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DESIGN OF A BARGE FOR SMALL SCALE EXCAVATOR IN NARROW CANAL

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ABSTRACT

The Sri Lanka Land Reclamation and Development Corporation (SLLRDC) is a Government Corporation operating under the Ministry of Megapolis and Western Development, mainly involved in dredging of canals, canal maintenance, and Civil Engineering projects in Sri Lanka. It is in possession of several excavators which are capable of dredging from large canals to small canals. The machines weight range is from 3.7 Tons to 25 Tons. There are several canals, which are narrower than the other canals. The width of such canals are 3 - 7 m range. Therefore, such canals could only be dredged using small scale excavator (3.7 Ton "Doosan 35Z excavator).

Due to the unavailability of a small barge to accompany the 3.7 Ton "Doosan 35Z excavator, the dredging of such canals has to be performed manually, which consumes a considerable amount of time and labor. Generally such manually performed processes are not performed to acceptable standards in comparison to a dredging process done by an excavator. The present work was to design a suitable barge considering three main factors, namely machine dimensions, machine weight and canal dimensions. First, a default set of dimensions were selected and the stability of the barge was checked with the aid of the draught and metacentric height. Then a set of dimension were used and the most suitable set of dimensions were selected.

KEYWORDS – Barge, narrow canal, excavator

1.0 INTRODUCTION

When the canal width is less than 7.5 m (25 feet) we cannot use excavator with a barge at present. Narrow canal excavation is done with an excavator moving along the canal bank. This makes it very difficult to do a complete excavation satisfactorily and hence manual labour has to be employed to supplement the work done by the excavator. If a suitable barge can be designed to mount a small excavator, then the excavation can be easily done while the excavator is moving along the canal. Thus, it has been observed that;

- Existing excavator with a barge cannot be used when the canal width is less than 25ft or when dredging is to be carried out under bridges.
- For canals less than 25ft width manual labour has to be used.
- Solution suggested here is the use of a smaller barge to carry a 3.7 Ton excavator, but smaller barges are not readily available in the market for outright purchase.

2.0 LITERATURE SURVEY

The literature survey is conducted in following areas.

- Identification of the Excavator Specification.
- Dredging Techniques used in SLLRDC.
- Dredging Techniques in Other Countries (Specially Narrow Canals).
- Identification of the Canals in Colombo Area.

Summary of literature survey

Table 01: Examples for Narrow canals in the Colombo Canal Network [2]

CANALS	Average Depth(m)	Average Width(m)	Length(m)
Peliyagoda Area Canals	1.5	5.4	3000
Thamilnadu Canal	1.2	7.5	500
Bluemendle Stadium Canal	1.3	6.0	800
Henamulla Canal	1.4	6.3	1000
KiriEla (Kotte)	1.1	5.4	600
OrsisEla (Kotte)	1.2	6.8	700
Dabare MW canal	1.5	6.0	800

MudunEla	1.4	6.5	1200
Abagaha junction Peripheral Canal	1.3	6.0	800
Salamulla ELA Peripheral Canal	1.2	5.7	900
Torington South Canal	1.4	6.8	1100

3.0 OBJECTIVES

To design a barge for supporting the small scale excavator (Doosan 35Z excavator), so that Doosan 35Z excavator can be used for excavation work in canals of width less than 7.5 m (25 feet)(narrow canals) and for under bridge excavation. Such details of narrow canals are shown in table 01.

The specific objectives of this project are;

- Design a cost effective reliable barge for the small scale excavator at SLLRDC.
- Prepare simplified fabrication plans and calculations for the new barge designed.
- Submitting a Budget report on the production of the barge.

4.0 METHODOLOGY

The methodology adopted in carrying out this project consists of the following steps;

- Literature Survey.
- Selecting the overall dimensions for the barge according to machine specifications and canal measurements that would provide stability.
- Carrying out detail Calculations of;
    - Draught
    - Metacentric Height
    - Structural Design (Reinforcement, Plate Thickness)
    - Sizes of Nut & Bolt, Pin, Lifting Eye
- Preparation of Engineering Drawings.

5.0 DESIGN OF BARGE

The main objective of the project is to design a barge which can be moved along narrow canals that could also carry the Doosan 35Z excavator as a reference for take dimensions. After studying the dimensions of the Doosan Excavator a barge of minimum length 4200 mm and width 3000 mm were considered as suitable dimensions (these were initial assumed dimensions). Based on the past experiences, it was evident that the above mentioned dimensions will not be sufficient to stabilize the barge under the relevant operating conditions. Therefore, we had to increase both the length and width of the barge in order to maintain stability, optimization based on Auto CAD 2013. With the selected dimension the stability was checked until a suitable set of dimension are found for the barge. The end product will be 4400mm in length and 3200mm in width. The barge will be 900mm in height in order to achieve the relevant amount of draught to maximize stability.

Calculating the stability of the barge is the most important calculation required. Stability is based on parameters such as draught and metacentric height. In order to calculate the draught, the immersed volume of the barge was calculated using the Archimedes' principle. Total weight of the excavator and the barge was used in this calculation.

5.1 Calculation of Draught

The draught of a barge is the vertical distance between the waterline and the bottom of the hull (keel). The draught determines the minimum depth of water a barge can safely navigate. The draught can also be used to determine the weight of the barge and excavator on board by calculating the total displacement of water and then using Archimedes' principle.

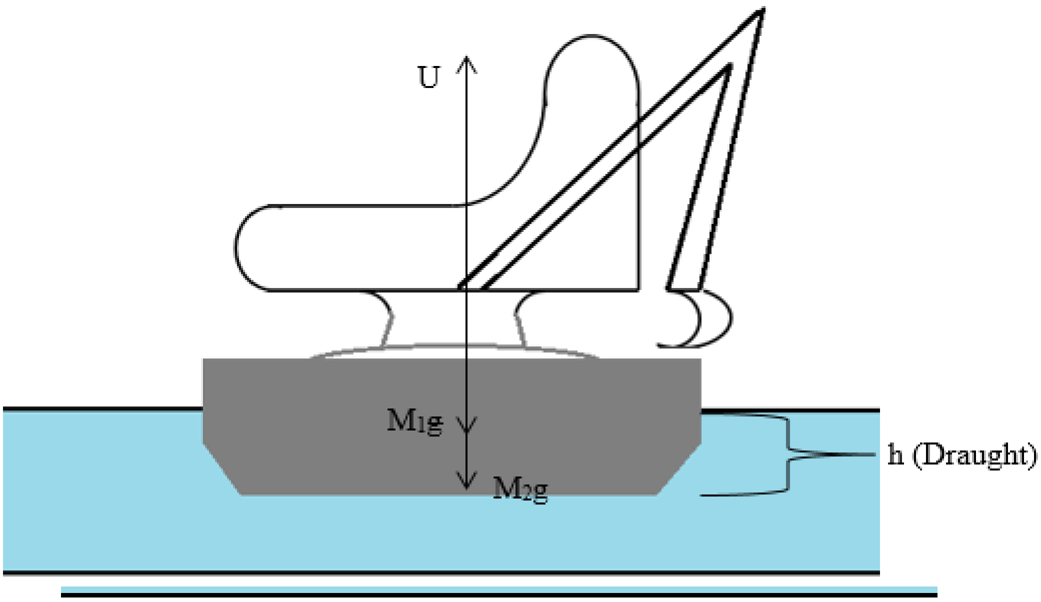


Figure 01: Force Application of the Barge and Excavator

Total volume of the barge taken from the drawing = 3.63×10^8 mm^3

(Use **massprop tool** from Auto CAD)

Density of the mild steel = $7850\ kgm^{-3}$

Mass of the barge (M_2) = $3.63 \times 10^8 \times 10^{-9} \times 7850$ kg

= 2849.55 kg

Mass of the excavator (M_1) = 3700 kg

Total Mass of the system = 2850 + 3700

= 6550 kg

The immersed volume of the barge was calculated using the Archimedes' principle. The figure 01 shows the immerse depth (draught) of barge.

$$\text{Up thrust} = M_1 g + M_2 g \quad [5] \tag{1}$$

$$Vrg = 6550 \times 9.81$$

$$V \times 1000 \times 9.81 = 6550 \times 9.81$$

$$V = 6.550\ m^3$$

$$\underline{\underline{V = 6.55 \times 10^9\ mm^3}}$$

V=Immersed volume (m^3 or mm^3)

r=Density of water (kg/m^3)

g= Acceleration Of Gravity (m/s^2)

U= up thrust

The immerse volume (V) was found to be $6.55 \times 10^9\ mm^3$. In order to find the immersed depth (draught) the slice function of the AutoCAD (Using the **slice tool**) was used to calculate the volume of the solid barge from the drawing.

Table 02: Barge height to volume from the bottom

Height (mm)	Volume ($\times 10^9\ mm^3$)	Slice Area ($\times 10^7\ mm^2$)
300.00	3.261	1.189
150.00	1.863	1.296
75.00	0.992	1.352
18.75	0.254	1.366
9.38	0.128	1.372
2.34	0.032	1.374
1.17	0.016	1.375
0.29	0.004	1.375
556.93	**6.55**	

The table 02 clearly shows how volume variates with the height of the barge. For an example, the first value of 3.261×10^9 mm^3 is the internal volume when the height of the barge is 300 mm from the base. The next value of 1.863×10^9 mm^3 is the internal volume of the next 150 mm from 300 mm height. If we need the value of the internal volume of the barge when the height is 450 mm from the base, we can add the above two values and get the answer. These values were obtained by using the Auto CAD slice tool and massprop tool. Above procedure was repeated till the value of the total volume converges with the calculated immersed volume of the barge. Therefore, the immersed height of the barge is 556.93 mm

Draught (h) =**557 mm**

5.2 Calculation of Metacentric Height

In order to assess the stability of the machine the following calculations were carried out according to the machine in rest position. To be adequately stable, the metacentric height (GM) of the loaded barge, floating upright in still water, is required to be above a minimum value.

GM_{min} = 0.35 meters is a recommended minimum guidance value. [3]

O = keel

G = Centre of gravity (Overall)

G_m = Centre of gravity of the Machine

G_b = Centre of gravity of the Barge

B = Centre of Buoyancy

M = Metacenter

Metacentric height can be calculated using this formula.

GM= OB + BM – OG [3] ———————— (2)

GM = Metacentric Height

OB = Height of the Centre of Buoyancy from the keel

OG = Height of the Centre of Gravity from the keel

OB = draught / 2 (The barge was assumed as rectangular type)

OB = 557/2

OB = 278.5 mm

BM = $Lb^3/12V$ [3]

The vertical distance between the Centre of Buoyancy (B) and the metacenter (M), that is BM = I/V (where I is the inertia of the water plane area and V is the volume of displacement). For a rectangular water plane area, such as that displaced by a barge, the 'roll inertia' is I= $(L \times b^3)/12$, where L is the length and b is the width of the barge.

L = 4400 mm, b = 3200 mm, V = 6.55×10^9 mm^3

BM= $4400 \times 3200^3 / 12 \times 6.55 \times 10^9$

BM= 1834.3 mm

OG_b= 442 mm (taken from the drawing)

OG_m= 700 + 2515/3 = 1538.3 mm (taken from the Doosan Shop Manual)

Taking moments of around O [3]

$6550 \times OG = 2850 \times OG_b + 3700 \times OG_m$

$$OG = \frac{2850 \times 442 + 3700 \times 1538.3}{6550}$$

OG = 1061.3 mm

Therefore from equation 2;

GM= 278.5 + 1834.3 – 1061.3 = 1051.5 mm

GM=1.05 m

This value is positive and more than 0.35 meters, therefore the Barge is stable.

5.3 Calculation of Operating Stability

The figure 02 shows a situation where the bucket consisting of it maximum loads, when the excavator is in operation. The metacentric height and angle of tilt for this condition can be calculated by,

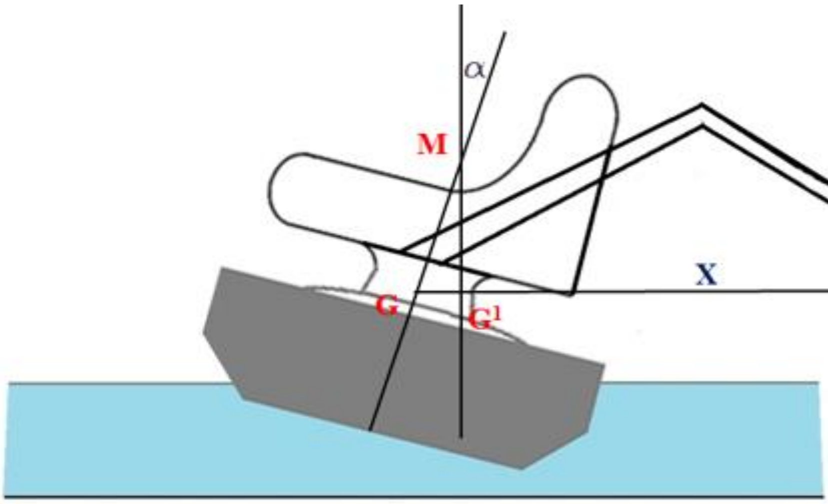


Figure 02: when the excavator is in operation

X = Maximum Digging Radius

= 4.4 m (from Doosan 35Z shop manual)

G = Centre of Gravity of the System at Rest

G^1 = New Centre of Gravity of the System in Operation

M = Metacenter

a = Angle of Tilt

G^1M = New Metacentric Height

The figure 03 shows a geometric representation of the boom, arm and bucket assembly, and the values for AB, BC and AC were obtained from the Doosan 35Z excavator shop manual. By using those values we can calculate the angle of "a". The shop manual states that the inclination of the boom is approximately close to the angle of tilt. Therefore, we can calculate the angle of tilt as below.

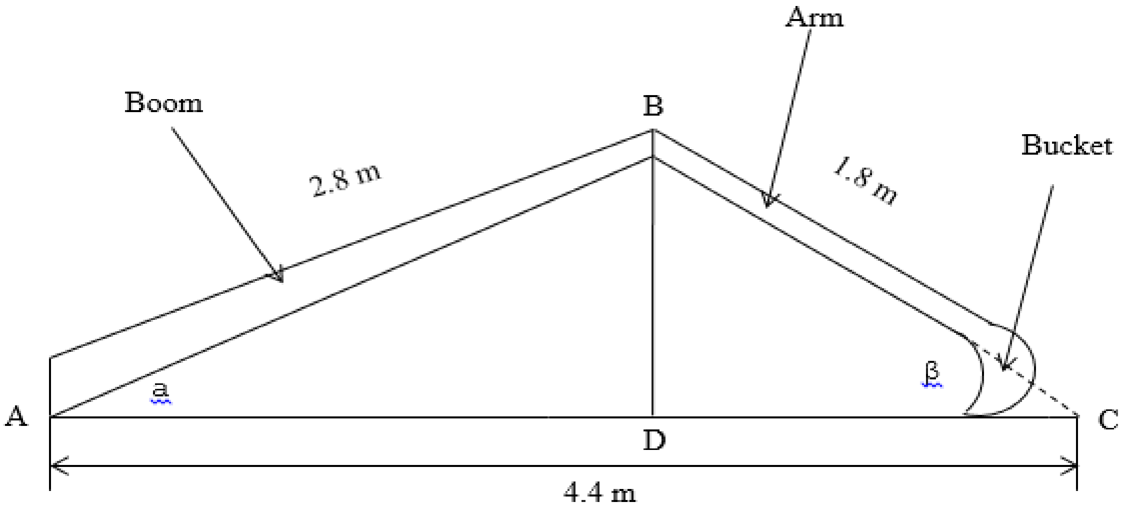


Figure 03: Geometric Representation of the Boom, Arm and Bucket

AB = Length of the Boom from point at A

= 2.8 m (from Doosan 35Z shop manual)

BC = Length of the Arm & Bucket

= 1.8 m (from Doosan 35Z shop manual)

Angle of Tilt = Angle of Boom to Horizontal [1]

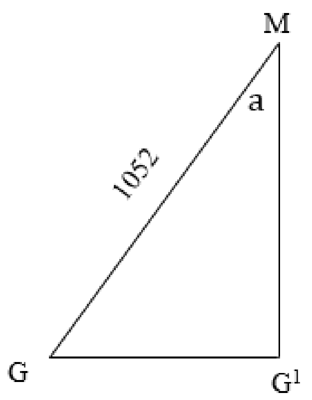
<u>By BCD triangle;</u>

$1.8^2 = (2.8 \sin\alpha)^2 + (4.4 - 2.8 \cos\alpha)^2$

$1.8^2 = 2.8^2 + 4.4^2 - 2 \times 2.8 \times 4.4 \cos\alpha$

$a = \underline{\underline{13.49^0}}$

Figure 04 shows how the center of gravity when the Excavator is in rest position (G) and when the Excavator is operating position (G^1). Since the angle of tilt (a) was calculated previously, the new metacentric height can be calculated.



G = Centre of Gravity of the System at Rest

G^1 = New Centre of Gravity of the System in Operation

M= Metacenter

Figure 04: Triangle of the M, G and G^1

<u>From the figure 04,</u>

$G^1M = GM\cos\alpha$

$G^1M = 1052 \times \cos 13.49^0$

$G^1M = 1022$ mm

$\underline{\underline{G^1M = 1.02 \text{ m}}}$

Therefore new metacentric height is **1.02m**, this value is positive and more than 0.35 meters, and therefore the Barge is stable.

As well as;

Angle of Tilt (a) = **13.5^0**

Safe loads have been calculated for plate thickness either simply supported on all four edges using Pounder's formulae. [4]

$$P = \frac{4ft^2}{3kB^2\left[1 + \frac{14}{75}(1-k) + \frac{20}{57}(1-k)^2\right]}$$

Where;

$$k = \frac{L^4}{L^4 + B^4}$$

L=length of plate in mm

B=breadth of plate in mm

t=thickness of plate in mm

f=allowable skin stress in Nmm^{-2}

P=pressure on plate in Nmm^{-2}

5.4 Calculation of the Hull Plate Thickness

Using Pounder's Formulae [4];

$$P = \frac{4ft^2}{3kB^2\left[1 + \frac{14}{75}(1-k) + \frac{20}{57}(1-k)^2\right]}$$

L= 550 mm

B = 540 mm

F = 30 Nmm^{-2} [4]

$$k = \frac{550^4}{550^4 + 540^4}$$

k = 0.518

The total pressure applying on the bottom hull plate, it's a maximum pressure of the system can be calculated by;

P = hrg

Where;

P = pressure

h = draught

r = density of water

g= acceleration of gravity

$P = 557 \text{ x } 1000 \text{ x } 10^{-9} \text{ x } 9.81 \text{ Nmm}^{-2}$

$P = \underline{\underline{5.464 \text{ x } 10^{-3} \text{ Nmm}^{-2}}}$

$$5.464 \text{ x } 10^{-3} = \frac{4 \text{ x } 30 \text{ x } t^2}{3 \text{ x } 0.518 \text{ x } 540^2 \left[1 + \frac{14}{75}(1 - 0.518) + \frac{20}{57}(1 - 0.518)^2\right]}$$

Solving the above equation;

$t = \underline{\underline{4.92 \text{ mm}}}$

After studying about the previously built barges and considering the available plate thickness, therefore I decided to use **6 mm** plates to build the barge.

5.5 Design of the Sufficient Reinforcement

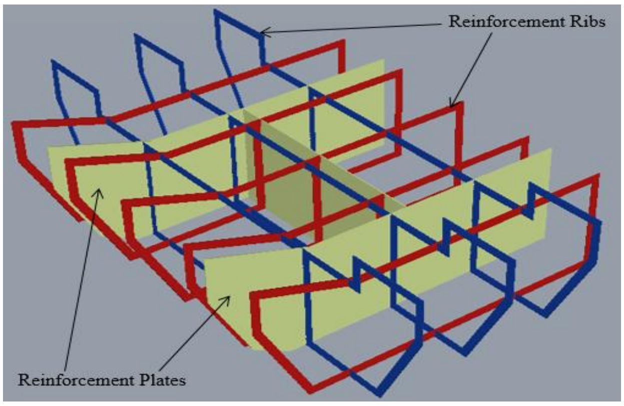


Figure 05: Reinforcement of the barge

The barge is to be designed with sufficient reinforcement that would enable the barge to withstand loads under working conditions. Drawing of a design reinforcement of the barge is given in figure 05.

5.6 Design of the Nuts, Bolts and Pins

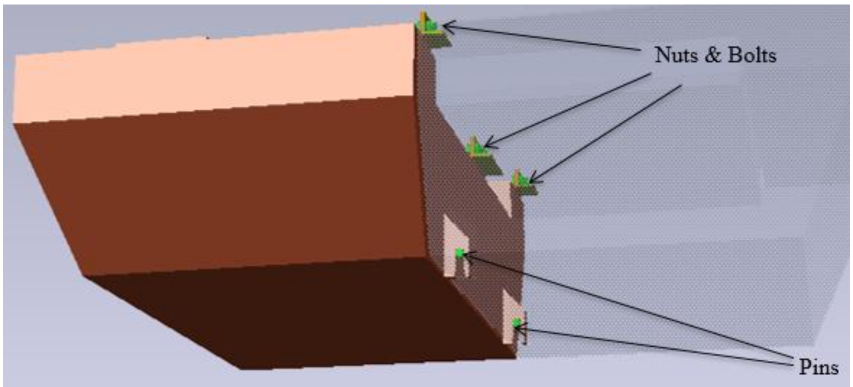


Figure 06: Nuts, Bolts and Pins used to connect of the two parts of the barge

The figure 06 shows the nuts, bolts and pins used to connect the two parts of the barge. Apply to the maximum load in the barge, and then the combine shear and tensile stress is induced in the bolts and pins. The shear stresses should be avoided as far as possible. It should be noted that when the bolts are subjected to direct loads, they should be located in such a way that the shear and tensile load come upon the body of the bolts and pins.

5.7 Design of the Lifting Eye Bolts

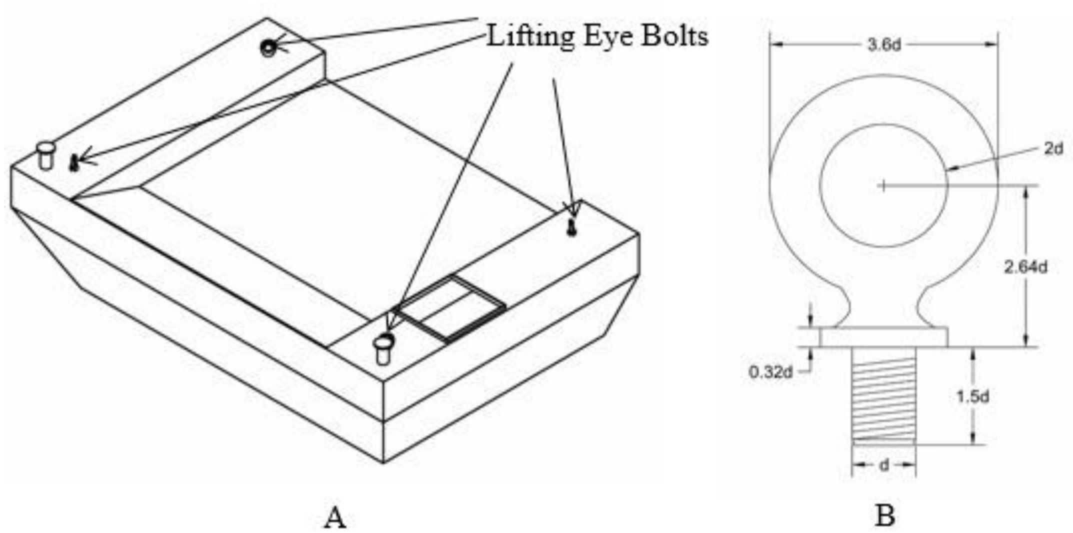


Figure 07: Lifting Eye Bolts for use to lift the piece of barge

Lifting eyes are used to attach the lifting cables which are used when deploying the barge. When designing the lifting eye, we need to consider about the tensile load. In some causes outer hull of the barge can be subjected to damages and this can allow water to leakage into the barge. In such causes, the tensile load can increase. Therefore, we need to calculate the maximum tensile load at an instant where the barge is completely filled with water.

Figure 07(A) shows the placement of lifting eye bolts of one half of the barge. Figure 07(B) shows the dimensions of the lifting eye bolt [13].

5.8 Design of the Bollard and Manhole

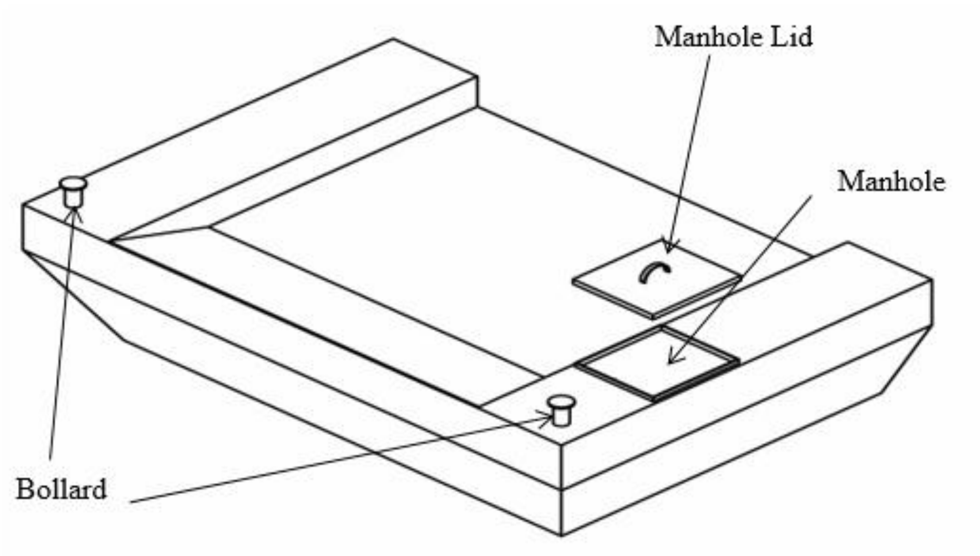


Figure 08: Bollard, Manhole and Manhole Lid

Bollard

Bollard will be usedwhen assembly two pieces of the barge together. By using bollards, the barge can be tied to a nearby object which holds the barge in place. Apart from that, the bollard does not hold any other significant practical value. Therefore, it was decided not to follow any design calculations and determine the bollard size and placement based on the design of current used barges.

Manhole

In designing the manhole, it has followed the design criteria which have been used when building existing barges. The manhole is used to gain easy access to the inner hull of the barge to perform maintenance activities. In practice, it is important to keep the manhole tightly covered to prevent water leakage. Therefore, the lid should be tightly held in place without any movement while operating the barge mounted excavator, as you can see the figure 08, it has welded four metal strips on to the square shaped perimeter of the manhole which extend outward from the manhole surface. The lid will tightly fit inside the manhole perimeter enclosing the four metal strips. This ensures that the lid will tightly seal the manhole and will be stable under operating condition.

5.9 Two Parts of the Barge and Boom Truck

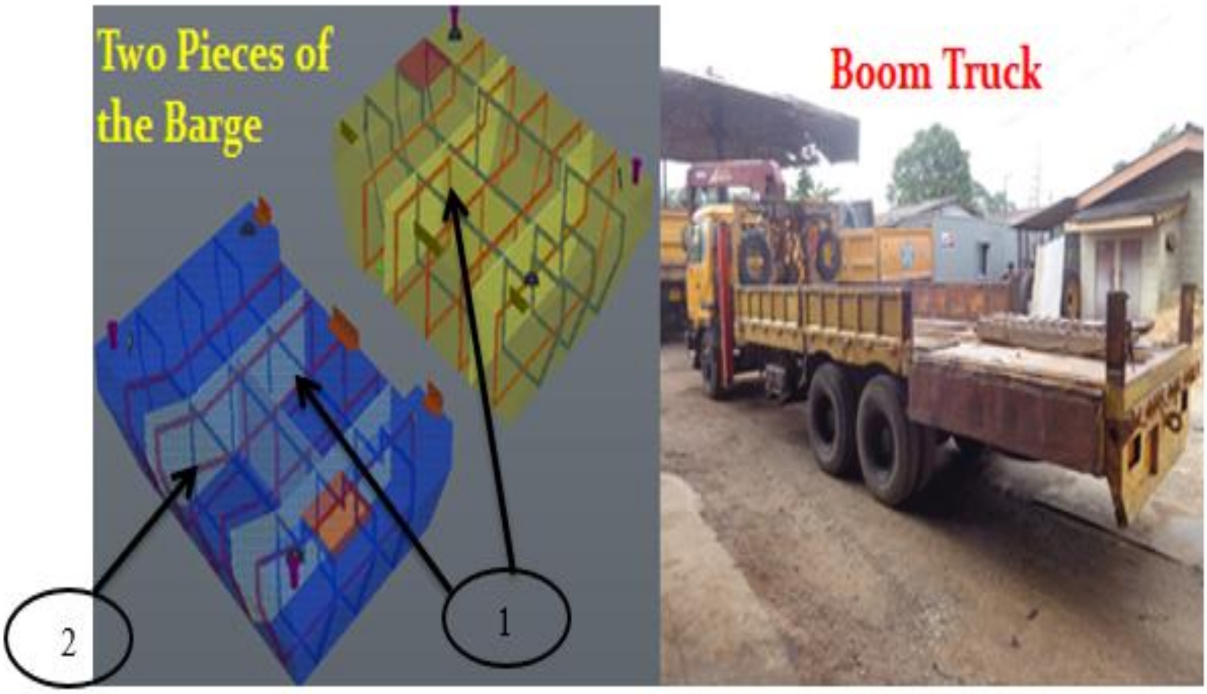


Figure 09: Two parts of the barge and boom truck

The figure 09 shows the two parts of the barge before assembly and transport vehicle (boom truck). The main reasons to build the barge in two pieces are to ease the transportation process. The boom truck which will be used to transport the barge has a trailer which is 25 feet in length are 8 feet in width. A single segment of the barge is 7.3 feet in width and it enables the barge to be transported using the trailer which is 8 feet.

5.10 Fabrication of the Barge

The barge is to be fabricated in two parts to facilitate a convenient method of transportation and for safety. The transportation is also a vital factor when transporting the barge over long distances. The barge was made to fit the standards of other barges. The two parts of the barge are to be connected by a set of nuts and bolts. The nuts and bolts were designed considering the stresses developed in the area and a safety factor too were considered in the design.

The barge is to be fabricated by a set of mild steel plates with mild steel flat irons welded into the mild steel plates. The mild steel plate is called the base plate. The thickness of the required base plate is governed by the 'Pounder's formula'. After selecting the required plate thickness for the bottom of the barge, the other plate thicknesses were also decided. It was decided to use fillet and butt welding for the flat irons of the barge. A painting process of the barge has also been determined in the project and it was decided to use sigma coatings marine paint.

6.0 RESULTS AND DISCUSSION

In order to design the barge the basic dimensions of the barge were selected by the dimensions of the Doosan 35z excavator. The basic dimensions of the barge so selected were found to be 4400 mm and the 3200 mm and the height of the barge was selected to be 900mm. Some additional space was allocated on top of the barge for operating personnel and to carry some tools.

The designing process of the barge was carried out using AutoCAD software. The barge was modeled using AutoCAD software and the total volume (Materials) of the barge was found to be 3.63×10^8 mm^3. After calculating the total volume of the barge the total weight of the barge was calculated. The upper lower side plates and reinforcement also contributes to increase the total weight of the barge.

In order to find the amount of the immersed volume of the barge, the up-thrust of the barge was equated to the weight of the barge and excavator. It was found that the barge has an immersed volume of 6.55×10^9 mm^3 and the draught of the barge was found to be 557 mm. AutoCAD software was used to calculate the draught, from the bottom of the barge.

The stability is one of the most important aspects of the barge. In order to properly excavate a canal the excavator needs to lift its arm and then pull soil in front of the barge. The long working range of the excavator may cause the barge to get inclined due to the pulling force of the arm. There is a real risk of the barge getting inclined and getting overturned. This may cause serious damage to the barge and could even lead to loss of life. Therefore the barge should be design to be able to operate safely in such inclined positions also. The metacentric height was calculated by considering the weight of the bucket with soil, the weight of the arm of the excavator, weight of the barge and volume of the barge.

The value of the metacentric height was thus found to be a positive value and the angle of tilt was determined to be 13.5 degrees. Therefore the barge was found to be stable in any working position. **It was noted that operator skills also play an important role for safe operation of the excavator when working on the barge.**

The excavator is intended to operate from a fixed location on the top of the barge. The excavator must be anchored and not allowed to move on the barge.

A detailed production drawing of the barge was prepared by the use of AutoCAD software. The front elevation, end elevation and the plan view of the production drawings are illustrated. Mild steel plates were used for the outer plate of the barge. After designing the appropriate shape of the barge the barge shell was designed with mild steel plates together with mild steel flat iron plates for reinforcement. The appropriate thickness of the hull plate was selected by the 'Pounder's formula'. Also other peripheral elements such as pins, nuts and bolts were designed according to proper calculations.

7.0 CONCLUSION

The aim of the project was to design of a barge which is capable of operating along narrow canals. The barge was designed to withstand the dead weight of barge and the machine engaged for dredging the canal. The draught of the barge was 557 mm which is an acceptable amount of draught for the canals to be dredging by SLLRDC.

It was decided to manufacture the barge in two pieces which would make the transportation of the barge to different locations easier. The barge was constructed using mild steel plates due to its availability and low cost and was reinforced by flat irons. These plates are made from mild steel and have a suitable tensile strength that provides an excellent amount of reinforcement. The thickness of the mild steel plate was found by the use of 'Pounder's formula' which is widely used in designing barges. The plate size was thus found to be 6 mm. This is an acceptable amount of thickness when considering other barges.

Since there was a requirement for a small size barge to be used with Doosan 35Z excavator, our management decided to call for estimates for the supply of a small barge from several companies. Only one company (Land Reclamation and Development Company Limited) responded and their estimate was $ 25,340. Receiving only one response shows the inability of other companies to produce a barge according to our specifications. When comparing their estimate with the Bill of Quantity prepared by me, it clearly shows that manufacturing the barge at our workshop is much more profitable than outsourcing the job. Our BOQ values sum up to $ 9,500.

Small excavators which have similar specifications as our Doosan 35Z excavator are being produced by all of the major construction equipment manufacturing companies. (E.g. Caterpillar 303CR, Kobelco SK40, Volvo EC27C, Hitachi ZA33U). Since these machines also fall into the same weight category, the design produced by me can be used to produce barges for those machines as well.

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