THE IMPROVEMENT OF CONNEAUT
HARBOR
OHIO AND BREAKWATER DESIGN

THESIS FOR THE DEGREE OF B. S.

Eric E. Bottoms
1930

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The Improvement of Conneaut Harbor Ohio and Breakwater Design

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By

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THESIS

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IMPROVEMENT OF CONNEAUT HARBOR OHIO
AND
DESIGN OF A BREAKWATER

The history of harbor engineering runs hand in hand, through the same stages from origin to development with the history of navigation. Because of poor harbors facilities, the first sailors were exceptionally fine ones for they had to stand ready for a quick run out to sea to save their ship from destruction upon the shore, by a sudden storm.

As these sailors increased in daring the boats increased in size and sailing distances in length. The steadily growing trade demanded better protection for the boats while loading and unloading cargoes.

The national harbors of the world are few and often off from the routes between established trading centers; so man had to construct harbors at locations to suit his convenience. Some harbors consisted only of a protection wall or arm extending out to sea, others connected the main land with an island, as at Alexandria. (figure 1 and 2) No record exists of the first artificial harbor.

In Medieaval times we find a vast expansion in wartime trade and a corresponding increase in number and size of harbors and boats.

Figure 1.

Ancient Harbor of ALEXANDRIA

This harbor was originated by the Conqueror of Tyre and was brought to a successful conclusion under the first two Ptolemies about 200 B.C.

Immediately in front of the city lay the long, low island, of Pharos, which in itself, constituted an admirable natural protection, and, opposite each end of this, two coastal promontories jutted out, almost completely enclosing a large area of water. These projections were extended by means of breakwaters, so that an excellent anchorage was obtained, well sheltered from the sea. A long narrow embankment, called the Heptastadium, constructed midway, divided the strait into two almost equal portions, that on the West being known as the Harbor of Eunostos, or the Happy Return, and that on the East as the Great Harbor. At each end of the Heptastadium was a passage, spanned by a bridge, forming a connection.

Figure 2

This type of Harbor was developed along the sea coast where there were no islands or irregularities. The step on inner the face of quay wall was used as a road way to carry unloaded goods into the town. Provisions were made for vessels to tie to the side of this wall.

There is an agreement with Canada that no warships nor ships of like character shall be on any of the Great Lakes. Because of this agreement there is no need for harbors for military defence. However, the nation as a whole does take a deep interest in the transportation facilities on the Great Lakes as goods from nearly all of the northern states and produce from Canada is shipped thru American ports.

To stimulate trade the government will develop important harbors for commerce and where needed, harbors for refuge.

If the harbor facilities of any port, either lake or ocean approach obsolescence the trade thru that port will speedily decline. It used to be the procedure years ago to collect a dockage fee from each boat which tied up at a port, and with this fund, enlarge and improve the harbor from time to time as the standards of shipbuilding rose. But often thru mismanagement or poor administration of funds or lack of funds, the port fell behind the times and gradually became extinct.

A harbor is primarily a place of rest and refuge--a place where safety and hospitality may be found--and the design of such a harbor is founded largely on assumptions and carried out by tentative measures. The data at the disposal of the engineer is often obscure and defective. There are always local interests which should be catered to.


LAKE ERIE
CONNEAUT RIVER
CONNEAUT HARBOR
OHIO
PRESENT CONDITION
SCALE IN FEET
Drawn By
Figure 2a

It is impossible to disregard every request made and an allowance made here calls for one there. The success of certain plans in one locality does not mean similar success in another. Each port has certain definite characteristics, peculiar defects, and special advantages making the harbor entirely new and different from all others. Generalization is therefore an impossibility. and classification becomes difficult.

Yet there must be some solid basis on which to rest the engineering of a harbor. Studies of various harbors with similar winds, topographical features and amount of commerce helps.

An Economic study should be made of the years passed and a prophecy made for the future increase of commerce which may reasonably be expected. And from this study determine the cheapest kind of design or breakwater lay-out which is suitable for the place and sufficient for the class of shipping which has to be accommodated. Also the smallest sizes of materials and thickness of break-water wall that are admissible in its construction.

Perhaps a few definitions at this point would not be amiss, as the names applied to various kinds of wharves and their parts are loosely used and vary greatly in different localities in this and other countries.

A wharf is a structure at which vessels may lie along side and load or unload their cargoes and passengers.

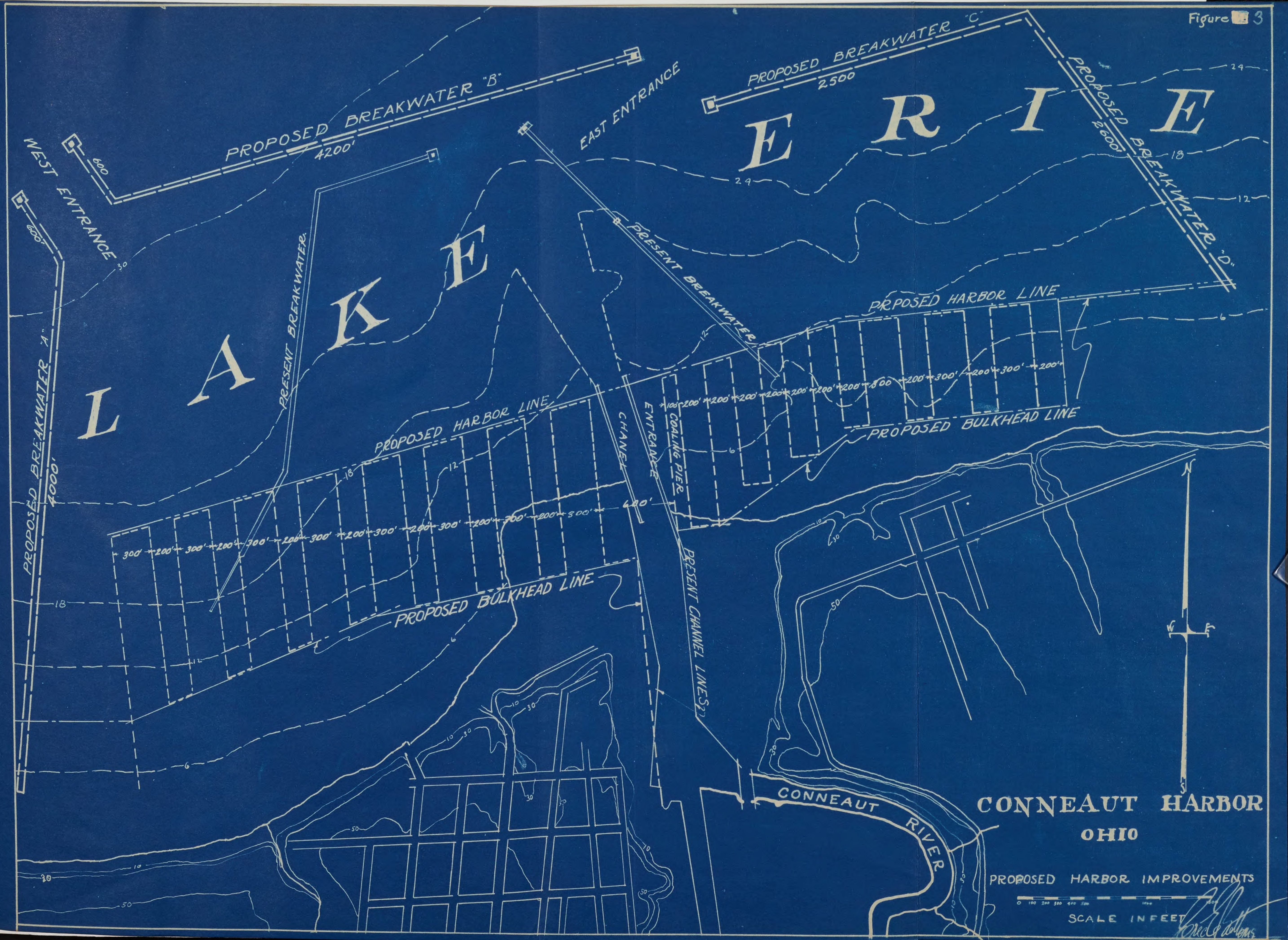


Figure 3
LAKE ERIE
PROPOSED BREAKWATER "B"
4200'
PROPOSED BREAKWATER "C"
2500
PROPOSED BREAKWATER "D"
2600'
PROPOSED BREAKWATER "A"
4000'
600
WEST ENTRANCE
EAST ENTRANCE
PRESENT BREAKWATER
PRESENT BREAKWATER
PROPOSED HARBOR LINE
PROPOSED HARBOR LINE
PROPOSED BULKHEAD LINE
PROPOSED BULKHEAD LINE
CHANNEL
ENTRANCE
COALING PIER
PRESENT CHANNEL LINES
CONNEAUT RIVER
N
W
E
S
CONNEAUT HARBOR
OHIO
PROPOSED HARBOR IMPROVEMENTS
SCALE IN FEET

It may be either marginal or projecting, but in most localities the name is applied only to marginal structure, thus distinguishing them from piers.--

A pier is a wharf projecting from the shore.

A quay is a marginal wharf. The name is common in Europe, but is used scarcely at all in this country.

A dock is an artificial basin for the use of vessels. The word dock is improperly applied to piers in some places in this country, notably New York, and to marginal wharves in other localities. On the Great Lakes and adjacent waters the word, dock, usually means only a re taining wall.

A slip is the space between two adjacent piers, but in some places such spaces are called docks.

A bulk head wall is a name given in New York City to a retaining wall for a marginal wharf, and the use of this name has spread to other American ports. A bulk head line is the line made by the shore end of the slips or the springing line of piers.

A dock or quay wall is a marginal wall on a wharf or pier.

The inner harbor is all of the harbor on the land side of the pierhead line. The outer harbor between that line and the breakwater.

An important item in harbor design is fire protection. Room should be left for easy and quick maneuvering. Land connections to the city fire mains should be conveniently located so fire tugs may connect to pump water.

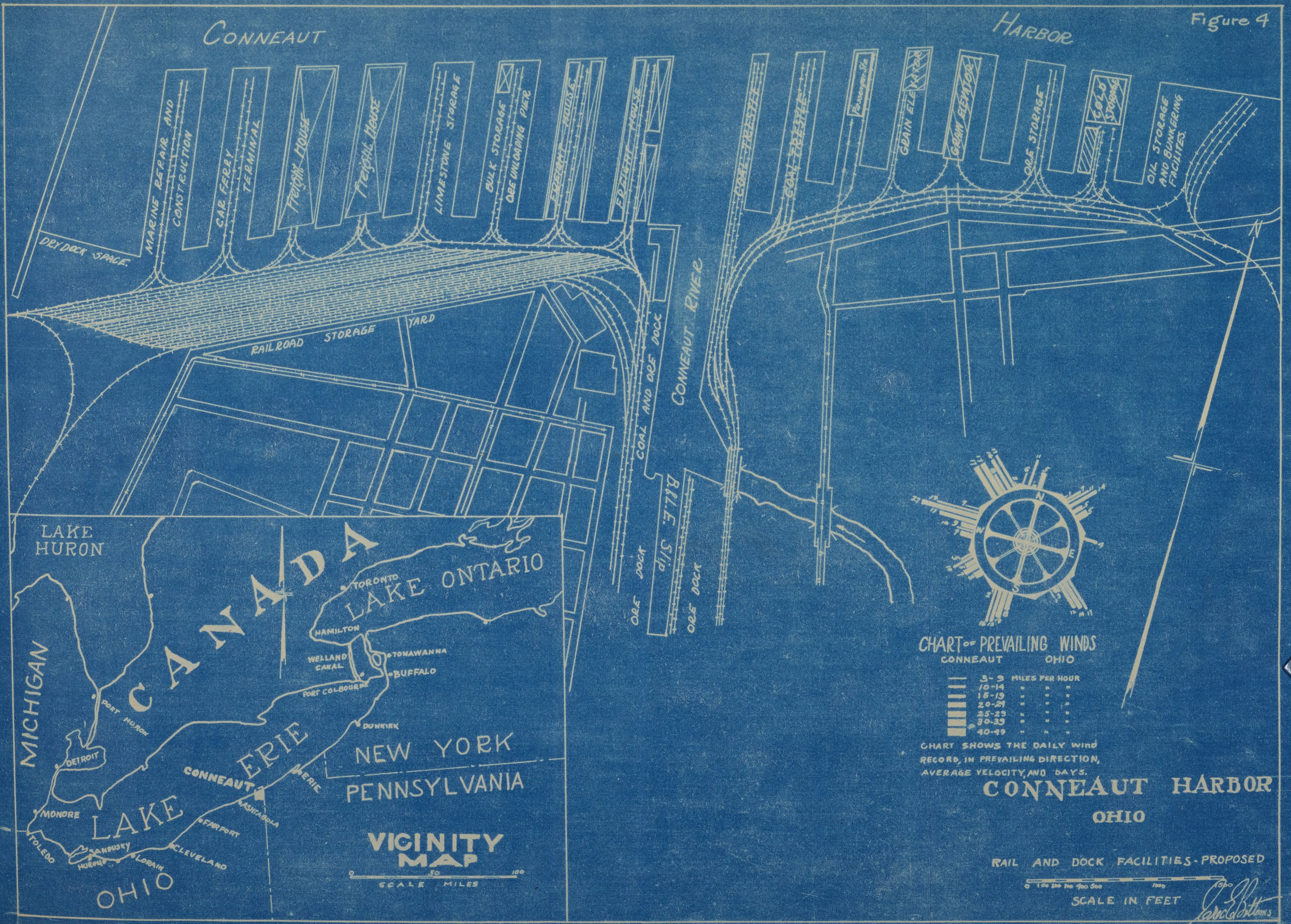

CONNEAUT
HARBOR
DRY DOCK SPACE
MARINE REPAIR AND CONSTRUCTION
CAR FERRY TERMINAL
FREIGHT HOUSE
FREIGHT HOUSE
LIMESTONE STORAGE
BULK STORAGE ORE UNLOADING PIER
FREIGHT HOUSE
FREIGHT HOUSE
COAL TRESTLE
COAL TRESTLE
PASSENGER STA.
GRAIN ELEVATOR
GRAIN ELEVATOR
ORE STORAGE
COLD STORAGE
OIL STORAGE AND BUNKERING FACILITIES
RAILROAD STORAGE YARD
COAL AND ORE DOCK
CONNEAUT RIVER
B.&L.E. SLIP
ORE DOCK
ORE DOCK
N
LAKE HURON
CANADA
LAKE ONTARIO
TORONTO
HAMILTON
WELLAND CANAL
TONAWANNA
BUFFALO
PORT COLBOURNE
DUNKIRK
MICHIGAN
PORT HURON
DETROIT
LAKE ERIE
CONNEAUT
ERIE
NEW YORK
PENNSYLVANIA
MONROE
TOLEDO
SANDUSKY
HURON
LORAIN
CLEVELAND
FAIRPORT
ASHTABULA
OHIO
VICINITY MAP
0 50 100
SCALE MILES
CHART OF PREVAILING WINDS
CONNEAUT OHIO
5-9 MILES PER HOUR
10-14
15-19
20-24
25-29
30-39
40-49
CHART SHOWS THE DAILY WIND RECORD, IN PREVAILING DIRECTION, AVERAGE VELOCITY, AND DAYS.
CONNEAUT HARBOR
OHIO
RAIL AND DOCK FACILITIES - PROPOSED
SCALE IN FEET

Figure 4

into them in case of a necessity.

Range lights should be provided to guide the boats in at night. Breakwater heads should be illuminated.

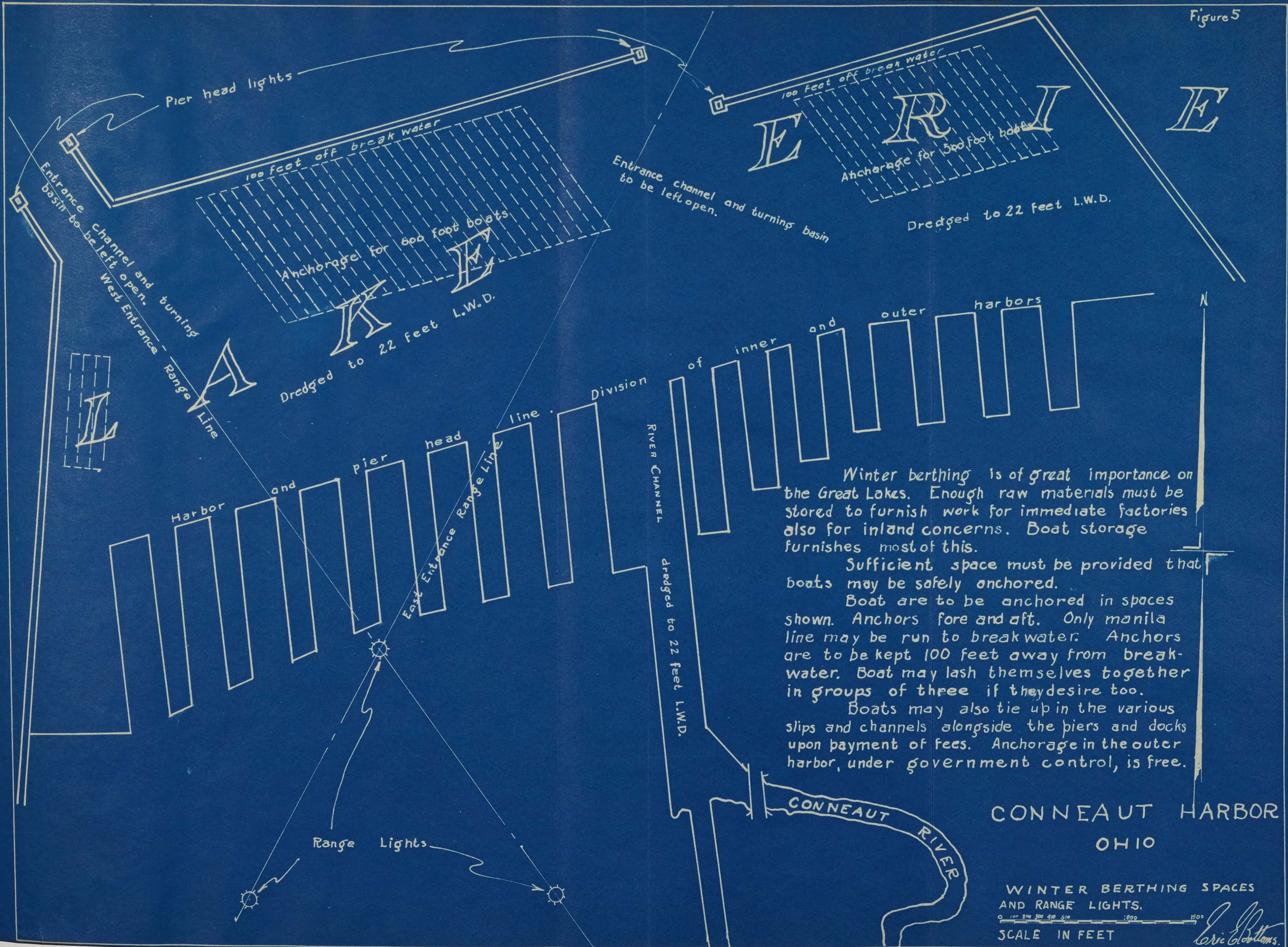
And possibly the last major point and certainly the most prominent thing about a artificial harbor is the breakwater.(figure 3) As the name implies, its function is to break up and disperse heavy seas, preventing them from exerting their destructive influence upon the area inclosed for the reception of shipping. Therefore, a breakwater must be of great strength and stability. The safety of helpless vessels and the efficiency of the harbor as a place of refuge are bound up in the essential performance and immobility of the breakwater.

The determination of size is largely arrived at by the number of vessels which must be berthed in winter (figure 5) to provide sufficient raw materials for the industries calling for such. The local industries (figure 4) at Conneaut Ohio are loading and unloading of ores, limestone and coal for the interior. Space must be provided for maneuvering inside of the breakwater.

The depth of this harbor to be in conformity of other Great Lake harbors will be 22 feet.

The breakwater line is controlled by the depth contours shown (figure 3). Breakwaters are always when possible run on the ridges.

While piers and pier sheds do not directly enter into this specific design they should be spoken of. The accompaning illustrations (figure 6) shows good practice.



Winter berthing is of great importance on the Great Lakes. Enough raw materials must be stored to furnish work for immediate factories also for inland concerns. Boat storage furnishes most of this.

Sufficient space must be provided that boats may be safely anchored.

Boat are to be anchored in spaces shown. Anchors fore and aft. Only manila line may be run to break water. Anchors are to be kept 100 feet away from break-water. Boat may lash themselves together in groups of three if they desire too.

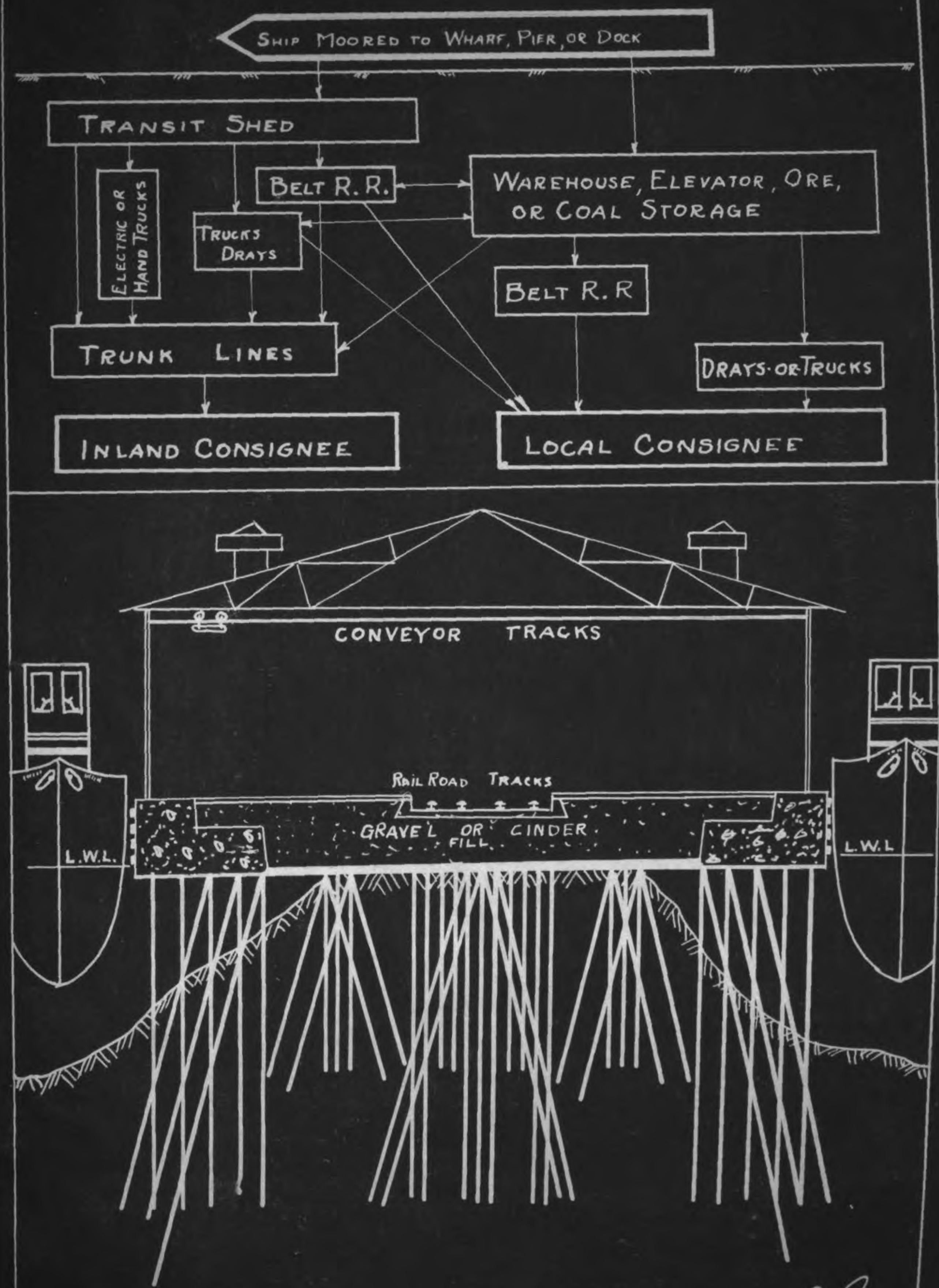
Boats may also tie up in the various slips and channels alongside the piers and docks upon payment of fees. Anchorage in the outer harbor, under government control, is free.

CONNEAUT HARBOR
OHIO

WINTER BERTHING SPACES AND RANGE LIGHTS.

Eric E. Bottoms.

Figure 6



Cross Section of a Modern Pier

The theory involved is quick and direct handling of commodities. Commodities should never be moved by drays or trucks when rails can be used.

Wood piles are used extensively on the Great Lakes because the fluctuation of water is never great. The tide is negligible being only a few inches. The wind causes more fluctuation, than any other medium. The water level has been raised eight feet at Buffalo during prolonged westerly wind storms. Conneaut need not fear any such rises of water. It is due to this lack of fluctuation and absence of marine borers in fresh water that wood piles have an indefinite life, as the wet surfaces of the piles are not exposed and allowed to dry. Most piers have a concrete cap or topping that begins at low water level and this cap is designed to receive the impact from vessels alongside. (figure 6)

When a wind blows over a body of water it imparts to the particles on the surface an osculatory motion. Where the depth is great, the particles move in a circular direction with the wind and a reverse motion below. (figure 14)

In shallow water, (figure 15) the frictional resistance of the bed retards the reverse flow of the particles to such an extent that the particles moving in the upper portions of their orbits cannot adjust themselves to the changed conditions. Then the wave breaks and the upper portions flows as an auxiliary wave over the lower part. (figure 16)

COASTAL CHANGES

Caused by the erection of breakwaters

Fig. 7

Fig. 11

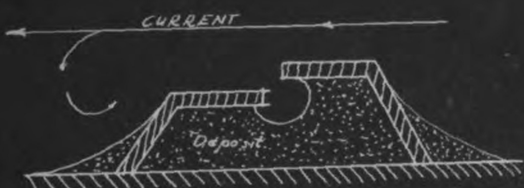


Fig. 8

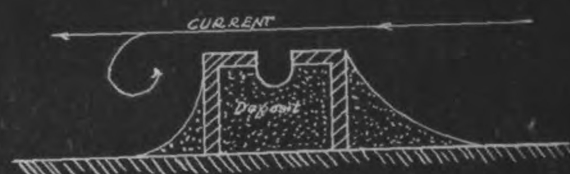


Fig. 12

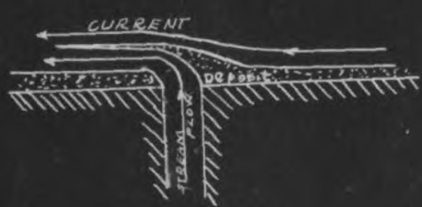
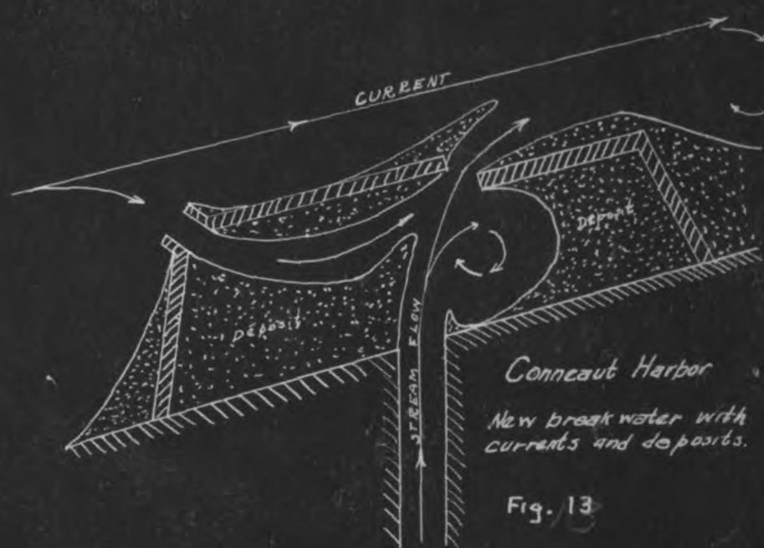


Fig. 9



Conneaut Harbor

New breakwater with currents and deposits.

Fig. 13

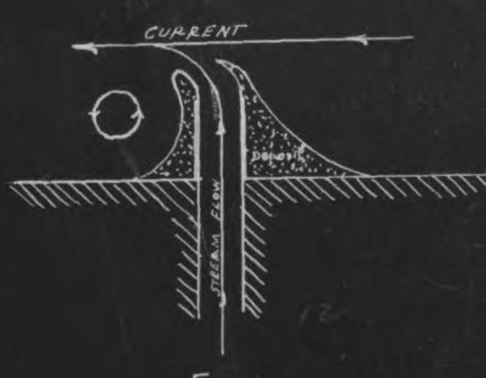


Fig. 10

The above diagrams show rather clearly the deposits caused by breakwaters and currents.

Conneaut Breakwater line is so designed as to utilize the currents in keeping as much of the Harbor down to depth as possible.

The prevailing winds are from the North-West. Lake current to the East. River as Shown.

Eric E. Bottoms

When a wave breaks perpendicularly on a sloping beach, its upper part is driven up the beach until its energy is exhausted. The water then recedes with increasing velocity until it meets the next wave which flows over it and the wave continues on as an undertow.

This action causes erosion and fill alternately. On shore wind, beach is destroyed; off shore winds tends to re-build it.

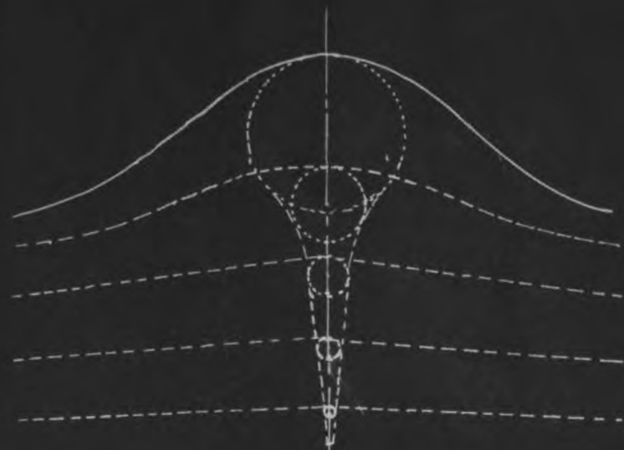
When waves approach the coast obliquely, their crests after they break run along the shore and their waters return to the sea by different paths. Which causes a movement of materials scoured along the shore in the direction the wind is blowing. If there is an obstacle along the beach the movement of material is checked and piles up on the windward side. Beyond, erosion still continues and the obstacle prevents the replacement of material. (figure 7-13 incl.)

A river discharging, its current along with the move--ment of water caused by the prevailing wind will cause certain general movements of suspended materials. Considering this movement the entrances to the harbor must be carefully located so no bar will form to hinder the entrance or exit of ships. (figure 13)

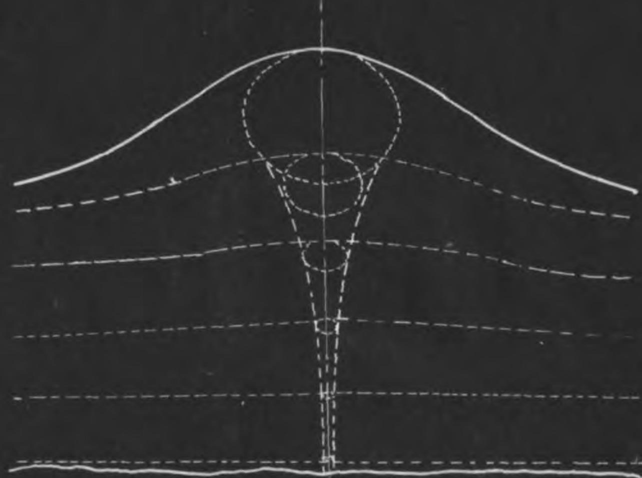
The entrance should be wide enough so a boat may come safely in during heavy sea. Usually the entrance is placed parallel with the prevailing wind and a width of five hundred to six hundred feet at pier heads. This is the general practice on all of the Great Lakes ports.

The Conneaut entrances (figure 3) is so placed as

Wave Action



Wave in deep water
Figure 14.



Wave in shallow water
Figure 15.

Inclination of wave axis
Figure 16.

Wave deflection
Figure 17.

to conform with the above principles. The entrance arms on the west entrance assist in keeping the entrance channel deep and preventing shoaling both in and out of the harbor (figure 13) The east entrance is kept clear by the water flowing out of the harbor. The east end of the harbor is open to allow circulation of water.

We have now to consider the manner in which a wave acts upon any fixed obstacle in its path, whether it be beach upon which it is spent or an artificial barrier which causes its abrupt collapse.

Figure 17 shows the directions of the particles of water in contact with a vertical wall. The whole motion in fact is the inverse of that which occurs in the unobstructed wave.

When, without meeting with any abrupt obstacle; the wave advances into rapidly shoaling water, its energy is communicated to smaller and successive by decreasing masses. Consequently there is a tendency to produce in those masses an agitation of increasing violence. But this effect is generally diminished, and sometimes entirely counteracted, by the loss of energy due to friction along the bottom, and to surging. The influence of concentration arising from funnel-shaped inlets is clearly to intensify the agitation, and the same effect is producible by submerged rocks with deep narrow gorges between, in passing through which the water is heaped up into masses of considerable volume.

When, however, the bottom friction has produced the necessary retartation, the crest of the wave falls forward, (figure 6) and the impact takes place at the precise stage at which the forward motion of the particles has become equal to the velocity of the wave, so that the stroke of the latter is delivered with maximun effect.

Taking these diverse phenomena into consideration, it is evident that the breaking wave result in the generation of four separate and distinct forces acting individually and collectively upon all obstacles and structures in their path.

(1) A direct horizontal force, exerting compression.

(2) A deflected vertical force, acting upwards and tending to shear off any projections beyond the face line of the obstacle, whether cliff or wall.

(3) A vertical downward force due to the collapse of the wave, exercising a particularly disturbing effect on mounds in shallow water and on beaches.

(4) The suction due to back draught or after tow. This also produces its most noticeable results on foundation beds, whether natural or artificial.

Applying these facts to breakwater design, it will be recognized that the phenomena to which they give rise are as follows:--

(1) A powerful momentary impact, combined with

(2) Hydrostatic pressure continuous for some period, however minute, after the first shock.

Attending these principal effects there will be several subsidiary results, such as:--

(1) A vibration of the whole structure, tending to weaken the connections at various parts.

(2) A series of impulses imparted to the water contained in the pores, joints, and interstices of the structure, producing internal pressures in various directions.

(3) The alternate condensation and expansion of the volumes of air which are confined in cavitives and which may be unable to escape freely or in any way.

The exact determination of these stresses is practically impassible.

The difficulties attending a determination of the precise effort of a wave are due to several causes. In the first place, there is the incompressibility of the water combined with the extreme mobility of its particles. Arrested suddenly in the course of motion, it produces all precissive effects of a solid body in an infinite number of directions. In the second place, the wave stroke is both abrupt and continuous. Its first action is a blow, sharp and decisive of high momemtary intensity. This is succeeded by a statical pressure during a small but perceptible interval of time, dispersal time of the wave. So there are two points to be considered (a) initial concussion and (b) subsequent pressure.

According to principles of dynamic reaction of a

TYPES OF BREAKWATERS

RUBBLE MOUND

Rubble mound are becoming more popular. Expensive with low upkeep makes them very attractive. Boats can not tie up to a rubble mound unless special provision is made.

Figure 18

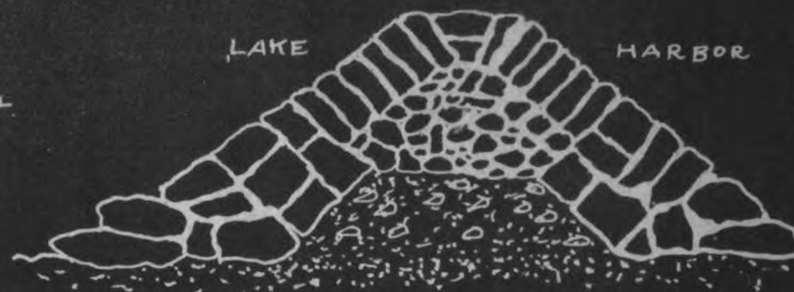


Figure 19

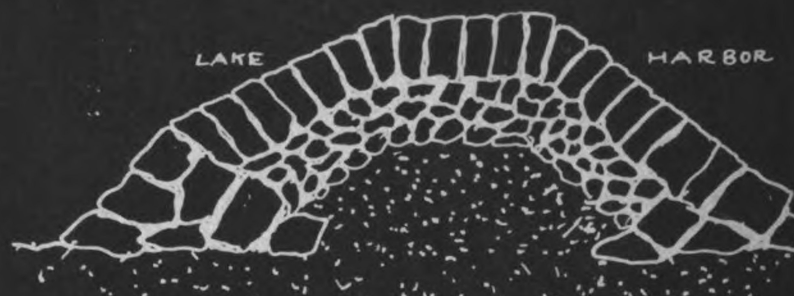


Figure 20

TIMBER CRIB

Expensive upkeep, The top is offen of concrete to the Low water line so as to prevent excessive decay. The Timber structure is held together with wooden pins.

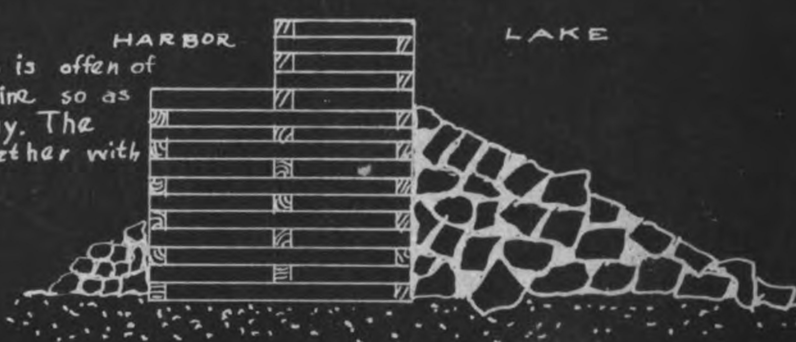


Figure 21

MASONRY

This type is most expensive to construct. When in need of repair, it is both difficult and expensive.

Figure 22.

surface subjected to continuous impact is measured by the rate at which momentum is destroyed. Let w be weight of unit volume of water, $\frac{wv}{g}$ is mass on unit surface in unit time, and $\frac{wv^2}{g}$ is at rate at which momentum is consumed. If p be pressure on unit surface, we have $p = \frac{wv^2}{g}$ (a)

Referring to Rankine "Civil Engineering" 18th edition, the speed (l = length of wave) $v, = \sqrt{2g \frac{l}{4\pi}} = 2.25\sqrt{l}$

Assuming the wave to be cycloidal in form (figure 14) the height bears to the length $l = \pi h$

or $$v, = \sqrt{2g \frac{h}{4}} = 4\sqrt{h}$$

and substituting this v for v in (a) above

$$p = 16 \frac{wh}{g} = \frac{wh}{2}$$

which says that the intensity of pressure of a wave in deep water is equal to a column one half as high as the amount of free fall required to generate specified velocity in particles of which wave is composed.

Darwin states in his paper on "The Tides" (page 34) that

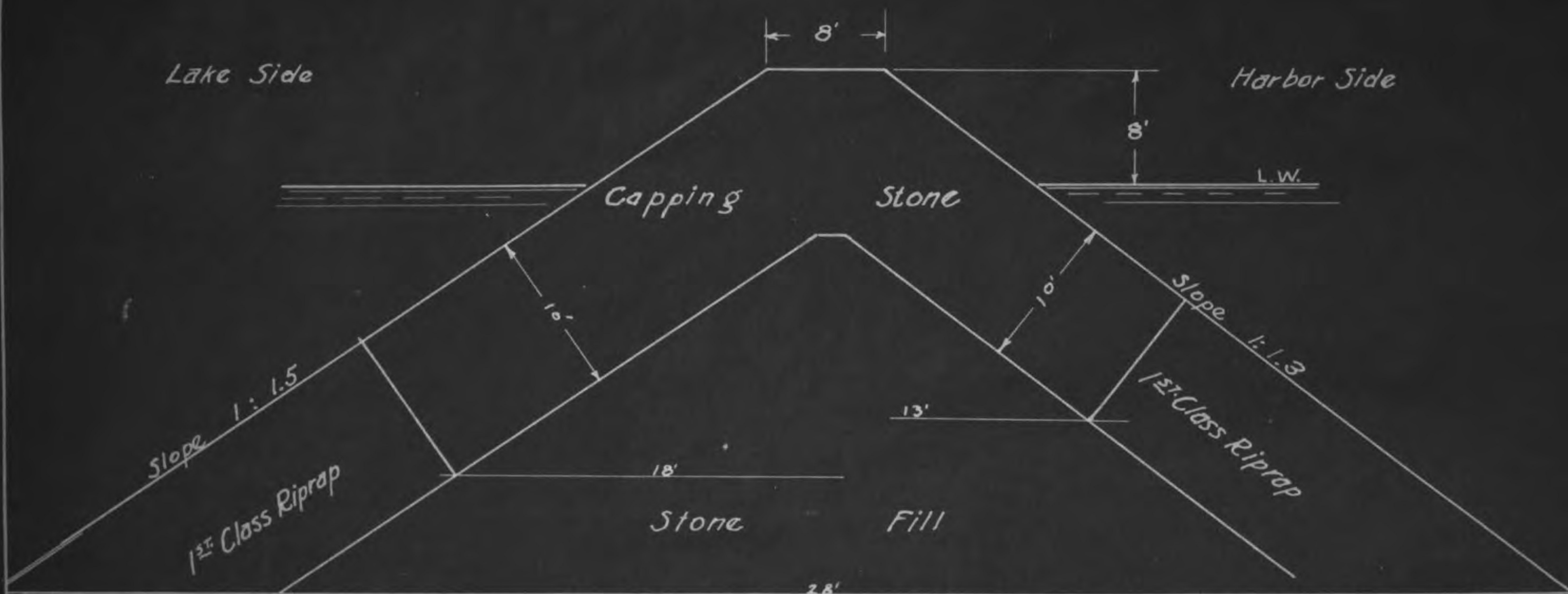
$$v = 5.73\sqrt{d}$$

which substituted in (a)

$$p = \frac{w}{g}(32.8d) \text{ or } p = wd \text{ approximately}$$

so when depth of water equals three times the height of wave the pressure will equal three times the unit weight times the height or when d equals h, p equals wh.

Some authorities place a constant k into the equation and assign it different values. p = kwh. This value of k may vary from 1.25 to 1.96.



-Type-

Capping Stone minimun wt. 3 tons
Riprap Stone minimun wt. ½ ton
(66% by weight in pieces not less than 3 tons each)
Stone Fill may be Shale, Quarry chips, Or waste Stone.

-Weights per Yard.-

Capping Stone	1.6	tons per Cu. Yd.
Riprap Stone	1.6	tons per Cu. Yd.
Stone Fill	1.4	tons per Cu. Yd.

CONNEAUT HARBOR
OHIO

CROSS SECTION OF PROPOSED BREAKWATER

SCALE IN FEET

Eric E. Bottoms

Figure 23

Based on these theories the following table is presented.

Height	Velocity ft/sec	Pressure of Impact lbs/sq. ft.
5	7	512
10	22	1,029
20	32	2,048

This of course is in a certain sense only a approximation as it is founded on assumptions. However, the pressure in pounds per square foot is about one hundred times the height of the wave.

Waves at Conneaut seldom exceed four feet so by assuming a pressure, normal to breakwater, of six hundred pounds we are within the limits of safety.

There are three main types of breakwaters as shown in figures 18 - 22 incl. The cost of various types depends on local materials and conditions: at Conneaut the notes on the figures govern.

Cheap construction and maintenance are points to be carefully weighed.

Mounds may be constructed by a relatively cheap crew. The Masonry wall requires skilled labor and timber crib, medium labor.

The side slopes one vertical on one and a half horzintal for lake side and one on one and three tenths for harbor side have been found by the Corps of Engineers U. S. Army to be the most satisfactory of slopes. The size of stone shown in figure 23 will assume this slope with but little help. The table (table 1) on costs

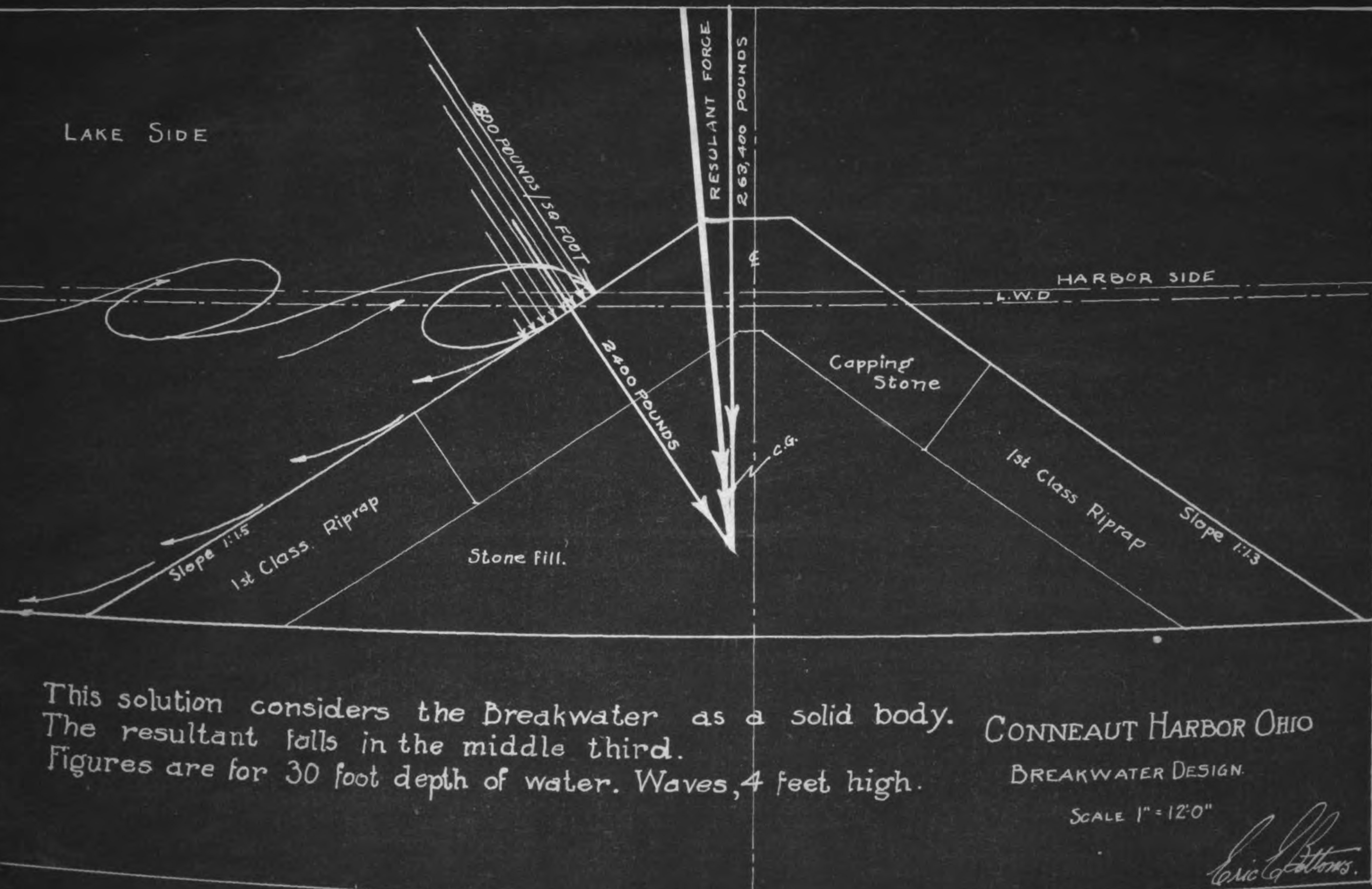
Quanities and Costs per Lineal Foot of Breakwater.

TABLE-I.

depth feet.	capping stone tons.	riprap stone tons.	stone fill tons.	cost per lineal foot dollars.
10	27.0	1.2	5.4	128.70
11	29.0	1.8	6.9	139.60
12	30.0	3.4	8.5	153.10
13	30.9	4.6	10.3	165.40
14	31.6	5.6	12.2	176.60
15	32.1	7.2	14.2	189.20
16	32.5	8.8	16.4	201.80
17	32.7	10.5	18.7	214.40
18	32.8	12.5	21.2	229.10
19	32.8	14.5	23.8	242.40
20	32.8	16.6	26.6	256.80
21	32.8	18.6	29.5	271.20
22	32.8	20.6	32.6	286.00
23	32.8	22.6	35.8	301.00
24	32.8	24.6	39.1	313.80
25	32.8	26.6	42.6	332.20
26	32.8	28.7	46.3	348.50
27	32.8	30.7	50.0	364.40
28	32.8	32.7	54.0	381.70
29	32.8	34.7	58.0	398.60
30	32.8	36.7	62.2	416.10
31	32.8	38.8	66.6	434.80
32	32.8	40.8	71.1	453.20
33	32.8	42.8	75.8	471.70
34	32.8	44.8	80.6	490.90
35	32.8	46.9	85.5	510.60
36	32.8	48.9	90.6	530.30
37	32.8	50.9	95.8	549.20
38	32.8	52.9	101.2	569.50
39	32.8	54.9	106.7	590.30
40	32.8	57.0	112.4	610.00
41	32.8	59.0	108.2	634.40
42	32.8	61.0	124.2	656.20
43	32.8	63.0	130.3	679.10
44	32.8	65.0	136.6	701.20
45	32.8	67.1	142.9	724.40
46	32.8	69.1	149.5	748.20
47	32.8	71.1	156.2	771.70
48	32.8	73.1	163.0	795.20
49	32.8	75.1	170.0	820.20
50	32.8	77.2	177.1	845.20
51	32.8	79.2	184.4	870.20
52	32.8	81.2	191.8	895.20
53	32.8	83.2	199.4	912.20
54	32.8	85.2	207.1	947.30

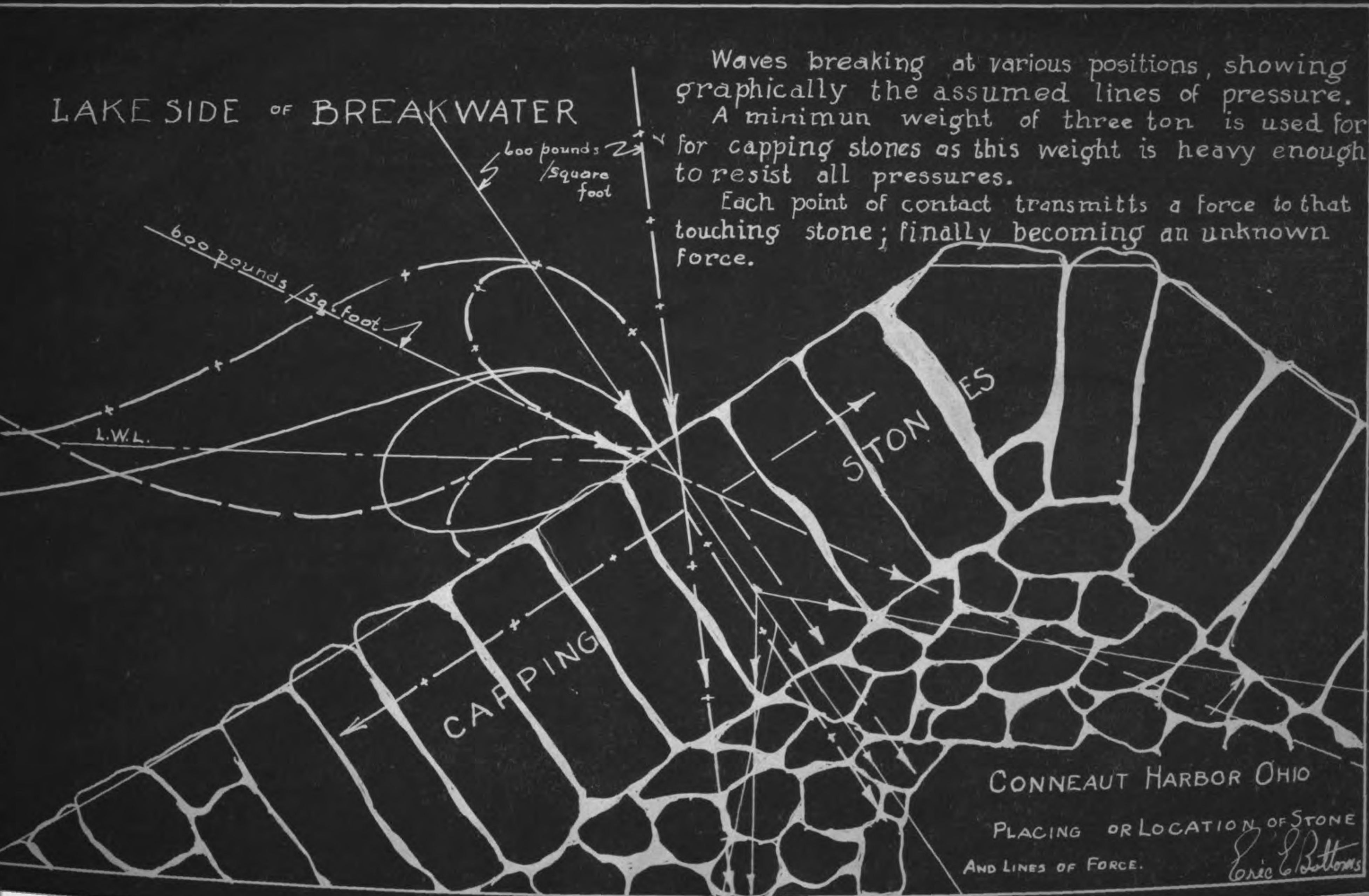
Depths are feet below Low Water
Capping Stone $4.00 per ton, Riprap $3.50 per ton. Stone Fill $2.50 per ton

Eric Bottoms.



LAKE SIDE
600 POUNDS / SQ FOOT
RESULANT FORCE
263,400 POUNDS
HARBOR SIDE
L.W.D
2400 POUNDS
C.G.
Capping Stone
1st Class Riprap
Slope 1:1.3
Slope 1:1.5
1st Class Riprap
Stone Fill.
This solution considers the Breakwater as a solid body.
The resultant falls in the middle third.
Figures are for 30 foot depth of water. Waves, 4 feet high.
CONNEAUT HARBOR OHIO
BREAKWATER DESIGN.
SCALE 1" = 12'0"
Eric G Bottoms.

Figure 24a.



LAKE SIDE OF BREAKWATER
Waves breaking at various positions, showing graphically the assumed lines of pressure.
A minimun weight of three ton is used for for capping stones as this weight is heavy enough to resist all pressures.
Each point of contact transmitts a force to that touching stone; finally becoming an unknown force.
600 pounds /square foot
600 pounds /sq. foot
L.W.L.
CAPPING STONES
CONNEAUT HARBOR OHIO
PLACING OR LOCATION OF STONE AND LINES OF FORCE.
Eric E Bottoms

Figure 24b

per lineal foot is average costs for stone from Kelly Isle, Ohio.

The mound type is chosen for Conneaut because it resists sufficiently the heavy seas of that region and because of the cheapness of construction and low maintenance costs.

For mound construction no dredging is necessary. The material is deposited directly on lake bottom, and it assumes the natural angle of repose and sinks into the bottom until a firm substrata is reached. The rubble or rip rap may be deposited in three different ways.

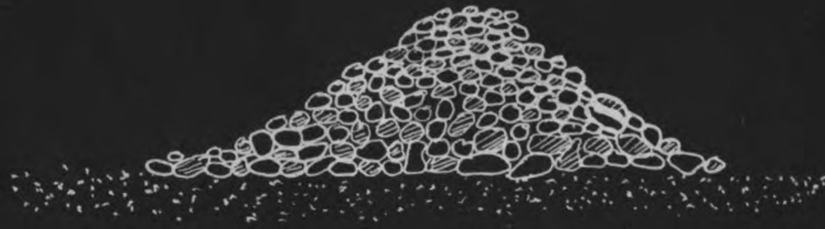
(1) Discharging from scows or barges.

(2) Discharging from temporary over head staging.

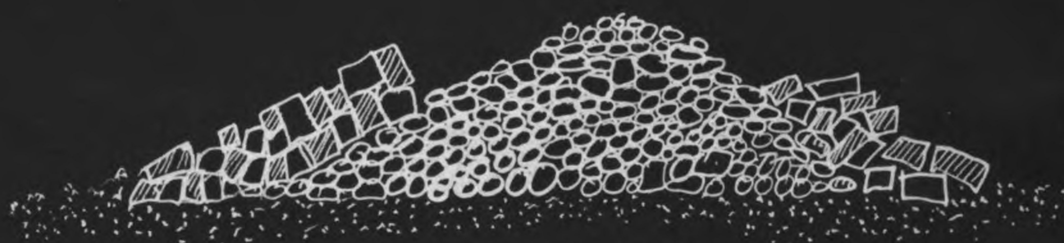
(3) Discharging from wagons, trucks, railroad cars in advance from the top of the finished mound. The road being continuously extended as the work proceeds.

The capping stone is set by the use of a diver if necessary in position shown (figure 24), and is so layed as to best resist the normal pressure of the waves upon it. Draw bars and hooks are used to lower the stones to place.

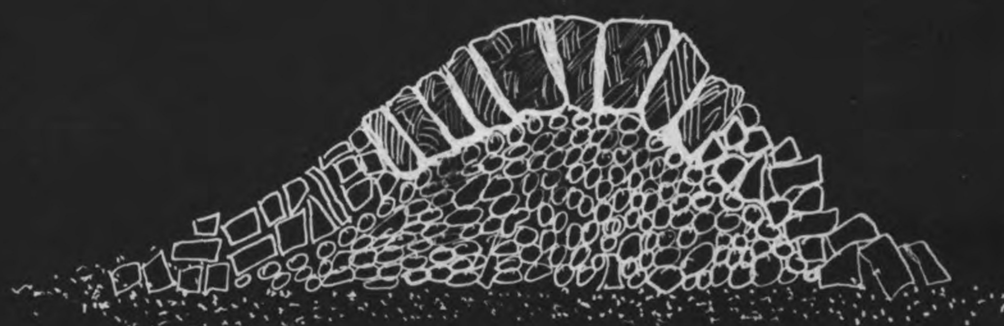
A breakwater constructed as a rubble mound has with normal up keep unkown life, the limiting load is also unknown and can be figured only approximately on many assumptions.



The Stone Fill is first deposited on bottom.



The heavy Riprap, first class, is then somewhat regularly placed, making certian



that the capping has a solid bearing and the Capping Stone is then placed with help of a diver.

CONNEAUT HARBOR OHIO

METHOD OF LAYING BREAKWATER

Figure 24c

Eric E Bottoms

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