ESTIMATION OF WAVE TRANSMISSION COEFFICIENTS FOR PERMEABLE BREAKWALLS

UNCLASSIFIED

CERC-CETA-79-6
Estimation of Wave Transmission Coefficients for Permeable Breakwaters

by

William N. Seelig

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The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.
The Madsen and White (1976) analytical model of wave transmission through permeable breakwaters is combined with a wave transmission by overtopping formula to provide a method of predicting wave transmission coefficients for permeable breakwaters. Comparison of this combined prediction technique with physical model laboratory tests shows that the technique is useful for estimating transmission coefficients for design. A computer program was found the most convenient method of making predictions. The computer program and an example showing program use are included in an Appendix.
This report describes methods for predicting wave transmission coefficients for permeable breakwaters using a transmission by overtopping equation together with the analytical model of Madsen and White (1976). This technique has been tested with physical model results for nonbreaking and some breaking waves, for monochromatic and irregular wave conditions, and for riprap and some concrete armor unit breakwaters (Seelig, in preparation, 1979). The technique was found to give useful predictions of transmission coefficients for design. The work was carried out under the offshore breakwaters for shore stabilization program of the U.S. Army Coastal Engineering Research Center (CERC).

This report was prepared by William N. Seelig, Hydraulic Engineer, under the general supervision of Dr. R.M. Sorensen, Chief, Coastal Processes and Structures Branch.

Comments on this publication are invited.

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TED E. BISHOP
Colonel, Corps of Engineers
Commander and Director
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CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

<table>
<thead>
<tr>
<th>Multiply</th>
<th>by</th>
<th>To obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>inches</td>
<td>25.4</td>
<td>millimeters</td>
</tr>
<tr>
<td></td>
<td>2.54</td>
<td>centimeters</td>
</tr>
<tr>
<td>square inches</td>
<td>6.452</td>
<td>square centimeters</td>
</tr>
<tr>
<td>cubic inches</td>
<td>16.39</td>
<td>cubic centimeters</td>
</tr>
<tr>
<td>feet</td>
<td>30.48</td>
<td>centimeters</td>
</tr>
<tr>
<td></td>
<td>0.3048</td>
<td>meters</td>
</tr>
<tr>
<td>square feet</td>
<td>0.0929</td>
<td>square meters</td>
</tr>
<tr>
<td>cubic feet</td>
<td>0.0283</td>
<td>cubic meters</td>
</tr>
<tr>
<td>yards</td>
<td>0.9144</td>
<td>meters</td>
</tr>
<tr>
<td>square yards</td>
<td>0.836</td>
<td>square meters</td>
</tr>
<tr>
<td>cubic yards</td>
<td>0.7646</td>
<td>cubic meters</td>
</tr>
<tr>
<td>miles</td>
<td>1.6093</td>
<td>kilometers</td>
</tr>
<tr>
<td>square miles</td>
<td>259.0</td>
<td>hectares</td>
</tr>
<tr>
<td>knots</td>
<td>1.852</td>
<td>kilometers per hour</td>
</tr>
<tr>
<td>acres</td>
<td>0.4047</td>
<td>hectares</td>
</tr>
<tr>
<td>foot-pounds</td>
<td>1.3558</td>
<td>newton meters</td>
</tr>
<tr>
<td>millibars</td>
<td>1.0197 x 10^{-3}</td>
<td>kilograms per square centimeter</td>
</tr>
<tr>
<td>ounces</td>
<td>28.35</td>
<td>grams</td>
</tr>
<tr>
<td>pounds</td>
<td>453.6</td>
<td>grams</td>
</tr>
<tr>
<td></td>
<td>0.4536</td>
<td>kilograms</td>
</tr>
<tr>
<td>ton, long</td>
<td>1.0160</td>
<td>metric tons</td>
</tr>
<tr>
<td>ton, short</td>
<td>0.9072</td>
<td>metric tons</td>
</tr>
<tr>
<td>degrees (angle)</td>
<td>0.01745</td>
<td>radians</td>
</tr>
</tbody>
</table>
| Fahrenheit degrees | 5/9       | Celsius degrees or Kelvins^{1}      

^{1}To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: C = (5/9) (F -32).
To obtain Kelvin (K) readings, use formula: K = (5/9) (F -32) + 273.15.
I. INTRODUCTION

The primary purpose of a breakwater is to reduce wave energy in an area to be sheltered. One of the important characteristics of a breakwater is the magnitude of the wave transmission coefficient, defined as the ratio of the transmitted wave height to the incident wave height.

Two basic types of wave transmission are: (a) by overtopping that occurs when wave runup exceeds the crest elevation of the breakwater, overtops the breakwater, and generates waves in the lee; and (b) through a permeable structure that occurs because some of the wave energy is not dissipated by the breakwater and is transmitted through the breakwater. The total wave transmission coefficient, $K_T$, is given by:

$$K_T = \sqrt{(K_{TO})^2 + (K_{TT})^2} = H_T/H_I$$

where

$K_{TO}$ = transmission by overtopping coefficient

$K_{TT}$ = coefficient of transmission through the structure

$H_I$ = incident wave height

$H_T$ = transmitted wave height

These and other symbols are defined in Figure 1.

Since the prediction method is complex, particularly for transmission through the structure, a computer program is presented in an Appendix to this report. The program incorporates the analytical model to determine $K_{TT}$ by Madsen and White (1976)\(^1\) and an empirical equation to determine $K_{TO}$ developed by Seelig (in preparation, 1979)\(^2\).

---


Figure 1. Definition of terms for wave transmission for permeable breakwaters.

II. WAVE TRANSMISSION BY OVERTOPPING

Wave transmission by overtopping occurs when wave energy is transmitted by flow over the top of a structure. The transmission by overtopping coefficient can be estimated using (Seelig, in preparation, 1979)\(^3\):

\[
K_{TO} = C (1 - F/R) \tag{2}
\]

\[
= 0 \text{ for } F/R \text{ greater than } 1.0
\]

where

\begin{align*}
R &= \text{wave runup} \\
F &= \text{breakwater freeboard, defined as the structure height, } h, \text{ minus the water depth, } d_s \\
C &= \text{an empirical coefficient} \\
(K_{TO})_{\text{max}} &= 1.0
\end{align*}

Laboratory tests show that the value of \(C\) is related to the crest width of the structure, \(B\):

\[
C = 0.51 - 0.11 \frac{B}{h} \tag{3}
\]

Thus, a slight decrease in the transmission by overtopping occurs as the structure crest width increases.

\(^3\)SEELIG, W.N., op. cit., p. 7.
Wave runup is estimated using the formula (Ahrens and McCartney, 1975):

\[
\frac{R}{H_r} = \frac{ae}{1 + be}
\]  

(4)

where \( a = 0.692 \) and \( b = 0.504 \) are recommended for rubble-mound breakwaters and \( a = 0.988 \) and \( b = 0.703 \) are recommended for a breakwater armored with two layers of dolos. \( \xi \) is the surf parameter given by

\[
\xi = \frac{\tan \phi}{\sqrt{H_r/L_0}}
\]  

(5)

where \( \phi \) is the angle of the seaward face of the breakwater, and \( L_0 \) is the deepwater wavelength obtained from linear wave theory. Calculations of wave transmission by overtopping are performed automatically in the program MADSEN (see App.).

III. WAVE TRANSMISSION THROUGH PERMEABLE BREAKWATERS

The coefficient of wave transmission through permeable breakwaters, \( K_{tr} \), is estimated using the analytical model of Madsen and White (1976). In this model the transmission coefficient is related to a complex function of the size and porosity of the materials used in building the breakwater (Table 1), the breakwater geometry, the seaward

<table>
<thead>
<tr>
<th>Armor unit</th>
<th>No. of layers</th>
<th>Placement</th>
<th>Porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quarry stone (smooth)</td>
<td>2</td>
<td>random</td>
<td>0.38</td>
</tr>
<tr>
<td>Quarry stone (rough)</td>
<td>2</td>
<td>random</td>
<td>0.37</td>
</tr>
<tr>
<td>Quarry stone (rough)</td>
<td>&gt;3</td>
<td>random</td>
<td>0.40</td>
</tr>
<tr>
<td>Cube (modified)</td>
<td>2</td>
<td>random</td>
<td>0.47</td>
</tr>
<tr>
<td>Tetrapod</td>
<td>2</td>
<td>random</td>
<td>0.50</td>
</tr>
<tr>
<td>Quadripod</td>
<td>2</td>
<td>random</td>
<td>0.49</td>
</tr>
<tr>
<td>Tribar</td>
<td>2</td>
<td>random</td>
<td>0.47</td>
</tr>
<tr>
<td>Tribar I</td>
<td>2</td>
<td>random</td>
<td>0.54</td>
</tr>
<tr>
<td>Tribar</td>
<td>2</td>
<td>random</td>
<td>0.63</td>
</tr>
<tr>
<td>Triar</td>
<td>1</td>
<td>uniform</td>
<td>0.47</td>
</tr>
</tbody>
</table>


slope of the structure, water depth, wave height and period, and the kinematic viscosity of water (Table 2). To use this method, waves should have

\[
\frac{d}{L} \leq \frac{1.25}{H_I \cot^2 \theta}
\]

where \( L \) is local wavelength.

Table 2. Kinematic viscosity of water.

<table>
<thead>
<tr>
<th>Water temperature (°C)</th>
<th>Kinematic viscosity of water (m²/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>0.00000018</td>
</tr>
<tr>
<td>10°</td>
<td>0.0000013</td>
</tr>
<tr>
<td>20°</td>
<td>0.0000010</td>
</tr>
<tr>
<td>30°</td>
<td>0.0000008</td>
</tr>
</tbody>
</table>

The Madsen and White model was tested against laboratory data for permeable breakwaters (Seelig, in preparation, 1979) and was shown to give useful estimates for both monochromatic and irregular waves. For irregular wave conditions, the wave input to the program should be the mean wave height and period of peak energy density. A few tests with breaking waves suggest that the prediction method can also be used with breaking waves. The Madsen and White model appears to effectively account for breaking wave energy losses, although it does not explicitly include breaking. Tests of breakwaters armored with dolos units suggest that the program can also be used for artificial armor units. Comparison with laboratory data shows that the model gives the best predictions for shallow-water waves. Predictions of transmission coefficients tend to be conservative for transitional or deepwater waves. Refer to Seelig (in preparation, 1979) or Madsen and White (1976) for more information. Figure 2 shows a comparison between wave transmission coefficients observed in a laboratory model and predicted using the methods described in this CETA.

IV. EXAMPLE

Use of the computer program (MADSEN) in the Appendix can be best illustrated by an example. The format of required input information is given in Table 3. Any number of breakwater geometries, water depths or wave conditions can be analyzed in a single run. The first 53 cards are a standard deck of look-up (input) tables (see Table A-1); card type 1 provides the number of breakwater configurations or water depths to analyze. Card types 2 to 6 give required input information for each breakwater of interest; however, a separate set of these card types is required when the breakwater geometry or water depth is changed.

---

7 SEELIG, W.N., op. cit., p. 7.
8 MADSEN, O.S., and WHITE, S.M., op. cit., p. 7.
Figure 2. Observed and predicted transmission coefficients for a rubble-mound breakwater.
Table 3. Format of input information.

<table>
<thead>
<tr>
<th>Card type</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>I2</td>
<td>53 standard input cards</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of breakwater configurations or water depths to test</td>
</tr>
<tr>
<td>2</td>
<td>20A4</td>
<td>Title card</td>
</tr>
<tr>
<td>3</td>
<td>3I2,4X,7Fl0.5</td>
<td>Number of wave conditions to test</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of materials</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of horizontal layers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Structure height (m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Water depth (m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kinematic viscosity (m²/s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Width of top of breakwater (m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Front slope of breakwater = tan (θ)</td>
</tr>
<tr>
<td>4</td>
<td>10x,2Fl0.5</td>
<td>Wave runup parameter a = 0.692</td>
</tr>
<tr>
<td></td>
<td>(1 card per material)</td>
<td>Wave runup parameter b = 0.504</td>
</tr>
<tr>
<td>5</td>
<td>10x,7Fl0.5</td>
<td>Material diameter (m) (armor 1st)</td>
</tr>
<tr>
<td></td>
<td>(1 card per horizontal layer)</td>
<td>Material porosity</td>
</tr>
<tr>
<td>6</td>
<td>2Fl0.5</td>
<td>Layer thickness (m)</td>
</tr>
<tr>
<td></td>
<td>(wave condition card; one card per wave condition)</td>
<td>Mean length of each material type in the layer (put in consecutive order; e.g., material 1 (armor) 1st, etc.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wave period (s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wave heights (m)</td>
</tr>
</tbody>
</table>

Repeat card types 2 to 6 for each water depth or breakwater configuration to be tested.

Card type 3 gives the number of wave conditions to analyze and summarizes general input information (Table 3). For the example breakwater (Fig. 3), 18 wave conditions with periods of 5, 10, and 20 seconds and with heights that range from 0.1 to 2.0 meters, are analyzed.

Card type 4 gives material characteristics, one card per material and the first card should describe the armor material. The example gives three materials (armor, underlayer, and core); diameter and porosity of the materials are shown in Figure 3.

Card type 5 is used to input the mean horizontal length of various materials in various horizontal layers of the breakwater. A new horizontal layer occurs when there is a change vertically in material type or slope and the layer next to the seabed should be designated as "layer number 1." In the case of the example breakwater, three horizontal layers...
are shown in Figure 4. Sample horizontal length calculations are also included. Note that when determining horizontal lengths of the armor material, the outer layer of the armor on the seaward side of the breakwater should be "removed" first because dissipation of the seaward face is determined in a separate part of the computer program.

Table 4 gives the computer program input information required for the example; Table 5 is the resulting program output. The output shows that predicted transmitted wave height for this example is a complex function of incident wave height and period.

<table>
<thead>
<tr>
<th>EXAMPLE PROBLEM</th>
<th>10 3 3</th>
<th>6.0</th>
<th>0.6</th>
<th>0.00000093</th>
<th>2.52</th>
<th>0.697</th>
<th>0.504</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAT 1</td>
<td>0.729</td>
<td>0.37</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAT 2</td>
<td>0.318</td>
<td>0.57</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAT 3</td>
<td>0.092</td>
<td>0.37</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAY 1</td>
<td>3.55</td>
<td>4.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAY 2</td>
<td>0.74</td>
<td>4.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAY 3</td>
<td>0.47</td>
<td>5.25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>others</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAT 1</td>
<td>0.729</td>
<td>0.37</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAT 2</td>
<td>0.318</td>
<td>0.57</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAT 3</td>
<td>0.092</td>
<td>0.37</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAY 1</td>
<td>3.55</td>
<td>4.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAY 2</td>
<td>0.74</td>
<td>4.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAY 3</td>
<td>0.47</td>
<td>5.25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>others</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

V. SUMMARY

A computer program is presented for estimation of wave transmission coefficients for permeable breakwaters. Extensive testing of the program with laboratory data has shown that the program can be used to estimate transmission coefficients for monochromatic or irregular waves and for rubble-mound or other types of permeable breakwaters. A limited amount of testing suggests that it can also be used for breaking and nonbreaking waves.

A copy of the card deck and more extensive program documentation for the computer program MADSEN (CERC Program Number 7S2X6R1CPO) are available from the ADP Coordinator at CERC. The cost of running the program on a CINC 6600 computer is only a few cents for each wave condition of interest.
Figure 4. Information required for (horizontal layer) example breakwater.
**Example Problem**

**Computations of Wave Transmission Through a Porous Breakwater**

<table>
<thead>
<tr>
<th>Num of Wave Conditions</th>
<th>18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Num of Materials</td>
<td>3</td>
</tr>
<tr>
<td>Num of Horizontal Layers</td>
<td>3</td>
</tr>
<tr>
<td>Structure Height (m)</td>
<td>4.00</td>
</tr>
<tr>
<td>Water Depth (m)</td>
<td>4.00</td>
</tr>
<tr>
<td>Kinematic Viscosity (m2/sec)</td>
<td>0.0000009430</td>
</tr>
<tr>
<td>SW Top Width (m)</td>
<td>2.520</td>
</tr>
<tr>
<td>Tan of Front Slope</td>
<td>0.670</td>
</tr>
</tbody>
</table>

**Material Characteristics (Make Armor Material Number 1)**

<table>
<thead>
<tr>
<th>Material</th>
<th>1 Diameter (m)</th>
<th>2 Diameter (m)</th>
<th>3 Diameter (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.729 Porosity</td>
<td>0.730 Porosity</td>
<td>0.730 Porosity</td>
</tr>
</tbody>
</table>

**Horizontal Layer Characteristics (Make Layer Next to Seabed Layer Number 1)**

<table>
<thead>
<tr>
<th>Material</th>
<th>1 Thickness (m)</th>
<th>2 Thickness (m)</th>
<th>3 Thickness (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.550 Lengths (m)</td>
<td>4.5 Lengths (m)</td>
<td>4.5 Lengths (m)</td>
</tr>
</tbody>
</table>

**Table 5. Sample output.**

<table>
<thead>
<tr>
<th>H(M)</th>
<th>T(SEC)</th>
<th>H/(GRT/FT)</th>
<th>H/L</th>
<th>D/(GRT/FT/)(KTY)</th>
<th>KT</th>
<th>KTO</th>
<th>KT</th>
<th>KR</th>
<th>W(H)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.00</td>
<td>4.00</td>
<td>200944</td>
<td>0.0335</td>
<td>0.0196</td>
<td>0.391</td>
<td>0.000</td>
<td>0.391</td>
<td>0.000</td>
<td>0.039</td>
</tr>
<tr>
<td>5.00</td>
<td>3.00</td>
<td>200944</td>
<td>0.0335</td>
<td>0.0196</td>
<td>0.391</td>
<td>0.000</td>
<td>0.391</td>
<td>0.000</td>
<td>0.039</td>
</tr>
<tr>
<td>5.00</td>
<td>4.00</td>
<td>200944</td>
<td>0.0335</td>
<td>0.0196</td>
<td>0.391</td>
<td>0.000</td>
<td>0.391</td>
<td>0.000</td>
<td>0.039</td>
</tr>
<tr>
<td>5.00</td>
<td>5.00</td>
<td>200944</td>
<td>0.0335</td>
<td>0.0196</td>
<td>0.391</td>
<td>0.000</td>
<td>0.391</td>
<td>0.000</td>
<td>0.039</td>
</tr>
</tbody>
</table>

**Key:**

- KTY = Wave Transmission Through the Structure
- KTO = Wave Transmission by Nettopping Coefficient
- KT = Total Wave Transmission Coefficient
- KR = Wave Reflection Coefficient
- HT = Transmitted Wave Height
APPENDIX

LISTING OF THE COMPUTER PROGRAM MADSEN

```fortran
PROGRAM HANSEN(INPUT,OUTPUT,TABLES,INPUT,TAPE6,OUTPUT,TAPE5)
COMMON/AUS1/AM,NL,L(J1),T(11),V(11),LL(11),TH(11),DATA,SM(IT),SM(TT)
REAL NL
DIMENSION THF(11),TITLE(20),NUM(10)
REAL L(J1),KX,JX,K1,NT,JL,JL,KX,K1
DATA NUM(/12,3,5,6,7,8,9,10)
PI=3.14159265
CALL READ
READ(*,590) NCUMP
590 FORMAT(15X,7F10.5)
DO 200 I=1,NCUMP
C READ INPUT [FORMATS]
READ(*,171) (TITLE(JJ),JJ=1,20)
171 FORMAT(20A4)
WRITE(*,172) (TITLE(JJ),JJ=1,20)
172 FORMAT(15X,10X,20A4)
READ(*,590) NT,J1,J2,J3,J4,J5,J6,J7,J8,J9,J10,J11,J12,J13,J14,J15,J16,J17,J18,J19,J20
DATA NUM(/12,3,5,6,7,8,9,10)
IF (J1,1,0) III,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,J1,
CONTINUE
N(M)=M+1
N(M)=0
N(M)=M+1
TTNL=M
LL(TNL)=M,0,N(1)
WRITE(A,960)

FORMAT(/a,N1,H(SEC) H/(GET/E)) H/L D/(GET/E) KIT
ON 190 IK=1,NT
READ(S,K,T,H)

FORMAT(210,5)
=+0.5
DHE=0.(1+0.5)
IF(A(TL,TT,TNL,0) .LT. TO)
IF(TANH(TL,0) .GE. 37)
CALL PFL(A,HTS,*M(I),H(I),TANR,TRI,TRI)
A=0.1

DHT=1.0
IF(ICTU.TE.1.4) GO TO 10
KCH=1
KIT=1

IF(TANH(TL,0) .GE. 37)
CALL INTER(I,1,T,1,1,MU,MU,0,1),KTT,KR,I,IFLAG)
IF(IFLAG,F0.1) DHE=0.45
IF(IFLAG,F0.1) GO TO 27
DHE=(1,40)*F11
IF(ICTU.TE.1,4) GO TO 10
KCH=1
KIT=1

IF(TANH(TL,0) .GE. 37)
CALL INTER(I,1,T,1,1,MU,MU,0,1),KTT,KR,I,IFLAG)
IF(IFLAG,F0.1) O=0.5
IF(IFLAG,F0.1) GO TO 37
SURF=SURF/SURF(H/(1,56656))
SURF=0.005
RETURN
RETURN
END
CEN,51 = 1.0*10P1/HS
KDO=0.1*4K
IF((TOPW/HS),GT,1.10000,FR,LT,0.01) KTEC=(1.0-FR)/(1.0-2.0FLidency)
IF(KDO,GT,1.0) KTP=1
IF(IP,GT,1.0) KTNP=1
HGT2=2.4/(1.001)*T
H=1.0
HGT=1.4/(1.001)*T
FLAG=0
KTS=0.001*KTS+2.001*KTS+2.0101
IF(KTS,LT,1.0) KTS=1.0
IF(KTP,GT,1.0) WRITE(A,981) H=3,GT2=1.0
IF(IP,GT,1.0) WRITE(A,981) H=3,GT2=1.0
IF(KDO,GT,1.0) WRITE(A,981) H=3,GT2=1.0
IF(IFLAG,GT,1.0) WRITE(A,981) H=3,GT2=1.0
IF(IFLAG,GT,1.0) WRITE(A,981) H=3,GT2=1.0
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IF(IFLAG,GT,1.0) WRITE(A,981) H=3,GT2=1.0
IF(IFLAG,GT,1.0) WRITE(A,981) H=3,GT2=1.0
* **FORMAT**: 

```
201 FORMAT(///2X,1X,IT=1,3W4,F2.0,3X,TX(4,10),RT(7,11),TX(9,10))
* 2X,1X = HAVE TRANSMISSION THROUGH THE STRUCTURE
* 2X,1X,IT = TOTAL HAVVE TRANSMISSION COEFFICIENT
* 2X,1X,IT= TOTAL HAVVE TRANSMISSION COEFFICIENT
* 2X,1X,IT= TOTAL HAVVE TRANSMISSION COEFFICIENT
* 2X,1X,IT= TOTAL HAVVE TRANSMISSION COEFFICIENT
```
177 FORMAT(5X,10F4.0)
   DO 1 NI=1,11
1   READ(5,177) (ST(N)+N4+9)
   DO 2 NE=1,11
2   READ(5,177) (HT(N)+N4+9)
   DO 3 NL=1,11
3   READ(5,177) (N(N)+N4+17)
   DO 4 NW=1,11
4   READ(5,177) (TX(N)+N4+19)
   DO 5 NH=1,11
5   READ(5,177) (NX(N)+N4+19)
   RETURN
END

SUBROUTINE LENGTH
REAL LI,LUN
LD=1.0/LI
LUN=1.0/0
NE=1
P1=1.0+I
1 ARG=dx+P1/LI
LUN=Li+TANH(ARG)
N2=1
DIFF=AHSLN=LD)
IF(N=200) GO TO 4
3 IF(DIFF<0.0005) PE=5
5 LD=LD+1.0/PA
GO TO 1
4 DL=1.0/LI
END

SUBROUTINE LENGTH NOT CONVERGED: D/L0 = *F10.5*
1 DL=1.0/LI
   RETURN
END

SUBROUTINE FORM(DML,MLT,LX,H,TS,TANH,NR,TOP)
COMMON/MUL1770L+?1(N)+L(1+11)+L(11+11),T(11+11)
DIMENS:REAL RETA(11)+T(11)
REAL NP=L/30
      REAL DP=-3.5
      RETA(1)=F2+373.1+2(N)+2(N)+3071)
      TM=20,
      THM=0.
      DO 4 J=1,10
         TM=TM+TH(J)
      NDL=0.
      TM=0.
         IF(TM<TH(J)/MD) MD=J+TMD)/MD
         IF(TM<TH(J)) GO TO 5
      4 THM=THM+TH(J)
5      SUM=0.
      DO 16 J=1,10
         SUM=0.
      16 J=1,10
      SUM=SUM+RETA(1)/TANH(J+1)
      RETURN
      END
Table A-1. Standard look-up tables to be read by subroutine REDI.

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Seelig, William N.

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Cover title.

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