Ch 4.5 Design Example D: Concrete Block Seawall

Design Example D

The following example demonstrates the design of a concrete block seawall as erosion protection at a site with low (0 to 15 foot high) bluffs along the shore. The design is demonstrated using the same project site as the low bluff revetment Design Example C. This example illustrates a design alternative to the low bluff revetment. The project site is fictitious but similar to the coastal features common along the south coast of Lake Erie's western basin.

Project Purpose

The purpose of Example Project D is to protect the toe of the silt and clay bluff from erosion due to wave action and to provide access to the waters of Lake Erie. In this case a concrete block seawall is selected to best achieve the project purpose.

Site Description

The description of this project site is the same as Example C.

The project site is located along the shore of Lake Erie in Ottawa County, between Port Clinton and Catawba Island. The shore in this area is oriented from west to east, and is irregular in shape with small bays and headlands. The predominant direction of sediment transport in the littoral zone is from northeast to southwest.

The shore at the project site consists of a 30 to 40-foot wide sand and gravel beach in front of a 6-foot high bluff (embankment). The bluff extends from a toe elevation of 572.7 feet to 579.0 feet at the crest as referenced to the International Great Lakes Datum of 1985 (IGLD 1985). A timber crib pier is present at the center of the site property and is trapping a small amount of sediment on its east edge. The crib pier is made up of two 16-foot long by 8-foot wide timber cribs with a crest elevation of 576.0 IGLD 1985.

The bluff is composed primarily of silt and clay with a thin layer of topsoil. A 2 to 4-foot thick layer of sand covers till in the nearshore zone and is distributed in a bar system. Limestone bedrock is present at an unknown depth. The nearshore slopes at approximately 4 degrees for the first 100 feet then levels to approximately 1 degree.

The site is exposed to storm waves from west-northwest to north directions but is partially protected by Catawba Island and the Bass Islands from northeast waves. A review of historic wave information results in a significant wave height of 1.6 feet at a period of 3.4 seconds. The most frequent wave direction was from the southwest. The largest wave recorded over the 32 year study was 6.9 feet with a 7.0 second period. The average direction of the largest waves was from the northeast. Wave data was measured at WIS station E04 located approximately 3.5 miles north of the project site in 20-foot deep water.

The expected erosion rate at the project site is 0.0 feet over 30 years based on the 2010 Coastal Erosion Area maps. The site is not located in a designated Coastal Erosion Area. There are no existing drainage measures causing localized erosion at the project site.

The eastern and western adjoining properties are similar to the project site in bluff elevation and upland topography. The beach width varies from 30 to 40 feet on both the eastern and western adjoining properties. There are no existing shore structures on either adjoining property.

Field Survey

The upland parcel is located within the Congress Lands district north and east of the First Principal Meridian of the Public Lands Survey System more specifically part of Fractional Section 35, Town 7 North, Range 17 East. Being within Catawba Island Township, and outside of any incorporated municipal boundaries, the parcel boundary extends to the centerline of the county road with a 60-foot right of way reservation for public ingress and egress centered on said centerline.

Horizontal control was established for this site by evaluating the location of published monumentation through the National Geodetic Survey (NGS) website: *www.ngs.noaa.gov*. The closest station to this site was determined to be "Clintport AZ MK" (PID MC1546) which is approximately 1.5 kilometers east. Based upon the NGS datasheet, the horizontal accuracy of the station is reported as a Cooperative Base Network Control Station with reports that attempts to recover the station were successful in 1995. Therefore this station was used within the horizontal control network. A closed traverse was performed between station "Clintport AZ MK" and the inter-visible station "Clintport" (PID MC1541) with intermediate stations located close to the project site. A least squares adjustment was made to generate resultant coordinates based upon Ohio State Plane 3401(NAD 83).

Vertical control was established for this site by evaluating the location of published monumentation through the NGS website. The closest station to this site was determined to be "J 317" (PID MC0994) which is approximately three (3) kilometers southwest. Based upon the NGS datasheet, the vertical accuracy of the station is First Order Class II with reports that attempts to recover the station were successful in 2004 and 2009. The NGS stainless steel rod, established in 1980, has a reported dynamic height of 585.05 feet at 45 degrees latitude. NGS Vertical Datum Transformation software (VDatum) was used to adjust for the hydraulic corrections for the project location based upon the latitude and longitude positions in the NGS datasheet for station "J 317." The resultant adjusted elevations provided by a closed level circuit were utilized for the project after confirming the elevation, relative to IGLD85, of the control stations by benching into the water level on a calm day with minimal wave activity and comparing that value to the water level station data retrieved from NOAA's Great Lakes Online website: *www.glakesonline.nos.noaa.gov/monitor.html* for station #9063079 (Marblehead).

With the horizontal and vertical control network established, recovery of boundary evidence was performed. Monumentation found and held as controlling stations included 5/8" iron pins at the intersecting centerlines of sixty (60) foot Sand Road and fifty (50) foot Spring Valley Road and along the centerline of Sand Road. A topographic survey was

performed that located the cultural (i.e. buildings, survey monuments, coastal structures) and natural (i.e. top and toe of bluff) features on the subject parcel and adjoiners. Notwithstanding the presence of the timber crib pier along the shore and centered on the upland parcel, the natural shoreline appears to be unaltered by artificially placed fill material.

A technical assistance request was made to the ODNR Office of Coastal Management to help in identifying the location of the natural shoreline prior to the artificial placement of the concrete material. A drawing was provided to the consultant that depicted the location of the natural shoreline on the May 1956 aerial photograph. This location was transferred to the site and compared to the descriptions within the current and previous title deeds. The natural shoreline was slightly adjusted based upon the description within the 1993 limited warranty deed for the subject parcel.

Analysis

Parcel data provided by the Ottawa County Auditor's Office was imported into the computer-aided design (CAD) drawing to establish a general orientation of the shoreline for a reach of approximately 1.5 kilometers. Methodology for partitioning the boundaries between the littoral adjoiners was examined including extending the upland parcel boundary lakeward without deflection and a radial projection from the general alignment of the 1.5 kilometers reach of shore from the intersection of the natural shoreline and the parcel sidelines. The radial projection method provided the most equitable distribution between the subject parcel and the east and west adjoiners.

A base map was provided to the engineering consultant that depicted the locations of the existing site improvements relative to the established parcel boundaries and littoral partitions. A general statement that the survey and plat were prepared that conforms to Ohio Administrative Code (A.C.) Section 4733-37 was included and the Ohio registered professional surveyor's signature and seal were affixed to the plat of survey (see Existing Site Plan "C").

Design

Design specifications and details are identified on the following design example drawings and supported by the included design calculations.

A critical component of the design of a seawall is its placement with respect to lake levels, the bluff, and geologic features. In this case, the controlling element of the design process is the beach in front of the seawall. When waves interact with an impermeable vertical structure, the motion of the water particles influenced by the waves has a scouring effect on sediments at the base of the structure. This effect is often amplified by the reflection of wave energy off the structure. To reduce the risk of the beach eroding, the seawall should be placed as far up the beach profile as possible. In this example, the base of the seawall is placed at the toe of the bluff at an elevation of 570.8 feet IGLD 1985. This elevation is selected because it is the natural boundary between the sand and clay layers at the project site.

Even with adequate structural connections it is generally not recommended to use concrete blocks stacked more than 3 units high. If 3-foot tall by 4-foot wide by 5-foot long precast concrete blocks are specified, the maximum recommended height is 9-feet tall. In this example, a 9-inch thick reinforced concrete cap is specified which brings the crest elevation to 580.5 feet IGLD 1985. In some cases a lower crest elevation may be required if a seawall is to be used for watercraft access. However, this is not a consideration for this design due to the wide beach at the project site.

The existing bluff and beach profile must be excavated in the area of the seawall, and all sand and gravel must be sidecast into the lake. A second row of concrete blocks are added to the design to increase the overall weight of the gravity structure and help prevent sliding failures. The concrete blocks should be connected with rebar installed in predrilled holes and set with grout.

The project site is in the Locust Point to Marblehead reach of the "Revised Report on Great Lakes Open Coast Flooding" (USACE 1988) and has a 30-year return period design water level of 576.2 feet IGLD 1985.

An initial 3.7-foot structure depth can be calculated from the beach profile elevation at the base of the structure and the design water level. Based on the breaking wave equation, a design wave height of 2.9 feet can be calculated for the initial case. If the beach profile in front of the structure is completely scoured away, the water depth at the base of the structure would increase to 5.4 feet. In this case, the design wave height would increase to 4.2 feet.

In order to confirm the external stability of the seawall it must be checked for both sliding and overturning. The seawall is to be placed above the average lake level and will, at most times, be completely dry. In this case, the seawall acts as a retaining structure. When design storm conditions are present, the seawall may be subjected to hydrostatic and hydrodynamic forces from 5.4 feet of water depth and up to 4.2-foot waves. In this example, a second design case is necessary.

In both design cases it is assumed that the ground water level is below the lake level. This requires that hydrostatic forces be considered on the structure (in the second design case) and leads to a more conservative design.

Case 1 – Low Water:

In this case the following forces will act on the structure:

- Gravity
- Earth forces
- Reactive forces
- Friction

The force of gravity is the total weight of the structure cross section. A total of 5.0 tons was calculated for a 1-foot section of the seawall (concrete blocks, cap, backfill, etc). In the absence of other vertical forces the normal reactive force is equal to the structure weight. If a minimum angle of internal friction of 35 degrees is assumed, friction forces can be estimated at 3.5 tons per linear foot of structure.

In most cases, soil borings are suggested to determine actual physical properties at the project site. For this design example it is assumed that the till beneath the seawall is sufficient to support the wall. A 110 lb/ft^3 unit weight is assumed for the backfill. An active earth pressure of 0.27 is calculated from the internal angle of friction using the Rankine Method. Earth forces are estimated at 0.7 tons per foot of structure.

In this case, the earth force is the only anti-stabilizing force and friction is the only stabilizing force to induce or resist sliding. The factor of safety for sliding stability is the ratio of stabilizing to anti-stabilizing forces. A factor of safety of 5.0 was calculated for the low water case.

To verify the seawall will be stable against overturning, moments are calculated about the structure toe. A 4-foot moment arm was assumed for the center of gravity and a 3.2-foot moment arm was assumed for the center of pressure for the earth forces. This results in a 20.0 ft-tons stabilizing moment per linear foot of structure and a 2.2 ft-tons per linear foot anti-stabilizing moment. A factor of safety of 9.0 was calculated for the low water case.

Case 2 – Design Water Level and Wave Height

In this case the following forces will act on the structure:

- gravity
- earth forces
- normal reactive forces
- friction
- wave uplift
- hydrostatic forces
- horizontal wave forces

The force of gravity was determined in the same method as the low water case. In this case, the normal reactive force will be reduced by the vertical wave uplift forces; therefore, wave forces on the seawall must be estimated next.

Several methods are commonly used to predict the forces due to waves. In this design example, a method described in the USACE Coastal Engineering Manual was used. Wave forces are calculated based on the Goda Formula for irregular waves modified to include impulsive forces from head on breaking waves. This method was adapted to the geometry of the proposed seawall. In particular the calculations have been simplified based on the exclusion of a rubble foundation in the design and the assumptions that Bm = 0 and hs = d = h' (water depth at toe of structure is the same as water depth in front of structure).

This method predicts a free surface height 6.3 feet above the design water level at the wave crest. Wave pressures are calculated at 216 lb/ft^2 at the base of the structure, 250 lb/ft^2 at the design water level, and 80 lb/ft^2 at the crest of the structure. Wave uplift pressures are also estimated at 213 lb/ft^2.

Notice that this calculation predicts that the structure will be slightly overtopped in design storm conditions. For this design, the reinforced concrete cap extending over the top of the low bluff will be sufficient to resist overtopping forces.

Based on these pressures, the total horizontal wave force is estimated to be approximately 0.9 tons per linear foot of structure, and the wave uplift force is estimated to be approximately 0.3 tons per linear foot of structure. Horizontal hydrostatic forces are predicted to be 0.5 tons per linear foot of structure.

Using the Rankine Method, a passive earth pressure coefficient of 3.69 was calculated. A 110 lb/ft3 unit weight is also assumed for the backfill. Earth forces are estimated at 9.5 tons per foot of structure.

stabilizing forces = (friction + earth forces)

anti-stabilizing forces = (wave + hydrostatic forces)

The resultant normal force is the difference between the structure weight and wave uplift forces (4.7 tons/ft). Friction was estimated at 3.3 tons per linear foot assuming a 35 degree internal angle of friction.

A total of 12.8 tons per foot of stabilizing forces (friction + earth forces) and 1.3 tons per foot of anti-stabilizing forces (wave + hydrostatic forces) were calculated. This results in a factor of safety of 9.6 against sliding.

To verify the seawall will be stable against overturning, moments are calculated about the structure heel. Assuming a 4-foot moment arm for the center of gravity and a 3.2-foot moment arm for the center of pressure for the earth forces, a total stabilizing moment of 50.6 ft-tons per linear foot of structure was calculated. Assuming a 3.6-foot moment arm for the center of pressure of the horizontal wave forces, a 5.3-foot moment arm for the center of pressure of the wave uplift force and a 1.8-foot moment arm for the center of pressure of the hydrostatic forces results in a total anti-stabilizing moment of 5.7 ft-tons per linear foot of structure. A factor of safety of 8.8 is calculated for overturning stability.

Discussion

Although the entire structure is located on the beach area above the water level at the time of the survey, an appropriate design still considers minimization of the overall project footprint. The seawall in this example will extend lakeward a maximum of 5.6 feet from the toe of the existing bluff. Comparing this design to the revetment design at the same site, the seawall would be the alternative with the minimal impact to littoral drift. A final design selection would need to weigh the risk of beach scour at the project site as well as wave reflection on adjoining properties. The advantages of each alternative should be considered as well as the property owner's beach/ lake access requirements.

Similar to the revetment, this seawall design is intended to prevent erosion of the existing bluff and will therefore decrease the amount of material added to the littoral system. Any sand or gravel in the footprint of the revetment must be excavated and sidecast into the lake prior to construction to prevent sediment from being permanently removed from the littoral system.

A row of toe stones is often included lakeward of a seawall. The toe stones both protect the base of the seawall from scour and dissipate wave energy. In some cases, the recreational purposes of the seawall precludes the use of toe stone because the reduced water depth at the base of the structure limits its use for watercraft access. In this case, the row of toe stones was not included in order to reduce the overall footprint of the structure and preserve the largest possible width of beach lakeward of the structure.

Observing and measuring changes to the beach over time should be part of the routine inspection of the structure's performance in the years following construction. A beach monitoring plan should be developed to quantify and mitigate long-term effects of the structure.

Final Survey Products

Based upon the design from the Ohio registered PE, a plat that depicted the boundaries of the submerged lands lease has been prepared. The proposed design of the armor stone revetment locates its occupation landward of the natural shoreline and therefore is not included in any lease parcel. The existing occupation of the timber crib pier is bisected by the location of the natural shoreline, and therefore the lease parcel only includes the area lakeward of said natural shoreline (see Submerged Lands Plat).

A metes and bounds description has been written for the area depicted on the plat of survey with direct relationship to the upland parcel boundaries as required in Ohio Revised Code Section 1506.11(B) (see Submerged Lands Lease description for the parcel).

Moment arm: In a rigid system, the distance between a reference point and the point at which a force is exerted on the system (torque).

Torque: A shorthand definition might be "force times distance."

SAMPLE ENGINEERING AND SURVEYING INC.
STREET ADDRESS

JOB: EXAMPLE D - BLOCK SEAWALL
SHEET NO. 1 OF 9
CALCULATED BY: MPC DATE: 02/01/11
CHECKED BY: DLB DATE: 02/01/11
SCALE:

SEAWALL DESIGN

A. DESIGN WATER LEVEL

30 YEAR DESIGN WATER LEVEL = 576.2 FT IGLD 1985
REFERENCE: "REVISED REPORT ON GREAT LAKES OPEN COAST FLOODING" USACE, 1988.

B. DESIGN WAVE HEIGHT

INITIAL DESIGN CASE
LAKE BOTTOM ELEVATION = 572.5 FEET IGLD 1985
STRUCTURE DEPTH = ds = 576.2 FT - 572.5 FT = 3.7 FT IGLD 1985
BREAKING WAVE HEIGHT = Hb = 0.78 x ds = 0.78 x 3.7 FT = 2.9 FT
REFERENCE: "COASTAL ENGINEERING MANUAL" USACE, 2006, PAGE II-4-3.

CONSERVATIVE CASE, IF TOE OF STRUCTURE IS SCOURED
TOE OF STRUCTURE = 570.8 FEET IGLD 1985
STRUCTURE DEPTH = ds = 576.2 FT - 570.8 FT = 5.4 FT IGLD 1985
BREAKING WAVE HEIGHT = Hb = 0.78 x ds = 0.78 x 5.4 FT = 4.2 FT
REFERENCE: "COASTAL ENGINEERING MANUAL" USACE, 2006, PAGE II-4-3.

C. CONCRETE CAP HEIGHT/OVERTOPPING

INITIAL DESIGN CASE
WAVE CREST ELEVATION = DWL + 0.7 Hb
= 576.2 FT + 0.7 (2.9 FT) = 578.2 FT IGLD 1985
CONSERVATIVE CASE, IF TOE OF STRUCTURE IS SCOURED
WAVE CREST ELEVATION = DWL + 0.7 Hb
= 576.2 FT + 0.7 (4.2 FT) = 579.1 FT IGLD 1985

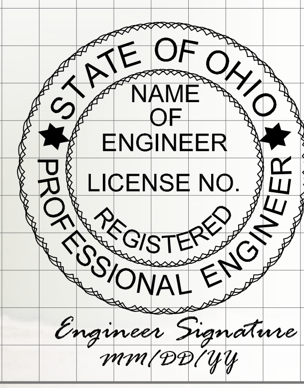
CONSERVATIVE DESIGN: SET SEAWALL CREST ELEVATION AT 580.5 FT IGLD 1985

D. EXTERNAL STABILITY

CONSIDER 2 DESIGN CASES:
1. WATER AT MEAN LOW LEVEL
2. DESIGN WATER LEVEL AND WAVE HEIGHT

CASE 1: LOW WATER (WATER LEVEL AT 569.2 FT IGLD 1985)

DETERMINE FORCES:
I STRUCTURE CROSS SECTION WEIGHT
II NORMAL FORCE
III FRICTION
IV EARTH FORCES



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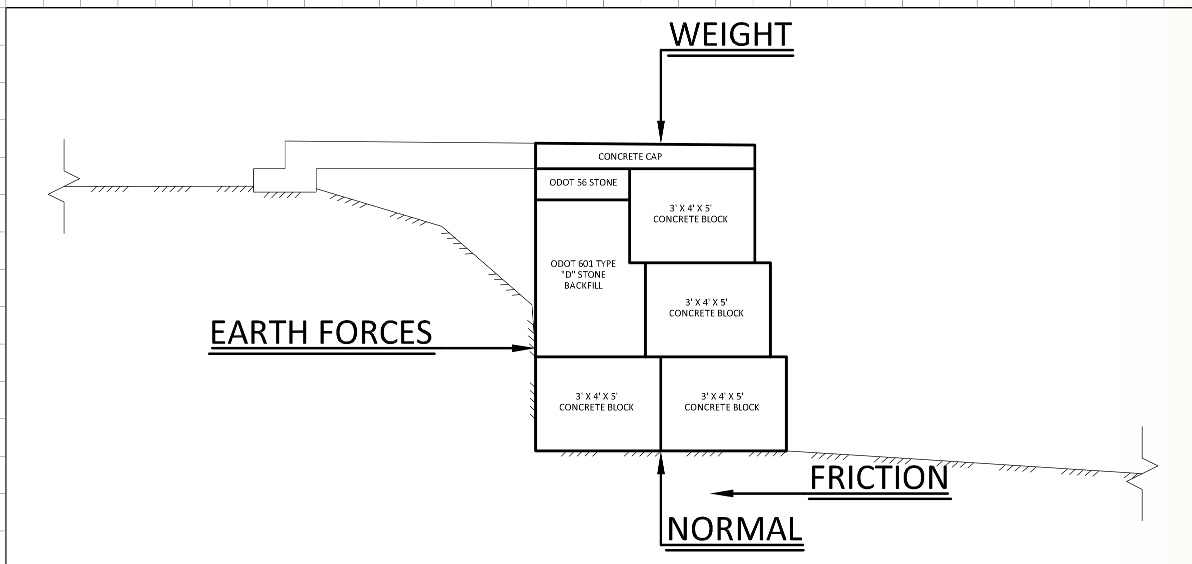
SEAWALL DESIGN (CONT.) - EXTERNAL STABILITY CASE 1



I STRUCTURE CROSS SECTION WEIGHT

COMPONENT	L (FT)	H (FT)	AREA (FT^2)	UNIT WT. (PCF)	NO.	WEIGHT/FT (LB/FT)
CONCRETE CAP	7	0.75	5.25	145	1	761
CONCRETE BLOCKS	4	3	12	145	4	6960
ODOT "D" FILL			16.5	110	1	1815
ODOT 56 FILL			3	120	1	360
REINFORCEMENT					1	120
					TOTAL	10016

WEIGHT PER LINEAR FOOT = 10016 LB/FT = 5.0 TON/FT

II NORMAL FORCE = WEIGHT = 10016 LB/FT = 5.0 TON/FT

III FRICTION

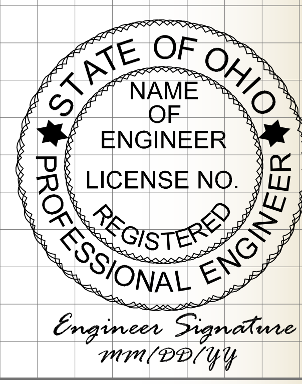
ANGLE OF INTERNAL FRICTION, α = 35 DEGREES (FROM SOIL SAMPLES)
COEFFICIENT OF STATIC FRICTION, $\mu = \tan \alpha = 0.7$

FRICTION = $N\mu$ = (10016 LB/FT)(0.7) = 7011 LB/FT = 3.5 TON/FT

IV EARTH FORCES

$$FE = \frac{1}{2} \gamma h_w^2 K_a \cos \beta$$

β = SLOPE OF BACKFILL = 0 DEGREES
hw = OVERALL HEIGHT OF STRUCTURE = 9.7 FT



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JOB	EXAMPLE D - BLOCK SEAWALL		
SHEET NO.	3	OF	9
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SEAWALL DESIGN (CONT.) - EXTERNAL STABILITY CASE 1

γ = UNIT WEIGHT OF BACKFILL = 110 LB/FT³ (FROM SOIL SAMPLES)
ϕ = ANGLE OF INTERNAL FRICTION OF BACKFILL = 35 DEGREES (FROM SOIL SAMPLES)

Ka = ACTIVE EARTH COEFFICIENT

$K_a = TAN^2 (45-\phi/2)$ RANKINE THEORY FOR LEVEL BACKFILL (β = 0°)

REFERENCE: "USS STEEL SHEET PILING DESIGN MANUAL" US STEEL, 1984.

$K_a = TAN^2 (45-(35°/2)) = 0.27$

$FE = \frac{1}{2} (110\ LB/FT^3) (9.7\ FT)^2 (0.27) (COS\ 0) = 1397\ LB/FT = 0.7\ TON/FT$

SLIDING STABILITY

STABILIZING FORCES = FRICTION = 7011 LB/FT

ANTI-STABILIZING FORCES = EARTH FORCES = 1397 LB/FT

FACTOR OF SAFETY = STABILIZING FORCES / ANTI-STABILIZING FORCES

FACTOR OF SAFETY = (7013 LB/FT) / (1397 LB/FT) = 5.0

OVERTURNING STABILITY - CALCULATE MOMENTS ABOUT STRUCTURE TOE

STABILIZING MOMENTS

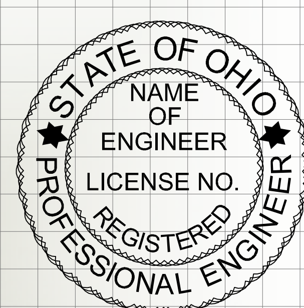
STRUCTURE WEIGHT = 10016 LB/FT
MOMENT ARM = 4 FT
STABILIZING MOMENT = 40064 FT-LB/FT = 20.0 FT-TON/FT

ANTI-STABILIZING MOMENTS

EARTH FORCES = 1397 LB/FT
MOMENT ARM = 3.2 FT
ANTI-STABILIZING MOMENT = 4470 FT-LB/FT = 2.2 FT-TON/FT

FACTOR OF SAFETY = STABILIZING / ANTI-STABILIZING

FACTOR OF SAFETY = (40064 FT-LB/FT) / (4470 FT-LB/FT) = 9.0



Engineer Signature
MM/DD/YY

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SEAWALL DESIGN (CONT.) - EXTERNAL STABILITY CASE 2

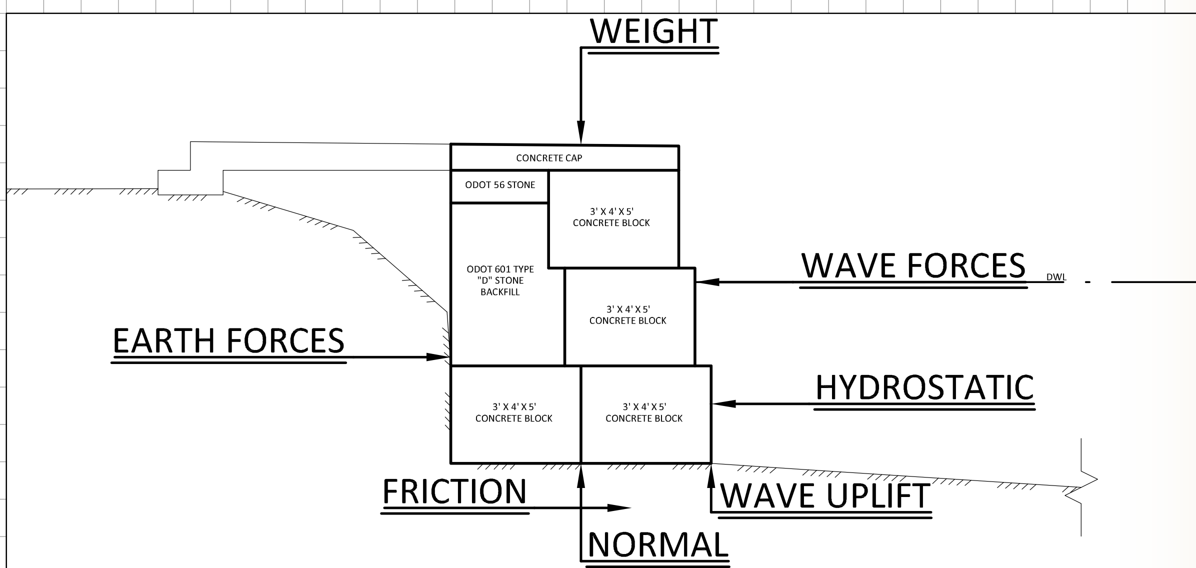
CASE 2: DESIGN WATER LEVEL AND WAVE HEIGHT

DETERMINE FORCES:

I STRUCTURE CROSS SECTION WEIGHT
II WAVE FORCES
III EARTH FORCES
IV HYDROSTATIC (BUOYANT) FORCES
V NORMAL FORCE (RESULTANT)
VI FRICTION

DESIGN ASSUMPTIONS:

- FOR CONSERVATIVE DESIGN ASSUME HIGH LAKE WATER LEVEL AND LOW GROUND WATER LEVEL (SEPARATED BY SEAWALL). HYDROSTATIC FORCES MUST BE CONSIDERED.



I STRUCTURE WEIGHT

TOTAL STRUCTURE WEIGHT = 10016 LB/FT = 5.0 TON/FT (PREVIOUSLY CALCULATED)

II WAVE FORCES

WAVE FORCE CALCULATION BASED ON GODA FORMULA FOR IRREGULAR WAVES MODIFIED TO INCLUDE IMPULSIVE FORCES FROM HEAD ON BREAKING WAVES AND ADAPTED TO THE GEOMETRY OF THE PROPOSED SEAWALL.
REFERENCE: "COASTAL ENGINEERING MANUAL" USACE, 1996, TABLES VI-5-53, 54 & 55.

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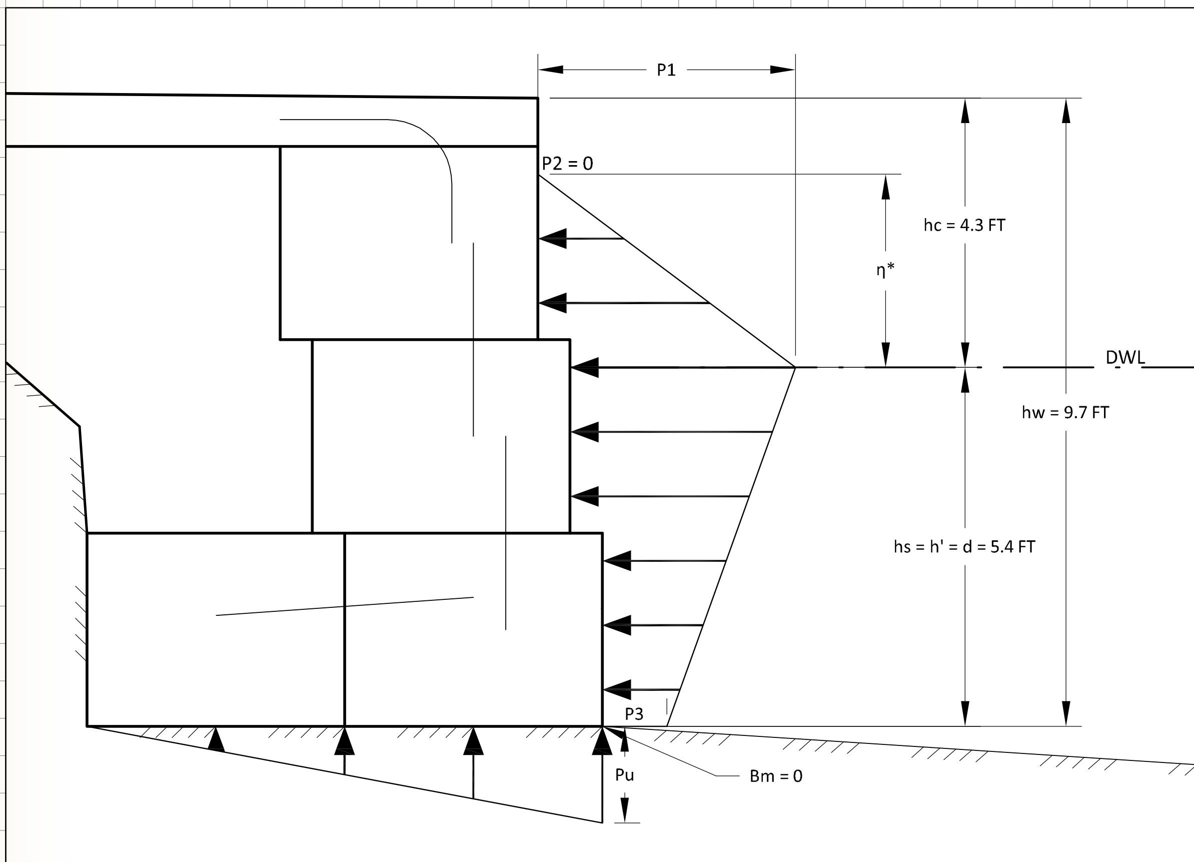
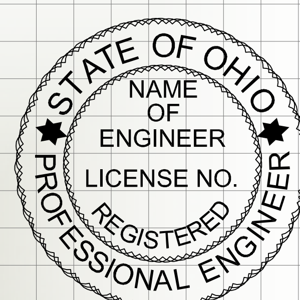
SEAWALL DESIGN (CONT.) - EXTERNAL STABILITY CASE 2



DEFINITIONS:
P1 = WAVE PRESSURE AT DESIGN WATER LEVEL
P2 = WAVE PRESSURE AT WAVE/SEAWALL CREST HEIGHT
P3 = WAVE PRESSURE AT BASE OF SEAWALL
Pu = WAVE UPLIFT PRESSURE AT BASE OF SEAWALL
η* = WAVE CREST HEIGHT
hs = DEPTH OF STRUCTURE TOE = 5.4 FT
d = WATER DEPTH AT TOE OF STRUCTURE = 5.4 FT
h' = TOTAL DEPTH OF STRUCTURE = 5.4 FT
β = ANGLE OF INCIDENCE OF DESIGN WAVES = 0 DEGREES
Hdesign = DESIGN WAVE HEIGHT = Hb = 4.2 FT
hw = OVERALL HEIGHT OF STRUCTURE = 9.7 FT
hc = HEIGHT OF STRUCTURE ABOVE DWL = 4.3 FT
Bm = WIDTH OF RUBBLE FOUNDATION = 0
Ts = WAVE PERIOD = 4.5 SECONDS (ASSUMED FOR 4.2 FT WAVE)
Ts = WAVE PERIOD = 4.5 SECONDS (ASSUMED FOR 4.2 FT WAVE)



Engineer Signature
MM/DD/YY

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SEAWALL DESIGN (CONT.) - EXTERNAL STABILITY CASE 2

hb = WATER DEPTH AT A DISTANCE 5 X Hdesign FROM SEAWALL

$= hs + 5 \times Hdesign \times \tan\phi = 5.4\text{ FT} + 5 \times 4.2\text{ FT} \times \tan(1°) = 5.8\text{ FT}$

L = WAVELENGTH AT WATER DEPTH hb $= Ts\sqrt{g\,hb} = (4.5\text{ S})\sqrt{(32.2\text{ FT/S}^2 \times 5.8\text{ FT})} = 61.5\text{ FT}$

DETERMINE MODIFICATIONS TO GODA FORMULA

$$\delta 22 = -0.36\left(\frac{Bm}{L} - 0.12\right) + 0.93\left(\frac{hs - d}{hs} - 0.6\right) = -0.51$$

$$\delta 2 = \begin{cases} 4.9 \times \delta 22 & \text{FOR } \delta 22 \le 0 \\ 3 \times \delta 22 & \text{FOR } \delta 22 > 0 \end{cases} \qquad \delta 2 = 4.9 \times -0.51 = -2.52$$

$$\delta 11 = 0.93\left(\frac{Bm}{L} - 0.12\right) + 0.36\left(\frac{hs - d}{hs} - 0.6\right) = -0.33$$

$$\delta 1 = \begin{cases} 20 \times \delta 11 & \text{FOR } \delta 11 \le 0 \\ 15 \times \delta 11 & \text{FOR } \delta 11 > 0 \end{cases} \qquad \delta 1 = 20 \times -0.33 = -6.55$$

$$\alpha 11 = \begin{cases} \cos\delta 2 / \cosh\delta 1 & \text{FOR } \delta 2 \le 0 \\ 1/(\cosh\delta 1 \times \sqrt{\cosh\delta 2}) & \text{FOR } \delta 2 > 0 \end{cases} \qquad \alpha 11 = 0.018$$

$$\alpha 10 = \begin{cases} Hdesign / d & \text{FOR } Hdesign / d \le 2 \\ 2.0 & \text{FOR } Hdesign / d > 2 \end{cases} \qquad \alpha 10 = 0.78$$

$\alpha 1 = \alpha 10 \times \alpha 11 = 0.014$

$$\alpha 2 = \text{SMALLER OF: } \frac{hb - d}{3hb}\left(\frac{Hdesign}{d}\right)^2 = 0.013 \quad \text{AND} \quad \frac{2d}{Hdesign} = 2.56, \qquad \alpha 2 = 0.013$$

$\alpha^* =$ LARGER OF $\alpha 1$ AND $\alpha 2 = 0.014$

STRUCTURE TYPE MODIFICATION FACTORS

$\lambda 1 = \lambda 2 = \lambda 3 = 1.0$ FOR CONVENTIONAL VERTICAL WALL STRUCTURES

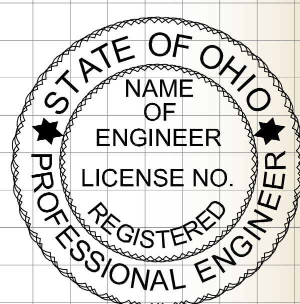
DETERMINE PRESSURE COEFFICIENTS FOR GODA FORMULA

$\alpha^* = 0.014$ (MODIFIED α^* FOR IMPULSIVE FORCES)

$$\alpha 1 = 0.6 + 0.5\left(\frac{4\pi\, hs / L}{\sinh(4\pi\, hs / L)}\right)^2 = 0.94$$

$\alpha 2 = 0.013$ (SAME AS ABOVE)

$$\alpha 3 = 1 - \frac{hw - hc}{hs}\left(1 - \frac{1}{\cosh(2\pi\, hs / L)}\right) = 0.86$$

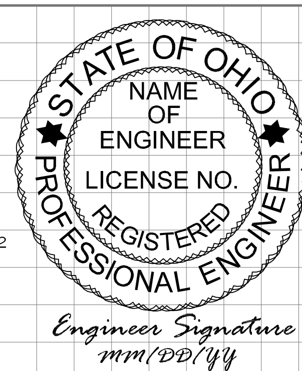


Engineer Signature
MM/DD/YY

SAMPLE ENGINEERING AND SURVEYING INC.
STREET ADDRESS

JOB: EXAMPLE D - BLOCK SEAWALL
SHEET NO. 7 OF 9
CALCULATED BY: MPC DATE: 02/01/11
CHECKED BY: DLB DATE: 02/01/11
SCALE:

SEAWALL DESIGN (CONT.) - EXTERNAL STABILITY CASE 2



CALCULATE WAVE PRESSURES

$\eta^* = 0.75\,(1 + \cos\beta)\,\lambda_1\,H_{design} = 6.3$ FT

$P1 = 0.5\,(1 + \cos\beta)\,(\lambda_1\alpha_1 + \lambda_2\,\alpha^*\cos^2\beta)\,\rho_w\,g\,H_{design} = 250$ LB/FT²

$P2 = \begin{cases} (1 - h_c/\eta^*)\,P1 & \text{FOR } \eta^* > h_c \\ 0 & \text{FOR } \eta^* \le h_c \end{cases}$ $\quad P2 = 80$ LB/FT²

$P3 = \alpha_3\,P1 = 216$ LB/FT²

$PU = 0.5\,(1 + \cos\beta)\,\lambda_3\,\alpha_1\,\alpha_3\,\rho_w\,g\,H_{design} = 213$ LB/FT²

DETERMINE LEVELS OF UNCERTAINTY
FOR HORIZONTAL FORCE, UFH = 0.90
FOR UPLIFT FORCE, UFU = 0.77
FOR HORIZONTAL MOMENT, UMH = 0.81
FOR UPLIFT MOMENT, UMU = 0.72

REFERENCE: "COASTAL ENGINEERING MANUAL" USACE, 2006, TABLE VI-5-55.

CALCULATE WAVE FORCES PER LINEAR FOOT OF STRUCTURE

HORIZONTAL WAVE FORCE, $FH = UFH\,(\tfrac{1}{2}(P1+P2)h_c + \tfrac{1}{2}(P1+P3)h')$ = 1772 LB/FT = 0.9 TON/FT

WAVE UPLIFT FORCE, $FU = UFU \times \tfrac{1}{2}PU \times B$ = 656 LB/FT = 0.3 TON/FT
B = 10 FT WIDTH OF STRUCTURE CROSS SECTION

III EARTH FORCES

$FE = \tfrac{1}{2}\,\gamma\,h_w^2\,K_p\cos\beta$

β = SLOPE OF BACKFILL = 0 DEGREES
h_w = OVERALL HEIGHT OF STRUCTURE = 9.7 FT
γ = UNIT WEIGHT OF BACKFILL = 110 LB/FT³ (FROM SOIL SAMPLES)
ϕ = ANGLE OF INTERNAL FRICTION OF BACKFILL = 35 DEGREES (FROM SOIL SAMPLES)

K_p = PASSIVE EARTH COEFFICIENT

$K_p = \tan^2(45 + \phi/2)$ RANKINE THEORY FOR LEVEL BACKFILL ($\beta = 0°$)
REFERENCE: "USS STEEL SHEET PILING DESIGN MANUAL" US STEEL, 1984.

$K_p = \tan^2(45 + (35°/2)) = 3.69$

$FE = \tfrac{1}{2}$ (110 LB/FT³) (9.7 FT)² (3.69) (COS 0) = 19096 LB/FT = 9.5 TON/FT

SAMPLE ENGINEERING AND SURVEYING INC.
STREET ADDRESS

JOB: EXAMPLE D - BLOCK SEAWALL
SHEET NO. 8 OF 9
CALCULATED BY: MPC DATE: 02/01/11
CHECKED BY: DLB DATE: 02/01/11
SCALE:

SEAWALL DESIGN (CONT.) - EXTERNAL STABILITY CASE 2

IV HYDROSTATIC FORCES

$F_{hydro} = \frac{1}{2} \gamma_w h^2$

γ_w = UNIT WEIGHT OF WATER = 62.4 LB/FT^3
h = WATER DEPTH AT TOE OF STRUCTURE = 5.4 FT

Fhydro = 910 LB/FT = 0.5 TON/FT

V RESULTANT NORMAL FORCE

RESULTANT VERTICAL FORCE, N = WEIGHT - WAVE UPLIFT

N = 10016 LB/FT - 656 LB/FT = 9360 LB/FT = 4.7 TON/FT

VI FRICTION

ANGLE OF INTERNAL FRICTION, α = 35 DEGREES (FROM SOIL SAMPLES)
COEFFICIENT OF STATIC FRICTION, μ = TAN α = 0.7

FRICTION = N μ = (9360 LB/FT)(0.7) = 6552 LB/FT = 3.3 TON/FT

SLIDING STABILITY

STABILIZING FORCES = FRICTION + EARTH FORCES
STABILIZING = 6552 LB/FT + 19096 LB/FT = 25648 LB/FT = 12.8 TON/FT

ANTI-STABILIZING FORCES = WAVE FORCES + HYDROSTATIC FORCES
ANTI-STABILIZING FORCES = 1772 LB/FT + 910 LB/FT = 2682 LB/FT = 1.3 TON/FT

FACTOR OF SAFETY = STABILIZING FORCES / ANTI-STABILIZING FORCES
FACTOR OF SAFETY = (25648 LB/FT) / (2682 LB/FT) = 9.6

OVERTURNING STABILITY - CALCULATE MOMENTS ABOUT STRUCTURE HEEL

STABILIZING MOMENTS

STRUCTURE WEIGHT = 10016 LB/FT
MOMENT ARM = 4 FT
STABILIZING MOMENT = 40064 FT-LB/FT = 20.0 FT-TON/FT

EARTH FORCES = 19096 LB/FT
MOMENT ARM = 3.2 FT
STABILIZING MOMENT = 61107 FT-LB/FT = 30.6 FT-TON/FT

SAMPLE ENGINEERING AND SURVEYING INC.
STREET ADDRESS

JOB: EXAMPLE D - BLOCK SEAWALL
SHEET NO. 9 OF 9
CALCULATED BY: MPC DATE: 02/01/11
CHECKED BY: DLB DATE: 02/01/11
SCALE:

SEAWALL DESIGN (CONT.) - EXTERNAL STABILITY CASE 2

TOTAL STABILIZING MOMENT = 101171 FT-LB/FT

ANTI-STABILIZING MOMENTS

HORIZONTAL WAVE FORCE = FH = 1772 LB/FT
MOMENT ARM = 3.6 FT
ANTI-STABILIZING MOMENT = 6379 FT-LB/FT = 3.2 FT-TON/FT

WAVE UPLIFT FORCE = FU = 656 LB/FT
MOMENT ARM = 5.3 FT
ANTI-STABILIZING MOMENT = 3477 FT-LB/FT = 1.7 FT-TON/FT

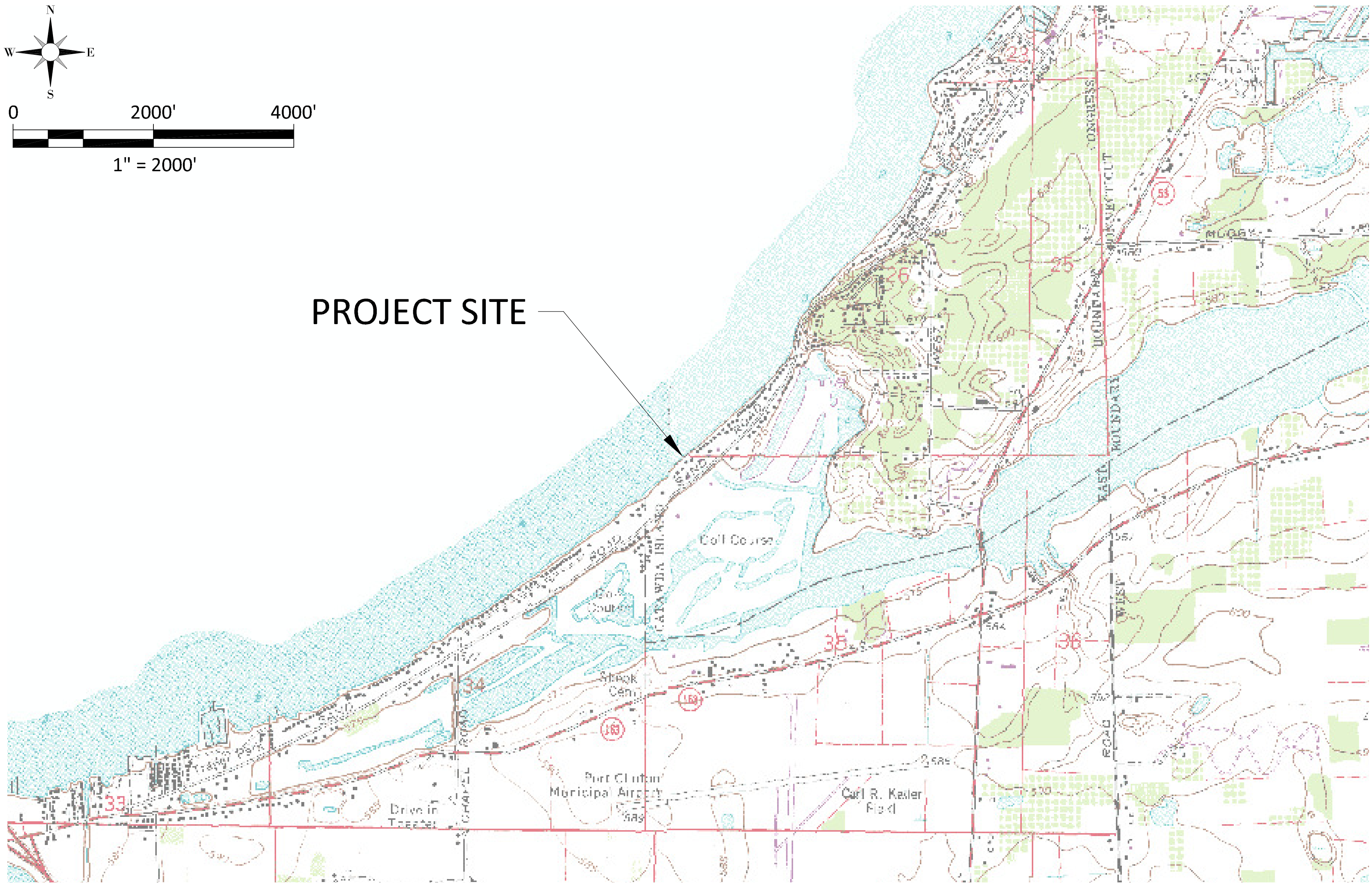
HYDROSTATIC FORCE = 910 LB/FT
MOMENT ARM = 1.8 FT
ANTI-STABILIZING MOMENT = 1638 FT-LB/FT = 0.8 FT-TON/FT

TOTAL ANTI-STABILIZING MOMENT = 11494 FT-LB/FT = 5.7 FT-TON/FT

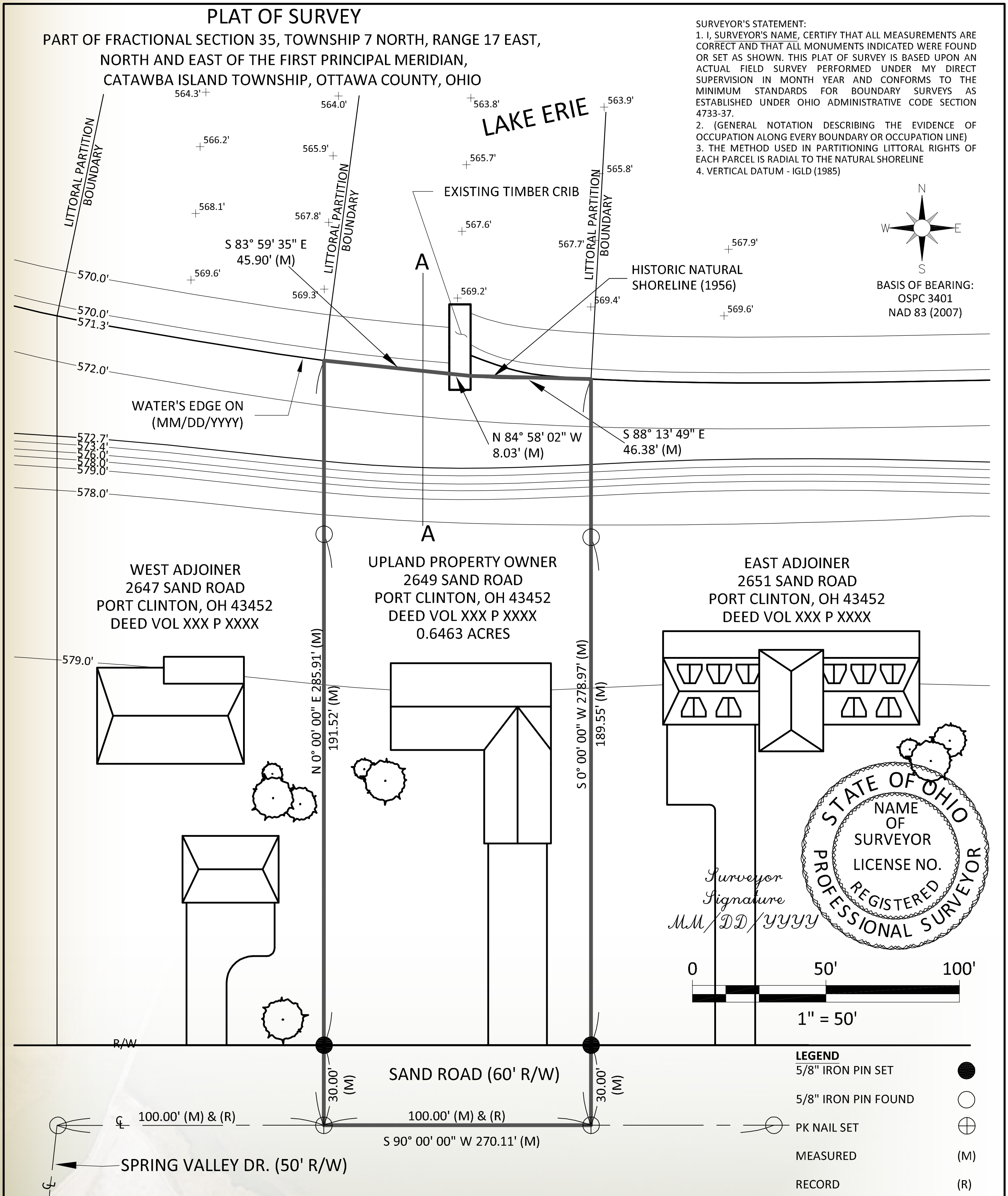
FACTOR OF SAFETY = STABILIZING / ANTI-STABILIZING

FACTOR OF SAFETY = 101171 FT-LB/FT / 11494 FT-LB/FT = 8.8

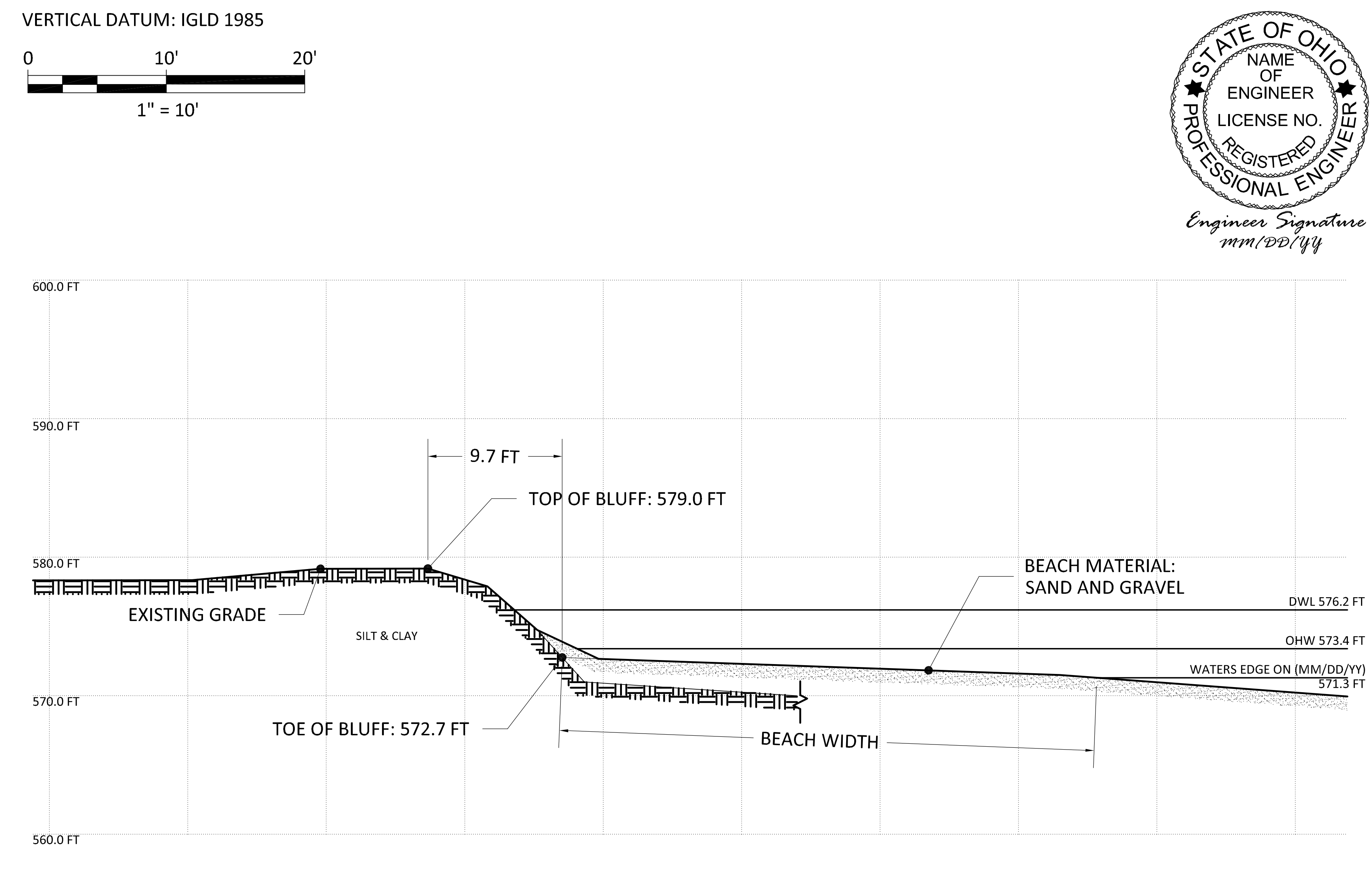
*NOTE: THE CALCULATIONS INCLUDED IN THIS EXAMPLE WERE ORIGINALLY COMPUTED USING EXCEL SPREADSHEETS. THE SOFTWARE DISPLAYS A SPECIFIED NUMBER OF SIGNIFICANT FIGURES BUT RETAINS THE ORIGINAL NUMBER FOR OPERATIONS. AS A RESULT SMALL ROUNDING ERRORS ARE INTRODUCED IN TRANSCRIBING THE STEP-BY-STEP CALCULATIONS. THESE ERRORS ARE ACCEPTABLE CONSIDERING THE OVERALL ACCURACY OF THE CALCULATION METHODS AND THE PURPOSE OF THIS DESIGN MANUAL.



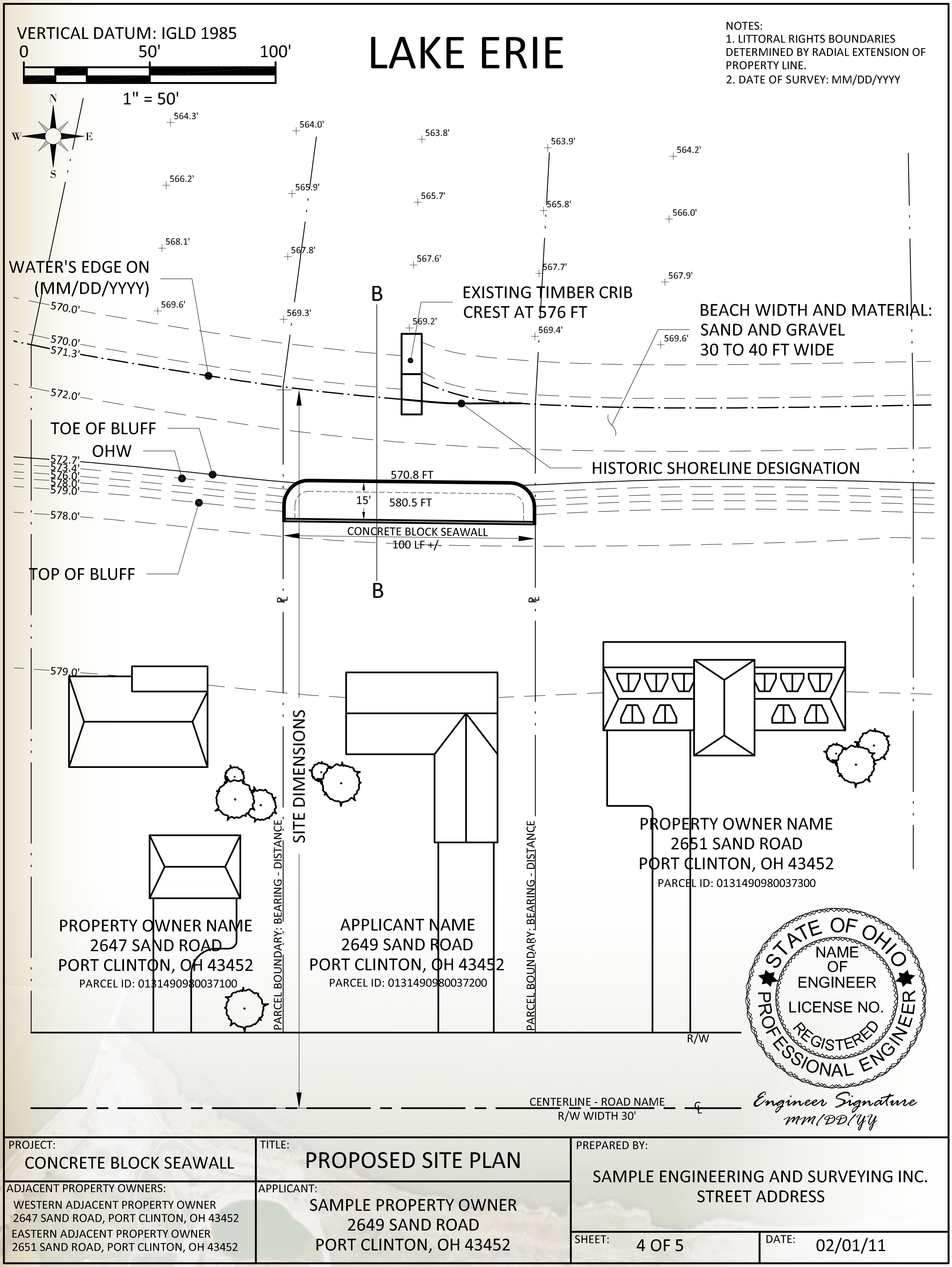
PROJECT: CONCRETE BLOCK SEAWALL	TITLE: VICINITY MAP	PREPARED BY: SAMPLE ENGINEERING AND SURVEYING INC. STREET ADDRESS
ADJACENT PROPERTY OWNERS: WESTERN ADJACENT PROPERTY OWNER 2647 SAND ROAD, PORT CLINTON, OH 43452 EASTERN ADJACENT PROPERTY OWNER 2651 SAND ROAD, PORT CLINTON, OH 43452	APPLICANT: SAMPLE PROPERTY OWNER 2649 SAND ROAD PORT CLINTON, OH 43452	SHEET: 1 OF 5 — DATE: 02/01/11

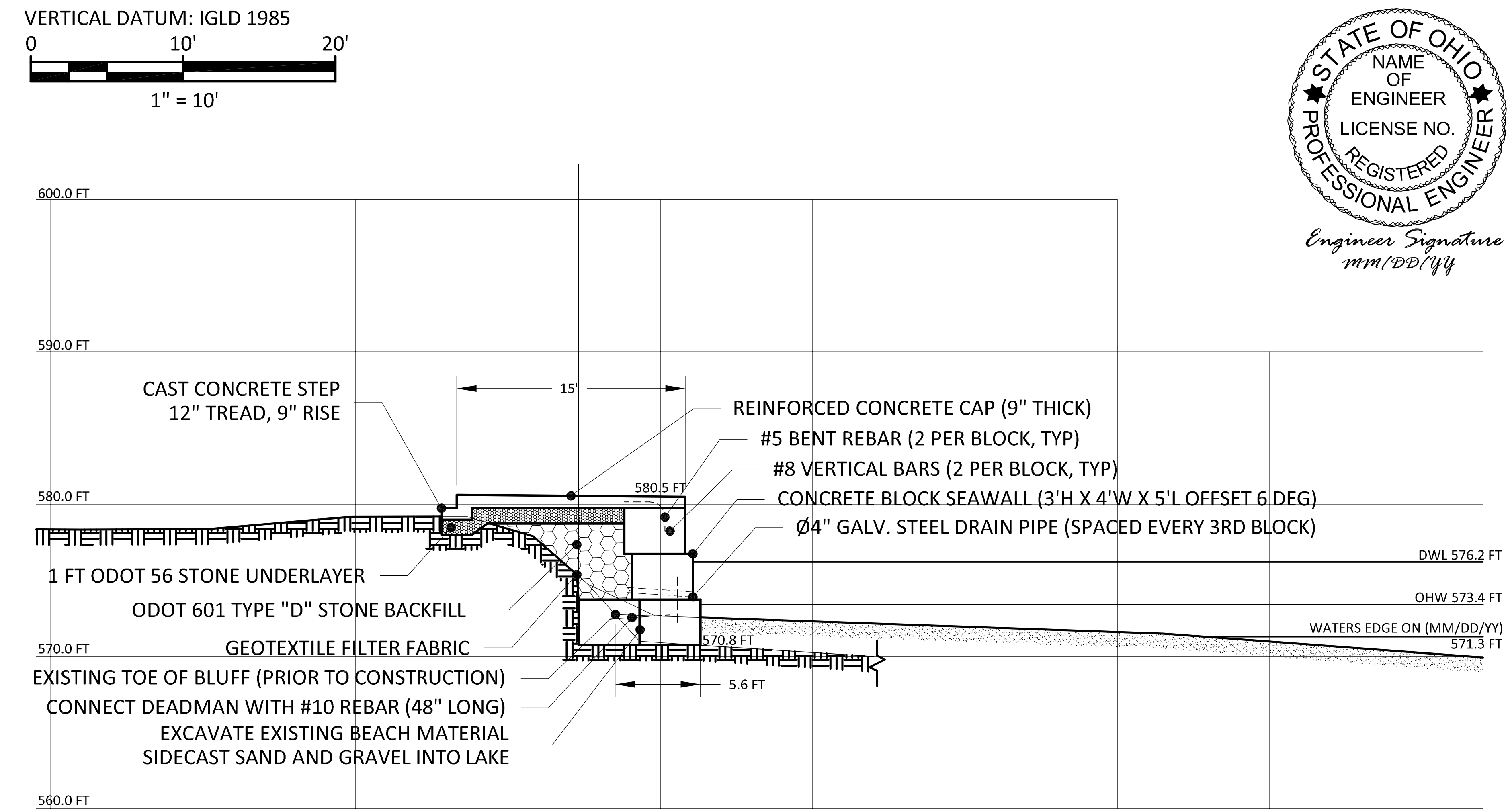


PROJECT: ARMOR STONE REVETMENT	TITLE: EXISTING SITE PLAN	PREPARED BY: SAMPLE SURVEYING AND ENGINEERING INC. STREET ADDRESS
ADJACENT PROPERTY OWNERS: WESTERN ADJOINER 2647 SAND ROAD, PORT CLINTON, OH 43452 EASTERN ADJOINER 2651 SAND ROAD, PORT CLINTON, OH 43452	APPLICANT: APPLICANT 2649 SAND ROAD PORT CLINTON, OH 43452	SHEET: 2 OF 5 — DATE: 02/01/2011



PROJECT: CONCRETE BLOCK SEAWALL	TITLE: SECTION A-A: EXISTING SITE	PREPARED BY: SAMPLE ENGINEERING AND SURVEYING INC. STREET ADDRESS
ADJACENT PROPERTY OWNERS: WESTERN ADJACENT PROPERTY OWNER 2647 SAND ROAD, PORT CLINTON, OH 43452 EASTERN ADJACENT PROPERTY OWNER 2651 SAND ROAD, PORT CLINTON, OH 43452	APPLICANT: SAMPLE PROPERTY OWNER 2649 SAND ROAD PORT CLINTON, OH 43452	SHEET: 3 OF 5 DATE: 02/01/11


VERTICAL DATUM: IGLD 1985
0
50'
100'
1" = 50'
N
W
E
S
LAKE ERIE
NOTES:
1. LITTORAL RIGHTS BOUNDARIES DETERMINED BY RADIAL EXTENSION OF PROPERTY LINE.
2. DATE OF SURVEY: MM/DD/YYYY
564.3'
564.0'
563.8'
563.9'
564.2'
566.2'
565.9'
565.7'
565.8'
566.0'
568.1'
567.8'
567.6'
567.7'
567.9'
569.6'
569.3'
569.2'
569.4'
569.6'
WATER'S EDGE ON (MM/DD/YYYY)
B
EXISTING TIMBER CRIB CREST AT 576 FT
BEACH WIDTH AND MATERIAL: SAND AND GRAVEL 30 TO 40 FT WIDE
570.0'
570.0'
571.3'
572.0'
TOE OF BLUFF
OHW
572.7'
573.4'
576.0'
578.0'
579.0'
578.0'
HISTORIC SHORELINE DESIGNATION
570.8 FT
15'
580.5 FT
CONCRETE BLOCK SEAWALL
100 LF +/-
TOP OF BLUFF
B
579.0'
SITE DIMENSIONS
PARCEL BOUNDARY: BEARING - DISTANCE
PARCEL BOUNDARY: BEARING - DISTANCE
PROPERTY OWNER NAME
2651 SAND ROAD
PORT CLINTON, OH 43452
PARCEL ID: 0131490980037300
PROPERTY OWNER NAME
2647 SAND ROAD
PORT CLINTON, OH 43452
PARCEL ID: 0131490980037100
APPLICANT NAME
2649 SAND ROAD
PORT CLINTON, OH 43452
PARCEL ID: 0131490980037200
STATE OF OHIO
NAME OF ENGINEER
LICENSE NO.
REGISTERED
PROFESSIONAL ENGINEER
R/W
CENTERLINE - ROAD NAME
R/W WIDTH 30'
Engineer Signature
MM/DD/YY
PROJECT:
CONCRETE BLOCK SEAWALL
TITLE:
PROPOSED SITE PLAN
PREPARED BY:
SAMPLE ENGINEERING AND SURVEYING INC.
STREET ADDRESS
ADJACENT PROPERTY OWNERS:
WESTERN ADJACENT PROPERTY OWNER
2647 SAND ROAD, PORT CLINTON, OH 43452
EASTERN ADJACENT PROPERTY OWNER
2651 SAND ROAD, PORT CLINTON, OH 43452
APPLICANT:
SAMPLE PROPERTY OWNER
2649 SAND ROAD
PORT CLINTON, OH 43452
SHEET:
4 OF 5
DATE:
02/01/11



NOTES:

1. PROVIDE 1 DEGREE OF SLOPE ON CONCRETE CAP FOR DRAINAGE
2. CONCRETE CAP SHALL HAVE 28 DAY COMPRESSIVE STRENGTH OF 4 KSI WITH CONTROL JOINTS SPACED EVERY 10 FEET.
3. REINFORCE CAP WITH #5 60 KSI DEFORMED BARS SPACED AT 16 INCHES IN LONGITUDINAL AND TRANSVERSE DIRECTION.
4. REINFORCE NOSE OF STEP TREAD WITH #5 REBAR.
5. PROVIDE MINIMUM OF 2 INCHES OF COVER OVER ALL REBAR.
6. EXCAVATE EXISTING BEACH TO STIFF CLAY. DEPOSIT EXCAVATED SAND & GRAVEL LAKEWARD OF PROJECT. NO SAND OR GRAVEL SHOULD BE TRAPPED UNDER SEAWALL.

PROJECT:	TITLE:	PREPARED BY:	
CONCRETE BLOCK SEAWALL	SECTION B-B: PROPOSED SITE	SAMPLE ENGINEERING AND SURVEYING INC. STREET ADDRESS	
ADJACENT PROPERTY OWNERS: WESTERN ADJACENT PROPERTY OWNER 2647 SAND ROAD, PORT CLINTON, OH 43452 EASTERN ADJACENT PROPERTY OWNER 2651 SAND ROAD, PORT CLINTON, OH 43452	APPLICANT: SAMPLE PROPERTY OWNER 2649 SAND ROAD PORT CLINTON, OH 43452	SHEET: 5 OF 5	DATE: 02/01/11

Lake Erie Submerged Lands Legal Description
Adjacent to 2649 Sand Road, Port Clinton

Situate in the State of Ohio and located within the waters of Lake Erie, County of Ottawa, Catawba Island Township, Town 7 North, Range 17 East, North and East of the First Principal Meridian, adjacent to a portion of fractional Section 35 conveyed to (NAME OF UPLAND OWNER) by Deed Volume (XXX), Page (XXXX), of the deed records of said county and being more particularly described as follows:

Commencing at a 5/8 inch solid iron pin found at the intersection of the centerline of sixty (60) foot Sand Road and the centerline of fifty (50) foot Spring Valley Drive, said point also being the southwest corner of (NAME OF WEST ADJOINER) parcel as conveyed by Deed Volume (XXX), Page (XXXX);

Thence along the centerline of sixty (60) foot Sand Road and the south line of said (NAME OF WEST ADJOINER), North 90 degrees, 00 minutes, 00 seconds East, 99.79 feet to a P-K nail set at the southeast corner of said (NAME OF WEST ADJOINER) parcel, also being the southwest corner of said (NAME OF UPLAND OWNER);

Thence along the west line of said (NAME OF UPLAND OWNER) parcel and the east line of said (NAME OF WEST ADJOINER), North 00 degrees, 00 minutes, 00 seconds East, 285.91 feet, and passing for reference, a 5/8 inch solid iron pin set at 30.00 feet on the north right-of-way of Sand Road and a 5/8 inch solid iron pin found at 221.52 feet to the location of the natural shoreline of Lake Erie present in (1956) as determined by the Ohio Department of Natural Resources, also being the northwest corner of said (NAME OF UPLAND OWNER);

Thence along the north line of said (NAME OF UPLAND OWNER), also being said natural shoreline, South 83 degrees, 59 minutes, 35 seconds East, 45.90 feet to a point not monumented due to the location on the submerged lands of Lake Erie, said point being the True Point of Beginning of the Lease Property described;

Thence departing the north line of said (NAME OF UPLAND OWNER) parcel, across the open waters of Lake Erie, North 00 degrees, 00 minutes, 00 seconds East, 25.65 feet to a point not monumented due to location on submerged lands of Lake Erie;

Thence continuing across the open waters of Lake Erie, North 87 degrees, 27 minutes, 17 seconds East, 8.01 feet to a point not monumented due to location on submerged lands of Lake Erie;

Thence continuing across the open waters of Lake Erie, South 00 degrees, 00 minutes, 24 seconds West, 26.71 feet to a 5/8 inch solid iron pin set on the north line of said (NAME OF UPLAND OWNER), also being said natural shoreline;

Thence along said natural shoreline, North 84 degrees, 58 minutes, 02 seconds West, 8.03 feet to the True Point of Beginning of the submerged parcel herein described. Said parcel contains 209 square feet (0.0048 acres) more or less and subject to all legal highways, easements, restrictions, and covenants of records. Based on a field survey performed by (NAME OF SURVEYOR), P.S. (#XXXX State of Ohio) performed in (MONTH, YEAR).

Basis of Bearings: The alignment of the centerline of Sand Road (North 90 degrees, 00 minutes, 00 seconds East) as determined by the Ohio State Plane Coordinate System North Zone (3401) NAD 83 (2007).

SEAL

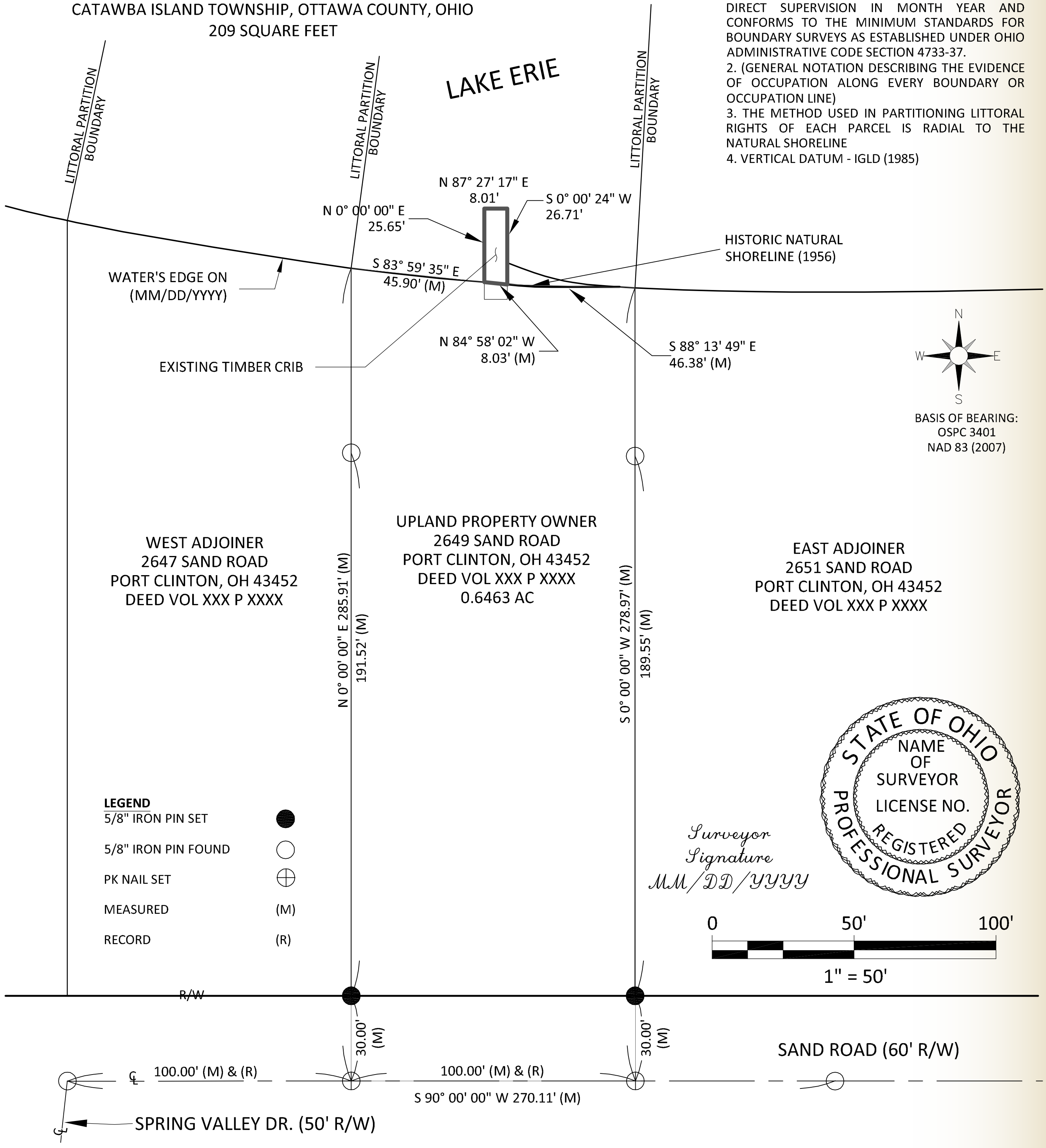
____
(NAME OF SURVEYOR)
Registered Surveyor (#XXXX)

SUBMERGED LANDS LEASE PLAT OF SURVEY

SUBMERGED LANDS ADJACENT TO
FRACTIONAL SECTION 35, TOWNSHIP 7 NORTH, RANGE 17 EAST,
NORTH AND EAST OF THE FIRST PRINCIPAL MERIDIAN,
CATAWBA ISLAND TOWNSHIP, OTTAWA COUNTY, OHIO
209 SQUARE FEET

SURVEYOR'S STATEMENT:

1. I, SURVEYOR'S NAME, CERTIFY THAT ALL MEASUREMENTS ARE CORRECT AND THAT ALL MONUMENTS INDICATED WERE FOUND OR SET AS SHOWN. THIS PLAT OF SURVEY IS BASED UPON AN ACTUAL FIELD SURVEY PERFORMED UNDER MY DIRECT SUPERVISION IN MONTH YEAR AND CONFORMS TO THE MINIMUM STANDARDS FOR BOUNDARY SURVEYS AS ESTABLISHED UNDER OHIO ADMINISTRATIVE CODE SECTION 4733-37.
2. (GENERAL NOTATION DESCRIBING THE EVIDENCE OF OCCUPATION ALONG EVERY BOUNDARY OR OCCUPATION LINE)
3. THE METHOD USED IN PARTITIONING LITTORAL RIGHTS OF EACH PARCEL IS RADIAL TO THE NATURAL SHORELINE
4. VERTICAL DATUM - IGLD (1985)



PROJECT: CONCRETE BLOCK SEAWALL	TITLE: SUBMERGED LANDS PLAT	PREPARED BY: SAMPLE SURVEYING AND ENGINEERING INC. STREET ADDRESS
ADJACENT PROPERTY OWNERS: WEST ADJOINER 2647 SAND ROAD, PORT CLINTON, OH 43452 EAST ADJOINER 2651 SAND ROAD, PORT CLINTON, OH 43452	APPLICANT: APPLICANT 2649 SAND ROAD PORT CLINTON, OH 43452	SHEET: 1 OF 1 — DATE: 02/01/2011