PROCEEDINGS OF THE THIRD DREDGING SEMINAR

November 20, 1970

August 1971

TAMU-SG-71-109

CDS Report No. 148

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ACKNOWLEDGEMENT

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Miss Loretta Bayer typed the manuscript for publication.

THIRD DREDGING SEMINAR - 1970

Sponsored jointly by the National Science Foundation Sea Grant Program and the Center for Dredging Studies, Texas A&M University.

Place: Assembly Room, Memorial Student Center, Texas A&M University, College Station, Texas

Date: Friday, November 20, 1970

8:45 A.M.	Late Registration
9:15 A.M.	*Welcoming Remarks* - Dean F. J. Benson, College of Engineering
9:30 A.M.	*"Particle Size and Density Effects on Cavitation Performance of Dredge Pumps"* - Dr. David R. Basco, Texas A&M University
10:15 A.M.	*"Materials Used in the Manufacture of Dredge Pumps"*, Mr. George D. Sheehy - Thomas Foundries, Inc.
10:45 A.M.	Break
11:00 A.M.	*"Research Needs of the Dredge Pump Manufacturer"*, Mr. Charles B. Pekor - Pekor Iron Works
11:30 A.M.	*"Report on WODCON 70"* - Dr. John B. Herbich, Texas A&M University
2:00 P.M.	*"Slurry Flow in Vertical Pipes"* - Mr. Robert H. Wing, U.S. Bureau of Mines
3:00 P.M.	*"Water Quality in the Dredging Industry"* - Dr. Roy W. Hann, Texas A&M University
3:30 P.M.	Break
4:40 P.M.	Discussion - Mr. Taylor
5:00 P.M.	Tour of Facilities - Hydromechanics Laboratories

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PARTICLE SIZE AND DENSITY EFFECTS ON CAVITATION PERFORMANCE OF DREDGE PUMPS

By

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Texas A&M University

INTRODUCTION

Increased dredging depths and pumping speeds have resulted in increased concern by the dredging industry with pump cavitation. Dr. Garrison's excellent paper presented at the Second Dredging Seminar (1)* summarized the many parameters currently employed to describe cavitation characteristics of a centrifugal pump and presented as typical results the model studies of Dr. Herbich at Lehigh University (2) using silt-clay-water mixtures. These tests indicated essentially that slurries exhibited no difference in cavitation performance from clear water tests if the results are expressed in feet of liquid or dimensionless form. The primary purpose of the current study at Texas A&M University sponsored by the University's Sea Grant Program, is to determine if larger sized sand particles behave in a similar fashion. If it is found that no "scale effects" arise due to particle size or density, then it can be concluded that clear water cavitation tests can be used to predict cavitation performance for any slurry concentration of interest. Limited tests to-date have confirmed this hypothesis.

REVIEW BACKGROUND - WHAT IS CAVITATION?

Theoretically, whenever the pressure in a liquid is reduced to the vapor pressure, the liquid will cavitate (boil) and turn into its vaporous state. When this pressure reduction occurs due to dynamic effects of local velocity increases and vaporous-filled cavities are formed; it is said that "cavitation" has begun. In centrifugal pumps this always occurs on the low pressure or

* See reference list at end of paper.

suction side of the impeller. The effects of the occurrence of cavitation are many.

Most important is the damage caused by the collapse of the cavitation bubbles in higher pressure regions. The implosion of the bubbles creates shock waves in the liquid which if near a metal boundary cause microscopic failure very similar to corrosion fatigue and a characteristic "pitting" results. Vapor clouds at the entrance of the impeller vanes also block the flow area reducing the amount of liquid that can pass through the pump. Cavitation clouds also cover the vane surface and reduce the ability of the vane to transmit energy to the liquid. Hence, the performance of the machine is noticeably effected. Cavitation also produces excessive vibration of the pump and consequently speeds up all problems connected with it.

What are the basic questions then that must be answered about cavitation?

1. Will it occur?
   When does it start, i.e., where is the inception point?
2. Will it prove harmful to the proper functioning of the machine? How intense is it?
3. What can be done to cushion or avoid its effects?

All three problems are currently being studied by a variety of university, private and industrial researchers.

Of primary academic interest is the question of the cavitation inception point. Visual observations, high speed movies and sound-level equipment are employed under controlled laboratory conditions to determine the effects of gas content; number of small solid nuclei; turbulence levels; wall roughness effects; etc. on when cavitation begins. All such studies stem from findings that cavitation usually begins at pressures slightly greater than the actual vapor pressure of the liquid. Traditionally, for engineering purposes the above effects have been lumped into an unknown "scale effect."

Industry, however, is properly concerned with "industrial" cavitation, i.e., the intensity of cavitation that causes the device not to function properly. This is schematically illustrated in Fig. 1 (3) where the essential machine functions are compared with cavitation intensity. The applied research previously conducted at Lehigh and now at Texas A&M is primarily interested in this practical question of what cavitation intensity effects the performance characteristics (head-capacity curve) of a dredge pump moving slurries of various particle size and density. It has been noted in these studies that the inception point occurs well before performance is notably effected. No studies at A&M are planned (at present) to look at intensity effects on cavitation produced damage, vibration, or noise.

CAVITATION INDICIES

From standard laboratory cavitation tests, the critical "industrial" type cavitation value expressed as the net positive suction head above vapor pressure (NPSH) can be determined. NPSH is computed from the following equation:

$$NPSH = \frac{(P_{atmos} - P_{vp})}{\gamma} + \left(\frac{P_s}{\gamma_m} + \frac{V_s^2}{2g}\right)$$

where:

P_{atmos} = local barometric pressure reading lb/ft^2

P_{vp} = liquid vapor pressure, lb/ft^2

γ_m = liquid unit weight, lb/ft^3

p_s = suction pressure, lb/ft^2

V_s = suction velocity, ft/sec

g = gravity acceleration, ft/sec^2

NPSH = net positive suction head, ft of liquid

The laboratory technique employed is to lower p_s by use of a vacuum pump until the head developed by the pump drops off for a given speed and flowrate. The value of the NPSH at this point is consequently "critical" to the proper performance of the pump and labeled $NPSH_{crit}$.

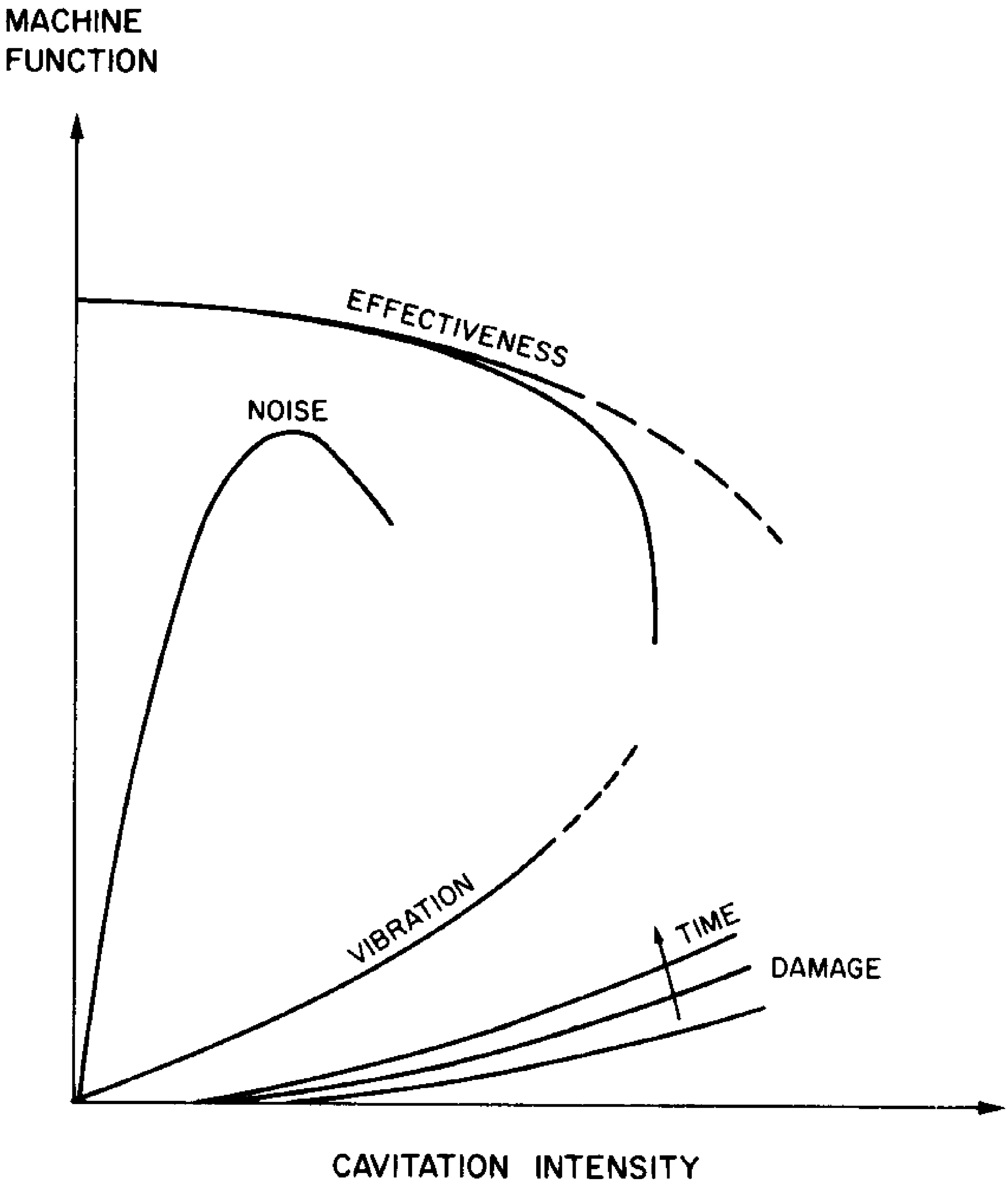

Fig. I - Schematic of Intensity Effects on Machine Functions (Ref. I)

Critical NPSH values are obtained for other flowrates and a curve developed.

HYPOTHESES

The basic hypothesis to be tested in this project can be summarized as follows:

1. Because cavitation inception and intensity levels are basically related to when and how much LIQUID in the slurry vaporizes, the critical NPSH expressed as feet of liquid will be unrelated to the density or size of solid particles present. Solid particles have velocity (kinetic energy) but cannot convert it to liquid pressure. Hence, no relation to local pressure reductions (or increases) can be attributed to the presence of solid particles.
2. Presence of more or larger solid particles increases gas content and number of nuclei present from which cavitation can begin <u>before</u> pressure reaches vapor levels. Solids will cause inception to occur sooner (scale factor) and increase intensity resulting in higher $NPSH_{crit}$ values.

Although some previous work has been concerned with number of small dust nuclei effects on inception, none have involved slurry flows.

TEST RESULTS TO-DATE

The initial tests at A&M used a standard 6" x 6" Morris slurry pump in the system. The sand was chosen to be highly uniform (Fig. 2) and had a median (d_{50}) grain diameter of about 0.175 mm. Only a minimum amount of sand abrasion took place during testing as illustrated in Fig. 2.

The liquid density was determined by averaging samples taken from three tubes in the discharge pipe spaced as shown in Fig. 3. The technique is

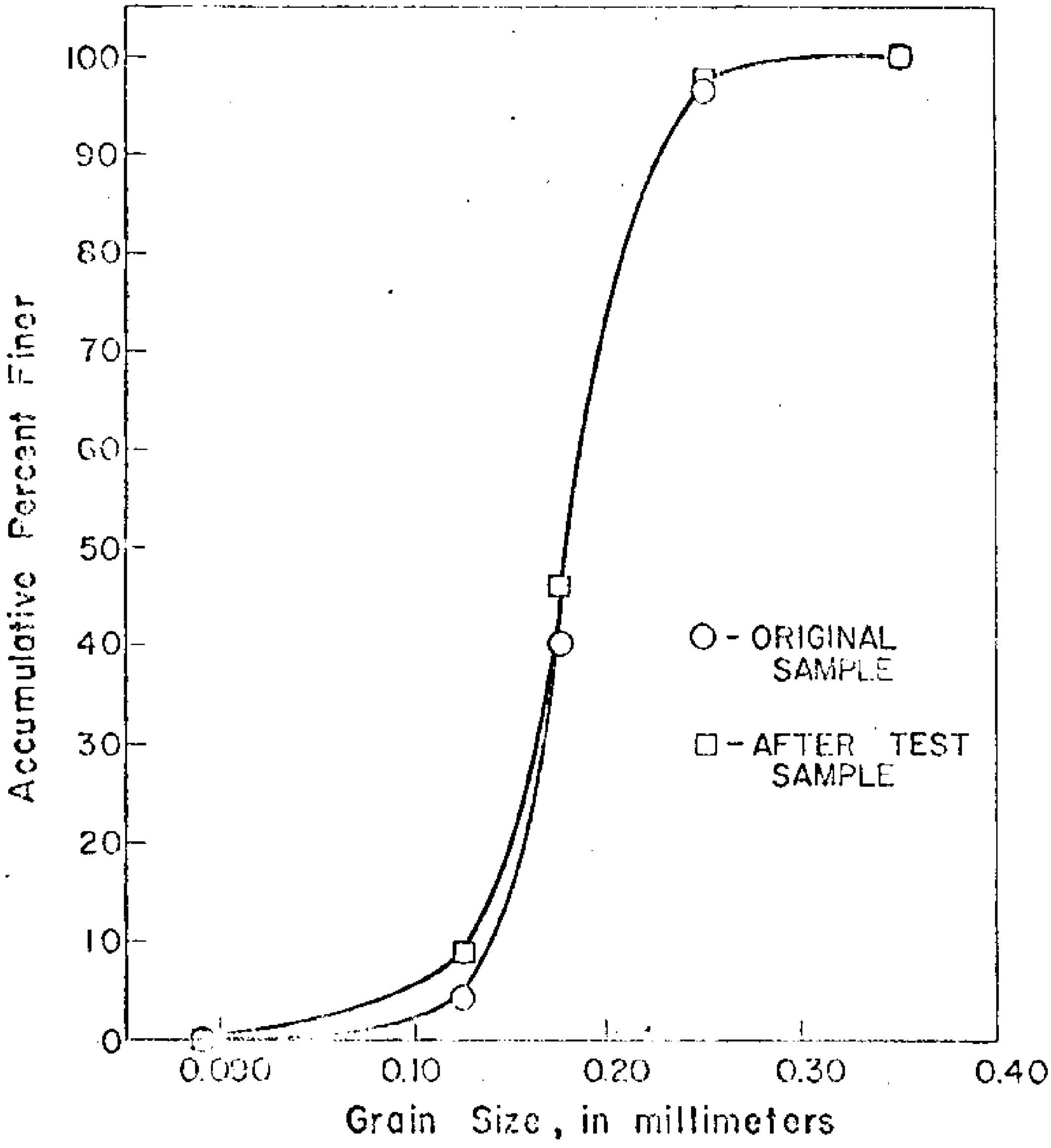

FIG. 2 - GRAIN SIZE DISTRIBUTION OF TEST SAND

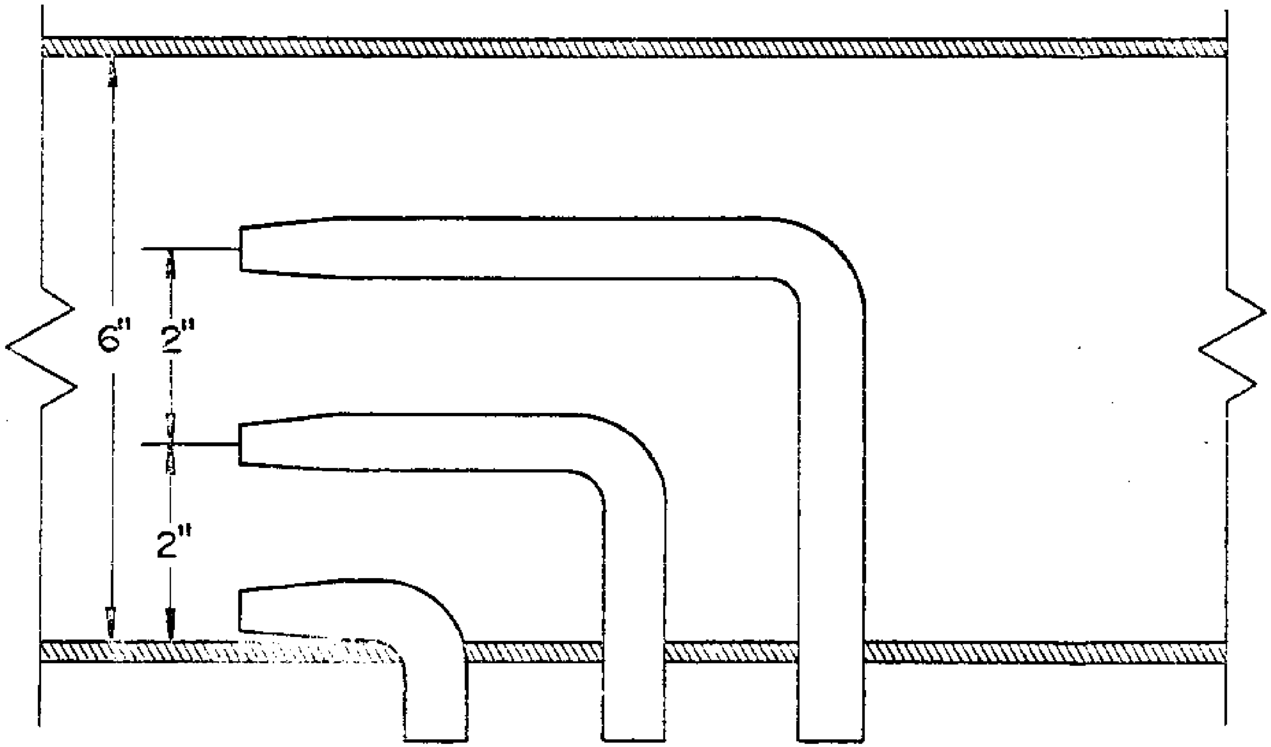

FIG. 3 - ARRANGEMENT OF PITOT TUBE SAMPLERS IN DISCHARGE PIPING

somewhat awkward, time consuming and inaccurate. Density measurements in the test facility will be greatly improved in the future by the installation of a continuous recording, nuclear density meter which is presently being calibrated.

Fig. 4 presents results of a typical cavitation tests. For a constant pump speed and liquid density, the NPSH is varied at a number of flowrates until the intensity of cavitation substantially effects the head developed. The critical values of NPSH are somewhat subjective because the head does not drop-off sharply. A constant percentage was employed for uniformity. The critical NPSH values for all densities tested, expressed in feet of liquid at 1182 rpm were then plotted against flowrate (Fig. 5). Although some scatter existed, there appeared to be no significant trend for densities ranging from clear water (S_m = 1.0) to a specific gravity of mixture, S_m equal to 1.4. Similar results were obtained at 1752 rpm.

The studies are currently continuing with a standard 8" x 6" Pekor dredge pump. A new larger sand grain will be employed with median diameter about 0.250 mm. Use of the continuous recording nuclear density meter should reduce the amount of scatter present in the results.

TENTATIVE CONCLUSIONS TO-DATE

Because of the extremely limited amount of data available to-date, the conclusions that can be drawn are only very tentative. Based on these tests results and those at Lehigh University (2), the mixture density and size have very little (if any) effect on the critical industrial cavitation requirements, ($NPSH_{crit}$) for dredge pumps. Estimates of $NPSH_{crit}$ in feet of liquid for slurries can be made from clear water tests if the specific gravity of the mixture is known.

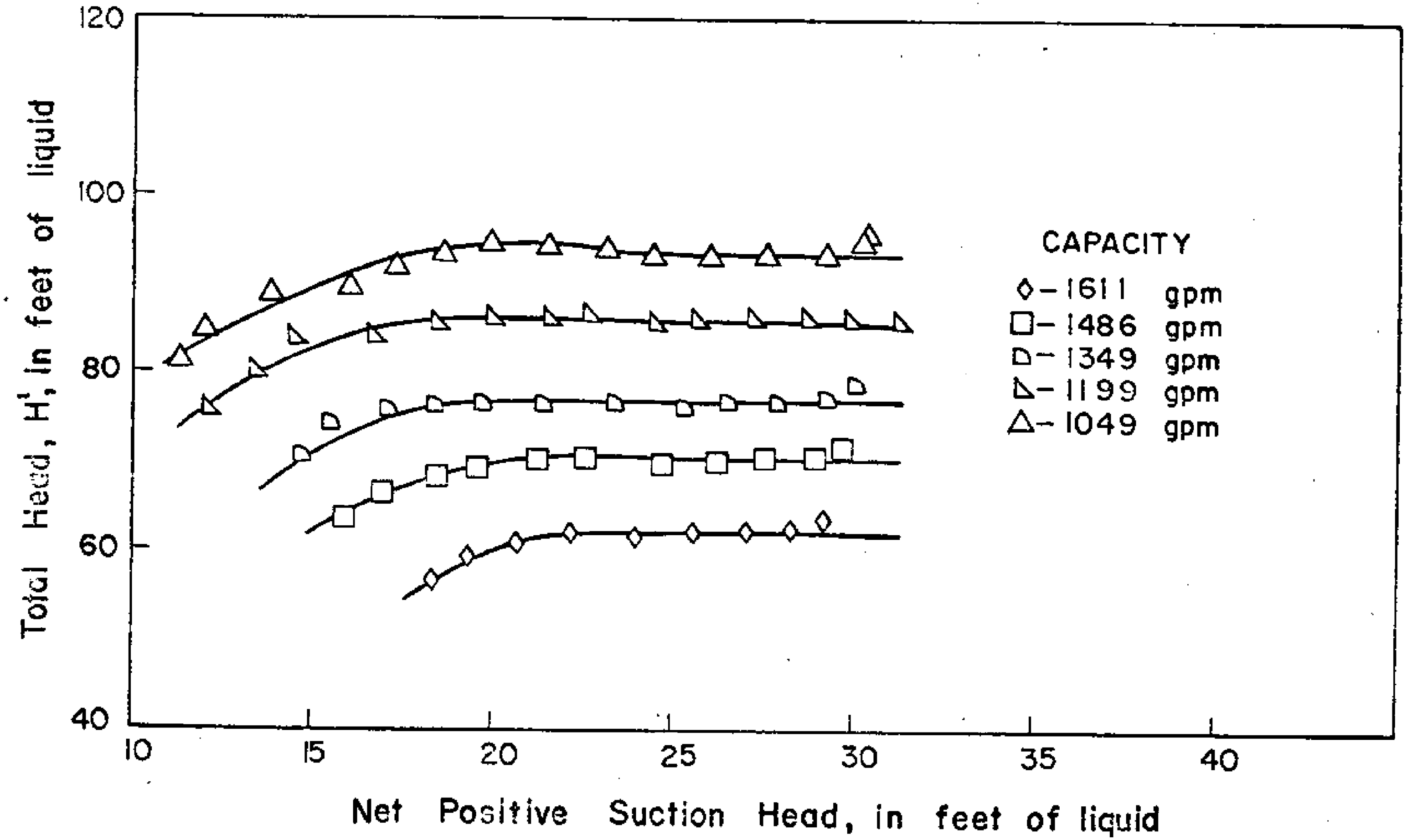

FIG. 4 — TOTAL HEAD VERSUS NET POSITIVE SUCTION HEAD AT 1182 RPM (SPECIFIC GRAVITY = 1.19)

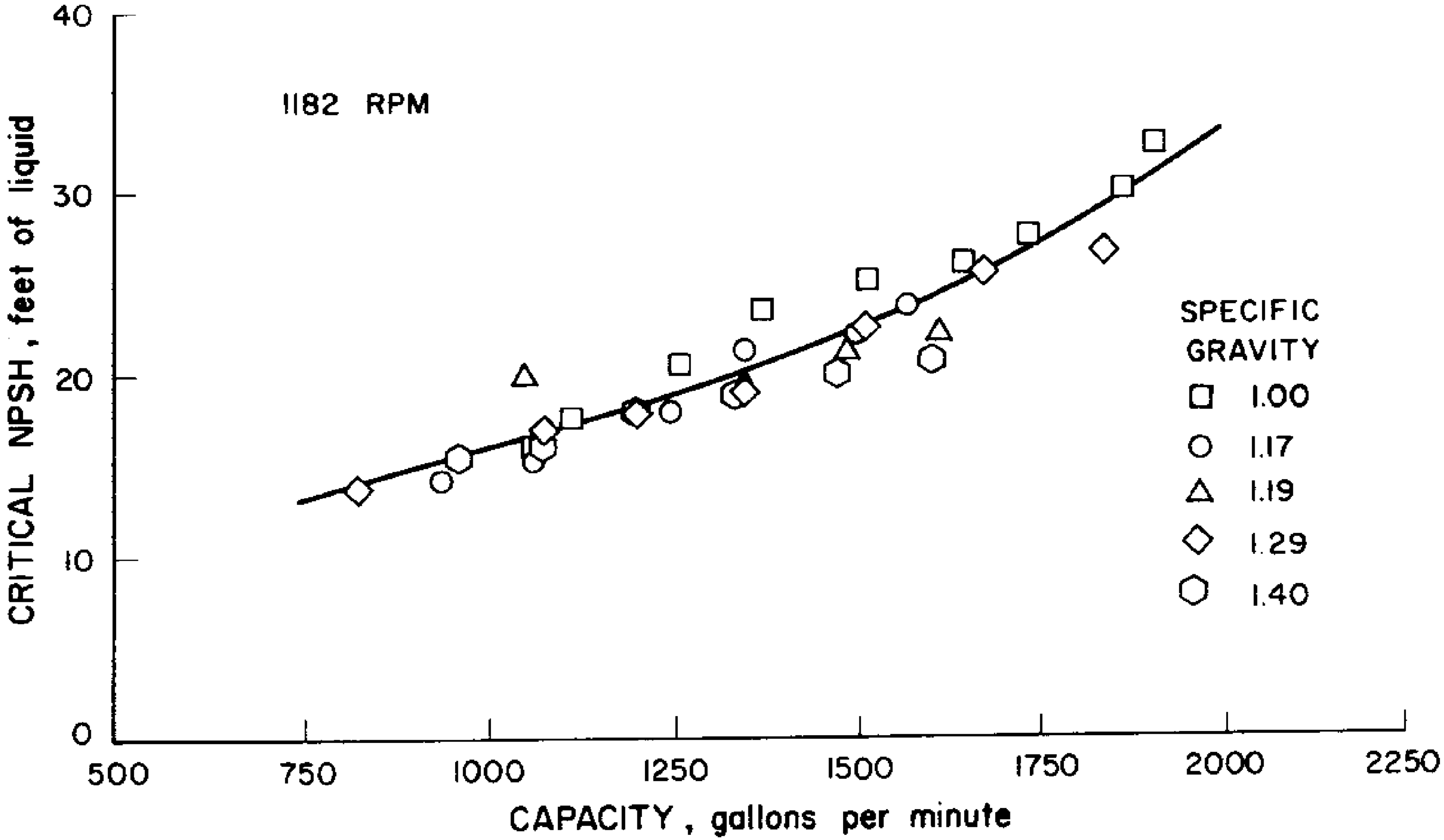

Fig. 5 - Effect of Specific Gravity on NPSH Critical (Texas A&M)

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1. "Cavitation in Dredge Pumps", by Dr. C. J. Garrison, Proceedings of Second Dredging Seminar, Texas A&M University, Nov. 21, 1969, (CDS Report No. 126, June 1970).

2. "Effect of Viscosity of Solid-Liquid Mixture on Pump Cavitation", by V. R. Mariani and J. B. Herbich, Fritz Lab Report No. 297, Lehigh University, Bethlehem, Pa., Jan. 1966.

3. "Cavitation-State of Knowledge", ASME Symposium, Feb. 1969.

ACKNOWLEDGEMENT

The writer gratefully acknowledges the tireless efforts of Mr. Ralph Cooper who initiated the Center for Dredging Studies pump test loop and who provided the data for this article.

MATERIALS USED IN THE MANUFACTURING OF DREDGE PUMPS

By

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Thomas Foundries Incorporated
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INTRODUCTION

The material selected in the manufacturing of a dredge pump and specifically the parts in contact with the flow depend on the size and abrasiveness of the material being pumped, discharge pressure, expected duration of the installation and the particular part's function in the dredge pump design.

If a part is subjected to abrasive wear and impact is not a prime factor an alloy white cast iron is usually selected. However, if impact becomes a prime factor, a heat treated mild carbon steel, heat treated low or high alloy steel or ductile iron is usually selected.

Other parts of a dredge pump may serve only as structural members and materials used for the manufacturing of these parts are selected for strength and rigidity.

PUMP SIDE COVERS

The dredge pump size covers are usually structural components and in most designs, two are employed.

The materials used in the casting of this part are low or medium carbon steel, ductile iron or Hadfield Austenitic Manganese Steel.

Sometimes this particular part is a fabrication rather than a casting and A-36 plating or similar plate material is used.

In some small dredge pump designs, no side cover liners are employed. In this case and depending on the nature of the material being pumped, the part is cast in an alloy white cast iron, ordinary cast iron or any of the materials already mentioned.

The side cover liners usually are a casting and most dredge pump designs employ two, suction and bearing side. Since this part is subjected to wear from abrasion, an alloy white cast iron is used more than any other available material.

Occasionally this part is cast in Austenitic Manganese Steel or a heat-treated low alloy carbon steel. However, usually this is a case where a particular user prefers to rebuild the casting by welding.

Some side liner designs do not lend themselves to a casting because of diameter to thickness size. Here an abrasion-resistant steel plate material is used.

Dredge pump designs sometimes employ other castings which are basically wear liners. These are usually termed throat rings, wearing rings, ferrule liners, impeller nose liners and stuffing box liners to mention a few. In almost every instance these are castings and usually are cast in an alloy iron material.

PUMP IMPELLER

The dredge pump impeller can be a casting or a fabrication. The impeller can be subjected to impact and/or abrasive wear depending on the material being pumped.

If impact is the governing factor and if a casting is employed, materials selected are heat treated high alloy steel, such as Hadfield Manganese Steel, heat treated low alloy steel, such as 4340 Steel, heat treated mild carbon steel, such as ASTM-A-27-65, or ductile iron.

If the impeller is subjected to abrasive wear only, an allow white cast iron is usually selected.

With a fabricated steel impeller, a T-1 plating or similar plate material is usually selected.

This design impeller will have an impeller hub which is cast in low or medium carbon steel. The impeller back shroud, which is steel plate, is welded to the hub. The vanes, which are rolled to the desired vane curvature, are then welded to the back shroud. The front shroud is then welded in place to the vanes.

Depending on the material selected and impeller hub design, an impeller insert or adapter may be required. If the impeller is cast in a material which is readily machinable, no insert or adapter is required.

However, if the cast material is an alloy white cast iron or Austenitic Manganese Steel usually an insert or adapter is required. Some alloy irons can be heat treated to a ductile condition for machining, followed by a second heat treatment to restore hardness.

By an insert, reference is made to an item which is either cast or shrunk into the impeller casting.

By an adapter, reference is made to an item which is secured to the impeller casting by mechanical means.

The insert is usually cast in mild steel, fabricated from bar stock or cast in ordinary cast iron.

If the insert is cast into the impeller, it is designed to prevent insert from pulling loose or turning within the casting.

If insert is shrunk into the impeller casting, it is usually designed for a class 8 interference fit.

When an adapter is employed, it is secured to the impeller by heat treated alloy steel bolts employing locking nuts.

PUMP CASING

The pump case or shell is usually a casting. Here again, the nature and size of the material to be pumped determines the material selection for the casting.

The same materials as used for the impeller when subject to impact and abrasive wear or just abrasive wear are used in casting the case or shell.

Some dredge pump designs consist of an outer casing which encases an inner shell liner.

The outer case, if a casting, is cast in mild carbon steel or ductile iron.

If the outer case is fabricated, A-36 plating or a similar plated steel is employed.

The shell liner is usually cast in an alloy white cast iron material. However if impact wear becomes a factor, a heat-treated alloy steel is selected.

OTHER PARTS OF PUMP ASSEMBLY

Stuffing box

Most dredge pump stuffing box designs are castings secured to the back cover by bolts.

The stuffing box is usually cast in a mild carbon steel or ductile iron.

Lantern ring

The lantern ring, located in the stuffing box, is either cast in brass or bronze. This material is selected because of its corrosion resistance, machinability and good strength. A typical brass is 83% copper, 4% tin, 6% lead, and 7% zinc.

There are various types of packing materials available for packing a dredge pump. One type which works well is made of ramie fiber and thoroughly impregnated with a combination of animal fat and petroleum base oils.

Packing gland

The packing gland is usually cast in ductile iron. This material possesses adequate strength and is readily machinable.

The radial and thrust bearing assemblies are housed in independent pillow block housings or a single cartridge type housing.

These housings are cast in ductile iron or mild carbon steel.

On some large dredge pump designs employing two independent pillow block housings, the radial housing is cast in mild carbon steel while the thrust pillow block housing is cast in ductile iron.

The mild carbon steel being employed for added strength and rigidity.

Pump shaft

Dredge pump shafts are made of various hot rolled or forged steel analysis. The selection depends on the forces acting upon the shaft.

Two popular hot rolled materials used are SAE-1045 and 4140. The Brinell hardness usually ranges from 200 to 320.

When forgings are employed, typical steels used are SAE-1045, 2340, 4140 and 4340. The Brinell hardness usually ranges from 248 to 330.

On most dredge pump designs, a shaft sleeve is fitted over the shaft through the stuffing box area. The material selected must be corrosion-resistant as well as abrasion-resistant.

Some materials employed are centrifugally cast, cast iron, various stainless steels or a mild carbon steel base casting with a hard coating. This coating is usually tungsten carbide, chromium carbide or a ceramic material.

Pump base

The base supporting the pump varies in design and is either fabricated from steel plating or cast in ordinary cast iron.

Cast iron is a good material because of the damping effect of vibrators, cost of material and machinability. However, high pattern cost and changes in base design within a particular size to suit a customer's requirements prohibits extensive use of this material.

Some dredge pump designs employ an adjusting plate or carriage which slides in the base and fitted to this plate or carriage are the bearing housings.

This plate or carriage is either fabricated from steel plating or cast in ordinary cast iron.

Gaskets and seals

Various gaskets are required to seal the dredge pump. These gaskets, if a flat ring type, are usually a wire inserted asbestos material or red rubber. With red rubber, the durometer range is 50 to 60.

Some dredge pumps employ a rubber wedge seal. This is usually made of black rubber in a 55 to 60 durometer range.

We have stated that wear occurs from impact and abrasion, or just abrasion.

IMPACT CONSIDERATIONS

If impact is the primary factor to be considered, the material selected to produce the casting usually will fall into a 170 to 300 Brinell range. This material can be a low or high alloy heat treated steel, a mild heat treated carbon steel or ductile iron.

In the low alloy heat treated material, a Chromium-Molybdenum-Nickel alloy steel with the chemical composition varying slightly, is usually selected.

This material is basically a 4340 material with a Brinell range of 225 to 300.

In the high alloy heat treated material, Hadfield Austenitic Manganese Steel is an available material.

This material, after heat treatment, usually falls into a Brinell hardness range of 170 to 220.

A typical chemical composition will contain 1.15% carbon, and 12 to 13% Manganese Steel.

Sometimes a 2% nickel addition is made to improve the tensile and yield strength. This addition, however, does reduce the ductility by approximately 5%.

A mild heat treated carbon steel grade 65-30 is also a material available.

This material may contain a small percentage of Nickel, Chromium and Molybdenum which is picked up from the scrap metal used in the melting process.

Ductile iron is also used as a material when ductility is required.

This material is a cast iron with the graphite substantially spheroidal in shape and essentially free of other forms of graphite. This material can be produced in different grades, so varying tensile strength, yield strength and ductility can be achieved.

One particular grade is 65-45-12 which has a 65,000 P.S.I. tensile strenth, 45,000 P.S.I. yield strength and 12% elongation in 2 inches. These are minimum properties for this grade.

Where abrasive wear is the primary factor, then alloy white cast irons are usually employed with a Brinell hardness range of 450 to 700.

The two most popular alloy irons are a nickel-chromium martensitic white cast iron and a high-chromium white cast iron.

The nickel-chromium white cast iron is made under different trade names with the most popular being No-Hard.

This alloy of iron will usually have a nickel content of 3.3 to 5.0%, and and chromium content of 1.4 to 2.5%. However, the chromium content can be increased up to 3.5% to prevent graphite formation in sections subject to slow cooling.

Another variation of this material is to increase the nickel and chromium content to approximately 6 and 8.5%, respectfully, to achieve greater strength.

The high-chromium white cast iron is produced under different trade names by different manufacturers.

This material has a chromium content of 24 to 28% with a 2.3 to 3% carbon range. This particular material can be heat-treated to a soft or ductile condition, machined and then heat-treated to restore the Brinell hardness.

Another alloy iron being employed is a chromium-Molybdenum white case iron. One variation of this material has a chromium content of 18 to 21%, Molybdenum of 1.4 to 2.0% and copper of .80 to 1.2%.

This material is normally heat-treated to achieve good abrasion resistance.

The materials thus mentioned cover a general scope of steels and irons available to solve some of the wear problems encountered with a dredge pump.

REPORT ON WORLD DREDGING CONFERENCE (WODCON'70)

By

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Director, Center for Dredging Studies
Texas A&M University

The country of Singapore provided a unique setting for the WODCON'70 Conference and as an anonymous article in World Dredging and Marine Construction magazine stated "EAST MET WEST" at the Third World Dredging Conference and the "RESULTS WERE IMPRESSIVE".[1]

Singapore is inhabited by people from at least four major backgrounds and religions striving to work together, in peace for the betterment of their country. Singapore is a fast growing city and is becoming a major port in South East Asia. The success achieved by people in Malaysia and Singapore under enlightened governments in meeting many complex problems could serve as an example in other parts of the world.

The Conference met during the week of July 5, 1970. The theme of the Conference was the "Importance of Dredging to Developing Nations."

Singapore is one of the key ports of Southeast Asia and enjoys expansion in the midst of industrial growth and natural resource development in the surrounding countries of Malaysia, Indonesia, Thailand, India and Australia.

The first two days of the Conference were devoted to field trips. One of the field trips was to the tin mining projects in the vicinity of Kuala Lumpur in Malaysia while the other trip took a group of those attending the Conference to visit the Singapore Harbor and dredging projects in the vicinity. Both field trips were most appropriate and timely. Those who saw the tin mining operations were most impressed by the magnitude of various projects.

Technical paper sessions were conducted from July 8 through July 10, 1970; in all 24 technical papers were presented at the Conference as well as several luncheon talks.

The largest number of papers were presented by United States engineers followed by Japanese, Dutch, Brazilian, British, German, Indian and Thai engineers.

Over 185 persons attended WODCON '70 with 29 countries represented, the largest contingent came from the United States (34 persons) followed by Singapore (27), Australia (19), the Netherlands (19), Japan (14), Malaysia (11), Indonesia (9), Britain (7), Canada (4), Belgium (2), Canal Zone (2), Republic of China (2), Germany (2), Venezuela (2), Argentina (1), Brazil (1), Denmark (1), France (1), Finland (1), India (1), Italy (1), Hong Kong (1), Phillippines (1), Pakistan (1), Sweden (1) and Thailand (1).

The luncheon meetings which were held each day during the technical session part of the Conference, were most interesting and covered many topics.

Norman Cleveland described how tin dredging has benefited the entire economy of Malaysia and also provided "seed" money for the development of the rubber industry. Industrial developments such as these in Malaysia contribute greatly to the modernization of the whole country.

Mr. Peter Van Lunteren drew attention to the growing shortage of sand used for construction all around the world and pointed out that the dredging industry must develop new sources of supply for the construction industry. It appears that we will have to look offshore for suitable supply of sand in the future, we already have dredges pumping sand from offshore deposits to reclaim beaches. An experiment was conducted by the U. S. Army Engineers off New Jersey (2) and large quantities were pumped by C. F. Bean, Inc. in cooperation with Ocean Science and Engineering at Pompano Beach, Florida during the summer of 1970.

It has been established that the continental shelves in many areas of the world contain large quantities of sand of sufficiently good quality for construction industry. In many cases more accurate surveys must be made to pin point the sand deposits and estimate their quality and quantity. These surveys should be made before any such job is undertaken and samples taken during the survey will permit better estimates of dredging costs.

Other new projects could involve the building of artificial islands for nuclear power stations, or offshore unloading facilities for tankers too big to enter existing ports.

It appears to me that the dredging industry must develop methods to operate offshore in currents, waves and winds normally expected along the coast and that it must carry out or sponsor research and development projects which would make the dredging industry "seaborne."

The "seaborne" dredges will cost more than the conventional river dredges and it may be difficult, if not impossible, for the small dredging contractors to raise sufficient funds for purchase of such equipment. This may lead to joint ventures, or only the largest contractors will be able to operate in ocean environment.

The joint ventures or large contractors will not only require new dredging plants but also better trained staff and experienced research and development-type personnel, since improvements in both plant and methods will have to be achieved before dredges can operate offshore economically.

Mr. Bauer, who is currently the president of World Dredging Association, at another luncheon address discussed "The Future of the Dredging Industry." He pointed out that although the present state of Industry is discouraging, this is not a time for looking back, but a time to plan for the future. The dredging industry must come up with the answers to the questions that are being raised regarding the effect of dredging on ecology and environment, particularly in the coastal zone. The dredging industry must also do a better public relations job in pointing out that "Dredgers" are not "Polluters" as had been said at some recent meetings. It is true that estuary beds are disturbed during dredging operations, but if only original bed material, be it silt or sand or clay is disturbed, this material is not a pollutant in itself, this is the same material which is present in the spoil area. Another example may be mentioned which concerns the Houston Ship Channel, called by some the most polluted body of water anywhere. When dredgers deepen the channel during maintenance operations the accumulated bottom sludge is removed and their sludge has to be deposited somewhere. The dredgers are not responsible for sludge accumulations in the channel, the pollution was caused by industry and municipalities in the first place. The dredgers are actually removing the pollutant in form of sludge from the channel.

What is recommended here is that research studies be conducted to determine the dispersion and final disposition of dredging spoil both through laboratory and field investigations. Also better methods should be developed for the disposal of spoil; this will require better knowledge of prevailing tidal currents during the ebb and flood tide, wave conditions, temperature, salinity of water, etc. This will probably mean more work, higher dredging unit costs and will require more experienced and better trained personnel.

The World Dredging Association was established to help in the professional development of the individual employed in the dredging industry. The Association is also interested in technological advancement and its application to design of dredge plant, navigation, soil surveys and ecological investigations as well as the system analysis and planning and logistic analysis and control.

WODA initiated a survey last year to determine what courses are taught at the Nation's Universities which may apply to dredging. The survey's results indicated that some 12 universities offered some courses that pursued dredging subjects and problems. It was reported in the survey, however, that only two schools had a positive program in dredging, and these are: Oregon State University and Texas A&M University.

The World Dredging Association is now proposing to sponsor a study on the effects of dredging on marine ecology and environment. A proposal was received from an independent research organization to conduct this study. The proposal is now being evaluated for possible funding.

It is intended that this study will result in a set of procedures that will be available as guides to dredging contractors in cooperating with its customers to conduct and plan dredging programs of any type in such a way as to minimize bad effects on the environment; or, in some cases to improve the environment. Drawing upon the latest in research and literature, the research organization will, in cooperation with WODCON and WODA members, develop these procedures. In regard to technical papers, the subjects ranged from tin mining and military dredging in South Vietnam to reclamation of Copacabana beach and the aspects of offshore land reclamation, yesterday, today and tomorrow; from characteristics of jet-pumps with liquids of different density and the effect of air-content on performance of a dredge pump to research on hydro-jet deep imbedment method and sedimentation effects of soil in hopper. Many other topics were also discussed including a review and analysis of insurance for the dredging industry.

The papers may be divided into several categories:

1. Dredging Operations
   - (a) Military Dredging in South Vietnam by Col. L. L. Reign, Jr., of U.S.A.
   - (b) Utilization of the Pusher Barge Line System in Reclamation Projects by Rinkai Construction Company, Ltd. Japan.
   - (c) Dredging of Minor Ports in India - Application of American Techniques by Capt. U. Shanker Rao of India.
   - (d) Reclamation of Copacabana Beach by Mr. M. de Valente Nicoletti of Brazil.
   - (e) Dredging of Hard Soil and Rock with Cutter Suction Dredge by Mr. T. Uchibayashi of Japan.
   - (f) The Dredging of Milford Haven by Mr. Swansbourne of England.

2. Dredging Equipment

   (a) Characteristics of the Jet Pump with Liquids of Different Density by Prof. R. Silvester of Thailand.

   (b) Research on Dredging Grab Buckets by H. Iwata of Japan.

   (c) A Nuclear Powered Dredge for the 70's by Mr. W. R. Murden and Captain R. E. Donovan of U.S.A.

   (d) Performance of an Improved Accumulator for Gas Removal by Dr. J. R. Adams and Dr. J. B. Herbich of U.S.A.

   (e) Booster Pump on Suction Side of a Pump Dredger by K. Nishi of Japan.

   (f) Effect of Air Content on Performance of a Dredging Pump by J. B. Herbich and R. E. Miller of U.S.A.

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(d) Factors Determining Dredge Production by M. T. Turner of U.S.A.

(f) Organic Sludges in the Houston Ship Channel; Their Source, Nature, Effect, and Removal, by Dr. R. W. Hann, Jr. of U.S.A.

(g) "Marine Insurance for Dredging Operations" by Mr. D. B. Adams of U.S.A.

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RESEARCH NEEDS OF THE DREDGE PUMP MANUFACTURER

By

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INTRODUCTION

I suspect that Dr. Herbich tapped me for this paper because the topic related to what I don't know. Some of the problems that I feel should be researched may already have been solved. So, I am hoping that some of you may be able to shed light on a few of these subjects today as a quick fringe benefit.

We might classify dredge research needs 3 ways: the dredge pump, related equipment, and the complete system.

Until the last few years, there had been very little published research on dredging technology. Nearly all of the technical information on pumps was oriented to clear liquid pumps. However, the most efficient design for a water pump is measured by GPM per $, but the efficiency of a dredge pumo is measured in tons of solid material per $. It's a different ball game. Further, the internal configuration of a dredge pump is constantly changing, due to abrasive wear.

Happily, the dredging industry is now getting organized to keep step with the technological explosion. Perhaps, then, this is a good time to inventory our needs, assign priorities, and get something going here at the Center for Dredging Research.

With the tremendous amount of research being done in both government and industry, it looks like a good bet that sometime soon new and better materials for pump construction will turn up. Maybe a better material is already available, but we just don't know about it!

The currently popular materials for the expendable (or wetted) parts are:

Ni-Hard, Manganese Steel, Hi-Chrome Iron, Rubber,
Polyurethane, and various other steel alloys.

Ni-Hard is usually the choice when pumping sand and gravel, rubber and polyurethane for fine grained slurries, manganese and hi-chrome for large stones, and the alloyed steels for large cutter-head dredges.

The ideal material for wear parts, of course, would be cheap, extremely durable, impact resistant and would be castable to such tolerances that no machining would be required. Our big problem, today, is that the more durable the material, the harder it is to machine.

Present developments that offer some promise are ceramics and urethane rubber, either separately or with the ceramic embedded in an abrasion resisting matrix, such as urethane rubber.

The mechanical problems unique to dredge pumps are generally caused by:

1. The extreme abrasion of the wetted parts due to the solids being pumped.
2. The constantly varying amounts and proportions of solids and water fed to the pump.
3. Large rocks or junk that cause heavy impact loads on the pump parts.
4. Cavitation, which can be induced much more readily than in the typical clear water pump installation.
5. The difficulty of machining abrasion resistant metals.

A persistent problem that needs a better solution is that of means for balancing Ni-Hard impellers. If you burn material from the vane tips, you alter the vane efficiency, change the micro-structure of the adjacent metal, and leave a ragged, blunt tip that makes cavities. If you grind material from the back side of the shaft-side impeller shroud, you frequently must remove a lot of material in a costly manner, which leaves the structure reduced in strength and reserve for wear. Our practice is to core-in pockets in the trailing face of the impeller vane. We then pour Babbitt material into the pockets as required. However, provision for the pocket requires increasing the thickness of the vane near the periphery. Further, the unfilled pockets are natural cavity-makers.

Of course, better manufacturing methods might be developed, eliminating the need for balancing, altogether.

Shaft seals are frequently a source of trouble. Typically, high pressure seal water is injected into the stuffing box through a lantern ring. This water then flows from the stuffing box into the pump bowl. It is supposed thereby to oppose infiltration of any grit into the stuffing box. Sometimes it works and sometimes it doesn't. Many operators fail to maintain an adequate pressure differential.

Then, there are process plant applications, or relay pumps on shore where seal water cannot be used. Mechanical seals are rather delicate and vulnerable to shaft vibration. We haven't had much luck using them on our dredge pumps. Possibly some of the new plastic or elastomeric materials can be used advantageously. Research into this problem might develop a method which provides a more durable and reliable seal.

Hydraulically, dredge pumps have several differences from centrifugal water pumps. The tongue clearance, for instance, is usually greater in dredge pumps to allow clearance for solids. Impeller shrouds and vanes are usually thicker to allow for wear. Recirculation problems in water pumps simply reduce efficiency slightly. In a dredge pump, water that recirculates in the space between the front shroud of the impeller and the front plate carries abrasive solids. (Fig. 1) This recirculation creates wear problems that can be quite severe. Efforts at so-called "counter-flow" are designed to oppose recirculation. Frankly, we think that much improvement can be made in solving this problem, on our pumps, certainly. Sometimes, the injected

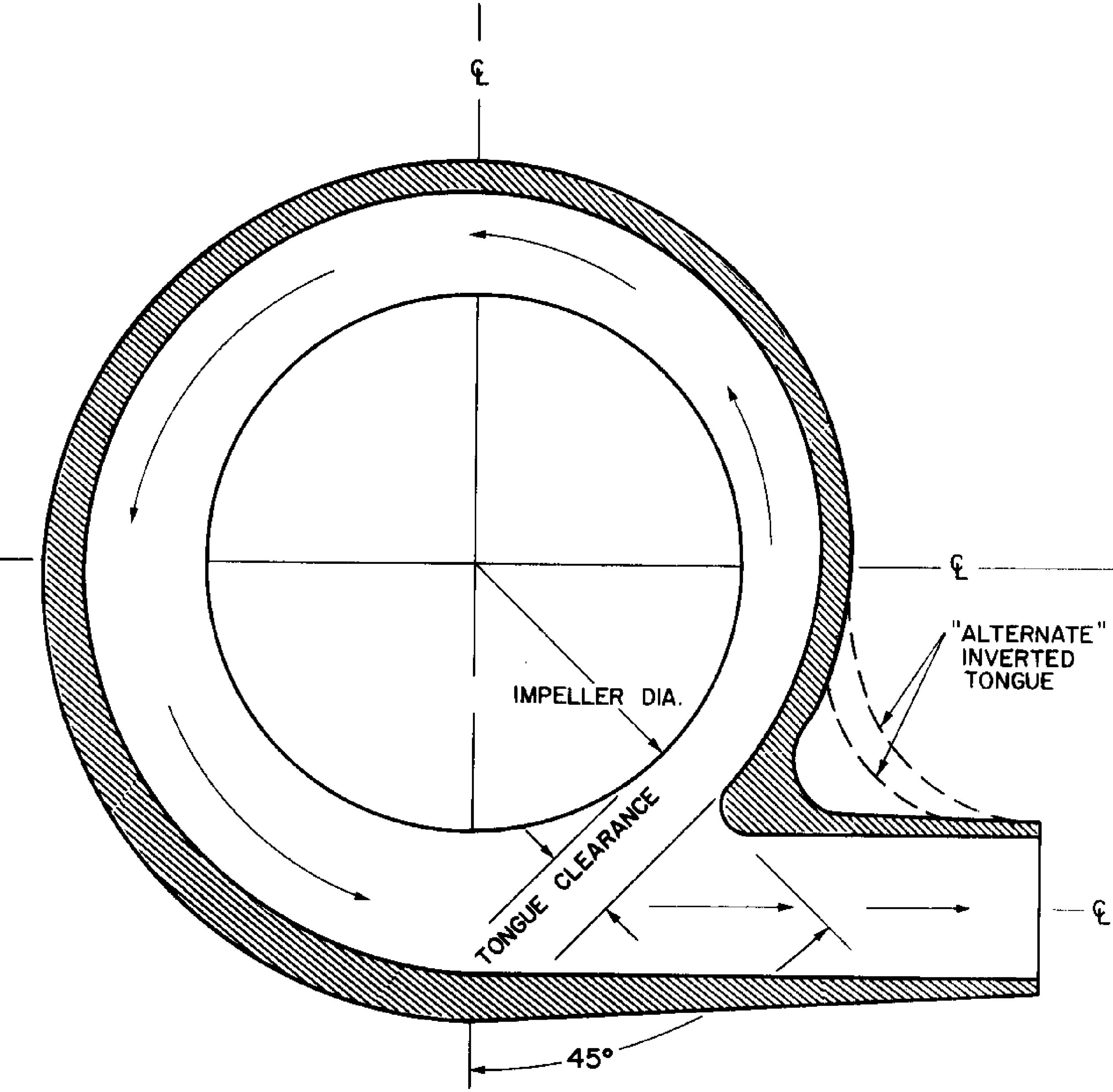

FIG. I DREDGE PUMP VOLUTE

water seems to contribute to erosion by causing local cavitation at the injection holes. A complete annular port sounds like a better solution, but takes a lot of additional water that absorbs additional horsepower.

If the best method of blocking the recirculation of grit-laden water turns out to be the way we are doing it now, then we still need to know the optimum size and arrangement of the injection ports, flows and heads.

Another route to consider is the use of expelling vanes on the front shroud of the impeller. If this little auxiliary pumping arrangement can be configured to just balance the normal recirculation, this would seem to be the ideal solution. If the vanes provide too much pumping capacity, they could conceivably cause cavitation damage as an undesirable substitute for erosion wear. If they do not provide sufficient capacity to oppose recirculation, they don't complete the job. Such an arrangement should work equally well throughout the normal performance range of the pump and should not require very frequent adjustment. This problem looks to me like a real research challenge.

Another hydraulic problem is the inlet geometry, which I feel is related to the previous problem of recirculation. In our 8", 10", and 12" pumps, we have curved the entrance to the impeller. (Fig. 1) This should provide a higher suction limit (without cavitating) than a sharp 90° entrance, and we believe that it does. However, some dredgers with this design have been complaining of excessive wear of the suction-side face plate liners. The wear is characterized by deep gouges, typical of cavitation damage. We made optional face plate liners and impellers with the conventional 90° entrance, and the wear life of the plates increased remarkably. I suspect that the reason is that the square design impeded recirculation which was the controlling factor in these particular cases. Here again is an interesting area for research to clarify the problem and find better answers.

Tongue clearance is another interesting question. In the past, we have thought that tongue clearance should be kept to the minimum compatible with passing rocks. (Fig. 2). A few years ago, pumps appeared in the Florida phosphate fields with what might best be described as a negative or inverted tongue. A well trained, experienced chief pump engineer assured me that they found no reduction of performance or efficiency, but did solve a bad wear problem. Sometimes a solution to a problem in Pump A will simply aggravate a problem in Pump B. Again, in a particular application, at or near the best efficiency point, it is conceivable that the tongue clearance might not be important, while it would be important, at operating points remote from the BEP. Anyway, the report of no adverse effect on performance caused by inverting the tongue suggests that our theory about the function of the tongue ought to be tested.

Now, to move on to related dredging equipment; we are becoming more interested in the design and application of suction nozzles, jet pumps, butterfly valves, pipe fittings, instrumentation and hydrocyclones.

Suction nozzles have been refined substantially on cutterhead dredges, but have been largely ignored for use on "sand suckers", or dredges without cutterheads, such as those typically used in sand and gravel mining. The kidney shaped cross-section required under a cutterhead is not necessary, here, posing a simpler problem regarding cross-section. However, the design of the suction nozzle of a plain suction dredge has two unique factors. First, this nozzle is the primary excavating tool. Naturally compacted deposits of aggregates must be scoured loose by the high velocities of a partially restricted pipe inlet. (Fig. 3). As the suction nozzle is moved close to the deposit, the circular flow area is proportionally reduced and the velocity increased. Thus, we have two contradictory objectives in designing the nozzle-minimizing the energy loss due to high velocity at the

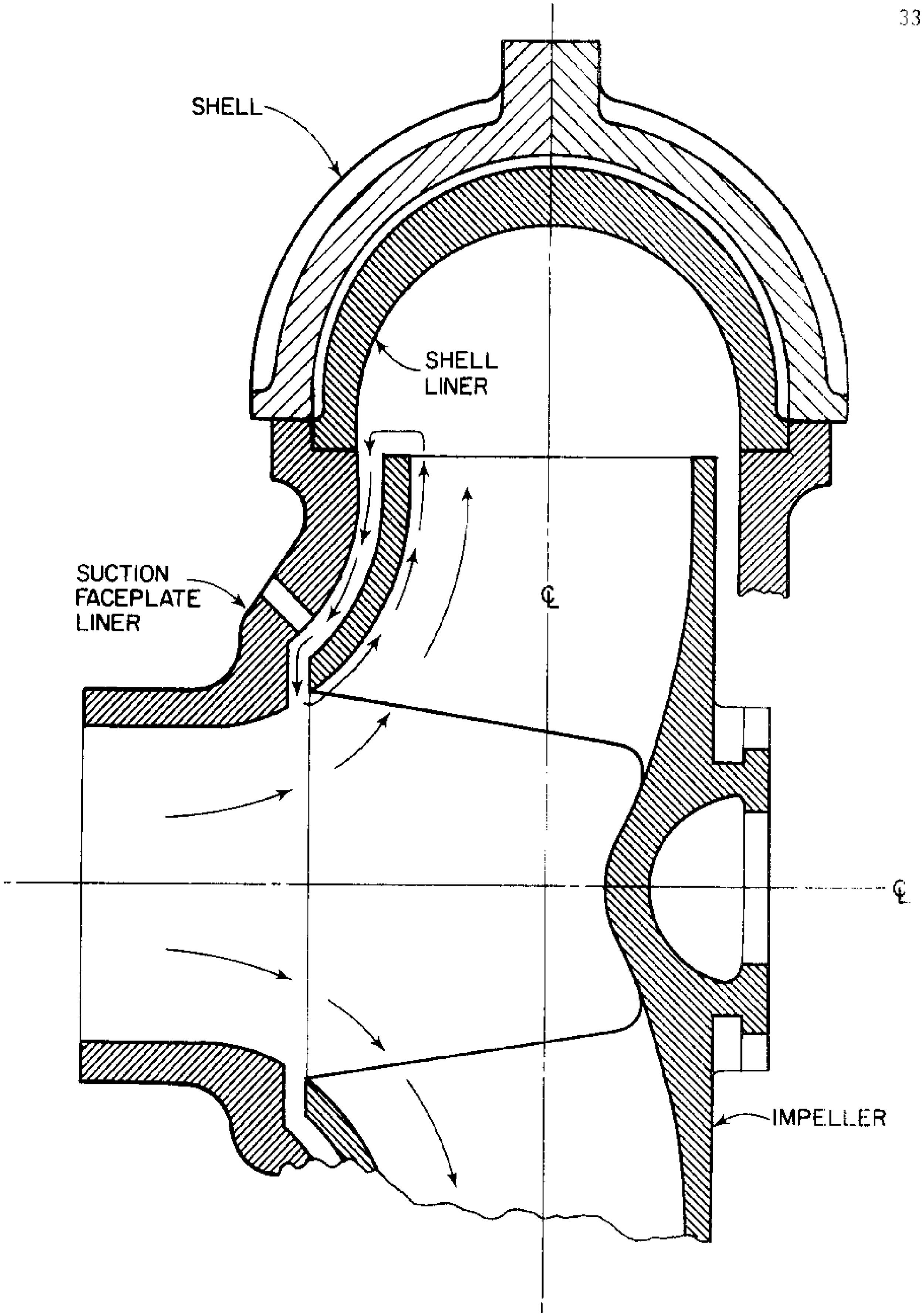

FIG. 2 DREDGE PUMP CROSS-SECTION

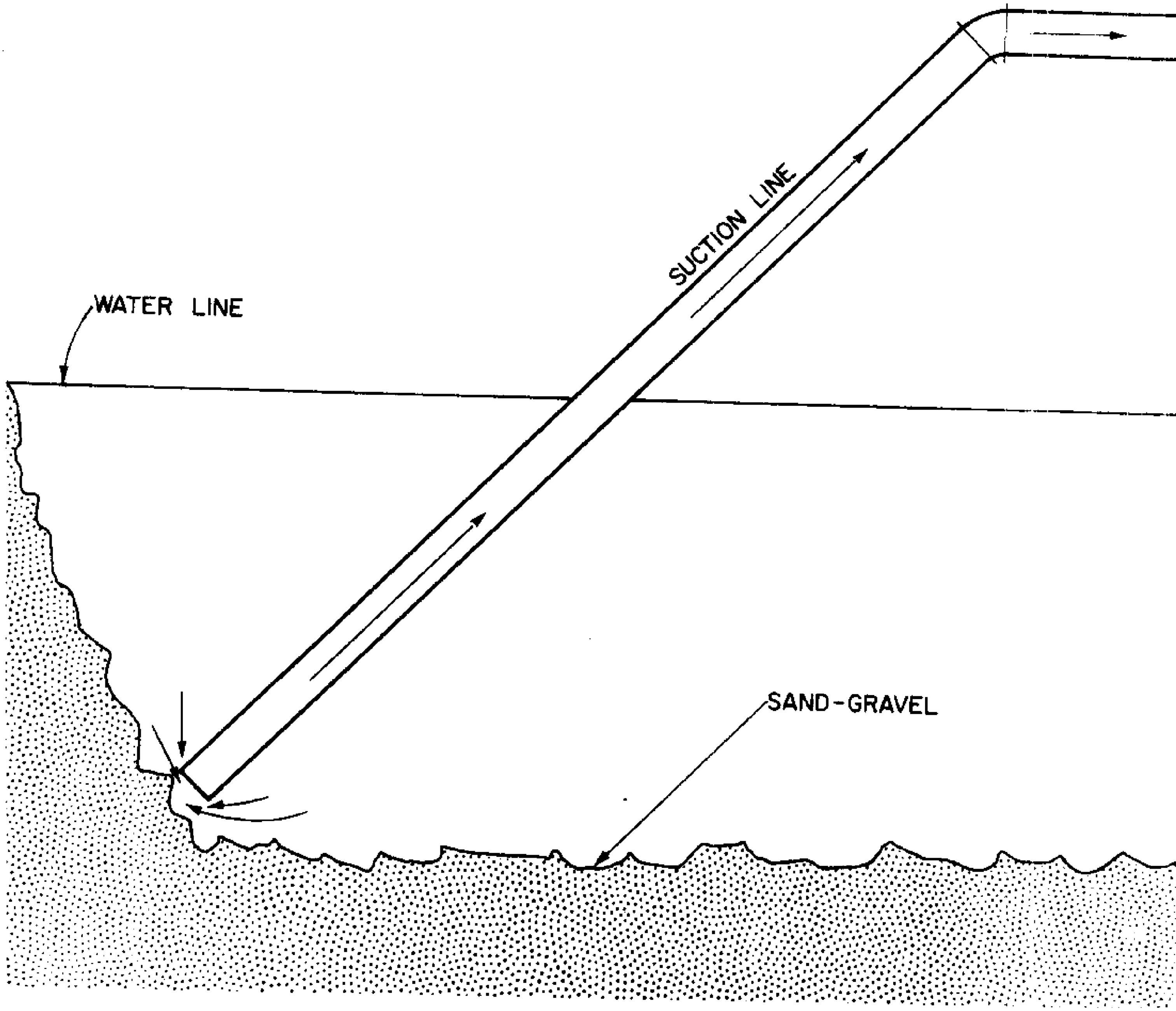

FIG. 3 SUCTION NOZZLE

entrance while increasing the velocity until the material is eroded from its in-situ deposit.

The second design factor is provision for maintaining at least the minimum critical flow of water immediately after a cave-in buries the suction nozzle. All of these factors pose a problem for which research might provide a better solution than we have at present.

The relationship of entrance head lost in excavating material from the deposit to the concentration entrained in the pipe could provide a separate project for investigation. To be useful to the application engineer, the findings need to be reduced to an analytical procedure whose input data requires only a rough classification of the deposit, such as might be obtainable by submitting a core sample to a soils lab, supplemented by an even cruder approach based on grain size distribution and a subjective categorization of the resistance to scour caused by compaction or cementation of the grandular material. Prior work in the study of stream bed erosion might provide a basis to be confirmed by experimental research.

Jet Pumps are by no means new as a dredging tool, but are enjoying a new surge in popularity, perhaps fueled by recent proprietary research. There is well established technology for the design and application of clear water jet pumps, but as usual, the inclusion of abrasive solids in the flow brings on new complications.

First, we must choose between the annular and the solid jet mode of injection. The annular injection creates a uniform cone of high pressure water which should give excellent mixing with the transfer of energy to the induced flow. However, it is penalized by wall friction at two cylindrical boundaries, the O.D. and the I.D. of the injected ring. The solid jet logically has less efficient energy transfer, but only one boundary. It also can be used to inject axially into the suction pipe at a bend

The optimum ratio of the area of the venturi throat to that of the jet flow for a dredging application is complicated by the erosive wear due to solids and the possibility of jamming a large rock in the throat of the venturi.

Perhaps the key difference between the clear water and the dredging application of the jet pump is that of the need to maximize the solids recovery in the suction pipe. The lower critical velocity for transporting solids is a function of the pipe diameter, the effective drag coefficient of the solids, and the concentration of solids. As the concentration increases, the critical velocity increases. Therefore, optimum design for each application must relate the pipe diameter at the suction of the jet pump, the suction flow rate, the jet pump discharge pipe diameter and flow rate, and the concentration of solids.

Having found these optima, it then becomes necessary to determine a combination of dredge pump speed, jet drive pump head and flow and jet orifice area which will produce these flows without cavitation of the dredge pump, the drive pump, or the jet pump. It further becomes economically desirable to do better than just getting <u>a</u> solution by getting the <u>best</u> solution.

I believe that existing knowledge in the area of solids flow is adequate to support an analytical approach to optimizing this combination of parameters but suggest that such a project would be a worthwhile subject for study and development as a practical working tool within the capability of the dredge operator or his pump manufacturer.

Occasionally the need arises for a valve in a slurry or dredge pipeline, such as for temporarily by-passing a booster pump, or for dividing flow in a mine process plant. Conventional valves used in such applications usually have a prognosis of sudden death. Butterfly valves and check valves have been used with better success where protected with rubber or urethane. However, the existing equipment still leaves a lot to be desired. Research might bear fruit in solving this problem; with emphasis on better wear life, minimum flow resistance when open, and correlation of flow resistance to velocity, concentration of solids, and drag coefficient.

Pipe fittings of hard metal work very well. Lately, we have produced additional configurations with urethane rubber. The big research need is a better method of predicting flow resistance. This is particularly true in the case of rubber dredge sleeves. Equivalent lengths for dredge sleeves, by pipe size, have been widely published, but we find variations from the published valves in the order of 600%. I believe this is due to variations in pipeline pressure, sleeve elasticity, placement of clamps, length of gap between steel pipe ends, and angular change in alignment at the joint. (Fig. 4).

With low pressures, stiff sleeves, closely spaced clamps, short gap, and small alignment angle, the resistance closely approximates the classical results for an enlargement plus a contraction using the O.D. and I.D. of the steel pipe. Under the opposite extreme of conditions, we sometimes find apparent valves in excess of the published guides. For long lines with many dredge sleeves, the sleeve resistance can affect the pump discharge head in the order of 30 to 50%. This matter clearly can stand more enlightenment.

With better means of predicting frictional head losses, it becomes possible to set up dredge pumps to optimize production of solids. To illustrate, for any given system, there is some minimum pump speed at which the pipeline becomes clogged at unacceptably low solids concentrations. At this point, the productivity is zero. At the other extreme of high pump speed, there is a limitation imposed usually by cavitation, less often by horsepower availability or by dangerously high pressure in the pump bowl. At this point also, the production approaches zero. For example, the pump speed can be increased to the point where cavitation occurs with just clear water. Somewhere between the lower and upper limits, there is a maximum production capability, determined by the combination of flow and solids

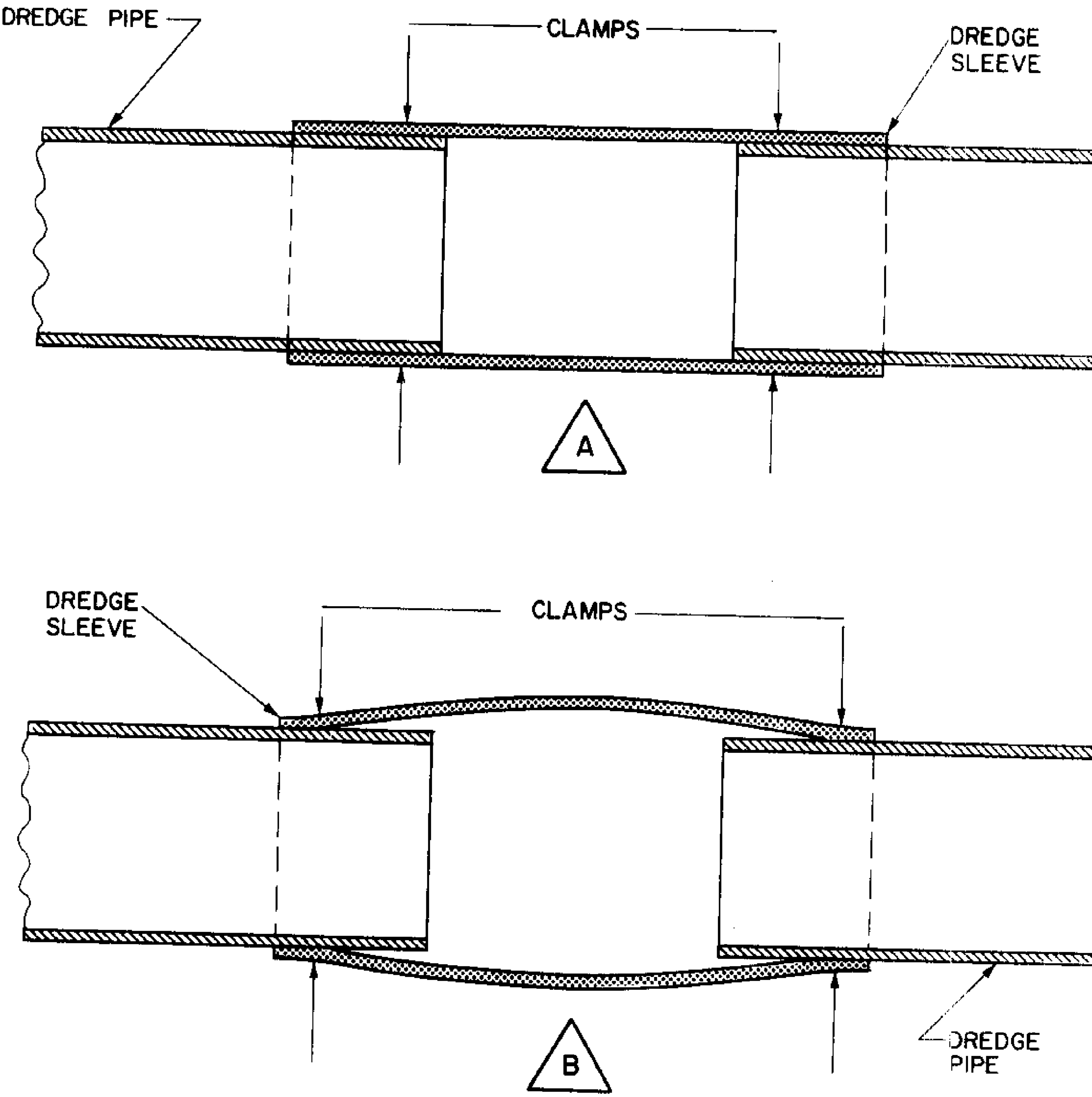

FIG. 4 RUBBER PIPE SLEEVES

concentration. (Fig. 5). We now have the analytical tools to estimate this point reasonably well. When we do, we come up with a pump speed, a vacuum gage reading and a discharge gage reading for this best point. To verify the validity of the input data, especially the drag coefficient and resistance of fittings, we would like very much to measure the flow rate of the mixture and the flow rate of the solids. Recently, here at A&M, the Hydromechanics Lab got an excellent correlation between flow rate measured by a 90° welded elbow and a flow meter. I believe that a little study could produce a method of confirming the specific gravity of the mixture and the flow rate with simple pressure gages. Such a development would then allow the operator to dredge very close to the maximum solids flow for every length of line, simply by controlling with the gages.

One final thought to improve the efficiency of the complete plant or system: We have made some crude studies of dredging economy, considering flow, type and concentration of solids, length and diameter of pipes, annual depreciation of capital equipment (based on estimated actual life rather tax allowances.), operating payroll, pump parts costs, engine maintenance, fuel cost, and pipe replacement cost by pump size. The parameters will, of course, vary widely between dredging companies and specific dredging projects. But what the study shows is that the cost per ton also can vary widely for a fixed installation. For instance, with enough data on a specific project, we could try two and sometimes three sizes of pumps which might reasonably be considered. One size of pump will produce the required tonnage at the least cost per ton. Often, in the case of gravel pits, a larger pump could be paid out quickly because of a substantially lower cost per ton of product.

Most businessmen like to keep their cost data confidential, so I don't really know how much has been done along these lines by dredging contractors, but I do feel quite sure that many small and some large sand and gravel producers are flying blind and passing up opportunities for big cost reductions.

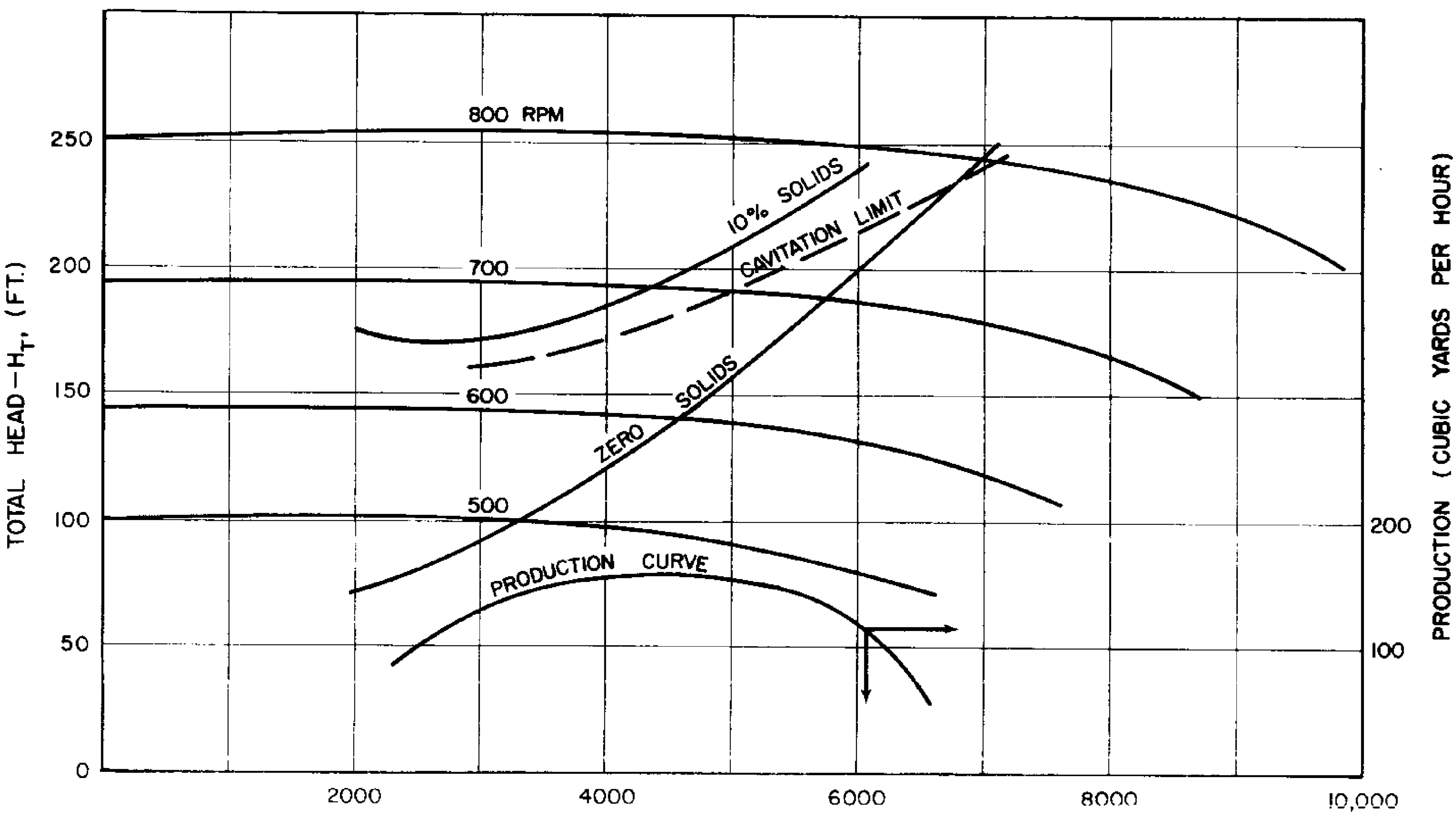

FIG. 5 DREDGE PUMP CHARACTERISTICS

Here is an area where possibly cooperation between dredge operators could produce statistics that would help all to compare their economy to the averages for their type and see where the areas for improvement lie. For example, confidential questionnaires could be collected by the Center for Dredging Studies, tabulated, and correlated in a study of dredging economics, where the sources of data would not be known even to the research workers. Most industries have trade associations which collect confidential statistics, are successful in keeping them confidential, and are able to analyze them to produce data of value to the whole industry. In addition to collecting, analyzing, and publishing economic data, standard forms and guides could be developed for the use of individual companies in analyzing their operations and comparing them with the statistics. The old saying is that you can make more money by increasing sales or by reducing costs. Research in dredging economics ought to show the way to reduce costs.

In summary, it looks like everything new that we learn about dredging raises several more questions that need to be answered. If the industry can get together on financial support for the research, I think that this Center for Dredging Studies has the plant and people to do the job.

SLURRY FLOW IN VERTICAL PIPES

By

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ABSTRACT

In this presentation, the theory of vertical flow is reviewed and the investigations of the major researchers of vertical flow are compared. The basic conclusion reached is that friction head loss for large particles at high velocities is equal to that of water at the same velocity. How large the particles must be, and how great the velocity must be are in doubt; however, guidelines are given in this respect.

INTRODUCTION

The study of the flow of solids through pipe lines has been a subject of major interest to many researchers during the past years. The major emphasis of this work has been placed upon the flow of solids through horizontal pipe lines; this has been due to the fact that the greatest application of this technique was in the transportation of solids from one point to another on land. The study of the flow of solids through a vertical pipe line has, therefore, been regarded as a second cousin, and has been relegated to a back seat position. In addition, vertical flow has been considered to be a simpler problem, and, therefore, has not merited the extensive research required by the more complicated problem of horizontal flow.

For the most part, the major application of vertical flow of solids to date has been in the transportation of mine products vertically out of a mine shaft and to the surface for processing, and it is in this respect that most research on the problems of vertical flow have been undertaken.

Generally these mine-oriented studies anticipated a vertical lift of no more than three hundred meters. In addition to these mine-oriented studies, there have been several other general studies published with no direct application in mind. The sum total of knowledge from all these studies leaves evidence of large gaps of knowledge which have yet to be filled. Over short vertical lifts of no greater than 300 meters these gaps may be of little significance, but for lifts of 3,000 to 7,000 meters which will be common place in the now burgeoning field of marine mining, these technological gaps may, in fact, be of major importance.

All of the studies which have been published to date have been concerned with the vertical flow of solids and water in small diameter pipe lines, that is, pipe lines with diameters of 15 cm or less. Therefore, the study of two-phase flow of water and solids in large diameter pipe lines, that is, pipe lines with diameter of 15 cm to 60 cm or more is an area requiring future study. Also the study of three-phase flow, that is, with air or gas in the mixture, as well as water and solids, in pipe lines with diameters from .25 cm up to 60 cm or more, and also the study of unconventional methods of inducing flow through vertical pipe lines such as new applications of air lift, and applications of such techniques as multi-media lift require extensive study. All of these studies would be of paramount importance to the field of marine mining.

The major researchers who have undertaken studies of vertical flow of solids and water in small diameter pipes and whose work is mentioned in this report are R. Durand, E. Condolios, and P. Kuratin of France, D. N. Newitt of England, S. P. Kostuik of Canada, and M. Toda of Japan.

With the present status of knowledge in vertical flow of solids and water, experimental data are still much in need for clarification of the subject matter. An orderly exposition of experimental results is therefore an indispensible process in gaining physical knowledge of this phenomenon.

The purpose of this brief presentation is not only to give an introduction to the theory of vertical flow, but also to give a review of the experimental results of the above mentioned researchers.

DEFINITIONS

Multi-phase flow problems are complex due to the large number of variables and parameters involved. The complexity of many of the interactions of parameters make empirical investigation sometimes impossible and even clear definitions difficult. The following definitions are necessary in order to gain an understanding of the vertical flow process.

Mean mixture velocity (V_m)* - the mean velocity of the solids-liquid mixture passing any given pipe section.

$$V_m = \frac{\text{volumetric flow rate of mixture}}{\text{cross-sectional area of pipe}}$$

Terminal settling velocity (v_s) - the maximum velocity a single solids particle attains relative to water when allowed to settle under undisturbed conditions.

Hindered Terminal Settling Velocity (v_s') - the maximum mean velocity with respect to the water of a group of particles where each particle is considered to be falling in an obstruction medium. This is a function of the number of particles settling, and the Reynolds' Number of the particles and is a calculated value. Kermack, McKendrick, and Ponder have exhibited the influence of settling velocity on concentration. It can be seen from Fig. 1 that when concentration reaches only 8 per cent, settling velocity drops by 50 per cent as compared to a single particle.

Slip velocity (V_{slip}) - where $V_{slip} = V_w - V_s$. Under actual pipe flow conditions, the settling velocity of solids is influenced not only

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* Symbols and nomenclature are defined at end of paper.

by other particles, but by the pipe wall, the turbulence of the liquid, and many other interactions.

Delivered concentration (C) - the ratio of the volume of solids delivered at the end of a pipe to the total volume of mixture delivered.

Transport (Spatial) concentration (C_t) - the ratio of the volume of solids contained in a length of pipe to the total volume of mixture in that same length of pipe while flowing at a given mixture velocity.

To further illustrate, when delivered concentration is zero, the transport concentration can be any value; this situation occurs when $V_w - V_{slip}$ or when the solids are just being suspended in the pipe by the water velocity. On the other hand, when $V_w = V_s$ or when $V_{slip} = 0$ (at high V_w), then both transport and delivered concentrations are equal.

Lag coefficient (α) - the ratio of delivered concentration to transport concentration. Alpha varies between 0 and 1.

$$\alpha = \frac{C}{C_t}$$

Delivered mixture specific gravity (S_m) - The specific gravity of the mixture as delivered:

$$S_m = 1 + C(S_s - 1)$$

The derivation of this equation is as follows:

$$P_{stat} = LS_m = LS_w + LC(S_s - S_w)$$

if $S_w = 1.0$

$$S_m = 1 + C(S_s - 1)$$

Transport mixture specific gravity (S_{mt}) - the specific gravity of mixture contained within a given section of pipe:

$$S_{mt} = 1 + C_t(S_s - 1)$$

THEORY

If the water moves upward in a pipe of diameter D with mean velocity V_w, and the solids move with mean velocity V_s, and settle downward with mean velocity V_{slip} with respect to the water, and if V_m is as previously defined, then by a mass balance of water flows:

$$A(1 - C)V_m \rho_w = A(1 - C_t)V_w \rho_w \tag{3}$$

or

$$V_w = V_m \frac{1 - C}{1 - C_t} \tag{3a}$$

By a mass balance of solids flow:

$$AC V_m \rho_s = AC_t V_s \rho_s = AC_t(V_w - V_{slip})\rho_s \tag{4}$$

or

$$V_w = V_m(C/C_t) + V_{slip} \tag{4a}$$

From equations (3) and (4):

$$V_m = V_w - C_t V_{slip} \tag{5}$$

and:

$$C_t = -1/2 \left(\frac{V_m}{V_{slip}} - 1\right) + \left[\left(\frac{\frac{V_m}{V_{slip}}}{2}\right)^2 + \frac{V_m}{V_{slip}} C\right]^{1/2} \tag{6}$$

From equation (6) we can see that the transport concentration can be found if V_m, C, and V_{slip} can be determined. V_m and C are easily measured; V_{slip} will be discussed in more detail.

Calculation of pressure drop in a situation such as that of a solid-liquid mixture flowing in a pipe presents a very complicated problem due to the large number of parameters which interact, e.g., solids parameters, fluid parameters, flow parameters, pipe parameters, and so forth. Because of this, a simplified approach has been taken to analyze this dynamic interaction. Such an approach has been taken by most researchers investigating this problem, and has been borne out by experimental result to be a good approximation. Whether or not this simplified approach and the subsequent experimental results are acceptable depends upon the application. This approach has been shown to be acceptable for pumping mine products 200 meters vertically, but is not necessarily acceptable for pumping ocean minerals 3,000 - 7,000 meters.

The simplified approach which is generally used is that head loss be attributed to several major fundamental interactions, and that the arithmetic sum of these will equal the total head loss for the mixture. The major sources of head loss are a) static head loss due to the suspended solids, b) head loss in the flowing fluid caused by the pipe wall, c) head loss required to suspend the solids, d) head loss due to the flowing solids interacting with one another, e) and head loss associated with the solids interacting with the pipe wall. It should be carefully noted that the flowing fluid and the solid particles are being treated as separate entities in this simplified view. It must also be noted that this approach holds true only for mixtures which are not collodal in nature; it does not hold for homogeneous suspensions where the solid particles alter the viscosity of the water, but only for heterogeneous suspensions of solids where the water viscosity is not altered.

Under the above simplifying assumptions, the total measureable head at the bottom of a vertical pipe of length L carrying a solids-water mixture at mean velocity V_m is the sum of the static head due to the solids and liquid and the pressure drop of the mixture due to flow losses:

$$\text{TOTAL HEAD} - \text{STATIC HEAD} + \Delta P_{friction}$$

$$\text{STATIC HEAD} \quad LS_m = S_w(1 - C_t)\,L + S_s\,C_t\,L$$

or per unit length of pipe where $S_w = 1$:

$$i_{stat} = (1 + C_t(S_s - 1))$$

where is the static head due to the pipe of unit length full of water and $C_t(S_s - 1)$ is the contribution of the solids of concentration C_t and specific gravity S_s.

The flow losses are the sum of the head loss due to water plus the head loss required to suspend the particles, plus the head loss due to particle - particle, and particle - wall interactions.

$$\text{Flow Losses} = \Delta P_w + \Delta P_{sus} + \Delta P_{s.\ inter.}$$

The head loss due to the flowing water is known from the familiar Darcy equation:

$$\Delta P_w = \frac{fLV_w^2}{D2g}$$

or per unit length of pipe:

$$i_w = \frac{fV_w^2}{2gD}$$

The head loss to suspend the solids in the flowing stream is determined as follows: In time L/V_w the solid particles move a distance $(V_{slip}/V_w)L$ with respect to the water. Therefore:

$$\text{Work to suspend particles} = C_t Qg(\rho_s - \rho_w)L \ \frac{V_{slip}}{V_w}$$

This same work determined from the head loss i_{sus} is:

$$\text{work} = i_{sus}\rho_w Qg1$$

Equating these:

$$i_{sus} = \frac{C_t(\rho_s - \rho_w)}{\rho_w} \ \frac{V_{slip}}{V_w}$$

$$i_{sus} = C_t(S_s - 1)\,\frac{V_{slip}}{V_w}$$

Total head per unit length of pipe is:

$$i = i_{stat} + i_{fric} = i_{stat} + i_w + i_{sus} + i_{inter}$$

$$i = 1 + C_t(S_s - 1) + i_w + C_t(S_s - 1)\,\frac{V_{slip}}{V_w} + i_{inter}$$

Total head loss due to friction forces is:

$$i_{fric} = i_w + C_t(S_s - 1)\,\frac{V_{slip}}{V_w} + i_{inter}$$

The quantity $C_t(S_s - 1)\,\frac{V_{slip}}{V_w}$ and i_{inter} will be small in turbulent pipe flow because (V_{slip}/V_w) is very small when compared with the head loss associated with water (i_w).

RESULTS OF PREVIOUS INVESTIGATIONS

Test parameters

Basic test parameters for various investigations mentioned are shown in Table 1.

Head loss

Numerous investigations have been conducted in order to determine the value of the head loss gradient i_{fric}. The experimental results of Condolios et. al., are shown in Fig. 2, and those of Toda, et. al., in Fig. 3. Both of these investigators and Durand reached the same conclusion.

Friction losses for vertical flow of a solids-water mixture are the same as for clear water, and the pressure difference between two points measured in terms of water head is the algebraic sum of the friction loss due to water plus the static head of the solids suspended in the water.

$$\Delta P/L = i_w + C_t(S_s - 1)$$

Kostuik (5) qualifies this conclusion in his statement that "the friction loss in the vertical conveyance of slurries in pipes is equal to the friction loss of water at the same velocity provided that $V_m/v_s > 10$."

This coincides generally with the conclusions of Newitt, et. al.[7] Newitt concluded the following:

a) Large particles - Slurries composed of particles having terminal falling velocities in the transition and turbulent flow regions are found to give frictional pressure drops which are either identical with the water-friction pressure drop at all velocities or which are slightly higher at low velocity but tend to the water-friction value at high velocities.

b) Small particles - Slurries composed of small particles of sand and also zircon give pressure drop-velocity curves which, at any given slurry concentration, diverge from the corresponding water-friction curve as the velocity increases.

Results for the small particles were found to be correlated by:

$$\frac{i - i_w}{Ci_w} = .0037 \left(\frac{gD}{V_m^2}\right)^{\frac{1}{2}} \left(\frac{D}{d_s}\right) S_s^2$$

Particle slip velocity

Particle slip velocity (V_{slip}) is a key to the solution of the thecretical equations as presented in this report. If the value of V_{slip} can be determined for any given set of conditions, then the relationship between transport concentration and delivered concentration, and also the relationship for friction pressure drop can easily be determined. As has been explained in the definition section, the V_{slip} is a function of many parameters, some of these being size and specific gravity of the solids, location of the pipe walls, the concentration of solids in a particular mixture, and also the effect of turbulence and shear rate created in the flow of fluid through the pipe. The effect of each of these parameters can be determined from experiment, except for the effects of the turbulence and shear rate created by the flow of fluid through the pipe. This effect can not be simulated except under actual conditions. Several approaches have been taken by investigators toward solving this problem. For the most part, these investigators have accepted the value of the hindered fall velocity of the particle as the value of V_{slip}. Because these two values may be very close under certain conditions, this method can be acceptable.

Condolios considered the problem with only the value of mean settling velocity of an isolated particle in a static fluid medium. The study by Kermack, McKendrick, and Ponder (Fig. 1) is mentioned by him, showing that this terminal fall velocity is greatly reduced in an obstructing medium.

Kostuik operates under the assumption that V_{slip} is the same as the hindered terminal fall velocity which can be determined by using curves developed by Bonnington, or the previously mentioned study by Kermack, McKendrick and Ponder.

Newitt on the other hand did not approach this problem directly. He defined V_{slip} as defined in this paper, as the difference between water velocity and the solids velocity, and then pursued the problem no further.

Toda (8) approached this problem more directly than any of the others, yet has still missed the mark of finding a value for V_{slip}. Toda measured both the velocity of a single particle in a verticle pipe line, and the mean velocity of a group of particles in a vertical pipe line. This procedure will not yield a value for V_{slip} because the location of the particle in the pipe cannot be determined. The same is true for the measurement of the mean velocity of a group of particles; the distribution of the particles cannot be determined. The importance of the particle location will be made obvious in the following discussion.

Velocity profiles

Water velocity profiles have been measured by several investigators. Durand (4) reached the conclusion that with up to 80% sand in a 15 cm pipe, there was little or no change of the water velocity profile in a mixture from that of pure water. Condolios (2) made the same conclusion with up to 15% sand.

However, Newitt and Toda state that either decreasing velocity at a given concentration, or increasing concentration at a given velocity, or both, causes the velocity profile to flatten towards the center of the pipe as compared to the parabolic profile for pure water. The results of Newitt can be seen in Fig. 4 and those of Toda in Figs. 5 and 6. Newitt explains with reference to Fig. 4: "The addition of the sand (C = 5% to C = 10%) has, therefore, reduced the maximum water velocity by about 10%. It should be noted, however, that the measured velocity near the pipe wall is greater than it would be if no sand were present.

On increasing the solids concentration to 15%, these effects are enhanced and the profile is almost flat over most of the cross section of the pipe with a very steep gradient near the wall. It may be supposed that the moving particles act in a manner analogous to that of a stationary wire screen breaking up the larger turbulent eddies and smoothing the flow."

Solids distribution

Solids distribution has been shown by Condolios and Durand to be even across the cross-sectional area of the pipe; however in both cases, measurements were not taken in the outermost section of the pipe where the velocity gradient is the steepest and where we would expect the solids concentration gradient to be greatest also.

Photographs (Toda, et. al.) of a flowing mixture in a clear section of pipe are shown in Fig. 7. It can be seen that the solids are concentrated toward the axis of the pipe. Photographs presented by Newitt are similar.

Toda, et. al., examined the velocity of a single particle as well as that of the mass of particles. The velocity of a single particle in the pipe was measured by means of photoelectric cells and the velocity of particles in a slurry by means of radioactive particles and scintillation counters. The findings for the relationship between mean particle velocity and the velocity of a slurry are shown in Fig. 8. It can be seen from the Fig. 8 that the mean particle velocity exceeds the mean slurry velocity above a certain value of V_m. It also shows that with increasing velocity of the slurry, solid particles tend to move more closely towards the center of the pipe. This is probably due to a combination of effects - Magnus force, and turbulence effects.

As stated by Toda, et. al.: "It is seen from the figure that the particle velocity exceeds the mean flow velocity of the water when the velocity is greater than a certain threshold value. It is assumed that with increasing flow velocity, the probability of particles passing near the pipe axis increases relatively. In this respect the behavior of a single particle resembles the behavior of particles in a slurry stream."

The following empirical equation was proposed by Toda to describe the mean velocity of a particle in a vertical pipe taking into consideration the velocity profile.

$$1.23 - U_s/V_w = 1.03\ (ds/D)^{0.18}\ (gD/V_w^2)^{0.43}\ (P_s/P_w - 1)^{0.45}$$

The accuracy of this empirical equation was stated to be $\pm$ 30%.

CONCLUSIONS

The following general conclusions concerning the vertical flow of water-solid slurries can be made from the previous investigations presented. These conclusions are of necessity "general" because experimental data are still much in need for clarification of the subject matter.

1) Friction head loss for large particles at high velocities is equal to that of water at the same velocity. How large the particles must be and how high the velocity must be are in doubt; however, the following guidelines from Kostuik and Newitt may be used:

"Large particles" may be defined as particle diameters greater than .01 in. "High velocities" may be defined as the ratio of mean slurry velocity to mean particle fall velocity be held greater than 10.

Kostuik further adds: "On the basis of observation, the minimum velocity which should be used for vertical transport is 1.5 times the unhindered terminal fall velocity of the largest particle in a given size range. To present pipe blockage, the largest particle diameter should not exceed one-third of the pipe diameter.

2) Particles tend towards the centerline of the pipe as velocity and solids size increase resulting in an even distribution over the center of the pipe, and zero distribution towards the walls.

3) As velocity decreases, and/or solids concentration increases, the velocity profile flattens at the center of the pipe as compared to plain water.

4) The true slip velocity of a particle in a stream has not been defined.

NOMENCLATURE AND SYMBOLS

Subscripts l, w, s, and m refer to liquid, water, solid, and mixture.

α	= lag coefficient	(-)
A	= cross sectional area of pipe	(m^2)
β	= coefficient of hindered settling velocity	(-)
C	= delivered concentration (volume fraction)	(-)
C_t	= transport (spatial) concentration (volume fraction)	(-)
D	= internal diameter of pipe	(m)

d_s	= diameter of particle	(m)
f_w	= Fanning friction factor (water)	(-)
S	= specific weight	(N/m^3)
g	= acceleration due to gravity	(m/s^2)
i	= hydraulic gradient (m water/m pipe)	(-)
i_{sus}	= hydraulic gradient to suspend solids	(-)
K	= constant	(-)
L	= length	(m)
N_R	= pipe Reynolds Number	(-)
N_r	= particle Reynolds Number	(-)
v	= volume	(m^3)
q	= volumetric flow rate	(m^3/S)
P	= pressure differential (water)	(m)
R	= pipe radius	(m)
S	= specific gravity	(-)
S_m	= mixture specific gravity (delivered)	(-)
S_{mt}	= mixture specific gravity (transport)	(-)
V	= local velocity	(m/s)
$\bar{V}$	= mean velocity	(m/s)
V_{slip}	= local slip velocity of a particle $(V_w - V_s)$	(m/s)
V_{slip}	= mean slip velocity of solids $(\bar{V}_w - \bar{V}_s)$	(m/s)
ν_s	= terminal settling velocity of particle	(m/s)
ν_s'	= hindered settling velocity of solids	(m/s)
ρ	= density	(g/cm^3)
μ	= viscosity	$(N\text{-}S/M^2)$

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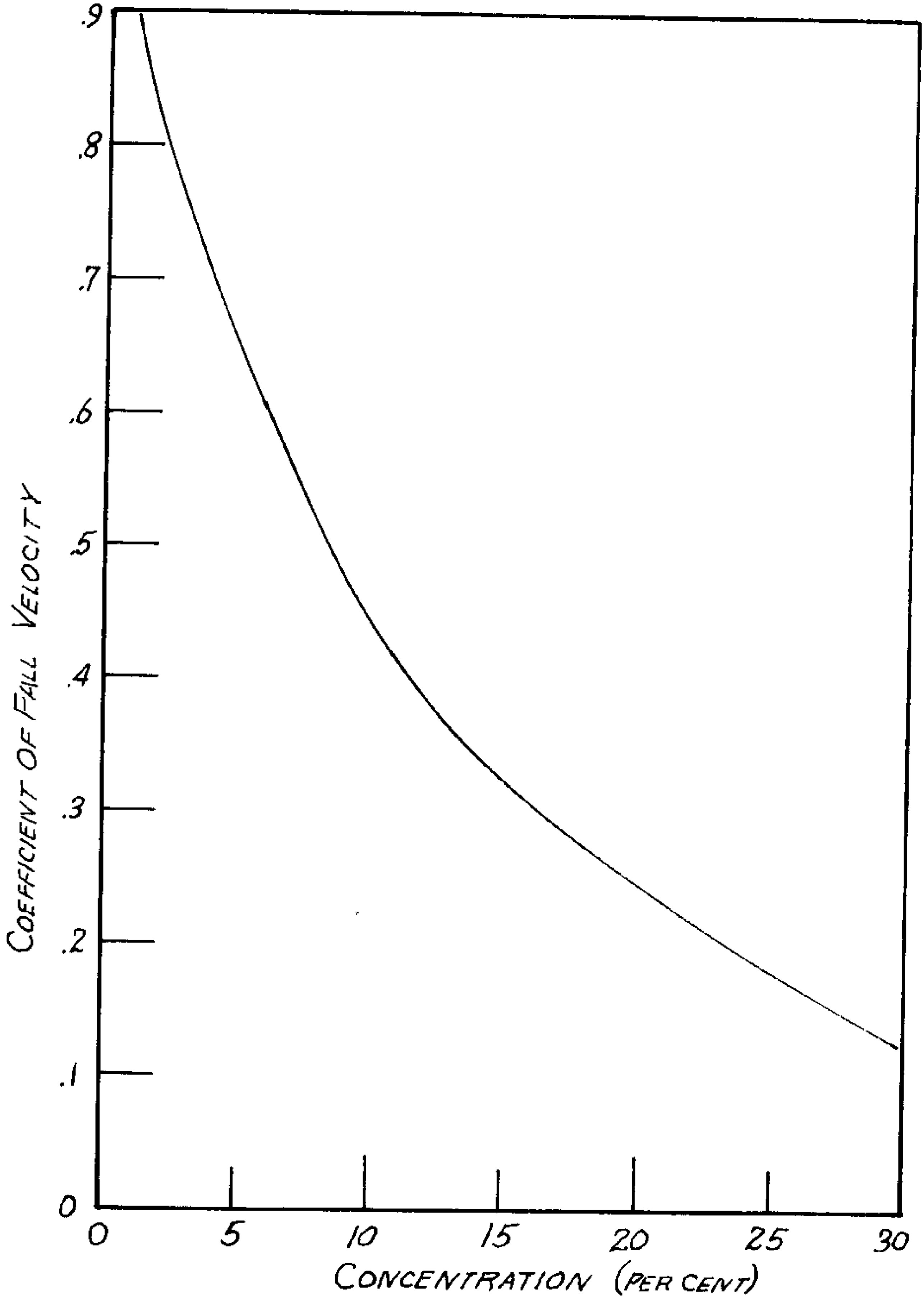


Fig. 1. Effect of solids concentration on terminal fall velocity. (Kermack, McKendrick, & Ponder)

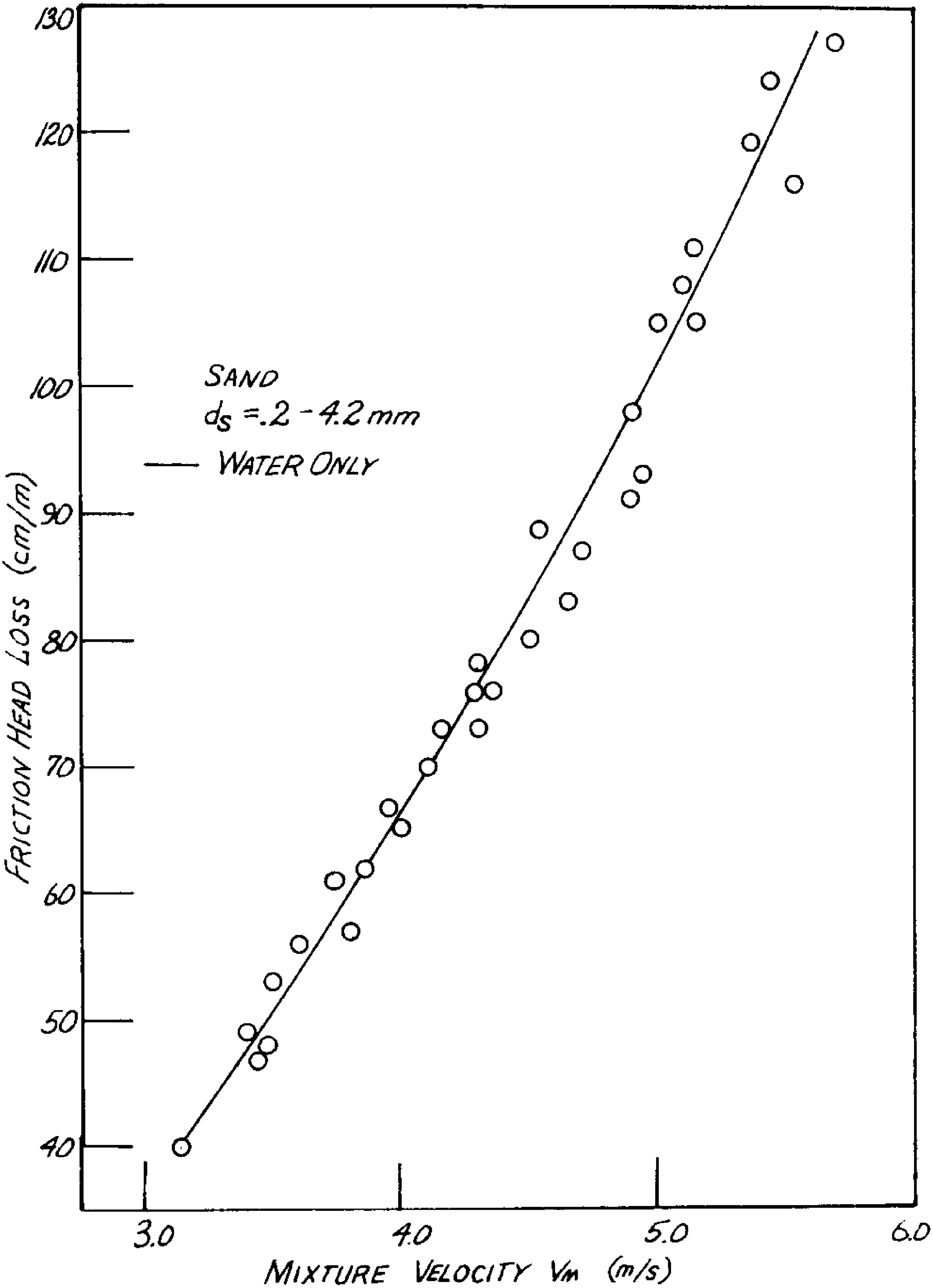


Fig. 2. Comparison of head loss for plain water and water-solid slurries. (Condolios)

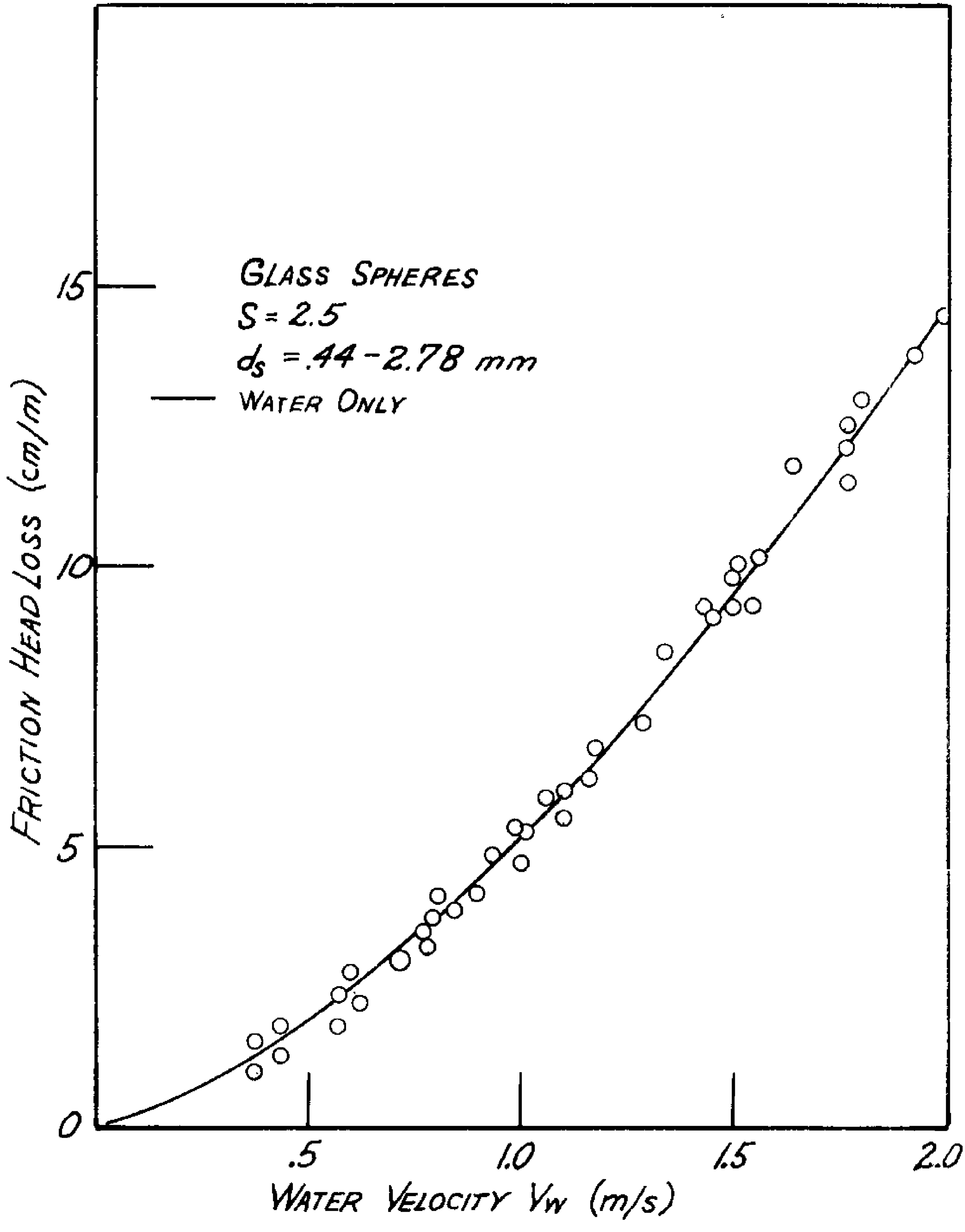


Fig. 3. (Toda, et.al.)

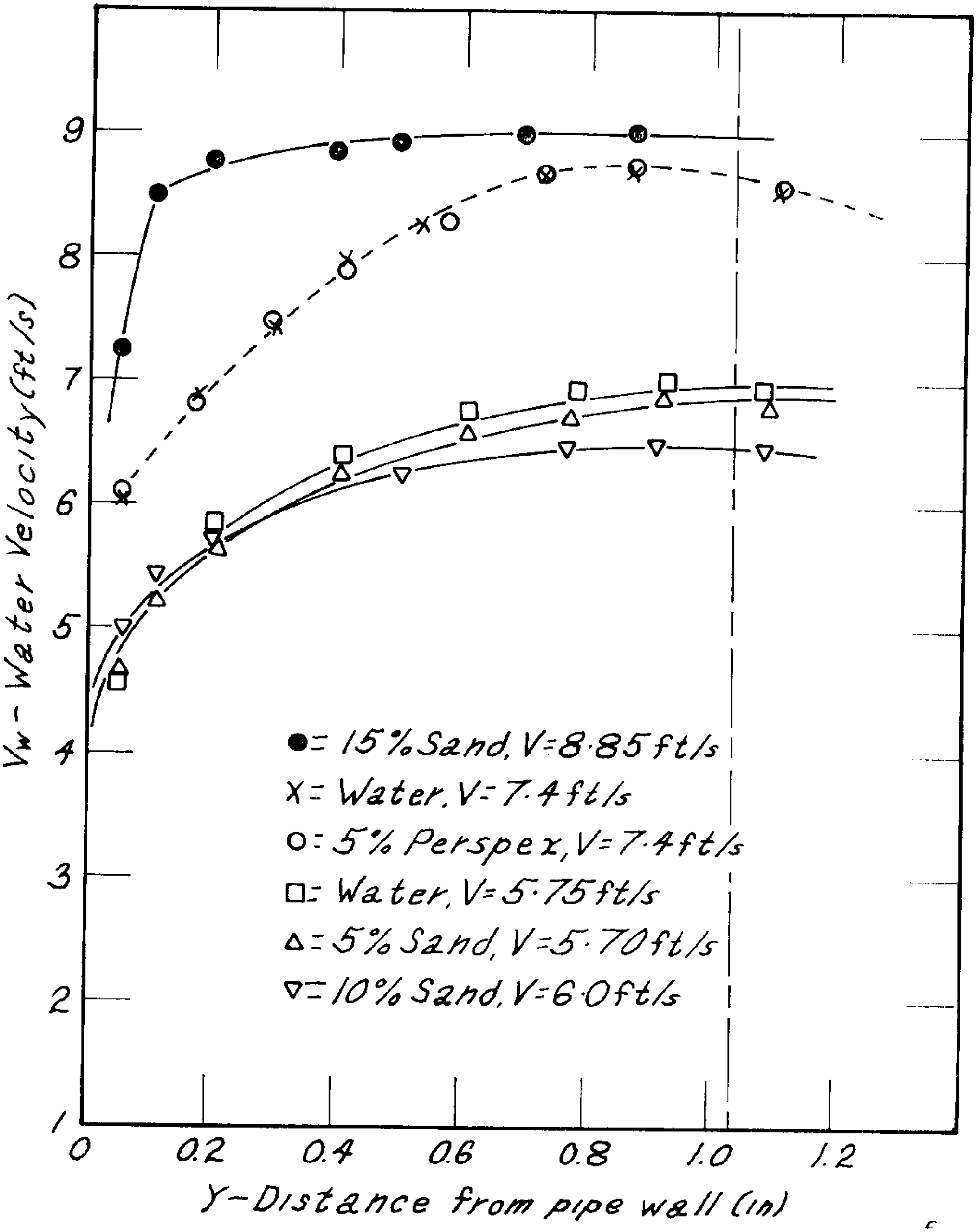


Fig. 4. Effect of solids on water velocity profiles.
(Newitt)

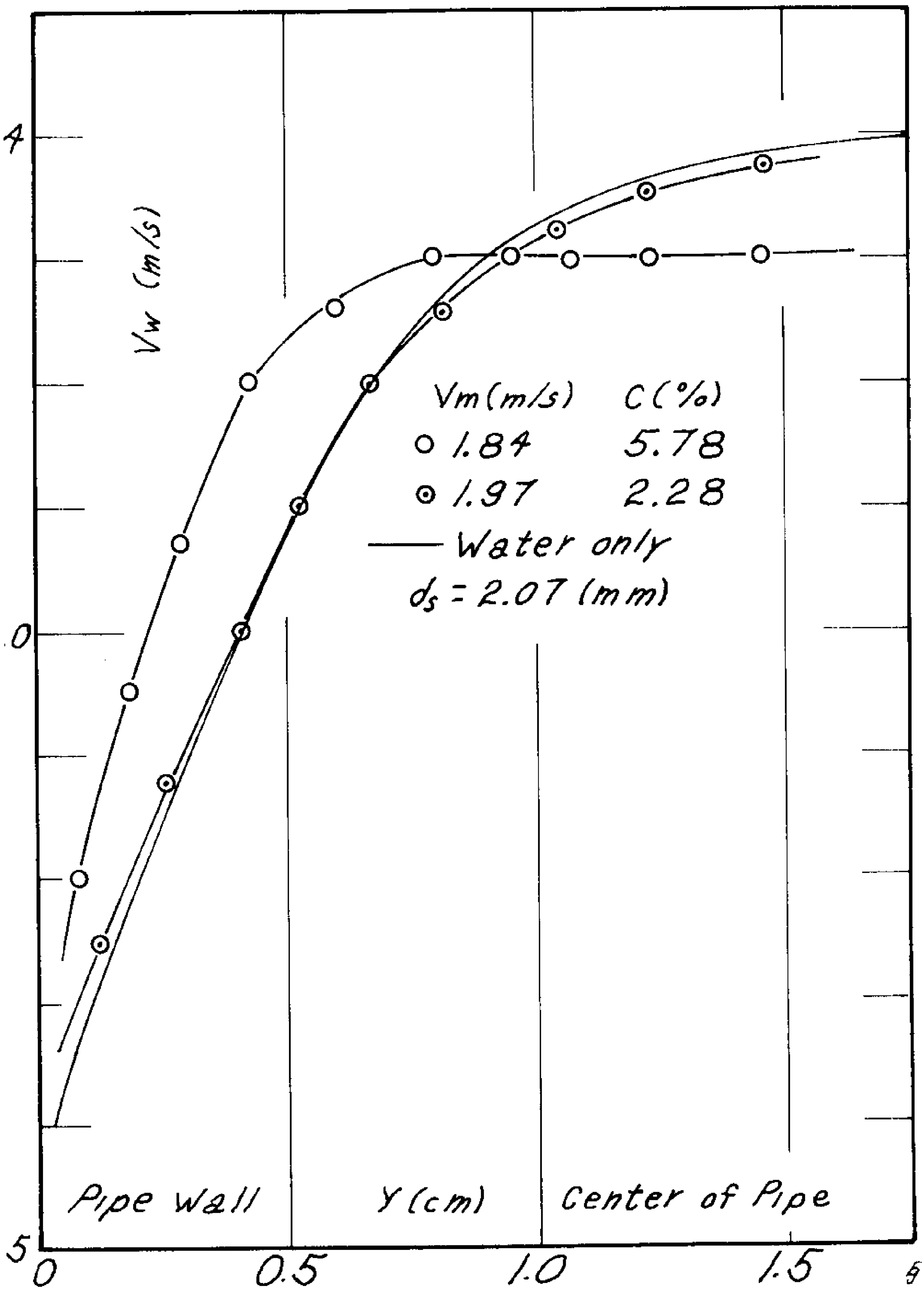


Fig. 5. Effect of varying concentrations of glass spheres on water velocity profiles. (Toda, et. al.)

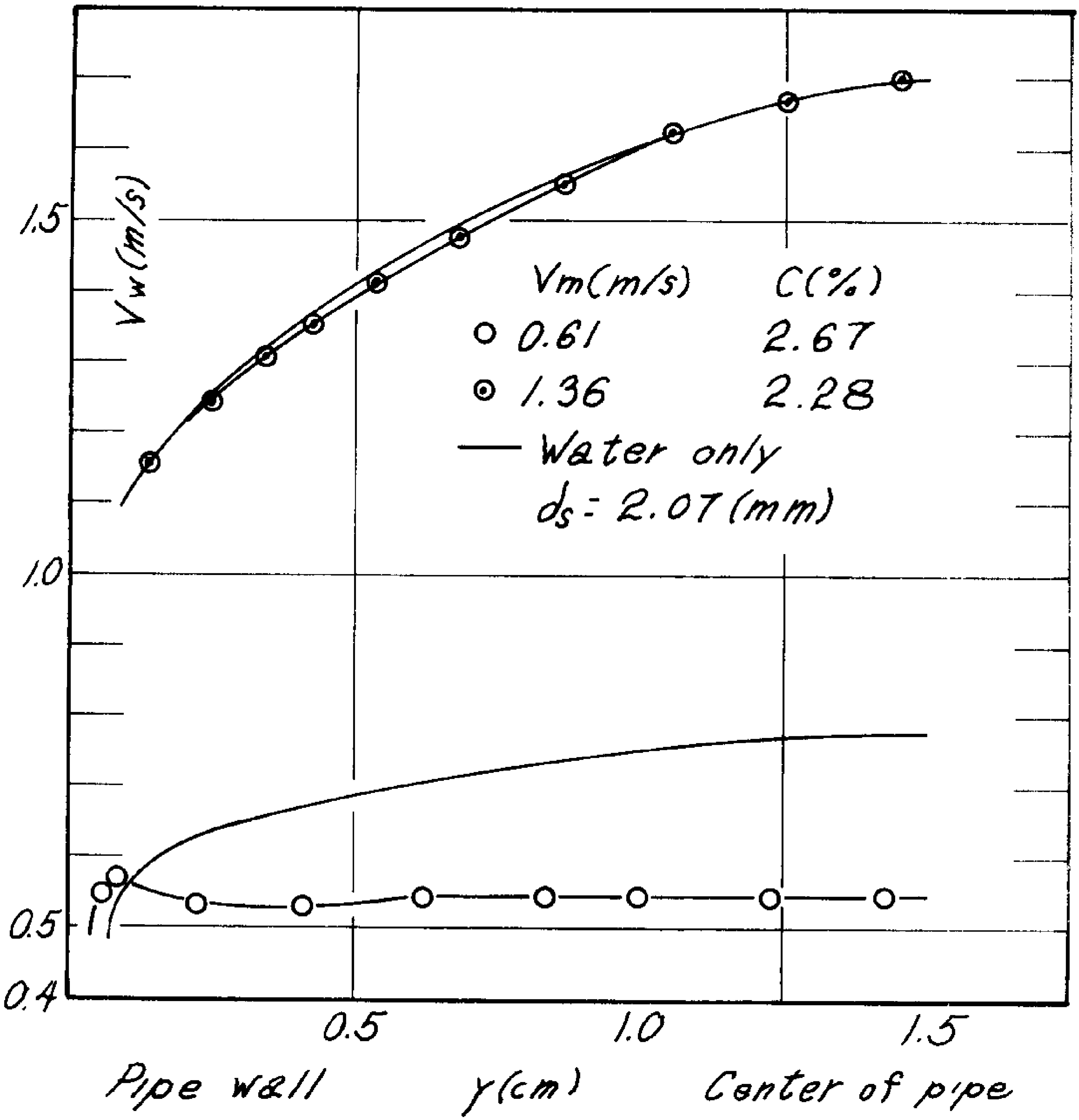
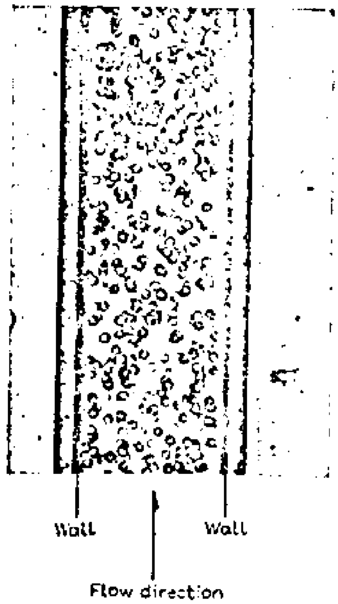
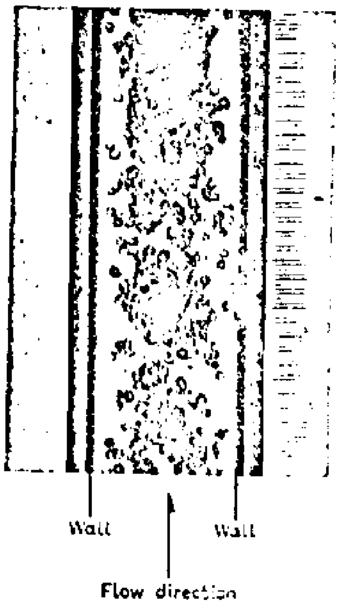


Fig. 6. (Toda, et.al.)



U_m=0.61 [m/s], m_c=2.67 [%], d_s=2.07 [mmφ]

Fig. 8 Flow of water suspension of glass particles in 1 in. diameter vertical pipeline



U_m=1.36 [m/s], m_c=2.28 [%], d_s=2.07 [mmφ]

Fig. 7. Flow of glass particled in 1 inch dia. pipe. (Toda, et. al.)

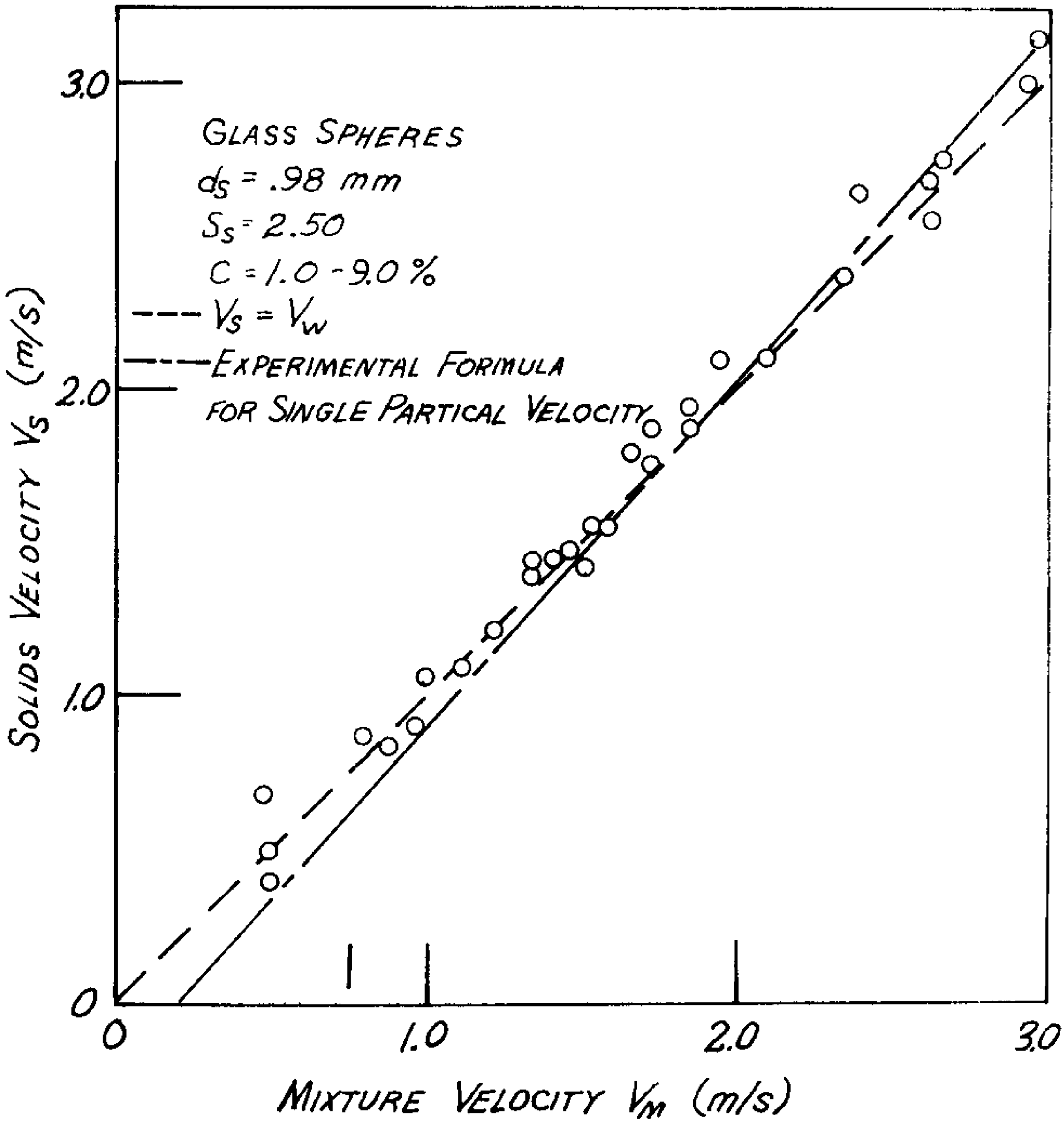


Fig. 8. Comparison of formula for single particle velocity with experimental results. (Toda, et. al.)

Investigator	Pipe Size and Material	Solids			Velocity Range and Solids Concentration Range
		Material	S_s	d_s (mm)	
R. Durand 1953	150mm dia. Material unknown	Sand Sand Sand	2.65 2.65 2.65	.18 1.0 4.6	C = 0 - 8%
Newitt, D. M. Richardson, J. F. Glidden, B. J. 1960	25.5mm dia. brass 51.mm dia. galv. steel	Sand Zircon MnO_2 Perspex	2.64 4.56 4.20 1.19	.102-3.81 .109 1.37 1.22	V_m = 0 -3.66 m/s C = 0 - 30%
Condolios, E. Couratin, P. 1963	152.5mm Material unknown	Wide range small particles also coal		< 82.5	$V_m \cong$ 0 -4.0 m/s C $\cong$ 0 - 15%
Kostuik, S. P. 1966	76.2mm dia. aluminum	Crushed Magnetite	4.08	2.7	V_m = 0 - 4.57 m/s C = 0 - 20%
Toda, M. Konno, H. Satto, S. Maeda, S. 1969	42.55mm I.D. Acrylic	Glass Plastic Coated Steel Plastic Steel	2.5 4.9 1.2 7.7	.44-3.55 10 6.0-10. 8.0	V_m = 0 - 3 m/s

Table 1. Basic Test Parameters of Investigations.

WATER QUALITY AND THE DREDGING INDUSTRY

by

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INTRODUCTION

During the past few years the Dredging Industry has become increasingly involved in the Environmental Quality Reform Movement. The involvement has to some extent been forced on a reluctant industry as a result of the dredging industries activities in the use of dredging as a tool for Environmental Modification and as a secondary source of Environmental Pollution.

In this presentation the author will explore briefly the concepts of Environmental Modification and Environmental Pollution as they apply to the dredging industry and present alternate courses of action which may be followed by the industry in relationship to the quest for a better environmental quality.

The author's studies relating to the source of organic sludges in the Houston Ship Channel, the quantity and quality of the resultant organic sludge deposits, the nature of the affect of these sludge deposits on the overlying waters, and the rate of buildup and removal of these sludges will each be presented along with conclusions needed for developing management plans for the Houston Ship Channel.

THE DREDGING INDUSTRY AND ENVIRONMENTAL MODIFICATION

In Coastal Bays, Marshes, and Estuaries and in the major navigable rivers of the world the major force to alter the environment is exercised by the dredging industry. This capability is utilized to direct the course of rivers, to dredge and maintain shipping channels, to fill and drain coastal land areas; to mine materials from reefs and from sub-bottom deposits and in a multitude of other activities.

When the scope of these activities is small when measured against the overall environmental aspects of a region, the cost in terms of environmental change may be negligible when measured against the social and economic benefits derived from the activity. When, however, the environmental effect is drastic such as occurs when huge marshland areas such as the Florida Everglades are drained, when significant filling of shallow aquatic areas is achieved as in the San Francisco Bay area, when deep draft channels and spoil bank islands significantly effect the physical and chemical structures of shallow estuaries as in Galveston Bay, and when major water diversions are contemplated as with possible Mississippi River diversions, it is necessary to anticipate the effect of such modification to the affected Ecological Systems and to carefully include both short and long term effects in making the judgement decisions relative to the economic and social justification for such large scale projects.

The above statement should be in no way considered as an endorsement of the status quo or an indictment for all environmental modification. A misconception which often is associated with the word "ecology" is the implication that todays system in a fixed and unchanging form is the best for mankind. Ecology is better defined in terms of the dynamic behavior of organisms to the variations existing in its environment. A modification may bring about a beneficial change to some organisms and an adverse effect to others.

Similarly a vast majority of the environmental changes wrought in the past have greatly benefited mankind.

On the other hand many people are coming to realize that the number of unaltered systems is finite and decreasing, they are concerned about those modifications that have had irreversible side effects, and they are becoming increasingly vocal in pointing out that "haste makes waste" and in urging a "look before you leap" philosophy. The fate of the dredging industry in future decades will be shaped by this growing concern for the long term preservation of our environment.

THE DREDGING INDUSTRY AND ENVIRONMENTAL POLLUTION

Environmental Pollution is a related problem which is also affecting the dredging industry.

A great portion of the physical, chemical and biological pollutants which are discharged into our waterways end up as bottom deposits in our navigable waterways and estuaries.

The dredging industry which has for decades been called on to move or remove these sediment materials is now coming under fire for the secondary pollution effects involved in the re-suspension and re-depositing of these materials.

The danger from this secondary pollution is particularly great where the bottom deposits may have unusually high pesticide, radio-nuclide or virus levels as a result of adsorption of these materials into sediment particles, where the bottom deposits are made up of large quantities of unoxidized organic material which may or may not be "preserved" by toxic constituents, where the deposits have high percentages of petroleum or petrochemical derivatives and where high nutrient levels exist in the bottom deposits.

THE HOUSTON SHIP CHANNEL - GALVESTON BAY SYSTEM

The Houston Ship Channel - Galveston Bay System (Fig. 1) is an estuarine system which has undergone substantial Environmental Modification and which is subjected to excessive levels of Environmental Pollution.

The Houston Ship Channel, which is a major Environmental Modification in itself, was dredged 25 miles across shallow Galveston Bay and another 25 miles

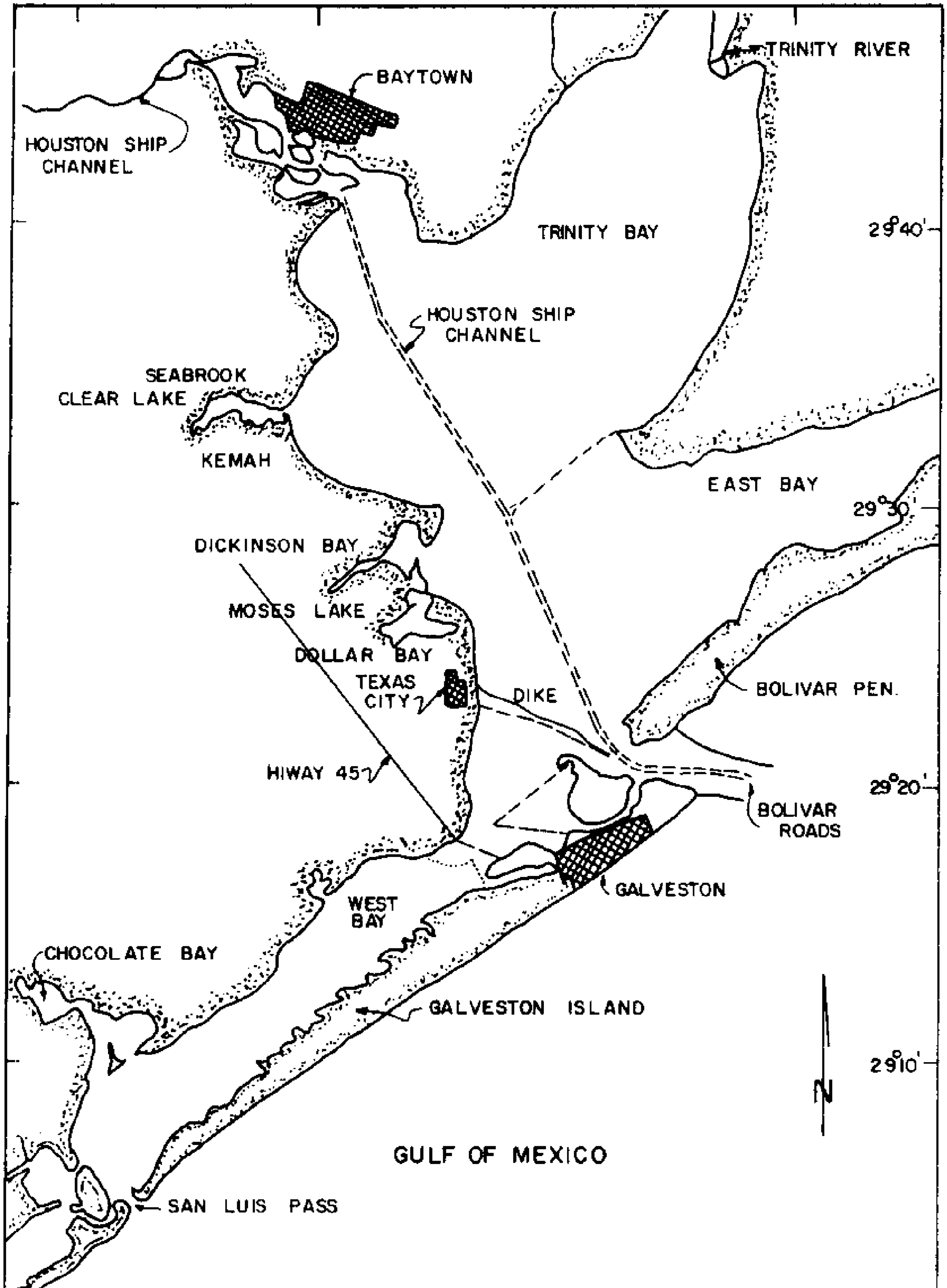

FIGURE 1

GALVESTON BAY AREA

up shallow bayous to near downtown Houston, Texas, USA. This channel has made Houston the third ranked port in the United States and the home of the most extensive petrochemical complex in the world. This development has, however, when coupled with the narrow confines of the channel and the minimal tidal action and limited freshwater flushing, caused a condition of environmental pollution believed to be unequaled in any port in the world or in any aquatic system in the United States. Figure 2 shows the project area in the 25 mile stretch of the Houston Ship Channel above Morgans Point.

The particular pollutants which are of significance in this system are biodegradable organic materials, petroleum and petrochemical organics, nutrients and toxic metal ions.

As a part of a broad research effort being carried out by the Estuarine Systems Projects staff of Texas A&M University, a major effort has been carried out to evaluate the role these sediment materials and their removal in the pollutant mass balances of the system.

This research effort is part of a broad research program to develop steady state and dynamic analytical models to predict the dispersion and ultimate fate of pollutants in estuarine waters. These analytical models involve the making of mass balances of the materials being analyzed within finite segments of the channels length.

A simplified example of the segment mass balance is shown in Figure 3 for organic waste material as the pollutant and dissolved oxygen as a secondary water quality parameter.

It is obvious that for a realistic evaluation to be made for a pollutant in a system it is necessary to evaluate the removal to and the return from the bottom sediments.

The purpose of the research reported herein was to evaluate the net removal of organic material from the aquatic system into the bottom sediments.

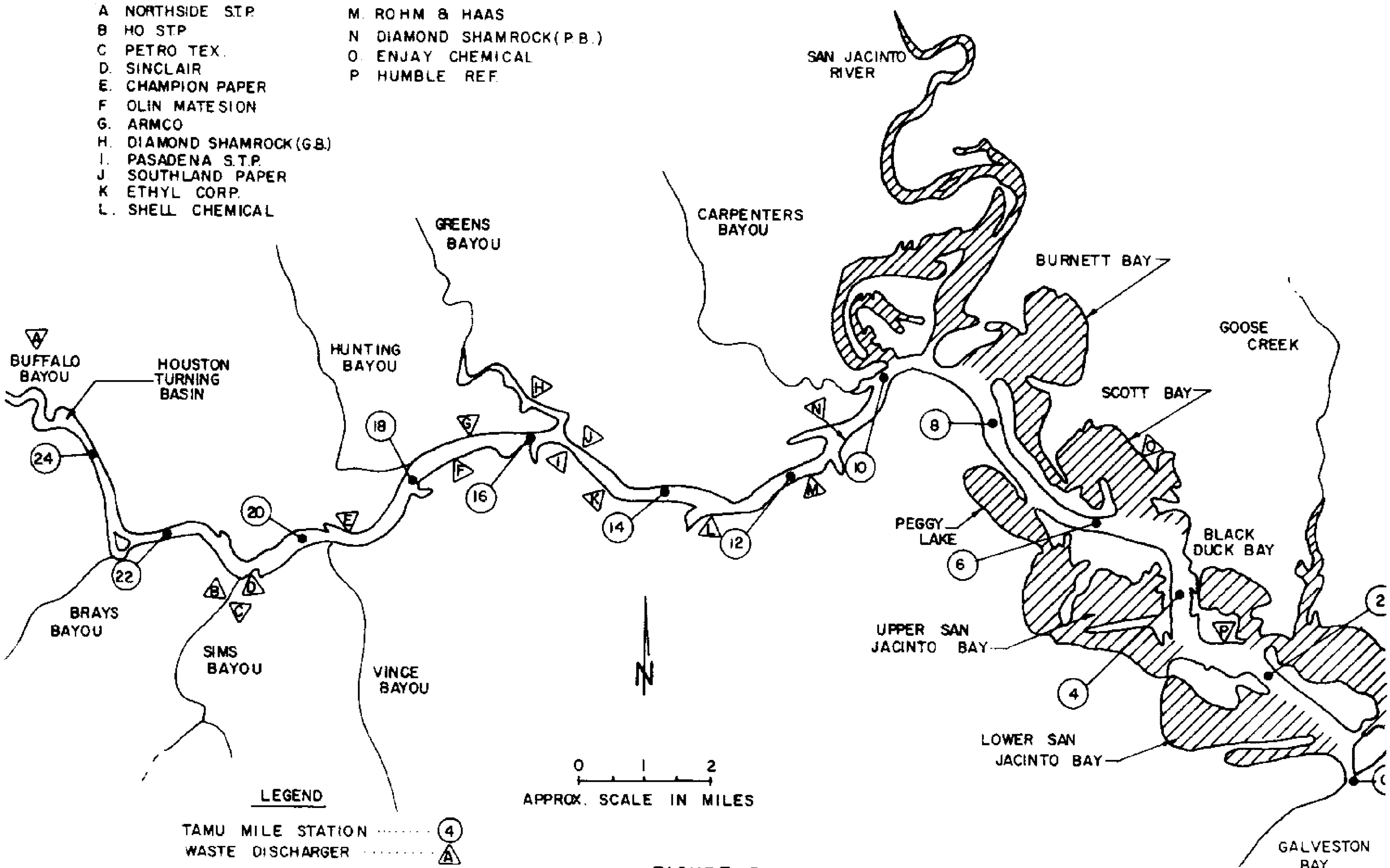

FIGURE 2

LOCATION OF DOMESTIC AND INDUSTRIAL DISCHARGES ON THE HOUSTON SHIP CHANNEL

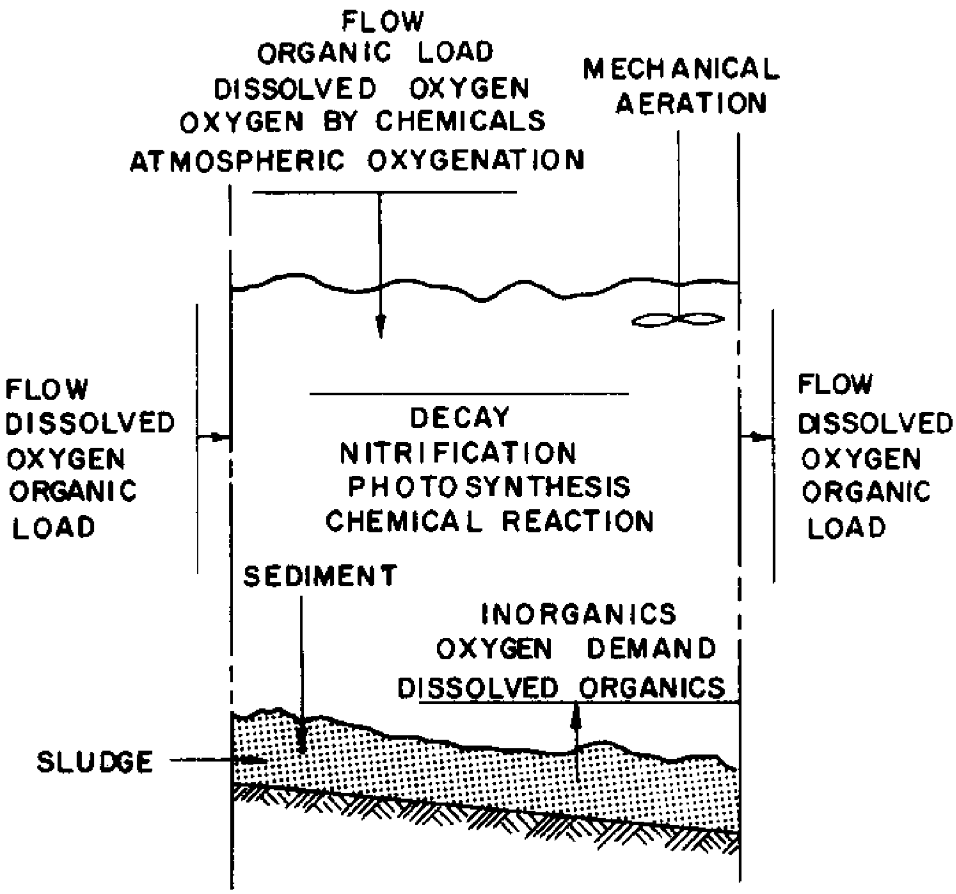

FIGURE 3

OXYGEN BALANCE IN A SEGMENT

A companion project is underway to evaluate the return effect of the sediment materials on the overlaying waters in terms of benthal oxygen demand and leached organic and other materials.

PROJECT PLAN

The primary project activity involved the evaluation of the pollutional input into the channel in terms of organic material and the evaluation of fraction thereof which was deposited as bottom sediment and removed by dredging.

The total input into the system is evaluated by the equation:

Total input = Domestic Waste Loading + Industrial Waste Loading + Runoff Loading

The domestic waste load input was evaluated from records of the City of Houston and the Texas Water Quality Board. The industrial waste inflows were evaluated from records of the Texas Water Quality Board and other sources. The urban runoff was evaluated by multiplying runoff quantity by runoff quality.

The runoff quantity was determined by utilizing the Urban Runoff Model developed by the Project staff which extrapolated data from seven U. S. Geological Survey gaging stations. Runoff quality was determined from U.S.G.S. records and City of Houston data.

The total quantity of bottom sediment within the system and that which was removed periodically by dredging was evaluated from a detailed study of U.S. Army Corps of Engineers sediment profiles. These profiles showed depth of virgin material and before and after dredging sludge depths as measured in place by a marked steel sounding rod. These profile sheets were examined for 500 foot increments along the channel length for two dredging cycles. Reasonable success was achieved in correlating the sediment deposition rate with total inflow.

The quality of the sediment materials was measured by an extensive program of coring and laboratory analysis. Figures 4 and 5 show the Texas A&M University water quality research vessel the RV/EXCELLENCE which was utilized for the sampling program and a typical sludge core extracted by the sampling crew.

A correlation was made between sludge depth as retrieved in the coring device and that measured by the marked steel sounding rod. In general a 3 foot core resulted from a measured 6 foot sludge depth.

The sludge cores were analyzed by a number of analytical tests including BOD_5, COD (chemical oxygen demand), total solids, total volatile solids and an oil and grease test.

Special techniques for sample mixing and splitting were devised in an attempt to obtain a representative component and some modifications were necessary in the analytical tests in order to deal with the high solids content encountered in the samples.

A similar coring and analysis program was made in the side bays along the channel (i.e. Burnett Bay, Scott Bay and San Jacinto Bay) (see Fig. 2) to determine the total sludge buildup in these areas.

Inasmuch as no dredging has taken place in these bays the sludges have been accumulating during the 60 year period since the Houston Ship Channel was put into operation. The fraction of organic material which is deposited in these bays was estimated by extrapolating the waste loads backwards to 1910 and applying a reasonable sediment organic material decay function to the waste loads backwards to 1910 and applying a reasonable sediment organic material decay function to the wastes deposited in any year.

PROJECT RESULTS

The total sediment deposition rates in the Houston Ship Channel over

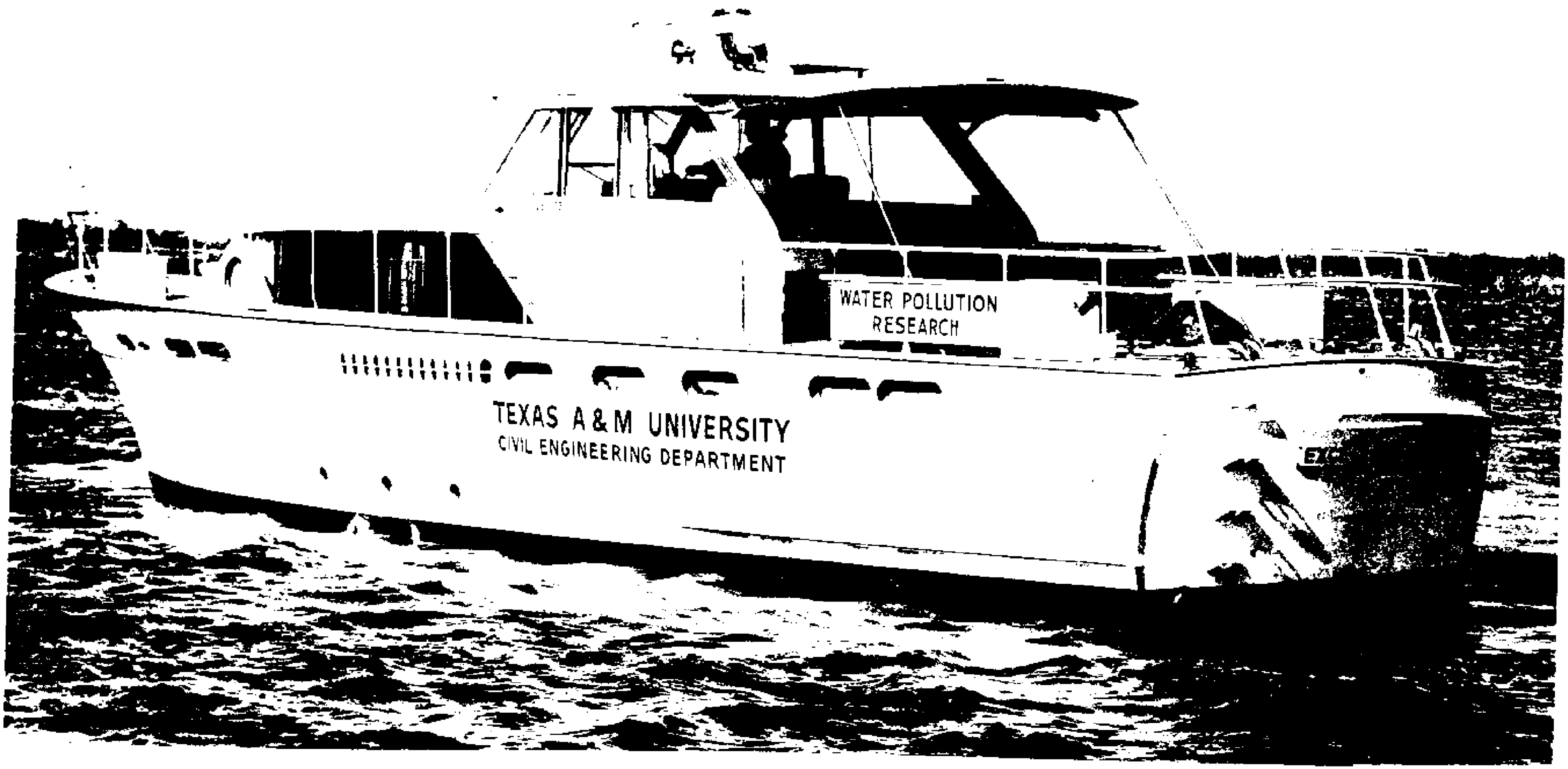

FIGURE 4

R/V EXCELLENCE

FIGURE 5

TYPICAL SLUDGE CORE SAMPLE

the two dredging cycles in the late 1960's is shown in Figure 6.

Figure 7 shows the results plotted on a finer grid for the lower four miles of the channel.

Sedimentation rates generally averaged 2.5 feet per year in the upper 12 miles, slightly under 2.0 feet per year from mile 5 to mile 12, and 4.0 feet per year in the lower 5 mile stretch.

This variation is due partially to channel construction and partially to source of sediment materials.

The organic quality of material found in the bottom sediments as expressed by BOD_5 is shown in Figure 8. The total deposition rate in the upper 12 miles of the channel during the last dredging cycle was 80,300 pounds per day and in the lower 12 miles the deposition rate is 64,800 pounds per day. The total organic material load in the channel is 145,100 pounds of BOD_5 per day. Similar although somewhat less accurate, mass balances are available for the other measures of organic material but the results are not presented herein.

The quantity of organic material added to the channel at various locations is shown in Figure 9. The locations of the various industries and tributaries contributing to this loading is shown in Figure 2.

The total loading in terms of BOD_5 in the upper 12 miles of the channel is 326,000 pounds per day and in the lower 12 miles is 126,000 pounds per day; making a total load to the channel of 452,000 pounds per day.

The removal to the bottom sludges thus amounts to 24.8% in the upper channel, 51.8% in the lower channel and 32.0% for the channel as a whole.

Three bays, upper San Jacinto Bay, Burnett Bay, and Scott Bay, were studied in order to estimate the rate of build-up of sludge deposits in side bays of the Houston Ship Channel system. By using the average sludge depth of each along with the sludge density, surface area, and the BOD_5 concentration in each bay the total organics, in terms of BOD_5, accumulated in upper

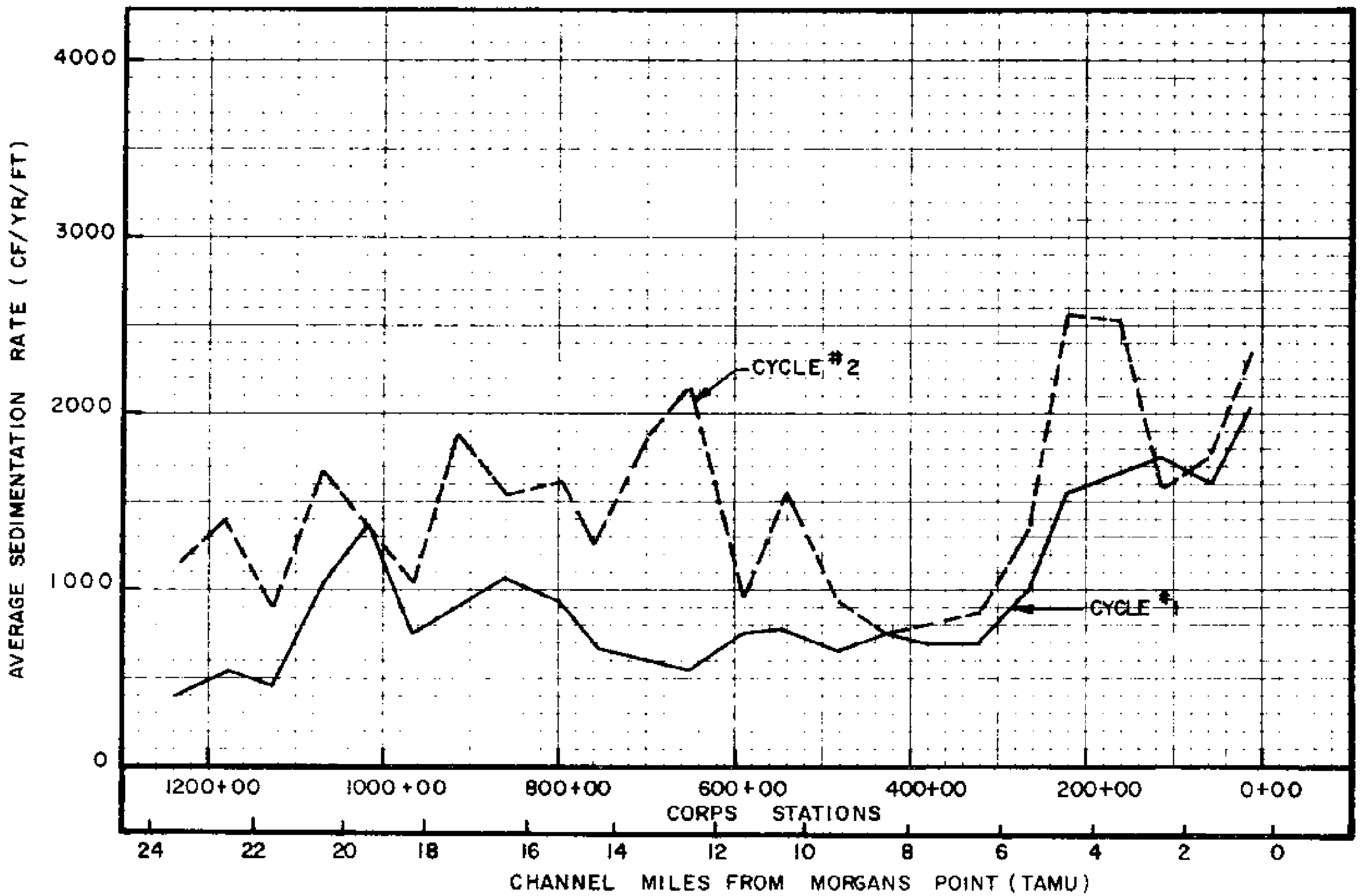

FIGURE 6

PROFILE PLOT OF SEDIMENTATION RATES FOR DREDGING CYCLES NO'S 1 & 2 IN TERMS OF CF/YR/FT

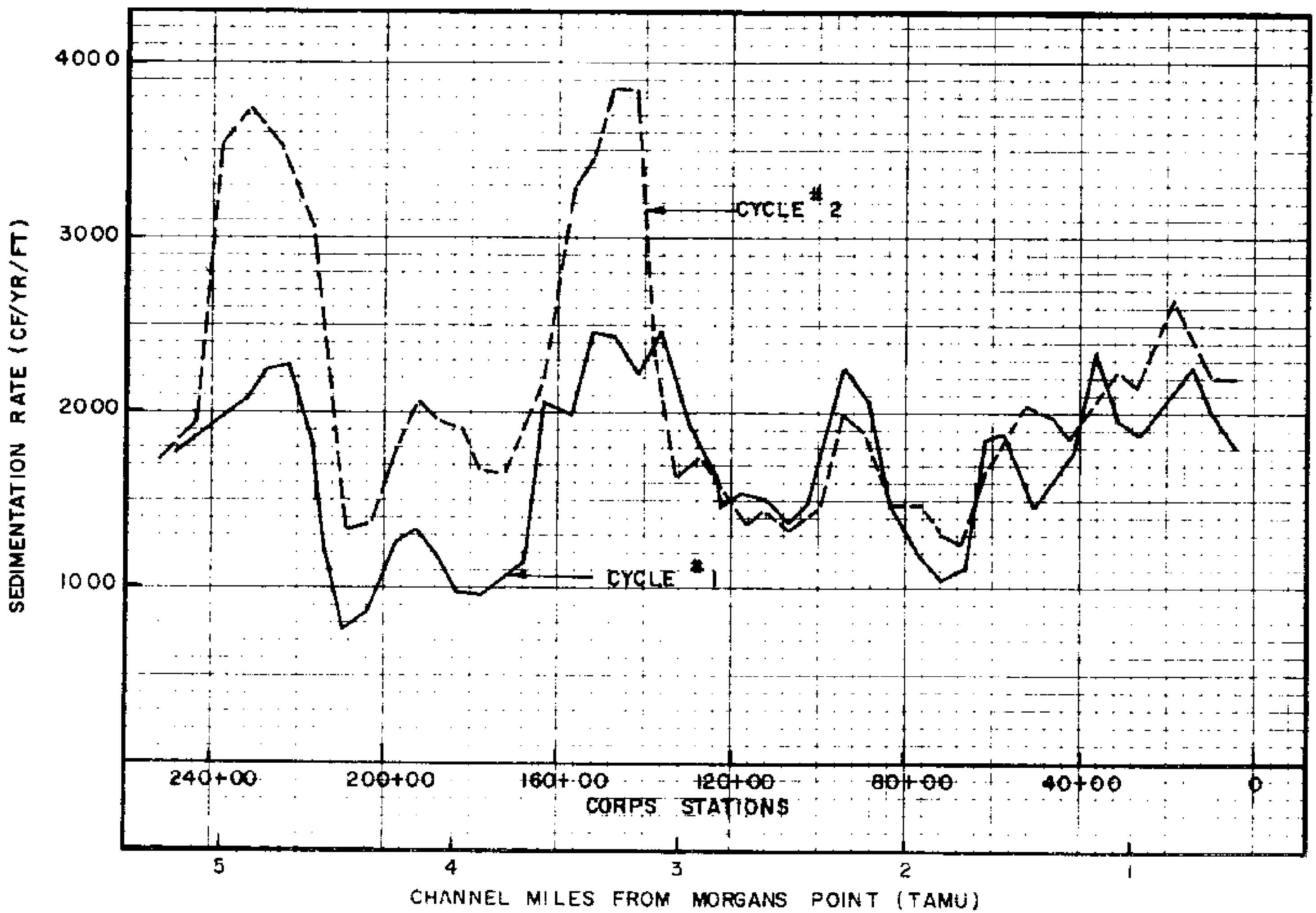

FIGURE 7

SEGMENTED PROFILE PLOT OF SEDIMENTATION RATES FOR DREDGING CYCLE NO'S 1 & 2
(500' INCREMENTS)

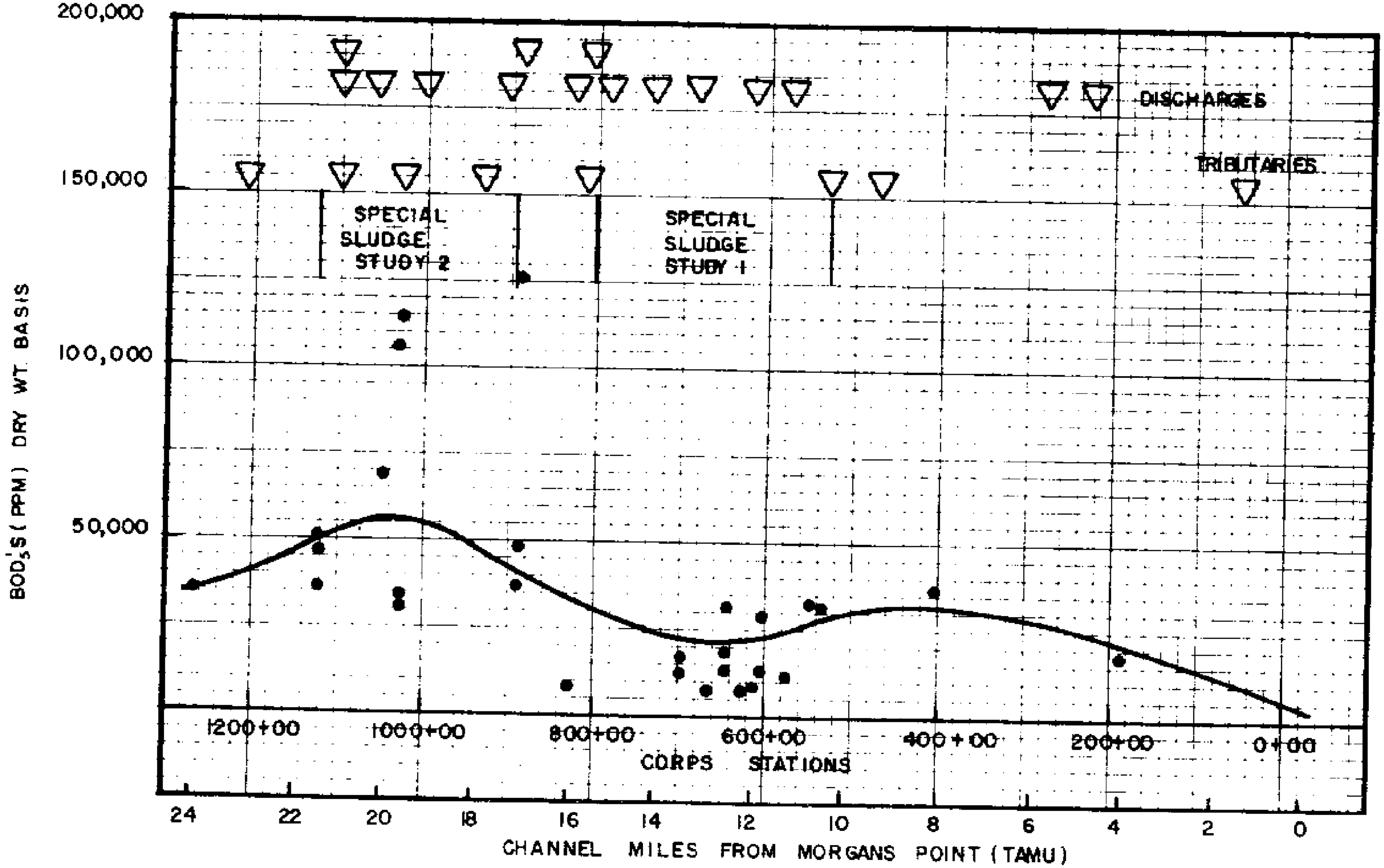

FIGURE 8

BOD$_5$ PROFILE OF BOTTOM SLUDGES

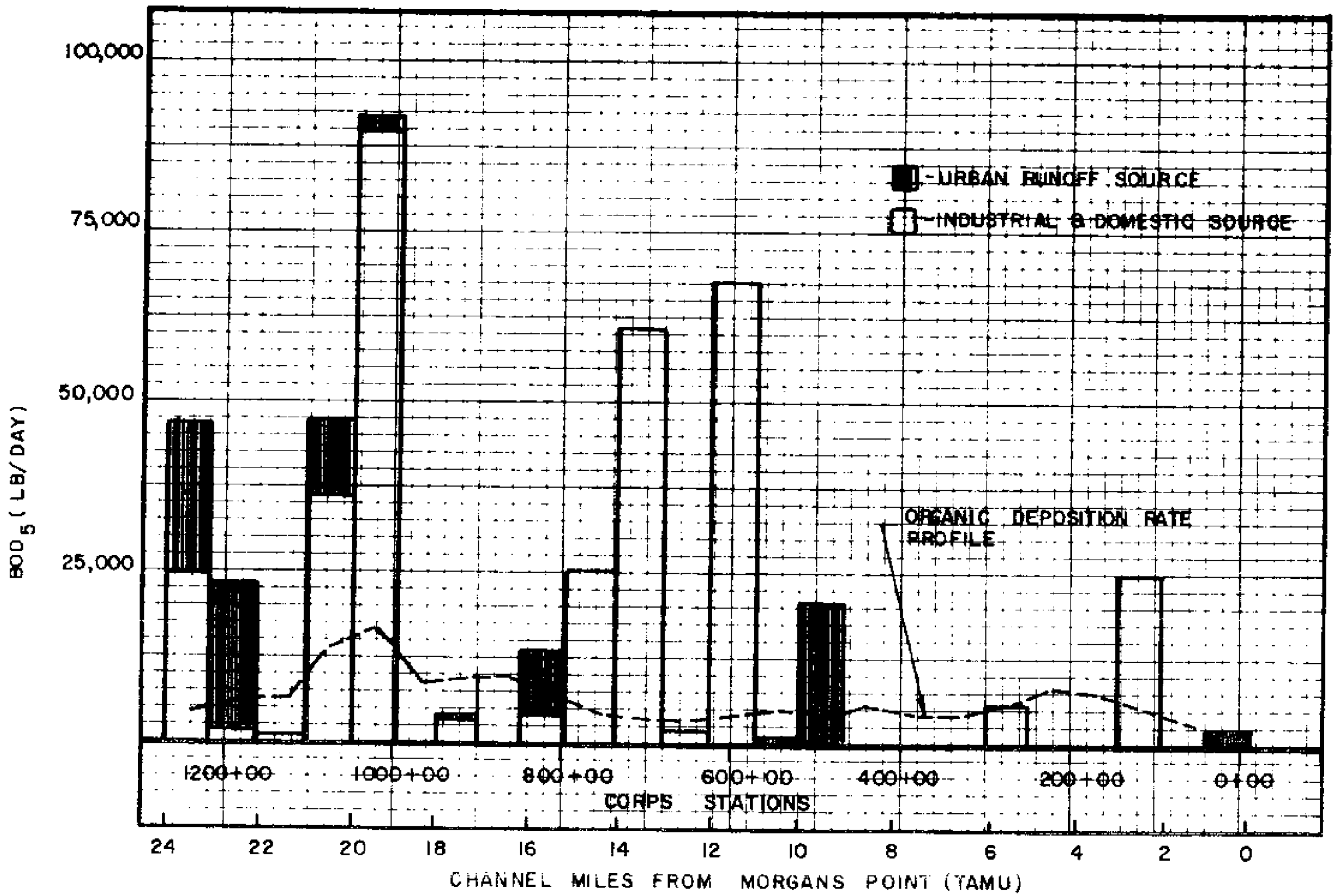

FIGURE 9

ASSUMED BOD WASTE LOADS RESULTING FROM URBAN RUNOFF AND INDUSTRIAL AND DOMESTIC WASTE DISCHARGES

San Jacinto, Burnett, and Scott Bays were computed to be 3,930,000, 5,860,000, and 20,720,000 pounds respectively. The sum of these totals yield a quantity of 30,510,000 pounds of BOD_5 for the three bays.

The analysis of the side bay deposition utilizing the history of waste loading shown in Figure 10 and a decay rate of .1 per year indicates a deposition rate of 14,000 pounds BOD_5 per day. Thus an additional 3.1% of the organic sediment is deposited in the side bays along the Houston Ship Channel. This analysis is however highly dependent in the decay rate function. Future work will attempt to define this rate more accurately.

The results for other parameters closely correlated with the results based on BOD_5. The use of the modified oil and grease test yielded interesting results when examined with regard to industrial outfall location. The general background level for this parameter in the channel was on the order of 1/2% extractable organics in the sediments. Near two petrochemical complex outfalls the value increased to almost 2% extractable organics. Additional work is planned to examine if this test can be used to determine the sedimentation pattern from these industries.

Several other studies were carried out by the project staff in support of this activity.

Sludge spoil area: The runoff from a sludge spoil area was analyzed during dredging operations. In this one instance the organic loading was comparable to that of the channel water outside of the dredging area and as a result of a high algal activity the runoff water carried a high level of dissolved oxygen which was not present in the channel waters.

Benthal decay: A study was initiated and is continuing to evaluate the decay characteristics of the bottom sediments. In several places in the channel toxic constituents or nutrient imbalance result is no apparent

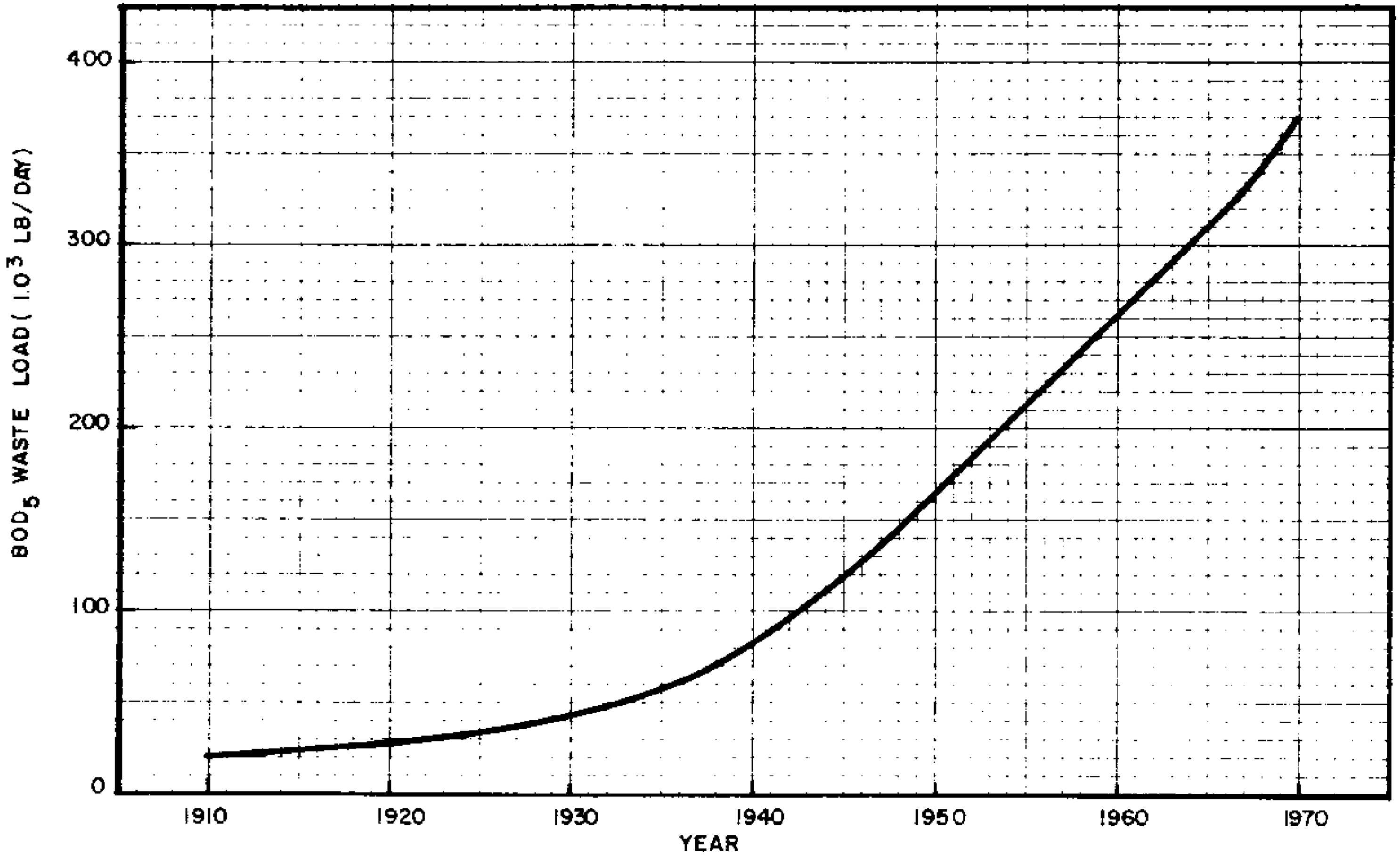

FIGURE 10

HISTORY OF BOD_5 WASTE LOADINGS FOR THE HOUSTON SHIP CHANNEL decay taking place. This negligible decay will effect future use of the extensive sludge spoil areas. Since this decay is negligible and material deposited on the bottom is thus stored until removed by dredging, methods of improving sedimentation for in-channel removal of wastes to the bottom is a definite possibility.

Correlation of organic sediment buildup to load source: It had been hoped that the organic sediment pattern would be sufficiently defined to permit an analytical model to be calibrated which would permit the prediction of organic sediments for altered waste loading conditions. Although useful trends were observed, additional study of sediment pattern from single outfalls is needed before such a model can be calibrated.

SUMMARY

The author has shown how a mass balance of the inflow of organic materials and the buildup of bottom sediments may be utilized to measure net organic removal to the bottom deposits. The nature and importance of these bottom deposits has been discussed with particular emphasis placed on the role the dredging industry will face in the removal and re-deposition of these materials.

The dredging industry faces a major challenge in the coming years as a result of the quest for a better quality environment.

The industry may choose to ignore the problem in hopes that it will go away or decline responsibility on the basis that the industry merely moves someone else's problem and does not create one of its own.

The author believes that a more forward looking aggressive program is desirable on the part of the dredging industry. This far reaching program will involve the supporting, in word and deed, of activities to eliminate the primary source of pollutant materials (i.e., municipalities, industries, agriculture, etc.) and the development of methodology and hardware to minimize the results of the secondary pollution associated with dredging operations.

One major activity which will be required on an industry-wide basis is to sell hiring organizations on the acceptance of dredging practices which minimize pollution.

These practices may include but not be limited to time of dredging (i.e., winter versus summer), location of spoil (i.e., on shore versus shallow water), shielding or isolation of dredging area, treatment of spoil area runoff, pre-dredging and past dredging survey of quality, and toxicity studies of sediments.

The industry may well benefit from studying and researching their own problems prior to activity from without the industry in order to have more lead time to develop a program in harmony with the higher demand for environmental quality.

By working together for "Standards of Operation" which will prevent the "Least Scrupulous Operator" to set competitive low quality standards with regard to environmental quality for the entire industry and by judiciously looking ahead it is believed that the dredging industry can avoid suffering and indeed benefit from the new demands for high environmental quality.

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