DDS 100-9

DESIGN DATA SHEET

NUCLEAR AIRBLAST DESIGN FOR SURFACE SHIP STRUCTURES

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
WASHINGTON, D.C. 20362-5101

Design Data Sheet

Nuclear Airblast Design for Surface Ship Structure

DDS 100-9

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100-9-a. INTRODUCTION

100-9-a.(1) Purpose.

The purpose of this DDS is to define and describe an acceptable procedure for the design of surface ship structure to resist nuclear blast loadings. The procedure included in this DDS is applicable for the design of surface ship structures to resist in-air non-contact tactical nuclear weapons explosions of low- to medium-yield. For design purposes, the blast and shock wave are considered to originate just above the surface, with the blast wave front perpendicular to the surface (see Figure 1). In-depth knowledge of gas dynamics involved in airblast phenomena is not needed to use this design procedure.

100-9-a. (2). Scope

This DDS is intended for use in the design of ship structure for practical ranges of airblast overpressure effects. The following design constraints are included:

- STRUCTURAL MODEL
  - Structural type consisting of open (truss) or closed (box) structures which can be modeled as single-degree-of-freedom systems and can develop the full plastic moment of the unaltered cross section at all points along the span. Response of multi-degree-of freedom systems are addressed in reference 1.
- AIRBLAST
  - The pressure loadings are given for each face of a "closed box" structure.
  - A method for calculating the structural resistance to airblast. This method provides the design/analysis approach.

- THERMAL PULSE

  - See section 100.9.g.

100-9-b. REFERENCES

1. Wang, S. L. and H. Gray, "Dynamic Response of Elastoplastic Beam Girder Systems," Computers and Structures, (Pergamon Press, 1972), Vol. 2, pp. 223-251.

2. DDS 170-0, Mast Designs, July 1980.

3. Gallagher, E.V., "Shock Tube Blast Loading on Scale Model Naval Vessels," Final Test Report No. 15, (Armour Research Foundation of Illinois Institute of Technology), ARF Project No. D141.

4. Dye, L. C. and B. W. Lankford, Jr., "A Simplified Method of Designing Ship Structure for Air Blast," Naval Engineers Journal, August 1966.

5. Norris, et. al., "Structural Design for Dynamic Loads," (McGraw Hill Book Co., Inc., New York, 1959).

6. Newmark, N. M., "An Engineering Approach to Blast Resistant Design," ASCE Transaction, Paper No. 2786, October 1953.

100-9-c. DEFINITIONS

Ambient Pressure. Ambient pressure is the external steady-state condition that has not been affected by the nuclear blast; at sea level, it is considered to be 14.7 psi.

Arrival Time. Arrival time is the time interval from detonation to the arrival of the blast front at the point in question.

Clearing Time. Clearing time, t_s, is the time required for the reflected overpressure, P_r, to decay to the stagnation pressure. The pressure loading on the surface during the clearing time is assumed to vary linearly with time and is averaged over the entire frontal surface.

Dynamic Pressure. Dynamic pressure is associated with the blast wind and is the result of gross violent movement of the air accompanying the blast wave. A dynamic pressure proportional to the square of the wind velocity and to the density of air in the shock wave accompanies the blast overpressure. For overpressure less than 480 kPa (70 lb/in^2), the dynamic pressure is less than the overpressure, but is additive to it for vertical surfaces.

Intermediate Stiffener. An intermediate stiffener is a stiffener which spans the space between two transverse frames or main longitudinal girders usually as a continuously supported beam. When analyzed for airblast load, the end conditions are considered fixed except when the stiffener is supported at the end or corner of a deckhouse or similar structure. The fixed end assumption is based on the typical conditions of equal spans, equal pressure load and prismatic, properties of the beam. The stiffener may be modeled as a single degree of freedom system with a stiffness equivalent to that of a fixed-fixed beam. An intermediate stiffener is sometimes referred to as a "Secondary Stiffener" or "Secondary Strength Member." An intermediate stiffener can be either primary or secondary structure.

Mach Reflection Region. Region where the pressure wave reflected from the ground or sea overtakes and adds to the incident shock front to form the Mach Stem.

Mach Stem. Pressure front formed by the combining of the direct wave and the ground or sea reflected front.

Overpressure. Overpressure is the very sharp rise in pressure above ambient at the shock front caused by a blast wave.

Positive Phase Duration. Positive phase duration is the elapsed time from arrival of the blast wave until it decays to ambient pressure.

Reflected Overpressure. Reflected overpressure is the resulting pressure above ambient which occurs when the incident overpressure wave strikes a surface approximately parallel to the blast front and is then reflected, resulting in an instantaneous increase in pressure above the existing cverpressure. The value of the reflected overpressure includes the incident overpressure Frequently the prefix "over" is dropped and reflected overpressure becomes simply reflected pressure. The maximum value is used in design.

Stagnation Pressure. Stagnation pressure is the algebraic sum of the overpressure and the peak dynamic pressure. It occurs after the peak incident reflected pressure.

Thermal Pulse. Thermal pulse is the intense radiated heat generated by the nuclear fireball preceding the blast wave.

100-9-d. SYMBOLS

The units listed are the ones most commonly used.

A_{SH} - Shear area, in^2

A_{WEB} - Cross sectional area of web, in^2

A_{TEE} - Cross sectional area of tee, in^2

A_{TOT}	-	Total cross sectional area of plate-beam combination, in^2
A_{PLT}	-	Cross sectional area of effective width of plate, in^2
A_{FLA}	-	Cross sectional area of flange, in^2
B_1	-	Horizontal dimension of exposed ship structure perpendicular to the approaching shock front, ft
C,D	-	Calculation Parameters
E	-	Modulus of elasticity, psi
F	-	Force, lbs
F_1	-	Load Factor = $f(t_E/t_n)$ (dimensionless)
F_2	-	Load Factor = $f(t_s/t_n)$ (dimensionless)
H_1	-	Height of exposed ship structure, ft (Freeboard for shell structure, deckhouse height for deckhouse and deck structure)
I	-	Moment of inertia, in^4
K_{LM}	-	Load-mass factor (dimensionless)
L	-	Length, in.
L_1	-	Length of exposed ship structure, ft
L'	-	Length of shadow load effected zone, ft
M_{PM}	-	Plastic moment capacity at midspan, in-lb
M_{PS}	-	Plastic moment capacity at support, in-lb
M_T	-	Total mass of a plate-beam combination, $\frac{lb\text{-}sec^2}{in.}$
P	-	Pressure, psi
P_a	-	Ambient atmospheric pressure, psi (14.7 psi at sea level)
P_c	-	Peak average pressure on top face, psi
$P_{c'}$	-	Shadow overpressure, psi
P_e	-	Equivalent static pressure, lbs
P_o	-	Peak incident or peak freefield overpressure, psi

P_r	-	Maximum reflected overpressure, psi
P_s	-	Stagnation pressure, psi
R_P	-	Plastic resistance provided by the member, lbs
R_R	-	Required dynamic plastic resistance of the member, lbs
$S_{req'd}$	-	Section modulus required, in^3
T_n	-	Natural period, sec
U	-	Ambient shock front velocity, fps
U_r	-	Shock front velocity in reflected region, fps
V	-	Shear force, lbs
W_a	-	Additional dead load weight for protection, etc., not including live loads, psf
Z_{PM}	-	Plastic section modulus at midspan, in^3
Z_{PS}	-	Plastic section modulus at the support, in^3
b	-	Longitudinal beam spacing, in.
b_e	-	Effective breadth or width of plating, in.
c_o	-	Ambient sound velocity (1126 fps at 20°C)
c_r	-	Sound velocity in reflected region, fps
d	-	Depth of stiffener, in.
d_{NAM}	-	Plastic neutral axis at midspan, in.
d_{NAS}	-	Plastic neutral axis at support, in.
f_{dy}	-	Dynamic yield stress, psi
f_{sdy}	-	Dynamic shear yield stress, psi
f_{sy}	-	Shear yield stress, psi
f_y	-	Yield stress, psi
k_e	-	Effective elastic stiffness, lbs/in.
q_o	-	Dynamic pressure, psi
t	-	Time, sec

t_+ - Positive phase duration time, sec

t_E - Approximate time of positive phase, sec

t_f - Thickness of flange, in.

t_p - Thickness of plate, in.

t_s - Clearing time, sec

t_w - Thickness of web, in.

w_f - Width of flange, in.

y_c - Centroid location of plate-stiffener combination, in.

β - Plate slenderness ratio (dimensionless)

γ - Angle of incidence of shock front, degrees

μ - Ductility factor (dimensionless)

ρ - Weight density of material, lbs/in_3

τ - Shear stress, psi

100-9-e. GENERAL REQUIREMENTS

The in-air non-contact explosion of a nuclear weapon will produce a thermal pulse and a pressure shock wave. The dominant effect on ship structure is the airblast overpressure. This overpressure occurs at the shock front and propagates radially outward at the speed of sound from the point of detonation. When this shock front hits the ocean surface it is reflected. This reflected pressure forms a secondary pressure wave traveling slightly faster than the incident shock front due to the increased air temperature, and thus overtakes and adds to it. This region of reflected pressure is called the Mach reflection region and the point where the reflected pressure and incident pressure fronts combine is the Mach stem (see Figure 1). The thermal pulse is a radiant energy flux that has the effect of raising the temperature of the structural material. The magnitudes of both the airblast overpressure and the thermal pulse and their effect on the ship structure are dependent on the weapon yield and distance from the burst.

The forces associated with the incident and reflected overpressures are called diffraction loadings and apply to closed structures with flat reflecting surfaces. Forces resulting from the high air velocities are called drag loadings and apply to open frame, round, spherical or truss type structures. This DDS provides the design data for the structural design of closed structures, such as the deckhouse. Open frame structures, such as masts and antennas, are covered in Design Data Sheet 170-0, reference 2.

Typical blast resistant ship deckhouse structure is characterized by having longitudinally-stiffened side panels bounded by decks on the top and bottom and supported by transverse bulkheads or web frames with bulkheads on the ends. These weather panels or grillage assemblies provide the first resistance to the impinging airblast and the resultant overpressures.

Ship structures subjected to non-contact nuclear explosions are designed using limit or plastic design procedures. Theories used are described in ref 5 and ref 6. The deformations that are allowed depend on the structure function and location and are permitted to the extent that a margin of safety against structural collapse and functional impairment of mounted or housed equipment is maintained. Ductibility factors greater than 1.0 mean that some permanent set is permitted.

100-9-f. AIRBLAST LOADS ON DECKHOUSE SHIP STRUCTURE

This Design Data Sheet contains information necessary to design the intermediate stiffeners of closed structure, as shown in Figure 2. This figure is an idealization of surface ship flat plate closed structure above the water line. In designing ship structure it is assumed that the blast wave originates above the surface anywhere other than immediately on top of the ship structure. This offset initiation produces a higher Mach stem loading and is the loading considered in the equations which follow. Based on these assumptions the front, sides, and back of the ship structure will be designed to support the reflected overpressure. Vertical flat plate structure will be designed for a blast pressure loading perpendicular to the structure (zero angle of incidence). The resistance to shearing, tearing loose, buckling, or collapse of the structure will be designed using the loads which occur on each face of the structure when the load originates from one direction and passes over the structure

The following parameters are used in defining the airblast loads on the front, sides, top, and back of closed deckhouse structure and are in terms of incident overpressure, P_o, and ambient pressure, P_a, (airblast loading parameters are provided in the applicable ship specifications),

$$q_o = \frac{5}{2}\left[\frac{P_o^2}{7P_a + P_o}\right] \quad (1)$$

$$U = c_o\left[1 + \frac{6P_o}{7P_a}\right]^{1/2} \quad (2)$$

$$U_r = c_o\left[1 + \frac{2P_o}{7P_a}\right] \Big/ \left[1 + \frac{6P_o}{7P_a}\right]^{1/2} \quad (3)$$

$$c_r = c_o\left[\frac{(7P_a + 8P_o)\ (7P_a + 2P_o)}{7P_a\ (7P_a + 6P_o)}\right]^{1/2} \quad (4)$$

Where: c_o = ambient sound velocity (1126 fps at 20°C)

Values for q_o, U, U_r and c_r are given in Table 1 for various values of P_o with P_a = 14.7 psi.

100-9-f.(1). Front, Sides, and Back Panel Design Loads.

The maximum loading for design of stiffeners and plating, assuming the blast can originate from any direction, occurs when the blast impinges perpendicular to the surface. Figure 3 shows the pressure loading on this surface as a function of time.

All plating panels and stiffeners that are perpendicular to the blast will be designed for the maximum reflected pressure loading. The equations necessary to determine the pressure loading on the surface are as follows:

$$P_r = 2P_o\left[\frac{7P_a + 4P_o}{7P_a + P_o}\right] \quad (5)$$

$$P_s = P_o + q_o \quad (6)$$

$$t_s = \frac{4S_1}{(1 + R_1)c_r} \qquad (7)$$

$$t_E = 0.75\ t_+ \qquad (8)$$

Where: $R_1 = \frac{S_1}{G_1}$

$S_1 = H_1$ or $B_1/2$ (minimum value)

$G_1 = H_1$ or $B_1/2$ (maximum value)

H_1 and B_1 are defined in Figure 2

Values for P_r and P_s are given in Table 1 for various values of P_o with P_a = 14.7 psi.

Plating panels and stiffeners that are not perpendicular to the blast front as might occur in gun sponsons shall be designed using the curves plotted in Figure 4. From these curves the reflected overpressure can be obtained by knowing the angle of incidence of the blast and the incident overpressure (P_o). These curves (Figure 4) do not apply to overhanging structures or cantilevers (such as sponsons on an aircraft carrier) with surfaces parallel to the direction of air movement and which create "pockets." This "pocketing" causes further reinforcing of the incident shock wave and results in pressures of 3.1 times the incident overpressure for sloping overhangs and 2.5 times the incident overpressure for cantilevers. The values for "pocketing" effects are results of shock tube tests conducted on ship models, reference 3.

100-9-f. (2). Top Structure Panel Design Loads.

The stiffeners on the top structure that are near the front surface, Figure 2, are loaded essentially at the same time as the front surface. The pressure on the top surface is assumed to rise instantaneously to the peak average overpressure, P_c, which is the incident overpressure less 40% of the peak dynamic pressure. Figure 5 depicts the pressure loading on the top surface as a function of time. The equation necessary for calculating this peak load is:

$$P_c = P_o - 0.4q_o \qquad (9)$$

The value of t_E can be determined from equation (8) to complete the pressure time loading curve of the top surface. Values for P_c are given in Table 1 for various values of P_o.

100-9-f.(3). Deck Panel Design Loads for Area in Front of Vertical Bulkhead.

The deck area in front of a vertical bulkhead facing the blast is loaded with an excess impulse due to reflection from the bulkhead.

(a) The affected area, see Figure 2, is limited to a distance L':

$$L' = \frac{S_1}{[(c_r/U_r)^2 - 1]^{1/2}} \qquad (10)$$

(b) The pressure loading time sequence for the deck panels is shown in Figure 6 and the maximum design pressure is given by:

$$P_c' = P_r - \frac{(P_r - P_o)L'}{2t_s U_r} \qquad (11)$$

The value of t_s can be determined from equation (7) to complete the pressure time loading curve for the deck panels. The values for U_r, c_r, and P_r can be determined from equations (3), (4) and (5), respectively, or Table 1; S_1 is defined in section 100-9-f.1.

100-9-g. THERMAL PULSE

The combined effect of blast and thermal pulse (blast and thermal synergisms) is of minor importance for low overpressures (7 psi and below) for aluminum plates thicker than 1/8 inch and can be neglected in the design/analysis of closed structure. The effect on steel is negligible for blast overpressures of 10 psi and less.

100-9-h. INTERMEDIATE STIFFENER DESIGN

The design analysis of an intermediate plate/stiffener combination of a deckhouse structure, see Figures 2 and 7, requires the computation of plate/stiffener areas, moment of inertia (I), and plastic modulus at mid-span (Z_{PM}) and at the support (Z_{PS}). If the plate/stiffener combination is known, the properties are computed directly. If the combination is not known, a preliminary sizing is made and the design is as follows (see reference 4):

(a) Using Table 2, find the LOAD FACTOR for (t_E/T_n or t_s/T_n) = 250 that corresponds to the appropriate value of μ.

(Note: values for μ are given in the ship specifications.)

(b) Determine an appropriate equivalent static pressure, P_e

$$P_e = P_r/\text{LOAD FACTOR}$$

(c) Determine an estimate of $S_{req'd}$

$$S_{req'd} = \frac{M}{f_{dy}}$$

Where: M = maximum bending moment due to uniform pressure loading, fixed-supports, in-lb

f_{dy} = dynamic yield stress, psi

(d) The plate/stiffener combination shall be chosen such that the plastic section modulus, Z_{PM}, is equal to or greater than $S_{req'd}$.

$$Z_{PM} \geq S_{req'd}$$

(e) The effective breadth of plating (b_e, Figure 7) in tension is equal to the smaller of the spacing between beams (b) or half the span. On the compression side the effective width (b_e, Figure 7) is computed as follows:

$$(1)\ b_e = b\,\frac{2}{\beta}$$

Where: $$\beta = \frac{b}{t_p}\left[\frac{f_y}{E}\right]^{0.5}$$

f_y = material yield strength

or $(2)\ b_e = b$

Select the smaller value (1) or (2).

(f) Compute plastic section modulus at midspan, Z_{PM}, and at the support, Z_{PS}, using equations in Tables 3 and 4. Additionally, compute necessary elastic property, the moment of inertia or second moment of area, I. These properties are calculated about an axis appropriate to the direction of the bending load.

(g) Compute the maximum beam resistance furnished, R_p, by the plate-stiffener combination, using the plastic section modulus at the support, Z_{PS}, and at the midspan, Z_{PM}, (see reference 4):

$$R_p = \frac{8 f_{dy}}{L} [Z_{PS} + Z_{PM}] \tag{13}$$

Where: f_{dy} = dynamic yield stress, psi

L = length of the stiffener, in.

(h) Compute the natural period of the stiffener,

$$T_n = 2\pi \left[\frac{K_{LM} M_T}{\bar{k}_e}\right]^{0.5} \tag{14}$$

Where: $M_T = \left[((bt_p + A_{TEE})L)\rho + W_a(bL/144.0)\right] / 386.4$

$386.4 = (32.2)\text{ft/sec}^2 (12)\text{in/ft}$

$$\bar{k}_e = \frac{307EI}{L^3} \quad \text{for } \mu > 1.0$$

$$\bar{k}_e = \frac{384EI}{L^3} \quad \text{for } \mu \leq 1.0$$

$$K_{LM} = \begin{cases} 0.66 & \text{for } \mu > 1.0 \\ 0.78 & \text{for } \mu \leq 1.0 \end{cases}$$

(i) Compute the required plastic load resistance, R_R,

- For single-pulse loading profiles (for sides and top):

$$R_R = \frac{P_c\ bL}{F_1} \tag{15}$$

- For bi-pulse loading profiles (front):

$$\text{if} \quad \frac{t_s}{T_n} \le \frac{t_E}{T_n} \le 0.3 \quad \text{or} \quad \frac{t_E}{T_n} \ge \frac{t_s}{T_n} \ge 20 \;;$$

$$R_R = \frac{(P_r - P_s)bL}{F_2} + \frac{P_s\, bL}{F_1} \tag{16}$$

$$\text{if} \quad \frac{t_s}{T_n} \le 0.3 \quad \text{and} \quad \frac{t_E}{T_n} \ge 20$$

$$R_R = 0.5 \left[\frac{P_s bL}{F_1} + \left[\left[\frac{P_s bL}{F_1}\right]^2 + \left[\frac{2(P_r - P_s)bL}{F_2}\right]^2 \right]^{0.5} \right] \tag{17}$$

$$\text{for all other durations of} \quad \frac{t_s}{T_n} \quad \text{and} \quad \frac{t_E}{T_n} \quad :$$

$$R_R = 0.5 \left[C + \left[C^2 + 4D \left[\frac{(P_r - P_s)bL}{F_2}\right]^2 \right]^{0.5} \right] \tag{18}$$

Where:

$$F_1 = \frac{T_n}{\pi t_E} \left[2\mu - 1\right]^{0.5} + \frac{2\mu - 1}{2\mu\,(1 + (0.7\; T_n/t_E))}$$

$$F_2 = \frac{T_n}{\pi t_s} \left[2\mu - 1\right]^{0.5} + \frac{2\mu - 1}{2\mu\,(1 + (0.7\; T_n/t_s))}$$

$$C = \frac{(1 - D)\;(P_r - P_s)bL}{F_2} + \frac{P_s bL}{F_1}$$

$$D = \frac{2\mu - 1}{2\mu\ (1 + (0.7T_n/t_E))} \left[\frac{F_2 - F_1}{F_1 F_2}\right]$$

Tables 2 and 5 may be used to determine values for F_1, F_2, and D in lieu of the above equations.

(j) Determine the shear loading at the intermediate stiffener supports, V (for $\mu \geq 1.0$):

$F = P_r bL$ for front, back, and side structure

$F = P_c bL$ for top face structure

$F = P_c' bL$ for area in front of a vertical bulkhead and is applicable to an area with $b \leq B_1$ and $L \leq L'$

$$V = 0.39\ R_p + 0.11F \quad \text{for } R_p \leq 2F \tag{19}$$

$$V = 0.89\ F \quad \text{for } R_p > 2F \tag{20}$$

(k) Check stiffener plate combination for bending and shear using the following criteria:

Bending: $R_p \geq R_R$

Shear: $\tau \leq f_{sdy}$

where: $f_{sdy} = 0.6\ f_{dy}$ and $\tau = V/A_{SH}$; $A_{SH} = A_{WEB}$

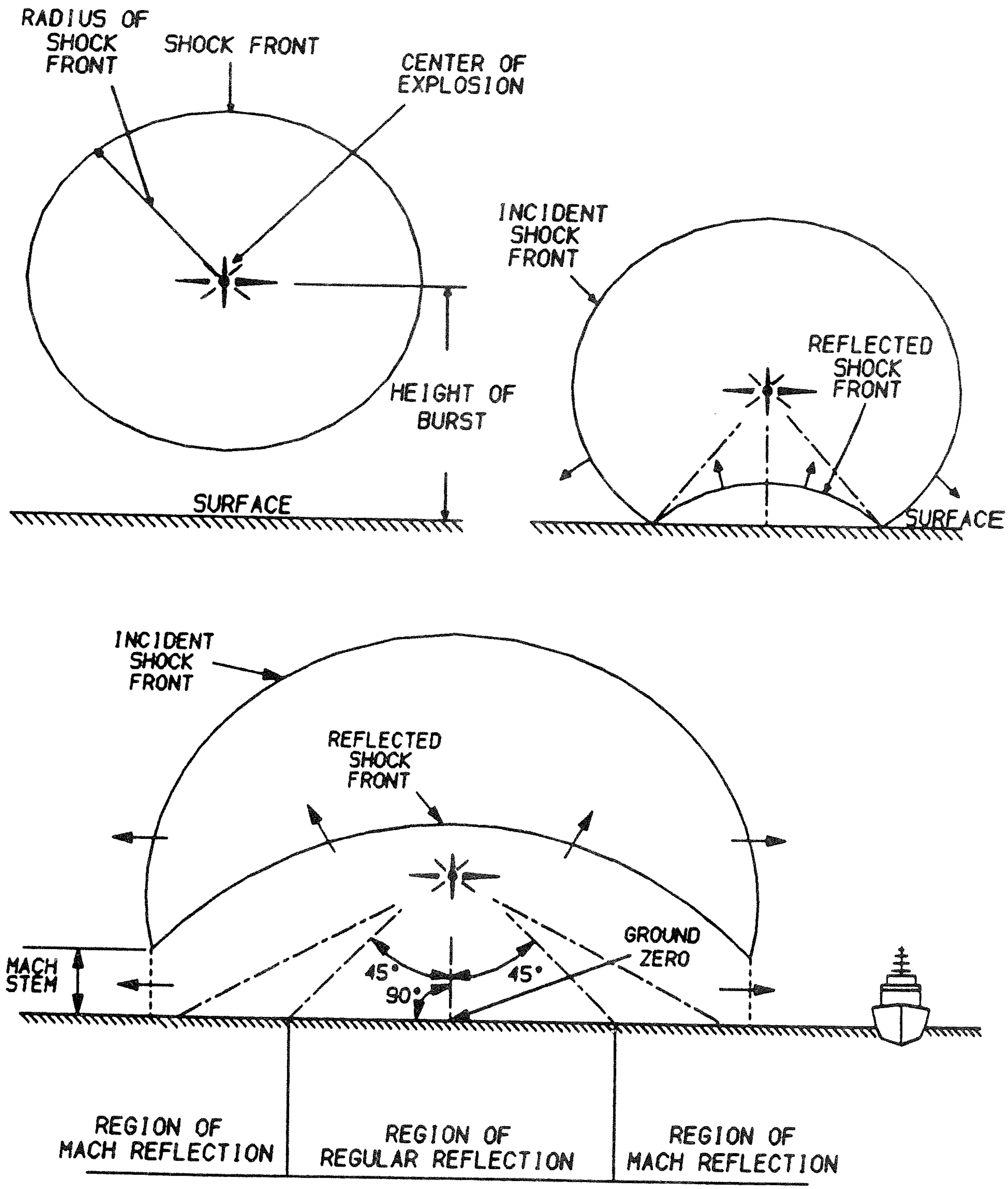


FIGURE 1

PROPAGATION OF A TYPICAL SHOCK FRONT

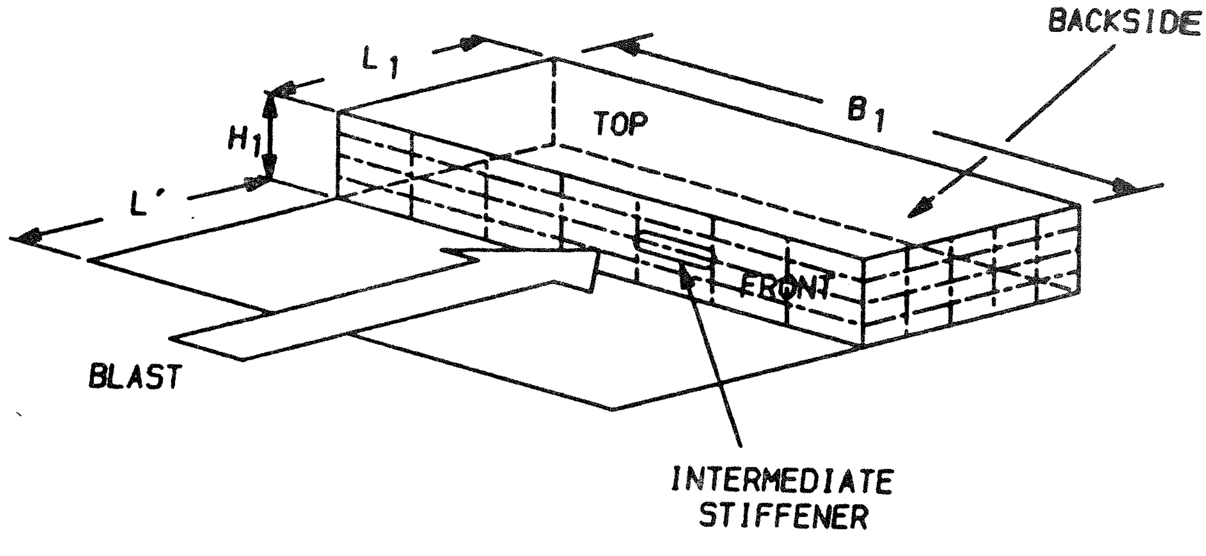


FIGURE 2

IDEALIZATION OF SHIP STRUCTURE ABOVE THE WATERLINE

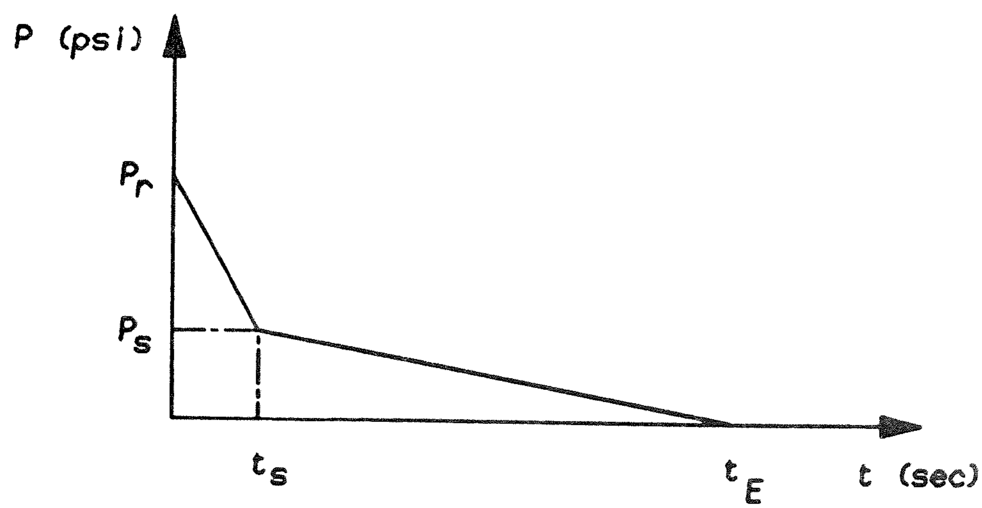


FIGURE 3

SURFACE PERPENDICULAR TO PRESSURE LOADING

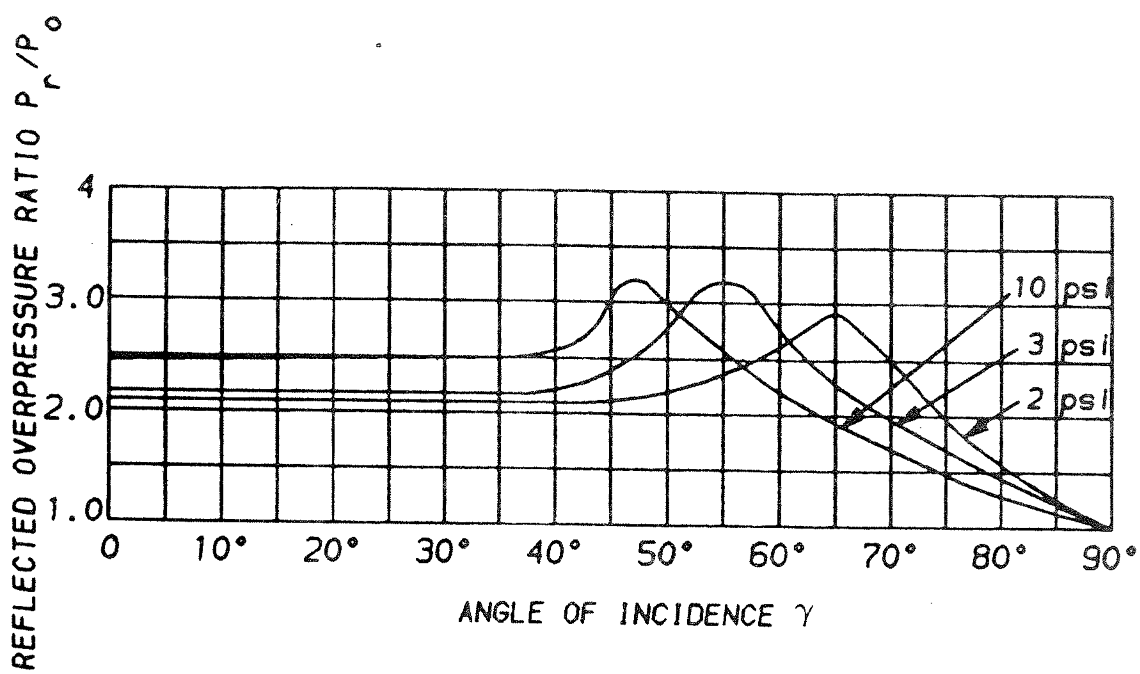


FIGURE 4

REFLECTED OVERPRESSURE AS A FUNCTION OF INCIDENT OVERPRESSURE AND ANGLE OF INCIDENCE

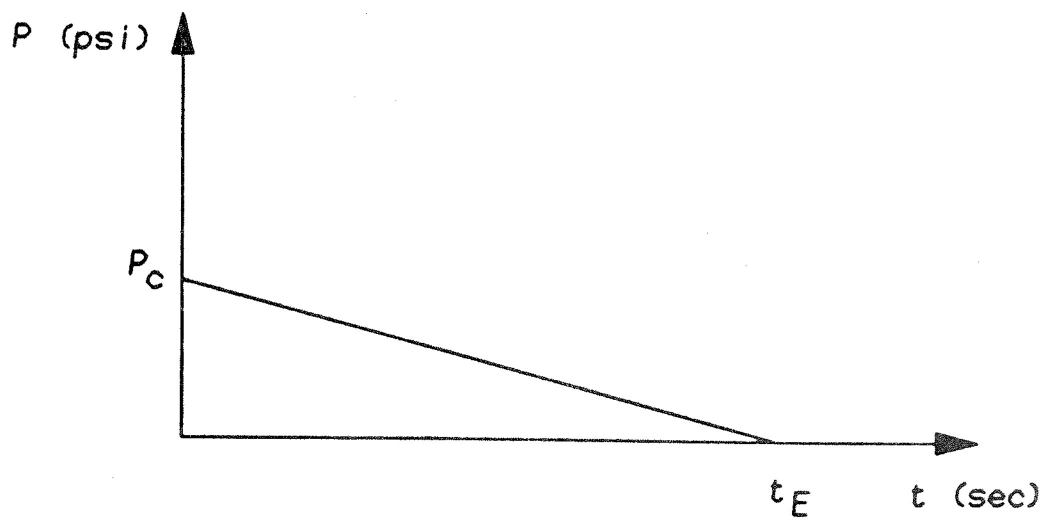


FIGURE 5

TOP SURFACE PRESSURE LOADING

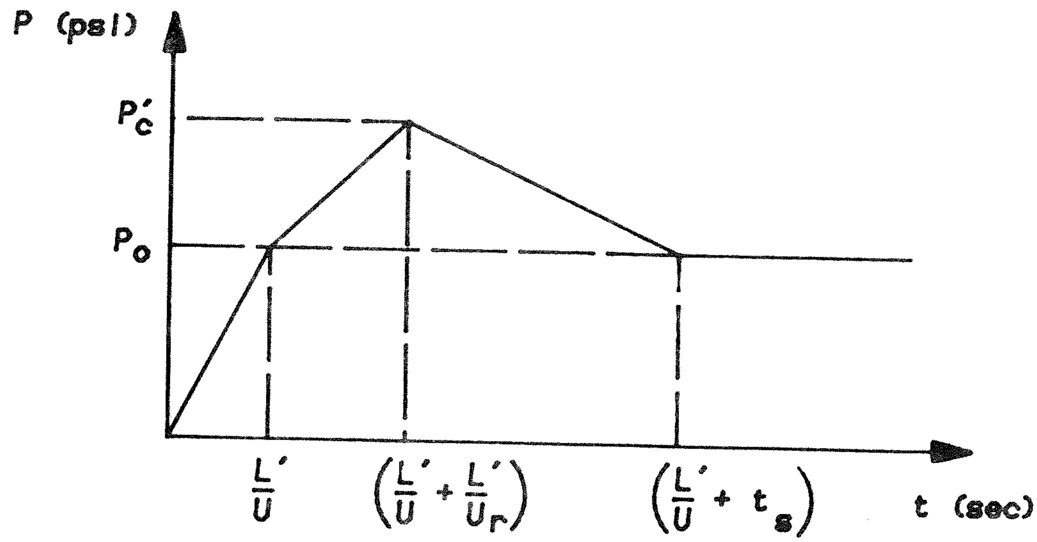


FIGURE 6

DECK PANEL LOADING IN FRONT OF A VERTICAL BULKHEAD

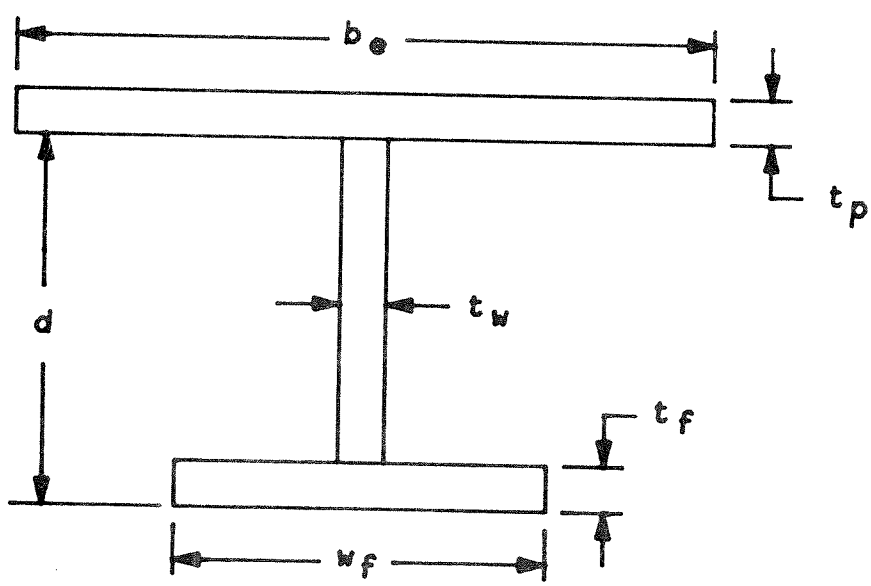


FIGURE 7

TYPICAL CONFIGURATION OF AN INTERMEDIATE STIFFENER

Table 1

AIR BLAST PARAMETERS

(P_a = 14.7 psi, c_o = 1126 fps)

P_o (psi)	q_o (psi)	P_r (psi)	P_s (psi)	P_c (psi)	U (fps)	U_r (fps)	c_r (fps)
1.000	.024	2.058	1.024	.990	1158.363	1169.000	1147.282
2.000	.095	4.229	2.095	1.962	1189.846	1210.557	1167.483
3.000	.212	6.510	3.212	2.915	1220.517	1250.803	1186.758
4.000	.374	8.898	4.374	3.850	1250.436	1289.851	1205.235
5.000	.579	11.390	5.579	4.768	1279.656	1327.799	1223.014
6.000	.826	13.983	6.826	5.669	1308.223	1364.734	1240.179
7.000	1.115	16.675	8.115	6.554	1336.180	1400.730	1256.799
8.000	1.443	19.463	9.443	7.423	1363.563	1435.853	1272.932
9.000	1.810	22.343	10.810	8.276	1390.408	1470.163	1288.627
10.000	2.214	25.314	12.214	9.114	1416.744	1503.714	1303.926
11.000	2.656	28.374	13.656	9.938	1442.599	1534.321	1318.864
12.000	3.133	31.520	15.133	10.747	1467.998	1568.719	1333.472
13.000	3.645	34.749	16.645	11.542	1492.966	1600.255	1347.777
14.000	4.192	38.060	18.192	12.323	1517.523	1631.195	1361.802
15.000	4.771	41.450	19.771	13.092	1541.689	1661.572	1375.568

Table 2

DETERMINATION OF LOAD FACTORS (F_1 OR F_2)

$\frac{t_E}{T_n}$ or $\frac{t_s}{T_n}$	DUCTILITY FACTORS, μ 1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	10.0	15.0	20.0
	LOAD FACTORS (F_1 or F_2)											
.10	3.245	4.584	5.606	6.465	7.221	7.903	8.530	9.113	9.660	13.991	17.260	19.997
.20	1.703	2.399	2.923	3.361	3.744	4.089	4.405	4.699	4.974	7.148	8.785	10.155
.30	1.211	1.700	2.063	2.362	2.622	2.856	3.070	3.267	3.453	4.910	6.003	6.918
.40	.978	1.368	1.651	1.882	2.082	2.261	2.423	2.574	2.714	3.814	4.637	5.324
.50	.845	1.178	1.415	1.606	1.771	1.916	2.049	2.171	2.285	3.171	3.831	4.382
.60	.761	1.058	1.265	1.430	1.571	1.695	1.807	1.911	2.007	2.751	3.303	3.763
.70	.705	.976	1.163	1.309	1.433	1.542	1.641	1.731	1.814	2.457	2.932	3.327
.80	.665	.918	1.089	1.222	1.334	1.432	1.519	1.599	1.674	2.241	2.658	3.005
.90	.635	.875	1.034	1.157	1.260	1.348	1.428	1.500	1.567	2.076	2.448	2.757
1.00	.612	.842	.992	1.107	1.202	1.284	1.357	1.423	1.484	1.946	2.283	2.561
1.50	.553	.755	.879	.970	1.043	1.104	1.158	1.206	1.250	1.573	1.802	1.990
2.00	.530	.719	.831	.911	.973	1.025	1.069	1.109	1.144	1.397	1.573	1.716
2.50	.518	.701	.806	.880	.936	.982	1.020	1.055	1.085	1.297	1.441	1.557
3.00	.512	.691	.792	.861	.913	.955	.990	1.021	1.048	1.233	1.355	1.453
3.50	.508	.684	.783	.849	.898	.937	.970	.998	1.023	1.188	1.295	1.380
4.00	.505	.680	.776	.840	.887	.924	.955	.982	1.005	1.155	1.251	1.327
4.50	.503	.677	.772	.834	.879	.915	.944	.969	.991	1.130	1.217	1.285
5.00	.502	.675	.768	.829	.873	.908	.936	.960	.980	1.111	1.191	1.253
5.50	.501	.673	.766	.825	.869	.902	.929	.952	.972	1.095	1.169	1.226
6.00	.501	.672	.764	.823	.865	.898	.924	.946	.965	1.082	1.151	1.204
6.50	.500	.671	.762	.820	.862	.894	.919	.941	.959	1.071	1.136	1.186
7.00	.500	.670	.761	.818	.859	.891	.916	.937	.955	1.062	1.124	1.170
7.50	.500	.670	.759	.817	.857	.888	.913	.933	.950	1.054	1.113	1.157
8.00	.500	.669	.759	.815	.855	.886	.910	.930	.947	1.047	1.103	1.145
8.50	.500	.669	.758	.814	.854	.884	.907	.927	.944	1.041	1.095	1.135
9.00	.500	.669	.757	.813	.852	.882	.905	.925	.941	1.036	1.087	1.125
9.50	.500	.668	.757	.812	.851	.880	.904	.923	.939	1.031	1.081	1.117
10.00	.500	.668	.756	.811	.850	.879	.902	.921	.937	1.027	1.075	1.110
11.00	.500	.668	.755	.810	.848	.877	.899	.918	.933	1.019	1.065	1.097
12.00	.500	.667	.755	.809	.847	.875	.897	.915	.930	1.013	1.056	1.087
13.00	.500	.667	.754	.808	.846	.873	.895	.913	.927	1.008	1.049	1.078
14.00	.500	.667	.754	.807	.844	.872	.893	.911	.925	1.004	1.043	1.071
15.00	.500	.667	.753	.807	.844	.871	.892	.909	.924	1.000	1.038	1.064
16.00	.500	.667	.753	.806	.843	.870	.891	.908	.922	.997	1.033	1.058
17.00	.500	.667	.753	.806	.842	.869	.890	.907	.921	.994	1.029	1.053
18.00	.500	.667	.753	.805	.842	.868	.889	.906	.919	.992	1.026	1.049
19.00	.500	.667	.752	.805	.841	.868	.888	.905	.918	.989	1.023	1.045
20.00	.500	.667	.752	.805	.841	.867	.888	.904	.917	.987	1.020	1.041
21.00	.500	.667	.752	.805	.840	.867	.887	.903	.916	.985	1.017	1.038
22.00	.500	.667	.752	.804	.840	.866	.886	.902	.916	.984	1.015	1.035
23.00	.500	.667	.752	.804	.840	.866	.886	.902	.915	.982	1.013	1.033
24.00	.500	.667	.752	.804	.839	.865	.885	.901	.914	.981	1.011	1.030
25.00	.500	.667	.752	.804	.839	.865	.885	.901	.914	.980	1.009	1.028
50.00	.500	.667	.751	.802	.836	.861	.880	.895	.907	.965	.988	1.001
75.00	.500	.667	.750	.801	.835	.860	.878	.893	.904	.960	.981	.992
100.00	.500	.667	.750	.801	.835	.859	.877	.892	.903	.957	.977	.988
125.00	.500	.667	.750	.801	.834	.859	.877	.891	.903	.956	.975	.985
150.00	.500	.667	.750	.801	.834	.858	.877	.891	.902	.955	.974	.984
175.00	.500	.667	.750	.800	.834	.858	.876	.890	.902	.954	.973	.982
200.00	.500	.667	.750	.800	.834	.858	.876	.890	.902	.954	.972	.982
225.00	.500	.667	.750	.800	.834	.858	.876	.890	.901	.953	.971	.981
250.00	.500	.667	.750	.800	.834	.858	.876	.890	.901	.953	.971	.980

-USE OF TABLE:

μ = DUCTILITY FACTOR
F_1 or F_2 = LOAD FACTOR

To get F_1 - Enter the table with $\frac{t_E}{T_n}$ and μ or to get F_2 - Enter the table with $\frac{t_s}{T_n}$ and μ

Table 3
Plastic Section Modulus at Midspan, Z_{PM}:

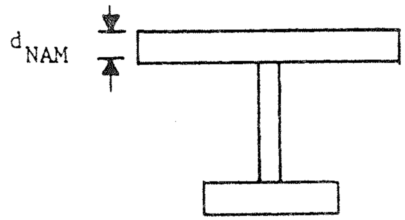
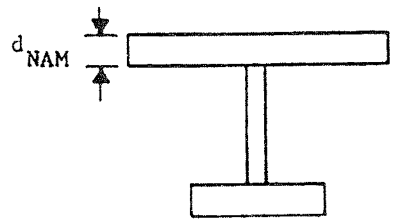
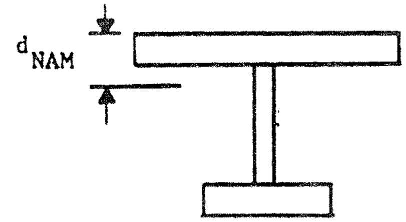
Z_{PM}		
$A_{TOT}/2 < A_{PLT}$	$A_{TOT}/2 = A_{PLT}$	$A_{PLT} + A_{WEB} > A_{TOT}/2 > A_{PLT}$
		
$d_{NAM} = \frac{A_{TOT}/2}{b_e}$	$d_{NAM} = t_p$	$d_{NAM} = \frac{A_{TOT}/2 - A_{PLT}}{t_w} + t_p$
$Z_1 = \frac{1}{2} b_e (d_{NAM})^2 = (b_e d_{NAM}) \frac{d_{NAM}}{2}$ $Z_2 = \frac{1}{2} b_e (t_p - d_{NAM})^2 +$ $A_{WEB} \left(\frac{d - t_f}{2} + t_p - d_{NAM}\right) +$ $A_{FLA} \left(d - \frac{t_f}{2} + t_p - d_{NAM}\right)$	$Z_1 = \frac{1}{2} b_e (d_{NAM})^2$ $Z_2 = A_{WEB} \frac{(d - t_f)}{2} +$ $A_{FLA} \left(d - \frac{t_f}{2}\right)$	$Z_1 = A_{PLT} (d_{NAM} - t_p/2) +$ $\frac{1}{2} t_w (d_{NAM} - t_p)^2$ $Z_2 = \frac{1}{2} t_w (d + t_p - t_f - d_{NAM})^2 +$ $A_{FLA} (d + t_p - t_f/2 - d_{NAM})$
$Z_{PM} = Z_1 + Z_2$		

Table 4

Plastic Section Modulus at the Support, Z_{PS}

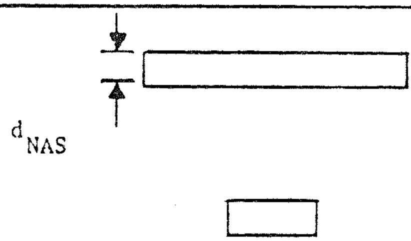
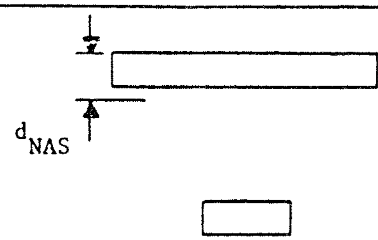
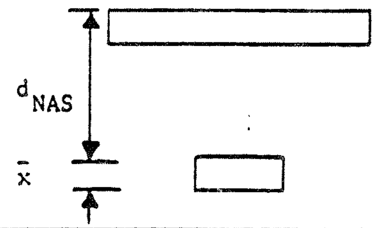
Z_{PS}		
$A_{PLT} > A_{FLA}$	$A_{PLT} = A_{FLA}$	$A_{PLT} < A_{FLA}$
		
$d_{NAS} = \frac{1}{2} \left(t_p + \frac{A_{FLA}}{b_e} \right)$	$d_{NAS} = \frac{d + t_p}{2}$	$d_{NAS} = d + t_p - \frac{t_f}{2} - \frac{A_{PLT}}{2\, w_f}$ $\bar{x} = \frac{1}{2} \left(t_f + \frac{A_{PLT}}{w_f} \right)$
$Z_1 = \frac{1}{2}\, b_e\, (d_{NAS})^2$ $Z_2 = \frac{1}{2}\, b_e\, (t_p - d_{NAS})^2$ $Z_3 = A_{FLA}\, (d + t_p - \frac{t_f}{2} - d_{NAS})$	$Z_1 = A_{PLT}\, (d_{NAS} - \frac{t_p}{2})$ $Z_2 = A_{PLT}\, (d_{NAS} - \frac{t_f}{2})$ $Z_3 = 0$	$Z_1 = A_{PLT}\, (d_{NAS} - \frac{t_p}{2})$ $Z_2 = \frac{1}{2}\, w_f\, (t_f - \bar{x})^2$ $Z_3 = \frac{1}{2}\, w_f\, \bar{x}^2$
$Z_{PS} = Z_1 + Z_2 + Z_3$		

Table 5

DETERMINATION OF FACTOR D

DUCTILITY FACTORS,

Tabulated CONSTANT = $D/((F_2-F_1)/F_1F_2)$

t_E / T_n	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	10.0	15.0	20.0
.10	.063	.083	.094	.100	.104	.107	.109	.111	.113	.119	.121	.122
.20	.111	.148	.167	.178	.185	.190	.194	.198	.200	.211	.215	.217
.30	.150	.200	.225	.240	.250	.257	.263	.267	.270	.285	.290	.293
.40	.182	.242	.273	.291	.303	.312	.318	.323	.327	.345	.352	.355
.50	.208	.278	.313	.333	.347	.357	.365	.370	.375	.396	.403	.406
.60	.231	.308	.346	.369	.385	.396	.404	.410	.415	.438	.446	.450
.70	.250	.333	.375	.400	.417	.429	.438	.444	.450	.475	.483	.488
.80	.267	.356	.400	.427	.444	.457	.467	.474	.480	.507	.516	.520
.90	.281	.375	.422	.450	.469	.482	.492	.500	.506	.534	.544	.548
1.00	.294	.392	.441	.471	.490	.504	.515	.523	.529	.559	.569	.574
1.50	.341	.455	.511	.545	.568	.584	.597	.606	.614	.648	.659	.665
2.00	.370	.494	.556	.593	.617	.635	.648	.658	.667	.704	.716	.722
2.50	.391	.521	.586	.625	.651	.670	.684	.694	.703	.742	.755	.762
3.00	.405	.541	.608	.649	.676	.695	.709	.721	.730	.770	.784	.791
3.50	.417	.556	.625	.667	.694	.714	.729	.741	.750	.792	.806	.813
4.00	.426	.567	.638	.681	.709	.729	.745	.757	.766	.809	.823	.830
4.50	.433	.577	.649	.692	.721	.742	.757	.769	.779	.822	.837	.844
5.00	.439	.585	.658	.702	.731	.752	.768	.780	.789	.833	.848	.855
5.50	.444	.591	.665	.710	.739	.760	.776	.789	.798	.843	.858	.865
6.00	.448	.597	.672	.716	.746	.768	.784	.796	.806	.851	.866	.873
6.50	.451	.602	.677	.722	.752	.774	.790	.802	.813	.858	.873	.880
7.00	.455	.606	.682	.727	.758	.779	.795	.808	.818	.864	.879	.886
7.50	.457	.610	.686	.732	.762	.784	.800	.813	.823	.869	.884	.892
8.00	.460	.613	.690	.736	.766	.788	.805	.817	.828	.874	.889	.897
8.50	.462	.616	.693	.739	.770	.792	.808	.821	.832	.878	.893	.901
9.00	.464	.619	.696	.742	.773	.795	.812	.825	.835	.881	.897	.905
9.50	.466	.621	.699	.745	.776	.798	.815	.828	.838	.885	.900	.908
10.00	.467	.623	.701	.748	.779	.801	.818	.831	.841	.888	.903	.911
11.00	.470	.627	.705	.752	.783	.806	.823	.836	.846	.893	.909	.917
12.00	.472	.630	.709	.756	.787	.810	.827	.840	.850	.898	.913	.921
13.00	.474	.633	.712	.759	.791	.813	.830	.843	.854	.901	.917	.925
14.00	.476	.635	.714	.762	.794	.816	.833	.847	.857	.905	.921	.929
15.00	.478	.637	.717	.764	.796	.819	.836	.849	.860	.908	.924	.932
16.00	.479	.639	.719	.766	.798	.821	.838	.852	.862	.910	.926	.934
17.00	.480	.640	.720	.768	.800	.823	.840	.854	.864	.912	.928	.936
18.00	.481	.642	.722	.770	.802	.825	.842	.856	.866	.914	.930	.939
19.00	.482	.643	.723	.772	.804	.827	.844	.857	.868	.916	.932	.940
20.00	.483	.644	.725	.773	.805	.828	.845	.859	.870	.918	.934	.942
21.00	.484	.645	.726	.774	.806	.829	.847	.860	.871	.919	.935	.944
22.00	.485	.646	.727	.775	.808	.831	.848	.861	.872	.921	.937	.945
23.00	.485	.647	.728	.776	.809	.832	.849	.863	.873	.922	.938	.946

24.00	.486	.648	.729	.777	.810	.833	.850	.864	.874	.923	.939	.947
25.00	.486	.649	.730	.778	.811	.834	.851	.865	.875	.924	.940	.948
50.00	.493	.657	.740	.789	.822	.845	.863	.877	.888	.937	.953	.962
75.00	.495	.661	.743	.793	.826	.849	.867	.881	.892	.941	.958	.966
100.00	.497	.662	.745	.794	.828	.851	.869	.883	.894	.943	.960	.968
125.00	.497	.663	.746	.796	.829	.852	.870	.884	.895	.945	.961	.970
150.00	.498	.664	.747	.796	.829	.853	.871	.885	.896	.946	.962	.970
175.00	.498	.664	.747	.797	.830	.854	.872	.885	.896	.946	.963	.971
200.00	.498	.664	.747	.797	.830	.854	.872	.886	.897	.947	.963	.972
225.00	.498	.665	.748	.798	.831	.854	.872	.886	.897	.947	.964	.972
250.00	.499	.665	.748	.798	.831	.855	.873	.886	.897	.947	.964	.972

- USE OF TABLE:

μ = DUCTILITY FACTOR

Tabulated CONSTANT = $D/((F_2-F_1)/F_1F_2)$: D = (Tabulated CONSTANT) $(F_2-F_1)/F_1F_2$

First, determine the t_E/T_n ratio and using the ductility factor, μ, find the appropriate value for the CONSTANT. Next, use Table 2 to determine F_1 and F_2; then solve for D.

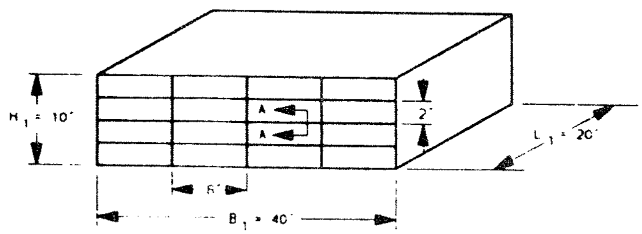
APPENDIX A

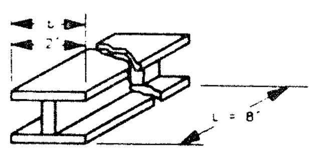
SHIP STRUCTURE DESIGN EXAMPLE

GIVEN: DECKHOUSE STRUCTURE, MILD-STEEL

E	$= 29{,}600$ ksi	f_y	$= 34$ ksi
f_{dy}	$= 45$ ksi	f_{sy}	$= 20.4$ ksi
f_{sdy}	$= 27$ ksi	ρ	$= 0.283$ lbs (force)/in^3
g	$= 386.4$ in/sec^2		

STRUCTURE:





PARAMETERS:

P_o	$= 2.9$ psi	μ	$= 3$ (dimensionless)
P_a	$= 14.7$ psi	t_+	$= 2.0$ sec.
t_p	$= 1/4$ in.	L	$= 8$ ft $= 96$ in.
b	$= 2$ ft $= 24$ in.	C_o	$= 1126$ fps

FIND: Determine the size of a tee-section to be used as a front face stiffener that will satisfy the above given parameters.

Calculate the loading parameters needed and develop loading profile.

$$P_r = 2\,P_o \left[\frac{7\,P_a + 4\,P_o}{7\,P_a + P_o}\right] \qquad \text{(Equation 5)}$$

$$P_r = 2(2.9)\left[\frac{7(14.7) + 4(2.9)}{7(14.7) + 2.9}\right]$$

$$= 6.3$$

$P_r = 6.3$ psi

$P_s = P_o + q_o$ (Equation 6)

$$q_o = \frac{5}{2}\left[\frac{P_o^2}{7P_a + P_o}\right]$$

$$P_s = 2.9 + \frac{5}{2}\left[\frac{(2.9)^2}{7(14.7) + 2.9}\right]$$

$= 3.1$ psi

$P_s = 3.1$ psi

$$t_s = \frac{4S_1}{(1 + R_1)\ c_r}$$ (Equation 7)

$S_1 = H_1$ or $B_1/2$
(use min)

$G_1 = H_1$ or $B_1/2$
(use max)

$R_1 = S_1/G_1$

c_r = Use Equation 4 or Table 1; $c_r = 1185$

$$t_s = \frac{4(10)}{(1 + 0.5)1185}$$

$= 0.0225$ sec

$t_s = 0.0225$ sec

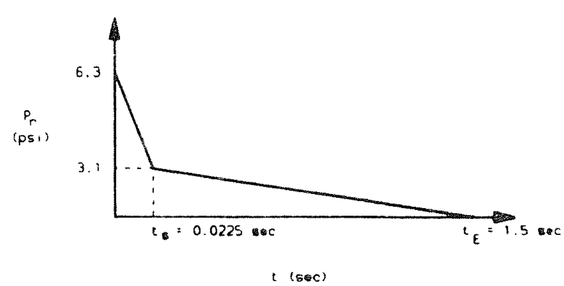
$t_E = 0.75\ t_+$

$= .75\ (2.0)$

$= 1.5$ sec

$t_E = 1.5$ sec

Loading Profile



Step a) Determine LOAD FACTOR for $t/T_n = 250$

From Table 2; using $\mu = 3.0$ and $t/T_n = 250$

LOAD FACTOR = 0.834

Step b)

$$P_e = \frac{P_r}{\text{LOAD FACTOR}}$$

$$= \frac{6.3}{0.834}$$

$$= 7.554 \text{ psi}$$

Step c)

$$S_{req'd} = \frac{M}{f_{dy}}$$

$$M = \frac{P_e L^2 b}{12}$$

$$= \frac{(7.554)(96)^2\ (24)}{12}$$

$$= 139{,}235 \text{ in-lbs}$$

$$S_{req'd} = \frac{139{,}235}{45{,}000}$$

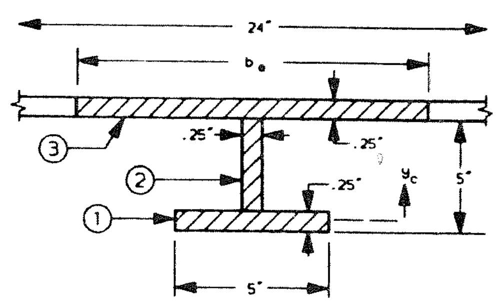
$$= 3.094 \text{ in}^3$$

$S_{req'd} = 3.094\ in^3$

Step d) Choose section such that:

$Z_{PM} > S_{req'd}$

First try, select a trial section



Step e) Determine effective width of plating, b_e

$$\beta = \frac{b}{t_p}\sqrt{\frac{f_y}{E}}$$

$$\beta = \frac{24}{.25}\sqrt{\frac{34}{29600}}$$

$$\beta = 3.254$$

1) $b_e = b\left[\frac{2}{\beta}\right] = 24\left[\frac{2}{3.254}\right]$

$b_e = 14.75$ in.

or

2) $b_e = b = 24$ in.

use $b_e = 14.75$ in. (the lesser value)

$b_e = 14.75$ in.

Step f) Calculate elastic and plastic section properties for chos section

$A_{PLT} = b_e t_p = (14.75)(.25) = 3.688\ in^2$

$A_{FLA} = w_f t_f = (5.0)(.25) = 1.250\ in^2$

$A_{WEB} = t_w\ (d-t_f) = .25\ (5 - .25) = 1.188\ in^2$

$A_{TEE} = A_{WEB} + A_{FLA} = 1.188 + 1.25 = 2.438\ in^2$

$A_{TOT} = A_{TEE} + A_{PLT} = 2.438 + 3.688 = 6.126\ in^2$

1) Elastic Section Properties

	PC	$AREA_i$	y_i	A_iy_i	d_i	$A_id_i^2$	I_i
FLA	(1)	1.250	0	0	3.495	15.28	0.007
WEB	(2)	1.188	2.5	2.97	0.995	1.18	2.233
PLT	(3)	3.688	5.0	18.44	1.505	8.35	0.019
		$\Sigma A_i = 6.126$		$\Sigma A_iy_i = 21.41$		$\Sigma A_id_i^2 = 24.81$	$\Sigma I_i = 2.259$

$A_{TOT} = \Sigma A_i$, $d_1 = 3.495$, $d_2 = 3.495 - \frac{5}{2}$, $d_3 = 5 - 3.495 = 1.505$

$$y_c = \Sigma\frac{A_iy_i}{A_i} = \frac{21.41}{6.126} = 3.495 \text{ in.}$$

$$I_{TOT} = \Sigma I_i + \Sigma A_id_i^2 = I$$

$$I = 2.259 + 24.81 = 27.069 \text{ in}^4 = 27.07 \text{ in}^4$$

2) Plastic Section Properties

a) at midspan, Z_{PM}

$$\frac{A_{TOT}}{2} = \frac{6.126}{2} = 3.063$$

$$A_{PLT} = 3.688$$

$$\frac{A_{TOT}}{2} < A_{PLT}$$

$$d_{NAM} = \frac{A_{TOT}}{2} \cdot \frac{1}{b_e} = \frac{3.063}{14.75}$$

$$= 0.208 \text{ in}$$

$$Z_1 = 1/2\ b_e\ (d_{NAM})^2$$

$$= \frac{14.75}{2}(0.208)^2 = 0.319 \text{ in}^3$$

$$Z_2 = \frac{1}{2} b_e (t_p - d_{NAM})^2 + A_{WEB}\left[\frac{d-t_f}{2} + t_p - d_{NAM}\right] + A_{FLA}\left[d - \frac{t_f}{2} + t_p - d_{NAM}\right]$$

$$= \frac{1}{2}(14.75)(0.25 - 0.208)^2 + 1.188\left[\frac{5 - 0.25}{2} + 0.25 - 0.208\right] + 1.250\left[5 - \frac{0.25}{2} + 0.25 - 0.208\right]$$

$$Z_2 = 9.029 \text{ in}^3$$

$$Z_{TOT} = Z_{PM} = Z_1 + Z_2 = 0.320 + 9.029 = 9.349 \text{ in}^3$$

Check Z_{PM} against $S_{req'd}$

$9.349 \text{ in}^3 > 3.094 \text{ in}^3$

$Z_{PM} \geq S_{req'd}$

Trial section OK, continue analysis. If $Z_{PM} < S_{req'd}$, a new section would have been selected.

b) at support, Z_{PS}

$A_{PLT} = 3.688$

$A_{FLA} = 1.250$

$A_{PLT} > A_{FLA}$

$$d_{NAS} = \frac{1}{2}\left[t_p + \frac{A_{FLA}}{b_e}\right]$$

$$= \frac{1}{2}\left[0.25 + \frac{1.25}{14.75}\right] = 0.167 \text{ in.}$$

$$Z_1 = \frac{1}{2} b_e (d_{NAS})^2$$

$$= \frac{14.75}{2}(0.167)^2 = 0.206 \text{ in}^3$$

$$Z_2 = \frac{1}{2} b_e (t_p - d_{NAS})^2$$

$$= \frac{14.75}{2} (0.25 - 0.167)^2$$

$$= 0.051 \text{ in}^3$$

$$Z_3 = A_{FLA} \left(d + t_p - \frac{t_f}{2} - d_{NAS}\right)$$

$$= 1.25 \left(5 + 0.25 - \frac{0.25}{2} - 0.167\right)$$

$$= 6.1975 \text{ in}^3 = 6.198 \text{ in}^3$$

$$Z_{TOT} = Z_{PS} = Z_1 + Z_2 + Z_3 = 0.206 + 0.051 + 6.198$$

$$Z_{PS} = 6.455 \text{ in}^3$$

Step g) Compute resistance furnished by section

$$R_p = \frac{8 (M_{PS} + M_{PM})}{L}$$

$$M_{PS} = f_{dy} Z_{PS}$$

$$M_{PM} = f_{dy} Z_{PM}$$

$$R_p = \frac{8 [(45)(6.455) + (45)(9.349)]}{96} \qquad \text{(Equation 13)}$$

$$= 59.265 \text{ Kips} = 59.27 \text{ Kips}$$

$$\boxed{R_p = 59.265 \text{ Kips}}$$

Step h) Compute natural period T_n

$$T_n = 2\pi \sqrt{\frac{K_{LM} \; M_T}{\bar{k}_e}}$$

$$M_T = \frac{L(bt_p + A_{TEE})\rho}{386.4} \qquad (W_a = o)$$

$$= \frac{96 \; (24(0.25) + 2.438) \; 0.283}{386.4}$$

$$= 0.593 \; \frac{\text{lb-sec}^2}{\text{in}}$$

$$\bar{k}_e = \frac{307 \; EI}{L^3} \qquad (\mu = 3)$$

$$= \frac{307 \; (29.6 \times 10^6) \; (27.07)}{(96)^3}$$

$$= 278{,}000 \text{ lbs/in}$$

$$K_{LM} = 0.66$$

$$T_n = 2\pi \sqrt{\frac{(0.66) \; (0.593)}{278{,}000}}$$

$$= 0.0074 \text{ sec}$$

$$\boxed{T_n = 0.0074 \text{ sec}}$$

Step i) Compute Plastic Load Resistance R_R

$$\frac{t_s}{T_n} = \frac{0.0225}{0.0074} = 3.04$$

$$\frac{t_E}{T_n} = \frac{1.5}{0.0074} = 202.70$$

- Use formula for all other durations of $\frac{t_s}{T_n}$ and $\frac{t_E}{T_n}$

$$R_R = 0.5 \left[C + \sqrt{C^2 + 4D \left[\frac{(P_r - P_s)\ bL}{F_2} \right]^2} \right] \quad \text{(Equation 18)}$$

- F_1 and F_2 may be found by two methods:

1) Equations

$$F_1 = \frac{T_n}{\pi t_E} \sqrt{2\mu - 1 + \frac{2\mu - 1}{2\mu \left[1 + \frac{0.7\ T_n}{t_E} \right]}}$$

$$= \frac{0.0074}{\pi 1.5} \sqrt{2(3) - 1} + \frac{2(3) - 1}{2(3) \left[1 + \frac{0.7\ (0.0074)}{1.5} \right]}$$

$$= 0.834$$

$F_1 = 0.834$

$$F_2 = \frac{T_n}{\pi t_s} \sqrt{2\mu - 1} + \frac{2\mu - 1}{2\mu \left[1 + \frac{0.7\ T_n}{t_s} \right]}$$

$$= \frac{0.0074}{\pi 0.0225} \sqrt{2(3) - 1} + \frac{2(3) - 1}{2(3) \left[1 + \frac{0.7\ (0.0074)}{0.0225} \right]}$$

$$= 0.9115$$

$F_2 = 0.9115$

2) By Table 2, using $\mu = 3.0$

$$F_1 = 0.834 \text{ for } \frac{t_E}{T_n} = 202.70$$

$$F_2 = 0.9118 \text{ for } \frac{t_s}{T_n} = 3.04$$

Likewise D may be calculated using its formula or Tables 2 and 5. Using calculated values for F_1 and F_2 and the equation for D,

$$1)\quad D = \frac{2\mu - 1}{2\mu\left[1 + \dfrac{0.7\,T_n}{t_E}\right]}\left[\frac{F_2 - F_1}{F_1\,F_2}\right]$$

$$= \frac{2(3) - 1}{2(3)\left[1 + \dfrac{0.7\,(0.0074)}{1.5}\right]}\left[\frac{0.9115 - 0.834}{(0.834)\ (0.9115)}\right]$$

$$= 8.47 \times 10^{-2}$$

$$\boxed{D = 8.47 \times 10^{-2}}$$

2) From Table 5, using $\mu = 3.0$, $t_E/T_n = 202.70$ and the values for F_1 and F_2 from Table 2

$$\text{CONST} = D\left[\frac{F_2\,F_1}{F_2 - F_1}\right]$$

$$= 0.830$$

$$D = 0.830\left[\frac{(0.9118 - 0.834)}{(0.9118)(0.834)}\right]$$

$$= 8.49 \times 10^{-2}$$

Note that a slight discrepancy may result between the calculated and the tabulated values for F_1, F_2 and D due to roundoff and interpolation between values on the table. However, the difference is considered negligible.

Now C may be calculated, using the calculated values

$$C = \frac{(1 - D)\ (P_r - P_s)\ Bl}{F_2} + \frac{P_s\ Bl}{F_1}$$

$$= \frac{(1 - 0.0847)\ (6.3-3.1)\ 24(96)}{0.9115} + \frac{3.1(96)24}{0.834}$$

$$= 7403.54 + 8564.03$$

$$= 15967.57$$

$$R_R = 0.5 \left[15967.6 + \sqrt{(15967.6)^2 + 4(0.0847)\left[\frac{(6.3 - 3.1)24(96)}{0.9115}\right]^2} \right]$$

$$= 16307 \text{ lbs}$$

$$= 16.3 \text{ Kips}$$

Now compare R_R to R_P

$R_P = 59.3$ Kips

$R_R = 16.3$ Kips; $R_P > R_R$

Beam is O.K. for bending

Step j) Determine shear loading at the supports, for front face for $\mu > 1.0$

$F = P_r bL$

$= 6.3(24)(96) = 14515.2$ lbs $= 14.5$ Kips

$R_P = 59.3$ Kips

$2F = 29$ Kips $R_P > 2F$

$V = 0.89F = 12.9$ Kips (Equation 20)

Step k) Check stiffener-plate combination for bending and shear using the following criteria:

Bending: $R_P > R_R = 59.3 > 16.3$

Shear: $\tau < f_{sdy}$

$f_{sdy} = 0.6\ f_{dy}$

$= 27$ ksi

$\tau = V/A_{SH};\ A_{SH} = A_{WEB}$

$= 12.9/1.188$ in

$= 10.86$ ksi

$f_{sdy} > \tau$ **Beam is O.K. for shear**

Conclusion: The section analyzed will withstand the prescribed loading; however, the section is over designed. A new section may be looked at to optimize design, if necessary, starting at step f.