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New Dredge Concepts and Designs for Placer Mining Applications

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Abstract

The rigorous working conditions confronting the dredge mining industry in higher latitude offshore locations of recent interest exceed the capabilities of the conventional bucket-ladder dredge; the traditional work horse of the industry. New concepts and designs developed by the Marine Minerals Technology Center (MMTC) offer solutions to these challenges. One, a hybrid suction system (conventional pump with jet pump assist) fitted with a motor drive, continuous, cutter/grizzly chain which sweeps the intake mouth clear of oversize rocks, removes same from digging face, cuts and force feeds material into intake mouth and drives side cutter wheels for lateral cutting and directing material to intake.

A second system, the continuous bucket dragline, incorporates the flexibility of the dragline and efficiency of the continuous bucket line ladder dredge without the limitations of the ladder.

The hybrid suction cutter chain/vheel design (CCW) is suitable for mounting on a low profile surface platform for increased stability in high latitude seas or on submersible bottom crawlers capable of operating beneath ice, in rough seas, or at greater than the traditional limits of the bucket-ladder system (greater than 15 m).

The continuous bucket dragline design (CBD) offers similar solutions under similar conditions as well as significant capital and operating cost advantages in conventional mining applications.

A prototype CCW dredge was designed and operated by the author for the purpose of evaluating submerged gold-bearing beach placers. The placers consisting of reworked bedrock and glacial material, ranging in size from clay to boulders, 2 to 4 meters in thickness, were successfully cut with transverse trenches. A prototype CBD dredge is currently in the planning stage in cooperation with a Mississippi gravel producer.

The prototype CCW system provided a means of solving some of the fundamental problems which have hindered its application in mining heavy placer ground by 1) providing means of efficiently clearing the intake of oversize to prevent jamming; 2) transporting oversize away from the digging face to prevent the build-up of an impenetrable pavement; 3) force feeding desired ore material into high velocity slurry entrainment to insure heavy mineral pick-up. With these problems solved a workable system is now available for adaptation to low profile surface mounted systems or bottom crawlers.

The CBD promises to be equally versatile with added economic advantages for both new and traditional applications.

Figures at end of paper.

introduction

in recent years there has been an increase in interest and activity in marine placer mining. Formerly offshore mining was mainly limited to the dredging of tin in Southeast Asia, iron sands in Japan and aggregate in the United Kingdom and Japan.

With the reported successful working of the offshore Nome gold placers, Norton Sound, Alaska, new focus has been directed at marine placer mining economics and technology. This study reviews both the favorable and unfavorable aspects of various traditional dredge mining systems in offshore placer applications and discusses alternative conceptual designs to meet the rigorous requirements of the deeper locations, and the rough seas and ice conditions of the higher latitudes.

Traditional Bucket-Ladder System

The bucket-ladder dredge, well known from the gold fields of the Western United States in the first half of this century and more recently from the tin districts of Southeast Asia, remains the only operating heavy duty dredge mining system capable of working tough, boulder-ladened placer deposits to depths as great as 45 meters. Its rugged simplicity of design represents a completely integrated unit, incorporating. 1) a continuous loop, bucket—line excavation system providing maximum power efficiency; 2) a wet processing plant, largely gravity fed; and 3) an efficient tailings disposal system; Figure 1. The design of these three primary functions is readily adaptable to accommodate variable site specific conditions such as dredging capacity/through put, dredging depth, and placer characteristics; some of the more important criteria considered in mining dredge design.

The basic bucket-ladder system has proven effective in a wide range of dredging conditions, but is known in river and paddock (dredge pond) applications. The bucket-ladder concept was successfully extended to the offshore for working submerged placer tin deposits in the relatively calm waters of the Java Sea near Banka Island, Indonesia.

The success of these offshore designs was facilitated by the similarity of working conditions and dredging requirements to those encountered onshore within the region, requiring little modification beyond strengthening of the hull, ladder, and superstructure. Nevertheless, these factors were all thoroughly considered in the design phase of the project; an absolute prerequisite for success in dredge mining.

More recent attempts to employ a similar Southeast Asian offshore design in dredging the Norton Sound gold placers have proven difficult. Although the system concept remains basically valid, the typical high profile (20 to 30 m) and the rigged ladder in contact with the bottom has presented significant problems in the more frequent and severe storm conditions of the higher latitudes. This, together with winter ice, has limited the design to a working season of about four to five months.

The purpose for the characteristic high profile of the bucket-ladder dredge is two-fold. Primarily it is a function of ladder length and the required fulcrum length ratio; i.e. the ratio of the length between the upper ladder mount and the bearing surface of contact between the ladder flanks and the hull ladder slot to the overall length of the ladder. A suitable fulcrum ratio is mandatory to withstand the severe transverse forces on the ladder during normal dredging operations, using the industry preferred sideline mooring system to effect the dredging traverse. This high top tumbler configuration also proves economical in providing for a largely gravity fed onboard processing plant. However advantageous this traditional design configuration, the sea conditions of the higher latitudes have proven less cooperative than those of the tropics. New designs will be required to successfully meet these cha i lenges.

The most effective approach in developing new dredge mining concepts to meet the requirements of the higher latitudes and deeper seas is to re-evaluate the favorable features and problem areas of the traditional systems and methods from the perspective of new requirements. The results can then be integrated with new designs capable of addressing the requirements of the total offshore mining environment in appropriate site specific terms.

Conceptual Continuous Bucket Dragline

The rationale of the continuous bucket dragline dredge concept (CBD) is to incorporate the flexibility of the dragline and the efficiency of the continuous loop bucket line without the constraints of the ladder. The traditional bucket-ladder dredge designers and operators will argue that the precision of the depth and width of cut will be lost without the positive control afforded by the ladder and lacking this high degree of control the variable geometries of ore bodies cannot be efficiently followed. They are correct to a point. Every effort must be directed in the selection and operation of a placer mining system to confine excavation within the ore zone. Working beyond cut-off grade limits, hence delution of ore, during the processing cycle must be avoided as much as possible. On the other hand, it must be acknowledged that a skilled dragline operator may also effect a high degree of control in bucket handling and excavation. If a continuous loop of buckets could be engineered and handled with a similar degree of designer and operator skill a suitable system for many otherwise unreachable placers may be possible. In addition, incorporating the efficiency of the continuous bucket line, loss of time and energy inherent in the interrupted cycle of the dragline bucket cast and retrieval can be significantly reduced.

The basic layout of the CBD would have the load tumbler mounted above a through-hull slot with the idler tumbler mounted forward; Figure 2. The load tumbler would be similar in design and function to the top tumbler of the bucket-ladder dredge, transferring the force of the drive motors to the bucket line by means of gear reduction and the polygonal surfaces of the tumbler. The forward idler tumbler would serve the function of directing or casting the bucket line in position for the cut. The hull would be so designed that the load tumbler would be mounted within the span of the pitch axis for the average heavier seas, thereby reducing undesirable heave loading. Heave at the forward idler could be more readily accommodated by the slack band of descending, empty buckets.

Increase in depth of cut would be managed by shifting the forward idler tumbler aft, in measured increments, along its track. When the after stop is reached, an additional bucket line length may be added and the operation repeated. Operational maneuvering of the dredge would be accomplished by means of a conventional mooring system of sidelines, but with the replacement of the headline by a sternline, securely anchored so as to counter the force of the bucket line under load; Figure 2.

The processing plant would be similar in design to that of a conventional dredge mounted plant except in the case where rough seas and high winds were a factor. The load tumbler would be lowered accordingly in the interest of increased stability, accepting a corresponding loss in gravity feed, with attendant increase in pumping. Disposal of tailings would also be handled in similar fashion as on a conventional placer dredge, stacking coarse to fine fore to aft and thickening slimes as appropriate to enhance settling. In deeper water, in the presence of a thermocline with sufficient temperature change, an effort would be made to handle and deliver slimes as rapidly as possible below the thermocline before warming, so as to reduce turbidity in the surface water.

A number of dredge mining applications may be appropriate for the CBD considering the ultimate economy of a balanced bucket line system, and its adaptability to rough sea conditions (Masuda, personal communications). Commodities such as heavy minerals, aggregate and phosphate could be readily mined from open sea locations. In addition, the basic CBD design could be modified to work in light sea ice where appropriate by adding ice belting to the liuli and providing an ice breaking bow to facilitate bucket line entry up to the forward stop of the Idler tumbler tract. In addition, power would be used to assist or serve in lieu of the standard mooring system, as ice conditions required.

Traditional Suction Dredge Systems

The history of attempts to effectively utilize the hydraulic or suction dredge concept in mining the heavier placer deposits (Sn, Au, Pt) has been largely unsuccessful regardless of the array of pumps and cutter devices employed. The problem is not so much an engineering constraint, but mainly the lack of familiarity of suction dredge designers with the many peculiarities of working these unusually difficult deposits. Notwithstanding the inherent inefficiency of moving high ratios of water to solids in any hydraulic dredge, relative to mechanical excavation, the extenuating circumstances of greater working depths rough sea and ice conditions may rule in favor of the hydraulic option. Whatever the reason for the selection, there are three basic problems in the application of hydraulic dredging technology to mining the heavier placer deposits. The problems may be best presented as fundamental laws; here deliberately generalized and over simplified to emphasize their importance. They are as follows: 1) First Law - Whatever the diameter of a simple suction intake, a rock will be encountered of sufficient size to clog it. Design Requirement - Must provide a means of limiting the size of material entering the suction intake and prevent clogging. 2) Second Law - Rejected oversize material not physically removed from the cutting face (mine cut) will progressively concentrate with increasing depth of cut, becoming increasingly difficult to penetrate. Design Requirement - Must incorporate a means of removing rejected oversize away from the cutting face. 3) Third Law - Heavier placer minerals (densities equal to or exceeding cassiterite) will be systematically displaced and rejected from slurry entrainment with each successive pass of the suction intake, biased by the inherent preference for the lighter, finer fractions. Design Requirement - a) Must maintain high intake velocity at given mining depth, utilizing a submersible pump, i.e. impeller or jet type, b) Should provide suction intake as close as possible to surface of excavation and include means of dislodging and force feeding material to the intake.

Conceptual and Prototype Cutter Chain/Wheel Dredge

Recognizing the advantages of the hydraulic system to certain applications as well as its limitations, the senior author had the opportunity to actively participate in the design, construction and operation of an innovative prototype design. The project called for the trenching/pilot dredging of gold bearing beaci: placers, developed on glacial material ranging in size from clay to boulders. The deposits were located offshore of The Ovens Headland, Nova Scotia, at depths of 10 to 20 meters respectively. Sea conditions were not of primary concern for the limited duration of the pilot project, but extended operations would require a system capable of working in high winds, rough seas and light sea ice. In addition, a very flexible system would be required to manuever around large erratic boulders and bedrock reefs, selectively mining discontinuous ore grade pockets. The system selected for the pilot project would have a dual role; to carry out the trenching mission and to provide a model concept that could be expanded in a full mining application.

Cognizant of the constraints of the three laws of hydraulic placer dredging and a fourth absolute, a limited budget, a number of systems were reviewed and considered against the wide range of critical aspects cited above. With the final integration, a hybrid suction system was selected for the prototype. The design utilized a jet pump, mounted in the intake, providing a high energy boost to a hull mounted conventional dredge pump system. To answer the requirement of the First Law, a continuous ladder chain was designed to sweep the intake mouth clear of oversized rocks which would otherwise clog the intake; restricted to 20 cm considering the limits of the selected pump and impeller wear. The chain was driven by a submersible hydraulic motor via a gear reduction and a pair of top tumbler drive sprockets mounted in the crotch of the "Y" shaped ladder. Figure 3. This mounting configuration provided a fortuitous removal of the motor and drive from the high impact zone at the cutter head; a significant advantage over conventional bucket wheel systems with integral drive.

Results of an earlier survey indicated a significant percentage of oversize that would have to be cleared from the cutting face that would concentrate into an impenetrable layer according to the Second Law. Teeth were added to the continuous ladder chain to assist in dislodging and transporting the oversize to the rear of the cut, dumping over the top tumbler.

The Fourth Law was answered in part by the inclusion of the jet boost pump at the intake and a pair of cutter wheels fitted to the lower idler sprockets of the ladder chain. The latter served to cut and force feed the placer material into high velocity slurry entrainment at the intake mouth.

The resulting design was named the Cutter Chain/ Wheel Dredge (CCW). The system proved successful in both its primary application, cutting eight evaluation trenches to bedrock, and in its prototype model role. The project demonstrated that a hydraulic system could be designed to effectively mine coarse placer ground provided the three basic laws of suction dredging were respected.

A number of generic improvements to the prototype can be considered for raining applications. The sprocket drive of the ladder chain may be replaced with a polygonal drive and the chain composed of links similar to that of a conventional bucket of a bucket-ladder system, modified with a lower profile, but retaining a cutting lip and incorporating a basal slot for force feeding the intake mount; Figures 3 and A. A high volume version could be fitted with multiple intakes and corresponding slotted cutting links feeding multiple pumps; thereby restricting the feed size to pumps tó less than about 25 cm with attendant increase in efficiency and savings in pump maintenance .

With these problems solved a workable model is available for modification to a wide variety of site specific needs as required. These may include in simplest application; 1) retro fitting to existing suction dredge systems of possible interest to limited budget operations in developing countries; 2) low profile surface mounted systems compatible with the more rigorous working conditions of the higher latitudes; and 3) bottom crawler mounted systems capable of working semi-remotely in the deeper depths, higher sea states and beneath sea ice; Figure 5.

Acknowledgments

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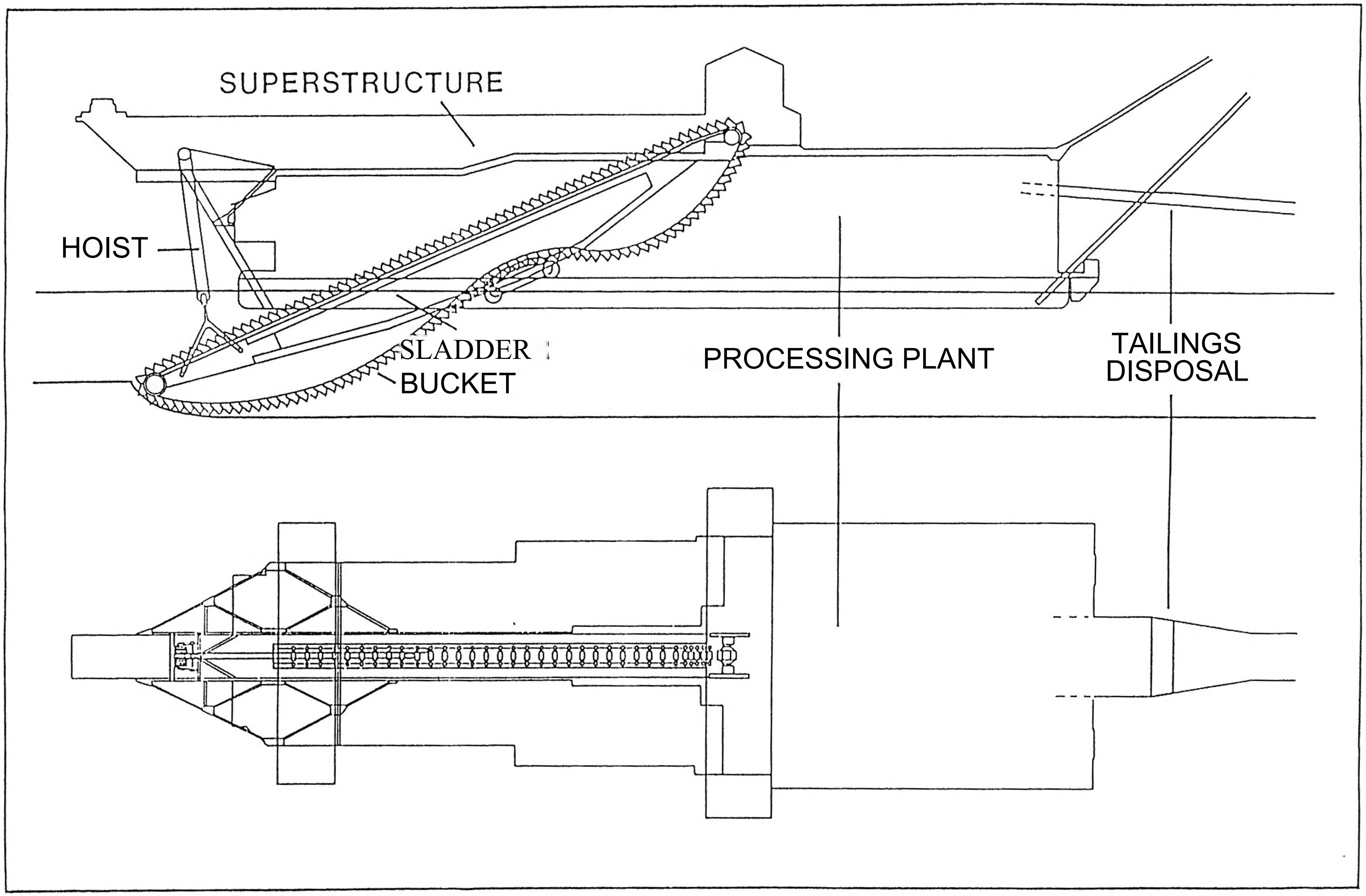


Figure 1: Conventional Bucket-Ladder Dredge

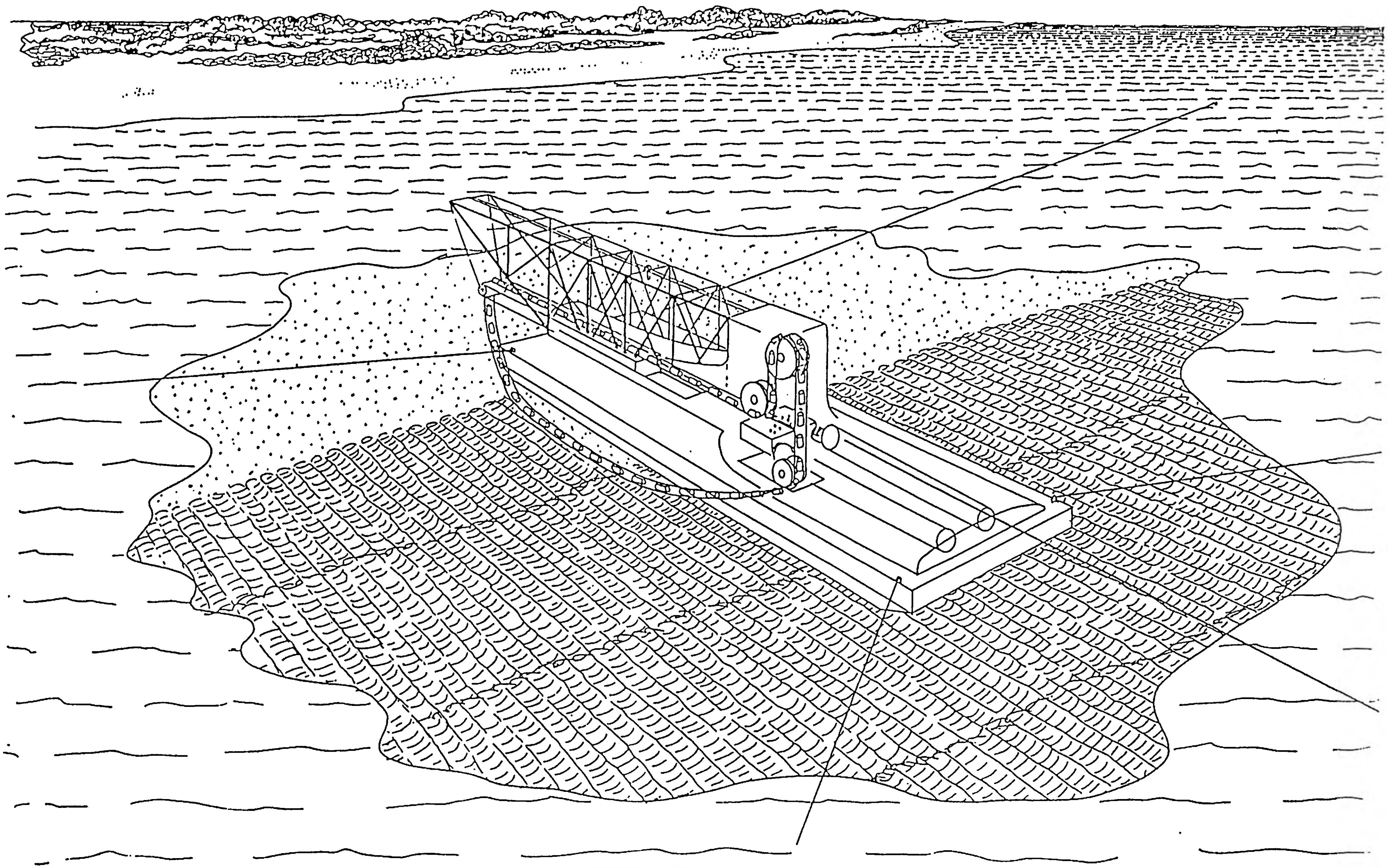


Figure 2: Conceptual Continuous Bucket Line Dredge
in Shallow Digging Configuration

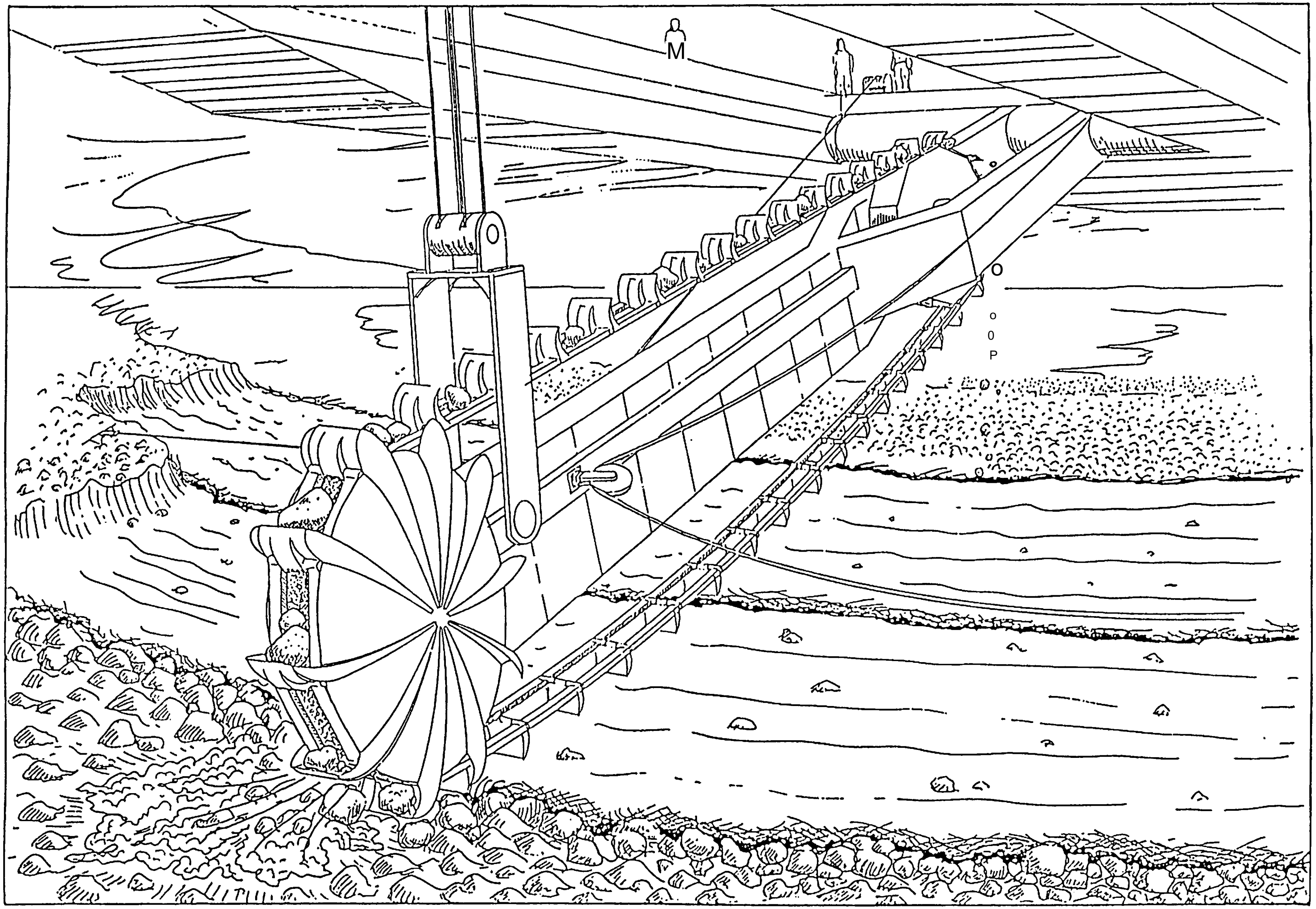


Figure 3: Prototype Cutter Chain/Wheel Dredge
with Updated Ladder Chain and Polygonal
Drive

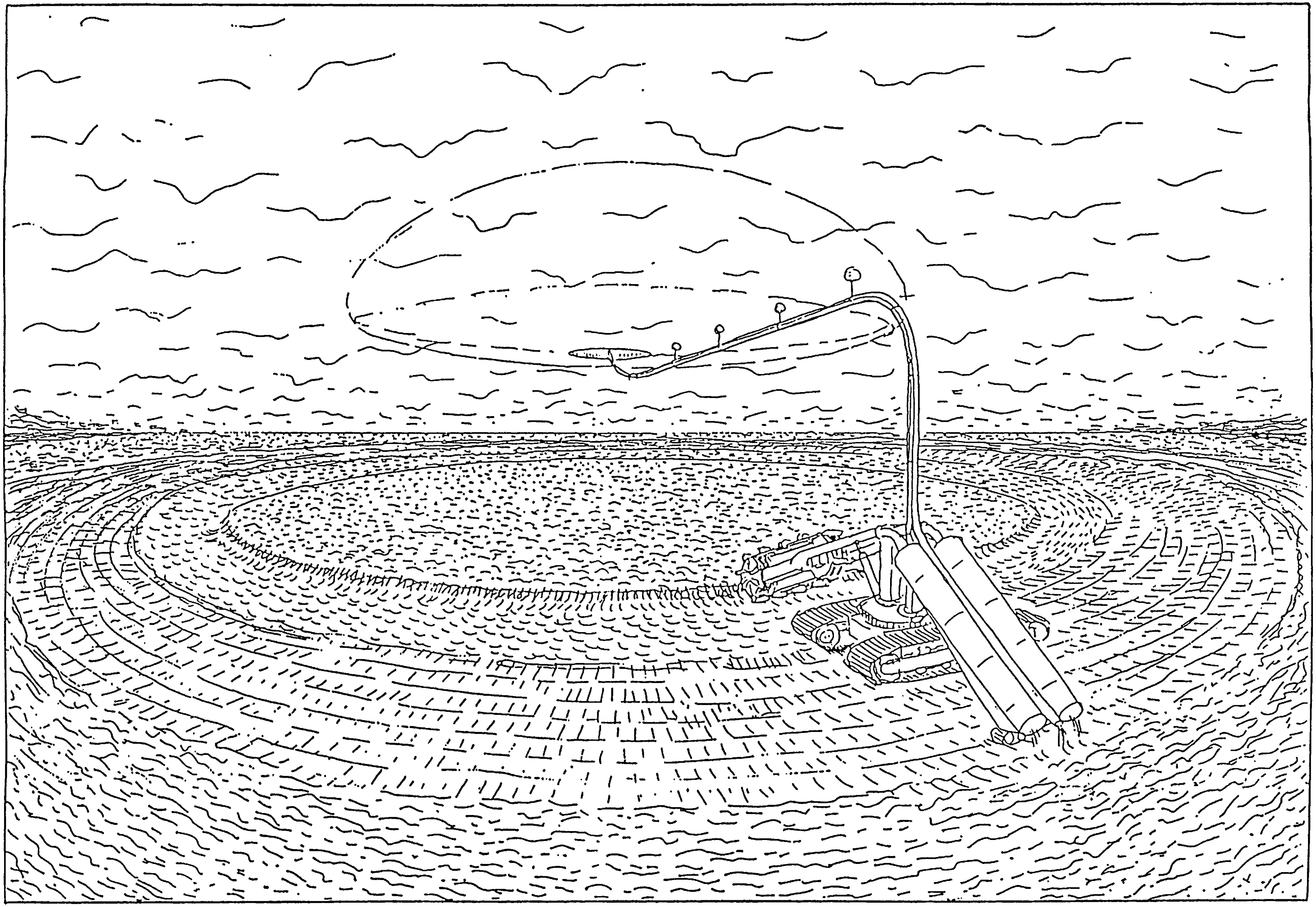
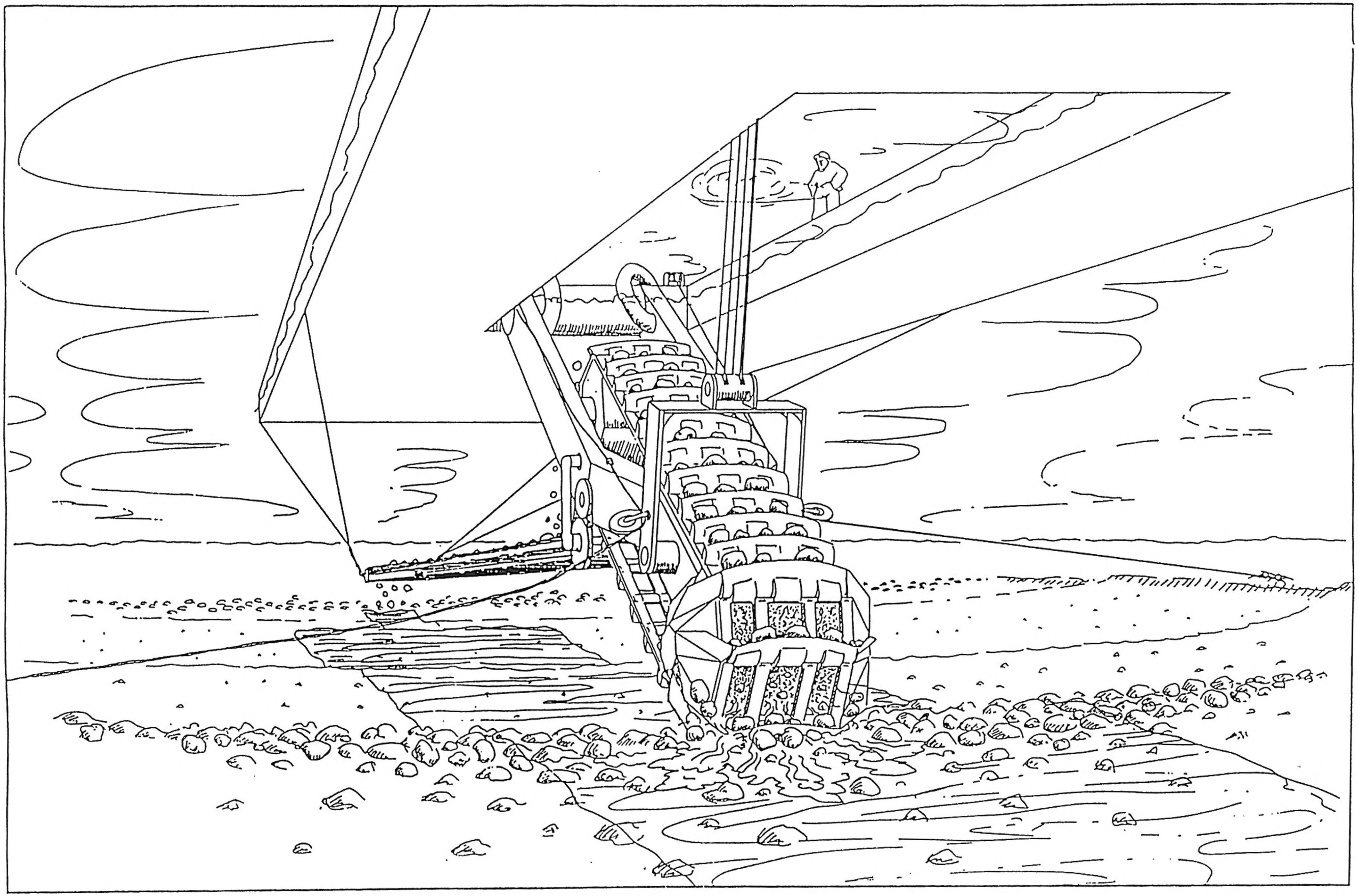


Figure 5: Conceptual Bottom Crawler Mounted
Cutter Chain/Wheel Dredge



Figuro 4: Conceptual Surface Mounted, High Production
Cutter Chain/Wheel Dredge