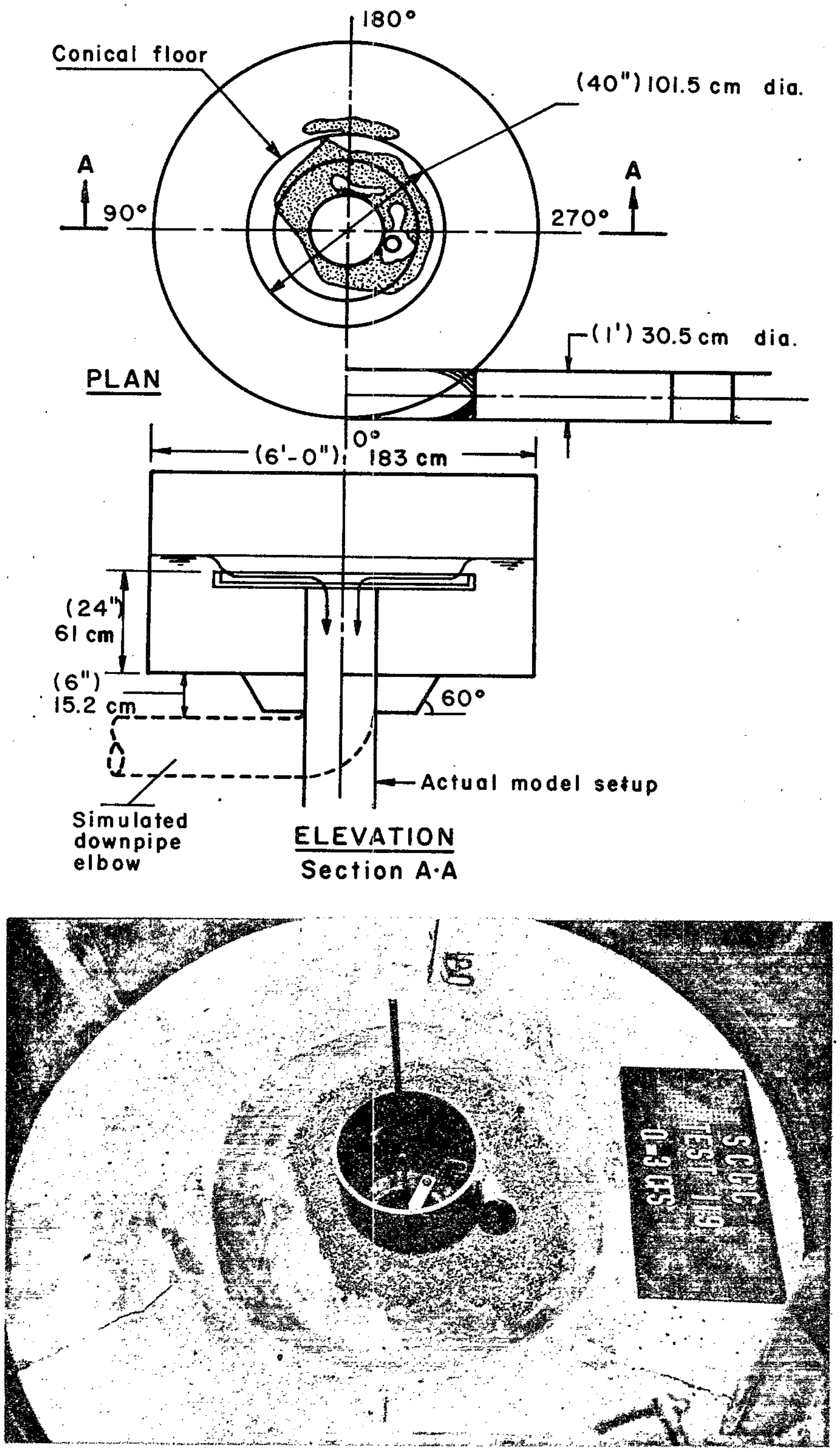
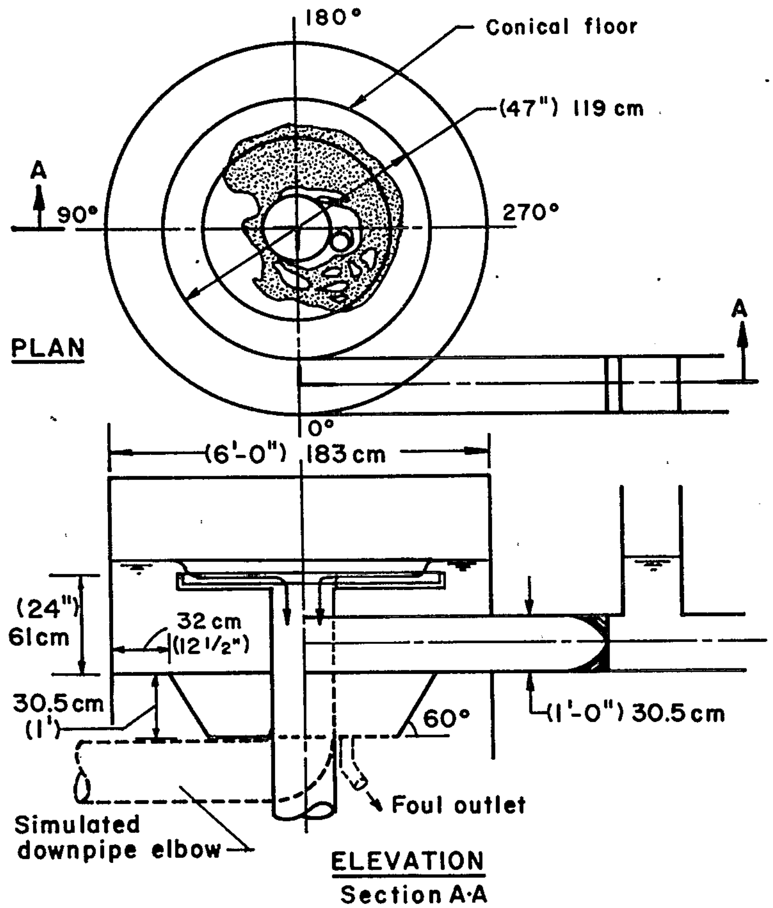


FIGURE 36 SMALL CONE, ELBOW 15.2 cm (6 in.) BELOW FLAT FLOOR



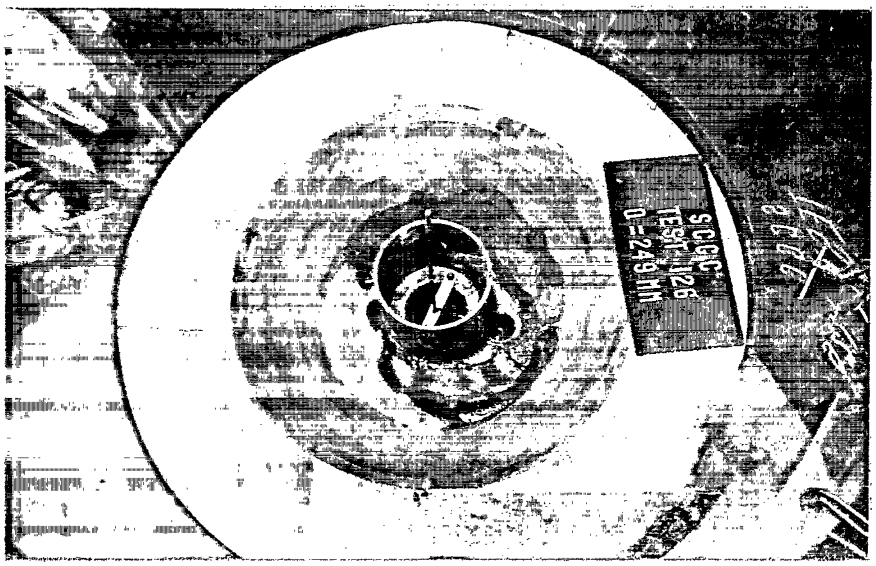


FIGURE 37 FINAL CONICAL FLOOR CONFIGURATION

Figure 38, Sketch Layout of Swirl Concentrator Grit Chamber, shows a possible layout for the Lancaster installation, with a 30.5-cm (1-ft) diameter inlet.

Testing to this point had been carried out over only a limited discharge range, so a complete detailed series of tests was undertaken to accurately define the operating efficiencies. The tests were planned to include varying width-depth ratios as well. The model modifications are shown in Figure 39, Nomenclature for Width-Depth Proving Tests. The same 91.5-cm (36-in.) diameter chamber was used for all tests, but the 15.3-cm (6-in.) supply line was changed respectively to 12.7, 11.1 and 7.6 cm (5,4 and 3 in.), as shown in Figure 40, Varying Sized Inlets Used in Width-Depth Tests. To maintain continuity in reporting, the scale was selected for each so that the prototype inlet pipe was always considered as being 30.5 cm (1 ft) in diameter. This procedure resulted, therefore, in simulating a constant inlet pipe diameter and varying chamber diameter.

The same weir assembly was used in all tests, so its diameter was considered as changing along with the chamber diameter. Three standard prototype discharges were selected, 28.3, 85 and 141.6 l/s (1,3 and 5 cfs).

The elements which were modified on the model during this test series are described on Figure 39. Following the concept of the inlet diameter being used as the basic dimension, it was the first to be given a symbol, D_1 in the test nomenclature. On the plan view, the value of D_1 is shown so as to represent the four different pipe diameters tested. Then on Section A-A, D_1 appears as the height and width dimension of the square inlet inside the chamber. As shown, the four different D_1's described above were put on the model, coming into the chamber tangentially at the 0° position.

The next pertinent dimension defined was the inside diameter of the chamber, called D_2. This remained constant for all tests. Finally, the height of the weir crest above the flat part of the chamber floor was called H_1. At least three different weir heights were tested with each inlet pipe diameter.

Proving Test Results and Analysis

In all cases, when pumice and sand were injected, the recoveries were either 100 percent or 99 percent plus, with only traces of the finest materials being lost over the central outlet weir. Therefore, in order to provide any kind of comparison, Gilsonite was used as the testing material. Recovery rates of Gilsonite for the four chamber diameters simulated are shown in Figures 41 and 42, Gilsonite Recovery in Final Form (12-Ft and 9-Ft Diameter) and Gilsonite Recovery in Final Form (7.2-Ft and 6-Ft Diameter).

To present a comprehensive picture of the total grit recovery represented by this data, it was combined with that for the pumice and sand as well. Reference to Figure 18 shows that the Gilsonite used on the model simulated the grit sizes in a little more than the lower half of the graph, leaving the area above the d_m = 3 mm line unrepresented. Conversely, Figures 20 and 23 show that this upper area was well covered by the sand and pumice.

Therefore it was assumed that the Gilsonite recoveries in the above series of tests simulated the area below the d_m = 3mm on Figure 22, and that the 100 percent recoveries for the sand and pumice covered the area above this. The first step in combining these two sets of data was to determine the grit size on the d_m = 3 mm line on Figure 22 for the different model scales. These sizes were taken to Figure 18, where the percentages of prototype finer grit were found. The percentages were plotted on Figure 43, Portions of Prototype Grit Samples Simulated by Gilsonite, Sand and Pumice, as indicated for Gilsonite. The differences between the Gilsonite line and 100 percent were determined and plotted simply on Figure 43 representing the portions of the prototype grit samples covered by the sand and pumice.

Next, the Gilsonite values on Figure 31 for the scales to be used in scaling up to selected prototype sizes were plotted on Figure 44, Portions of Prototype Grit Samples Represented by Gilsonite Recovered in Tests, above the 100 percent position for Gilsonite recovery in the tests, and the straight line

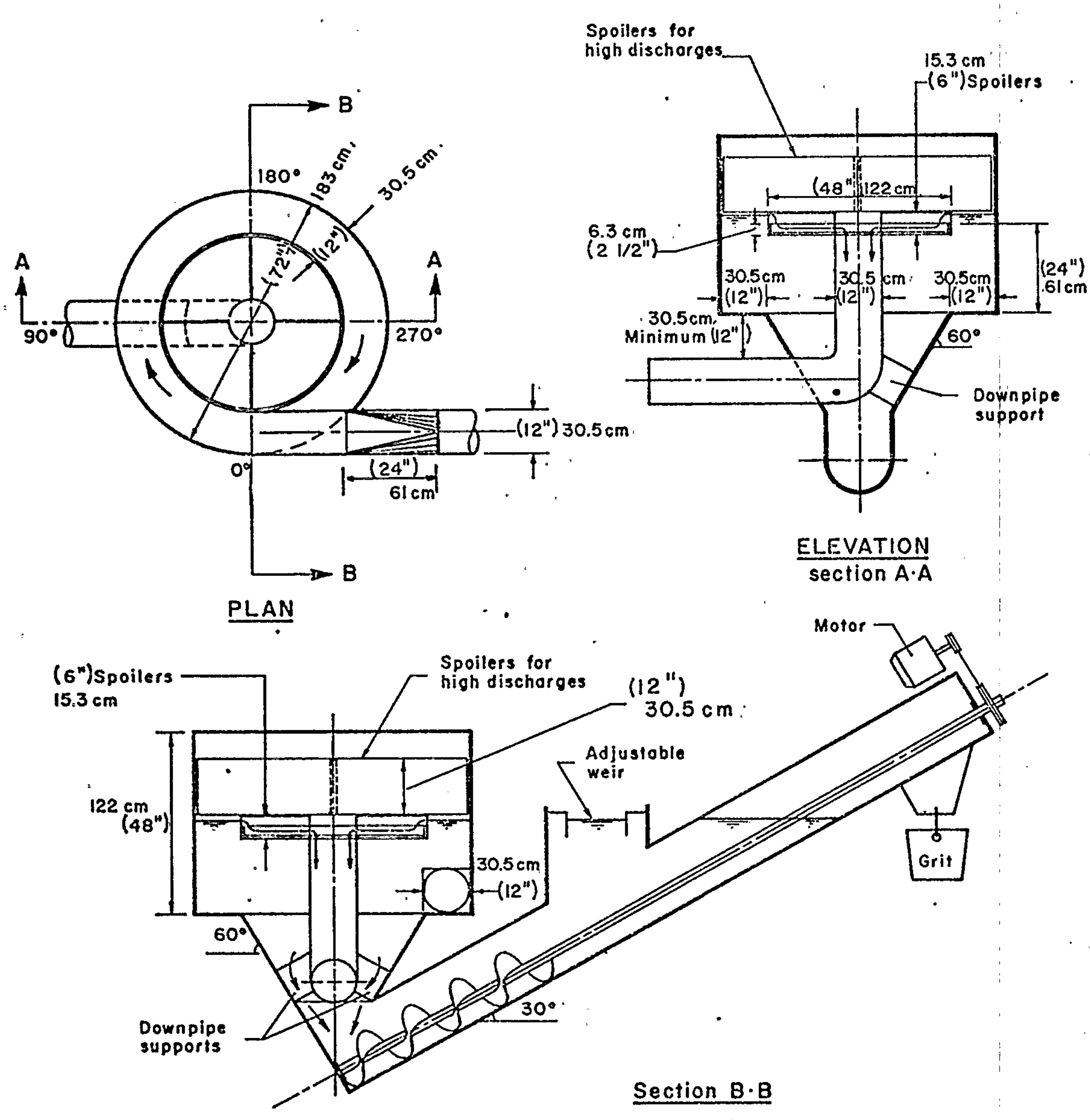


FIGURE 38 SKETCH LAYOUT OF SWIRL CONCENTRATOR GRIT CHAMBER

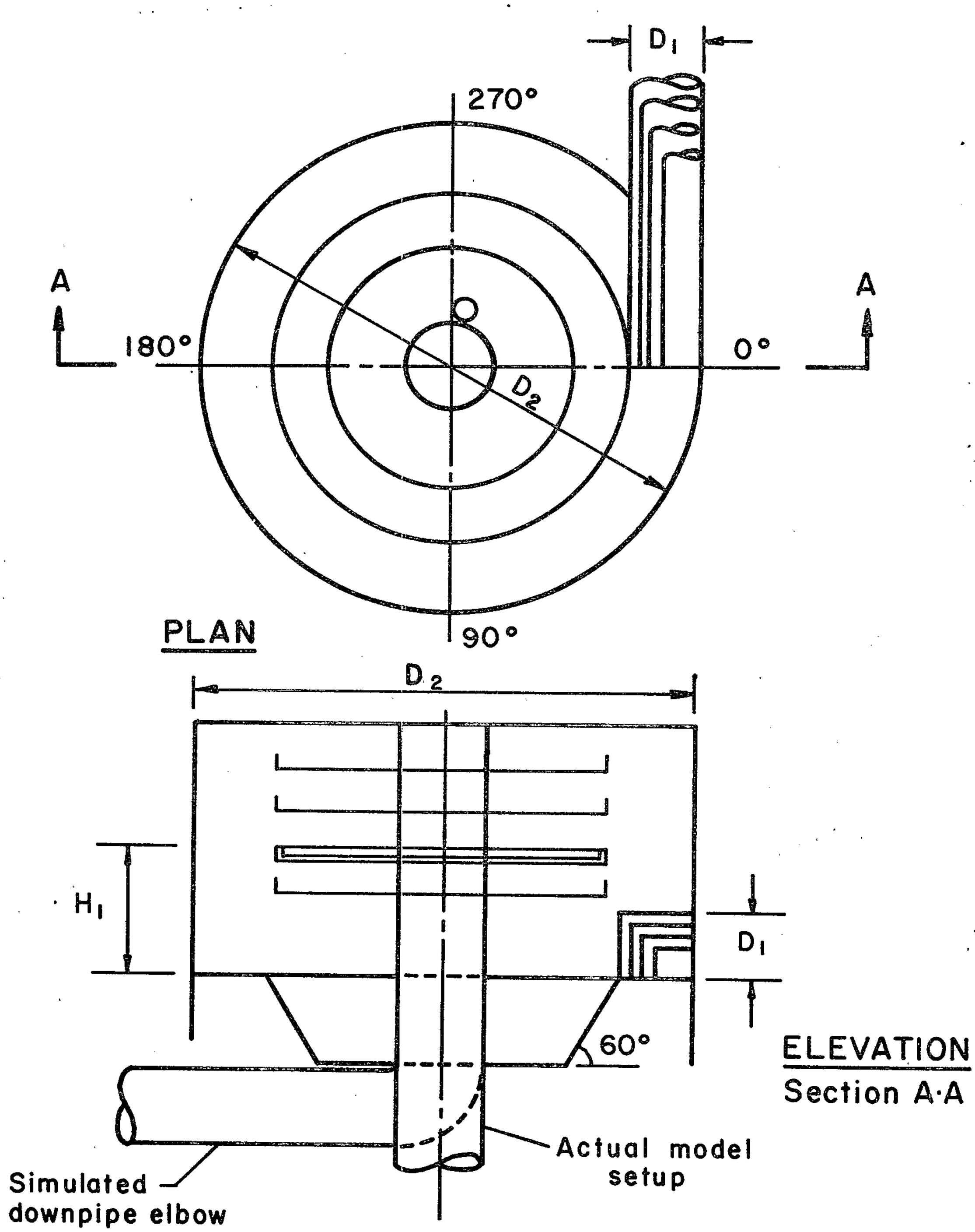
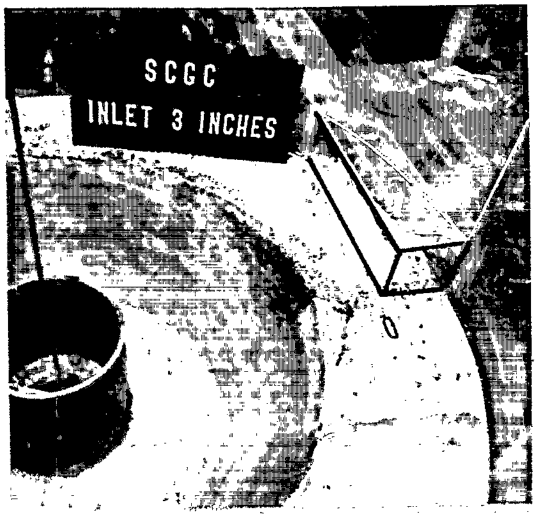
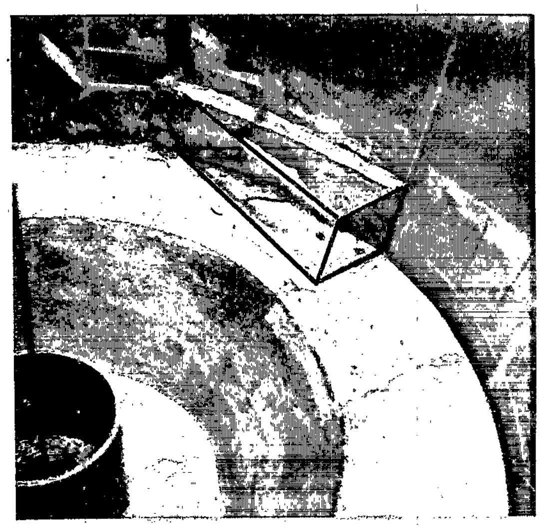


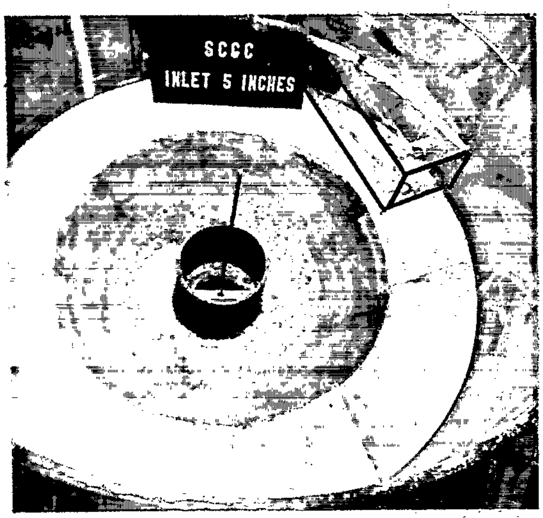
FIGURE 39 NOMENCLATURE FOR WIDTH-DEPTH TESTING



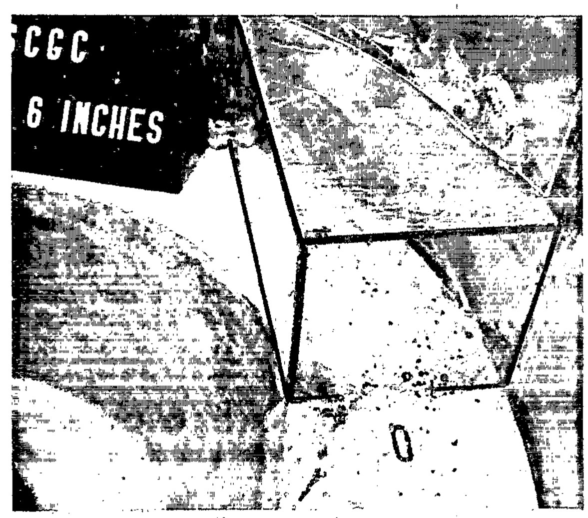
7.6 cm (3 in) Inlet



11.1 cm (4 in) Inlet



12.7 cm (5 in) Inlet



15.3 cm (6 in) Inlet

FIGURE 40 VARYING SIZED INLETS USED IN WIDTH-DEPTH TESTING

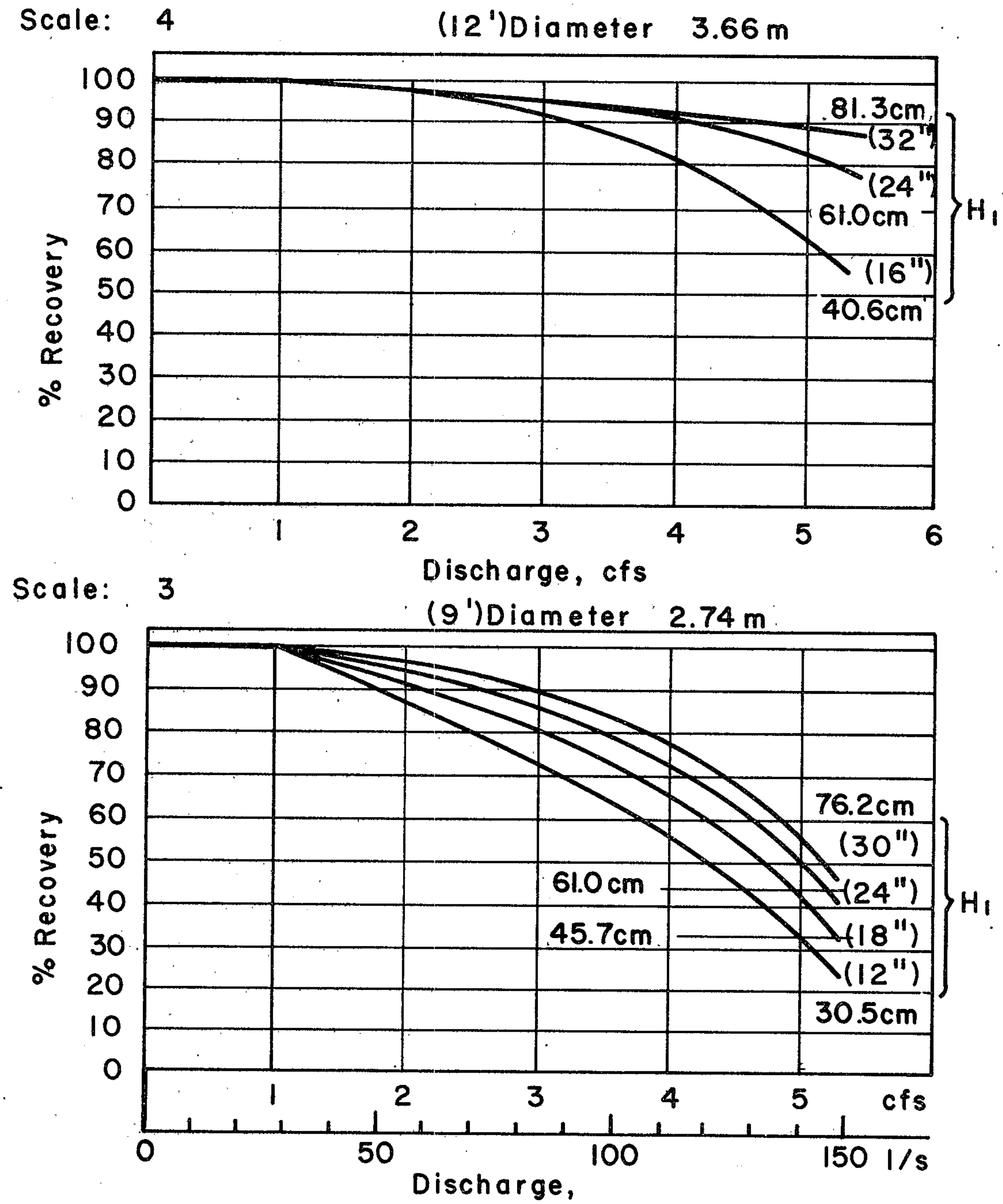


FIGURE 41 GILSONITE RECOVERY IN FINAL FORM
3.66 AND 2.74 m (12 ft & 9 ft) DIAMETERS

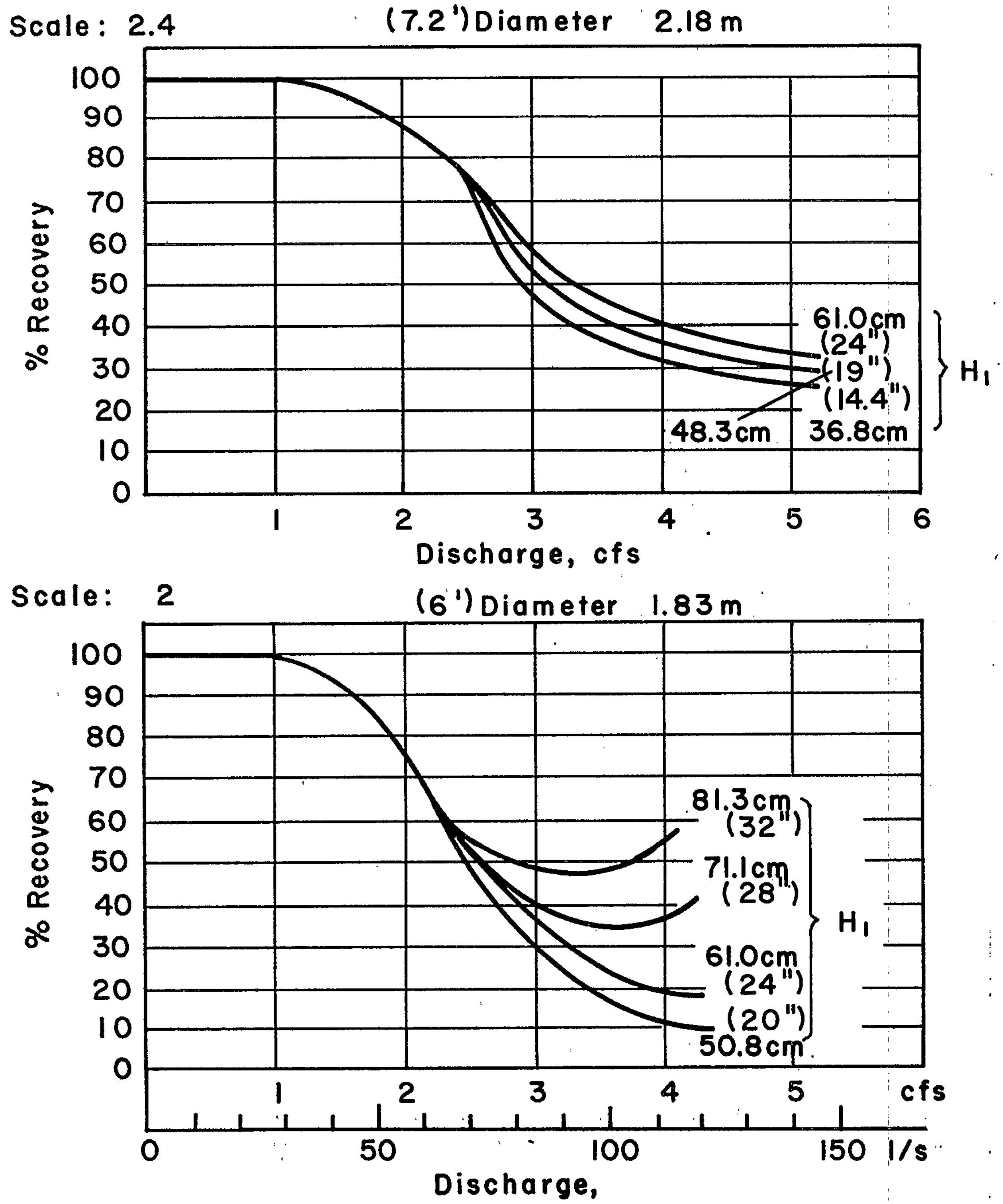


FIGURE 42 GILSONITE RECOVERY IN FINAL FORM
2.18 AND 1.83 m (7.2 ft & 6 ft) DIAMETERS

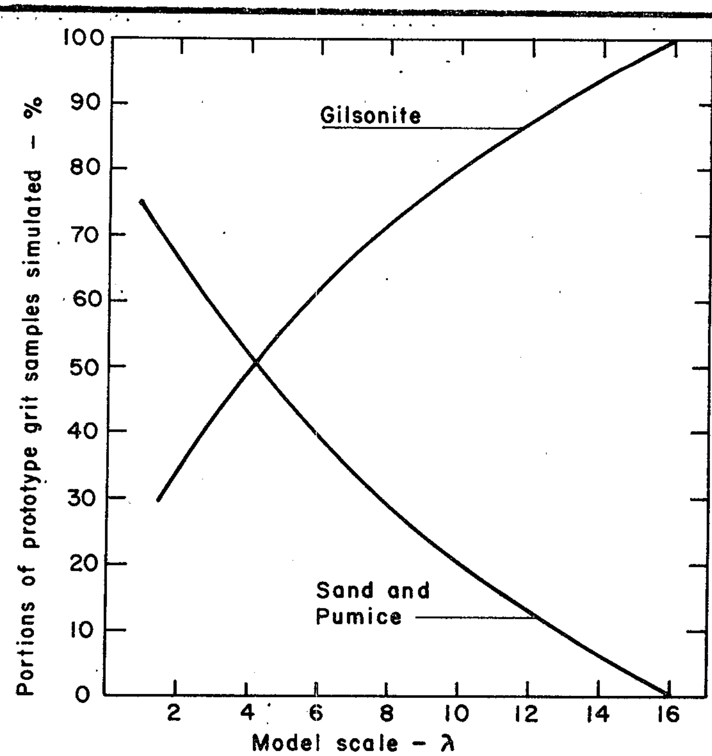


FIGURE 43 PORTIONS OF PROTOTYPE GRIT SAMPLES SIMULATED BY GILSONITE, SAND AND PUMICE

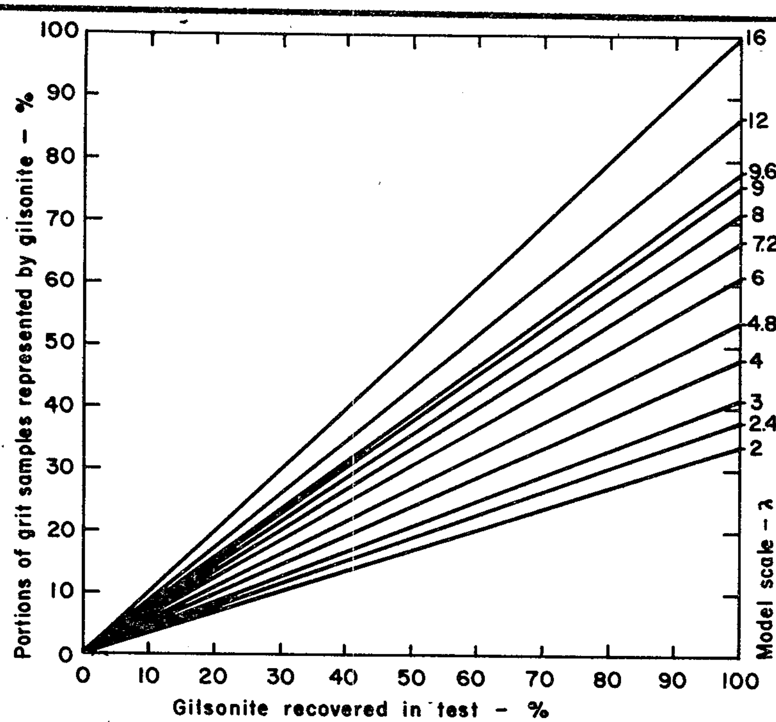


FIGURE 44 PORTIONS OF PROTOTYPE GRIT SAMPLES REPRESENTED BY GILSONITE RECOVERED IN TESTS

relations drawn simply to zero. The last step in constructing the working sheets was to add the grit percentage for sand and pumice for each retained scale on Figure 43 to the varying grit percentages for Gilsonite on Figure 44. The resulting values were plotted on Figure 45, Portions of Prototype Grit Samples Represented by Gilsonite Recovered in Tests plus Sand and Pumice.

It was then possible to take a Gilsonite recovery value from Figures 41 and 42, enter Figure 45 with this, and read off the total grit represented by that test on the appropriate scale line. This procedure was followed to transpose the data for Gilsonite only on Figures 41 and 42 to the complete prototype grit represented by the same tests as shown on Figure 46, Grit Recovery for 30.5 cm (1 ft) Inlet with 2.74 and 3.66 m (9 and 12 ft) chambers, and Figure 47, Grit Recovery for 30.5 cm (1 ft) Inlet With 1.83 and 2.18 m (6 and 7.2 ft) chambers.

Since it was desired to consider several different inlet pipe sizes, the laboratory data as it existed at this stage contained five variables; discharge, inlet dimension, weir height, recovery rate and chamber diameter. These could not all be conveniently presented in a design procedure, so some had to be eliminated.

It can be seen on Figures 46 and 47 that for each inlet pipe diameter tested, the weir height changes resulted in relatively modest recovery rate changes. Over most of the discharge range, a change in weir height equal to half the inlet dimension resulted in a recovery rate change of less than 3 percent. It was therefore decided to select the weir height of 61 cm (24 in.), corresponding to twice the inlet dimension, or $H_1/D_1 = 2$, for further analyses.

The choice of the 61 cm (24 in.) high weir was based first on the fact that it gave the most consistent results over the range tested. Secondly, observations in the model showed that it still retained a certain degree

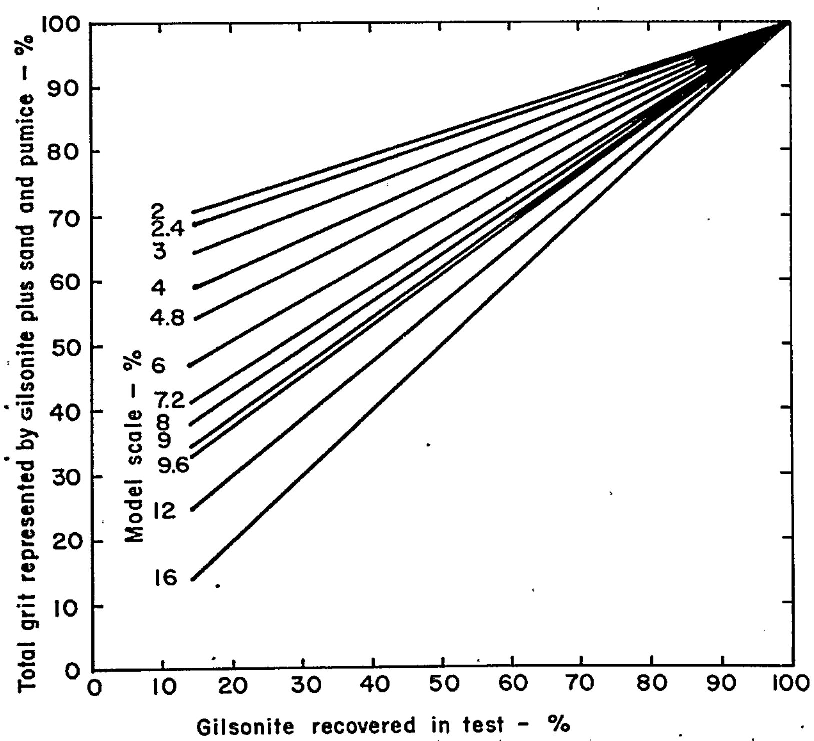
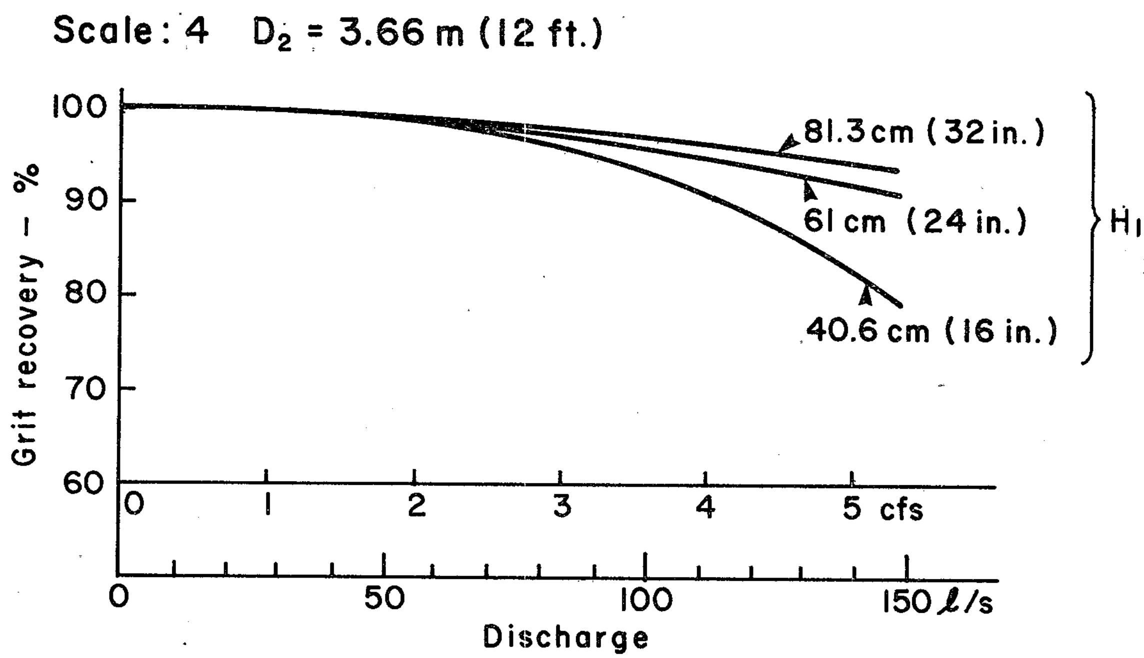


FIGURE 45 PORTIONS OF PROTOTYPE GRIT SAMPLES REPRESENTED BY GILSONITE RECOVERED IN TESTS PLUS SAND PUMICE



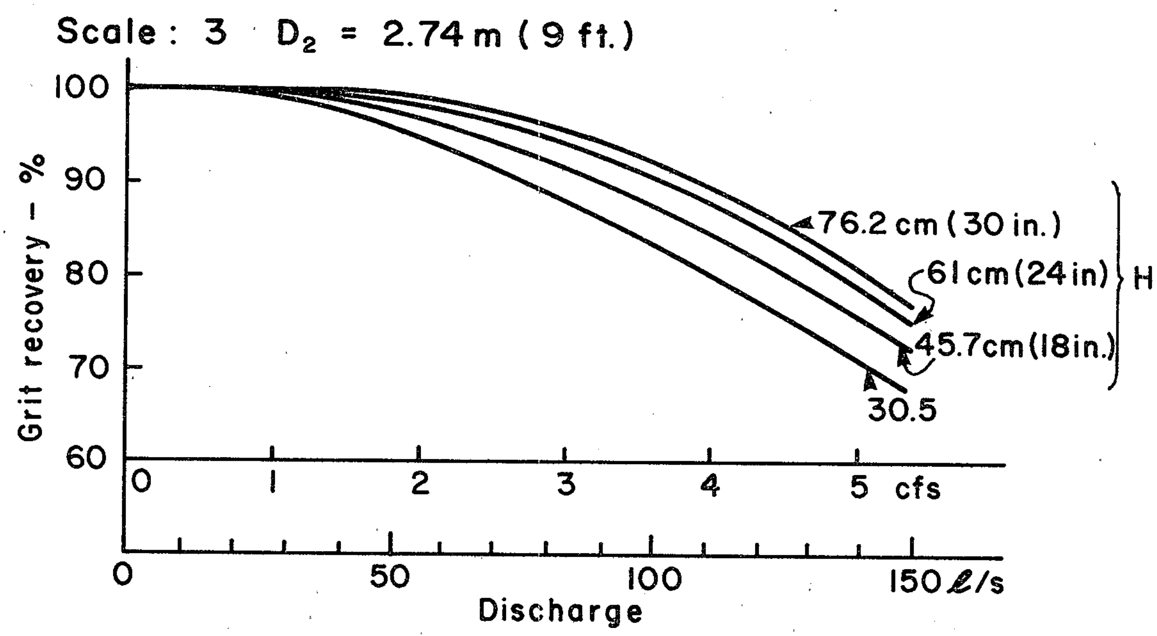


FIGURE 46 GRIT RECOVERY FOR 30.5 cm (1 ft) INLET WITH 2.74 and 3.66 m (9 ft & 12 ft) CHAMBERS

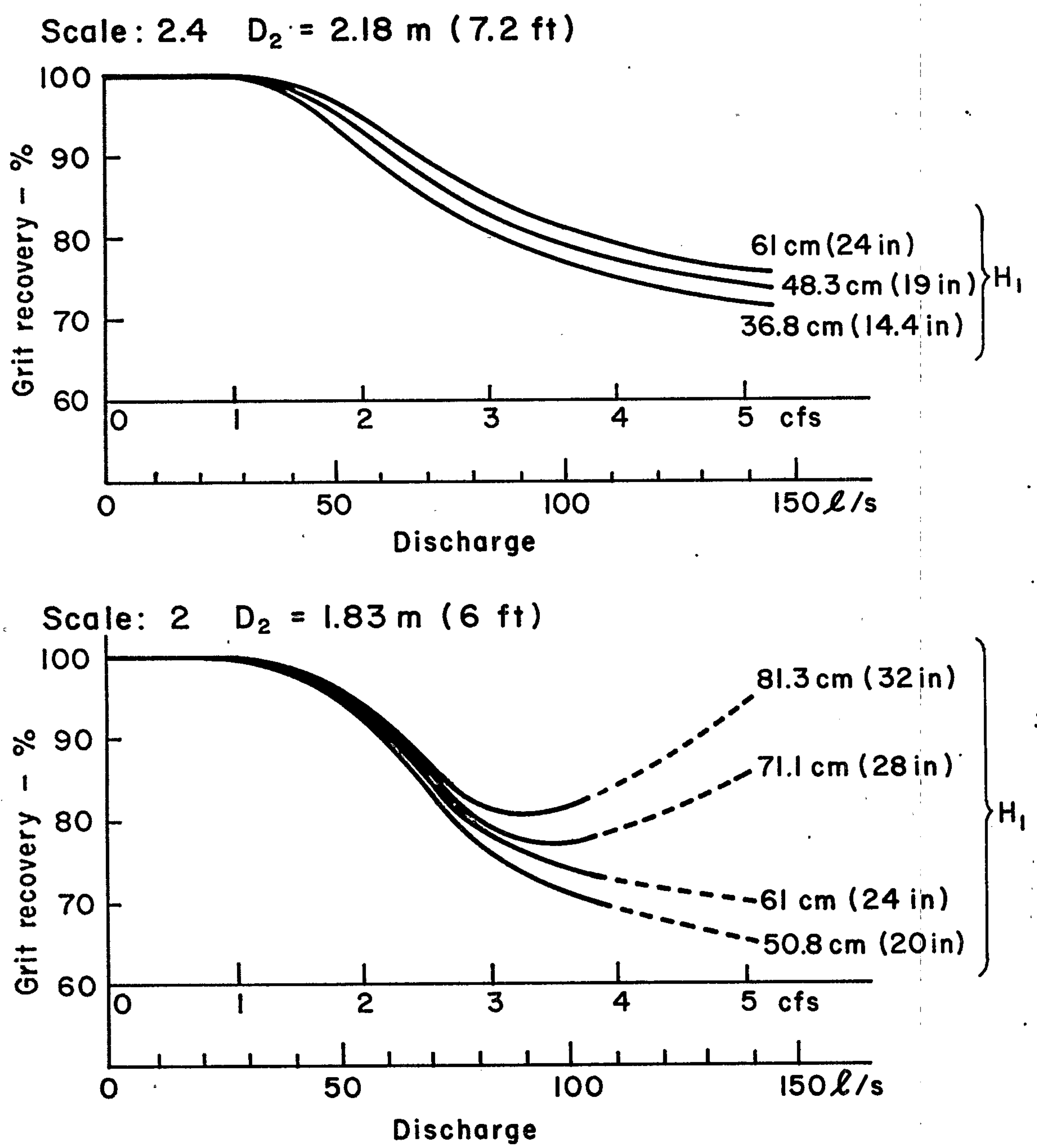


FIGURE 47 GRIT RECOVERY FOR 30.5 cm (1 ft) INLET WITH 1.83 AND 2.18 m (6 ft & 7.2 ft) CHAMBERS

of turbulence in the chamber which was interpreted as an advantage in separating the organics from the grit.

Further support for this argument was found in comparative measurements of Gilsonite, sand and pumice recoveries for a given set of conditions. It was found that the Gilsonite consistently gave lower recovery rates than the sand and pumice, although for particular tests they simulated the same prototype grit sizes. The salient difference between them was that for a given prototype grit size, the Gilsonite particle on the model was much larger than the pumice or sand.

Means available for making this scale interpretation are a function of the particles' settling velocities in still water. (See Fig. 19) However, it appeared that in the presence of the slightly turbulent flow in the chamber, the larger Gilsonite particles tended to remain in suspension longer and to be drawn up over the weir more easily. This behavior can be explained by the fact that the larger Gilsonite particles would have larger Reynolds numbers than the smaller pumice or sand particles and therefore reduced drag, since we are dealing with particle drag coefficients in the transition zone. Since the reduced drag coefficient of the Gilsonite resulted in a smaller force to convect the particle, the Gilsonite particles in motion tended to behave more like the larger lighter organic material in the prototype.

The curves for H_1 = 61 cm (24 in.) on Figures 46 and 47 were then taken for the 30.5 cm (1 ft) inlet and scaled up to three larger inlet sizes, 61, 91.5, 122 cm (2,3,4 ft) to give the recovery rates or efficiencies of the various grit chamber diameters as shown on Figure 48, Grit Recovery for 30.5 cm (1 ft) Inlet Pipe and Different Sized Chambers; Figure 49, Grit Recovery for 61 cm (2 ft) Inlet Recovery and Different Sized Chamber; Figure 50, Grit Recovery for 91.5 cm (3 ft) Inlet Pipe and Different Sized Chambers; and Figure 51, Grit Recovery for 1.22 m (4 ft) Inlet Pipe and Different Sized Chambers. Figure 52, Prototype Discharges – Range Covered by Model Tests, shows the discharge

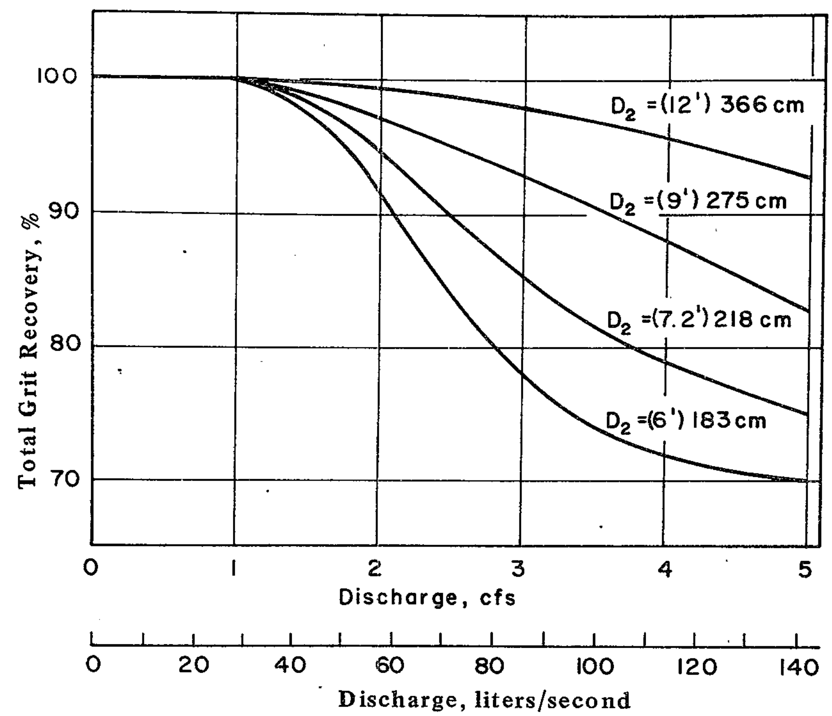


FIGURE 48 GRIT RECOVERY FOR ONE (D_1 = 1 ft = 30.5 cm) FOOT INLET PIPE AND DIFFERENT SIZED CHAMBERS

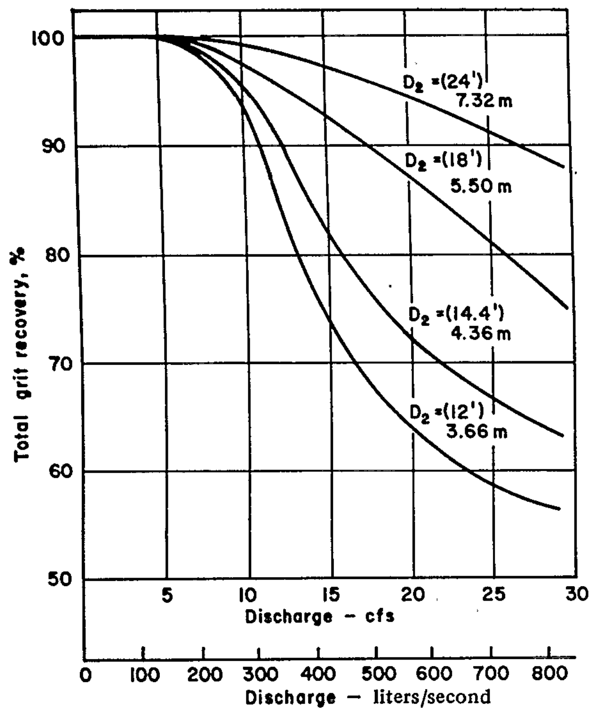


FIGURE 49 GRIT RECOVERY FOR TWO (D_1 = 2 ft = 61 cm) FOOT INLET PIPE AND DIFFERENT SIZED CHAMBERS

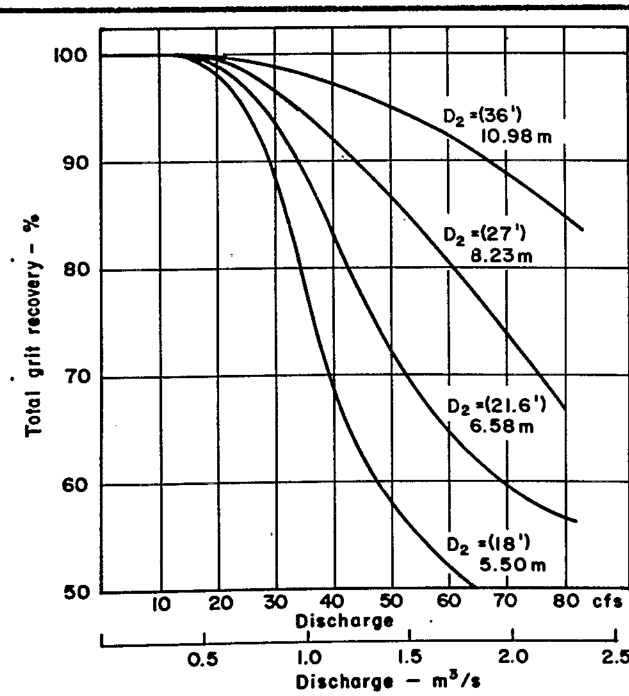


FIGURE 50 GRIT RECOVERY FOR THREE (D_1 = 3 ft = 91.5 cm) FOOT INLET PIPE AND DIFFERENT SIZED CHAMBERS

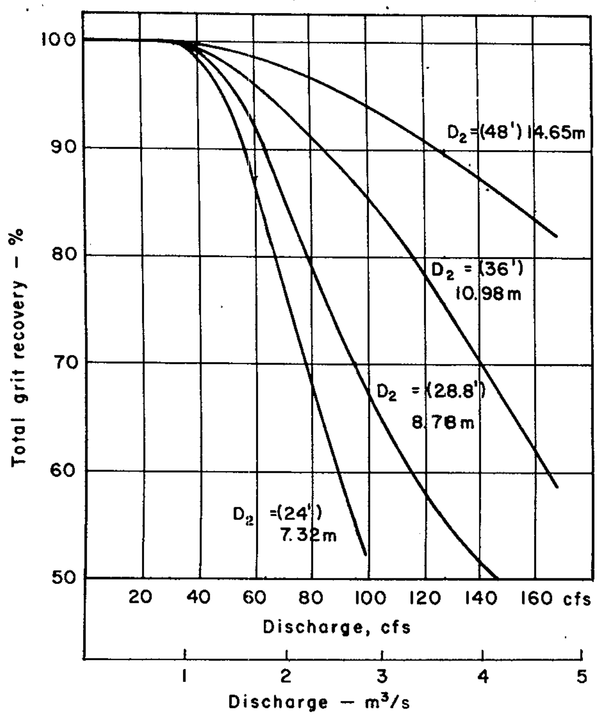


FIGURE 51 GRIT RECOVERY FOR FOUR (D_1 = 4 ft = 122 cm) FOOT INLET PIPE AND DIFFERENT SIZED CHAMBERS

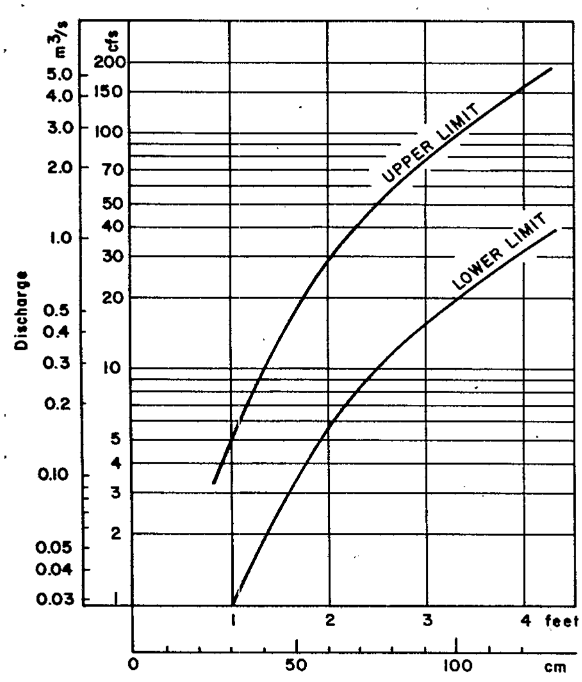


FIGURE 52 PROTOTYPE DISCHARGE-RANGE COVERED BY MODEL TESTS

range which the tests covered when scaled up to these same inlet pipe sizes.

The data presented on Figures 48, 49, 50 and 51 therefore represent the predicted efficiencies of the structures as dimensioned. However, although the figures contain all the pertinent test results, they are in a form which is not convenient for design purposes. The further analysis explained in the following section attempts to generalize this information over the complete range of applicable inlet pipe sizes, presenting it in such a way as to make it readily usable for design purposes.

Design Curve Development

As mentioned previously, the weir height equal to twice the inlet dimension was retained to allow reduction of the test data to a usable form. Then it was necessary to eliminate another variable to have manageable design curves. Particular recovery rates were selected, and the corresponding relations between discharge, and chamber diameter were plotted. This data also included the ratios of weir height to inlet diameter, then inlet diameter to chamber diameter, meaning that all of these elements were defined.

The recovery rates selected for design were 95 percent, 90 percent and 80 percent. It was felt that 95 percent represented about optimum operating conditions, whereas 90 percent would be acceptable for higher but still normal operating discharges. The 80 percent value was retained as likely the lowest recovery that would be desirable for maximum discharges.

The first step in constructing the design curves, for example, 95 percent was to pick off Figures 48, 49, 50 and 51 the discharges where the 95 percent line cut the various D_2 lines. Their values were plotted on Figure 12, Chamber Diameter for 95 percent Recovery and $H_1/D_1 = 2$, and a smoothed set of curves drawn to fit the points. This gave figures for the even foot sized inlet dimensions, so values for the half-foot sizes were interpolated and drawn individually. The same procedure was followed for the 90 percent and 80 percent recovery rates resulting in Figure 13, Chamber Diameters for 90 percent Recovery and $H_1/D_1 = 2$; and Figure 14, Chamber Diameters for 80 percent Recovery and $H_1/D_1 = 2$.

Conclusions

1. A flat floor concept of swirl concentrator grit chamber was developed but found inadequate over wider ranges of discharge. At lower flows, deposits would likely be a serious problem.

2. A conical floor concept was then developed to a satisfactory form adaptable over a wide range of sizes.

3. A generalized design procedure has been defined for dimensioning the swirl concentrator as a grit chamber with this conical floor concept.

4. The Lancaster application with the 30.5 cm (1 ft) inlet sewer, discharge range from 42.5 l/s to 141 l/s (1 to 5 cfs) and optimum operation for 56.6 l/s (2 cfs) would require a chamber diameter, D_2, of 183 cm (6 ft) as found on Figure 51. A possible layout for such an installation is shown on Figure 28.

5. The general case using a 61 cm (2 ft) inlet sewer, and discharge range of 85 to 425 l/s (3 to 15 cfs) would need further definition of the design discharge. Depending on the shape of the particular daily hydrograph, the design discharge could vary, for example, from 283 to 368 l/s (10 to 13 cfs). From Figure 37 the chamber diameter, D_2, would be 3.05 to 4.27 m (10 to 14 ft) respectively.

REFERENCES

1. Meyer-Peter, E. and R. Muller, *Formulas for Bed-Load Transport.* Proceedings I.A. H.R. Second Meeting Stockholm, 1948.
2. Einstein, H. A., *The Bed-Load Function for Sediment Transportation in Open Channel Flows.* U.S. Department of Agriculture, Technical Bulletin No. 1026, September 1950.

APPENDIX B
GRIT CHAMBER FOR SEWAGE TREATMENT PLANT *

I The Grit Chamber and Its Functions

The purpose of the grit chamber is to remove the large amount of insoluble mineral matter, which has been mixed with the sewage, before the organic putrescible material has time to settle out. This decreases the amount of sewage to be treated and also decreases the danger of clogging pumps, while, at the same time, it aids the putrefaction process.

Grit removal is done chiefly mechanically in settling chambers. The grit, which is generally dragged along the bottom of the pipes is able to settle out by means of cross-sectional expansions at lower velocities. It is then collected in a lower chamber which is cleaned out from time to time.

The difficulties in finding a perfect solution to the complete removal of grit in sewage through sedimentation are as follows:

1. In order to separate the mineral matter from the organic matter in the sewage different rates of descent are used, but often the difference is only slight and sometimes there may be none at all.

2. The organic matter, being sticky, often clings to the grit and must be removed before the grit settles out.

3. Both the amount and composition of the sewage, from which the grit is to be removed, fluctuate with respect to time of day and amount of precipitation.

4. The usable area of the settling chamber fluctuates as the grit which has already settled out is cleaned out at various intervals.

5. The flow through the settling chamber is uneven due to temperature changes in the sewage and abrupt expansion at the entrance.

Therefore a practical grit chamber must satisfy the following conditions:

a. The grit must be as clean as possible and have a kernel size of 0.5 mm to 0.2 mm.

b. The inside of the grit chamber should be as free of equipment as possible in order to simplify its construction and maintenance and to prevent clogging.

c. The grit chamber should be near a low flat area and take up as little space as possible. Increasing its depth increases its cost.

d. It should be possible to remove the grit dry during the operation of the chamber.

e. It should be possible to remove it with simple machinery so that there is no foreign equipment disturbing the plant's operation.

II The Best Known Grit Chambers

Even before the turn of the century settling tanks with sewage running through at low velocities were used for grit removal. Fruhling[1] was probably the first to point out the importance of maintaining a sufficiently constant rate of flow in the settling chamber so that only the mineral particles remained and the organic material would be carried on through the treatment plant. The first practical structure in accordance with these principles was the grit chamber in Essen, Germany built by Imhoff. This chamber had a long slightly sunken chamber containing a steplike passage from the inlet channel to the outlet channel.

A pipe with pores, which were kept closed, was built underneath the deepest section of the floor. Both ends of the grit chamber had to be closed off when the settling chamber was full. The water was then drained off through the openings in the pipe. According to Imhoff, the sectional area of the grit chamber must be large enough for a constant average rate of flow of 0.3 meters/second (1 fps).

In order to maintain a constant rate of flow in a chamber with a flat bottom and perpendicular walls the amount of water must increase exactly linear with the height of the water. What cannot be gained by raising the water level must be gained partly by the use of more chambers and partly by the increase in the width upwards of the grit chamber channel. Two chambers are necessary in order to remove the settled sand so that one can be cleaned while the other is still in use. The second chamber is also used to control storm flow which keeps the area of the grit chamber small.

Correct dimensions for the grit chamber in this type of construction creates a difficult problem to solve. The grit chamber is either too small when the settling chamber is full or

* Abridged and Edited from the Archive for Hydraulics 1942; by H. Geiger, Dr. of Eng.; Translated for the American Public Works Association by Mrs. Patricia Ure Petersen.

too large when it is empty. These dimensions are based on the smallest daily flow which is even smaller at night and during long periods of drought, especially during the summer. This creates a heavy sedimentation of organic material which turns the grit chamber into a putrefaction chamber with sewage flowing through it. The collection chamber was finally separated from the settling chamber since the use of several chambers did not even out the disturbing influence of the change in usable size in the collection chamber. This has the disadvantage that the sewage no longer flows through the collection chamber. The separation effect is now greatly impaired as the organic materials which stick to the grit cannot be cleaned off.

Long grit chambers are often difficult to accommodate and are costly to construct because of their considerable size. The equipment used in cleaning them out becomes more expensive. In shorter, deeper grit chambers there is the danger of heavy organic sedimentation during smaller flow periods as the cleansing action on the bottom decreases because of the uneven water distribution.

With the above difficulties in mind, grit chambers were built so large cross-sectionally that most of the heavy organic particles settled out with the grit. Separation took place mechanically using special equipment. This was done either by blowing air in on the bottom or by using a circular scraper. This can be done in the settling chamber. If the blowing in of air took place while the chamber was in operation there was the danger that the fine grit would be carried upward on the air stream and finally arrive at the exit.

Long, extended grit chambers with separate collection chambers and overly large (oversized) settling chambers were first developed by Eddy in America. The grit was removed from the settling chamber by means of suction hoses which were led away over the layers of sand and hung on movable carts. Suitable, durable suction pumps had to be used and the rate of depreciation was great. Grates with bar separations of 10 to 15 mm were placed in front of the grit chamber to prevent the pumps from clogging. These bars were cleaned mechanically.

In order to decrease the amount of space needed by the grit chamber and to facilitate the cleaning and removing of the sand, it was obvious that the length of the grit chamber with oversized settling chambers had to be limited and therefore it had to be deepened, as the danger of heavy organic sedimentation existed in the long grit chamber too.

The Dorr grit chamber uses scrapers for later separation of the grit and organic matter. Sewage is led into a square settling basin with a flat bottom. Here there is a rotating scraper with numerous blades and removable arms. The deposited material is scraped along the floor toward the outside and here, on one side, it is caught up by a second scraper moving back and forth. This then conveys the material up on a sloping plane. The heavy organic material which has been deposited is separated at the same time. Naturally this procedure means cumbersome and costly equipment, which needs a great deal of attention as they work continuously in sand and water. There is also a large consumption of energy.

The direction of flow in the above grit chamber is horizontal and is therefore perpendicular to the rate of descent, so that the settling material describes more or less diagonal paths. Blunk lets the sewage travel from bottom to top against the direction of descent. In this way, all the material which has a rate of descent faster than the rate of ascent of the sewage falls slowly to the floor. The material with the slower rate of descent is carried on upward. By controlling the rate of ascent of the sewage the grit is kept on the bottom. In putting this idea into practice, the sewage is next led downward all at once inside a round fountain (well) with a funnel-shaped bottom and then it is forced to rise again slowly. Individual ductlike partitions of different heights are built concentrically arranged. These act as weirs which maintain a constant rate of ascent that is less than the rate of descent of the smallest grain of grit to be collected. The settling grit, still mixed with heavy organic material, collects on the tip of the funnel. Here air is pumped in to remove organic material again before the clean grit mixed with wastewater is pushed up by means of a compressed air pump. A rotary must be installed just under the lowest water level in order to prevent retention of floating particles in front of the grit chamber. In this way the grit chamber need only be measured for the highest amount of sewage less the amount which flows over the rotary. There is, however, a danger here that some of the fine sand will be carried along over the rotary during greater periods of flow.

III The Round Grit Chamber

New structures were developed from the simple square sedimentation tanks with manual cleaning. These new structures, although they functioned better, became more and more complex. This was due to the desire for a minerally clean sand which should settle out independently of the change in amount of sewage and amount of grit already settled in the collection chamber, and the desire for a small structure which could be cleansed mechanically. The author (i.e., Geiger) has attempted to develop a grit chamber which would more than satisfy these conditions and yet would remain simple in structure.

1. Hydraulic Basis. It is a known fact that loose material settles on the inside of curves during water flow. The cause of this is not due to a decrease in the rate of flow on the inside shore, as was often assumed, but rather just the opposite is true; that is, by taking an even cross section, we find that the velocities are the greatest on the inside of the curve. An ideal rate of flow in a smooth, eddy-free current is given by the equation:

$$v = \frac{C}{r}$$

This has been proven by Boss, basing his proof not only on the "Potential Flow Theory," but also on the Bernouilli Law of Energy.

The constant C can be found by the following function:

$$Q = \int_{R_1}^{R_2} t \cdot \frac{C}{r} \cdot dr$$

The following results if we assume a constant height of the energy line for the entire current as is stated by:

$$\frac{v^2}{2g} + t = \frac{v_0^2}{2g} + t_0 = H$$

H represents the elevation of the *energy* contour (line) of the undisturbed parallel motion and $v = C/r$.

So that the depth of the water becomes:

$$t = H - \frac{C^2}{r^2 \cdot 2g}$$

and with that the entire amount of sewage:

$$Q = \int_{R_1}^{R_2} \left(H - \frac{C^2}{r^2 \cdot 2g}\right) \cdot \frac{C}{r} \cdot dr$$

so that the constant C can be determined from the following:

$$Q = H \cdot C \cdot \ln \frac{R_2}{R_1} + \frac{C^3}{4g} \left(\frac{I}{R_2^2} - \frac{I}{R_1^2}\right)$$

with the values for Q, H, R_2 and R_1 already given.

The equation has unlimited value for curve currents only at the curve vertex as a complete circle is not present. We have had good correlation between actual and calculated values in models with open channel curves and flat bottoms except for narrow strips near the walls. It can be seen from the above expression for the water depth "t" that the water surface contour in a curve current does not form part of a "rotation paraboloid" curved downward, as is often assumed, but rather it is curved upward and represents a part of the surface of a "Rankin individual eddy." The diagonal slope inward creates a crosscurrent in a flow subjected to energy and friction loss. Because of the friction of the water, particles on the bottom and especially the loose material, are delayed so that the diagonal slope becomes too great for them here. They are therefore pushed inward with a greater velocity by the neighboring particles. In the same way water particles on the outside wall are constantly being slowed and therefore forced downward. This action creates a crosscurrent which runs down the outside wall along the bottom toward the inside and eventually along the inside wall up again. In this way the faster particles present are able to travel outward, where the flow disperses upward, and there is no closed current. It is common to call the entire flow, consisting of the lengthwise and crosswise currents, a spiral current.

Hinderks had already suggested using this spiral current for sedimentation plants. As far as is known, no use has been made of his suggestion. It is easy to see why the use of these principles in sedimentation tanks promises little success. The force of the spiral current which is to be used to aid the sedimentation process, ignoring the slight differences in wall surfaces, is entirely dependent on the cross slope which is determined by the equation:

$$J = \frac{v^2}{gr}$$

This calls not only for a curve radius as small as possible but most of all for an adequate rate of flow. In sedimentation plants there must be a current as smooth and eddy-free as is allowed considering the economical size of the basin, so that the sedimentation process is not disturbed.

Besides, the spiral current which is to be used runs not only on the outside of the curve from top to bottom and along the floor toward the inside, but unavoidably it also runs up the curve again even though somewhat slower. In sedimentation plants where all depositable material is to settle out, the majority of the lighter organic material, with a rate of descent less than the rate of the upward current, would of necessity be carried upward again, and, therefore, not settle out, providing they do not stick together. It is of little use therefore, to force the sewage through such a winding spiral in order to precipitate all depositable material as Hinderks had in mind. The effectiveness is still less than in normal sedimentation plants. By comparison, in grit chambers where adequate rate of flow is required so that the heavier organic material does not settle out with the mineral particles and where only grit is to deposited, one can successfully use this effect of the curve. It would not do to use the suggested form simply as a grit chamber; that is, the form as suggested by Hinderks for a sedimentation plant, where the collection chamber is connected by a continuous slit in the ceiling near the inside wall to the deposition chamber lying above it. As has been mentioned, heavy deposits of organic material are unavoidable in those types of grit chambers with separate collection chambers with no flow-through. On the other hand, the rinsing of the grit by the current again later on must be avoided.

The author, after careful testing of all possibilities, has arrived at the simplest and most practical solution. The collection chamber is arranged inside a channel curve (elbow) with a small radius. In this way the disadvantageous separation of the settling chamber and collection chamber is avoided due to the omission of the inside channel wall at this point. The basic form, which must remain simple for practical reasons, was attained by leading the water to be treated into a circular chamber tangentially and after flowing through a central angle of 180°, flows out again through a wide opening in the wall. The floor is funnel-shaped to aid the spiral current movement of the grit inward. At the same time this floor allows for a collection chamber which is large enough for the grit.

The expected course of the current in connection with this is diagramed in Figure 53, Schematic View of Flow in a New Type Grit Chamber. A plane of separation is created by the sharp edge at the passageway from the inlet to the circular settling and collection chambers. Otherwise the velocity of one of the particles streaming around the edge would approach infinity as has been shown by Helmholtz. This plane of separation can best be explained as a crowd of threads of eddies which periodically become eddies. This surface separates the actual circular current, which keeps the same approximate width from the eddy with perpendicular axis which is created inside. After the current has traversed the curve it flows out again over the outlet notch.

Despite the absence of the inside wall the current in the curve must run its course to the boundary layer just the same as a normal curve current, so that the rule $v = C/r$ and the other equations already mentioned are also valid. The water surface rising toward the outside is curved concavely upward. The position of the surface of the water in the vortex must be calculable with sufficient accuracy after the constant C has been determined. Even the spiral current must occur undiminished in spite of the absence of the inside wall as it is created by the friction of the water particles on the outside wall and the floor. Not only is the movement of the

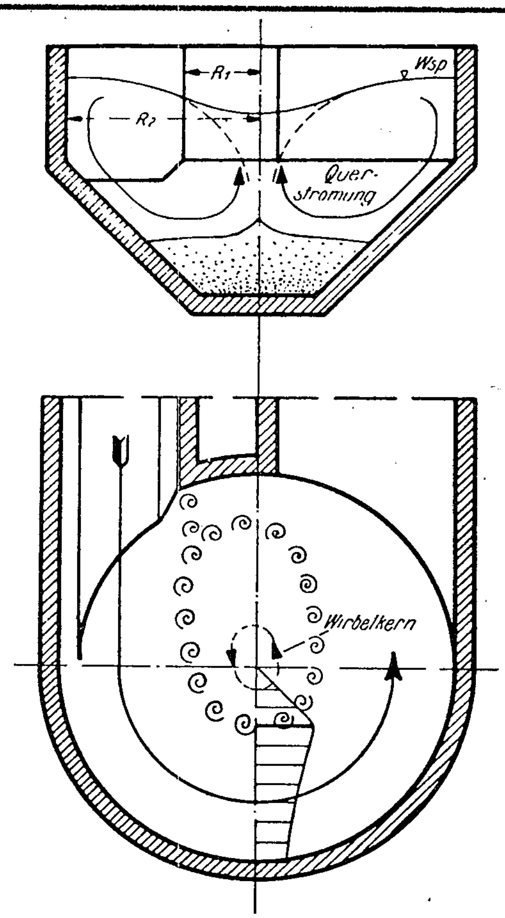


FIGURE 53 SCHEMATIC VIEW OF FLOW IN A NEW TYPE GRIT CHAMBER

loose material in the spiral current aided by the funnel shaped floor, but, because of the water depth which is increased, and the removal of the friction on the inside wall, there is an increase in the water velocity toward the inside.

However, in the region of the eddy, in the so-called core of the whirlpool, the equation $v = Cr$ is valid. The water surface here appears as if in a rotation-paroboloid-shaped container which rotates on a perpendicular axis.

Although no current in a rotating container can develop in radial planes after inertia has set in, a crosscurrent inward does develop in connection with an eddy due to the friction of the water particles on the floor. This is due to the fact that, as in the curve current, the diagonal slope is too large for the slowed water particles. For that reason they are pushed downward toward the center by faster particles, and there, in the center, an ascending current develops which enables these particles to travel outward.

Since the water content of the eddy must be assumed approximately constant, a circular current develops, which, together with the rotating current, forms a spiral current. The diagonal slope in connection with the eddy decreases to the point of zero toward the center, contrary to the diagonal slope in the flow curve which increases toward the center, so that only a weak crosscurrent develops, which peters out toward the center.

Rohr had already observed this in water currents in harbor basins but did not search for the cause. These investigations also show how loose material from a current flowing along a level floor pushes through the surface of separation into the eddy and is pushed by it toward the center.

The crosscurrent created by the curve does not curve upward because of the absence of the inside channel wall but rather runs through the eddy vortex of the plane of separation, even though a bit delayed. This course of flow consisting of a curve current and an eddy is shown schematically in Figure 1. The course continues in the rectified crosscurrent which forms the eddy here, so that a spiral current is created over the entire radius of the circular settling and collection chambers. This effectively aids the sedimentation of grit which is pushed together along the bottom toward the center, helped along by the slope of the floor. In this way the grit from the sewage which is near the floor reaches the region of the eddy quickly and there it is held in place.

2. Basis for the Experimental Model

a. Description of the Model. In order to develop a workable grit chamber a model was built which relied heavily on relationships and conditions in actual treatment plants. The model was built as large as possible in the experimental channel at the Technical Institute in Karlsruhe. A circular duct was built onto the channel in order to exclude the disturbing influence of temperature differences. Then a finely graded regulating centrifugal pump was switched on to the duct and this pump lifted the water from a collection tank at the end of the channel to a stagnation basin at the entrance. From there it flowed on a natural slope through a long open channel to the grit chamber. The water surface in the grit chamber could be regulated in the usual way by the use of removable locks (blocking apparatus) in the outlet. There was a sharp-edged measuring weir with a grate used to calm the water already in place at the end of the runoff channel. The measurement of the height of the drop over the weir and of the height of the water surface in the inlet channel were taken by means of adjustable, pointed measuring rods. The amount of water and surface height were chosen with reference to the actual conditions in a southern German city.

b. Measurements and Velocities. According to what was learned from the model, the following forces determine the adherence of certain relationships between the basic measurements for the linear measurements, times and forces, the force of inertia, the force of gravity, the force of friction and the capillary force. If, along with the force of inertia, more than one of these forces occur, we are no longer able to obtain strict mechanical similarity at the same temperature by using the same fluid in nature as in the model. In the case at hand, which is concerned with an outflow in an open channel with a rough wall, the inside forces of friction and the capillary forces *vis a vis* the force of inertia and of gravity can be ignored without hesitation, all the more so as the experiment occurs during turbulence and the critical Reynolds number is exceeded by more than four times. We can expect therefore a conformity between the occurrences in the model and in nature if we use Frouds Law of Similarity which actually takes into account the effect of the forces of inertia and gravity.

A fluid must be used which is similar to city sewage with regard to physical properties under study here. As mentioned earlier, only that sedimentation process where the rate of descent is decisive can be used for the separation of mineral and organic particles. In order to arrive at the correct relationships (ratios) in the experimental model, the rate of descent of the substituted materials must so suit the model standards, that they are in a correct ratio to the rates of flow in the model. The path, which a particle makes in nature under the simultaneous effect of the rates of flow and descent, must correspond to the path in the model, i.e., it must appear in the same position on the floor as it is in reality under given conditions.

According to Froud's Law of Similarity the following equation for the relationship (ratio) of the rate of flow in nature – v_n – to the rate of flow in the model –v_m – is valid where x = measure (standard) of the model.

$$v_m = \frac{v_n}{x^{0.5}}$$

If we have u_n as the rate of descent in nature and u_m as the rate of descent in the model, it then follows that:

$$\frac{v_m}{v_n} = \frac{u_m}{u_n} \text{ and with } v_n = V_m \cdot x^{0.5}$$

$$\frac{v_m}{v_m \cdot x^{0.5}} = \frac{u_m}{u_n} \text{ or } u_m = \frac{u_n}{x^{0.5}}$$

If we take an arbitrary measure for the model, i.e., x = 10

$$u_m = \frac{u_n}{\sqrt{10}} = \frac{u_n}{3.16}$$

For the experimental model with the model measure x = 10, material must be added to the liquid which has a rate of descent one-third that of the rate of descent of the grit. One realizes, therefore, that it is not only impractical to work with real sewage in experimental models, but that it is also theoretically unsuitable

From experimental work by Blunk, it has been shown that it is only possible to keep those mineral particles with a grain size of over 0.5 mm in the grit chamber because the smallest rate of descent of those borders on the largest determined rate of descent of organic matter.

c. Choice of Suitable Material. In strict adherence to the laws of similarity, a material had to be found to be used in place of grit in the chosen model with the smallest kernel size of 0.5 mm; 10 = 0.05 mm and a rate of descent of over 4; 3.16 = 1.2 cm/sec, while the rate of descent of the substitute organic material could not exceed 1.3 cm/sec. Since the size of the grain cannot be normally reduced according to scale in experimental models because such a fine mud can no longer be handled in experimental channels, practical considerations limited the corresponding reduction in the rate of descent. Lignite slack was found to be the best suited substitute for the grit for use in the model and sawdust was used as a substitute for the organic material. When the kernel size of the lignite chosen was over 1 mm the rates of descent of the materials to be separated bordered on each other. Wet lignite with a kernel size of 1 to 1.5 mm has a rate of descent of 3 to 6 cm/sec, whereas normal newly softened sawdust has a rate of descent of approximately 1 to 3 cm/sec. Moreover, the rate of descent of the wet lignite grit in the experimental model is almost exactly the rate of descent of grit with a kernel size of 1 mm in nature – 9 to 18 cm/sec (taking into consideration the factor 3.16). The experimental model corresponds to the actual relationships in a grit chamber which retain grit up to a size of 1 mm, ignoring the scale reduction of the kernel size. It could be expected that the experimental model would show support for practical use. In fact, existing plants, which shall be discussed later, have confirmed these expectations.

Since the depositable mineral and organic materials stand in a 1:2.5 ratio in normal city sewage, one part wet lignite and 2.5 parts wet sawdust were thoroughly mixed in a special container and slowly added to the water through a funnel at the beginning of the inlet channel. The entire amount of lignite and sawdust which was added in each experiment corresponded approximately to the daily load of depositable material in the sewage in the treatment plant which was the basis for the experimental model. Room for the grit collection was determined for this amount assuming a daily mechanical cleaning. In order to shorten the duration of the individual experiments, the addition of the material had to take place much more quickly than what corresponded to the correct measured time for the model. This was a circumstance which could only favorably affect the results of the experiment with respect to reality, as less time remained to clean out the heaviest organic matter which had settled out.

d. Determining the Degree of Efficiency. The efficiency of grit chambers cannot be determined by one individual percentage table. The unavoidable dependence on the changing amount of influent according to time interval must be taken into account.

Even the ratio of deposited grit to added grit does not give us satisfactory information, but rather it must be supplemented by the ratio of the amount of organic material unintentionally retained to that amount which was added. A light grit is to be settled out by means of oversized settling chambers which is all contained in the sewage, if one accepts a corresponding sedimentation of organic material at the same time. Without additional mechanical treatment of the grit it is only practical, within a narrow area, to have 100 percent of the mineral material and as close to 0 percent of the organic material as possible deposited.

A perfect solution to the problem of grit sedimentation with a heavy changing rate of sewage is only possible by means of grit chambers with oversized settling chambers and subsequent mechanical removal of the heavy organic material which settles out at the same time. Finer grit can be retained in the grit chamber while the heavier organic particles must be removed by mechanical means such as agitators or condensed air conveyances.

In the experiment the water which flowed out was led below the measuring weir over a fine wire sieve which kept back the remaining loose material. This remaining amount of wet sawdust and lignite was determined after every experiment according to volume, and always set in a ratio to the constant volume of lignite and wet sawdust which had been added originally. The rate of flow according to time interval was changed from experiment to experiment in close dependency on the actual conditions of the smallest drought flow to the largest storm flow. The percentage, which was applied over the rate of flow, of the amount of volume of lignite and sawdust which had been sieved out in the runoff always gives a pair of lines which show the effectiveness of the grit chamber. These lines give information necessary to the perfection of the grit chamber. There is an unavoidable inaccuracy inherent when determining the amount of material strained according to volume. This must be accepted as it is not feasible to determine through weights, for both lignite and sawdust soak up and emit water quickly and their specific gravity in the wet state is near 1.

3. *Description of an Experimental Model.* As with any new type of building, a great distance had to be covered from the initial idea to the finished workable product. Figure 54, Cause of the Course of the Current in a Model Grit Chamber, shows the last form of the model. The water to be cleansed of grit

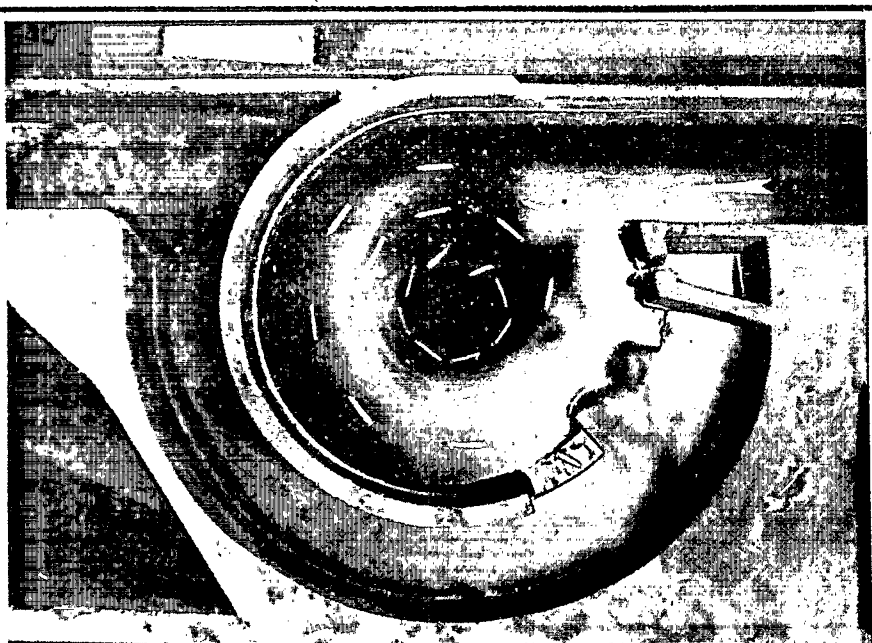


FIGURE 54 CAUSE OF THE COURSE OF THE CURRENT IN A MODEL GRIT CHAMBER

flows tangentially from the inlet channel which is divided into a narrow dry-weather channel and a wider channel for rainy weather lying above it, into a cylindrical chamber with a funnel-shaped floor, which serves simultaneously as a sedimentation chamber and a collection room. This chamber is divided the same as the inlet channel, a dry-weather chamber with a small diameter and a larger cylinder lying above it to control the storm flow. After entering the settling chamber the water must flow around a curve of more than 180° along the wall before it can run off through a cut in the outside wall. As the water to be treated enters the grit chamber some of the heaviest mineral matter which is near the floor slides immediately on the funnel-shaped floor into the collection chamber and some settles down due to the slightly reduced rate of flow. Figure 55, Model Grit Chamber Showing Sediments, shows this process, looking down onto the top of the model. In order to see the lignite which was substituted for the grit, the floors of the channel and the grit chamber were painted white. Shortly before the picture was taken we added a sizable amount of lignite grit to the entrance of the channel.

The paths of the fine grit which settles as the water runs through the curve could not be seen due to their small size at the present rate of flow. In order to show clearly the effective flow procedures here, waving flags were fastened on to show the current on the bottom. The course of the surface current was shown by sprinkling paper shreds on the surface of the water. Figure 54 shows the direction of flow as seen from above during lesser rates of flow according to time intervals, while Figure 56, Course of the Current in Model Grit Chamber, shows the same during greater rates of flow. Figure 57, Side Views of Course of Current in a Model Grit Chamber, gives us a side view of the inner room of the grit chamber.

Along with the current which runs concentrically on the surface, a powerful crosscurrent, the so-called spiral current, can be seen, running along the outside wall downward and along the bottom inward as it appears in open-curved channels. Since this crosscurrent depends on the average velocity, the flags point, for the most part, toward the center (c.f. Fig. 56 which has an average velocity in the inlet channel but a larger flow as compared with Fig. 54) so that a constant settling effect is produced. Not only is the grit being extraordinarily aided in the settling process by this spiral current, but, once it has settled, it is also being constantly pushed toward the center. In this way the sand particles cross over the plane of separation between the curve current and the eddy present inside, are removed from the sewage which flows onward and are deposited in the tip of the funnel in the chamber. The continuous circular flow, which reigns in the bottom part of the funnel washes away the lighter particles clinging to the grit. These rise slowly in the center due to the spiral current, and are finally torn out into the area of the curve current by small wandering eddies, which rythmically dissolve at the tapered mouth of the inlet and so are carried away again by the sewage.

Determining the Most Suitable Shape and Measurements

Separating walls were built in the grit chamber between the settling room and the collecting room in the first model. Later on we tried to increase its effectiveness by adding conducting walls at the inlet and the outlet. This only showed us that walls of any kind produce unwished for and unexpected eddies and whirlpools which disturb the settling process. If a separating wall between the collection chamber and the settling chamber was built, lighter materials settled out due to the fact that the cleaning out process was stopped. It was further shown that to obtain a strong circular current it was best to build the inner chamber of the grit chamber as smooth and as round as possible.

The position and type of outlet were also experimented with as an outlet which functioned as smoothly as possible greatly influenced the effectiveness of a grit chamber. The outlet was systematically shifted from a position which continued the direction of the inlet channel on the other side further and further toward the direction of flow. The best results were reached with an outlet whose final edge falls with its axis parallel to the inlet and whose width does not exceed 60°. In this way an adequate length of bend in the

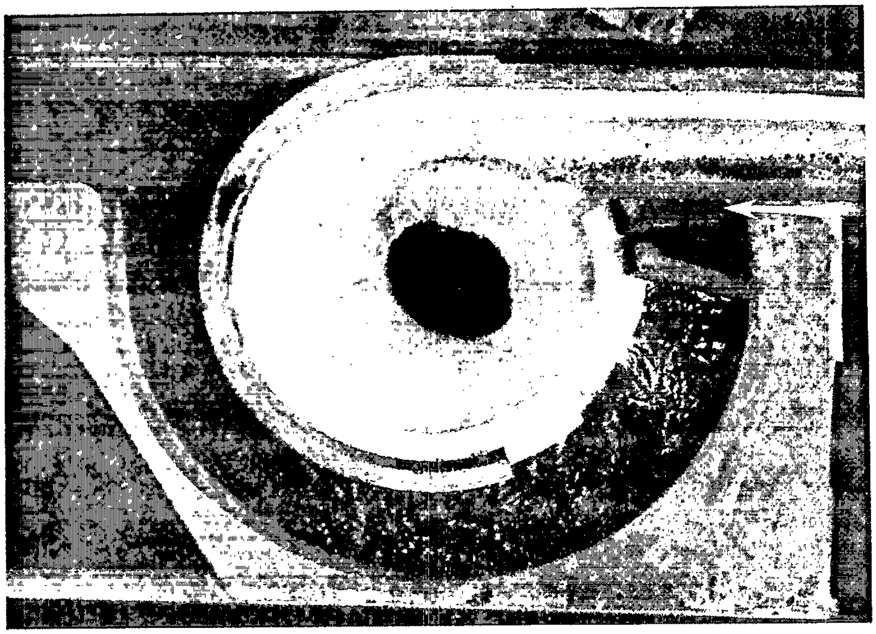


FIGURE 55 MODEL GRIT CHAMBER SHOWING SEDIMENT

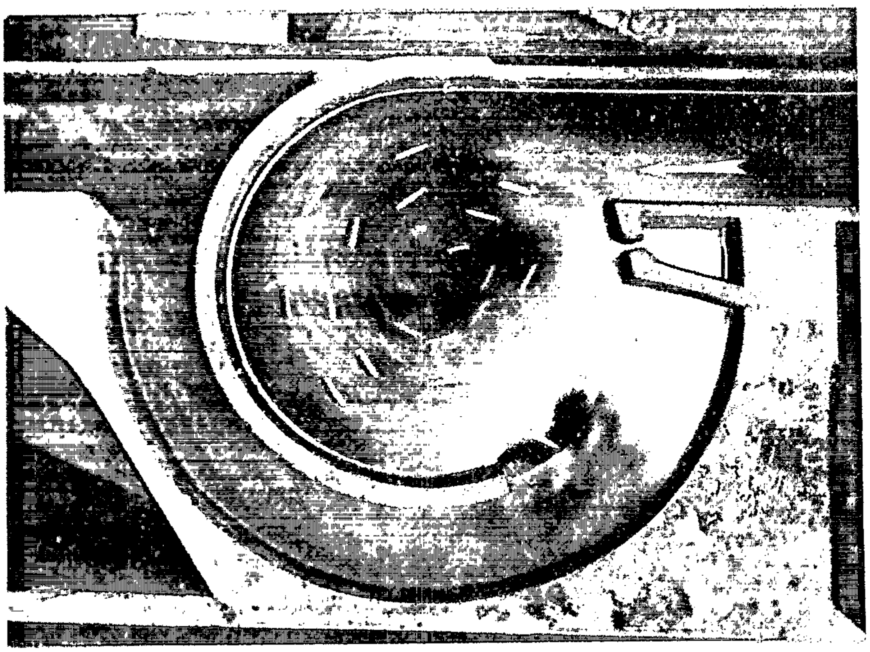


FIGURE 56 COURSE OF THE CURRENT IN MODEL GRIT CHAMBER

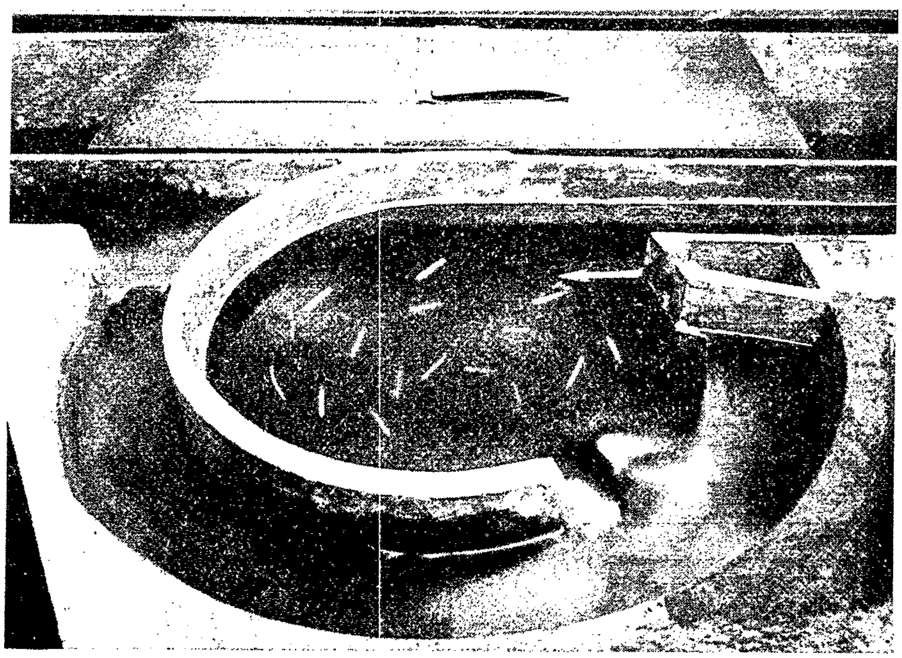


FIGURE 57 SIDE VIEWS OF COURSE OF CURRENT IN A MODEL GRIT CHAMBER

curve is obtained and there is no opposing disturbance from outlet and inlet. The velocity in the runoff may not exceed 0.5 m/sec and its bottom edge should be higher than the inlet if possible. The outlet is divided purposely into a narrow part for the dry weather flow and a symmetrical part lying above it for the rainy weather flow.

We further ascertained in which way the effectiveness of the grit chamber depends on the rate of flow and the size of the sedimentation chamber. Since the rate of flow cannot be determined unequivocally, the average rate in the inlet channel was used as a point of comparison. It revealed that the rate of influent should be approximately 0.75 m/sec and should not exceed 1 m. The ratio between the usable area in the sedimentation chamber and the amount of water added at that second proved to be a useful rule for determining the necessary measurements of the sedimentation chamber. This ratio $a \doteq J/Q$ is known as theoretical delay time in connection with grit chambers which are flowed through horizontally. In the above type of construction a value for a of 25-30 is recommended when the sedimentation chamber is not oversized. In comparison, a has a value of 50 for long grit chambers with normally sized settling chambers with the minimum length of 15 meters and the rate of flow equalling 0.3 m/sec. There is then a considerable saving in construction costs. Savings can be increased even more through compact structure.

The rate of flow and the height of the water surface were determined with respect to actual values in a large southern German city. The main collector there has a slope of 1:2000 with a diameter of 1.8 m, so that there the ratios are unfavorable as a small increase in water height corresponds to a heavy increase in the amount of flow with this small a slope. For that reason, all ratios between the rate of flow and the area of the sedimentation chamber were considered in the experiment and a higher inlet velocity was permitted with high rates of flow. These ratios were much more favorable in reality because the experiments in the model take place over such a short period of time that the current is unable to cleanse out the organic materials, as it does in reality.

A part of the heaviest organic material settles out with the sand in the center of the funnel in dry-weather periods. It can be

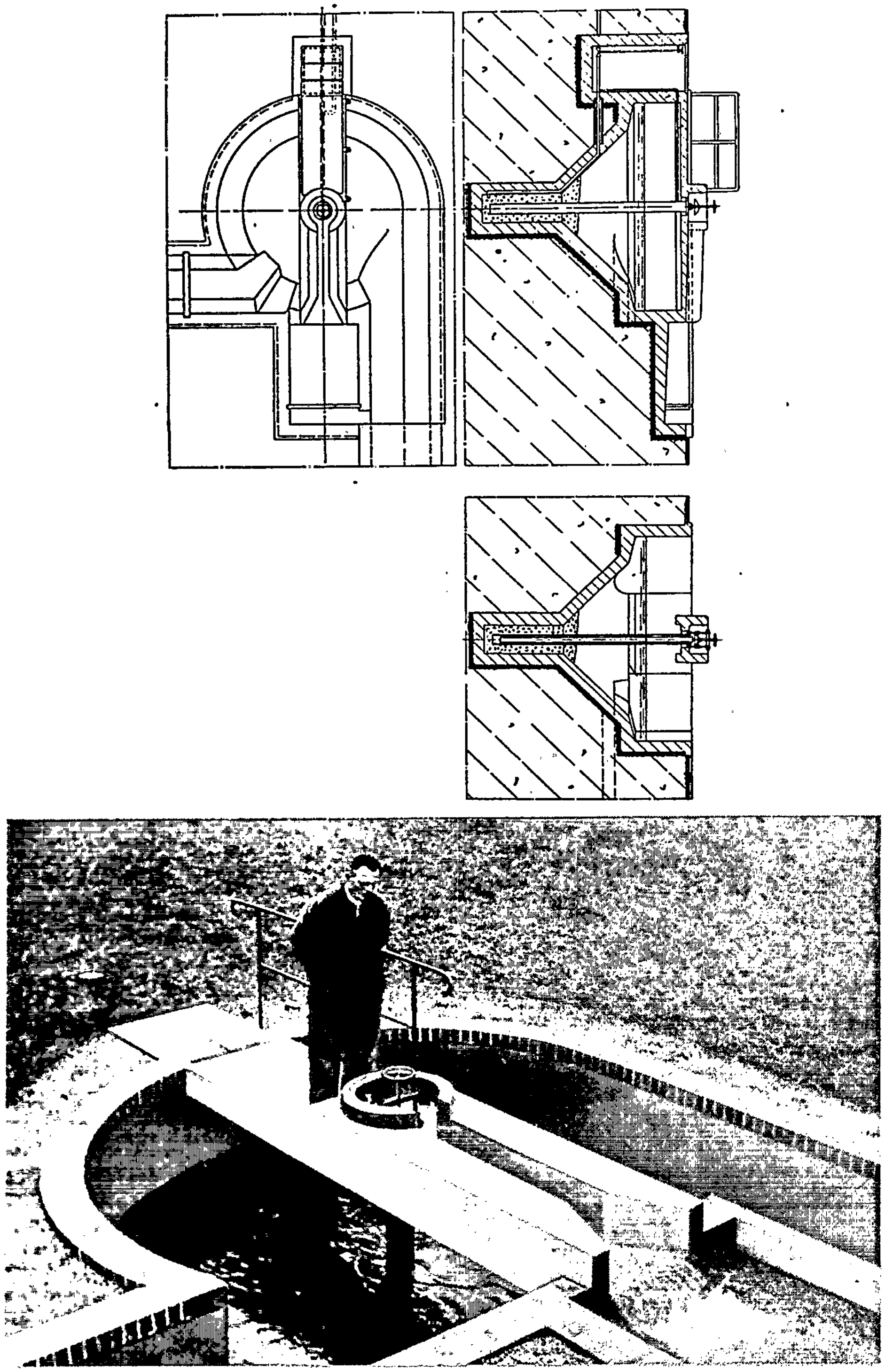


FIGURE 58 GRIT CHAMBER FOR A SMALLER CITY

cleaned out easily in practical applications by short blasts of air from the middle of the floor. This creates a gentle rolling and stirring of the settled material which, along with the spiral current, aids in the separation process without the danger of the stirred up grit reaching the outlet of the grit chamber.

A constant, slight over-measurement of the settling chamber is therefore recommended if there is a great fluctuation in the amount of water even in this type of structure. In this way, post-treatment of the grit is possible in the simplest way using the smallest amount of air because of the form of the settling and collection chambers.

4. Attempts at Practical Applications

a. Surface Current. The various models were later enlarged for practical applications. The grit chamber used here was determined as to size for the minimum amount of sewage as 125 l/sec and the maximum amount of 625 l/sec. It has a diameter of 3.9 meters and is shown in Figure 58, Grit Chamber for a Smaller City. Both the surface current and the rates of flow were shown by means of floating candles which were interrupted at regular intervals as shown in Figure 59, Course of Current in an Aerated Grit Chamber. Even though the concrete bridge which crosses over the grit chamber covers a part of the settling chamber, both the course of the current through the curve and especially the eddies which lie inside this current are more clearly recognizable here than in the model. As was expected, the current in the curve did not keep strictly to the width of the inlet channel during its course through the settling chamber but rather it widens out toward the inside

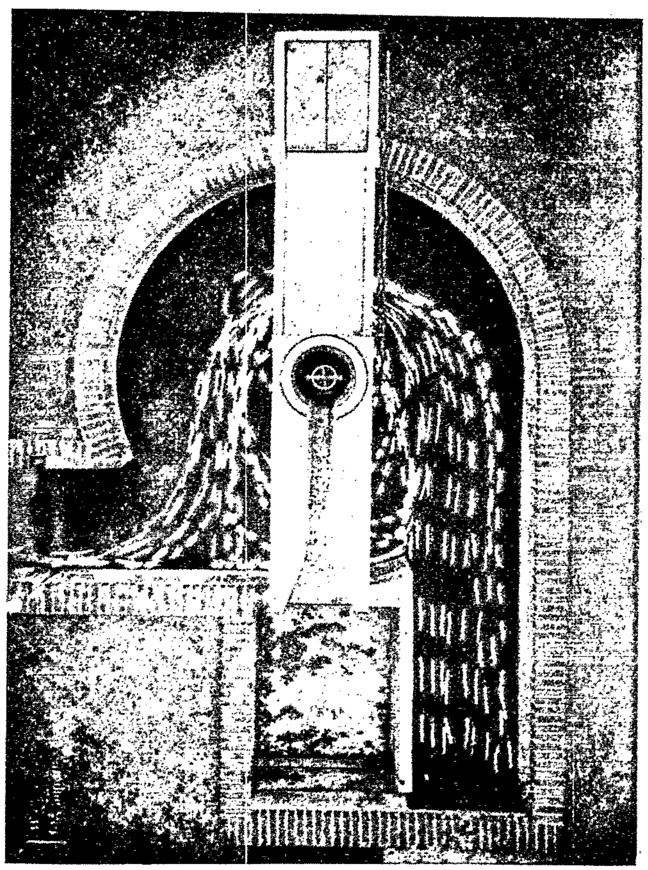


FIGURE 59 COURSE OF CURRENT IN AN AERATED GRIT CHAMBER

whereby the average velocity decreased correspondingly. The lines of the course on the surface push together toward the inside even on the surface in certain opposition to the experiments in the model and other experimental results and also in opposition to theoretical results. This phenomenom can be explained by the influence of the wind which cannot be entirely eliminated when working outdoors, but also by the fact that the fairly heavy floats used were carried inward through their own weights.

b. Profile of the Water Surface. Along with the surface current the profile of the water surface is determined in the curve. The measurements were taken by means of a tapered measuring rod and a leveling instrument in radial cross sections with angle intervals of 30° each time. In the crown (vertex) of the cross section which was the same as the axis of the concrete path, no measurements could be taken. The surface curved upward. The same hydraulic ratios are as valid here in this type of structure even though the inside wall is missing, as in a curve of 180°.

The proof of this can be found in a comparison with the calculated water surface line for a channel curve of the same measurements on the basis of the potential theory. Next the height of the energy line for the cross section and the runoff amount for the inlet sectional area are determined with reference to the water velocities taken from Figure 60. The radius of the inside wall of the settling chamber and a value decreased by about the width of the inlet channel are inserted for the radii of the curve. In this way the constant *C* can be obtained from the equation:

$$Q = H \cdot C \cdot \ln \frac{R_2}{R_1} + \frac{C_3}{4g} \left(\frac{1}{R_2{}^2} - \frac{1}{R_1{}^2}\right)$$

as being 4200/cm/sec.

From the simplified formula:

$$C = \frac{Q}{t_0 \cdot \ln \frac{R_2}{R_1}} .$$

the constant *C* would be 4250 cm/sec with the measured average water depth in the straightaway before the curve equal to 54.6 cm.

c. Properties and Amount of the Settled Grit. Figures were finally received on the cleanness and kernel size of the sand in the three different grit chambers of similar size. The grit chambers were planned for a dry weather flow of 125 to 140 l/sec and a storm weather flow of 560 to 625 l/sec and have a diameter of 3.9 to 4.5 meters. The grit deposited was almost completely minerally clean and also contained a large portion of fine kerneled grit as is shown by the following table:

Plant	I	II	III
	%.	%	%
Mineral Particles	97.0	98.5	97.5
Organic Particles	3.0	1.5	2.5
Kernel size of grit:			
Over 4 mm	6.0	2.5	3.5
4-2 mm	15.0	10.5	10.0
2-1 mm	15.5	28.0	24.0
1-0.5 mm	32.0	42.0	38.5
0.5-0.2 mm	24.5	14.0	20.5
Under 0.2 mm	7.0	3.0	3.5

5. Description of Practical Application

Grit chambers are generally cleaned out with a special air pressure pump which is useful because of its simple construction and durability.For this reason the floor of the chamber is not leveled off but rather built in the shape of a funnel with the air pressure pump (compressed air pump) put in its axis. Since the height (lift) of this pump is only equal to its immersion depth, the addition of a corresponding pump basin is most often necessary. Its diameter should be just a little larger than the outside diameter of the pump so that the settling area can be kept as clean as possible. The settled material is cleaned in the following manner before the sand is finally removed. First the stop valve in the conveying pipe for the sand-water mixture is closed before the pump is started. Meanwhile, the compressed air used in operating the conveying pump gently flows out at the bottom end of the pump pipe. A small amount of air is required for only a short period of time. It has been shown from experience that a blast of 10 minutes is sufficient for a complete cleansing before grit removal. The treated grit and water mixture flows into an individual settling basin with a runoff alongside the grit chamber by opening the stop valve. Here the sand is deposited while the surplus water is led back into the inlet to the grit chamber. In this way, traces of grit cannot get into the outlet of the grit chamber. The grit is then left to dry and loaded manually onto carts which carry it away. A water pipe is led into the pump basin bottom through which water from the city water supply line can be led before and during the operation of the pump. In this way the removal of the sand-water mixture is made easier and the material from the grit chamber, which during long pauses in grit removal, has thickened on the bottom part of the pump.

The first practical application of the new type of grit chamber for a smaller city (Villingen in the Black Forest) is shown in Figure 58. A grate with bar separation of 40 mm is built into the inlet in order to hold back large bulky material. This is cleaned mechanically. It is obvious that this new type of grit chamber is noteworthy because of its simplicity and the small amount of space it needs. It has also been shown here, that the construction costs for this type of grit chamber, including the compressed air pump, are no higher than those for the two-chambered grit chamber of usual construction.

The purification plant was started chiefly without a separated grit chamber in the fall of 1935. The sand (grit) collected in the settling basin of the grit chamber had a bright color and was practically free of organic material. The kernel size was as small as 0.2 mm and was completely odorless. Villingen is the second coldest city in Germany and for that reason uses a large amount of sand in winter. For this reason the performance of the grit chamber is of special interest. The sand which is collected is reused for spreading on sheet ice. The servicing of the grit chamber is simple and in fact is limited to operating the stop-valve of the sand conveyance. It has also been shown that there is no danger of stoppage to the compressed air pump. A rotary can be dispensed with since the sand is removed during the operation of the grit chamber.

Double layouts are used for large cities. Here the inlet pipe is divided and the chambers lie touching each other. Both the inlets and outlets are fitted with slide-valves so that they can be shut off individually. A common grate can be constructed in front of the grit chamber.

There are countless solutions with respect to different physical conditions. Figure 60, Double Grit Chamber Layout for a Large City, shows a grit chamber which serves a population of 750,000, which is the largest German grit chamber at present (1942). The grit chambers, one of which takes the sewage from the part of the city to the east of the Rhine River while the other takes the sewage from the western part, are measured for different work loads. The ratios here create great difficulties for the construction of a grit chamber which is to work perfectly. The amount of sewage from one area fluctuates between 1.48 and 6.73 m^3/sec (cubic meters) and for the other area, between 1.26 and 4.8 m^3/sec. The surface heights applied over the water amount in the inlet pipe at the entrance to the purification plant result in quite irregular broken lines due to the effect of very narrow pipes in the old part of the city from storm sewers and siphons. Unlike the usual purification plant, these grit chambers must operate a greater part of the year with a strongly fluctuating back-up from the Rhine, which can sometimes be as high as 2.9 meters. For that reason a considerable lengthening of the delay period with a similar reduction of the inlet velocity must be taken into account from time to time, especially with a strong back-up. The heaviest organic material, which has settled out along with the sand near the center of the axis of the settling chamber can be removed by corresponding blasts of air near the funnel tip before the sand is removed. If there is a large back-up and a small rate of influent, which would seldom occur, an overly large depositation of organic material can be avoided by constant blasts of small amounts of air.

In order to prevent a back-up over the top of the inlet channel from further worsening the effect of the cleansing in the settling chamber, this is arched over, which is easy to do in this type of grit chamber. In this way a further increase in the ratios between the content of the settling chamber and rate of flow at that second is prevented. This gives better results as the rate and velocity of flow

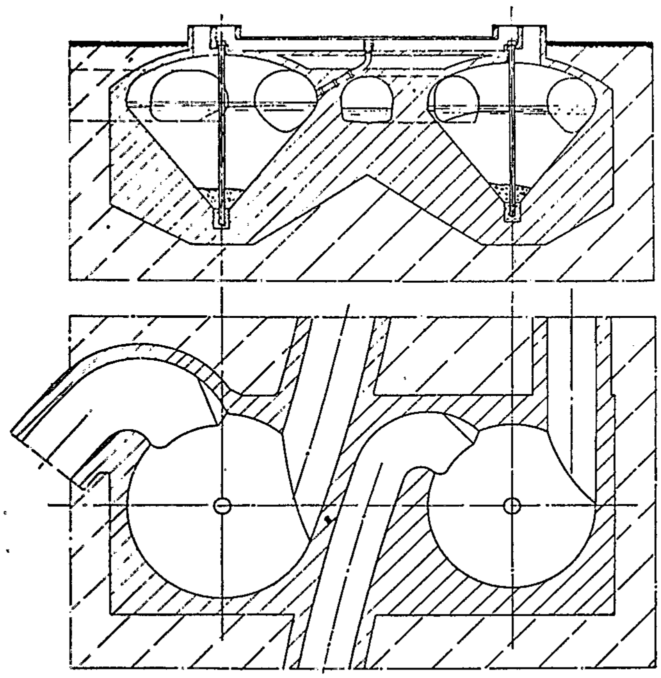


FIGURE 60 DOUBLE GRIT CHAMBER LAYOUT FOR A LARGE CITY

decrease very quickly with the increase in back-up from the Rhine. The new type of grit chamber also allows the controlling of unusual ratios. The grit is conveyed here by means of compressed air pumps. The settling chambers for the grit-water mixture could thereby be set at the surface.

Without a doubt this new type of grit chamber can be used over a wide area, due to its great simplicity, its outstanding separating ability, easy operation, and its minimal construction and operating costs.

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APPENDIX C
SCALE EFFECTS ON PARTICLE SETTLEMENT

As discussed in the main portion of the report, the appropriate modeling parameter to relate the prototype to model mathematical relationship is the Froude number, since gravity effects predominate the flow performance in this free surface flow case. This results in the expression $V_m = V_p/L_p/L_m$.

If the model to prototype ratio is $L_p/L_m = 2/1$, the expression becomes $V_m = V_p/1.414$. For example, a 0.2 mm diameter particle of sand is selected, which has a specific gravity of 2.65. From Figure 15, the particle settling velocity for a 0.2 mm diameter sand particle is 2.6 cm/sec in the prototype. In the model this corresponds to a velocity of settlement of 1.84 cm/sec or 0.0603 fps. If other materials are to be used in the model to simulate a 0.2 mm sand particle, they must correspond to a comparable settling velocity of 1.84 cm/sec. From Figure 15, Appendix A, these particles would be: sand – specific gravity 2.65, diameter 0.17 mm; pumice – specific gravity 1.35, diameter 0.34 mm; Gilsonite – specific gravity 1.06, diameter, 1.0 mm.

When settlement of individual particles occurs in a flow of water, however, each of the above particles will settle in accordance with the principle of particle settling dynamics, which relates the gravitational and viscous forces, and therefore follows the traditional coefficient of drag and Reynolds number relationship.

Assume for purposes of this example that the velocity in the flow field in the model is 0.85 fps. The horizontal motion of a sand particle 0.17 mm is approximately 0.255 fps, using an experimentally determined constant.[1]

From the same reference, the following relationship for particle settling holds:

$$\frac{4}{3}\ \pi \frac{D}{2}^{3}\ \rho_i - \rho\ \ g = \rho_D\ \pi\ \frac{D}{2}^{2}\ \rho \frac{V_s}{2}\ \rho OS\ \phi$$

this can be reduced to the following equation:

$$\frac{4}{3}\ D\ \frac{\rho_1}{\rho} - 1\ \ g = \rho_D\ V_S{}^2\ \rho OS\ \phi$$

Substituting values of D = 0.00055 665 ft (0.017 cm), $\rho_1 = 2.65\ \rho$, and g = 32.2 ft/sec^2 (980 cm/sec^2) into the left side of the equation yields the value 0.0394, thus the above equation is reduced to

$$0.0394 = \rho_D\ V_S{}^2\ \rho OS\ \phi$$

The velocity relative to the particle horizontally is $V - V_p = V_x$
where

V = the streamline velocity

$V\rho$ = the horizontal velocity of the particle

V_x = the horizontal velocity relative to the particle

Let V_o equal the actual settling velocity of the particle; thus the total velocity relative to the particle as it settles is $V_s = V_x{}^2 + V_o{}^2$ For this example V_x = 0.85 fps – 0.255 fps – 0.595 fps.

The settling velocity V_o is then obtianed by selecting a value for V_o, calcualting V_s, Reynolds No., $C_D\ \Sigma\ \phi$. For the conditions described above, V_o = 0.027 fps, which is less than the settling velocity in still water for this size particle of 0.0603 fps (1.84 cm/sec).

Similar calculations are performed to determine the velocity of settlement of the Gilsonite particle, sp. gr. 1.06, diameter 1.0 mm, which was used in the model to simulate sand particles 0.2 mm in size. Since this particle is larger, a different experimental constant S is used from reference 1. For this diameter S = 0.5, thus the horizontal velocity of the particle is 0.5 (.85 fps) or 0.425 fps. The horizontal component of fluid velocity relative to the particle is 0.425 fps. Again utilizing the above equation

$$\frac{4}{3}\ D\ \frac{\rho_1}{\rho} - 1\ \ g = \rho_D\ V_S{}^2\ \rho OS\ \phi$$

and specifying values of D = 1 mm (0.00327 ft) g = 32.2 fps^2 (980 cm/sec.^{2}) and ρ_1 = 1.06 P, the left hand side of the equation becomes 0.0084, or the above equation reduces to

$$0.0084 = \rho_D\ V_S{}^2\ \rho OS\ \phi.$$

The equation is solved by selecting values for V_0 and calculating Reynolds No., C_d (obtained from an experimental plot) and ϕ. For the conditions described above, V_o = 0.013 fps, which is considerably different than the velocity of settlement in still water.

The distance required to settle these particles can be calculated from the relationships $L = \frac{V_p}{V_o} H$

where H is the depth of flow

For sand, 0.17 mm diameter, using the velocities determined above

$$L = \frac{0.455 \text{ fps}}{0.013 \text{ fps}} H = 9.44 H$$

For Gilsonite, 0.2 mm diameter, using the velocities

$$L = \frac{0.455 \text{ fps}}{0.013 \text{ fps}} H = 35 H$$

The above calculations illustrate the scale effects of the model studies. Since the Gilsonite requires a longer distance to settle, it can be concluded that if the settlement of Gilsonite occurs in the model, better settling performance of grit in the prototype can be expected.

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16. ABSTRACT

A study was conducted by the American Public Works Association to determine the applicability of a swirl concentrator chamber to perform the functions of a grit separation and removal facility. The swirl concentrator principle was originally developed in Bristol, England, and subsequently modified and applied by the APWA to act as a combined sewer overflow regulator.

The ability of the swirl flow pattern to effectively remove solids of particular sizes or specific gravities was noted during the first study. This hydraulic flow configuration was developed and adapted to effectively remove grit from either the underflow from the combined sewer overflow regulator or from domestic sanitary sewage.

Hydraulic model studies were used to develop optimum design configurations. For an average flow of 0.084 m^3/sec (3 cfs), the diameter of the unit would be 2.19 m (7.2 ft) and 1.1 m (3.6 ft) deep. The efficiency of removing grit particles of 2.65 sg and size greater than 0.2 mm will be equal to that of conventional grit removal devices. The unit has no moving parts. Conventional grit washers and lifts can be employed.

The complete report on studies carried out on a swirl grit removal model by the LaSalle Hydraulic Laboratory Ltd. is included as an appendix.

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*Grit chambers, Design, Waste treatment, *Grit removal, Combined sewers, Swirling—separation, Sewage treatment, *Grit removal—sewage treatment, Flow rate	*Swirl concentrator, Combined sewer overflow regulation, Recovery rate	13B

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