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Analysis of a Self-Propelled Dredger Capability in Shallow Waters Operation

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Abstract
This research presents a numerical and regressional analysis of a self-propelled trailing suction hopper dredger capability in the Chanomi creek of 4m depth. The analysis considered using relation that expresses the payload, lightweight, deadweight, hopper capacity, work schedule, pump capacity, engine performance, and sand density to determine the possible operation and duration of the excavation project based on the vessel cycle time. Using the regressional relationship, the dredger capacity was obtained, and the result shows that a propulsive power of 678.75kW, bow thrusters power of 116.9kW, and pump power of 540kW is needed for a 2324 tonnes hopper dredger capacity for the project. The result further revealed that the pump flow rate of 0.45m^3/s per suction tube with a suction diameter of 0.338m is needed to fill the hopper capacity of 1000m^3 every 60 minutes. For a payload of 1356tonnes, the reclamation operation requires 466trips for one year. This provides an operational guide to operators in the sector on decision making and cost reduction operation.

Keywords – *Dredgers, Pumps, Self-Propelled, Power, Pipelines*

I. INTRODUCTION

Dredging is an excavation activity or operation usually carried out partly underwater, in shallow or deep seas or freshwater areas to gather up bottom sediments and dispose of them at a different location, mostly to keep waterways navigable or for reclamation. A dredge is a device for scraping or sucking the seabed, used for dredging, while a dredger is a ship or boat equipped with a dredge. The process of dredging creates spoils (excess material), which are conveyed to a location different from the dredged area. Dredging can produce materials for land reclamation or other purposes (usually construction-related. Dredging can create disturbance in aquatic ecosystems, often with adverse impacts (Environmental & Socio-economic) [1].

Hopper dredger is a self-propelled floating plant capable of dredging material, storing it on board, transporting it to the disposal area, and dumping it [2]. Hopper dredgers perform the largest and most dangerous jobs – clearing channels and offshore sandbars from the mouths of major rivers. Hopper dredgers move like a ship. When dredging, they move very slowly. When the dredger's hopper is loaded, the dredge manoeuvres both in and out of the channel to reach the relocation or dumpsite; during this time, the dredger may move much faster and may turn frequently. Direct pump out is a standard method of removing dredged material from hopper dredgers. A hopper dredger fills its hoppers as it dredges the bottom of the sea. The dredger then moors to a berth. Hoses connected to a pipeline extending to shore are attached to the hopper dredger discharge manifold [3]. The dredger mixes the dredged material with water to form a slurry and pumps the slurry from its discharge manifold through the hoses and pipeline to a designated discharge location.

Dredging is needed generally to clear or "sweep" waterways to make them navigable or to mine (in most cases) sand/sandstones for reclaiming land. Dredging is, therefore, an essential infrastructural activity in the Niger Delta region of Nigeria. While many waterways are being deepened or periodically dredged to maintain their depths, some other areas require sand filling/reclamation to construct industrial and/or other significant projects or facilities. For reclamation, the process requires the dredging of suitable materials and depositing at the designated location. This can sometimes present difficult challenges since the suitable material may not be found in the vicinity of the reclamation area. The Niger Delta sand search shows isolated areas of fatty deposits of suitable sandstones for sand filling for constructing significant projects, especially major Oil & Gas projects like Fertilizer plants, Tank farms, LNG plants.

A simple cutter and suction dredger, floating, and land pipelines arrangement can readily achieve reclamation work at project locations. However, for the reclamation of certain areas located remotely from appropriate sand deposits, there is a need to convey the dredge materials (Sandstones) by some other means (rather than by pipelines), and depositing required place. This requires the use of a self-propelled hopper dredger (SPHD).

The SPHD is a free sailing vessel and does not hinder other shipping during dredging and is therefore ideal for dredging in harbors and shipping channels inshore and offshore. The seagoing vessels are very suitable for borrowing sand under offshore conditions (wind and waves) and large sailing distances. The dredged material is dredged, transported, and discharged by the vessel without any other equipment. (De) mobilization is very easy for this type of dredger. It can sail under its power to every place in the world. Suitable materials for the SPHD to dredge are soft clays, silt sand, and gravel [4]. Firm and stiff clays are also possible but can give either blocking problems in the drag head and/or track forming in the clay. In that case, the drag head slips into preceding tracks, resulting in a very irregular clay surface. Dredging rock with an SPHD is, in most cases, not profitable. It requires weighty drag heads with rippers, and the productions are relatively low. All dredgers except the trailing suction hopper dredgers are stationary dredgers, which means they are anchored by wires or (spud) poles.

There are few industrial activities today that involve such exposure to abrasion and consequent component wear as dredging [5]. The equipment does its work in one of the most unforgiving environments in the world. The material to be dredged is almost always abrasive, sometimes excessively so, the high levels of production, necessary mean high flow rates and enormous stresses, and the working conditions do not favor simple solutions.

Although systems for describing dredgers vary, three broad classifications are recognized based on the means of excavation and operation. These are known as mechanical dredgers, hydraulic dredgers, and hydrodynamic dredgers, briefly explained above. Trailing suction hopper dredgers (SPHDs), also explained in brief above, are classified as hydraulic dredgers [6]. Hydraulic dredgers include all dredging equipment that uses centrifugal pumps for at least part of the transport process of moving the dredged materials, either by raising material out of the water or horizontally transporting material to another site.

SPHDs are used on a wide variety of maritime construction and maintenance projects. These range from maintenance dredging of ports and access channels to remove sand to bring them to necessary depths. To capital dredging projects such as giant land reclamation projects that require millions of cubic meters of sand [7]. The performance efficiency of an SPHD has a direct influence on the costs of a project. Consequently, research and development on SPHDs is an ongoing Endeavour to improve cost-effectiveness. The reason we are considering an SPHD fit to dredge the Chanomi creek is to achieve these advantages listed.

1. Deepen the access channel and maintain a required depth for international trade navigation.
2. The dredged materials (Sandstones) will reclaim lands for significant projects, in this case, by the Escravos estuary.

A. Pumps and drive systems

Pump and drive systems cover all dredging hardware that physically moves the dredge mixture. The cost-effectiveness of dredging today depends significantly on the performance of pumps, dredge pumps, submerged dredge pumps, and jet pumps; and targeting the efficient transport of either the dredging mixture or water. They are critical components in almost all dredging systems. Their capacity has to be adapted to the task at hand, and their practical operating life in often difficult operating conditions maximized. Capital design, reducing the effects of wear, and ensuring easy repair and replacement all play vital roles in upgrading efficiency and minimizing overall lifetime costs [8].

Inboard dredge pumps are the primary power source for transporting the mixture to the hopper or discharge location. Submerged dredge pumps in suction pipe offer the combined facility of lifting mixture cost-effectively from great depths and higher output. High-efficiency pumps are redesigned pumps created to minimize flow resistance and wear and increase production efficiency.

Jet pumps ensure high-pressure water for significant bottom soil loosening at the drag-head and hopper discharge. High-efficiency pump design has been optimized to upgrade pump production and suction characteristics and reduce wear, though this necessarily involves a higher investment than in the case of conventional pumps [5]. The logic behind the development of high-efficiency pumps was that a marginal improvement in pump efficiency creates a huge multiplier effect on improving the cost-effectiveness of production and reducing the length of the dredge cycle. Ongoing research into yet other ways of improving pump performance is a permanent element of all design efforts.

B. Framework of an SPHD

SPHDs or hoppers are self-propelled ships that contain a hopper or hold inside their hulls. They are primarily used for dredging loose material such as sand, clay, or gravel. The main features of an SPHD are drag heads, suction pipes, swell compensators, and gantries [1]. Typically, an SPHD is equipped with one or two suction pipes to which the drag heads are attached. A drag head is often compared to a giant vacuum cleaner. The suction pipes are lowered underwater, and the drag heads are "dragged" over the seabed, sucking up material as the ship slowly moves forward, i.e., trails.

The suction pipes and drag heads can be positioned according to the performance needs of the intended dredging operation so that they can be transported to the hopper [9]. Through a pump system, the sand/water mixture, called slurry, is drawn upwards to the hopper or hold of the vessel. Gantries and winches operate the suction pipes, moving them either overboard or bringing them back inboard. A swell compensator controls the contact between the drag head and the seabed when dredging in waves. Besides, the SPHD must have an overflow system to separate the slurry and discharge excess water. The efficiency of each of these elements will directly affect the productivity of the SPHD [4].

Although all SPHDs have drag heads attached to suction pipes, drag heads can differ. The job of the drag head is to excavate the seabed material and to mix this material with water to create a slurry. The drag head is the first 'touchdown' place for contact with the soil [10]. In general, the force that makes the points of the drag head penetrate the soil is the weight of the drag head and the suction pipe. When dredging stony soils, however, if this weight is not sufficient, the drag head will not penetrate enough and will drag on top of the surface without cutting the soil. This results in a low mixture density, which lowers the production of the hopper dredger. The higher the density of the mixture created by the drag head, the better the performance.

Continuing research has resulted in the development of drag heads that excavate with high-pressure water jets assisted by teeth. They loosen the material and increase the productivity to form the slurry. To improve the efficiency of the water jets, sometimes the nozzle is integrated into the points of the drag head so that the water jets cut the soil moments before the point penetrates the soil. As a result, the forces needed to penetrate the soil are reduced, and the cutting efficiency is increased. The suction power of the pump then captures the seabed material and allows the slurry to be transported hydraulically. The sediment is hydraulically transported through suction lines by the centrifugal pump into the hopper [11]. There the solids settle out and are held awaiting transport and subsequent placement.

A more recently developed drag head is "the ripper, "a drag head with teeth. Usually, rock is dredged by a cutter suction dredger (CSD), equipped with a unique head that bores through hard material. However, when sea conditions are rough, or a waterway has high vessel traffic, a cutter is not suitable. A ripper drag head can be placed on a traditional SPHD and combines the cutting power of a CSD with the flexibility and stability of an SPHD.

SPHDs are very flexible and can operate independently of other equipment and, since they are self-propelled, can transport the dredged material over long distances. Once fully loaded, the vessel sails to the unloading or placement site where the dredged material is offloaded [9]. Depending on the type of project, the dredged material will be offloaded/discharged in one of three ways: the material is either deposited at the placement site by opening the hatches in the bottom of the ship; it may be pumped ashore through pipelines, which may be submerged or floating; or massive duty pumps may propel the material into the air, a process known as rainbowing. The method of offloading or discharging is directly related to the type of project. When a material is dredged out of a harbour or access channel, and the material is clean, the SPHD will sail out to sea to a designated location and deposit the dredged sediment by opening its bottom doors (hatches). Discharging through bottom doors allows quick, direct, and total offloading of dredged material at a selected location. This is a reliable and effective method, but only in certain specific circumstances. During extensive land reclamation or beach nourishment projects, the SPHD will navigate to a selected borrow area, which may be many kilometres away from the construction site. At the borrow site, the dredger will load up its hopper with sand and then sail to the site where new land is being built.

This material is then either rainbowed into place or pumped on-site through floating or submerged pipelines. To connect the pipeline to the vessel requires a unique link known as the bow coupling. If the distance from ship to shore is rather long, then booster pumps as an additional source of power can be added along the pipeline. The nozzle for rainbowing is also a part of the bow coupling [12].

A submerged pipeline is less sensitive to weather conditions and provides no obstacle to other ships crossing in the area. It is usually assembled onshore and then pulled out until the open end is positioned correctly on the beach. Sections may be added if necessary. Floating pipelines, although more sensitive to rough seas have the advantage that they are visible above the surface of the water and can be reached easily if in need of repair.

II. MATERIALS AND METHODS

A. Adaptive Design of SPHD for Chanomi Creek Application

The required production capacity is expressed in m^3/week or m^3/month or even cubic meters per year. Besides that, insight required about the expected average cycle time of the trailing suction hopper dredger on the different jobs and the type of soils to be dredged. Then the production capacity can be translated to:

- The required payload in ton mass.
- The maximum hopper volume in m^3.

The design of a dredge installation includes the determination of the required main dimensions and required powers of the following dredging components

- Number of suction pipes
- Pump capacities
- Suction and discharge pipe diameter (m)
- Type of dredge pump
- Sand pump drive and power (W)
- Type and size of drag head(s)
- Hopper shape
- Discharge system

B. Case Study Workability

Design a Trailing Suction Hopper Dredger that can dredge 200,000m^3 coarse sand and gravel at 31.5km (17Nm) from the point of discharge.

- The dredger works 5 days at 12 hours per week
- Bunkers will be taken at the weekends
- An overhaul is 2 weeks in a year
- Weather delays are 3 weeks in a year
- Workability is 95%
- Christmas is 1 week.

C. Particulars:

Given the requirements and constraints stated above, the primary particular of the vessel analyzed is shown in Table 1

Table 1: Dredger Types Particular [1]

Dimensions	Easy Dredge
Length Overall	81.75m
Length bpp	79.80m
Beam	15.80m
Depth	5.90m
Draft on dredging mark	5.50m
Hopper Capacity	2700m³
Loading capacity	4,320t
Diameter of the suction pipe	1 X 500mm
Dredging depth	5-15m
Deadweight	4100t
Laden speed	11.5kn
Density of Sand	1.6T/ m³
Power and Speed	
Dredge pump	940kw
Main engines	2 X 1,250kw
Jet pump	360kw
Bow thrusters	385kw
AC Diesel Gen-set for main electric power	2 X 200kw
Total power	4,585kw
Laden speed	11.5 knots
Total storage space of diesel oil	220 m³
Total storage space of freshwater	30 m³
Accommodation	8-12

1. *Main Particulars and Theoretical Formulation*

$$Displacement\ \Delta = L \times B \times D \times C_b \times \rho_{sw} \qquad (1)$$ [13]

Given that Vessel length = 60.0m,
Block Coefficient = 0.9,
Beam = 12.0m,
Depth = 4.0m,
Draft = 3.5m

$$\Delta = 60 \times 12 \times 3.5 \times 0.9 \times 1.025 = 2{,}324.7 Tonnes$$

- **Operations Specification**

i. Reclamation of 10 hectares of swamp approximately 100,000m^3
ii. Depth of fill = 2m
iii. Distance from sand deposit to fill area = 31.5km = 17Nm
iv. Period of work = 5 days/12 hours, Bunkers at weekends
v. Overhaul = 2 weeks /year
vi. Holidays (Charismas) = 1 week.

- **Cycle Time**

i. Distance to dredge site = 31.5km = 17Nm
ii. Vessel Speed= 11.5Knot = 11.5Nm/hour

The first estimate of the dredge cycle:

i. Sailing to dredge area = $\frac{17Nm}{11.5}$= 1.48 hours
ii. Loading of sand= 1.0 hours
iii. Sailing to dumpsite = 1.48 hours
iv. Unloading = 1.0 hours

$$Total\ time\ /Cycle = (2 \times 1.48) + 2 = 5.96 hours,$$

Approximately = 6.0 hours

- **Required Load Trip**

i. Available hours = $[52 - 3]$ x5 x 12 = 2,940 hours
ii. Effective hours = 0.95 x 2,940 = 2,793 hours
iii. Number of trips/year = $\frac{2793}{6}$ = 465.5 = 466
iv. Available volume/trip = 900m^3
v. In coarse sand and gravel, minimum filling of hopper = 90%
vi. Required Hopper volume = $\frac{900m^3}{0.9}$ = 1,000m^3
vii. Payload/Trip = 900 x 1.5 = 1350 Tonnes

- **Trip Management**

Since the time taken to complete one cycle of trip = 6 hours.
This means each day of 12 hours crew can handle 2 trips. The implication of this is that the total cycle will be completed in $\frac{466}{2}$ days = 233 days.

Payload per trip = 1350 Tonnes
Payload/day (12 hour) = 2700 Tonnes
Required/ Tonnage of Sand = 200,000 x 1.5
= 300,000 Tonnes

Number of days required to deliver 300,000 tonnes of sand for reclamation = $\frac{300{,}000}{2700}$ = 111.1111 days

Number of weeks = $\frac{111.1111}{5}$ = 22.22 weeks

Number of months = $\frac{22.22}{4}$ = 5.5/months

2. *Deadweight and Lightweight Relationship*

To estimate the deadweight, we considered the crew and their possession, consumer goods, spare parts, ballast water, and payload.

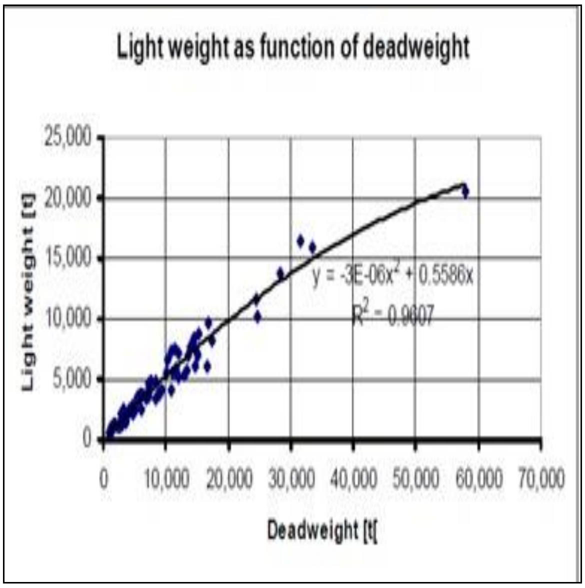

Figure 1 Plot of Lightweight against Deadweight [7]

$$Deadweight = 1.05 \times payload$$

From Figure 1, the relation that describes the lightweight and deadweight gives

$$Y = 3E - 06X^2 + 0.5586X$$

where Y is the lightweight and X is the payload or cargo weight

- **Capabilities of the Dredger**

i. Hopper (cargo capacity) = 900m^3 =1350tonnes
ii. Sand Density = 1.5 Tonnes/m^3

$$\text{Displacement in Tonage } \Delta_T = Lightweight + Deadweight$$

Therefore, for a given value of payload

X = 1350 Tonnes.
Y = $-3 \times 10^{-6} \times (1350)^2 + 0.5586 \times 1350$
= -5.4675 + 754.11
Y = 748.6425 Tonnes
Lightweight = Y = 748.6425 Tonnes
Recall that Deadweight = W_d = 1.05X
We know that X = 1350 Tonnes,
Hence Deadweight = 1.05 x 1350= 1417.5Tonnes

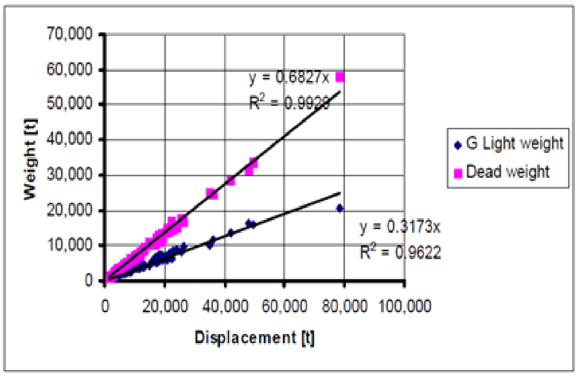

Figure 2 Plot of Weight against Displacement in Tonnes for Light and Dead Weights [7]

Since Δ_T = Light weight + Deadweight
Δ_T = y + W_d
= (748.6425 + 1417.5) Tonnes
Δ_T = 2166.1425 Tonnes

Compare with particulars; where displacement;
Δ_p = 2324.7 Tonnes

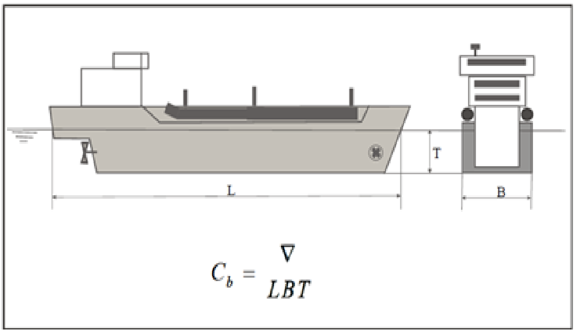

Figure 3 Schematic Representation of the SPHD Plan [14]

III. RESULTS AND DISCUSSIONS

A. *Propulsion and Machinery Analysis*

The analysis of the SPHD is tailored to maintain two main engines for both propulsion and dredging (i.e., also used to drive the pump). The configuration entails and gearing system that connects the propeller on one end and the pump on the flywheel end. This is feasible since the propulsion system is on sleep mode when the dredger is at work, with only the bow thruster used for the navigation. Based on the mathematical calculations deduced, the following results were obtained:

The result shows that the main propulsion power is 543kW but was validated with an efficiency of 80% to compensate for mechanical losses and the effect of external current. The absolute power after validation was 678.75kW however, from the engine catalogue, the closes rating that agreed with validation is a power of 746kW. The Bow Thruster Power was 81kW but was validated with an efficiency of 70% to compensate for mechanical losses and the effect of external current. The absolute power after validation was 116.9kW; however, from the engine catalogue, the closes rating that agreed with validation is a power of 129kW.

The result of the Pump analysis gave us a pump power of 540kW. However, it was validated with an efficiency of 75%, to compensate for mechanical losses and the effect of bends. The absolute power after validation was 746kW, which highlights the possibility of also using the main propulsion engine to drive the pump, and from the engine catalogue the closes rating that agreed with validation is power.

The analysis further shows that at a block coefficient C_b of 0.9, the theoretical displacement of the ship was determined and used as a guide to ensuring that other hydrostatic parameters will bring about a matching specification as it relates to the stability. The block coefficient is the ratio of the underwater volume of the ship to the volume of a rectangular block having the same overall length, breadth, and depth (draft). Using the block coefficient, the vessel displacement of 2,324 Tonnes and the design was considered a 0.73% error margin.

Further analysis also revealed that from the Hopper capacity of 900m^3, the required hopper size to be provided in the dredger gives = 1000m^3. Hence the matching pump to fill this capacity in 60 minutes was a pump capable of delivering a flow rate of 0.45m^3/s per suction tube, from which we obtained a suction diameter of 0.338m. Using a pump selection catalogue, the matching pump rating for this selection was found to be 540kW; recall that to compensate for losses, we chose to drive the pump with the main propulsion engine of 746kW, which has already compensated for a pump efficiency of 75%.

Based on the preceding, the following load and trip management we have that

- Payload/trip = 900m^3 x 1.5 = 1350Tonnes

- Time taken to complete one round trip is 6 hours approximately. This implies that two trips can be covered in one working day of 12 hours.
- About 466 trips are needed to complete the reclamation project in one year, which gives 233 days will be several days; this dredger will work to complete the project, which is 5.2 months or approximately 6 months.
- That the carry capacity of the dredger if increased (Hopper =1350 tonnes)/trip = 2700 tonnes/day will deposit 300,000 tonnes of Sand; the dredger will work in 300,000/2700 days = 111.111 days = 22.222 weeks = 5.55 weeks. Approximately 6 months.

IV. CONCLUSION

This research work considered the feasibility of using the SPHD in the Niger Delta region of Nigeria for the canalization of the narrow and shallow creeks towards making them deep enough for the international maritime business in Exploration and Exploitation of its vast and rich resources. The application of the preliminary analysis to ascertain the operational vessel capacity at Escravos terminal through which reclamation of the island can be achieved in a short time provide vital information for various company players.

However, based on sand search statistics, the Chanomi creek (10-17) nautical mile away from the Escravos terminal hold the same type of sandstone required to hold the project, but as the availability of the SPHD, the project can be handle despite the shallow and narrow Chanomi creek. The analysis further shows:

i. That the turnaround time of dredging and depositing from the Chanomi creek is safer, faster and more secure than dredging from the Lekki area.

ii. That a smaller shallow draft SPHD is feasible and required for the rapid development of the Niger delta.

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