# WAVE ANALYSIS

## GRAND MARAIS, MI

by

U.S. ARMY CORPS OF ENGINEERS
DETROIT DISTRICT

MAY 2002

Wave Analysis
Grand Marais, MI

## Still-Water Elevation

The design water-surface elevations near Grand Marais, MI are summarized in Table 1. These elevations correspond to the still-water elevation plus storm surge for the given recurrence intervals and were determined in *Design Water Level Determination on the Great Lakes*, USACE, Detroit District, 1993. The elevations are based on a gage analysis of 122 years of data at Marquette, MI, and do not include the runup component. Lake Superior low water datum (LWD) is at 600.0 ft, IGLD 1955.

**Table 1: Summary of still-water elevations near Grand Marais, MI**

| Recurrence Interval | Still-Water Elevation | | |
|---|---|---|---|
| | IGLD 1955 | IGLD 1985 | Feet above LWD |
| 10 year | 603.0 ft | 604.1 ft | +3.0 |
| 20 year | 603.2 ft | 604.3 ft | +3.2 |
| 30 year | 603.4 ft | 604.5 ft | +3.4 |
| 50 year | 603.6 ft | 604.7 ft | +3.6 |

## Wave Analysis

A wave hindcast was performed and is described in *Design Wave Information for the Great Lakes: Lake Michigan*, U.S. Army Corps of Engineers, Waterways Experiment Station, 1978. This analysis of wind data from WIS station 49 yielded the 20-yr deep-water waves shown in Table 2.

**Table 2: Summary of deep-water wave heights from WIS hindcast**

| Angle Class | Significant Wave Height, ft ($H_s$) | Peak Period, sec ($T_p$) |
|---|---|---|
| 1 | 12.8 ft | 8.5 ft |
| 2 | 18.4 ft | 9.9 ft |
| 3 | 19.7 ft | 10.8 ft |

Given the configuration of the existing jetties and shoreline, waves from all three angle classes will impact the proposed configuration along the existing pile dike and the 15° offset breakwater. However, only waves from angle class 1 and 2 will impact the proposed structure with a 55° offset. To determine the angle class, a bearing is measured perpendicular to the harbor. The bearing at Grand Marais has been determined to be 180°. A perpendicular line is drawn through the origin of this bearing creating a half-plane in Cartesian space. The half-plane can be divided into three 60° arcs. Each arc represents an angle class starting with angle class 1 and increasing counter-clockwise.

The water depth in front of the proposed structures and the slope of the nearshore were estimated from NOAA Navigation Chart 14962. The water depths at the toe of the proposed structures are summarized in Table 3. These depths, which include storm surge and setup, are based on a historic survey, which may have significantly changed. The water depths in East Bay are dynamic as littoral material from the erosion of Lost Island and the east accretion fillet moves towards the shore and into West Bay.

**Table 3: Summary of depths and wave parameters**

| Configuration of proposed breakwater | Water depth at toe of structure w/ 20-yr SWL | Deep-water wave | Shallow-water wave | | Peak Period ($T_p$) |
|---|---|---|---|---|---|
| | | | $H_s$ | $H_{10}$ | |
| Existing Pile Dike | 19.2 ft | 19.7 ft | 11.7 ft | 13.8 ft | 10.8 sec |
| 15° Offset | 14.2 ft | 19.7 ft | 9.0 ft | 10.7 ft | 10.8 sec |
| 55° Offset | 12.2 ft | 18.4 ft | 7.5 ft | 8.7 ft | 9.9 sec |

The deepwater waves in Table 2 were transformed to shallow water waves using the TMA procedure and Goda's method. In all three instances, Goda's method produced a larger shallow-water wave and should be used in design calculations. The principal approach direction for all Goda calculations was assumed to be 0°.

## Summary

The design wave information for the three proposed structures at Grand Marais is summarized below:

- Design wave:

  Existing Pile Dike

  $H_s =$ 11.7 ft, non-breaking wave

  $H_{10} =$ 13.8 ft, non-breaking wave (use for stone sizing)

  $T_p =$ 10.8 sec

15° Offset

$H_s$ = 9.0 ft, non-breaking wave

$H_{10}$ = 10.7 ft, non-breaking wave (use for stone sizing)

$T_p$ = 10.8 sec

55° Offset

$H_s$ = 7.5 ft, non-breaking wave

$H_{10}$ = 8.7 ft, non-breaking wave (use for stone sizing)

$T_p$ = 9.9 sec

- Design still water elevation: 603.2 ft, IGLD 1955 (+3.2 ft above LWD)
  (20-yr recurrence) 604.3 ft, IGLD 1985

# RECONNAISANCE REPORT

for

# HARBOR OF REFUGE

# GRAND MARAIS, WISCONSIN

## APPENDIX B

## COST

| | |
|---|---|
| Harbor/River: | Grand Marais Harbor |
| State: | Michigan |
| Project Name: | Rubblemound Structure |
| (Describe) : | Reconnaissance Report |

# PLANNING ESTIMATES

Date of Estimate: 30 May 2002

EPD: 30 September 2002

| CWBS No. | Bid Item No. | Description of Features/Sub-Features | Alternative 1 (7,000 Lineal Feet Long) Quantity | UOM | U.P. | Estimate | Alternative 2 (4,800 Lineal Feet Long) Quantity | UOM | U.P. | Estimate | Alternative 3 (2,500 Lineal Feet Long) Quantity | UOM | U.P. | Estimate |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ***DREDGING*** | | | | | | | | | | | | |
| | 1 | Site Work | 1.00 | L.S. | $300,000.00 | $300,000.00 | 1.00 | L.S. | $300,000.00 | $300,000.00 | 1.00 | L.S. | $300,000.00 | $300,000.00 |
| | 2 | Armor Stone | | | | | | | | | | | | |
| | | a) (6 - 12 Ton) | 254,900.00 | Ton | $40.75 | $10,387,175.00 | | | | | | | | |
| | | b) (3 - 6 Ton) | | | | | 99,500.00 | Ton | $40.75 | $4,054,625.00 | | | | |
| | | c) (1.5 - 3 Ton) | | | | | | | | | 35,700.00 | Ton | $40.75 | $1,454,775.00 |
| | 3 | Underlayer Stone | | | | | | | | | | | | |
| | | a) (1,100 - 2,100 Lbs.) | 27,300.00 | Ton | $32.00 | $873,600.00 | | | | | | | | |
| | | b) (500 - 1,000 Lbs.) | | | | | 23,200.00 | Ton | $32.00 | $742,400.00 | | | | |
| | | c) (250 - 600 Lbs) | | | | | | | | | 7,700.00 | Ton | $32.00 | $246,400.00 |
| | 4 | Core Stone | | | | | | | | | | | | |
| | | a) (4 - 100 Lbs.) | 35,700.00 | Ton | $26.50 | $946,050.00 | | | | | | | | |
| | | b) (2 - 50 Lbs.) | | | | | 53,800.00 | Ton | $26.50 | $1,425,700.00 | | | | |
| | | c) (1 20 Lbs) | | | | | | | | | 21,800.00 | Ton | $26.50 | $577,700.00 |
| | 5 | Dredging | | | | | | | | | | | | |
| | | a) | | | | | | | | | | | | |
| | | b) | | | | | 36,000.00 | C.Y. | $12.25 | $441,000.00 | | | | |
| | | c) | | | | | | | | | 19,000.00 | C.Y. | $12.25 | $232,750.00 |
| | | ***Subtotal Contruction*** | | | | $12,506,825.00 | | | | $6,963,725.00 | | | | $2,811,625.00 |
| | | ***Contigency 15.0%*** | | | | $1,876,024.00 | | | | $1,044,559.00 | | | | $421,744.00 |
| | | ***Total Construction*** | | | | $14,382,849.00 | | | | $8,008,284.00 | | | | $3,233,369.00 |
| | | ***Non-Construction*** | | | | | | | | | | | | |
| | | ***Miscellaneous Costs*** | | | | | | | | | | | | |
| | | ***As Builts*** | | | | $10,000.00 | | | | $10,000.00 | | | | $10,000.00 |
| | | ***E & D During Construction*** | | | | $143,800.00 | | | | $80,100.00 | | | | $32,300.00 |
| | | ***Subtotal Miscellaneaous Costs*** | | | | $153,800.00 | | | | $90,100.00 | | | | $42,300.00 |
| | | ***Contigency 15.0%*** | | | | $23,100.00 | | | | $13,500.00 | | | | $6,300.00 |
| | | ***Total Miscellaneous Costs*** | | | | $176,900.00 | | | | $103,600.00 | | | | $48,600.00 |
| | | ***Planning & Design Analysis*** | | | | $130,000.00 | | | | $130,000.00 | | | | $130,000.00 |
| | | ***Construction Management*** | | | | $1,150,600.00 | | | | $640,700.00 | | | | $258,700.00 |
| | | ***Total Non-Construction*** | | | | $1,457,500.00 | | | | $874,300.00 | | | | $437,300.00 |
| | | ***Total Project*** | | | | $15,840,349.00 | | | | $8,882,584.00 | | | | $3,670,669.00 |

**Recommended TAB II Program Amount**

Prepared By: ____________________ Cost Engineer

Coordinated W/: ____________________ Technical Manager

# RECONNAISANCE REPORT

for

# HARBOR OF REFUGE

# GRAND MARAIS, WISCONSIN

## APPENDIX C

## DESIGN

✓BY: H CALAPPI

GRAND MARAIS

RUBBLEMOUND QTY

VOL OF STONE = (AREA OF CROSS SECTION) x (LENGTH)

CROSS SECTION AREAS FROM MICROSTATION

BREAKWATER LENGTHS FROM PLAN

EXISTING PILE DIKE (EPD)

| TYPE | AREA | LENGTH | VOL |
|---|---|---|---|
| ARMOR | 664.99 $FT^2$ | 7000 FT | 4654930 $FT^3$ |
| UNDERLAYER | 71.00 $FT^2$ | ↓ | 497000 $FT^3$ |
| CORE | 184.00 $FT^2$ | | 1288000 $FT^3$ |

15°

| TYPE | AREA | LENGTH | VOL |
|---|---|---|---|
| ARMOR | 378.48 $FT^2$ | 4800 FT | 1816704 $FT^3$ |
| UNDERLAYER | 88.04 $FT^2$ | ↓ | 422592 $FT^3$ |
| CORE | 204.48 $FT^2$ | | 981504 $FT^3$ |

55°

| TYPE | AREA | LENGTH | VOL |
|---|---|---|---|
| ARMOR | 260.16 $FT^2$ | 2500 FT | 650400 $FT^3$ |
| UNDERLAYER | 55.87 $FT^2$ | ↓ | 139675 $FT^3$ |
| CORE | 158.97 $FT^2$ | | 397425 $FT^3$ |

UNIT WEIGHT STONE : 168.48 lbs/$FT^3$

GRAND MARAIS – RUBBLEMOUND QTY

EPD

ARMOR

4654930 $FT^3 \cdot .65 \cdot 168.48 LBS/FT^3$ = 509770694 LBS

= 254885 TONS

UNDERLAYER

497000 $ft^3 \cdot .65 \cdot 168.48 lbs/ft^3$ = 54427464 lbs

= 27214 tons

CORE

1288000 $ft^3 \cdot .65 \cdot 168.48 lbs/ft^3$ = 141051456 lbs

= 70526 tons

15°

ARMOR

1816704 $ft^3 \cdot .65 \cdot 168.48 lbs/ft^3$ = 198950888 lbs

= 99475. tons

UNDERLAYER

422592 $ft^3 \cdot .65 \cdot 168.48 lbs/ft^3$ = 46278895 lbs

= 23139 tons

CORE

981504 $ft^3 \cdot .65 \cdot 168.49 lbs/ft^3$ = 107486466 lbs

= 53743. tons

GRAND MARAIS

RUBBLEMOUND QTY

55°

ARMOR

650400 $ft^3$ · .65 · 168.48 lbs/$ft^3$ = 71226605 lbs

= 35613. tons

UNDERLAYER

139675 $ft^3$ · .65 · 168.48 lbs/$ft^3$ = 15296089 lbs

= 7648. tons

CORE

397425 $ft^3$ · .65 · 168.48 lbs/$ft^3$ = 43522807. lbs

= 21761 tons

GRAND MARAIS

ARMOR STONE

PRIMARY RUBBLEMOUND PROTECTION IS DESIGNED USING THE HUDSON FORMULA. REF 1984 SHORE PROTECTION MANUAL PG 7-205, FORMULA 7-116

$$W = \frac{W_r H^3}{K_D (S_r - 1)^3 \cot\theta}$$

$W$ = WEIGHT INDIVIDUAL ARMOR UNIT IN THE PRIMARY LAYERS, lbs

$W_r$ = UNIT WEIGHT OF ARMOR STONE, lbs/ft$^3$

$H$ = DESIGN WAVE HEIGHT, ft

$K_D$ = STABILITY COEFFICIENT (TB 7-8, SPM)

$S_r$ = SPECIFIC GRAVITY OF ARMOR STONE, $W_r/W_w$

$S_r$ = 2.7 $W_w$ = UNIT WT $H_2O$

$\theta$ = ∡ OF STRUCTURE SLOPE FROM HORIZONTAL

$G_s = 2.7$ PER RLE

GRAND MARAIS

$W_r = G_s \times 62.4 \text{ lbs/ft}^3$

$= 2.7 \times 62.4 \text{ lbs/ft}^3$

$W_r = 168.48 \text{ lbs/ft}^3$

RUBBLE SLOPE BOTH SIDES

1V : 2H

$\theta = \tan^{-1}(1/2) = 26.57^\circ \quad \cot\theta = 2$

$K_D = 2.8$ FROM TABLE 7-8 1977 SPM
STRUCTURE HEAD

REFERENCE: GRAND MARAIS WAVE ANALYSIS
21 MAY 02
SPS

EXISTING PILE DIKE (EPD) $H_{10} = 13.8$ ft

150 $H_{10} = 10.7$ ft

55° $H_{10} = 8.7$ ft

EPD $W = \dfrac{168.48 \text{ lbs/ft}^3 \cdot (13.8 \text{ ft})^3}{2.8(2.7-1)^3 \cdot 2}$

$= 16094$ lbs

$= 8.04$ tons $\approx 8$ tons

GRAND MARAIS

15°
$$W = \frac{168.48\ lbs/ft^3 \cdot (10.7\ ft)^3}{2.8\,(2.7-1)^3 \cdot 2}$$

= 7502 lbs

= 3.75 tons ≈ 4 tons

55°
$$W = \frac{168.48\ lbs/ft^3 \cdot (8.7\ ft)^3}{2.8\,(2.7-1)^3 \cdot 2}$$

= 4032 lbs

= 2.01 tons ≈ 2 ton

UNDERLAYER STONE/CORE LAYER STONE

FIG 7-117 SPM

UNDERLAYER STONE

EPD $\frac{W}{10} = \frac{16094\ lbs}{10} = 1609\ lbs$

15° $\frac{W}{10} = \frac{7502\ lbs}{10} = 750\ lbs$

55° $\frac{W}{10} = \frac{4032\ lbs}{10} = 403\ lbs$

CORE LAYER STONE

EPD $\frac{W}{200} = \frac{16094\ lbs}{200} = 80.5\ lbs$

15° $\frac{W}{200} = \frac{7502\ lbs}{200} = 37.5\ lbs$

55° $\frac{W}{200} = \frac{4032\ lbs}{200} = 20.2\ lbs$

GRAND MARAIS

CORE LAYER STONE

EPD $\frac{W}{4000} = \frac{16094 \text{ lbs}}{4000} = 4.02$ lbs

15° $\frac{W}{4000} = \frac{7502 \text{ lbs}}{4000} = 1.9$ lbs

55° $\frac{W}{4000} = \frac{4032 \text{ lbs}}{4000} = 1$ lbs

LAYER GRADATION

ARMOR STONE

EPD 1.5 W = 1.5( 16094 lbs) = 24141 lbs

.75 W = .75 ( 16094 lbs) = 12071 lbs

USE 1.5 W PER RLE

∴ 6 – 12 ton STONE W/75% GREATER THAN 8 ton

15° 1.5 W = 1.5( 7502 lbs) = 11253 3 lbs

.75 W = .75 ( 7502 lbs) = 5627 lbs

∴ 3 – 6 lbs STONE W/75% GREATER THAN 7500 lbs

55° 1.5 W = 1.5( 4032 lbs) = 6048 lbs

.75 W = .75 ( 4032 lbs) = 3024 lbs

∴ 3000 – 6000 lbs STONE W/75% GREATER THAN 4000 lbs

GRAND MARAIS

UNDERLAYER STONE

EPD $1.3 (W/10) = 1.3 (1609 \text{ lbs}) = 2092 \text{ lbs}$

$.7 (W/10) = .7 (1609 \text{ lbs}) = 1126 \text{ lbs}$

∴ 1100 – 2100 lbs STONE W/ 75%

GREATER THAN 1600 lbs

15° $1.3 (W/10) = 1.3 (750 \text{ lbs}) = 975 \text{ lbs}$

$.7 (W/10) = .7 (750 \text{ lbs}) = 525 \text{ lbs}$

∴ 500 – 1000 lbs STONE W/ 75%

GREATER THAN 750 lbs

55° $1.3 (W/10) = 1.3 (403 \text{ lbs}) = 524 \text{ lbs}$

$.7 (W/10) = .7 (403 \text{ lbs}) = 282 \text{ lbs}$

∴ 250 – 600 lbs STONE W/ 75%

GREATER THAN 400 lbs

CORE STONE

EPD ∴ 4 – 100 lbs (UNIFORM GRADE)

15° ∴ 2 – 50 lbs

55° ∴ 1 – 20 lbs ↓

GRAND MARAIS

LAYER THICKNESS

$$R = n k_\Delta \left(\frac{W}{W_r}\right)^{1/3} \quad (\text{EQ } 7\text{-}121, \text{ SPM})$$

R = LAYER THICKNESS, ft

$k_\Delta$ = LAYER COEFFICIENT (SPM - TABLE 7-13)

n = # STONE UNITS

ARMOR STONE: $n = 2$ $k_\Delta = 1.0$

EPD

$$r = 2 \cdot 1.0 \left(\frac{16094 \text{ lbs}}{168.48 \text{ lbs/ft}^3}\right)^{1/3}$$

$= 9.1$ ft $\approx 9$ ft

15°

$$r = 2 \cdot 1.0 \left(\frac{7502 \text{ lbs}}{168.48 \text{ lbs/ft}^3}\right)^{1/3}$$

$= 7.1$ ft $\approx 7$ ft

55°

$$r = 2 \cdot 1.0 \left(\frac{4032 \text{ lbs}}{168.48 \text{ lbs/ft}^3}\right)^{1/3}$$

$= 5.76$ ft $\approx 6$ ft

UNDERLAYER STONE: $n = 2$ $k_\Delta = 1.0$

EPD

$$r = 2 \cdot 1.0 \left(\frac{\quad \text{ lbs}}{168.48 \text{ lbs/ft}^3}\right)^{1/3}$$

$= 4.2$ ft $\approx 4$ ft

GRAND MARAIS

15°

$$r = 2 \cdot 1.0 \left( \frac{750 \text{ lbs}}{168.45 \text{ lbs/ft}^3} \right)^{1/3}$$

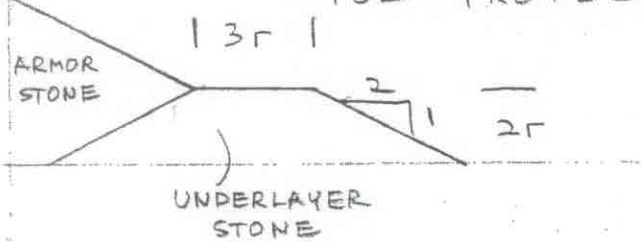
$$= 3.3 \text{ ft} \simeq 3 \text{ ft}$$

55°

$$r = 2 \cdot 1.0 \left( \frac{403 \text{ lbs}}{168.45 \text{ lbs/ft}^3} \right)^{1/3}$$

$$= 2.7 \text{ ft} \simeq 2.5 \text{ ft}$$

TOE PROTECTION




EPD $3r = 12$ ft

$2r = 8$ ft

15° $3r = 9$ ft

$2r = 6$ ft

55° $3r = 7.5$ ft

$2r = 5$ ft

GRAND MARAIS

CREST WIDTH

$$B = n k_{\Delta} \left(\frac{W}{w_r}\right)^{1/3} \quad (\text{EQ } 7\text{-}120 \text{ SPM})$$

EPD

$$B = 3 \cdot 1.0 \left(\frac{16094 \text{ lbs}}{168.48 \text{ lbs/ft}^3}\right)^{1/3}$$

$$= 13.7 \text{ ft} \simeq 14 \text{ ft}$$

15°

$$B = 3 \cdot 1.0 \left(\frac{7502 \text{ lbs}}{168.48 \text{ lbs/ft}^3}\right)^{1/3}$$

$$= 10.6 \text{ ft} \simeq 11 \text{ ft}$$

55°

$$B = 3 \cdot 1.0 \left(\frac{4032 \text{ lbs}}{168.48 \text{ lbs/ft}^3}\right)^{1/3}$$

$$= 8.6 \text{ ft} \simeq 9 \text{ ft}$$