MASTER OF ENGINEERING (Mechanical Design)

McMASTER UNIVERSITY Hamilton, Ontario

TITLE: Feasibility Study for the Transportation of Steel Billets by Amphibious Vehicle

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SCOPE AND CONTENTS:

The problem of transporting steel billets from the No. 3 Bloom and Billet Mill to the No. 2 Rod Mill of The Steel Company of Canada is dealt with in this report. An original solution is proposed in the form of amphibious vehicles plying a water route in Hamilton Bay between the two mills.

The following Study will prove the feasibility of such a scheme.

ACKNOWLEDGEMENTS

The writer wishes to express his gratitude to the Committee on Graduate Admissions and Study of McMaster University for their patience, and Professor J. N. Siddall for his guidance.

The writer also directs his sincere thanks to The Steel Company of Canada, Ltd., for encouraging a program of continuing education, to Mr. N. A. Morrison, P.Eng., Senior Supervisor in the Hilton Works Engineering Department for suggesting the topic of this thesis, and to Mr. M. Khattab, P.Eng., for his constructive advice.

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1. INTRODUCTION

1.1 STELCO TRANSPORTATION SYSTEM

It is a known fact that most, if not all, steel producing companies occupy a vast area of land to accomodate the great stockpiling and storage areas as well as the huge mill buildings necessary for the steelmaking and steel finishing processes.

The Steel Company of Canada is no exception to this rule if one considers that it occupies an area of about 1050 acres at Hilton Works in Hamilton, with dozens of mill buildings interconnected by roadways and a 100 mile long railway network. The transportation system for road and track operations is one which requires very large investments of capital for the purchase and maintenance of a variety of trucks, locomotives and rolling stock. The Steel Company of Canada at Hilton Works alone operates a fleet of road vehicles of about 40 large trucks, and railway equipment consisting of 30 locomotives and approximately 800 pieces of rolling stock representing an investment in locomotives, cars and road vehicles of approximately 20 million dollars not counting tracks, roads and maintenance. Theoretically considerable savings could be realized by eliminating, or at least reducing, the need for transportation within a steel plant. This could be done to some extent if a company decided to build a new Plant on a "green field" site.

1. INTRODUCTION (cont'd.)

1.1 STELCO TRANSPORTATION SYSTEM (cont'd.)

This was not the case with Stelco: the present company was formed in 1910 by the amalgamation of 5 existing companies already operating on the site of the present Hilton Works, so that no overall planning could be done effectively.

One must also mention that the Dominion of Canada in 1910 had a population of only about 7 million - too small a market for a very large investment at the outset for a steel works as large as we have today.

The Plant developed therefore with the increase in population and new mills were added to the existing ones, thereby complicating the movement of material from one to the other. Today Hilton Works has almost reached the saturation point and the Company must look elsewhere for expansion.

Present operations in Hilton Works involve the making of Steel products such as Plate, Skelp, Tin Plate, Galvanized Coils, Sheets, etc., through mostly conventional processes.

Four Blast Furnaces produce the liquid iron which is transformed into steel in the Open Hearth Furnaces and Oxygen Vessels, poured into ingots and delivered to the rolling mills for the finishing operations.

1. INTRODUCTION (cont'd.)

1.1 STELCO TRANSPORTATION SYSTEM (cont'd.)

The importance of transportation equipment will be appreciated if one looks at the dispersion of the different mills on the 1050 acres of the Hilton Works property.

In addition, Stelco must supply steel to the other finishing works located elsewhere in Hamilton, the main ones being the No. 2 Rod Mill located on a 120 acre lot bordering the bay and the Reinforcing Dept. which occupies 32 acres, again along the bay.

The following study will deal with one of the existing transportation problems. Specifically it will be the supply of steel billets from the producing mill - No. 3 Bloom and Billet Mill - to the finishing mill - the No. 2 Rod Mill.

1.2 EXISTING PROBLEM OF TRANSPORTING BILLETS TO NO. 2 ROD MILL

The production of billets was originally carried out in the No. 1 Bloom and Billet Mill, which was built in 1913 and therefore was one of the first buildings to go up after the amalgamation. Next to that building are located the 12-10 Mill and the No. 1 Rod Mill which were the only recipients of the billet production in order to transform them into bars and coils of various sizes. Today these mills are still in operation and the billets coming off the No. 1 Bloom and Billet Mill are

1. INTRODUCTION (cont'd.)

1.2 EXISTING PROBLEM OF TRANSPORTING BILLETS TO NO.2 ROD MILL (cont'd)

carried approximately 50 feet on transfer cars before they are unloaded directly onto the billet yard of both 12-10 and No. 1 Rod Mills. (Fig. 1). This does not represent a very great transportation problem. In the early sixties the need for more billet production arose and it was decided to build a separate billet producing facility to lighten the load of the ancient No. 1 Bloom and Billet Mill. In 1966 the continuous billet casting machine was installed next to the No. 2 Open Hearth in order to supply the new No. 2 Rod Mill, which was being built outside the Hilton Works property, approximately 2 miles to the East. Lack of space prevented locating the two mills close together and precipitated a transportation nuisance to cross the 2 mile wide gap. Movement by railroad was chosen, supplemented, as needed, by trucks. As can be seen on the track layout, (Fig. 2), the loaded gondola cars must be switched several times before they can be taken outside the property. At that point, since Stelco locomotives are not allowed on the regular railroad networks, C.N. locomotives take over until destination at the No. 2 Rod Mill site.

Lack of production capacity, among other reasons, made it necessary to provide new facilities for the production of blooms and billets.

Fig.1- Transfer of Billets from the No.1 Bloom & Billet Mill to the Billet Yard.

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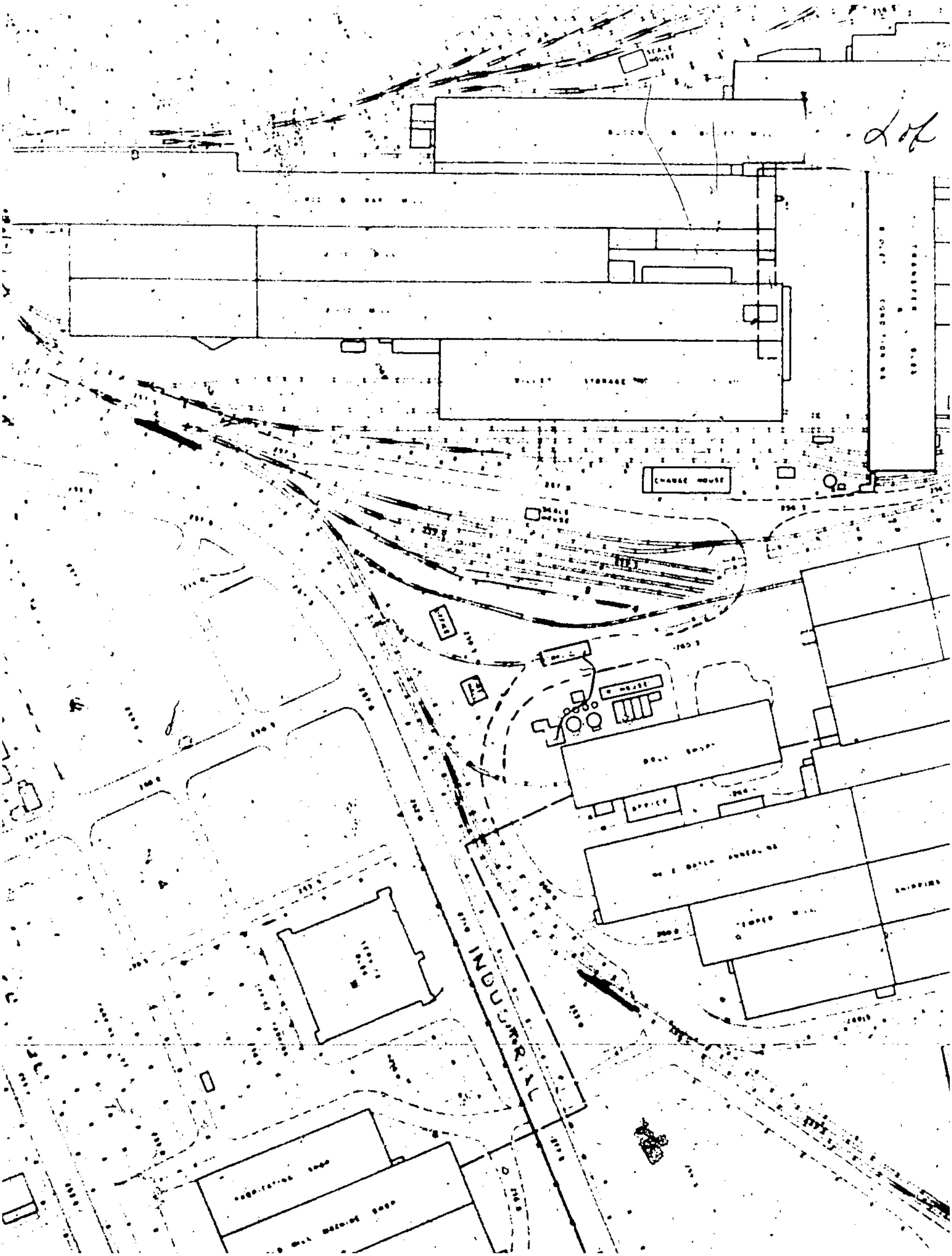
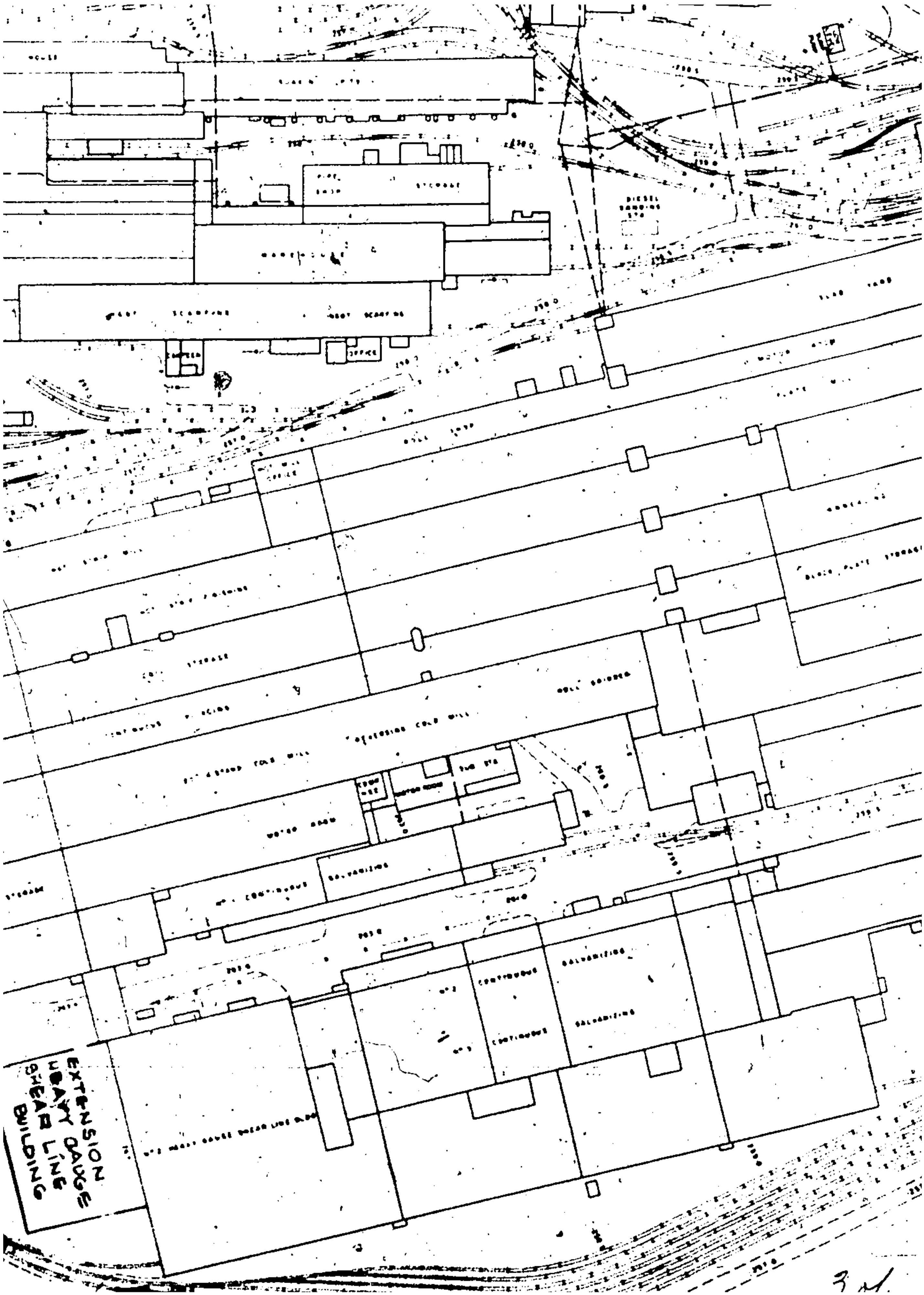
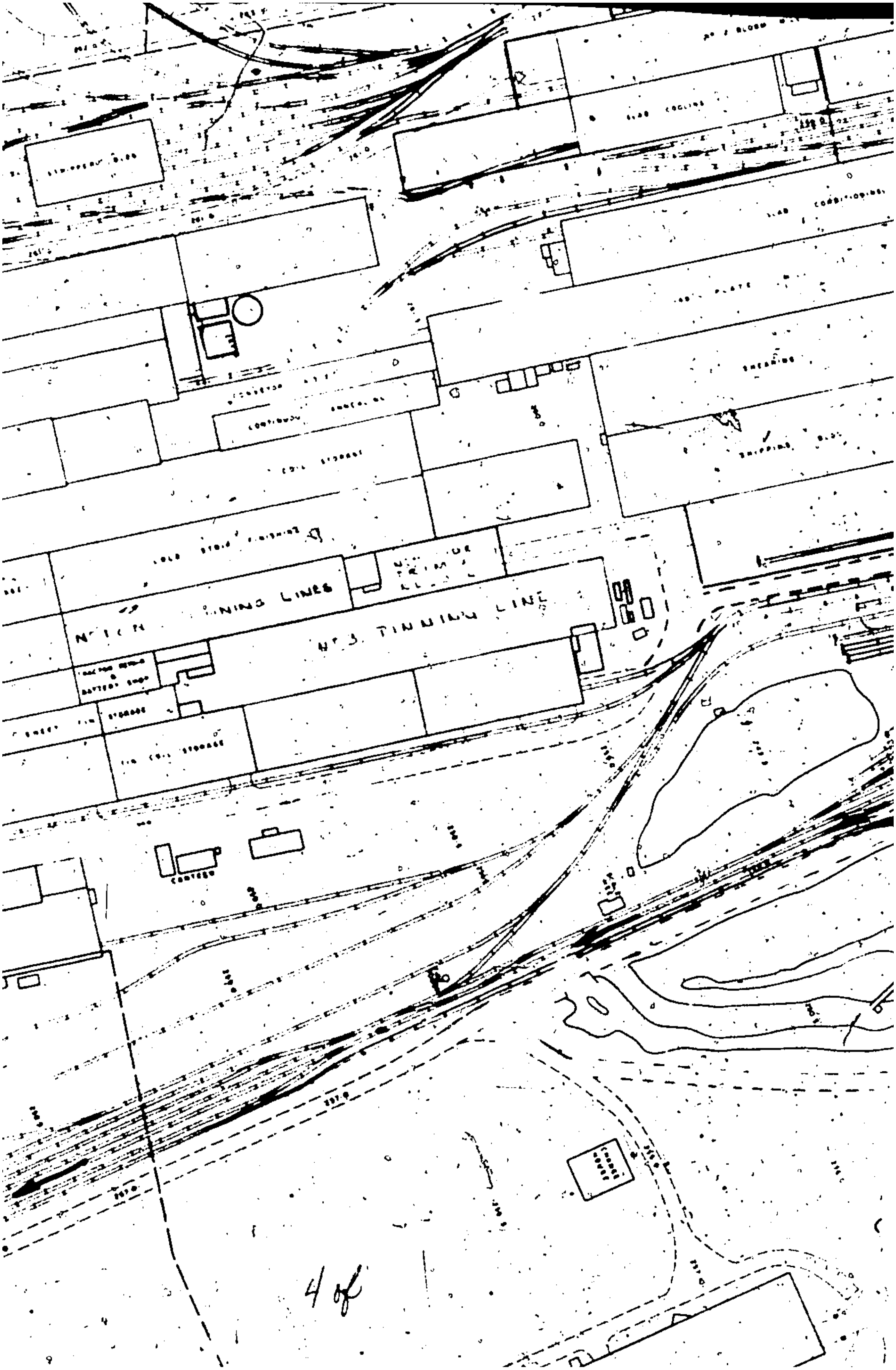
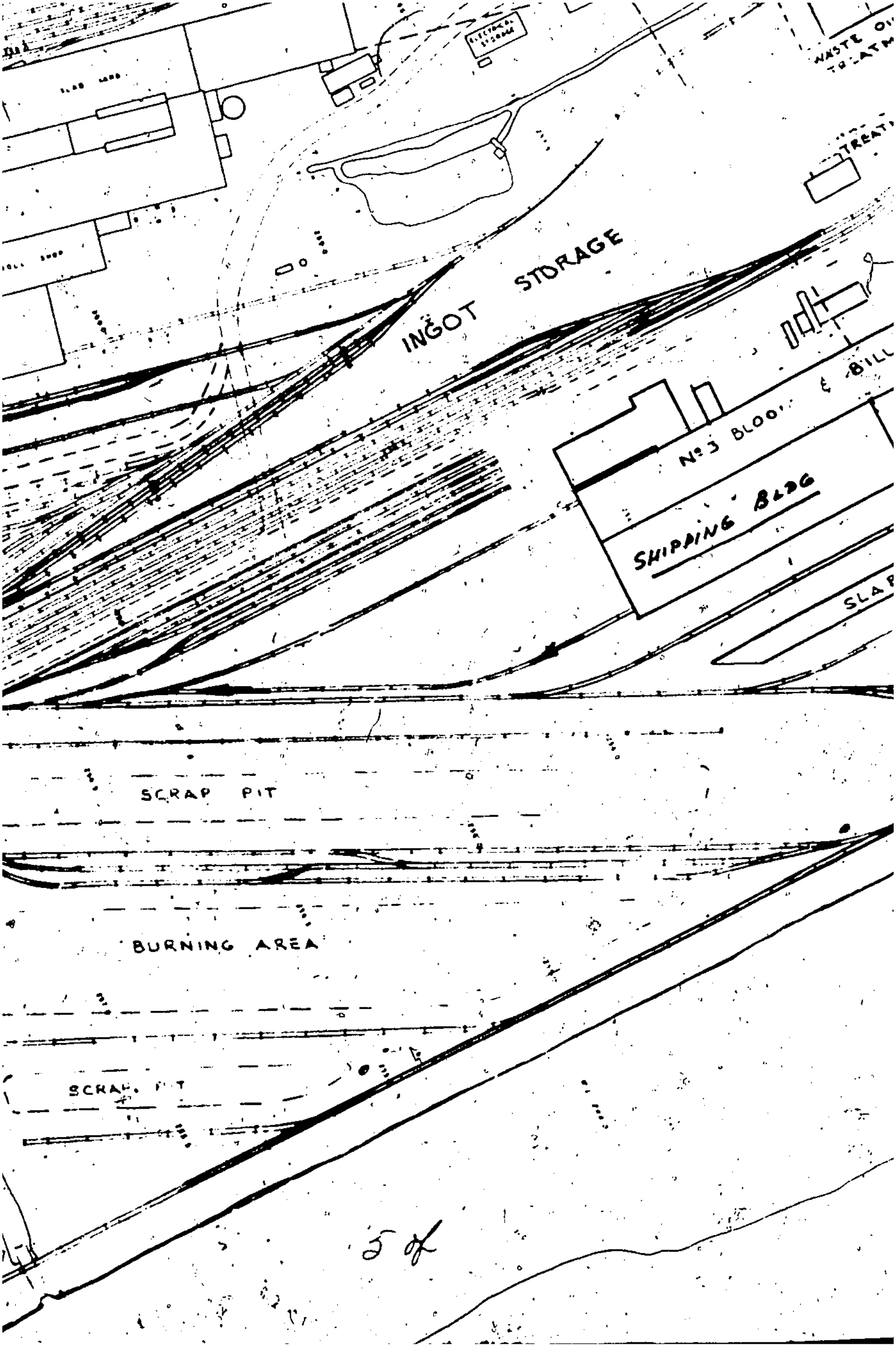

CHANGE HOUSE
OFFICE


EXTENSION
HEAVY GAUGE
SHEAR LINE
BUILDING



SLAB COOLING
SLAB CONDITIONING
SHEARING
COIL STORAGE
COLD STRIP FINISHING
TINNING LINES
No. 3 TINNING LINE
TIN COIL STORAGE
4 of


INGOT STORAGE
No 3 BLOO & BILL
SHIPPING BLDG
SCRAP PIT
BURNING AREA

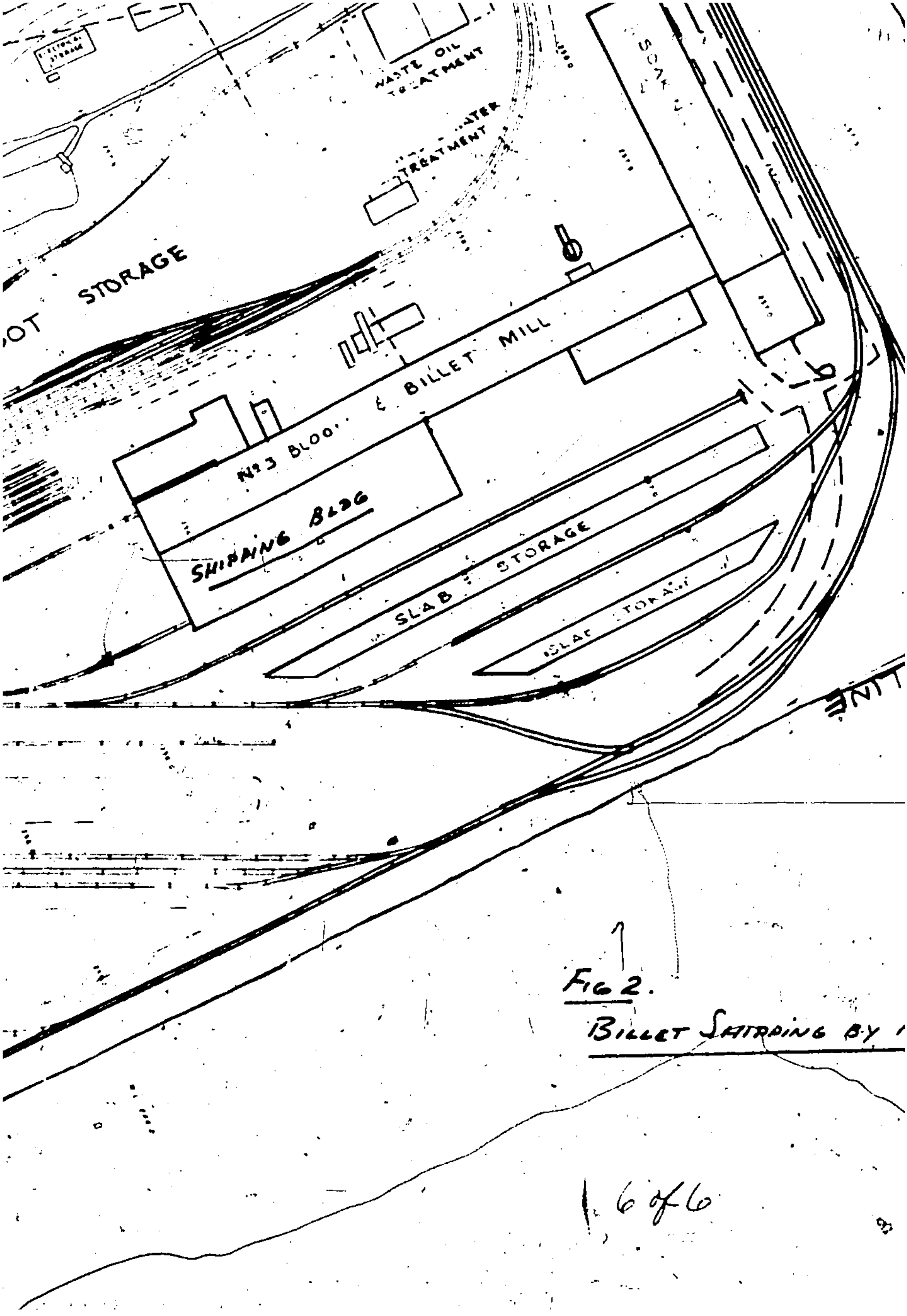


Fig 2.

Billet Shipping By

1, 6 of 6

1. INTRODUCTION (cont'd.)

1.2 EXISTING PROBLEM (cont'd.)

Construction of the new No. 3 Bloom and Billet Mill started in 1971 on land reclaimed from the Bay at the North East corner of the property. In 1972 the mill started producing blooms and billets and became the sole supplier of the No. 2 Rod Mill when the continuous billet casting facility was phased out. Once more, rail transportation was chosen.

The distance was not reduced in any way as can be seen from the map. Again there is almost complete reliance on outside railway companies for delivering the billets to the finishing mill. The main drawbacks of this system are:

1. Reliance on an outside Company for transporting goods from one Stelco Mill to another.

2. Vulnerability to strikes against the Railroad Company.

3. Delays.

4. Maintenance of trackage inside Stelco properties.

5. High operating cost.

In 1971 studies were started to find solutions to these problems by having a transportation system controlled and operated by Stelco.

1. INTRODUCTION (cont'd.)

1.3 PROPOSED SOLUTIONS IN THE PAST

7 It was seen earlier that to get from the No. 3 Bloom and Billet Mill to the No. 2 Rod Mill the land route was rather devious.

Both properties being located on the Hamilton Bay, the map indicates that the shortest route between them is the water route thus pointing the way towards a waterborne transportation system. It is on that reasoning that a local Engineering Consulting Firm was asked to conceive a feasible scheme for a tug and barge transportation system.

The first feasibility study was completed and presented to Stelco on December 15, 1971 and was based on the following design criteria:

Design Criteria:

Billet Size: 4 in. x 4 in. x 30 ft.

Bundle Size: 20 in. x 16 in. x 30 ft.

Weight of one bundle: 15 Tons

#2 Rod Mill production capacity: Average: 2000 tons/day
Peak: 2400 tons/day

1. INTRODUCTION (cont'd.)

1.3 PROPOSED SOLUTIONS IN THE PAST (cont'd.)

Operation:

24 hour/day with 90% availability: 21.6 hours/day

Use 3 shifts of 7 hours: 21 hours/day

Barge Capacity: 16 bundles, i.e., 240 tons.

No. of trips/day at peak load: $\frac{2400}{240} = 10$ trips

Stockpile at Billet Mill: 2400 T. minimum

Stockpile at #2 Rod Mill: 240 T. minimum

The first scheme proposed consisted of a system using barges with storage racks for carrying the bundles of billets. The barges are loaded at a dock by side loaders from a stockpile and similarly unloaded at destination. Both stockpiles being at dockside, double handling is imposed at each end.

This first study was turned down and the Company was instruct[ed] to concentrate on a barging system capable of handling railroad cars. In December of 1972 a new feasibility study, based on the new directives, was presented to Stelco. The design criteria remain unchanged but the method is different.

1. INTRODUCTION (cont'd.)

1.3 PROPOSED SOLUTIONS IN THE PAST (cont'd.)

Four loaded gondola cars are to be pushed onto each barge which is fitted with two tracks.
The overall dimensions of the barges were established at 150 ft. long by 40 ft. wide. Its shape incorporates a "V" notch at the stern for locating the "pusher" tug.
To alleviate the problem of varying water levels, hydraulic jacks raise the barge to bring its deck level with the dock.
In this scheme, railroad sidings would be required at both ends with proper motive power to shunt the cars.

This last proposal has not been turned down but no action has been taken on it as of this date.
In the writer's opinion, the shortcomings of this system are as follows:

1. Excessive handling.

2. Huge investment in equipment, e.g., locomotives, railroad cars, tracks, barges, tugs, docking facilities, hydraulic lifting equipment, etc.

3. Permanent occupation of valuable land by storage tracks.

4. Number of personnel required for manning the locomotives, the boats and the docks.

5. Underwater operation of the hydraulic equipment.

2. PROPOSAL FOR AMPHIBIOUS SELF-PROPELLED VEHICLE

2.1 PROPOSAL

It is proposed to move billets from the No. 3 Bloom and Billet Mill to the No. 2 Rod Mill in using an amphibious self-propelled vehicle without intermediate handling of the cargo.

This amphibious vehicle shall have enough capacity to insure an adequate supply of billets at the No. 2 Rod Mill with a reasonable frequency of runs.

This vehicle shall consist of a tractor and a trailer, as shown in the sketch, (Fig. 3) capable of driving into the mills for loading and unloading.

The foreseen advantages are:

1. Elimination of expensive equipment like locomotives, gondola cars, tugs, trackage, etc.
2. Release of expensive land for future use.
3. Versatility.
4. Minimum number of personnel.

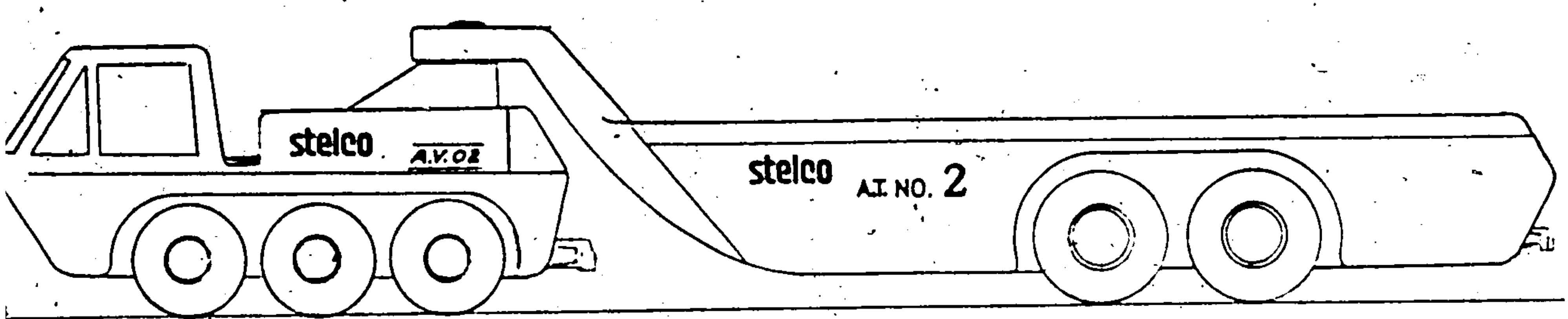


FIG. 3 - General Outline of the Amphibious Vehicle

2. PROPOSAL FOR AMPHIBIOUS SELF-PROPELLED VEHICLE (cont'd.)

2.2 EXISTING CONSTRAINTS

The constraints shown below are by no means fixed but are merely existing at the present time. They will be respected "a priori" unless further studies warrant a change.

1. Product Dimensions

Billet: 4 in. x 4 in. x 30 ft. long

Bundle Size: 20 in. x 16 in. x 30 ft. long

Bundle Weight: 15 Tons

2. Tonnage Requirements

#2 Rod Mill Average Production Requirements in billets: 2000 Tons/Day

#2 Rod Mill Peak Billet Requirements: 2400 Tons/Day

3. Buildings

(a) No. 3 Bloom and Billet Mill

In the No. 3 Bloom and Billet Mill complex, the only building to set constraints is the Shipping Building where the vehicles will be loaded with billets. The doors dimensions are therefore important so that clearances are satisfactory. Similarly access to these doors must be adequate in terms of grade and turning radius.

2. PROPOSAL FOR AMPHIBIOUS SELF-PROPELLED VEHICLE (cont'd.)

2.2 EXISTING CONSTRAINTS (cont'd.)

3. Buildings (cont'd.)

(a) No. 3 Bloom and Billet Mill (cont'd.)

The following data is relevant:

Shipping Door Dimensions: 25 ft. wide x 17 ft. high

Turning Area Available Outside
Shipping Door: 200 ft. x 150 ft.

Length of Shipping Building: 250 ft.

Possibility of Driving Through: Yes

Capacity of Overhead Cranes: 20 Tons

As can be seen on Drawing PD875A, an extension is planned for the Shipping Building. In addition a new Billet Conditioning Building is to be built immediately East of the Shipping Building.

(b) #2 Rod Mill: (Billet Storage Building)

At the present time, the billets transported in railroad cars are unloaded at destination in the Billet Storage Building. From there, these billets are eventually loaded into the reheat furnace to bring them up to rolling temperature.

2. PROPOSAL FOR AMPHIBIOUS SELF-PROPELLED VEHICLE (cont'd.)

2.2 EXISTING CONSTRAINTS (cont'd.)

3. Buildings (cont'd.)

(b) #2 Rod Mill (cont'd.)

The outlet of the furnace is in the building adjoining the Billet Storage area.

The following data is relevant: Billet Storage Building

Door Dimensions: 25 ft. wide x 17 ft. high

Length of Building: 500 ft.

Possibility of driving through: Yes (with reservations)

Capacity of overhead cranes: 20 Tons (Two cranes)

Turning area available outside access door: Approximately 150 ft. x 300 ft.

4. Terrain

The transportation problem that is to be solved in this study, is not one where a vehicle is to be capable to negotiate all sorts of terrains. Although this vehicle might well be able to do so, it is not designed to that end. At Hilton Works and at No. 2 Rod Mill, the terrain is defined and can even be altered to facilitate the movement of the vehicle involved.

2. PROPOSAL FOR AMPHIBIOUS SELF-PROPELLED VEHICLE (cont'd.)

2.2 EXISTING CONSTRAINTS (cont'd.)

4. Terrain (cont'd.)

In his book Introduction to Terrain Vehicle Systems, M. G. Bekker makes the distinction between two systems, namely:

-The Deterministic System which has a fixed mission in a fixed environment.

-The Probabilistic System which depends on the probability density functions of the parameters defining the systems.

It is clear that the Stelco system is a deterministic one so that a very detailed terrain evaluation shall not be necessary.

Terrain Data

(a) Hilton Works

The distance that the vehicle will travel on land is approximately 1200 ft., all located at the North East corner of the property. The terrain is free of natural obstacles and consists of well compacted fill with little or no sinkage. The vehicle shall use existing roadways except near the launching site where a new roadway and ramp shall be provided. (Fig. 5)

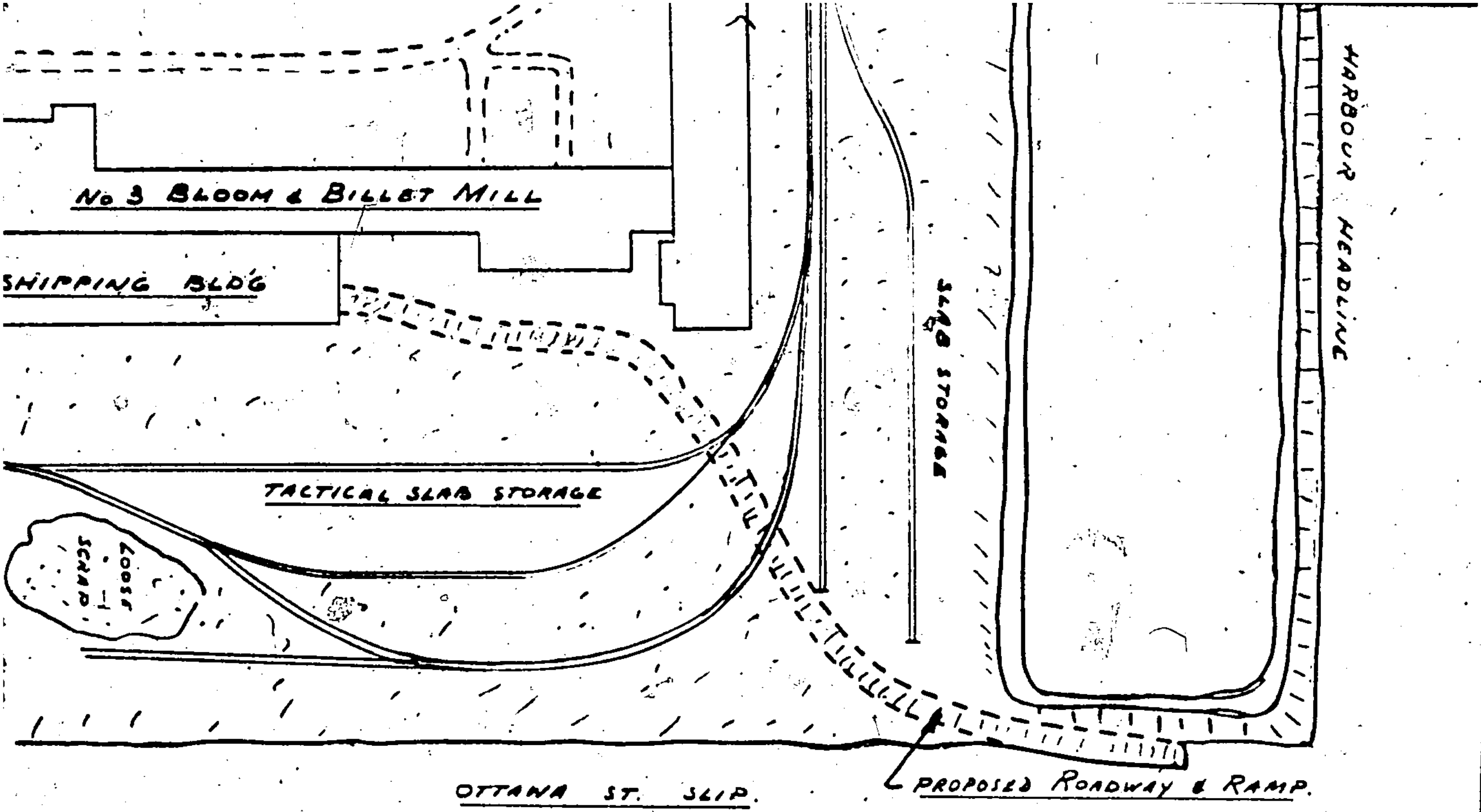


Fig. 5 - No. 3 Bloom & Billet Mill - Approach & Landing Area

2. PROPOSAL FOR AMPHIBIOUS SELF-PROPELLED VEHICLE (cont'd.)

2.2 EXISTING CONSTRAINTS (cont'd.)

. Terrain Data (cont'd.)

(a) Hilton Works (cont'd.)

The only obstacles are railway crossings which are level and relatively smooth. Except for the grade at the landing site, the roadway shall be flat.

(b) #2 Rod Mill

At the Rod Mill site, the vehicle will have to cover approximately 1200 ft. on land to get to the Billet Storage Building. (See Fig. 6) The terrain is relatively flat and is composed mainly of fill with slag topping but well compacted. A grade of about 2% exists in a 200 ft. section of the route.

The only obstacles are railway tracks which shall be crossed on level. Overall the terrain at No. 2 Rod Mill is more favorable, because it is more open (thereby requiring less turns) and because the fill is much older than the one at Hilton Works, thereby providing a better settled ground.

5. Water

The water route that the vehicle will follow is within the confines of Hamilton Bay and relatively close to its southern shore. (See Fig. 4)

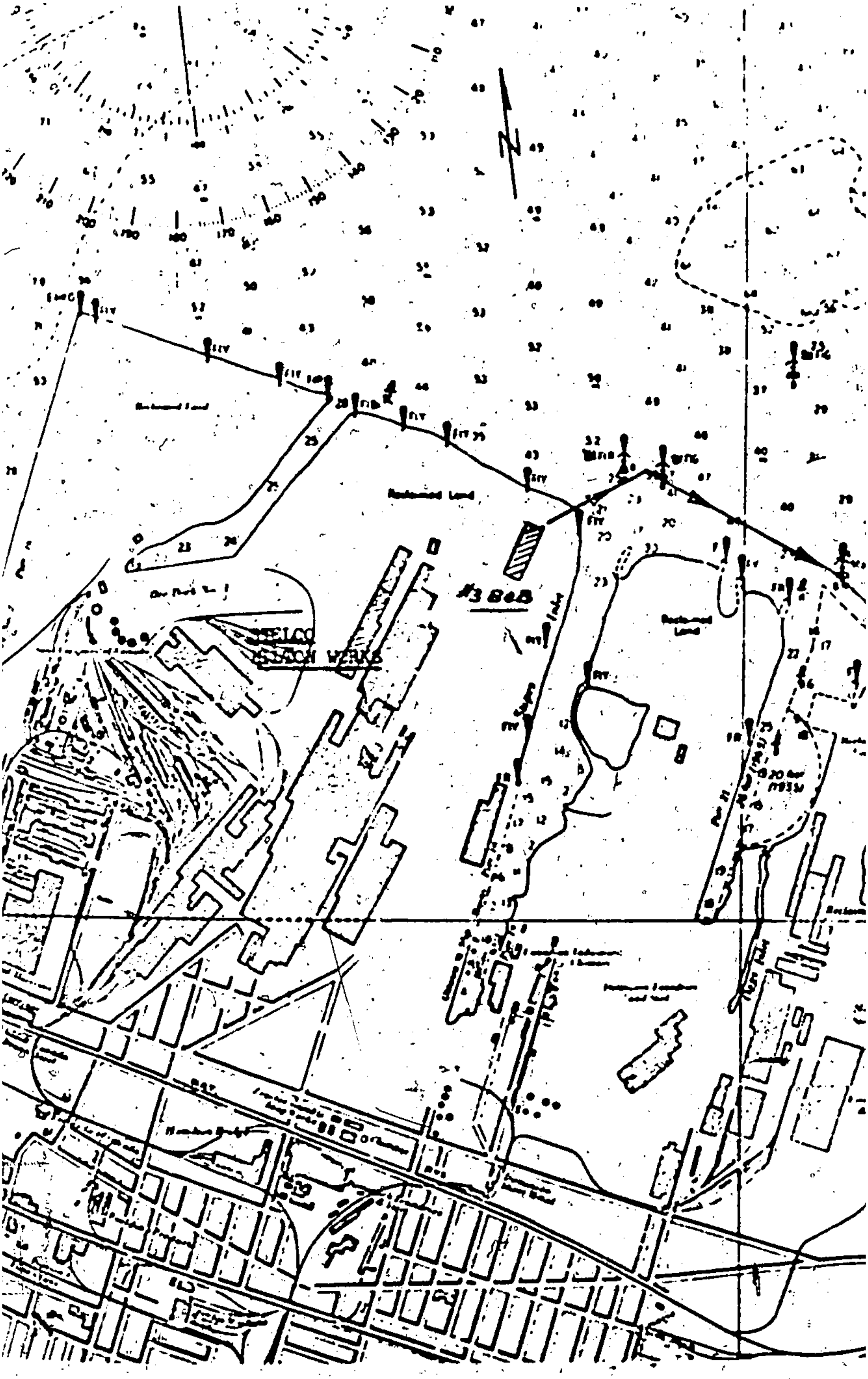


Fig. 4 - Water Route of Amphibious Vehicle

2. PROPOSAL FOR AMPHIBIOUS SELF-PROPELLED VEHICLE (cont'd.)

2.2 EXISTING CONSTRAINTS (cont'd.)

5. Water (cont'd.)

The length of the route is approximately 8500 ft. and does not present great navigational difficulties. Because of the size of Hamilton Bay, waves, when present, are always low. The average water pH varies between 6.8 and 7.2 while the maximum and minimum water temperatures are respectively approximately 70°F. and 40°F. Although the surface water can freeze over, it is found that at depths of 4 ft. and below, the temperature stays constant around 40°F. throughout the year. If a craft plies the same route several times a day, a channel can be kept open very easily.[1] Contrary to popular belief, the clarity of the Bay Water is good; suspended solids are present but only from a trace to 10 p.p.m.[2] The mean water level can vary greatly from year to year so that proper measures will be taken in order that operations remain unaffected at the launch and landing points. It appears that dredging will be required to provide a deep enough channel at the #2 Rod Mill landing site for a length of about 3000 ft. over a 30 ft. width to get an average depth of water of 10 ft. but never less than 8 ft. except at the landing.

1 - As per conversation with Marine Captain C. Dean - expert on Navigational Matters on Stelco's Construction Engineering Staff.

2 - Parts per million.

2. PROPOSAL FOR AMPHIBIOUS SELF-PROPELLED VEHICLE (cont'd.)

2.2 EXISTING CONSTRAINTS (cont'd.)

5. Water (cont'd.)

The land - launch ramps will be made of precast concrete slabs with a very rough surface to provide adequate traction.

The sections located approximately 25 ft. on either side of the water's edge will have to be fitted with a de-icing device. For the underwater portion, an air bubble system is possible whereas the dry portion could receive a steam pipe network or electrically heated wires embedded in the slabs.

At Hilton Works, in order to save space, the ramp would be built on the flank of the North Eastern most water lot in a North South direction, (Fig. 5.) parallel to the Ottawa Street inlet. Besides the saving in land, this particular ramp will be sheltered from the prevailing west winds and thereby will facilitate the maneuvering of the vehicle for proper positioning at landing.

Similarly at the No. 2 Rod Mill Site, the landing ramp is at the end of a narrow slip which runs North South and therefore provides protection. (See Fig. 6).

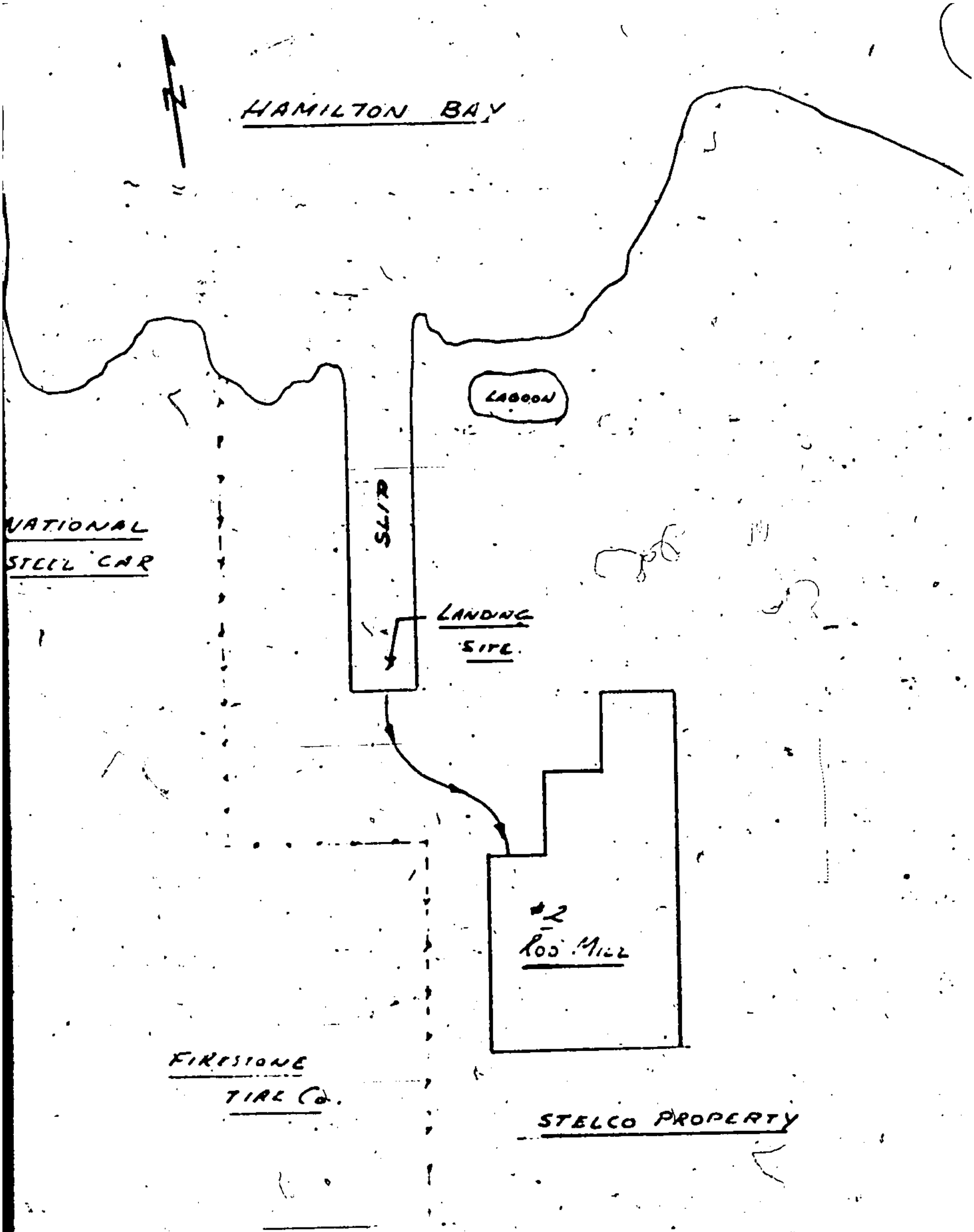


Fig.6 No.2 Rod Mill Site

2. PROPOSAL FOR AMPHIBIOUS SELF-PROPELLED VEHICLE (cont'd.)

2.3 VEHICLE DESIGN CRITERIA

1. OPERATING DATA

Billet Size: 4 in. x 4 in. x 30 ft.

Bundle Size: 20 in. x 16 in. x 30 ft.

Weight of one Bundle: 15 tons

#2 R.M. Average Billet
Requirements: 2000 tons/day

#2 R.M. Peak Billet
Requirements: 2400 tons/day

90% Availability of
24 hr. operation: 21.6 hrs/day

Using 3 shifts/day
@ 7 hrs/shift: 21 hrs/day

Total Distance to be Covered: 10,000 ft.

Land Portion: 2,000 ft.

Water Portion: 8,000 ft.

Assumed Land Speed: 5 m.p.h.

Assumed Water Speed: 5 knots

2. PROPOSAL FOR AMPHIBIOUS SELF-PROPELLED VEHICLE (cont'd.)

2.3 VEHICLE DESIGN CRITERIA (cont'd.)

1. OPERATING DATA (cont'd.)

Travel Time: $\dfrac{10{,}000 \text{ ft.}}{5{,}280 \text{ ft./mile} \times 5 \text{ m.p.h.}} = 0.38$ hr.

Loading Time Assumed: 6 min.

Unloading Time Assumed: 6 min.

Return Trip (Empty): 22.8 min. *

Total Turnaround Time: 57.6 min.

Assuming 2 Vehicles:
No. of Trips/day: $\dfrac{21}{0.5} = 42$ trips

Vehicle Capacity Required at Peak Load (3 shifts): $\dfrac{2{,}400 \text{ T}}{42} = 57.1$ Tons

Vehicle Capacity Required at Peak Load (2 shifts): $\dfrac{2{,}400 \text{ T.} \times 0.5}{7 \text{ hrs.} \times 2} = 85.7$ Tons

No. of Bundles/trip: $\dfrac{85.7}{13} = 6.6 = 7$

* The return trip should be faster with no cargo.

2. PROPOSAL FOR AMPHIBIOUS SELF-PROPELLED VEHICLE (cont'd.)

2.3 VEHICLE DESIGN CRITERIA (cont'd.)

1. OPERATING DATA (cont'd.)

If one 12 hr. shift is chosen
the Required Vehicle Capacity is: $\frac{2400 \times 0.5}{12} = 100$ Tons

The design load is assumed to be 100 Tons.

2. CONCEPT

According to the foregoing data and information, it is decided to use an amphibious vehicle that would carry the required tonnage of billets between the No. 3 Bloom and Billet Mill and the No. 2 Rod Mill. This vehicle shall be capable of driving into the respective mills for loading and unloading operations and shall not require other assistance than the mills' overhead cranes.

A tractor trailer system is selected to obtain greater versatility and load carrying capability. Indeed if a tractor experiences mechanical troubles, a spare tractor can be put into service without immobilizing the payload carrying part of the vehicle, as well as the load being carried, as the case could be.

2. PROPOSAL FOR AMPHIBIOUS SELF-PROPELLED VEHICLE (cont'd.)

2.3 VEHICLE DESIGN CRITERIA (cont'd.)

2. CONCEPT (cont'd.)

It is visualized that initially the amphibious fleet would consist of three complete units (i.e., tractor and trailer) and one single tractor. Two units would be in operation together, one would be a back up and the remaining tractor would be a reserve spare. The dimensions of the equipment are chosen in order to provide adequate capacity and clearances.

Other considerations, like flotation, seaworthiness and tractive power, will be investigated in the section devoted to the feasibility calculations. At the outset it is assumed that the billets will be handled as they are now, in square bundles. Therefore the trailer bed will be designed, with proper supports, in order to accomodate these bundles, and adequate clearances so that the existing lifting equipment is not hindered. (See Fig. 7). The trailer will be supported by four non-driven wheels mounted on two axles. Their positions will be such that a nominal and relatively constant load remains on the tractor hitch. (See Fig. 3).

The tractor is a six wheeled amphibious vehicle capable of pulling the loaded trailer at a speed of approximately 5 m.p.h. on land and 3 to 5 knots in the water.

Fig. 7- Billet Lifting Bale In Action

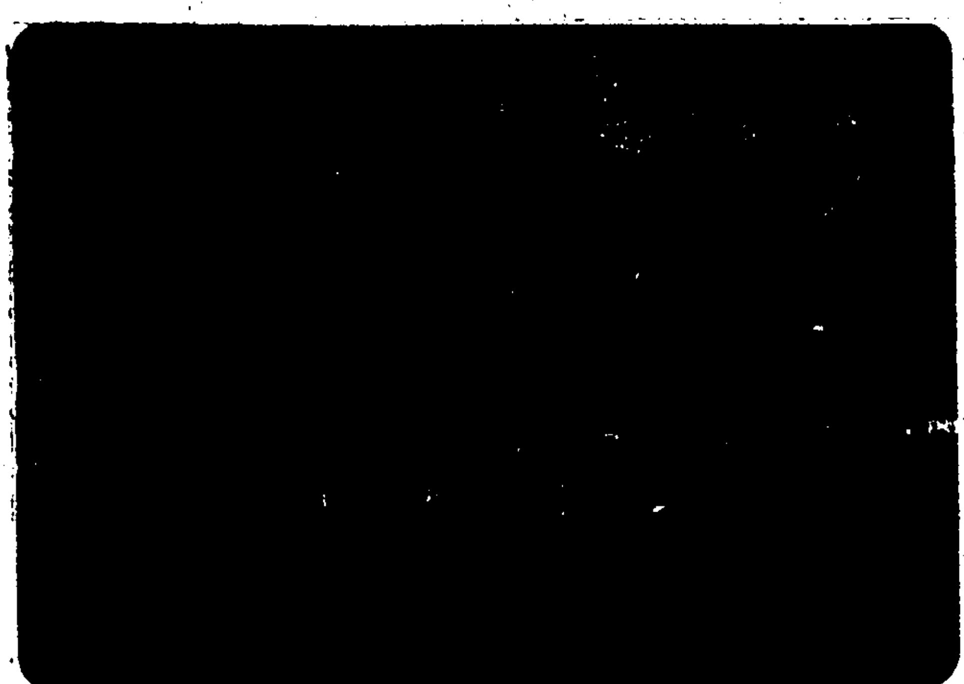


Fig. 8- Model Of Amphibious Vehicle

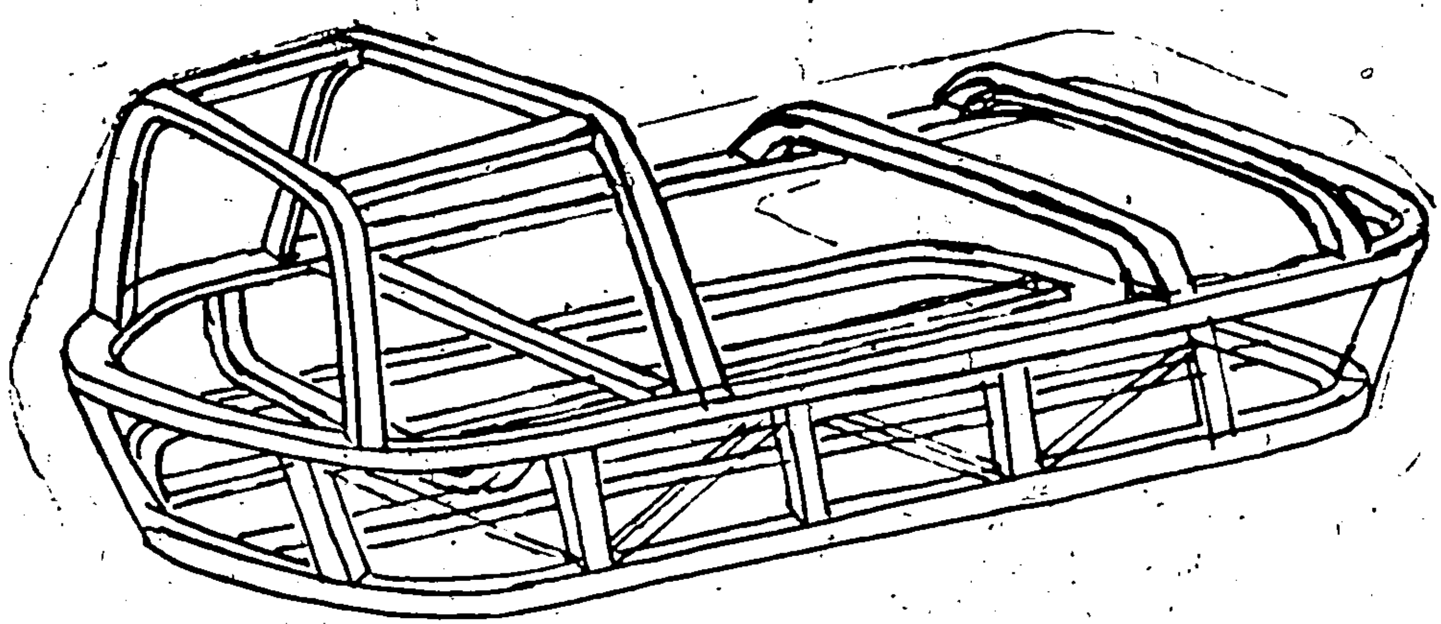


Fig. 9 - Sketch of Suggested Tractor Cage Structure

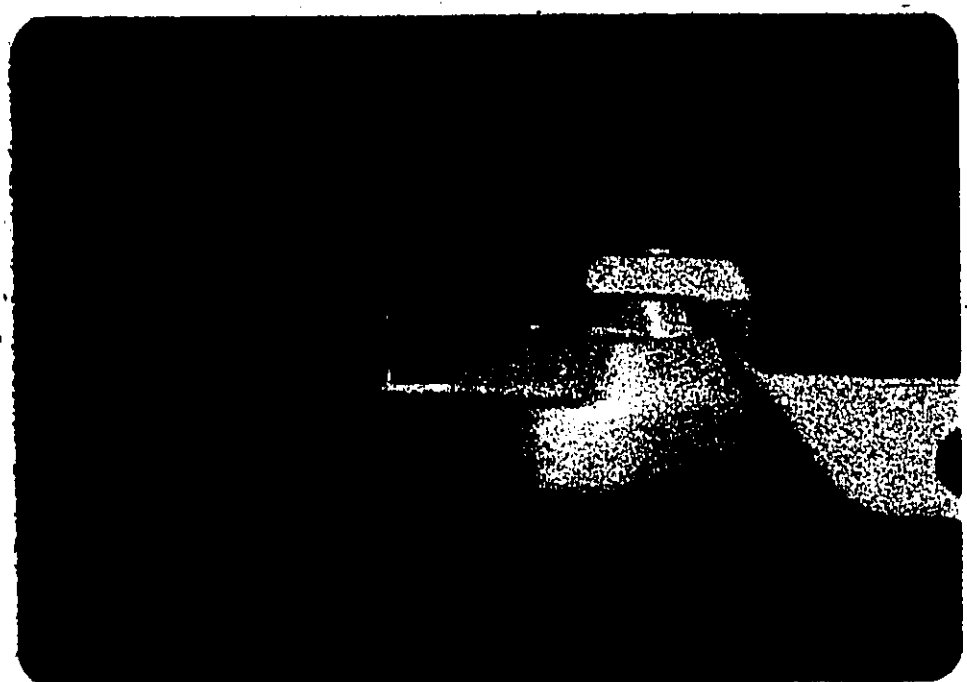


Fig. 10 - Tractor Hitch Arrangement.

2. PROPOSAL FOR AMPHIBIOUS SELF-PROPELLED VEHICLE (cont'd.)

2.3 VEHICLE DESIGN CRITERIA (cont'd.)

2. CONCEPT (cont'd.)

Its shape is such that water resistance will not become excessive. (See Fig. 8). All six wheels are driven for maximum traction on land and high flotation tires are chosen for the reason implied. We shall see later that these same tires also present advantages for land locomotion when compared with regular truck tires. For maximum rigidity the vehicle has an all welded cage type structure which is made up of hollow rectangular structural sections. (Fig. 9). The pilot's cabin is located forward for maximum visibility and has enough room for a crew of two. Access to the cabin is gained through a rear door which is located opposite the access hatch to the engine room. Because of the cage type construction, the engine room has no obstructions and provides more than six feet of headroom in the rear half of the vehicle.

The tractor is entirely watertight so that should its deck get awash, no water could get into the cabin or the engine compartment. The link between tractor and trailer, or hitch, is located in the aft section of the tractor and provides enough freedom to allow the trailer to roll, pitch and yaw. (Fig. 10).

2. PROPOSAL FOR AMPHIBIOUS SELF-PROPELLED VEHICLE (cont'd.)

2.3 VEHICLE DESIGN CRITERIA (cont'd.)

2. CONCEPT (cont'd.)

From the foregoing, one can get an idea of what the amphibious unit will look like and what its function will be. Nothing, however, has been said so far about the kind of propulsion system to be incorporated in this vehicle. In effect we are faced with a dual objective: the vehicle must be able to move on land as well as in the water.

Let us look at a few possibilities in that area.

Automotive Systems:

1. A rather conventional system would consist of installing two separate sources of power to perform the two separate functions. An engine would drive the wheels through a conventional power transmission arrangement, while another would turn a propeller or two through conventional marine shafting. This is a proven system but necessarily expensive because of the use of two engines.

2. Another possibility is to have hydrostatic drives, i.e., hydraulic motors, driving all six wheels for land locomotion, with two additional hydraulic motors driving two water jet pumps used for water locomotion.

One Diesel or gasoline engine would drive a main pump supplying all the motors.
In this particular system all six wheels could be individually controlled to obtain maximum traction. Steering on land would be accomplished by skidding one side or the other as in a tracked vehicle. Steering in the water is accomplished by reversing the flow in one of the jets as will be seen later, instead of a vulnerable rudder system as would be required in the first possibility.

3. An alternate way of accomplishing land and water locomotion is to combine a mechanical transmission system for land, and a jet pump system for water, both deriving power from a single internal combustion engine. (Fig. II).

Alternate number three is essentially the same as number one except for the water locomotion portion.

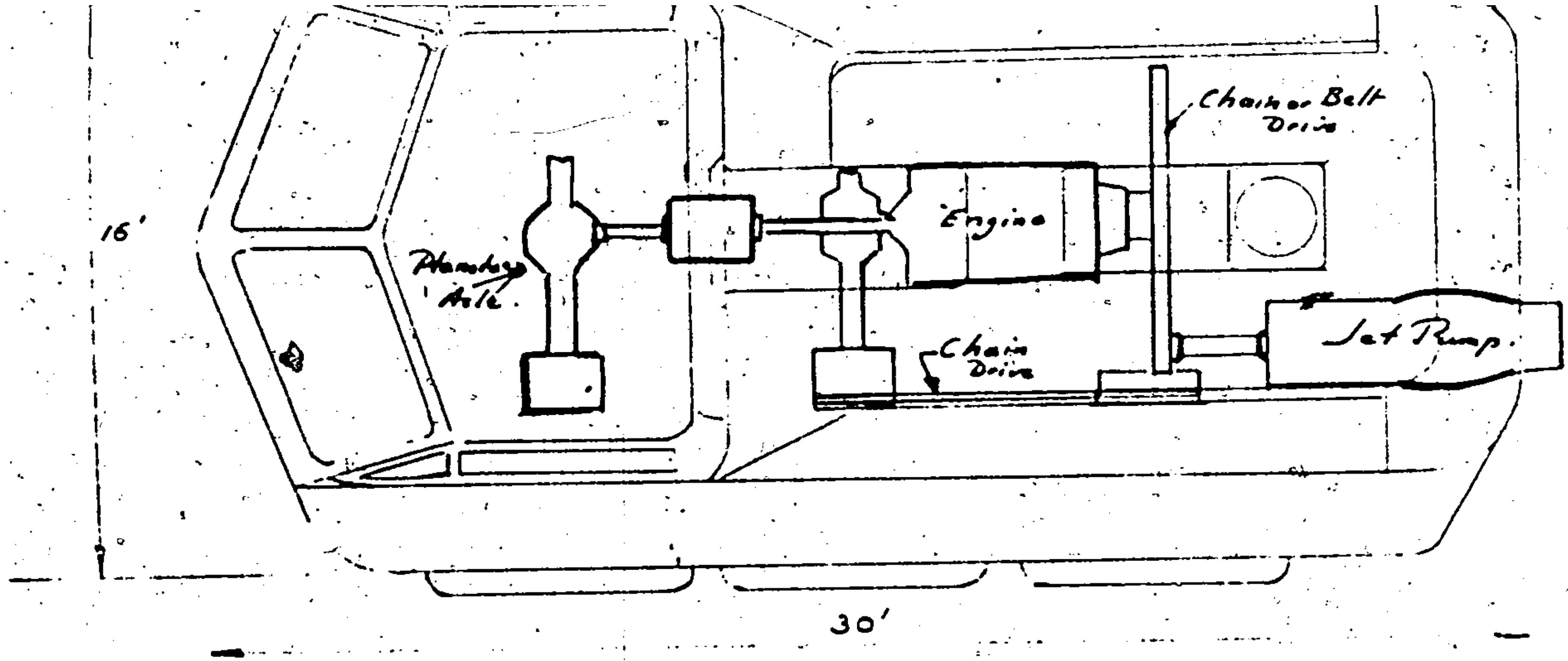
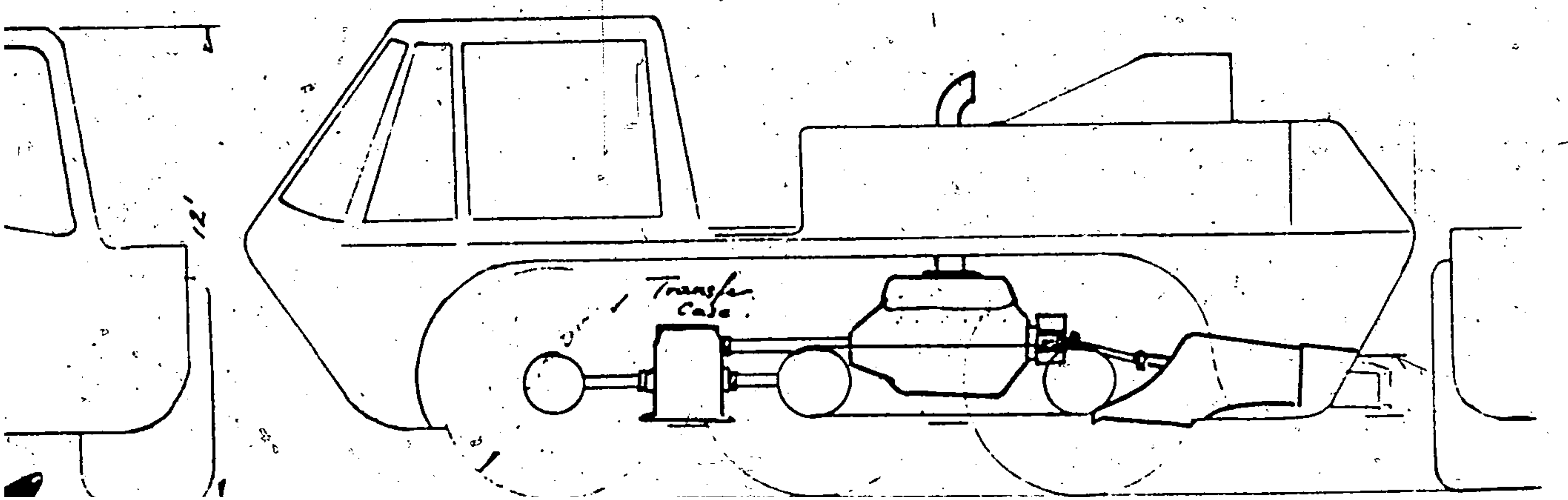


Fig. 11 Suggested Layout of Mechanical Equipment



2. PROPOSAL FOR AMPHIBIOUS SELF-PROPELLED VEHICLE (cont'd.)

2.3 VEHICLE DESIGN CRITERIA (cont'd.)

2. CONCEPT (cont'd.)

Automotive Systems (cont'd.)

Alternate number two, which utilizes hydraulic motors, is one which will not readily be accepted primarily because of the very high pressures involved (up to 6,000 p.s.i.), hence high cost of the components, and because of lack of data to confirm the reliability of the system, at least in this particular application.

It is therefore decided at this point to adopt the third proposal which combines the conventional land locomotion system with the less than conventional water locomotion system.

To design an amphibious vehicle, as described, or indeed any vehicle, from the ground up, is a task that requires many groups of engineers, each specializing in a particular part of the total concept. A workable design with a tested prototype can be obtained after several months and possibly years of work.

It is clearly not possible, in this preliminary design study, to do more than a feasibility analysis of the original design concept described. The design concept has considerable promise as a solution to the problem.

2. PROPOSAL FOR AMPHIBIOUS SELF-PROPELLED VEHICLE (cont'd.)

2.3 VEHICLE DESIGN CRITERIA (cont'd.)

2. CONCEPT (cont'd.)

Automotive Systems (cont'd.)

This promise will be confirmed in a preliminary way by the feasibility study. For each section of the vehicle, that is, structure, wheels, powerplant, etc., a design shall be corroborated by the necessary calculations. In other words, any design put forth shall have its workability ensured, at least on paper. The success of the prototype in field tests will be obtained by the projection of the mind through engineering intuition.

The feasibility study that follows shall be divided into six different parts:

1. Basic Dimensional Assumptions.
2. Land Mode Propulsion System
3. Water Mode Propulsion System
4. Structural Design
5. Overall Design Synthesis
6. Cost Estimate

3. FEASIBILITY STUDY

3.1 VEHICLE DIMENSIONS

(A) Trailer

Length: 50 ft. Overall

Width: 18 ft. Overall

Height: 9 ft. (top of Sideboard)

Estimated Weight (Tare):

Steel Structure: 50,000 lbs.

Al-Alloy Structure: 25,000 lbs.

Type of Structure: Box structure with centre backbone boxed beam for torsional resistance.

Hitchload: Assumed to be 10,000 lbs.

Estimated Total Trailer Weight (Loaded):

(a) Steel Structure: 250,000 lbs.
(b) Al-Alloy Structure: 225,000 lbs

Wheels and Tires:

Number: 4
Type: Non-Flotation
Suspension: None

3. FEASIBILITY STUDY (cont'd.)

3.1 VEHICLE DIMENSIONS (cont'd.)

(B) Tractor

Length: 30 ft. Overall

Width: 16 ft. Overall

Height: 12 ft. Overall

Estimated Weight: 25,000 lbs., Minimum

Type of Structural Frame: Cage type built with Hollow Structural Sections.

Number of Wheels: 6

Wheels Selected: Goodyear high flotation Terra-Tire

3. FEASIBILITY STUDY (cont'd.)

3.2 LAND MODE PROPULSION SYSTEM

For maximum buoyancy and traction, it is decided to make use of the Goodyear Terra-Tire high flotation tires which feature low pressure, low profile and a relatively large contact area.* These characteristics should give this type of tire a higher rolling resistance than a conventional truck tire. Tests have proven that the opposite is true. The following table, taken from the Goodyear Engineering Data Book, lists resistance forces in pounds for each 1000 pounds of load on the tire. It is found that this resistance force varies in direct proportion with the resistance to flexing of the tire carcass and inversely with an increase in tire width.

Table 1 - Rolling Resistance per 1000 lbs. load on the Tire[1]

	Terra-Tire lbs.	Truck Tire lbs.
Hard Surface	16	25
Sod	24	85
Mud	40	130
Soft Sand	78	275

* Goodyear Engineering Data Book

1 - Goodyear Engineering Data Book

3. FEASIBILITY STUDY (cont'd.)

3.2 LAND MODE PROPULSION SYSTEM (cont'd.)

We shall see later that although the high flotation tire is well suited to the tractor, it is less than ideal for the loaded trailer.

3.2.1 Performance Data:

Most of the formulas used to arrive at an adequate motive power have been taken from the Engineering Data Sheets called "Automotive Vehicle Performance Formulas" issued by Clark Equipment Co." of Buchanan, Mich.[1]

In order to obtain the engine torque requirements, all the resistances must be known.

Minimum Drawbar Force Required = Road Rolling Resistance
\+ Air Resistance
\+ Grade Resistance
\+ Mechanical Friction Resistance

1 - See Appendix

3. FEASIBILITY STUDY (cont'd.)

3.2 LAND MODE PROPULSION SYSTEM (cont'd.)

3.2.1 Performance Data: (cont'd.)

1. Road Rolling Resistance

(a) Tractor

The rolling resistance on smooth dirt is given as 25 lbs./1000 lbs. load for truck tires[1] and 16 lbs./1000 lbs. load for Goodyear Terra-Tire tires.[2]

The preliminary estimated tractor weight was 25,000 lbs.

$$\text{Rolling Resistance (R.R.)} = \frac{\text{G.V.W.} \times R}{1000}$$

where G.V.W. = Gross Vehicle Weight

R = Ground Resistance

For the tractor then:

$$R.R._1 = \frac{25,000 \times 16}{1000} = 400 \text{ lbs.}$$

1 - Clark Equipment Data Sheets - Appendix.

2 - Table 1, Page 28.

3. FEASIBILITY STUDY (cont'd.)

3.2 LAND MODE PROPULSION SYSTEM (cont'd.)

3.2.1 Performance Data: (cont'd.)

1. Road Rolling Resistance (cont'd.)

(b) Trailer

The preliminary estimated trailer weight was: 250,000 lbs.

Therefore, with truck tires:

$$R.R._2 = \frac{250,000 \times 25}{1000} = \underline{6250} \text{ lbs.}$$

The total Road Rolling Resistance becomes:

$$R.R._T = R.R._1 + R.R._2$$

$$= 400 + 6250 = \underline{6650} \text{ lbs.}$$

2. Air Resistance A.R.

The air resistance against a vehicle is given by:[1]

$$A.R. = 0.0025 \text{ (Speed in miles/hr.)}^2 \times \text{Frontal Area}$$

Due to the outline of the amphibious unit, only the frontal area of the tractor shall be taken into account.

1 - Clark Equipment Engineering Data Sheets - Appendix

3. FEASIBILITY STUDY (cont'd.)

3.2 LAND MODE PROPULSION SYSTEM (cont'd.)

3.2.1 Performance Data: (cont'd.)

2. Air Resistance A.R.

This area is approximately 100 $ft.^2$. The operational land speed being set at 5 miles/hour, the air resistance is:
A.R. = $0.0025 (5)^2 \times (100)$ = 6.25 lbs. which is negligible. However, if the vehicle is moving against a 30 miles/hour head wind[1], the air resistance becomes:
A.R. = $0.0025 (30 + 5)^2 (100)$ = 306 lbs., almost a fifty fold increase! For design purposes, the maximum Air Resistance shall be taken as 310 lbs.

3. Grade Resistance G.R.

Most of the land route that the vehicle will travel will be flat and level except at the landing sites where necessarily a grade will exist. The maximum design grade is set at 3%. The Grade Resistance, G.R., of a vehicle is:[2]
G.R. = 0.01 (G.V.W.) (% Grade)
where G.V.W. = Gross Vehicle Weight

1 - Assumed wind velocity on a windy day.

2 - Clark Equipment Engineering Data Sheets - Appendix

3. FEASIBILITY STUDY (cont'd.)

3.2 LAND MODE PROPULSION SYSTEM (cont'd.)

3.2.1 Performance Data: (cont'd.)

3. Grade Resistance G.R. (cont'd.)

In this case the G.V.W. will be the sum of the gross weights of the tractor (25,000 lbs.) and the loaded trailer (250,000 lbs.).

G.R. = 0.01 (275,000) (3) = 8,250 lbs.

If, for the time being, the Mechanical Resistance is disregarded, the Total Resistance to propulsion becomes:

Total Resistance = $R.R._T$ + A.R. + G.R.

= Minimum Force Required

= 6650 + 310 + 8250

= 15,210 lbs., assume 15,500 lbs.

The foregoing resistance calculations imply a constant speed which is 5 miles/hour in our case. The vehicle must accelerate to reach that speed and to do so requires an additional force called force of acceleration, Fa.

A reasonable acceleration rate would be from 0 to 5 m.p.h. in 7 seconds.

5 m.p.h. ≃ 7.5 ft./sec.

3. FEASIBILITY STUDY (cont'd.)

3.2 LAND MODE PROPULSION SYSTEM (cont'd.)

3.2.1 Performance Data: (cont'd.)

$$\text{Acceleration} = a = \frac{V_2 - V_1}{T}$$

$$= \frac{7.5}{7} \simeq 1 \text{ ft./sec.}^2$$

V_1 = Initial Speed

V_2 = Final Speed

T = Time

Therefore the force of acceleration is:

$$Fa = \frac{\text{Total Weight} \times a}{g}$$

$$= \frac{275,000 \times 1}{32.2}$$

$$= 8540 \text{ lbs.} \simeq \underline{8550} \text{ lbs.}$$

where g = acceleration of gravity

= 32.2 ft./sec.^{2}

The Total Resistance, including acceleration Force becomes:

$$R_T = 15,500 + 8550 = \underline{24,050} \text{ lbs.}$$

3. FEASIBILITY STUDY (cont'd.)

3.2 LAND MODE PROPULSION SYSTEM (cont'd.)

3.2.1 Performance Data: (cont'd.)

To ensure that adequate traction can be obtained, the force required to slip the driven wheels must always be smaller than the total resistance.

This "slip" Force is given by: $F_s = \mu N$

where μ = coefficient of friction between tires and ground

N = load on driven wheels

The coefficient of friction of rubber tires on an average road surface is approximately 0.6.[1] Therefore

$F_{s_1} = 0.6 \ (25{,}000)$

$= 15{,}000$ lbs. which is smaller than the total resistance R_T.

We must either decrease R_T or increase F_s.

The easier alternative is to increase F_s by increasing the weight of the tractor. If we arbitrarily double the weight of the tractor, the Force F_s, required to slip the wheels becomes: $F_{s_1} = \mu N$

$= 0.6 \ (25{,}000) \times 2$

$= \underline{30{,}000}$ lbs. without hitch load

1 - Clark Equipment Engineering Data Sheets - Appendix.

3. FEASIBILITY STUDY (cont'd.)

3.2 LAND MODE PROPULSION SYSTEM (cont'd.)

3.2.1 Performance Data: (cont'd.)

When the 10,000 lbs. hitch load is present - and assumed distributed - F_s becomes: F_{s_2} = 0.6 (60,000)

= 36,000 lbs.

The total resistance R_T must now be corrected to include the increase in weight of the tractor.

Referring back to the components of R_T, the changes, with the new total weight of 300,000 lbs., are:

1. Road Rolling Resistance $R.R._T$.

   The Road Rolling Resistance of the tractor was $R.R._1$ = 400 lbs. It now becomes $R.R._1$ = 400 x 2 = 800 lbs

   The Road Rolling Resistance $R.R._2$ of the Trailer does not change and remains 6250 lbs.

2. The Air Resistance A.R., stays constant.

3. The Grade Resistance G.R., was 8250 lbs. It now becomes:

$$G.R. = \frac{(8250) \times (300,000)}{275,000} = 9000 \text{ lbs.}$$

3. FEASIBILITY STUDY (cont'd.)

3.2 LAND MODE PROPULSION SYSTEM (cont'd.)

3.2.1 Performance Data: (cont'd.)

4. Force of Acceleration Fa

$$\text{It was } F_a = \frac{\text{Total Weight} \times a}{g} \simeq 8550 \text{ lbs.}$$

$$\text{It becomes } F_a = \frac{(8550) \times (300{,}000)}{275{,}000} = 9327 \text{ lbs.}$$

Let us use = 9500 lbs.

The Total Resistance R_T becomes:

$$R_T = R.R._T + A.R. + G.R. + Fa$$

$$= (800 + 6250) + 310 + 9000 + 9500$$

R_T = 25,860 lbs., which is less than F_{s_2} = 36,000 lbs.

Adequate traction is therefore theoretically provided.

Tire Selection

(a) Tractor

For maximum flotation, reduced rolling resistance, higher shock absorption and cost savings, the Goodyear "Terra-Tire" Tire is selected. This relatively low pressure tire eliminates the need for a suspension system.

3. FEASIBILITY STUDY (cont'd.)

3.2 LAND MODE PROPULSION SYSTEM (cont'd.)

3.2.1 Performance Data: (cont'd.)

Tire Selection (cont'd.)

(a) Tractor (cont'd.)

Assuming an even weight distribution, each of the six tires will have to support $\frac{50,000}{6} \approx$ 8335 lbs.

According to the Goodyear Engineering Data booklet,[1] a suitable tire would be the 66 x 43.00 - 25 tubeless "Terra-Tire" with the "Super Terra-Grip" tread design. It has an overall diameter of approximately 70 in., and can withstand a load of 13,000 lbs. at 25 p.s.i. and 10 m.p.h. Each tire weighs 544 lbs., has a ground contact area of 800 $in.^2$ and makes 315 revolutions per mile.

As we shall see later, the downward force on the hitch will have to be added to the tractor tare weight.

(b) Trailer

The tare weight of the trailer was assumed to be 50,000 lbs., and the payload 200,000 lbs. If the tires

1 - Dimension, Load and Inflation Tables - Page 11 of booklet.

3\. FEASIBILITY STUDY (cont'd.)

3.2 LAND MODE PROPULSION SYSTEM (cont'd.)

3.2.1 Performance Data: (cont'd.)

Tire Selection (cont'd.)

(b) Trailer (cont'd.)

are mounted so that they bear all the load (disregarding hitch force) and if the number of tires is kept to 4 to facilitate manoeuvres, the load per tire will be:

$$W_{LT} = \frac{250,000}{4} = 62,500 \text{ lbs.}$$

This load is beyond the capabilities of the "High Flotation" Tires and must be carried on conventional off-the-road bulldozer tires.

A suitable size is the 37.5 - 33 available from Goodyear or Firestone. The Goodyear Tire is called the "Sure Grip Lug L_2" and has a rated load of 63,940 lbs., @ 55 p.s.i.[1] The Firestone Tire is called the "Super Rock Grip" and has a rated load of 63,990 lbs., @ 55 p.s.i.[2] These loads are for 5 m.p.h. operation and can be increased with an increase in inflation pressure. The main dimensions are shown in the following table:

1 - Goodyear Tire Data Book, Page D15.

2 - Firestone Tire Data Book, Pages 023 and 048.

3. FEASIBILITY STUDY (cont'd.)

3.2 LAND MODE PROPULSION SYSTEM (cont'd.)

3.2.1 Performance Data: (cont'd.)

Tire Selection (cont'd.)

(b) Trailer (cont'd.)

TIRE SIZE: 37.5 - 33

	Width	Diameter
Goodyear	38.1 in.	93.5 in.
Firestone	34.25 in.	94.1 in.

As was suggested on Page 20, 4 wheels will be used to support the trailer. It would be impractical to use 8 wheels in tandem given the width constraint of the trailer.

Because of the low speeds involved, and because of the available roads, no suspension system shall be used for the trailer.

No safety factor was used because the tire manufacturers have it already included in their load rating.

Furthermore because of the non-continuous operation of the vehicle, the tires will not be subjected to extreme service. Of the total mileage travelled in one day on land by the vehicle, only half will be with full load.

3. FEASIBILITY STUDY (cont'd.)

3.2 LAND MODE PROPULSION SYSTEM (cont'd.)

3.2.1 Performance Data: (cont'd.)

Selection of Motive Power

In order to select an engine capable of moving the vehicle efficiently, the required torque must be obtained.
On Page 37, the total resistance R_T was found to be approximately 26,000 lbs. when the acceleration was set at 1 ft./sec.^{2}, i.e., an increase in speed form rest to 5 m.p.h. in 7 seconds on flat ground.
If, more realistically, the gain in speed in 7 seconds is limited to 3 m.p.h. going up the 3% grade, the reduction of the Total Resistance R_T amounts to:

$$Fa_5 - Fa_3 = 9500 - \frac{300,000\left(\frac{4.5}{7}\right)}{32.2}$$

$$= 9500 - 5989$$

$$\simeq 3510 \text{ lbs.}$$

3 m.p.h. $\simeq$ 4.5 ft./sec.

$Fa_3 \simeq$ 6000 lbs.

R_T becomes approximately $R_T = 25,860 - 3510$

R_T = 22,350 lbs.

3. FEASIBILITY STUDY (cont'd.)

3.2 LAND MODE PROPULSION SYSTEM (cont'd.)

3.2.1 Performance Data: (cont'd.)

Selection of Motive Power (cont'd.)

The Force required to slip the wheels was found to be:

$$Fs_2 = 36{,}000 \text{ lbs.}$$

The torque necessary to spin the wheels is given by:

$$T_{max.} = Fs \times \text{Tire Radius}$$

$$= 36{,}000 \left(\frac{35}{12}\right)$$

$$= 105{,}000 \text{ lbs. ft. at slippage.}$$

$$\text{Tractor Tire Radius} = \frac{70}{2} = 35''$$

The minimum torque necessary is given by:

$$T_{min.} = R_T \times \text{Tire Radius}$$

$$T_{min.} = 22{,}350 \left(\frac{35}{12}\right)$$

$$= 65{,}262 \text{ lbs. ft.}$$

where R_T = Total Resistance[1]

= 22,350 lbs.

1 - See previous page.

3. FEASIBILITY STUDY (cont'd.)

3.2 LAND MODE PROPULSION SYSTEM (cont'd.)

3.2.1 Performance Data: (cont'd.)

Selection of Motive Power (cont'd.)

Since the operating ground torque $T_{min.}$ is smaller than the slip torque $T_{max.}$, adequate traction will be provided. The maximum tractive effort T.E. is equal to the total resistance R_T.

Therefore T.E. = R_T = 22,350 lbs.

Let us set T.E. = 23,000 lbs.

The tractive effort is given by:[1]

$$T.E. = \frac{T \times R \times e \times C \times 12}{r}$$

The gross engine torque will be:[1]

$$T = \frac{(T.E.)\ (r)}{(R)\ (e)\ (C)\ 12}$$

$$T = \frac{23{,}000\ (35)}{R\ (0.85)\ (0.85)\ 12} \quad \text{.........................(1)}$$

where T = Gross Engine Torque lbs. ft.

C = Conversion factor to get net engine torque ($\simeq$ 0.85)

R = Overall gear reduction including axle and transmission

1 - Clark Equipment Engineering Data Sheets.

3. FEASIBILITY STUDY (cont'd.)

3.2 LAND MODE PROPULSION SYSTEM (cont'd.)

3.2.1 Performance Data: (cont'd.)

Selection of Motive Power (cont'd.)

where e = Mechanical efficiency of drive line (≃ 0.85)

r = Rolling radius in inches

At this point, the overall gear reduction R must be known or chosen in order to arrive at a figure for the required engine torque.

According to data available to-date, a suitable power transmission system would be a combination of a truck transmission with a combined differential and planetary drive axle.

Such a combination is used in the Euclid R-35 tractor.[1]

1. Allison CLBT - 5860 full powershift transmission with integral torque converter:

Gear Ratios:	1st	-	4.00 : 1
	2nd	-	2.68 : 1
	3rd	-	2.01 : 1
	4th	-	1.35 : 1
	5th	-	1.00 : 1
	6th	-	0.67 : 1
	Reverse	-	5.12 : 1

1 - White Motor Corp., Specification Sheets for the Euclid R-35 Tractor.

3. FEASIBILITY STUDY (cont'd.)

3.2 LAND MODE PROPULSION SYSTEM (cont'd.)

3.2.1 Performance Data (cont'd.)

Selection of Motive Power (cont'd.)

2. Euclid Planetary Drive Axle:

		Std.	Opt.
Ratios:	Differential:	3.92 : 1	3.13 : 1
	Planetary:	4.59 : 1	4.59 : 1
	Total	17.99 : 1	14.37 : 1

The overall gear reduction in 1st gear would be (with standard ratios): $R = 17.99 \times 4.00 \simeq 72$

Substituting in equation 1, one gets:

Gross Engine Torque

$$T = \frac{23,000\ (35)}{72\ (0.85)\ (0.85)\ 12} \simeq 1290 \text{ lbs. ft.} \quad ....(2)$$

With the above transmission system a popular engine in Euclid trucks is the following:

Detroit Diesel 12V - 71N - 2 Cycle Diesel Engine	
Gross Vehicle Horsepower @ 2100 r.p.m.	434 H.P.
Flywheel Horsepower @ 2100 r.p.m.	394 H.P.
No. of Cylinders	12
Bore and Stroke	4.25 in. x 5 in.
Piston Displacement	852 $in.^3$
Maximum Torque @ 1200 r.p.m.	1205 lbs. ft.

3. FEASIBILITY STUDY (cont'd.)

3.2 LAND MODE PROPULSION SYSTEM. (cont'd.)

3.2.1 Performance Data: (cont'd.)

Selection of Motive Power (cont'd.)

The engine is marginal according to the requirements stated earlier. One would have to go to more powerful engines, of the Caterpillar series as an example. At this point, it would be appropriate to bring refinements to some of the assumptions made earlier.

It is recalled that the Total Resistance to locomotion, or Minimum Drawbar force required, was the sum of the Road Rolling Resistance, the Air Resistance and the Grade Resistance. It was assumed that the ground would be smooth dirt and that the maximum grade would be 3%, to be climbed at full load. These assumptions must be refined as follows:

1. The entire land route will not have a smooth dirt surface. The sloped sections, i.e., the land-launch portions, shall be made of rough concrete.

2. The maximum gradient of 3% will exist at the Hilton Works launch site only. The No. 2 Rod Mill landing site will have a 2% gradient.

3. FEASIBILITY STUDY (cont'd.)

3.2 LAND MODE PROPULSION SYSTEM (cont'd.)

3.2.1 Performance Data: (cont'd.)

Selection of Motive Power (cont'd.)

3. The vehicle will climb the 2% slope when fully loaded and will negotiate the 3% gradient only on the return trip when empty.

These refinements produce the following changes:

1. The Road Rolling Resistance $R.R._2 = \frac{G.V.W. \times R}{1000}$ for the trailer was calculated using a ground resistance R = 25 lbs. for smooth dirt. Using the value for rough concrete R = 18 lbs.[1], the Road Rolling Resistance $R.R._2$ becomes:

$$R.R._2 \text{ corrected} = \frac{250{,}000 \times 18}{1000} = 4500 \text{ lbs.}$$

or a reduction of 6250 - 4500 = 1750 lbs.

2. The Grade Resistance @ #2 Rod Mill, i.e., when the vehicle is fully loaded becomes:

$G.R._{corrected} = 0.01 \text{ (G.V.W.) (\% grade)}$

$G.R._{corrected} = 0.01 \ (300{,}000)^2 = 6000$ lbs.

or a reduction of 9000 - 6000 = 3000 lbs.

1 - Clark Equipment Engineering Data Sheets.

3. FEASIBILITY STUDY (cont'd.)

3.2 LAND MODE PROPULSION SYSTEM (cont'd.)

3.2.1 Performance Data: (cont'd.)

Selection of Motive Power (cont'd.)

The Total Resistance R_T which was 22,350 lbs. (Refer to Page 41) now becomes: $R_T = 22,350 - (3000 + 1750) = \underline{17,600}$ lbs.

The Gross Engine Torque required which was found to be $T = 1290$ lbs. ft., now becomes

$$T_{corrected} = \frac{1290 \times 17,600}{23,000} \simeq 988 \text{ lbs. ft.}$$ (See equ. 2, Pg. 45)

or approximately $T_{corrected} = \underline{1000}$ lbs. ft.

It is interesting to note that the Force of Acceleration Fa_3 and the Grade Resistance $G.R._{corrected}$, are both approximately 6000 lbs. and each amount to approximately 35% of the Total Resistance R_T.

The general disposition of the mechanical components, within the vehicle, will be suggested in a later section of the study.

3. FEASIBILITY STUDY (cont'd.)

3.3 WATER MODE PROPULSION SYSTEM

An Amphibious Vehicle is defined as a vehicle that can move over land and on water.

After having asserted the capability of the vehicle to move itself on the land portion of the itinerary, its adequacy on water must also be proven in order to obtain a completely functional transportation system.

The vehicle shall now be treated as a watercraft.

3.3.1 Performance Data:[1]

As was done for land locomotion, the total resistance of the craft to motion must be known in order to determine the power requirements. Of course a prerequisite in this case is that the craft would float.

Naval Architecture being a very specialized field, the design of a watercraft shall not be attempted. Nevertheless, some basic knowledge in this field has been acquired through reading pertinent literature in order to arrive at a compromise.

1 - John P. Comstock - Principles of Naval Architecture, Chapter VII.

3. FEASIBILITY STUDY (cont'd.)

3.3 WATER MODE PROPULSION SYSTEM (cont'd.)

3.3.1 Performance Data (cont'd.)

In other words it will be shown, we hope, that the land vehicle described previously will indeed be able to float safely and reach its destination within a reasonable length of time under its own power.

Resistance and Propulsion

The draft of a vessel is defined as the depth of its keel below the water line. The draft must not be excessive to the point of taking water over the sides, and must be large enough to provide good stability in the water.

The draft of a vessel is given by:

$$\text{Draft} = \frac{W}{(L)\ (D)\ 62.4}$$

where W = Total Weight in lbs.

L = Length at waterline in ft.

D = Width at waterline in ft.

Both tractor and trailer have flat bottoms, therefore, their respective draft will be the distance from bottom to waterline. (See Fig. 12). The added buoyancy provided by the tires shall be neglected for now.

3. FEASIBILITY STUDY (cont'd.)

3.3 WATER MODE PROPULSION SYSTEM (cont'd.)

3.3.1 Performance Data (cont'd.)

Resistance and Propulsion (cont'd.)

(a) Tractor

$W = 50{,}000$ lbs.

$L \approx 26$ ft. @ waterline

$D \approx 10$ ft.

$$Draft_{Tractor} = \frac{50{,}000}{(26)\,(10)\,62.4} \approx 3 \text{ ft.}$$

(b) Trailer

1. $W_{full} = 250{,}000$ lbs.

2. $W_{empty} = 50{,}000$ lbs.

$L \approx 40$ ft. @ waterline

$D \approx 18$ ft.

The drafts corresponding to the loaded or empty conditions will be:

$$Draft_1 = \frac{250{,}000}{(45)\,(18)\,62.4} \approx 5 \text{ ft. when loaded}$$

leaving a freeboard of about 2 feet.

$$Draft_2 = \frac{50{,}000}{(40)\,(18)\,62.4} \approx 1.1 \text{ ft. when empty}$$

leaving a freeboard of about 6 feet.

3. FEASIBILITY STUDY (cont'd.)

3.3 WATER MODE PROPULSION SYSTEM (cont'd.)

3.3.1 Performance Data (cont'd.)

Resistance and Propulsion (cont'd.)

Both tractor and trailer shall therefore float satisfactorily, since in all cases, the drafts are smaller that the distances from bottoms to top of sides.

In calculating the drafts, buoyancy of the tires was neglected. However, since 6 high flotation tires were used on the tractor, it would be interesting to see what their contribution is to the overall draft of the tractor. According to the Goodyear Terra-Tire Data Book, the capacity of the 66 x 43.00 - 25 tire is 258 gallons[1] and its weight is 544 lbs.

For equilibrium one must have:

Weight of tire = weight of displaced water.

Therefore the volume needed per tire will be

$$V_o = \frac{544}{\rho}$$

$$V_o = \frac{544}{62.4} = 8.7 \text{ ft.}^3 \approx 9 \text{ ft.}^3$$

where ρ = 62.4 lbs./ft.^{3} for fresh water

1 - Goodyear Tire Data Book, Page 22.

3. FEASIBILITY STUDY (cont'd.)

3.3 WATER MODE PROPULSION SYSTEM (cont'd.)

3.3.1 Performance Data (cont'd.)

Resistance and Propulsion (cont'd.)

and if 1 $ft.^3$ = 7.481 gallons, the total volume of the tire is $\frac{258}{7.481} \simeq 34.5\ ft.^3$ plus the volume occupied by the rubber itself. As an approximation, V_o can be taken as 37 $ft.^3$ including the rubber.

Each tire will therefore be able to support in equilibrium:

$$W = (37 - 9)\ 62.4$$

$$= \underline{1747}\text{ lbs. in addition to its own weight.}$$

The corrected draft for the tractor is:

$$Draft_{corrected} = \frac{50{,}000 - (6)\ 1700}{(26)\ (10)\ 62.4}$$

$$\approx \underline{2.5\text{ feet}}$$

The Tow Rope or Effective Horsepower required to propel the boat is given by:

$$E.H.P.\ (\text{or } P_E) = \frac{R_T\ V}{326} \quad \ldots\ldots\ \ldots\ldots\ldots\ldots (I)$$

where V = Speed in knots

R_T = Total Resistance in lbs.

$$326 = \frac{550\ ft.\ lb./sec.}{1.689\ ft./sec.\ knot}$$

3. FEASIBILITY STUDY (cont'd.)

3.3 WATER MODE PROPULSION SYSTEM (cont'd.)

3.3.1 Performance Data (cont'd.)

Resistance and Propulsion (cont'd.)

$$\text{or E.H.P.} = P_E = \frac{R_T V_f}{550}$$

where V_f = Speed in ft./sec.

Total Resistance = Frictional Resistance + Wave Making Resistance + Eddy Resistance + Air Resistance.

It has been found that at low speeds, Frictional Resistance accounts for more than 80% of the total resistance. Since the vehicle will operate at between 3 to 5 knots, only Frictional Resistance shall be considered for design purposes " a priori". However, Air Resistance shall be calculated for maximum wind force and assessed against Frictional Resistance.

As per the International Towing Tank Conference (I.T.T.C.) proceedings of 1951 (Washington), it was set that for fresh water the Frictional Resistance R_F is given by: [1]

$$R_F = \left[0.00849 + \frac{0.0516}{(8.8 + L)}\right] S.V^{1.825} \qquad \text{.............(2)}$$

1 - Which is a refinement of the empirical formula arrived at by Froude in 1872, i.e., $R = f.S.V^n$ where f and n depended upon length and nature of surface.

3. FEASIBILITY STUDY (cont'd.)

3.3 WATER MODE PROPULSION SYSTEM (cont'd.)

3.3.1 Performance Data (cont'd.)

Resistance and Propulsion (cont'd.)

where R_F = Frictional Resistance in lbs.

S = Wetted Surface in $ft.^2$

V = Speed in knots

L = Length of Craft in feet.

The exponent n is taken as 1.825.

According to Froude's skin friction coefficients[1] for a length of surface of about 50 ft., n is approximately 1.83 for a varnish surface.

In order to find the wetted surface of both tractor and trailer, an average draft of 3 feet shall be used for both units. (Fig. 12).

Assuming that at waterline the total length of the craft is approximately 80 ft. and average width is approximately 15 ft., the wetted surface S will be:

$$S = 3\ (80 + 15)\ 2 + 15\ (80)$$

$$= 570 + 1200 = 1770\ ft.^2$$

1 - Principles of Naval Architecture, Page 294.

3. FEASIBILITY STUDY (cont'd.)

3.3 WATER MODE PROPULSION SYSTEM (cont'd.)

3.3.1 Performance Data (cont'd.)

Resistance and Propulsion (cont'd.)

Although on the sketch the total length is 66 ft. (40 + 26), the gap between tractor and trailer (where turbulence will create resistance) is arbitrarily set equivalent to an additional 14 ft. in length.

Using a safety factor of 1.5, the wetted surface is set equal to $S = 1770 \times 1.5 = 2655 \text{ ft.}^2$

We shall use $S = \underline{3000 \text{ ft.}^2}$

The maximum water speed of the craft was set at $V = 5$ knots. Substituting the values of S and V in equation 2, we have

$$R_F = \left[0.00849 + \frac{0.0516}{(8.8 + 80)}\right] 3000\ (5)^{1.825}$$

$$= \left[0.00973\right] 3000\ (5)^{1.825}$$

$$= (29.2)\ (18.9) = 551.7$$

or $\underline{R_F \approx 552 \text{ lbs.}}$

For a head wind the expression for Air Resistance is:[1]

$$R_{A.A.} = 0.0041\ A_T\ (V_R)^2 \quad \ldots\ldots (3)$$

1.- Principles of Naval Architecture, Page 315.

3. FEASIBILITY STUDY (cont'd.)

3.3 WATER MODE PROPULSION SYSTEM (cont'd.)

3.3.1 Performance Data (cont'd.)

Resistance and Propulsion (cont'd.)

where A_T = Transverse projected area of above water hull in ft.^{2}.

V_R = Wind velocity in knots.

For the tractor, A_T is approximately equal to:

$A_T = 8 \times 12 = 96 \text{ ft.}^2 \simeq 100 \text{ ft.}^2$

Assuming a head wind of 25 knots into which the vehicle is to do 2.5 knots, the air resistance becomes:

$R_{A.A.} = 0.0041 (100) (25 + 2.5)^2 \quad 300 \text{ lbs.}$

$R_{A.A.} = 300 \text{ lbs.}$

The Total Resistance is:[1]

$R_T = R_F + R_{A.A.} = 552 + 300$

$R_T = 852 \text{ lbs.}$

1 - At much higher speeds, in addition to the resistances listed on Page 54, shallow water resistance would have had to be taken into account.

3. FEASIBILITY STUDY (cont'd.)

3.3 WATER MODE PROPULSION SYSTEM (cont'd.)

3.3.1 Performance Data (cont'd.)

Resistance and Propulsion (cont'd.)

In view of the length of the amphibious vehicle, and of the fact that only the tractor is powered, serious maneuvering difficulties would be encountered in side winds when the trailer would pivot about the hitch point. (Fig. 13)

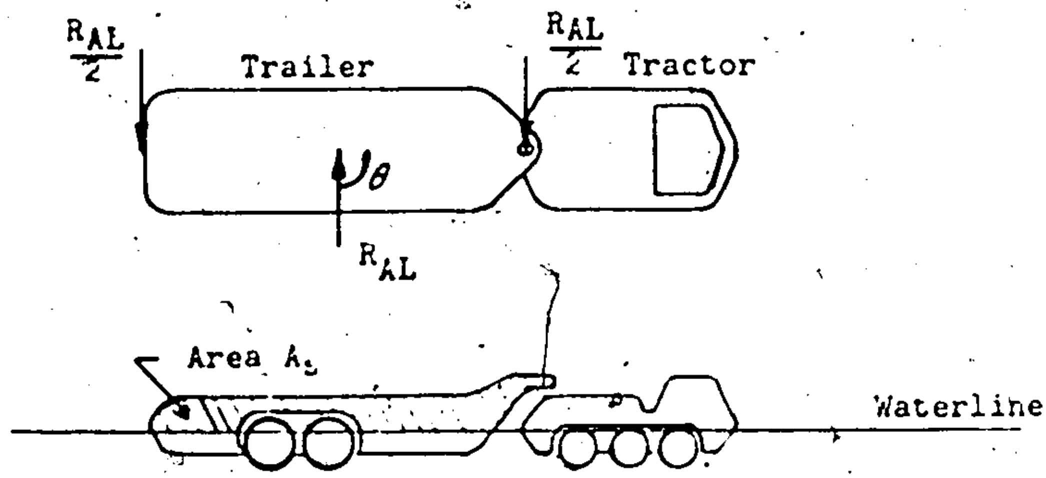


Fig. 13

The side wind thrust on the trailer is:

$R_{AL} = 0.004\ (A_s)\ (F_R)^2$

where A_s = Normal area $\approx$ 150 ft.^{2}

For $\theta = 90^o$ and V_R = 25 knots

where V_R = Wind speed in knots

3. FEASIBILITY STUDY (cont'd.)

3.3 WATER MODE PROPULSION SYSTEM (cont'd.)

3.3.1 Performance Data (cont'd.)

Resistance and Propulsion (cont'd.)

we have: $R_{AL} = 0.004\ (150)\ (25)^2$

$= 0.6\ (25)^2$

$R_{AL} = 375$ lbs.

A counterthrust of 375 lbs. is therefore needed to neutralize the wind force. However since a pivot point exists at the hitch, it will absorb $\frac{R_{AL}}{2} \approx 188$ lbs.

Therefore the counterthrust needed in the aft portion of the trailer shall also be 188 lbs.

A safety factor of 2 shall be retained and the design counterthrust becomes:

$F_T = 375$ lbs.

Choice of Propulsion

Given the particular conditions of operation of the Amphibian, it was deemed reasonable to use a water propulsion system well adapted to shallow waters, namely a jet propulsion system.

Although this type of propulsion is getting increased

3. FEASIBILITY STUDY (cont'd.)

3.3 WATER MODE PROPULSION SYSTEM (cont'd.)

3.3.1 Performance Data (cont'd.)

Resistance and Propulsion (cont'd.)

Choice of Propulsion (cont'd.)

acceptance in the pleasure craft field, its use in heavier crafts has not been widespread to date because of the excessive power required to attain speeds in the order of 20 or 30 knots. However, the low speed operation of the amphibious vehicle negates that drawback.

Letters of inquiries have been sent to companies manufacturing Jet Drives[1] in order to assess their performance in this particular application. The Companies involved were:

1. Chrysler Corp. Marine Products Div.
2. Hardin Marine.
3. Jacuzzi Brothers, Inc.
4. O.M.C. Stern Drive. Outboard Marine Corp.
5. Waukesha Motor Co. Pleasurecraft Marine Engine Division.

1 - Boating - December 1973, Page 118.

3. FEASIBILITY STUDY (cont'd.)

3.3 WATER MODE PROPULSION SYSTEM (cont'd.)

3.3.1 Performance Data (cont'd.)

Resistance and Propulsion (cont'd.)

Choice of Propulsion (cont'd.)

At the moment out of the Five Companies mentioned, only Jacuzzi has units large enough to satisfy our requirements. According to Jacuzzi of Canada, given the operating weight and the maximum speed desired (5 knots), satisfactory performance could be obtained by using either two 20 YJ pumps, or three 14 YJ's or even only two 14 YJ's.[1]

Referring to the Jacuzzi Engineering Data Book for the 14YJ unit, for a speed of 5 knots the thrust is as follows:[2]

1150 lbs. for 100 S.H.P. Input

1560 lbs. for 150 S.H.P. Input

1900 lbs. for 200 S.H.P. Input

S.H.P. - Shaft H.P.

1 - Lett of 10 January 1974, from Jacuzzi Canada, Ltd.

2 - Jacuzzi 14YJ Engineering Data Book - Thrust Performance Curve No. 905074, Page 7.

3. FEASIBILITY STUDY (cont'd.)

3.3 WATER MODE PROPULSION SYSTEM (cont'd.)

3.3.1 Performance Data (cont'd.)

Resistance and Propulsion (cont'd.)

Choice of Propulsion (cont'd.)

Originally it was found that the total resistance to motion in water was 852 lbs. @ 5 knots. Using an efficiency factor of 2, (for unforeseen drag conditions), the pump or pumps must be capable of producing a thrust which is:

$$T_p = 852 \times 2 = 1704 \text{ lbs.}$$

Therefore the design thrust will be:

$$T_p = 2000 \text{ lbs.}$$

From a hydrodynamic point of view it would be wiser to obtain this thrust with 2 jet pumps for better control and better evacuation of the water jets around the obstacle formed by the prow of the trailer.

Assuming, therefore, that 2 jet pumps are installed in the tractor, the individual pump thrust requirement drops to

$$T = \frac{2000}{2} = 1000 \text{ lbs.}$$

$$T_{Jet} = 1000 \text{ lbs.}$$

3. FEASIBILITY STUDY (cont'd.)

3.3 WATER MODE PROPULSION SYSTEM (cont'd.)

3.3.1 Performance Data (cont'd.)

Resistance and Propulsion (cont'd.)

Choice of Propulsion (cont'd.)

The Speed Vs Thrust graph[1] for the 14 YJ jet pump shows that each pump would require approximately 100 S.H.P. for a total of 200 S.H.P.

The design Shaft Horsepower is 200.

Referring back to the Land Mode Choice of Propulsion section of this report, it was found one of the suggested engines, i.e., Detroit Diesel 12V - 71N has a flywheel horsepower of 394 @ 2100 r.p.m. Therefore, theoretically, it can drive both pumps if connected through a dual output gearbox, the losses of which could be absorbed in the excess horsepower available.

This implies that the single prime mover shall have a dual power take-off system in order to handle both land and water locomotion.

Aside from propulsion requirements, it was discovered earlier[2] that a counterthrust was required in the aft section of the trailer to balance side winds.

1 - Jacuzzi 14YJ Engineering Data Book - Thrust Performance Curve No. 905074, Page 7.

2 - Page 59 of this report.

3. FEASIBILITY STUDY (cont'd.)

3.3 WATER MODE PROPULSION SYSTEM (cont'd.)

3.3.1 Performance Data (cont'd.)

Resistance and Propulsion (cont'd.)

Choice of Propulsion (cont'd.)

Its magnitude was determined to be F_T = 375 lbs. To provide this control thrust (as well as an additional forward thrust when needed) it is decided to install another 14 YJ jet pump in the trailer. For the trailer then we have:

Jet Pump Unit: Jacuzzi 14 YJ

Impeller: G

Suggested Engine: Detroit Diesel GV - 53

S.H.P.: 200

Maximum R.P.M.: 2800

Available thrust for 200 S.H.P. @ 5 knots: 1800 lbs. $= T_C$

The total propulsive force T_T available, is the sum of the thrusts provided by the three jet pumps.

$T_T = T_P + T_C$

$T_T = 2600 + 1800$

T_T = 4400 lbs.

3. FEASIBILITY STUDY (cont'd.)

3.3 WATER MODE PROPULSION SYSTEM (cont'd.)

3.3.1 Performance Data (cont'd.)

Resistance and Propulsion (cont'd.)

Choice of Propulsion (cont'd.)

Steering

Steering in the water shall be accomplished through the use of the jet deflectors (40° Arc) as supplied with the jet pump units[1]. Reverse motion is obtained by dropping reversing gates thus deflecting the jet downward and forward. The reverse thrust is approximately 50% of the forward thrust. The actuation of Steering and Reverse functions is as follows:

(a) Steering: A tiller arm inside the hull moves the jet from side to side through a 40° Arc.

Tiller Arm Travel: 7.25 in.

Required Force: 160 lbs.

1 - Jacuzzi 14YJ Engineering Data Book.

3. FEASIBILITY STUDY (cont'd.)

3.3 WATER MODE PROPULSION SYSTEM (cont'd.)

3.3.1 Performance Data (cont'd.)

Resistance and Propulsion (cont'd.)

Choice of Propulsion (cont'd.)

(b) Reverse: The reverse gate is controlled by a push-pull cable.

Travel: 3"

Required Force: 80 lbs.

It is intended to have both steering and reverse controlled from the Driver's Cabin. Both functions shall be accomplished hydraulically using an auxiliary power steering pump unit on the engines.

It is believed that a very versatile control system can be obtained with proper co-ordination of the 3 jet pumps.

Location of the components within the vehicle shall be discussed in the Design Synthesis Section.

3. FEASIBILITY STUDY (cont'd.)

3.4 STRUCTURAL DESIGN NOTES

Both the tractor and the trailer making up the amphibious transport must have the necessary strength in their structures in order to withstand the loads imposed on them. Because of its function as payload carrier, the trailer, naturally, will have a chassis or structure capable of supporting a total weight of 250,000 lbs.[1]

Intuitively, it was already suggested[2] that a box structure should be used with a boxed beam as a backbone, for torsional resistance. This suggestion will now have to be proved out with the necessary strength analysis in order to satisfy the conceptual design criteria.

The detailed structural design of the frames will be left to the specialists.

3.4.1 Trailer

The loaded trailer's weight was assumed to be 250,000 lbs. Of this, 50,000 lbs. was tare weight and 200,000 lbs. was payload.

1 - See Design Criteria - Page-' of this report.

2 - See Page 26 of this report.

3. FEASIBILITY STUDY (cont'd.)

3.4 STRUCTURAL DESIGN NOTES (cont'd.)

3.4.1 Trailer (cont'd.)

The shape of the payload is such that, for practical purposes, we have a uniformly distributed load over the length of the billets, i.e., 30 feet.

Two conditions of loading are present:

(a) on land

(b) in the water

Only the first condition, which is the worst, shall be considered here. Indeed, in theory, for a distributed load in a boat, no bending moment to speak of should exist with a continuous body of water surrounding it.

Bending Moment and Shear Stress[1]

For the Land Mode, the simplified diagram of the reactions is shown on Fig. 14.

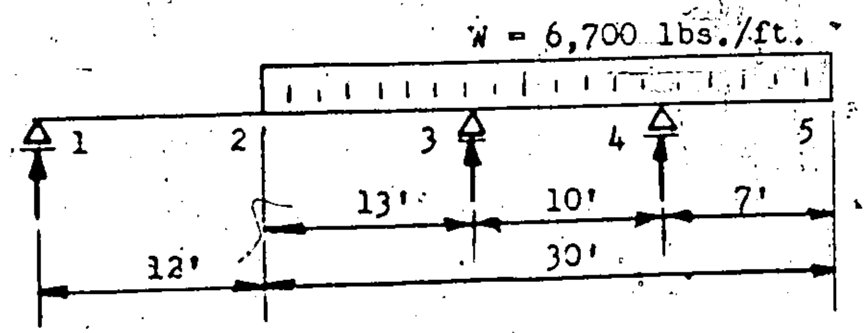


Fig. 14 - Trailer Loading Diagram (Typical)

1 - The spring constants of the tires are disregarded for this feasibility study.

3. FEASIBILITY STUDY (cont'd.)

3.4 STRUCTURAL DESIGN NOTES (cont'd.)

3.4.1 Trailer (cont'd.)

This is equivalent to a Statically Indeterminate Beam because the two static equations must be supplemented by one equation involving deformations.

The continuous beam, i.e., beam resting on more than two supports, is subjected to a uniform load for a portion of its span. The three Moment Theorem shall be used, where the bending moments are the unknowns.[1]

$$M_A L_1 + 2M_B (L_1 + L_2) + M_C L_2 = - \frac{6A_1 \bar{a}_1}{L_1} - \frac{6A_2 \bar{b}_2}{L_2}$$

Where M_A, M_B and M_C designate the bending moments at supports A, B and C, A_1 and A_2 represent the areas of the moment diagrams and $\bar{a}_1$ and $\bar{b}_2$ designate the distances of the centroids of each of the moment diagrams from A and B respectively.

However for feasibility purposes we shall use the case where the load is centered on the axles.

1 - Strength of Materials by W.A. Nash, Schaum Publishing Co., 1957, Page 185.

3. FEASIBILITY STUDY (cont'd.)

3.4 STRUCTURAL DESIGN NOTES (cont'd.)

3.4.1 Trailer (cont'd.)

Neglecting the hitch reaction, we have a continuous beam overhanging 2 supports as shown below:

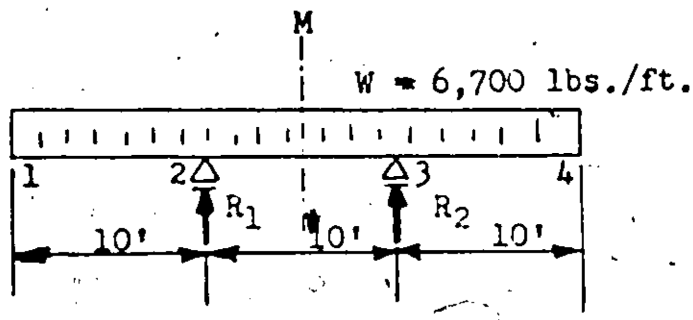


Fig. 15 - Idealized Trailer Loading

From symmetry the reactions are:

$$R_1 = R_2 = \frac{200,000 + 50,000}{2} = 125,000 \text{ lbs}$$

Visually, it is seen that the moments at points 1 and 4 will be 0. $M_1 = M_4 = 0$

Assuming that the tare weight of the trailer is uniformly distributed, it will contribute $\frac{50,000}{42} \simeq 1200$ lbs./ft.

Therefore over the 30 ft load supporting length, the total unit load will be:

$$w = \frac{200,000}{30} + 1200 \simeq 7,900 \text{ lbs./ft.}$$

3. FEASIBILITY STUDY (cont'd.)

3.4 STRUCTURAL DESIGN NOTES (cont'd.)

3.4.1 Trailer (cont'd.)

From symmetry we have $M_2 = M_3$

$$M_2 = M_3 = -\ 7{,}900\ (10)\ \frac{10}{2}$$

$$M_2 = M_3 = -\ \underline{395{,}000}\ \text{lbs. ft.}$$

At the centre of the beam, the bending moment will be:

$$M_M = -\ 7900\ (15)\ \frac{15}{2} + 125{,}000\ (5)$$

$$= -\ 888{,}750 + 625{,}000$$

$$M_M = -\ \underline{263{,}750\ \text{lbs.}}\ \text{ft.}$$

The bending moment diagram takes the following shape:

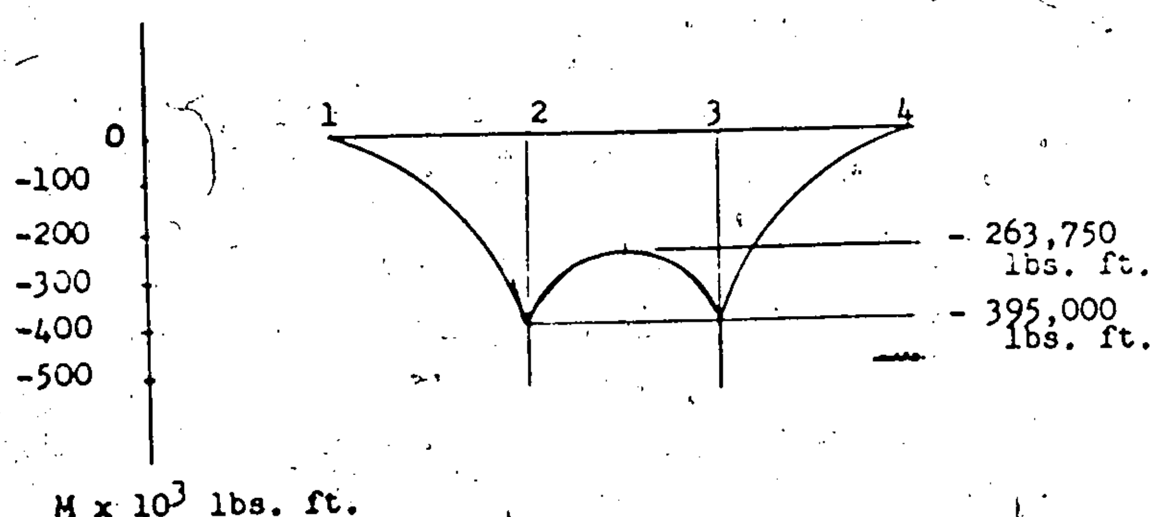


Fig. 16 - Idealized Bending Moment Diagram of Trailer.

3.0 FEASIBILITY STUDY (cont'd.)

3.4 STRUCTURAL DESIGN NOTES (cont'd.)

3.4.1 Trailer (cont'd.)

Using a load factor of 1.5 with a steel having 50,000 p.s.i. yield stress, the design stress is:

$$\text{Design Stress} = \frac{S_{max.}}{1.5}$$

which is derived from the maximum bending stress formula:

$$S_{max.} = \frac{Mc}{I} = \frac{M}{I/c} \quad \text{where} \quad \frac{I}{c} = Z = \text{section modulus}$$

Therefore using the idealized diagram we get:

$$\text{Design Stress} = \frac{50,000}{1.5} = \frac{M_3\ (12)}{Z}$$

The required section modulus Z of the main beam is:

$$Z = \frac{M_3\ (12)\ 1.5}{50,000}$$

$$= \frac{395,000\ (12)\ 1.5}{50,000}$$

$Z = 142.2$ in.^{3}

If torsional resistance were not a consideration, the following beam would be satisfactory:

12 x 12 WF beam 106 lbs./ft. $Z = 144$ in.^{3}

3. FEASIBILITY STUDY (cont'd.)

3.4 STRUCTURAL DESIGN NOTES (cont'd.)

3.4.1 Trailer (cont'd.)

However, because of the torsional requirements, it is preferable to use a boxed section, in which case one could use two Z sections welded together or an equivalent built up X section.

This boxed section would form the backbone of the trailer and would be continuous from the hitch on. (See Fig.17). The rest of the trailer would be made up of steel plates welded also in a box fashion as shown.

Although the hitch reaction R_1 shown on Fig. 15 Page 70 has been disregarded for the selection of the backbone beam, a reasonable hitch load would be 10,000 lbs. This reaction is necessary for proper traction and control of the vehicle. If a smaller hitch force is deemed necessary, both trailer axles can be moved forward to suit, while maintaining the wheelbase of 10 ft.

3.4.2 Tractor

For adequate traction, the tractor weight had earlier been set at 50,000 lbs. For all practical purposes, this weight will be assumed to be constant. It is relatively modest compared to the loaded trailer.

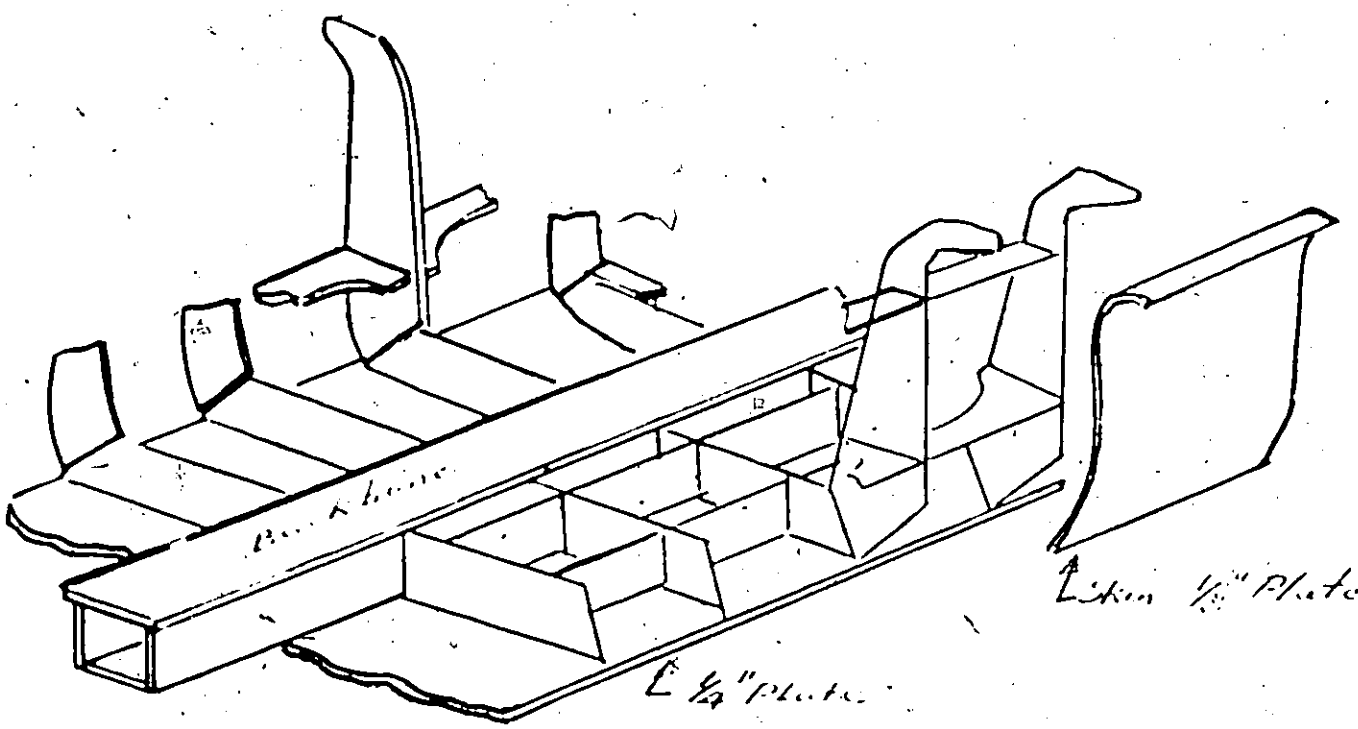


Fig. 17 - Sketch of Trailer Frame

3. FEASIBILITY STUDY (cont'd.)

3.4 STRUCTURAL DESIGN NOTES (cont'd.)

3.4.2 Tractor (cont'd.)

The hitch load of about 10,000 lbs. (loaded trailer) will also have to be added. If uniform loading is assumed, the load per axle will be:

$$W_A = \frac{60,000}{3} = 20,000 \text{ lbs. or 10 Tons}$$

To gain maximum room inside the tractor for all the equipment, a cage type structure is indicated. It would give good resistance to torsion. (See Fig. 9).

It is suggested to use steel hollow structural sections (H.S.S.) in an all welded structure thus taking advantage of their stiffness and physical shape that provides 4 flat surfaces that would facilitate the installation of the motive equipment.

Unlike the trailer, which is open top, the tractor is totally enclosed and allows a rib cage structure.

A suitable opening must be provided at the top for removal or installation of the machinery.

Although this rib cage design will be much stronger than the finite backbone beam one, the worst case shall be considered here to arrive at a safe design.

3 FEASIBILITY STUDY (cont'd.)

3.4 STRUCTURAL DESIGN NOTES (cont'd.)

3.4.2 Tractor (cont'd.)

Let us assume that the entire tractor load (60,000 lbs.) is distributed over 25 ft. of its length (Fig.19), and supported by 2 beams with overhanging ends resting on the 3 axles as shown. This is equivalent to a statically indeterminate continuous beam subjected to a uniform load (Case 1). Again, as was done for the trailer, a worse case shall be considered namely the one where only the front and rear axles would support the load (Case 2).

In this particular instance the reactions R_1 and R_3 are:

$$R_1 = R_3 = \frac{60,000}{2} = 30,000 \text{ lbs.}$$

Visually the moments at A and E are:

$$M_A = M_E = 0$$

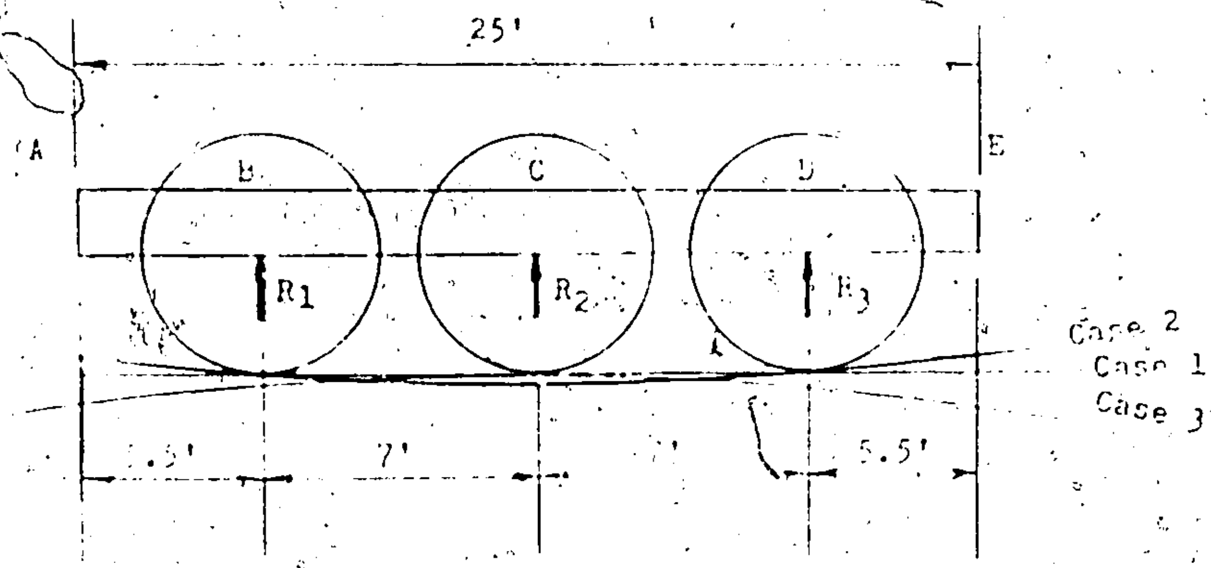
The distributed load is: $w = \frac{60,000}{25} = 2,400$ lbs./ft.

Again by symmetry at points A and D the bending moment is:

$$M_B = M_D = -2,400\ (5.5)\ \frac{5.5}{2}$$

$$= -\underline{36,300 \text{ lbs. ft.}}$$

TOTAL LOAD: 60,000 lbs.



$$\text{Distributed Load } W = \frac{60,000}{25} = 2,400 \text{ lbs./ft.}$$

Fig. 19 - Idealized Tractor Loading.

3. FEASIBILITY STUDY (cont'd.)

3.4 STRUCTURAL DESIGN NOTES (cont'd.)

3.4.2 Tractor (cont'd.)

At C the bending moment is:

$$M_C = -2,400 (5.5 + 7) \frac{(5.5 + 7)}{2} + R_1 (7)$$

$$= -187,500 + 30,000 (7)$$

$$M_C = +\ 22,500 \text{ lbs. ft.}$$

Therefore in Case 2 the maximum bending moment occurs at the front and rear axles.

The bending moment diagram is as follows:

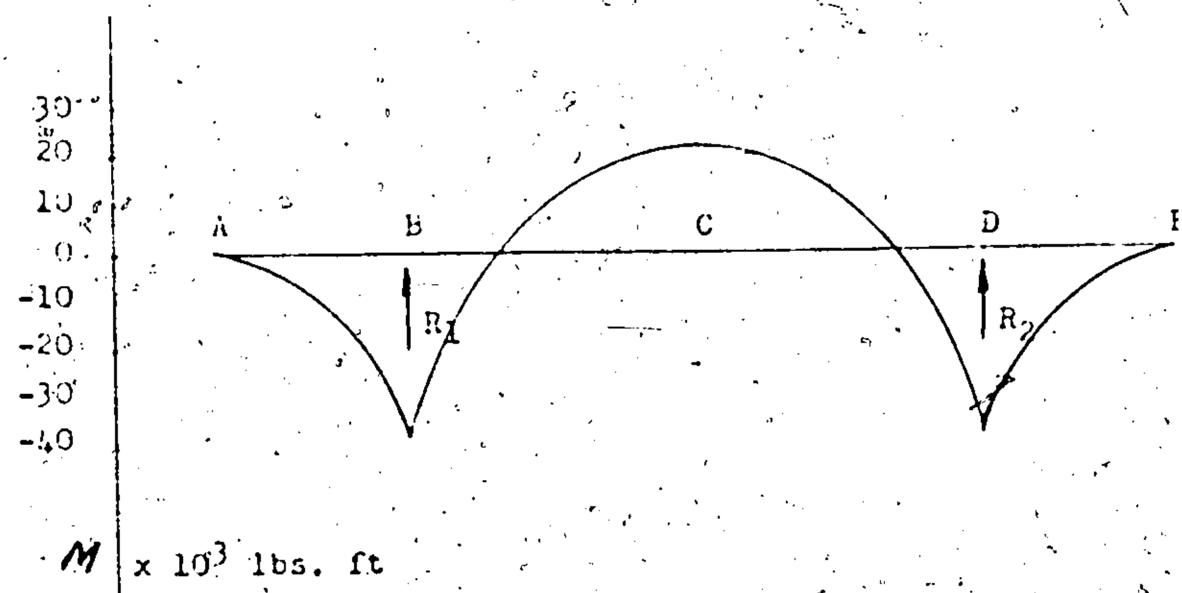


Fig. 20 - Idealized Bending Moment Diagram of Tractor

3. FEASIBILITY STUDY (cont'd.)

3.4 STRUCTURAL DESIGN NOTES (cont'd.)

3.4.2 Tractor (cont'd.)

Using a load factor of 1.5 with a steel having 50,000 p.s.i. yield stress, the design stress is:

$$\text{Design Stress} = \frac{S_{max.}}{1.5}$$

where $S_{max.}$ = Maximum Stress

but $S_{max.} = \frac{M}{Z}$

where M = Max. bending moment

Z = Section modulus in in.^{3}

$$\text{Therefore, Design Stress} = \frac{50,000}{1.5} = \frac{M_B\,(12)}{Z}$$

$$Z = \frac{M_B\,(12)\,1.5}{50,000}$$

$$= \frac{36,300\,(12)\,1.5}{50,000}$$

$$Z = 13 \text{ in.}^3.$$

This condition is satisfied by many H.S.S., as for example, a rectangular H.S.S.[1], 8.000 in. x 4.000 in. with a 0.3120 in. wall thickness and weighing 23.28 lbs./ft. for which the section modulus Z is 13.466 in.^{3}.

1 - Hollow Structural Sections - Design Manual - Stelco 1973

3. FEASIBILITY STUDY (cont'd.)

3.4 STRUCTURAL DESIGN NOTES (cont'd.)

3.4.2 Tractor (cont'd.)

With two beams supporting the load, we could use two H.S.S. rectangular sections, such as 6.000 in. x 4.000 in. (standing on their smaller sides) with a 0.2500 in. wall thickness and weighing 13.60 lbs./ft. Each beam would have a section modulus of Z = 7.354 in.^{3}.

Case 3

This is the extreme case where the vehicle goes over a hump and has, momentarily, its load supported by the middle axle only. (See Fig. 19).

The maximum bending moment would occur at the middle axle. Its value would be:

$$M_C = - 2{,}400\ (5.5 + 7)\ \frac{(5.5 + 7)}{2}$$

$$M_C = - 187{,}500 \text{ lbs. ft.}$$

With a load factor of 1.5, the required section modulus would be:

$$Z = - \frac{187{,}500\ (12)\ 1.5}{50{,}000}$$

$$Z = 67.5 \text{ in.}^3$$

With two beams, the section modulus required would be:

$$Z = \frac{67.5}{2} \simeq 34 \text{ in.}^3$$

3. FEASIBILITY STUDY (Cont'd.)

3.4 STRUCTURAL DESIGN NOTES (cont'd.)

3.4.2 Tractor (cont'd.)

The following H.S.S. would be adequate:

Square Section: 10.000 in. x 10.000 in.

Wall thickness: 0.3120 in.

Weight: 40.25 lbs./ft.

Section Modulus: Z = 36.633 in.^{3}.

The rib cage design with its inherent strength would permit the use of smaller H.S.S. beams. The skin could be of 1/8" thick steel plates reinforced at the bow and stern in case of collisions.

If a 8.00 x 8.00 H.S.S. Square is chosen for estimating purposes, it is found that at 35 lbs./ft., the cage structure would weigh approximately 30,000 lbs., leaving a margin of 20,000 lbs. for machinery and ballast if required. (See Fig. 9).

3. FEASIBILITY STUDY (cont'd.)

3.5 OVERALL DESIGN SYNTHESIS

In the previous sections of this report, the feasibility of the amphibious transportation system was demonstrated. Conceptual solutions to the basic design problems were advanced in order to support the viability of the overall scheme.

It remains to discuss how these conceptual solutions can be brought together to form a functional piece of machinery or in other words, synthesized into a realistic overall design.

3.5.1 Terrain and Buildings

As was mentioned earlier, the design constraints imposed by terrain or buildings were taken into consideration for the design of the vehicle. However, these are not fixed, immovable constraints. If the amphibious transportation system is accepted and substituted for the present railway system, the constraints can also be changed to suit the vehicle if need be. This is especially true if the savings are considerable. For example, the size of a truck building access door could be changed, crane handling could be altered, roads could be paved, etc. Therefore, the static constraints are in fact flexible.

3. FEASIBILITY STUDY (cont'd.)

3.5 OVERALL DESIGN SYNTHESIS (cont'd.)

3.5.2 Amphibious Vehicle

The basic functions of the vehicle, i.e., load carrying capability, land locomotion and navigability, have been studied and proven to be feasible. In each case, solutions have been suggested to obtain these functions down to the selection of a suitable piece of equipment. The following is a suggested overall system broken down to its components:

(a) Suspension

As was decided earlier, because of the low operating speeds and the good paved surfaces, suspension systems will not be used in either tractor or trailer.

(b) Body

The bodies of both tractor and trailer can be made up of 1/8" thick steel plates in an all welded construction. The body of the tractor could be designed in such a way that some sections at the top could be readily removed for easy access to the machinery. In all cases, however, proper naval techniques must be used to insure a water-tight construction.

3. FEASIBILITY STUDY (cont'd.)

3.5 OVERALL DESIGN SYNTHESIS (cont'd.)

3.5.2 Amphibious Vehicle (cont'd.)

(b) Body (cont'd.)

Due to the tractor's structural configuration, the engine room is relatively spacious; nevertheless, the equipment must be installed with several objectives in mind.

- Proper Weight Distribution

- Ease of Maintenance

- Optimum Space Utilization

Depending on the arrangement of the mechanical components, it might be necessary to add weight to the front of the tractor in order to provide a fairly even ground pressure at all six tires especially with maximum hitch load. This added weight could be in the form of removable ballast like water.

The design of the trailer is straightforward. Care must be taken to provide the load supporting bed in such a way as to allow enough clearance for the existing motorized lifting bales presently operating in the No. 3 Bloom and Billet Mill Shipping Building (Fig. 7). A compartment is provided at the stern to house the single jet pump and engine.

3. FEASIBILITY STUDY (cont'd.)

3.5 OVERALL DESIGN SYNTHESIS (cont'd.)

3.5.2 Amphibious Vehicle (cont'd.)

(c) Engines

For reliability, power and minimum maintenance, it is suggested to use Diesel engines, the power and torque of which are well suited to the requirements set forth in the previous sections. Several manufacturers produce[1] engines suitable for this application. The Caterpillar Co., for example, makes engines in a wide horsepower and torque range well adapted to rugged conditions.

It was shown in the land propulsion system study[2] that the grade and acceleration requirements account for more than 70% of the power requirements and yet, these two peaks only occur for a short duration. This fact points the way towards the application of an energy storing device that would give up this energy for the two peaks mentioned. If the so-called super flywheels proved feasible in this particular application, a less powerful engine would be required resulting in a capital cost reduction as well as a reduction in fuel consumption.

1 - Diesel and Gas Turbine Catalogue - Volume 34 - 1969 Edition, Published by Diesel and Gas Turbine Progress - Milwaukee.

2 - See Page 47 of this report.

3. FEASIBILITY STUDY (cont'd.)

3.5 OVERALL DESIGN SYNTHESIS (cont'd.)

3.5.2 Amphibious Vehicle (cont'd.)

(c) Engines (cont'd.)

This flywheel could be revved up during loading and unloading, on flat ground, when empty, in the water, etc.

(d) Transmission and Driveline

It was decided earlier to use a Diesel engine to drive the wheels through a conventional transmission system. For optimum space utilization it is suggested to drive the two forward axles conventionally but to drive the rear wheels by sprockets and chains from the middle axle. (See Fig. 11). This layout would eliminate one expensive planetary axle and would provide room in the back of the vehicle to fit the water propulsion systems. The two front axles would not get their power directly from the transmission but from a transfer case as shown on Fig. 11 . Similarly the two jet pumps would be shaft driven through a dual output gearbox connected directly to the engine through a universal shaft. This implies that the engine will be supplied with dual power take-off. The engine position would necessitate the installation of 2 access ladders into the engine room, located on either side of the engine.

3. FEASIBILITY STUDY (cont'd.)

3.5 OVERALL DESIGN SYNTHESIS (cont'd.)

3.5.2 Amphibious Vehicle (cont'd.)

(d) Transmission and Driveline (cont'd.)

All wheels will have their bearings totally sealed to withstand hydrostatic pressure.

(e) Jet Propulsion

In the feasibility study for the water mode propulsion system[1], it was concluded that two jet pump units would be used to obtain the required thrust, assisted by a third unit installed in the trailer. The paddle wheel action of the 6 tires was not taken into consideration but should perhaps be considered in view of the spare power available, at least for assistance in steering or braking.

The water intakes for the jet pumps will be located on the flat bottoms of tractor and trailer and be provided with an adequate screening device.

To save space, the trailer jet pump engine could be transversely mounted with the use of a right angle gear-box. The location of the jet pumps in the tractor is as shown on Fig. 11 .

1 - See Page 62 of this report.

3. FEASIBILITY STUDY (cont'd.)

3.5 OVERALL DESIGN SYNTHESIS (cont'd.)

3.5.2 Amphibious Vehicle (cont'd.)

(e) Jet Propulsion Cont'd.)

In view of their experience to-date with heavy barges and ferries, the Jacuzzi Company seems to be a likely supplier for the jet propulsion equipment as was already discussed in the feasibility section.

(f) Hitch Mechanism

The hitch will be one very similar to the present "fifth wheel" design extensively used on Stelco's ingot carrier trucks.[1] Our design hitch load of 10,000 lbs. is about one third of the everyday operating hitch loads of the ingot carrier trucks. The "fifth wheel" hitch provides a spherical movement of 22° from the vertical, which is deemed adequate for the type of operation discussed previously.[2] To compensate for the changes in draft of the trailer, it is proposed to allow the hitch to have a vertical adjustment of about 3 feet in order to maintain a reasonably level attitude of the tractor in the water.

1 - Euclid R35 Tractor Specifications - Appendix.

2 - See Page 51 of this report.

3\. FEASIBILITY STUDY (cont'd.)

3.5 OVERALL DESIGN SYNTHESIS (cont'd.)

3.5.2 Amphibious Vehicle (cont'd.)

(f) Hitch Mechanism (cont'd.)

Field tests, however, might prove that a hitch positioned for loaded conditions could well be acceptable as such; the consequence being that the stern of the trailer would ride high in the water when empty.

(g) Controls

The driver's cab - or pilot's cabin - will contain all the necessary controls for both land and water modes of operation. It will have interior dimensions sufficient to accomodate a crew of two.

All control functions, including control of the trailer jet pump, shall be accomplished from the cab. In effect the cab will be a hybrid design, combining land and water operation control equipment. For example, the land steering controls - whether joystick or wheel type - will perform double duty by also controlling the steering deflectors on the jet pumps.

Navigational lights, searchlights, etc., will also be provided as needed.

3. FEASIBILITY STUDY (cont'd.)

3.5 OVERALL DESIGN SYNTHESIS (cont'd.)

3.5.2 Amphibious Vehicle (cont'd.)

(h) Operations

The approach to the transportation problem stated has been one of substitution, that is the new concept could eliminate the old. It would be appropriate in this case to do a Value Engineering Analysis of the operations in order to determine whether, in certain cases, both old and new could be complementary. For example, it may be more economical to operate the amphibious vehicles in good weather only. This could be determined after the analysis of the performance trials of the prototype. As it stands, the objective is to operate the amphibious vehicle year round. Unless otherwise indicated, it is proposed that routine maintenance of this new equipment be carried out in the existing Mobile Equipment Centre which is equipped to handle the big Euclid Tractors.

3. FEASIBILITY STUDY (cont'd.)

3.6 COST ESTIMATE

In the context of a money making concern, no scheme or idea is a good one if it does not save money or otherwise brings some benefits to the company. An idea will remain an idea if the "Return on Investment"[1] is too long especially if it tries to replace a proven method. An attempt will be made here to arrive at a "shotgun" cost estimate in order to get a feel for the capital outlay required to make this scheme operational.

The following scope of work is contemplated:

1. Roads and Buildings

(a) Provide approximately 2,000 feet of paved roadway where necessary, excavation and backfill where required.

(b) Provide approximately 200 feet of concrete ramp by 30 feet wide for land-launch purposes.

(c) Modify railway track crossings where necessary to bring to level.

(d) Clear an area inside buildings for adequate vehicle clearance.

1 - Number of years to amortize the capital expenditure with the savings accrued.

3. FEASIBILITY STUDY (cont'd.)

3.6 COST ESTIMATE (cont'd.)

1. Roads and Buildings (cont'd.)

Purchase 2 motorized lifting bales for No. 2 Rod Mill.

2. Waterways

(a) Dredge at the No. 2 Rod Mill site to remove an average of 4 feet of muck to provide 8 feet of water over a distance of 2,500 feet (from red channel marker to loading area).

(b) Provide floodlights at each land-launch site.

(c) Provide de-icing devices if necessary.

3. Mobile Equipment

(a) Purchase 3 amphibious Tractor-Trailer Units.

(b) Purchase one spare amphibious Tractor.

(c) Purchase necessary spare parts.

The corresponding cost estimates, based on current costs, are as follows:

1. Roads and Buildings

(a) Paved Roadway

Area: 2,000 ft. x 30 ft. wide = 60,000 ft.^{2}

3. FEASIBILITY STUDY (cont'd.)

3.6 COST ESTIMATE (cont'd.)

1. Roads and Buildings (cont'd.)

(a) Paved Roadway (cont'd.)

Using a unit cost of \$5/yd.^{2}, the cost of paving is:

$\frac{60,000 \times 5}{9} \simeq 33,350$ Say \$35,000

(b) Concrete Ramps

200 feet long by 30 feet wide by 2 feet thick.

Volume = 200 x 30 x 2 = 12,000 ft.^{3}

At \$125/yd.^{3} installed, the cost is:

$\frac{12,000 \times 125}{27} \simeq \$56,000$ \$56,000

(c) Modifications to Railway Crossings

Allow \$5,000 \$ 5,000

(d) Area Clearance Inside Buildings

Allow \$5,000 \$ 5,000

(e) Purchase of Lifting Bales

Purchase 2 motorized lifting bales:

Allow \$20,000 \$20,000

3. FEASIBILITY STUDY (cont'd.)

3.6 COST ESTIMATE (cont'd.)

2. Waterways

(a) Dredging at No. 2 Rod Mill

Dredge 4 feet over an area of 2,500 feet by 100 feet wide.

Volume = 2,500 x 100 x 4

= 1,000,000 $ft.^3$

At $2/$yd.^3$, the dredging cost is:

$\frac{1,000,000}{27} \times 2 = 74,000$ Say $75,000

(b) Floodlighting

Allow $35,000 — $35,000

(c) De-icing Equipment

An allowance of 50,000 is made. — $50,000

3. FEASIBILITY STUDY (cont'd.)

3.6 COST ESTIMATE. (cont'd.)

3. Mobile Equipment

(a) Tractor-Trailer Units.

The present cost of a tractor-trailer unit with 120 Ton payload is approximately $120,000.

(70,000 tractor + 50,000 trailer)

For the amphibious vehicle - prorating the above cost - we will use:

$200,000 per unit.

i.e., $120,000 for the tractor

$ 80,000 for the trailer

Therefore for 3 complete units the cost will be:

$200,000 x 3 = $600,000	$ 600,000
(b) Spare tractor $120,000	$ 120,000
(c) Spare parts, allow	$ 25,000
Total	$1,026,000

3. FEASIBILITY STUDY (cont'd.)

3.6 COST ESTIMATE (cont'd.)

Approximately 20% of this total is added on as contingency and escalation to bring the total approximate cost of this project to:

$1,250,000

For comparison purposes, transportation of billets by barges as described earlier[1] would have cost approximately $4,000,000 in equipment alone, not counting the annual tug rental fee and the wages of the manning personnel.

1 - See Page 8 of this report.

4. SUMMARY OF PROPOSAL

The proposal that has been discussed in the foregoing feasibility study is not meant to be only the presentation of a new vehicle, but instead the suggestion of a new, original transportation scheme within which a new vehicle is created.

In recapitulation here are again, the main lines of this proposal:

1. Problem to be Solved

The present rail transportation system used to carry steel billets from the No. 3 Bloom and Billet Mill, where they are produced, to the No. 2 Rod Mill, where they are rolled into rods, is an expensive and slow process because of the distance involved - over 2 miles - and the use of an outside railway company. A better scheme would be one that would use Stelco Personnel and equipment along a quicker itinerary.

2. Proposed Solution

The new transportation scheme proposed, utilizes a water route charted on the waters of Hamilton Bay over a distance of approximately 8,500 feet between the two mills in question. (See Fig. 4)

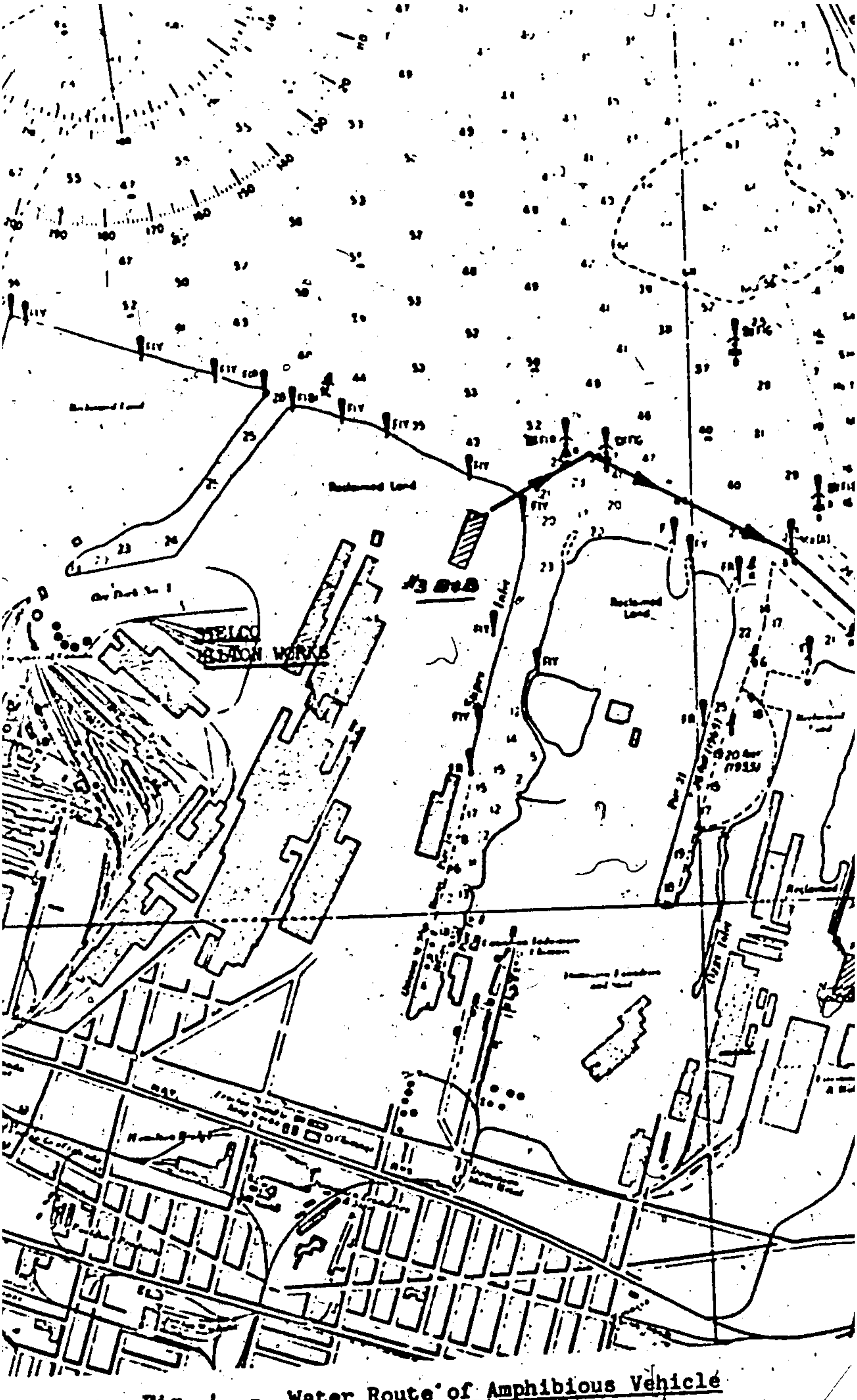


Fig. 4 - Water Route of Amphibious Vehicle

4. SUMMARY OF PROPOSAL (cont'd.)

2. Proposed Solution (cont'd.)

The means of conveyence will be a hybrid vehicle capable of propelling itself on land as well as on water in order to carry the billets from mill to mill without intermediate handling of the load.

3. Description of the Vehicle

The amphibious vehicle will consist of a tractor and a trailer capable of hauling 100 Tons of billets per trip if necessary, in order to sustain the maximum production requirements of No. 2 Rod Mill which are 2,400 Tons/day. The maximum speeds required of this vehicle are set at 5 m.p.h. on land and 5 knots on water. The tractor consists of an amphibious 6 wheeled vehicle designed for adequate movement on land and on water. (See Fig. 3) Land locomotion is accomplished by driving all 6 wheels of the vehicle through a conventional Diesel engine and transmission system. (See Fig. 11). Propulsion in the water is insured by two water jet pumps driven by the same Diesel engine. The tires used are of the high flotation type, well suited for this kind of operation. A standard "Fifth Wheel" hitch links the tractor and the trailer.

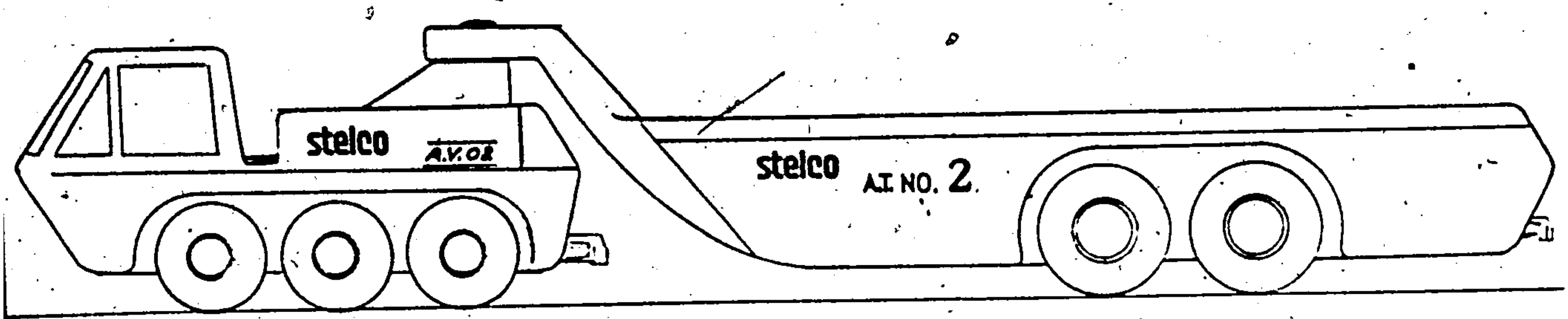


FIG. 3 - General Outline of the Amphibious Vehicle

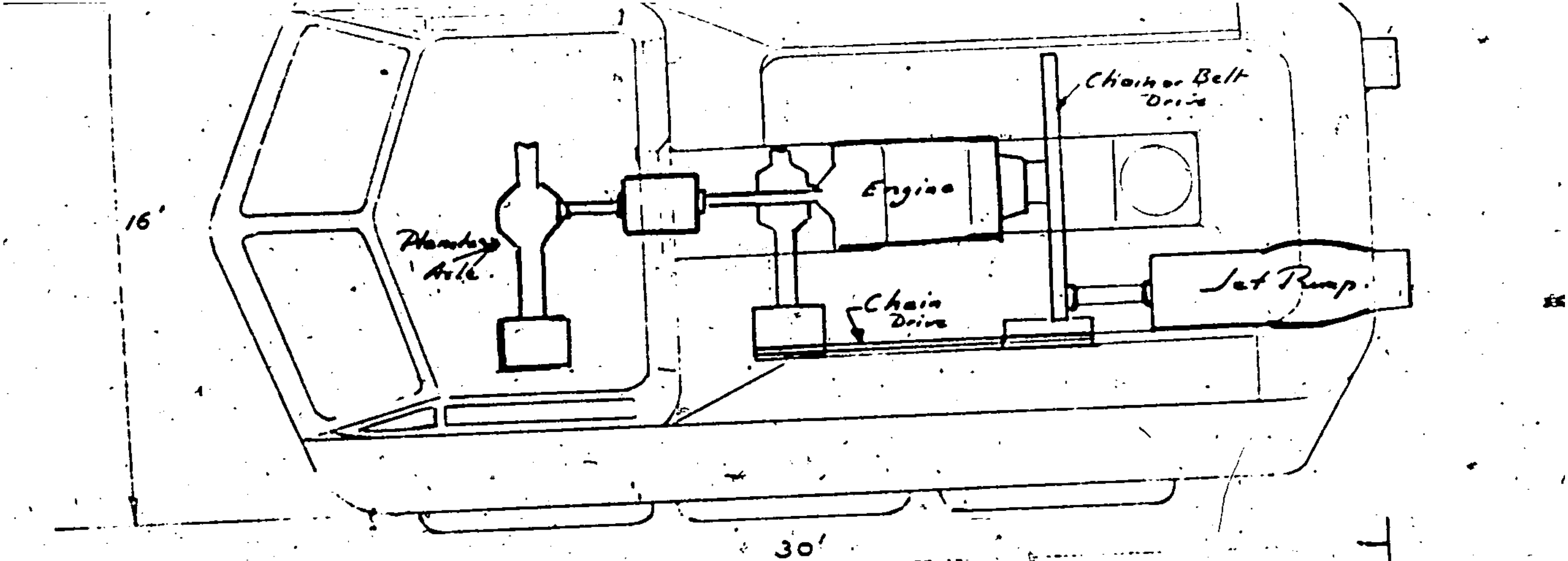
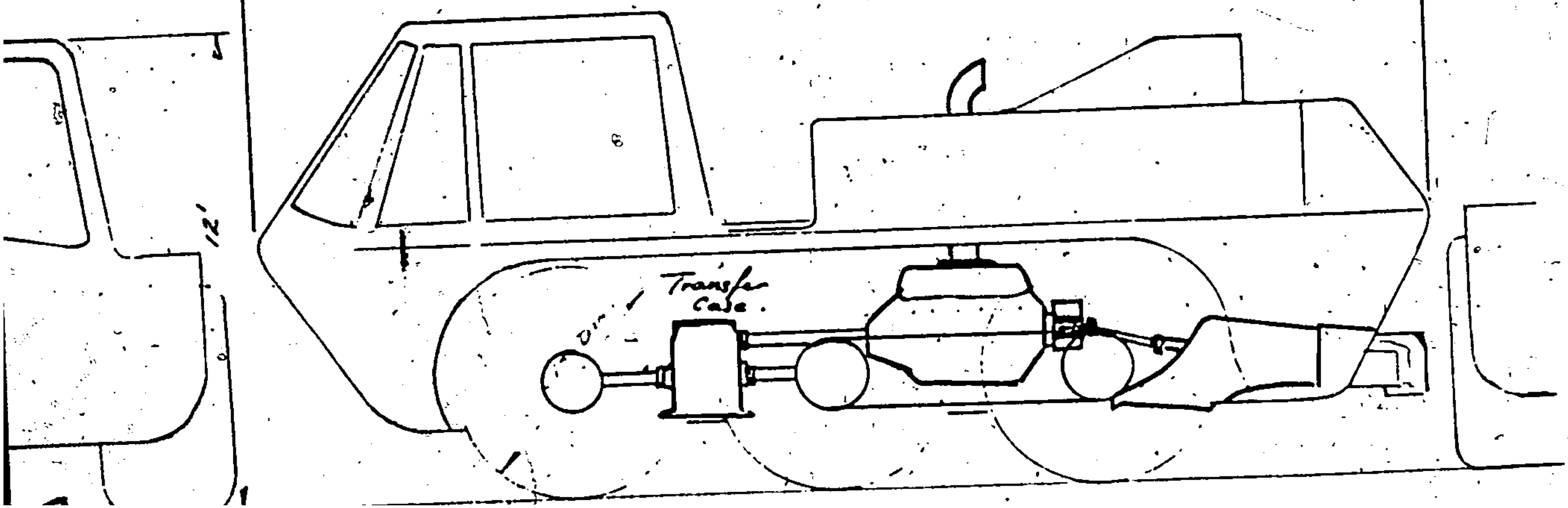


Fig. 11 Suggested Layout of Mechanical Equipment



4. SUMMARY OF PROPOSAL (cont'd.)

3. Description of the Vehicle

The tractor is approximately 30 feet long, 16 feet wide and 12 feet high.

The trailer is approximately 50 feet long, 18 feet wide and 9 feet high. Its box structure can carry the 200,000 lbs. payload, and is supported on 4 non-flotation wheels, positioned in such a way as to allow a hitch load of 10 Tons. (See Fig. 3). A third water jet pump, with its own diesel prime mover, is mounted at the stern in order to provide proper steering control and additional propulsion when required.

4. Changes Required

The adoption of this new proposed scheme would require only minimal changes to existing conditions. These changes essentially involve the construction of a suitable land-launch ramp at both ends, grading and paving roadways where required, lighting, etc. In other words no major alterations to the landscape or existing buildings are contemplated.

4. SUMMARY OF PROPOSAL (cont'd.)

The originality of this new scheme lies, to a certain extent, in the fact that a water route is used, but more so in the fact that this water route is plied by an amphibious vehicle capable of driving directly into the respective mills for loading and unloading.

It is estimated that the total cost of this proposed scheme would be approximately $1,250,000.

5. CONCLUSIONS

The evolution of Steelmaking operations at the Hilton Works of the Steel Company of Canada, Ltd., in Hamilton, Ontario, has created over the years problems of transportation within the 1,050 acres property, problems which had to be solved, more or less happily, in order to have a relatively efficient and profitable Steel Plant.

The particular problem, studied in this report, is the one that has been created when, because of space limitations, the No. 2 Rod Mill had to be built some 2 miles away from Hilton Works, on the southern shore of Hamilton Bay. This problem is to transport the steel billets produced in the No. 3 Bloom and Billet Mill at Hilton Works to the No. 2 Rod Mill where they are rolled into rods of various sizes. The present solution is to transport the billets in railroad cars which must be forwarded on an outside railway company trackage and therefore precludes the use of Stelco equipment or personnel. This reliance on an outside company, coupled to the necessary maintenance of trackage inside Stelco properties, result in a high operating cost for a vulnerable system. A better transportation system would be one directly controlled and operated by Stelco.

5. CONCLUSIONS (cont'd.)

Since both mills are located close to a common shore, the shortest route would be a water route. Along these lines, studies have already been made for Stelco by an outside engineering firm to prove the feasibility of transporting the billets by barge. The latest of these recommends the use of barges, each capable of carrying 4 railroad gondola cars loaded with billets.

The capital investment, required in this scheme, is a very large one because of the equipment required, e.g., locomotives, railroad cars, tracks, barges, tugs, docking facilities, etc. Added to this financial drawback, one must also consider the excessive handling, the loss of valuable land, the personnel requirements as well as the hypothetical reliability of the hydraulic barge lifting mechanism that would function underwater.

If, however, one considers the new scheme proposed in this thesis, namely the transportation of billets by self propelled amphibious vehicles, one will appreciate the advantages that it possesses over the barging system, namely:

1. Elimination of expensive equipment like locomotives, gondola cars, tracks, etc.

2. No permanent occupation of valuable land.

5. CONCLUSIONS (cont'd.)

3. Minimum number of personnel.

4. Versatility.

On the basis of the foregoing feasibility study, it is recommended that this original scheme of transporting billets by amphibious vehicles be investigated further and eventually adopted as a replacement for the present railway transportation system.

6. APPENDIX

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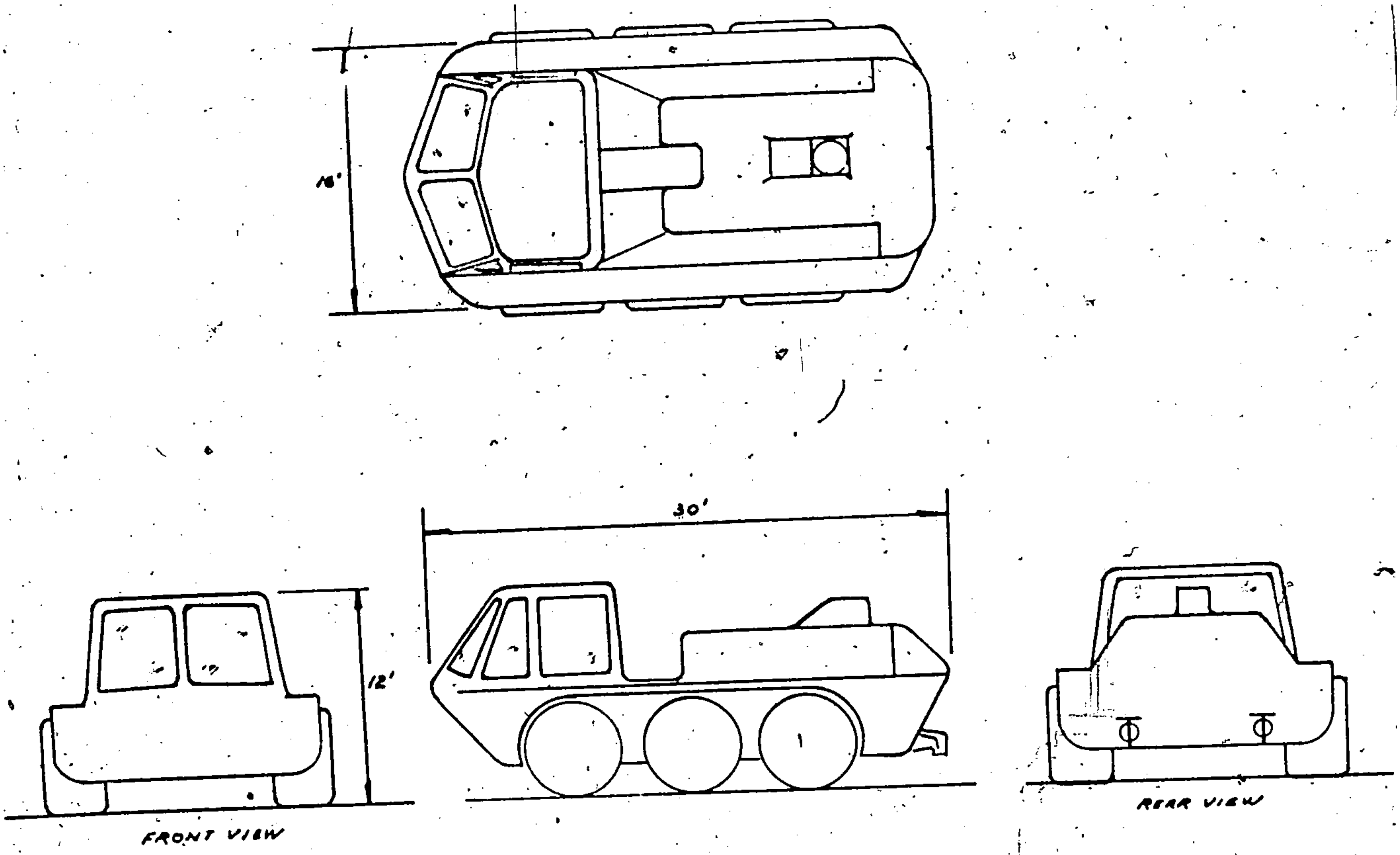
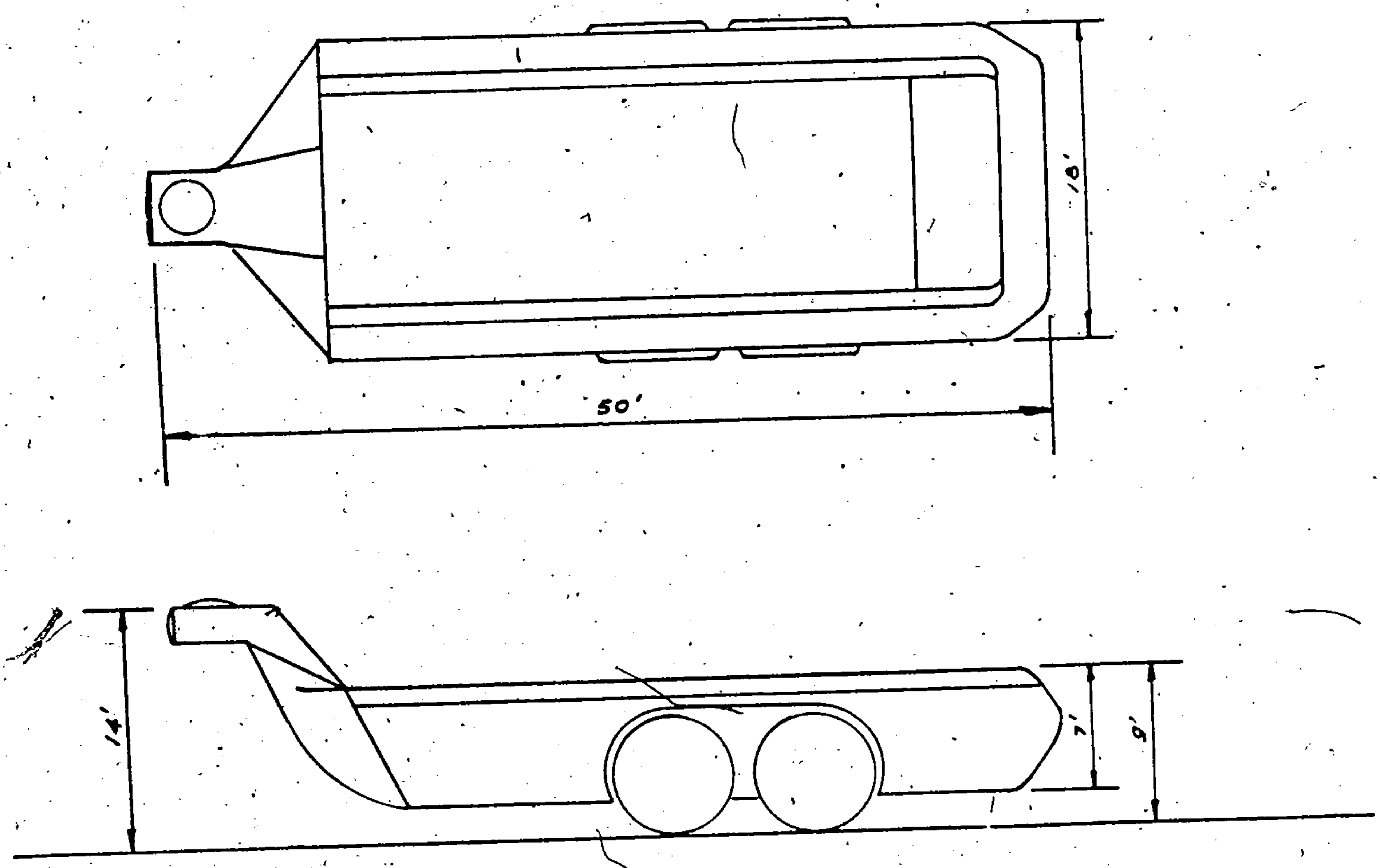


Amphibious Tractor - Overall Dimensions



Amphibious Trailer — Overall Dimensions

Fig.21- No.3 Bloom & Billet Mill- Mill Building.

Fig.22- No.3 Bloom & Billet Mill- Shipping Building.

Fig.23- No.3 Bloom & Billet Mill- Shipping Building.

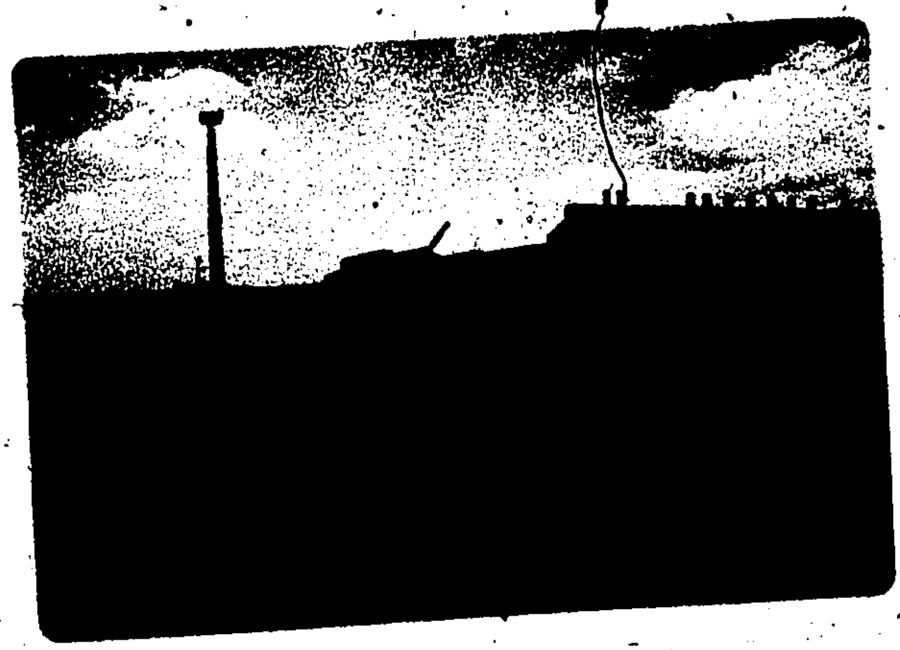


Fig.24- No.3 Bloom & Billet Mill- View From Water's Edge.

Fig.25- No.3 Bloom & Billet Mill-Land,Launch Site.

Fig.26- No. 3 Bloom & Billet Mill - View Towards No.2 Rod Mill

Fig.27- No.2 Rod Mill- Landing Area.
View Towards Billet Storage Bldg.

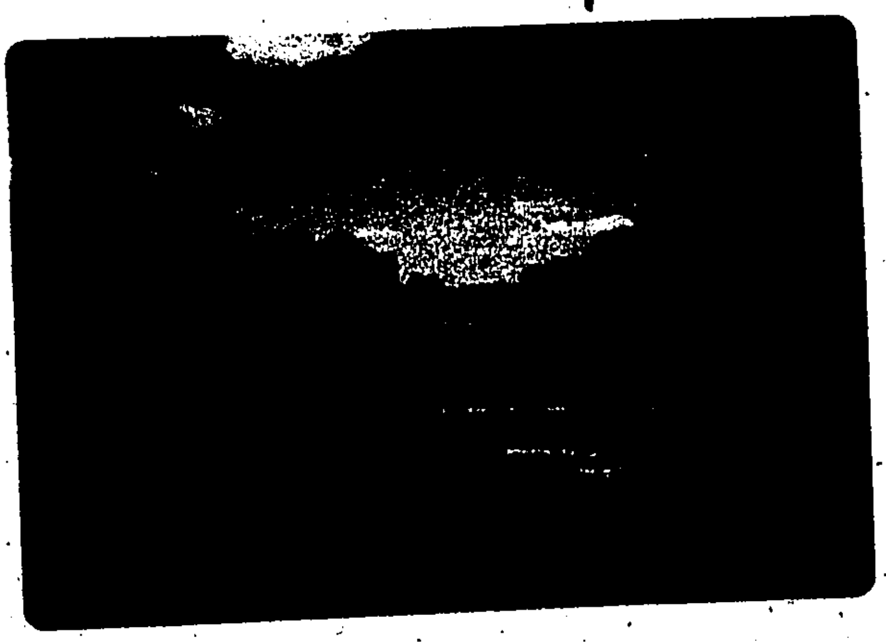


Fig.28- No.2 Rod Mill-Landing Site and [illegible]

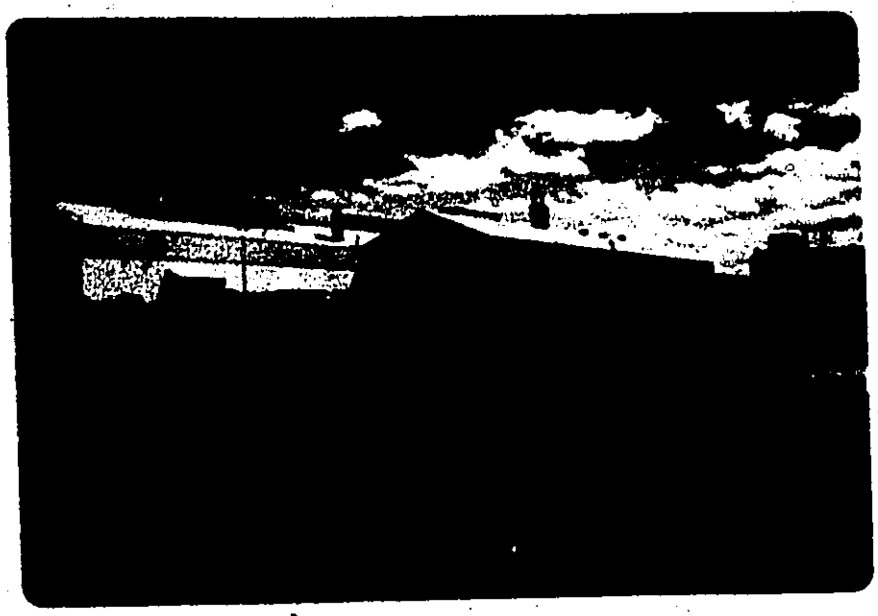


Fig.29-No.2 Rod Mill-Roadway from Landing Site to Billet Storage Bldg.

Fig.30-No.2 Rod Mill-Entrance to Billet Bldg.

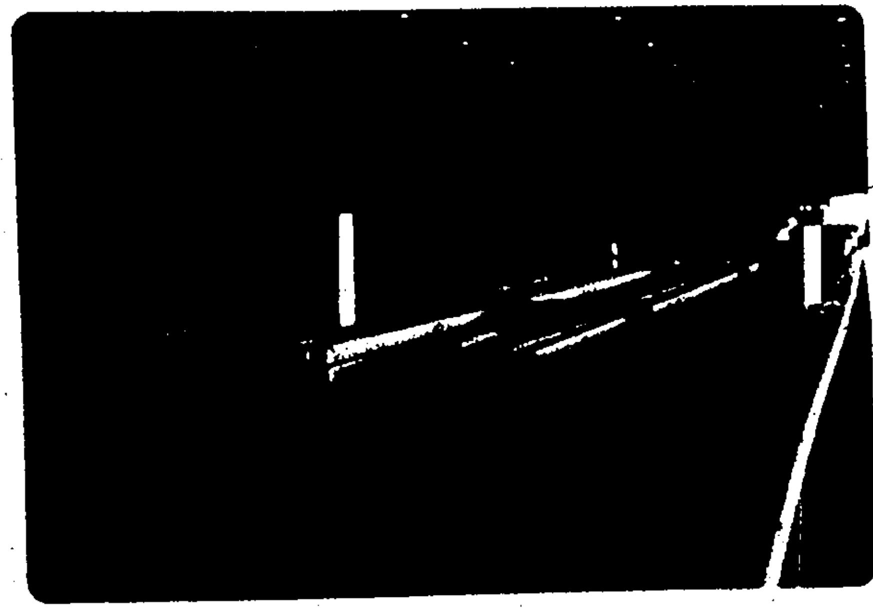


Fig. 31 - No. 2 Rod Mill-Billets in Railway Car.

Fig.32-No.2 Rod Mill-Unloading Billets.

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