DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
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No. 1110-2-530

15 December 1986

Engineering and Design
FIELD APPLICATIONS OF POLYETHYLENE PIPE IN DREDGING

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1. Purpose. The purpose of this ETL is to present recent experimental data on the abrasion resistance of polyethylene pipe used in a dredging situation along with recently collected information on a variety of field applications. The laboratory investigation was conducted at the U. S. Army Engineer Waterways Experiment Station, Hydraulics Laboratory, by D. R. Richards, V. R. Pankow, and M. P. Alexander.

2. Applicability. This letter is applicable to all divisions and districts having responsibility for monitoring or performing dredging operations.

3. Discussion. This ETL discusses the results of laboratory tests comparing the abrasion resistance of high density polyethylene (HDPE) pipe with conventional mild steel pipe as reported at the ASCE Dredging Conference 1984. A third material, ultra high molecular weight high density polyethylene was also tested. The results indicate that under the test conditions HDPE outperforms mild steel significantly in wear characteristics. Comparisons between the performance of different types of HDPE suggested that higher molecular weight materials provide better resistance to abrasion. Conversations with users of HDPE pipe confirmed the laboratory results and resulted in the development of practical field application guidelines.

FOR THE COMMANDER:

Encl

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FIELD APPLICATIONS OF POLYETHYLENE PIPE IN DREDGING

Introduction

1. In recent years there has been a slow but steady increase in the number of dredges using high density polyethylene (HDPE) pipe in discharge lines. HDPE's increased popularity is the result of material properties that make it ideal for many dredging applications.

2. HDPE is a lightweight, flexible material that if applied properly can be used to advantage over rigid steel pipelines. Its light weight allows for easy assembly of long lines with a fraction of the labor and lifting machinery required for steel lines. Standard 40-ft sections of HDPE are joined using portable heat fusion machines which true, heat and compress the ends of the pipe together to form joints that are stronger than the pipe itself. Since the material is lighter than water, it can be towed in long lengths to the dredge site using small tenders. The flexibility of HDPE allows pipelines to be bent to radii approximately 25 times the pipe diameter thereby minimizing the need for expensive ball joints or other flexible connectors.

3. While the advantages of using HDPE are extensive, there are special requirements for its successful use which are quite different from conventional practices in rigid steel lines. Engineering design manuals are available from all of the reputable suppliers of HDPE. They address such topics as pressure ratings, anchoring, flotation, water hammer, and others. Most also provide engineering services for applications not specifically addressed in their manuals.

Study Approach

4. A two phase approach was taken in addressing the benefits and applications of HDPE pipe. First, to evaluate the abrasion resistance of HDPE, a test loop was constructed in the Hydraulics Laboratory (HL) of WES. Two conditions of slurry velocity and concentrations (homogeneous and heterogeneous) were run with steel and HDPE pipe and elbows. A third material, ultra high molecular weight, high density polyethylene pipe (Ultra) was also used to compare two types of polyethylene pipes. The experimental test loop results were favorable and the second phase of investigation was undertaken. This phase, which is not yet completed, consists of a field test and the documentation of HDPE user experiences. Dredging companies and District offices have been contacted and their dredging experiences with HDPE pipe recorded. The field test involves the installation of a section of HDPE pipe in the discharge line on a maintenance dredging project. The performance of both the traditional steel and the test HDPE section will be monitored and documented.

Material Properties

5. Polyethylenes are plastics that are formed by the polymerization of a group of straight chain unsaturated hydrocarbons (ethylene) into long chain molecules. Pipe quality polyethylene is extensively polymerized giving it

superior qualities. The American Society of Testing and Materials (ASTM) in the D-1248 standard classifies polyethylene into three categories according to density. Types I, II, and III correspond to low, medium, and high density. As the density of polyethylene increases so does its tensile strength, surface hardness, stiffness, softening temperature, and chemical resistance. Additional classifications in ASTM D-1248 refer to the class of the material based on the color compositions of the material; the category, which identifies the melt index; and the grade, which identifies key characteristics such as tensile strength, elongation, brittleness temperature, and stress crack resistance. A detailed explanation of each category can be found in the engineering design manuals published by the suppliers. They should be consulted and compared prior to the purchase of HDPE pipe. In general, it is safe to say that for most dredging applications Type III, Class C (2 percent carbon black for UV protection) material is sufficient. Higher grade polyethylene is certainly available from the manufacturers but decisions to purchase these materials will involve economic trade-offs.

Abrasion Resistance Tests

6. The primary purpose for the abrasion resistance tests was to independently evaluate claims made by pipe manufacturers that HDPE has superior abrasion resistance qualities when compared with conventional mild steel pipe. To achieve that end, a jet-pump-driven, recirculating slurry pipe loop was constructed and equipped to monitor the velocity, flow rate, and specific gravity of the slurry. Since the pipes would take a considerable time to show wear, uninterrupted, 24 hours per day testing was required. All instrumentation in the test loop was hard-wired to an HP-3497 data acquisition system where it was controlled and monitored by an HP-85 microcomputer. The computer monitored and recorded flow rates and densities and was programmed to shut down the pumps if the flows varied substantially from desired values and specifically in the event of a wear-induced blowout or power loss.

7. Homogeneous Test. Prior to the start of the tests, little data existed on the length of time required to wear the test materials. The only wear data generated used blanks of the materials extended into and normal to the slurry flow path. This procedure was adopted after earlier experiments with larger diameter pipes yielded slow results.

8. In an attempt to estimate the amount of time required to sufficiently wear 4-in.-diam test sections of each pipe material for comparison, the first of two test loops was designed and constructed to simulate accelerated wear conditions. The accelerated condition data was then used to design a test that would more closely resemble prototype dredging conditions.

9. The accelerated test used alternating sections of 4-in.-diam HDPE and steel straight sections and elbows (Figure 1). HDPE elbows were not suggested for use in slurry applications by their manufacturers because they were segmented, a factor that causes increased turbulence, wear and early failure. They were included, however, and the manufacturers' statements about them

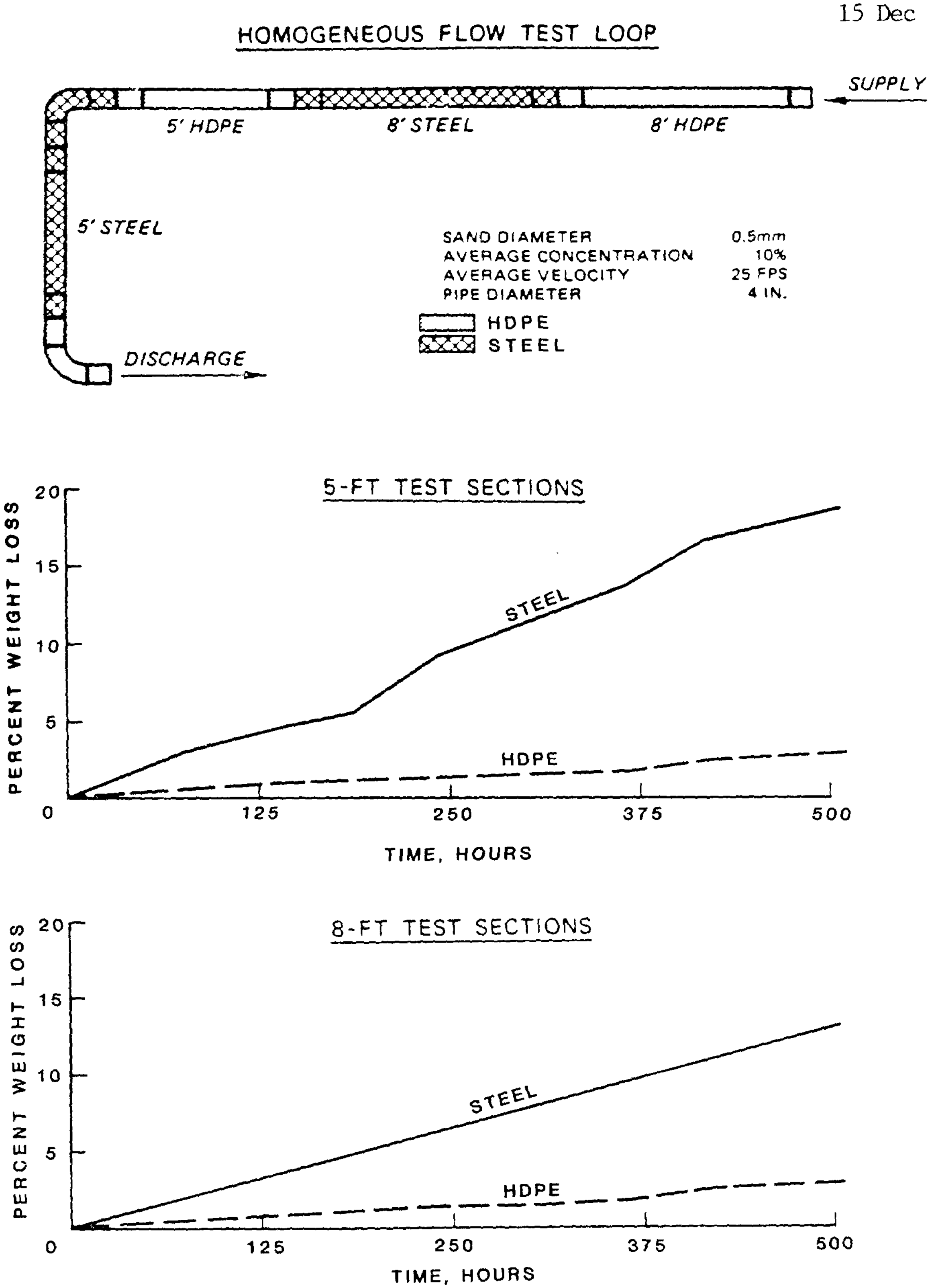

FIG. 1.--Homogeneous test loop and data

proved to be correct. HDPE elbows failed sooner than steel; however, it is interesting to note that they did so with less weight loss.

10. Full-circle clamps were used to join the pipes, minimizing local edge scour resulting from flanged connections. The clamps also facilitated breaking down the loop for rotation and weighing the pipe for wear measurements. Once the loop was assembled, it was subjected to flow velocities of 25 fps with a 10 percent concentration by volume of sand. The slightly rounded sand grains had a median diameter of 0.5 mm. These values placed the slurry in the homogeneous range, meaning there was no density gradient between the top and the bottom of the pipe. This is atypical for most dredging applications where a lower velocity and a heterogeneous flow regime are more efficient from the standpoint of fuel consumption and abrasion.

11. The purpose of the homogeneous test was accomplished in that comparisons of wear potential were provided for steel and HDPE in a reasonably short period of time. The data also agreed fairly well with abrasion resistance estimates supplied by HDPE manufacturers for similar slurry conditions. However, before the data supplied in Figure 1 are given too much credence, it should be noted that corresponding sections of HDPE and steel lay in different sections of the loop with respect to the elbows. Previous studies and field experience have proven that elbows and straight sections just downstream of elbows experience greater wear than other sections of the pipeline. A legitimate comparison of steel and HDPE would require that both sections of pipe lie in similar portions in the test loop. This was not the case in the homogeneous test. The 5-ft section of HDPE was on the upstream side of the steel elbow while the 5-ft steel section occurs just downstream. The 1-ft sections on each side of the test sections mitigated this effect somewhat but were not totally successful. At the end of 500 hours of testing, the 5-ft steel section showed approximately six times greater wear than the 5-ft HDPE section. The effect of loop position in this case slightly overestimates the advantage of HDPE.

12. The 8-ft test section results confirmed the effect of loop positioning on relative wear rates. Both of the 8-ft sections lay in a section of the loop distant from turbulence and excessive wear associated with elbows. If any bias existed it would be to underestimate the advantage of HDPE. At the end of 500 hours of testing, the 8-ft steel section showed approximately four times greater wear than HDPE. A good indication of our ability to make accurate comparisons between different materials can be seen by comparing 5- and 8-ft sections of HDPE. In similar sections of the loop, identical materials showed nearly identical wear rates in time.

13. In summary, the homogeneous test suggests that HDPE pipe experiences four to five times less weight loss due to abrasion than steel under the given test conditions. This compares favorably with abrasion studies conducted by or for HDPE manufacturers.

14. <u>Heterogeneous Test.</u> Armed with the data from the homogeneous test and the knowledge that the materials wear in a reasonable period of time, the next

test was designed to model typical dredging conditions more closely. Basically, the conditions included a greater sand concentration (20 percent by volume) and a lower slurry velocity (13 fps). This placed the slurry in the heterogeneous flow regime, a flow pattern in which all the solid particles are suspended and the concentration increases from the top to the bottom of the pipe. Again, a slightly rounded 0.5-mm sand was used.

15. This time the pipe loop was designed to place materials to be compared in hydraulically similar sections of the loop (Figure 2). Four-ft long sections were located downstream of elbows for comparisons in a heavy wear environment. Eight-foot sections were located downstream of the 4-ft sections to approximate conditions that would be more typical of the long lines used in dredging. A third material called ultra high molecular weight, high density polyethylene or more simply Ultra, was included in the heterogeneous loop. Ultra, made from a higher molecular weight resin than standard HDPE, is more difficult to extrude. It is, however, reported to have abrasion resistance characteristics greater than HDPE. Ultra is frequently used in highly abrasive industries such as mining where larger and sharper aggregates are common. The material is expensive by comparison and has limited size availability but could be useful in some applications. It was included in the test loop to determine if higher molecular weight polyethylenes show significant improvement over conventional HDPE. Both straight sections and elbows of Ultra were used in the loop.

16. The heterogeneous test included the addition of a 34-ft section of HDPE for determining head losses in new HDPE versus abraded HDPE. Head losses were measured using a differential pressure manometer connected to the pipe at its extreme ends. Some have speculated that the initial hydraulic advantage of the smooth interior walls in HDPE would soon be lost after the pipe was exposed to abrasive slurries. However, after 1620 hr of testing, no detectable increase of head loss was noticed in the 34-ft test section.

17. Results from the heterogeneous test along with a pipe schematic are shown in Figure 2. This test was run for 1620 hours with much less wear than the 500 hr of homogeneous test conditions. The effects of high velocity slurry flow on pipe life can be deduced by comparing Figures 1 and 2, noting the vertical and horizontal scale dimensions.

18. A comparison of the 4-ft sections in the most abrasive condition downstream of elbows gives HDPE the advantage once again. Steel 4-ft sections experienced three times faster wear than 4-ft HDPE sections. Under the less abrasive conditions of the 8-ft sections, steel still showed two times faster wear. Wear rates from the Ultra straight sections and elbows are not plotted but are given in the following table.

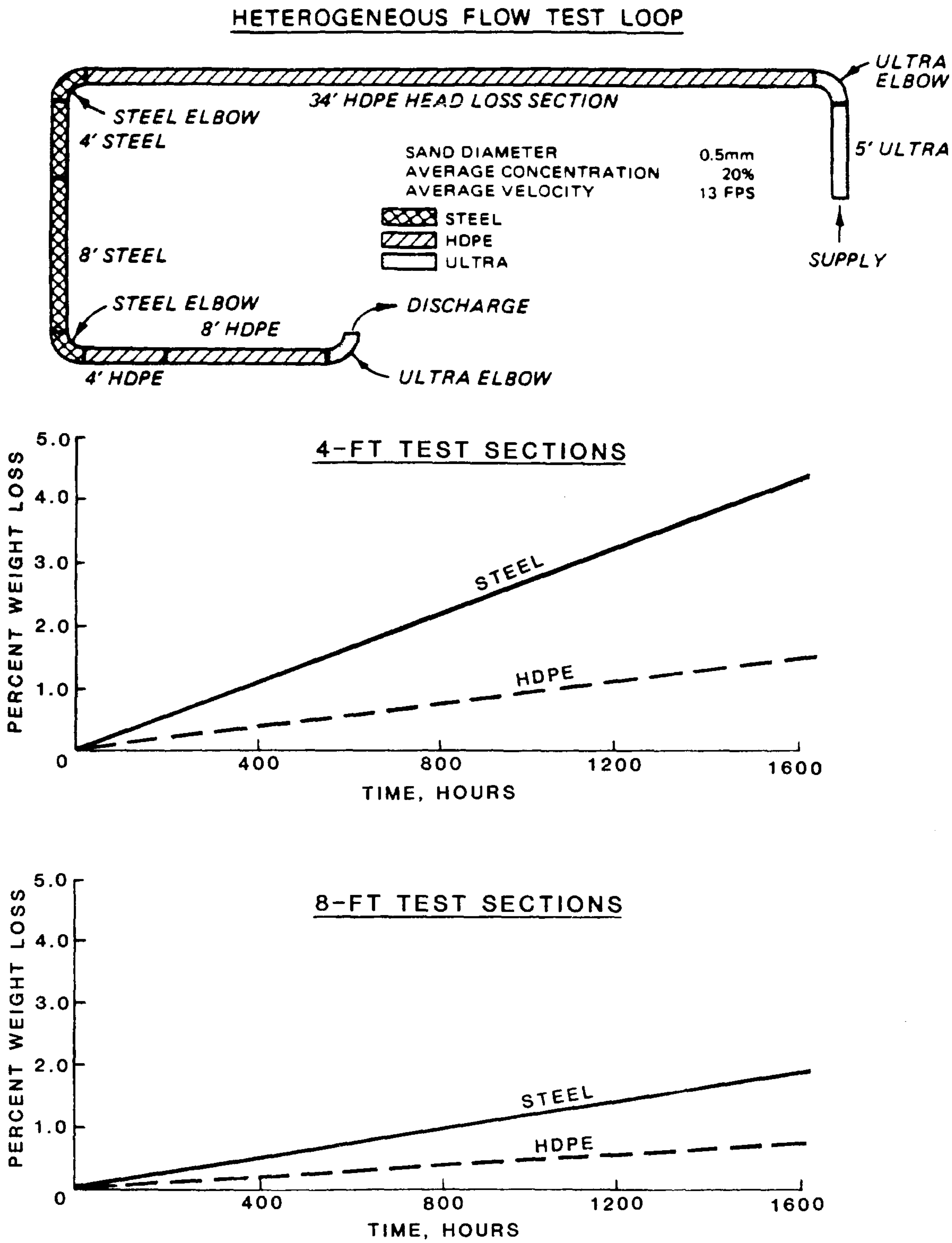

FIG. 2.--Heterogeneous test loop and data

Percent Weight Loss at End of Test

Straight Pipe	Homogeneous Flow 500 hr Steel	Homogeneous Flow 500 hr HDPE	Heterogeneous Flow 1620 hr Steel	Heterogeneous Flow 1620 hr HDPE	Heterogeneous Flow 1620 hr Ultra
4 ft	--	--	4.48	1.53	--
5 ft	17	2.4	---	--	0.16
8 ft	13	3	1.89	0.89	---
Elbows	35 failed 320 hr	10 failed 130 hr	7.05*	---	0.24*

* Average of two.

19. The straight section of Ultra clearly shows a five- to nine-fold increase in wear resistance over HDPE and an eleven- to twenty-eight-fold better performance than steel under heterogeneous flow conditions. Another notable advantage of using Ultra is in elbows. Conventional mild steel elbows wore 29 times faster than Ultra elbows.

20. When the results of both tests are combined, a clear picture is developed of the relative abrasion resistance of HDPE and steel. Depending upon slurry flow and concentration, HDPE, on the average, is three to five times more abrasion-resistant than conventional mild steel pipe and Ultra elbow and straight sections outperformed both steel and HDPE by significant amounts.

Field Information

21. The laboratory test results were encouraging, but real world information was needed in order to determine the effectiveness of HDPE in full-scale dredging operations. Included in this information survey were dredging companies that do private and Corps dredging, some Corps offices who contract and monitor dredging operations, and HDPE pipe manufacturers. Everyone contacted was cooperative, helpful, and willing to pass on useful tips and information. All were enthusiastic about polyethylene pipe but had cautions concerning situations that had potential for problems.

22. In general, those responding had been using HDPE for 3-6 years and are still using most of the original pipe they purchased. They considered many of their jobs to be relatively small (0.5 to 1 million dollars) maintenance dredging contracts that dredge mud and fine sand. One dredger had 11,000 ft of HDPE pipe while others have 75 to 98 percent of their pipe in polyethylene. The dredge sizes reported in the survey ranged from 12 to 18 in. in diameter. The following comments have been combined and loosely grouped into

advantages, disadvantages, problems, cautions, useful tips, and failures. Most comments were made by more than one respondent.

23. Advantages. Every respondent agreed that in the proper application their HDPE pipe outlasted steel, for some by as much as five times. Some found that HDPE was slightly less expensive than steel and its ease of handling made mobilization and demobilization faster and less expensive. Some contracts have been won by HDPE users because decreased mobilization and demobilization costs led to lower bids. One dredger remarked that in a sensitive beach nourishment project, the use of HDPE pipe may have been less objectionable than steel (which tends to look rusty) for there were noticeably fewer than expected citizen complaints.

24. All respondents agreed that the lightweight fusable nature of HDPE pipe was an economic blessing. Working lengths of 500 to 1,500 ft of butt fusion joined HDPE are easily floated to the project site. The reduced need for flanged joints results in less turbulence and wear inside the pipe. As the pipe is filled with slurry, it sinks to the bottom and easily conforms to the contours of the terrain. Ease of repair was also cited as a favorable feature. Damaged sections of pipe can be removed with a chainsaw and repaired with a circle clamp or a butt fusion joint. The need for elbows is reduced by the flexible property of the material which not only allows the pipe to comfortably conform to the terrain but allows for bends of 20 to 40 pipe diameters. Fewer elbows also provide improved hydraulic efficiency requiring less pumping power.

25. Disadvantages. The major disadvantage cited was the need to teach field personnel to be more careful in the handling of HDPE pipe. External damage may result in weaknesses and eventually leaks.

26. Problems. Anchoring submerged HDPE pipe in water deeper than 15 ft or with currents greater than 4 knots was a common problem. Unless the slurry can be maintained at 30 percent solids, there may be problems placing the weights needed to anchor the pipe. Although HDPE pipe manuals explain proper anchoring procedures, several dredgers choose to use steel in these situations, thereby avoiding the requirement for HDPE anchoring.

27. It is always important to know the character of the material to be dredged especially if HDPE pipe is used and sharp materials (such as oyster shells) will be encountered. Experience has taught some dredgers that although limited amounts of sharp stones or shell is acceptable, dredging this type of material for more than 24 hours frequently results in tears and leaks.

28. Cautions. Several common sense cautions were presented. Most important was to always use quality pipe and follow the manufacturer's suggestions and recommendations for use. An HDPE company engineer is always available to answer questions and supply the technical information that a salesperson might not have.

29. When handling and installing HDPE pipelines, care should be taken not to quickly bend or kink the pipe. It was also suggested that bends not exceed 15 deg and a minimum number of flanges be used. Bends and flanges create turbulence zones 4 to 10 pipe diameters downstream. Careful alignment of the flanged ends is also important to keep wear at a minimum.

30. Conversations with an HDPE pipe manufacturer's engineer revealed that overpressuring a pipe is acceptable in some instances but the wear life will be greatly reduced. Manufacturer's tests of pipe under given pressure and slurry velocity produce a predicted wear life of 50 years. Changing the pressure and/or slurry velocity will correspondingly change this value. There are valid applications of HDPE pipe where the wear life of the pipe will be reduced but will still be sufficient for the project requirements. It is not a recommended procedure--properly sized pipe for the working pressures and velocities is always preferred. Overpressuring HDPE pipe does not change the material density, the shorter life span caused by overpressuring is a function of the long-term creep property of the material. This long-term creep (relaxation) results in a slow thinning of the pipe wall which lowers the pipe pressure rating. HDPE material has the ability to "recover" from overpressuring if certain limits are not exceeded. (Manufacturer's engineers can provide guidance in this area.)

31. There are situations that are not suited to the use of HDPE pipe. One manufacturer cautioned against dredging sharp material such as coral or volcanic sands. Another dredger does not use HDPE pipe because his needs require large (30 in. ID) high pressure (280 psi) pipe which in polyethylene material is very expensive. However, he was willing to field test some sections because it sounded like an interesting and promising material.

32. Useful Tips. All the information, cautions, and useful tips are intended to reduce the dredger's operating expenses by maximizing the life of his pipeline and reducing nonproductive downtime, the need for heavy equipment, transportation costs, and mobilization and demobilization time. Many practices are common to all dredging situations such as rotating dredge pipe to distribute wear and prolong the usefulness of the pipe. Some recommendations are made specifically for polyethylene pipe. None of the HDPE users employed HDPE pipe in the suction line of the dredge and all use steel pipe following the dredge pump. In these locations the rigid nature of steel is important. The length of steel used before switching to HDPE varied from 40 ft (manufacturer's minimum recommendation) to 200 to 500 ft or 4,000 to 5,000 ft (actual users preference). This gives the slurry an opportunity to become less turbulent before it reaches the HDPE sections. Depending on the availability, frequency of use, and size of pipe, it may be cost effective to rent rather than buy the butt fusion equipment. Pipe sections can also be joined using circle clamps. If circle clamps are used, they should be 1-1/2 pipe diameters wide to distribute pressure and not deform the HDPE pipe.

33. Failures. No product or procedure is without some failures and the use of HDPE pipe in dredging is no exception. Most failures can be evaluated and understood and added to the pool of HDPE pipe information.

34. One maintenance dredging project reported very disappointing results almost immediately. The recommended high pressure pipe was not purchased and 12-in. nominal size low pressure (50 psi) 40-ft sections flanged on both ends were used. The material dredged consisted of sand, some angular 1/4- to 1/2-in. diam, and gravel with some 6-in.-diam rocks. A working pressure of 60 psi was maintained with a pumping velocity of 15 ft per sec and a 12 percent solids concentration. The first failure was located 2 to 3 ft from the flanged ends and occurred within 3 days. At first, the dredger was surprised at the smoothness of the slurry flow but within 24 hours he was aware of a dramatic increase of pipe resistance. When the pipe failed, the interior walls were examined and found to be badly torn with shreds of material loosened from the pipe wall. It was the practice of this dredger to rotate the dredge pipe 1/4 turn every 2 days.

35. A combination of factors resulted in this poor performance and could be attributed to misapplication rather than to poor quality material. Slight overpressure, sharp dredged material, and many flanges would not have resulted in this damage had steel been used. The character of HDPE is such that the fused connections are recommended to reduce slurry turbulence and pipe wear. In this application, the additional turbulence induced by the flanges and the sharpness of the material quickly eroded the pipe. There was also evidence of poor pipe alignment which augmented the turbulence.

36. This dredger agreed that perhaps higher pressure-rated pipe would have lasted longer but that HDPE is not well suited to this type of dredged material. He did remark that the HDPE pipe was considerably easier to handle and install and conformed very nicely to the uneven terrain. He does not plan to use HDPE in similar dredging situations but would consider using it if the dredged material was of a finer nature.

37. Another dredger felt he had received poor quality pipe or butt fusion equipment when his HDPE pipe experienced failure at the stubb end fusion joint. The dredger was not discouraged by this experience; he is more careful in his selection of pipe manufacturer and continues to use HDPE pipe.

38. Within the dredging community, certain pipe companies have the reputation of producing a quality product while others have earned the distinction of producing "cheaper stuff" which does not wear well. A manufacturer's reputation and guarantee policy should be considered when purchasing HDPE pipe.

39. Other Notes. A field test is planned as part of phase two of this study. Forty feet of 30-in.-ID HDPE pipe has been purchased and delivered to a west coast dredge site. Dredging was to begin in early summer 1985 but was delayed more than a month due to very low river flows and sediment load. When dredging starts, the wall thickness of the pipe will be regularly monitored using an ultrasonic wall thickness gage. Results of pipe wear and gage performance will be available from HL personnel. The test has some unfavorable conditions (flanged sections that create turbulence and highly abrasive sands), and can be regarded as a "worse case" condition. The data will be

treated accordingly. Steel and HDPE pipe will be monitored for wear, failure, ease of handling, anchoring, supporting, and repair.

40. As the dredging industry expands accompanied by higher operating costs and increased distances to disposal sites, new technology and materials are being introduced. HDPE can be an efficient alternative or supplement to steel discharge lines. The physical and mechanical properties of HDPE are sufficiently different from steel that problems may develop if it is treated as a rigid pipe. Its flexible, lightweight, abrasion-resistant nature offers the dredger new freedom in pipeline design, life, cost, and maintenance.