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19. ABSTRACT (Continue on reverse if necessary and identify by block number) This report contains a software program for the optimum design of sandwich panels. This program calculates the minimum weight design of sandwich beams and plates subject to stiffness and/or strength constraints. The program has been designed to run on an IBM PC compatible computer. The analysis performed by the program is described together with a complete listing of program. The program is available on diskette which interested users may obtain from Professor Lorna Gibson at MIT.			
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OPTIMUM DESIGN METHODS FOR
STRUCTURAL SANDWICH PANELS



Final Technical Report

by

Lorna J. Gibson

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ANALYSIS AND MINIMUM WEIGHT DESIGN IN SANDWICH BEAMS WITH RIGID FOAM CORE

I. Introduction

A sandwich beam is shown in Figure 1. It has a span l and a width b . The face and core thicknesses are t and c respectively and the core density is ρ_c . The face material has a density ρ_f , a Young's modulus E_f and a yield strength σ_{yf} . The core has a Young's modulus E_c , a shear modulus G_c , a uniaxial yield strength σ_c^* and a shear strength τ_c^* . The solid from which the core is foamed has a density ρ_s , a Young's modulus E_s and a yield strength σ_{ys} .

In order to simplify the analysis of sandwich beams, the following assumptions are made in this program :

- (1) Both the face and core materials are isotropic.
- (2) The sandwich beam has an antiplane core and thin faces.
- (3) The beam is narrow, so that normal stresses in the y direction can be neglected.
- (4) Ordinary beam theory is valid for the sandwich beam.

The foam core property-density relationships are

$$E_c = C_3 \left(\rho_c / \rho_s \right)^A E_s$$

$$\tau_c^* = C_4 \left(\rho_c / \rho_s \right)^B \sigma_{ys}$$

$$G_c = C_5 \left(\rho_c / \rho_s \right)^G E_s$$

where C_3 , C_4 , C_5 , A , B and G are material properties.

For a sandwich beam, the maximum moment is given by

$$M = \frac{Pl}{C_1}$$

The maximum shear force in the beam is

$$V = \frac{P}{C_2}$$

The maximum deflection due to bending and shearing stresses can be expressed as

$$\Delta = \Delta_b + \Delta_s$$

$$= \frac{Pl^3}{C_3 D} + \frac{Pl}{C_6 A G_c}$$

where C_1 , C_2 , C_3 and C_6 are constants related to the loading geometry.

$$D = E_f \frac{bt^3}{6} + E_f \frac{btd^2}{2} + E_c \frac{bc^3}{12}$$

$$A_c = \frac{bd^2}{c}$$

$$d = c + t$$

Figure 2 shows the load constants for six different loading configurations which are available in this program.

The program has four parts :

- (1) Analysis of sandwich beam deflections and stresses.
- (2) Minimum weight design of a sandwich beam for stiffness.
- (3) Minimum weight design of a sandwich beam for strength.
- (4) Minimum weight design of a sandwich beam for both stiffness and strength.

II. Analysis of Sandwich Beam

The critical normal and shear stresses in the face material are

$$\sigma_f = \frac{Mz}{D} E_f \quad (c/2 \leq z \leq h/2 ; -h/2 \leq z \leq -c/2)$$

$$\tau_f = \frac{V}{D} E_f \left[\frac{((c/2)+t)^2 - z^2}{2} \right]$$

The critical normal and shear stresses in the core are

$$\sigma_c = \frac{Mz}{D} E_c \quad (-c/2 \leq z \leq c/2)$$

$$\tau_c = \frac{V}{D} \left[E_f \frac{td}{2} + \frac{E_c}{2} \left(\frac{c^2}{4} - z^2 \right) \right]$$

The maximum deflection in the beam is

$$\Delta = \frac{Pl^3}{C_s D} + \frac{Pl}{C_s A_s G_c}$$

Note that the location of applied force can be arbitrary in the analysis of sandwich beam.

The failure equations for the sandwich beam are :

Face yielding :

$$P_{fy} = C_1 \sigma_{yf} bct/l$$

Face wrinkling :

$$P_{fw} = 0.57 C_1 C_3^{2/3} E_f^{1/3} E_s^{2/3} (\rho_c/\rho_s)^{2A/3} bct/l$$

Core shearing :

$$P_{cs} = \frac{C_4 (\rho_c / \rho_s)^3 \sigma_{ys} bc}{\left(\left[\frac{C_3 (\rho_c / \rho_s)^4 E_s}{2 C_1 (\tau / l) E_f} \right] + \left(\frac{1}{C_2} \right)^{1/2} \right)}$$

This program will make a comparison of P_{xy} , P_{tw} , P_{cs} and pick one critical loading, then check whether the stress state is safe or not.

III. Minimum Weight Design for Stiffness in Sandwich Beams

The maximum deflection of the sandwich beam is

$$\Delta = \frac{Pl^3}{C_5 D} + \frac{Pl}{C_6 A G_c}$$

Solving for the density of the core, we obtain

$$\rho_c = \left[\frac{1}{C_5} \frac{C_3}{C_6} \frac{E_f}{E_s} \frac{Pltc}{(\Delta C_5 b \tau c^2 E_f - 2Pl^3)} \right]^{1/G} \rho_s$$

The weight of the sandwich beam is

$$\begin{aligned} W &= 2\rho_f b l \tau + \rho_c b l c \\ &= 2\rho_f b l \tau + \left[\frac{1}{C_5} \frac{C_3}{C_6} \frac{E_f}{E_s} Pl^{(1+G)} \tau c^{(1+G)} b^G \right]^{1/G} \rho_s \\ &\quad [\Delta C_5 b \tau c^2 E_f - 2Pl^3]^{-1/G} \end{aligned}$$

Letting $\partial W/\partial t = 0$ and $\partial W/\partial c = 0$ and solving, we find that

$$c_{opt} = \left(4 \left[\frac{G}{G-1} \left(\frac{4}{G-1} \right)^{1/G} \right] \left(\frac{2+2G}{G-1} \right)^{1-1/G} \frac{\rho_f}{\rho_s} \right)^{1/2}$$

$$\left(\frac{l C_s P E_f}{C_s C_6 E_s} \right)^{-1/G} F l^3 \left(\frac{1}{\Delta C_s b E_f} \right)^{1-1/G} \frac{G/(3G-1)}{1}$$

$$t_{opt} = \frac{2(1+G) P l^3}{(G-1) \Delta C_s E_f b c_{opt}^2}$$

$$(\rho_c)_{opt} = \rho_s \left[\frac{l C_s P E_f t_{opt} c_{opt}}{C_s C_6 E_s (\Delta C_s E_f b t_{opt} c_{opt}^2 - 2 P l^3)} \right]^{1/G}$$

Also, we can calculate the nondimensional parameter which gives a measure of the relative face and core stiffnesses.

$$\theta = \frac{l}{c_{opt}} \left(\frac{C_s (\rho_c/\rho_s)_{opt}^G E_s}{2 E_f} \frac{c_{opt}}{t_{opt}} \left(1 + 3 \frac{c_{opt}^2}{t_{opt}^2} \right) \right)^{1/2}$$

Allen suggests that θ should be greater than 20 to ensure that shear lag does not occur.

IV. Minimum Weight Design for Strength in Sandwich Beams

There are three possible failure modes considered in this program. For each case, the critical loading can be calculated

Face yielding :

$$P_{fy} = C_1 \sigma_{yf} bct/l$$

Face wrinkling :

$$P_{fw} = 0.57 C_1 C_3^{2/3} E_f^{1/3} E_s^{2/3} (\rho_c / \rho_s)^{2A/3} bct/l$$

Core shearing :

Assuming $\sigma_c \ll \tau_c$

$$P_{cs} = C_2 C_4 \sigma_{ys} (\rho_c / \rho_s)^B bc$$

The transition equation between two failure modes can be found by equating the corresponding applied forces.

Face yielding-Face wrinkling :

$$P_{fy} = P_{fw}$$

$$\rightarrow \rho_c / \rho_s = \left(\frac{\sigma_{yf}}{0.57 C_3^{2/3} E_f^{1/3} E_s^{2/3}} \right)^{3/2A}$$

Face yielding-Core shearing :

$$P_{fy} = P_{cs}$$

$$\rightarrow \tau/l = \frac{C_2 C_4}{C_1} \left(\frac{\rho_c}{\rho_s} \right)^B \frac{\sigma_{ys}}{\sigma_{yf}}$$

Face wrinkling-Core shearing :

$$P_{fw} = P_{cs}$$

$$\rightarrow \tau/l = \frac{C_2 C_4}{0.57 C_1 C_3^{2/3}} \left(\frac{\rho_c}{\rho_s} \right)^{B-2A/3} \frac{\sigma_{ys}}{E_f^{1/3} E_s^{2/3}}$$

A typical failure mode map is shown in Figure 3.

The optimum design lies on the transition line between two failure modes. There are four possibilities.

(a) Face yielding-Face wrinkling fail simultaneously

$$P_{fy} = C_1 \sigma_{yf} b c t / l$$

$$\rightarrow t = \frac{P l}{C_1 \sigma_{yf} b c}$$

$$P_{fw} = 0.57 C_3 C_2^{2/3} E_f^{1/3} E_s^{2/3} (\rho_c / \rho_s)^{2A/3} b c t / l$$

$$\rightarrow \frac{\rho_c}{\rho_s} = \left(\frac{\sigma_{yf}}{0.57 C_3^{2/3} E_f^{1/3} E_s^{2/3}} \right)^{3/2A}$$

Therefore, the weight function

$$W = 2 \rho_s b l \left(\frac{P l}{C_1 \sigma_{yf} b c} \right) + \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2A} \rho_s b c l$$

$$\text{where } \alpha = 0.57 C_3^{2/3} E_f^{1/3} E_s^{2/3}$$

Letting $\partial W / \partial c = 0$, we find

$$c_{opt} = \left[\frac{2 \rho_s P l \alpha^{3/2A}}{C_1 \rho_s (\sigma_{yf})^{(1+3/2A)} b} \right]^{1/2}$$

$$t_{opt} = \frac{P l}{C_1 \sigma_{yf} b c_{opt}}$$

$$(\rho_c)_{opt} = \rho_s \left(\frac{\sigma_{yf}}{0.57 C_3^{2/3} E_f^{1/3} E_s^{2/3}} \right)^{3/2A} = \text{constant}$$

From the failure mode map, it is realized that there is a

restriction in τ/l for the co-occurrence of face yielding and face wrinkling failures.

$$\frac{\tau_{opt}}{l} = \frac{P}{C_1 \sigma_{yf} b c_{opt}} \leq \frac{\tau}{l} = \frac{C_2 C_4}{C_1} (\rho_c / \rho_s)^B \frac{\sigma_{ys}}{\sigma_{yf}}$$

$$\rightarrow \frac{P}{b l} \leq \frac{C_2^2 C_4^2}{C_1} \sigma_{ys}^2 \frac{2 \rho_f}{\rho_s \sigma_{yf}} \left(\frac{\sigma_{yf}}{\alpha} \right)^{(6B-3)/2A}$$

(b) Face wrinkling-core shearing fail simultaneously

$$P_{fw} = 0.57 C_1 C_3^{2/3} E_f^{1/3} E_s^{2/3} (\rho_c / \rho_s)^{2A/3} b c \tau / l$$

$$\rightarrow \tau = \frac{P l}{0.57 C_1 C_3^{2/3} E_f^{1/3} E_s^{2/3} (\rho_c / \rho_s)^{2A/3} b c}$$

$$P_{cs} = C_2 C_4 (\rho_c / \rho_s)^B \sigma_{ys} b c$$

$$\rightarrow \rho_c = \rho_s \left(\frac{P}{C_2 C_4 \sigma_{ys} b c} \right)^{1/B}$$

Therefore, the weight function

$$W = 2 \rho_f \frac{P l^2}{C_1 \alpha (\rho_c / \rho_s)^{2A/3} c} + \rho_s l \left(\frac{P}{C_2 C_4 \sigma_{ys}} \right)^{1/B} (b c)^{1-1/B}$$

Letting $\partial W / \partial c = 0$. It is found

$$c_{opt} = \left[\frac{\rho_s (3-3B) C_1 \alpha b}{2 \rho_f (2A-3B) P l} \left(\frac{P}{C_2 C_4 \sigma_{ys} b} \right)^{(2A+3)/3B} \frac{3B}{3B/(2A-6B+3)} \right]$$

$$(\rho_c)_{opt} = \rho_s \left(\frac{P}{C_2 C_4 \sigma_{ys} b c_{opt}} \right)^{1/B}$$

$$t_{opt} = \frac{Pl}{C_1 \alpha (\rho_c / \rho_s)_{opt}^{2A/3} b c_{opt}}$$

Similarly, from the failure mode map, there is a restriction in ρ_c / ρ_s for face wrinkling-core shearing failure mode.

i.e.

$$(\rho_c / \rho_s)_{opt} \leq \rho_c / \rho_s = \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2A}$$

Therefore,

$$\frac{P}{bl} \leq \frac{2\rho_s(2A-3B)C_2^2 C_4^2 \sigma_{ys}^2}{\rho_s(3-3B)C_1 \alpha} \left(\frac{\sigma_{yf}}{\alpha} \right)^{(6B-2A-3)/2A}$$

(c) Face yielding-core shearing fail simultaneously

$$P_{ty} = C_1 \sigma_{yf} b c t / l$$

$$\rightarrow t = \frac{Pl}{C_1 \sigma_{yf} b c}$$

$$P_{cs} = C_2 C_4 (\rho_c / \rho_s)^B \sigma_{ys} b c$$

$$\rightarrow \rho_c = \rho_s \left(\frac{P}{C_2 C_4 \sigma_{ys} b c} \right)^{1/B}$$

Thus, the weight function is :

$$W = \frac{2\rho_f Pl^2}{C_1 \sigma_{yf} c} + \left(\frac{P}{C_2 C_4 \sigma_{ys}} \right)^{1/B} (bc)^{1-1/B} \rho_s l$$

Letting $\partial W / \partial c = 0$. We can find

$$c_{opt} = \left[\frac{2\rho_f B P l}{\rho_s (B-1) b C_1 \sigma_{yf}} \left(\frac{C_2 C_4 \sigma_{ys} b}{P} \right)^{1/B} \right]^{B/(2B-1)}$$

$$t_{opt} = \frac{Pl}{C_1 \sigma_{yf} b c_{opt}}$$

$$(\rho_c)_{opt} = \rho_s \left(\frac{P}{C_2 C_4 \sigma_{ys} b c_{opt}} \right)^{1/B}$$

In order for face yielding and core shearing to occur at the same time there is a limitation in ρ_c / ρ_s according to the failure mode map. That is

$$(\rho_c / \rho_s)_{opt} \geq \rho_c / \rho_s = \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2A}$$

Therefore,

$$\frac{P}{bl} \geq \frac{2\rho_f B C_2^2 C_4^2 \sigma_{ys}^2}{\rho_s (B-1) C_1 \sigma_{yf}} \left(\frac{\sigma_{yf}}{\alpha} \right)^{(6B-3)/2A}$$

(d) Face yielding-face wrinkling -core shearing fail
simultaneously

$$P_{fy} = C_1 \sigma_{yf} b c t / l$$

$$P_{fw} = C_1 \alpha (\rho_c / \rho_s)^{2A/3} b c t / l$$

$$P_{cs} = C_2 C_4 \sigma_{ys} (\rho_c / \rho_s)^B b c$$

The three equations in three unknowns give :

$$c_{opt} = \frac{P}{C_2 C_4 \sigma_{ys} b} \left(\frac{\sigma_{yf}}{\alpha} \right)^{-3B/2A} = \text{constant}$$

$$t_{opt} = \frac{Pl}{C_1 \sigma_{yf} b c_{opt}} = \text{constant}$$

$$(\rho_c)_{opt} = \rho_s \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2A} = \text{constant}$$

In running this program, the P/bl requirement is checked first. The optimal design is evaluated for each case for which the condition is met. Among the above possible failure modes, the one with the minimum weight is selected as the overall optimum design.

V. Minimum Weight Design for Both Stiffness and Strength

In practice, the minimum weight design should take both stiffness and strength requirements into account. In this program, there are three kinds of failure mode considered for sandwich beams.

(a) Stiffness and face yielding failure

$$P_{ty} = C_1 \sigma_{yf} b c t / l$$

$$\rightarrow c = \frac{Pl}{C_1 \sigma_{yf} b t}$$

$$\Delta = \frac{Pl^3}{C_5 D} + \frac{Pl}{C_6 A G_c}$$

$$\rightarrow \rho_c = \left[\frac{C_5 E_f P l t c}{C_6 C_6 E_s (C_5 \Delta b t c^2 E_f - 2 P l^3)} \right]^{1/G} \rho_s$$

Therefore, the weight function becomes

$$W = 2 \rho_f b t l + \left[\frac{\Delta C_6 C_6 E_s C_1^{(G-1)} \sigma_{yf}^{(G-1)}}{P^G \rho_s^G l^{2G}} t^{(G-1)} - \frac{2 C_6 C_6 E_s C_1^{(G+1)} \sigma_{yf}^{(G+1)} b}{C_5 E_f P^{(G+1)} \rho_s^G l^{(2G-1)}} t^G \right]^{-1/G}$$

Since the weight of the sandwich beam is a real number, the value in the bracket should be larger than zero. From this observation it is concluded that

$$0 < t < \frac{\Delta C_5 E_f P}{2 C_1^2 \sigma_{yf}^2 b l}$$

There is a constraint for face yielding failure.

$$(\rho_c / \rho_s)_{opt} \geq \rho_c / \rho_s = \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2A}$$

Within the range, a minimum weight can be found by incrementally increasing t . The corresponding face and core

thicknesses and foam density are the optimal design values.

(b) Stiffness and face wrinkling failure

$$P_{fw} = C_1 \alpha (\rho_c / \rho_s)^{2A/3} b c t / l$$

$$\rightarrow t = \frac{P l}{C_1 a b c} (\rho_c / \rho_s)^{-2A/3}$$

$$\Delta = \frac{P l^3}{C_5 D} + \frac{P l}{C_6 A G_c}$$

$$\rightarrow c = \frac{2 l^2 C_1 \alpha}{C_5 \Delta E_f} (\rho_c / \rho_s)^{2A/3} + \frac{P l}{C_8 C_6 E_s b \Delta} (\rho_c / \rho_s)^{-G}$$

Thus, the weight function can be expressed as

$$W = \frac{2 \rho_s b P l^2}{C_1 \alpha} \left[\frac{C_8 C_6 E_s C_5 \Delta E_f (\rho_c / \rho_s)^{-4A/3}}{2 l^2 C_8 C_6 E_s \alpha C_1 b + C_5 E_f P l (\rho_c / \rho_s)^{(-2A-3G)/3}} \right] + \rho_c l \left[\frac{2 l^2 C_8 C_6 E_s C_1 a b + C_5 E_f P l (\rho_c / \rho_s)^{(-2A-3G)/3}}{C_8 C_6 E_s C_5 \Delta E_f (\rho_c / \rho_s)^{-2A/3}} \right]$$

From the failure mode map, it is known that there is a limitation in ρ_c / ρ_s for occurrence of face wrinkling.

$$0 < \rho_c / \rho_s \leq \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2A}$$

There is a constraint for face wrinkling failure.

$$\frac{t}{l} \leq \frac{C_2 C_4 \sigma_{ys}}{C_1 \alpha} (\rho_c / \rho_s)^{B-(2A/3)}$$

The value which corresponds to the minimum weight can be found using the same argument as that for the constraints of stiffness and the face yielding failure mode.

(c) Stiffness, face yielding and face wrinkling

$$P_{fy} = C_1 \sigma_{yf} bct/l$$

$$P_{fw} = C_1 \alpha (\rho_c / \rho_s)^{2\lambda/3} bct/l$$

$$\Delta = \frac{Pl^3}{C_5 D} + \frac{Pl}{C_6 A G_c}$$

The three constraints in three variables can be solved for :

$$(\rho_c / \rho_s)_{opt} = \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2\lambda}$$

$$c_{opt} = \frac{2l^2 C_1 \sigma_{yf}}{C_5 \Delta E_f} + \frac{Pl}{C_6 C_8 E_s b \Delta} \left(\frac{\sigma_{yf}}{\alpha} \right)^{-3G/2\lambda}$$

$$t_{opt} = \frac{Pl}{C_1 \sigma_{yf} b c_{opt}}$$

In running this program, the three failure modes considered above will be compared with each other to determine the overall minimum weight design.

It is noted that the stiffness-core shearing failure mode is not included in this program because it ends up with an impractically large core thickness.

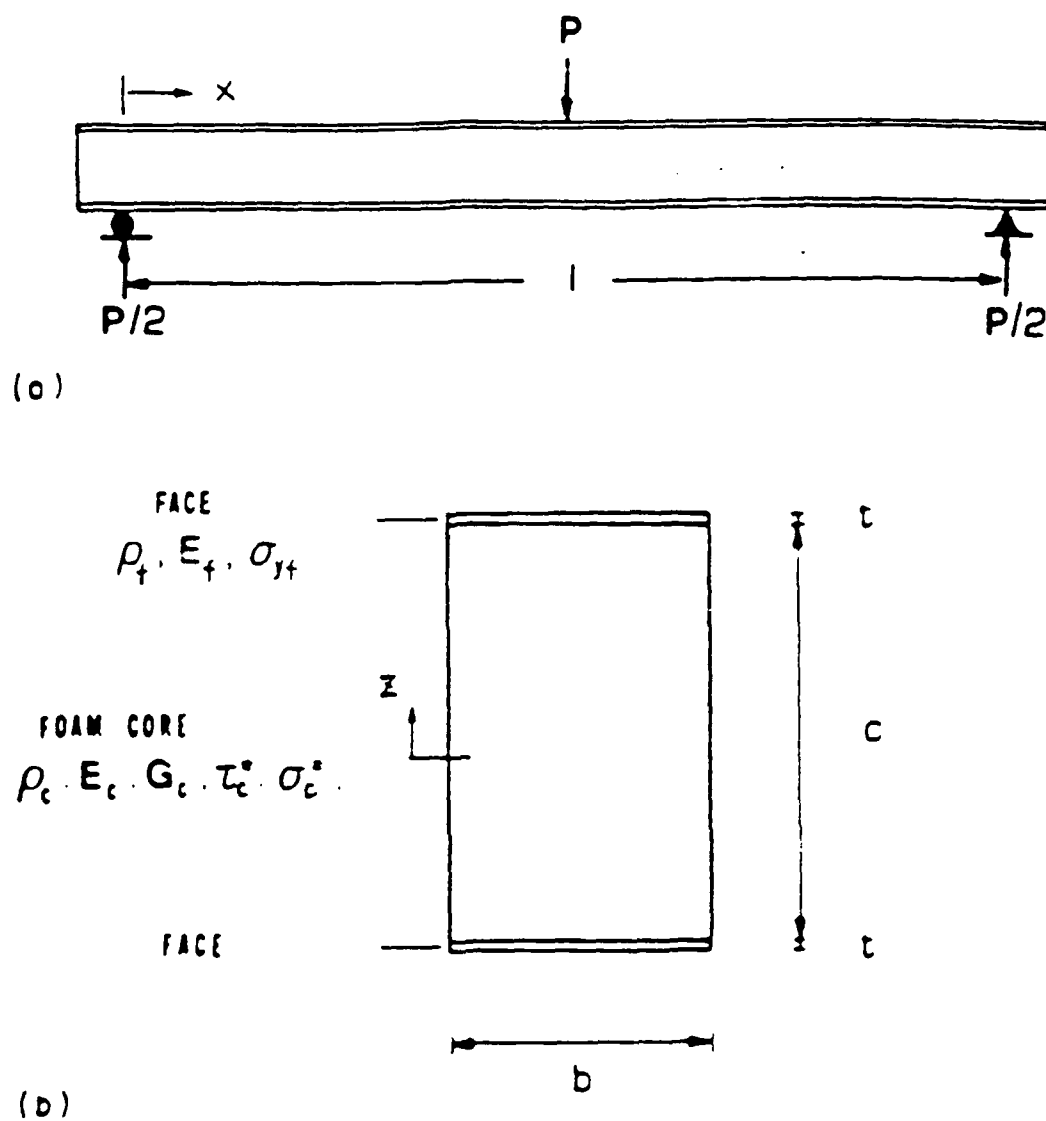


Figure 1. The geometry of the sandwich beam.

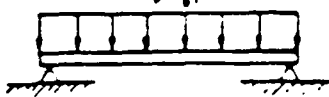
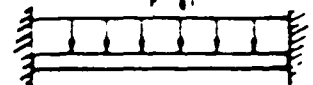
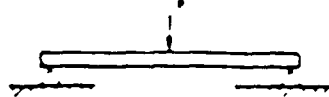
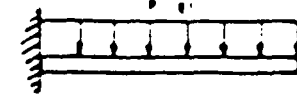
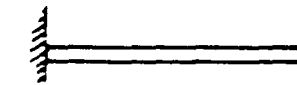
BEAM TYPE	MAXIMUM SHEAR FORCE C_2	MAXIMUM BENDING MOMENT C_1	BENDING DEFLECTION CONSTANT C_5	SHEAR DEFLECTION CONSTANT C_6
SIMPLE SUPPORT UNIFORM LOAD 	2	8	76.8	8
BOTH ENDS FIXED UNIFORM LOAD 	2	12	384	8
SIMPLE SUPPORT CENTER LOAD 	2	4	48	4
BOTH ENDS FIXED CENTER LOAD 	2	8	192	4
CANTILEVER UNIFORM LOAD 	1	2	8	2
CANTILEVER END LOAD 	1	1	3	1

Figure 2. The load constants for different geometry.

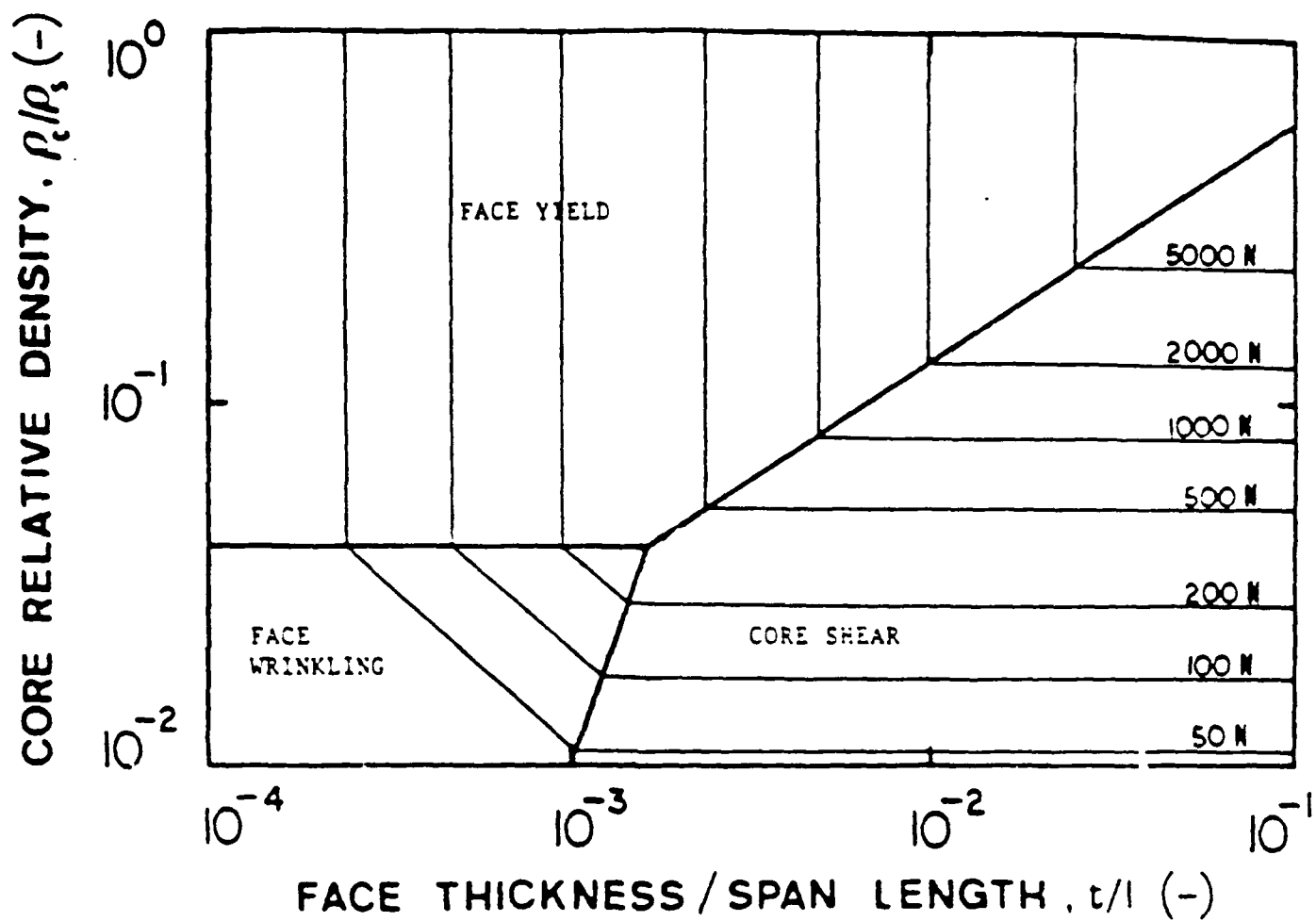


Figure 3. A failure mode map for a sandwich beam loaded in three-point bending with strength contours superimposed on the map ($b-c=25$ mm).

ANALYSIS AND MINIMUM WEIGHT DESIGN
IN SANDWICH PLATES WITH RIGID FOAM CORE

I. Introduction

There are three kinds of sandwich plate considered in this program :

1. A simply supported circular sandwich plate under a distributed load over a central circular portion of its area.
2. A clamped circular sandwich plate under a distributed load over a central circular portion of its area.
3. A simply supported rectangular sandwich plate under a distributed load over its entire area.

Figure 4 shows a circular sandwich plate which spans a radius r and carries a distributed load q over a central circular portion of its area of radius a . The thickness of each face is t , while that of the foam core is c . The faces have a density ρ_f , a Young's modulus E_f , Poisson's ratio ν_f and a yield strength σ_{yf} . The solid polymer of which the core is made has a density ρ_s , a Young's modulus E_s and a yield strength σ_{ys} . The density of the foamed core is ρ_c , its Young's modulus is E_c , its shear modulus is G_c and its shear strength is τ_c^* .

A rectangular sandwich plate which has a length b and width a (note that $b \geq a$), is shown in Figure 5.

There are three assumptions made in this program :

- (1) Both the face and core materials are isotropic.

- (2) The sandwich plate has an antiplane core and thin faces.
 (3) Stresses in the faces and core in the z-direction are of no importance and neglected.

The foam core property-density relationships are

$$E_c = C_3 \left(\rho_c / \rho_s \right)^A E_s$$

$$\tau_c^* = C_4 \left(\rho_c / \rho_s \right)^B \sigma_{ys}$$

$$G_c = C_8 \left(\rho_c / \rho_s \right)^G E_s$$

where C_3 , C_4 , C_8 , A , B and G are material properties.

For a sandwich plate, the maximum deflection can be expressed

as

$$\Delta = \frac{qa^4}{16D} g_1 + \frac{qa^2}{4S} g_2$$

The maximum stresses in the face material are

$$\sigma_x \text{ (or } \sigma_r \text{)} = \frac{qa^2}{ct} (g_3 + \nu_f g_4)$$

$$\sigma_y \text{ (or } \sigma_t \text{)} = \frac{qa^2}{ct} (g_5 + \nu_f g_6)$$

$$\tau_{xy} \text{ (or } \tau_{rt} \text{)} = \frac{qa^2}{ct} (1 - \nu_f) g_7$$

The maximum stresses in the core are

$$\tau_{xz} \text{ (or } \tau_{rz} \text{)} = \frac{qa}{c} g_8$$

$$\tau_{yz} \text{ (or } \tau_{tz} \text{)} = \frac{qa}{c} g_9$$

where $g_1, g_2, g_3, g_4, g_5, g_6, g_7, g_8$ and g_9 are constants related to the loading geometry of the sandwich plate.

$$D = \frac{E_f t c^2}{2 (1 - \nu_f^2)}$$

$$S = c G_c$$

The loading geometry constants for three different configurations which are available in this program is given in Appendix.

The program has four parts :

- (1) Analysis of sandwich plate deflections and stresses.
- (2) Minimum weight design of a sandwich plate for stiffness.
- (3) Minimum weight design of a sandwich plate for strength.
- (4) Minimum weight design of a sandwich plate for both stiffness and strength.

II. Analysis of Sandwich Plate

The maximum stresses in the face material are

$$\sigma_x \text{ (or } \sigma_r \text{)} = \frac{qa^2}{ct} (g_3 + \nu_f g_4)$$

$$\sigma_y \text{ (or } \sigma_t \text{)} = \frac{qa^2}{ct} (g_5 + \nu_f g_6)$$

$$\tau_{xy} \text{ (or } \tau_{rt} \text{)} = \frac{qa^2}{ct} (1 - \nu_f) g_7$$

The maximum stresses in the core are

$$\tau_{xz} \text{ (or } \tau_{zx} \text{)} = \frac{qa}{c} \epsilon_3$$

$$\tau_{yz} \text{ (or } \tau_{zy} \text{)} = \frac{qa}{c} \epsilon_5$$

The maximum deflection in the plate is

$$\Delta = \frac{qa^4}{16D} \epsilon_1 + \frac{qa^2}{4S} \epsilon_2$$

The failure equations for the sandwich plate are :

Face yielding :

$$\epsilon_{fy} = \frac{\sigma_{yf} c t}{a^2 (\epsilon_3 + \nu_f \epsilon_4)}$$

Face wrinkling :

Plantema pointed out that the superposition of the perpendicular normal stresses in the plane of the face does not affect the wrinkling stress. Therefore,

$$\epsilon_{fw} = \frac{\alpha c t (\rho_c / \rho_s)^{2A/3}}{a^2 (\epsilon_3 + \nu_f \epsilon_4)}$$

$$\text{where } \alpha = 0.57 C_3^{2/3} E_f^{1/3} E_s^{2/3}$$

Core shearing :

Assuming $\sigma_c \ll \tau_c$ and the core material is isotropic. Thus,

$$q_{cs} = \frac{C_s (\rho_c / \rho_s)^B \sigma_{ys} c}{a \epsilon_5}$$

This program will make a comparison of q_{fy} , q_{fw} , q_{cs} and pick

one critical loading, then check whether the stress state is safe or not.

III. Minimum Weight Design for Stiffness in Sandwich Plates

The maximum deflection of the sandwich plate is

$$\Delta = \frac{qa^4}{16D} g_1 + \frac{qa^2}{4S} g_2$$

Since

$$G_c = C_s (\rho_c / \rho_s)^G E_s$$

Solving for the density of the core, it is found

$$\rho_c = \rho_s \left(\frac{a^2 g_2}{4C_s E_s c} \left[\frac{\Delta}{q} - \frac{a^4 (1-\nu_f^2) g_1}{8E_f t c^2} \right]^{-1/G} \right)^{1/G}$$

The weight of the sandwich plate is

$$W = 2\rho_f abt + \rho_c abc \quad (\text{or } W = 2\rho_f \pi r^2 t + \rho_c \pi r^2 c)$$

Letting $\partial W / \partial t = 0$ and $\partial W / \partial c = 0$ and solving, we find

$$(\rho_c)_{\text{opt}} = \rho_s \left(\frac{(G+1)^2 (G-1)^2 g_2^3 \rho_s E_f}{256 C_s^3 G (1-\nu_f^2) g_1 \rho_f E_s^3} \left(\frac{qa^2}{\Delta} \right)^{1/(3G-1)} \right)$$

$$c_{\text{opt}} = \frac{a}{2} (4^{G+1} C_s \frac{G^G (G+1)^{G-1} (1-\nu_f^2)^G g_1^G \rho_f^G E_s^G}{(G-1)^{2G} g_2^G \rho_s^G E_f^G} \left(\frac{qa^{G-1}}{\Delta} \right)^{\frac{1}{3G-1}})$$

$$\tau_{opt} = 4a \left(\frac{(G^2 - 1)^{G+1} (1 - \nu_f^2)^{G-1} g_1^{G-1} g_2^2 E_f^{1-G}}{2^{13G+1} C_s^2 G^2 G E_s^2} \right)$$

$$(\rho_s / \rho_f)^{2G} \left(\frac{q_s}{\Delta} \right)^{G+1} \left(\frac{1}{3G-1} \right)$$

IV. Minimum Weight Design for Strength in Sandwich Plates

Similar to those of the sandwich beams, there are three possible failure modes considered in this program.

Face yielding :

$$q_{fy} = \frac{\sigma_{yf} c t}{a^2 (g_3 + \nu_f g_4)}$$

Face wrinkling :

$$q_{fw} = \frac{\alpha c t (\rho_c / \rho_s)^{2\Lambda/3}}{a^2 (g_3 + \nu_f g_4)}$$

Core shearing :

$$q_{cs} = \frac{C_s \sigma_{ys} c (\rho_c / \rho_s)^3}{a g_8}$$

The transition equation between two failure modes can be obtained by equating the corresponding applied distributed forces.

Face yielding-Face wrinkling :

$$q_{fy} = q_{fw}$$

$$\rightarrow \rho_c / \rho_s = \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2\Lambda}$$

Face yielding-Core shearing :

$$q_{fy} = q_{cs}$$

$$\rightarrow \tau/a = \frac{C_s \sigma_{ys} (g_3 + \nu_s g_4) (\rho_c / \rho_s)^B}{\sigma_{yf} g_8}$$

Face wrinkling-Core shearing :

$$q_{fw} = q_{cs}$$

$$\rightarrow \tau/a = \frac{C_s \sigma_{ys} (g_3 + \nu_s g_4) (\rho_c / \rho_s)^{B-2A/3}}{g_8 \alpha}$$

The failure mode map is the same as that of sandwich beams except that the coordinate τ/l replaced by τ/a .

The optimum design lies on the transition line between two failure modes. There are four possibilities.

(a) Face yielding-Face wrinkling fail simultaneously

$$q_{fy} = \frac{\sigma_{yf} c \tau}{a^2 (g_3 + \nu_s g_4)}$$

$$\rightarrow \tau = \frac{q a^2 (g_3 + \nu_s g_4)}{\sigma_{yf} c}$$

$$q_{fw} = \frac{\alpha c \tau (\rho_c / \rho_s)^{2A/3}}{a^2 (g_3 + \nu_s g_4)}$$

$$\rightarrow \rho_c / \rho_s = \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2A}$$

Therefore, the weight function becomes

$$W = 2\rho_f abt + \rho_c abc \quad (\text{or } W = 2\rho_f \pi r^2 t + \rho_c \pi r^2 c)$$

$$= 2\rho_f ab \frac{qa^2(g_3 + \nu_f g_4)}{\sigma_{yf} c} + \rho_s \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2\lambda} abc$$

Letting $\partial W / \partial c = 0$, we find

$$c_{opt} = \left[\frac{2\rho_f qa^2(g_3 + \nu_f g_4) \alpha^{3/2\lambda}}{\rho_s \sigma_{yf}^{(1+3/2\lambda)}} \right]^{1/2}$$

$$t_{opt} = \frac{qa^2(g_3 + \nu_f g_4)}{\sigma_{yf} c_{opt}}$$

$$(\rho_c)_{opt} = \rho_s \left(\frac{c_{yf}}{0.57 C_3^{2/3} E_f^{1/3} E_s^{2/3}} \right)^{3/2\lambda} = \text{constant}$$

From the failure mode map, it is realized that there is a restriction in t/a for the co-occurrence of face yielding and face wrinkling failures.

$$\frac{t_{opt}}{a} = \frac{qa(g_3 + \nu_f g_4)}{\sigma_{yf} c_{opt}} \leq \frac{t}{a} = \frac{C_4(g_3 + \nu_f g_4)}{g_8} \left(\frac{\rho_c}{\rho_s} \right)_{opt} \frac{\sigma_{ys}}{\sigma_{yf}}$$

$$\Rightarrow q \leq \frac{C_4^2(g_3 + \nu_f g_4)}{g_8^2} \sigma_{ys}^2 \frac{2\rho_f}{\rho_s \sigma_{yf}} \left(\frac{\sigma_{yf}}{\alpha} \right)^{(6B-3)/2\lambda}$$

(b) Face wrinkling-core shearing fail simultaneously

$$q_{cs} = \frac{C_4 \sigma_{ys} c(\rho_c / \rho_s)^B}{g_8 a}$$

$$\begin{aligned} \rightarrow \quad \rho_c / \rho_s &= \left(\frac{q a g_8}{C_4 \sigma_{ys} c} \right)^{1/3} \\ q_{tw} &= \frac{\alpha c t (\rho_c / \rho_s)^{2A/3}}{a^2 (g_3 + \nu_f g_4)} \\ \rightarrow \quad t &= \frac{q a^2 (g_3 + \nu_f g_4)}{\alpha c} \left(\frac{C_4 \sigma_{ys} c}{q a g_8} \right)^{2A/3B} \end{aligned}$$

The weight function is

$$W = 2\rho_f a b t + \rho_c a b c$$

Letting $\partial W / \partial c = 0$. It is found

$$\begin{aligned} c_{opt} &= \left[\frac{\rho_s (3-3B) \alpha}{2\rho_f (2A-3B) q a^2 (g_3 + \nu_f g_4)} \right. \\ &\quad \left. \left(\frac{q a g_8}{C_4 \sigma_{ys}} \right)^{(2A+3)/3B} \frac{3B}{(2A-6B+3)} \right] \end{aligned}$$

$$(\rho_c)_{opt} = \rho_s \left(\frac{q a g_8}{C_4 \sigma_{ys} c_{opt}} \right)^{1/3}$$

$$t_{opt} = \frac{q a^2 (g_3 + \nu_f g_4)}{\alpha (\rho_c / \rho_s)_{opt}^{2A/3} c_{opt}}$$

Similarly, from the failure mode map, there is a restriction in ρ_c / ρ_s for face wrinkling-core shearing failure mode.

i.e.

$$(\rho_c / \rho_s)_{opt} = \left(\frac{q a g_8}{C_4 \sigma_{ys} c_{opt}} \right)^{1/3} \leq \rho_c / \rho_s = \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2A}$$

Therefore,

$$q \leq \frac{2\rho_f(2A-3B)C_4^2\sigma_{ys}^2(g_3+\nu_f g_4)}{\rho_s(3-3B)g_f^2 a} \left(\frac{\sigma_{yf}}{a} \right)^{(6B-2A-3)/2A}$$

(c) Face yielding-core shearing fail simultaneously

$$q_{fv} = \frac{\sigma_{yf} c t}{a^2(g_3+\nu_f g_4)}$$

$$\rightarrow t = \frac{q a^2(g_3+\nu_f g_4)}{\sigma_{yf} c}$$

$$q_{cs} = \frac{C_4(\rho_c/\rho_s)^B \sigma_{ys} c}{g_8 a}$$

$$\rightarrow \rho_c = \rho_s \left(\frac{q a g_8}{C_4 \sigma_{ys} c} \right)^{1/B}$$

The weight function is

$$W = 2\rho_f a b t + \rho_c a b c$$

Letting $\partial W/\partial c = 0$. We can find

$$c_{opt} = \left[\frac{2\rho_f B q a^2(g_3+\nu_f g_4)}{\rho_s(B-1)\sigma_{yf}} \left(\frac{C_4 \sigma_{ys}}{q a g_8} \right)^{1/B} \right]^{B/(2B-1)}$$

$$t_{opt} = \frac{q a^2(g_3+\nu_f g_4)}{\sigma_{yf} c_{opt}}$$

$$(\rho_c)_{opt} = \rho_s \left(\frac{q a g_8}{C_4 \sigma_{ys} c_{opt}} \right)^{1/B}$$

In order for face yielding and core shearing to occur at the

same time there is a limitation in ρ_c/ρ_s according to the failure mode map. That is

$$(\rho_c/\rho_s)_{\text{opt}} = \left(\frac{q a g_8}{C_4 \sigma_{ys} c_{\text{opt}}} \right)^{1/B} \geq \rho_c/\rho_s = \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2A}$$

Therefore,

$$q \geq \frac{2\rho_s B C_4^2 \sigma_{ys}^2 (g_3 + \nu_f g_4)}{\rho_s (B-1) \sigma_{yf} g_8^2} \left(\frac{\sigma_{yf}}{\alpha} \right)^{(6B-3)/2A}$$

(d) Face yielding, face wrinkling -core shearing fail
simultaneously

$$q_{fy} = \frac{\sigma_{yf} c t}{a^2 (g_3 + \nu_f g_4)}$$

$$q_{fw} = \frac{\alpha c t (\rho_c/\rho_s)^{2A/3}}{a^2 (g_3 + \nu_f g_4)}$$

$$q_{cs} = \frac{C_4 (\rho_c/\rho_s)^B \sigma_{ys} c}{a g_8}$$

The three equations in three unknowns give :

$$c_{\text{opt}} = \frac{q a g_8}{C_4 \sigma_{ys}} \left(\frac{\sigma_{yf}}{\alpha} \right)^{-3B/2A} = \text{constant}$$

$$t_{\text{opt}} = \frac{q a^2 (g_3 + \nu_f g_4)}{\sigma_{yf} c_{\text{opt}}} = \text{constant}$$

$$(\rho_c)_{opt} = \rho_s \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2A} = \text{constant}$$

In running this program, the q requirement is checked first. The optimal design is evaluated for each case for which the condition is met. Among the above possible failure modes, the one with the minimum weight is selected as the overall optimum design.

V. Minimum Weight Design for Both Stiffness and Strength

In practice, the minimum weight design should take both stiffness and strength requirements into account. In this program, there are three kinds of failure mode considered for sandwich plates.

(a) Stiffness and face yielding failure

$$q_{fy} = \frac{\sigma_{yf} c t}{a^2 (g_3 + \nu_1 g_4)}$$

$$\rightarrow c = \frac{q a^2 (g_3 + \nu_1 g_4)}{\sigma_{yf} t}$$

$$\Delta = \frac{q a^4}{16D} g_1 + \frac{q a^2}{4S} g_2$$

$$\rightarrow \rho_c = \left(\frac{a^2 g_2}{4C E_s c} \left[\frac{\Delta}{q} - \frac{a^4 (1 - \nu_1^2) g_1}{8 E_f t c^2} \right] \right)^{1/3} \rho_s$$

Therefore, the weight function becomes

$$W = 2\rho_f abt + \frac{\rho_s abqa^2(g_3 + \nu_f g_4)}{\sigma_{yf}} \left[\frac{8q^2 a^4 g_2 E_f (g_3 + \nu_f g_4)}{4C_s E_s \sigma_{yf}} \right]^{1/6} \\ \left[\frac{8\Delta E_f q^2 a^4 (g_3 + \nu_f g_4)^2 t^{G-1} - a^4 q (1 - \nu_f^2) E_1 \sigma_{yf}^2 t^G}{\sigma_{yf}^2} \right]^{-1/6}$$

Since the weight of the sandwich plate is a real number, the value in the bracket should be larger than zero. From this observation it is concluded that

$$0 < t < \frac{8\Delta E_f q (g_3 + \nu_f g_4)^2}{(1 - \nu_f^2) E_1 \sigma_{yf}^2}$$

There is a constraint for face yielding failure.

$$(\rho_c/\rho_s)_{opt} \geq \rho_c/\rho_s = \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2\lambda}$$

Within the range, a minimum weight can be found by incrementally increasing t . The corresponding face and core thicknesses and foam density are the optimal design values.

(b) Stiffness and face wrinkling failure

$$q_{tw} = \frac{\alpha c t (\rho_c/\rho_s)^{2\lambda/3}}{a^2 (g_3 + \nu_f g_4)} \\ \rightarrow t = \frac{q a^2 (g_3 + \nu_f g_4)}{\alpha c} (\rho_c/\rho_s)^{-2\lambda/3}$$

$$\Delta = \frac{qa^4}{16D} g_1 + \frac{qa^2}{4S} g_2$$

$$\rightarrow c = \frac{a^2 \alpha g_1 (1 - \nu_f^2)}{8 \Delta E_f (g_3 + \nu_f g_4)} (\rho_c / \rho_s)^{2\lambda/3} + \frac{qa^2 g_2}{4 C_s E_s \Delta} (\rho_c / \rho_s)^{-6}$$

The weight function is

$$W = 2\rho_f abc + \rho_c abc$$

From the failure mode map, it is known that there is a limitation in ρ_c / ρ_s for occurrence of face wrinkling.

$$0 < \rho_c / \rho_s \leq \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2\lambda}$$

Also, there is another constraint for face wrinkling failure.

$$\frac{c}{a} \leq \frac{C_s \sigma_{ys} (g_3 + \nu_f g_4) (\rho_c / \rho_s)^{3-2\lambda/3}}{\alpha g_8}$$

The value which corresponds to the minimum weight can be found using the same argument as that for the constraints of stiffness and the face yielding failure mode.

(c) Stiffness, face yielding and face wrinkling

$$q_{fy} = \frac{\sigma_{yf} c t}{a^2 (g_3 + \nu_f g_4)}$$

$$q_{fw} = \frac{\alpha c t (\rho_c / \rho_s)^{2\lambda/3}}{a^2 (g_3 + \nu_f g_4)}$$

$$\Delta = \frac{qa^4}{16D} g_1 + \frac{qa^2}{4S} g_2$$

The three constraints in three variables can be solved for :

$$(\rho_c/\rho_s)_{opt} = \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2\Delta} = \text{constant}$$

$$c_{opt} = \frac{a^2 \sigma_{yf} g_1 (1 - \nu_f^2)}{8 \Delta E_f (g_3 + \nu_f g_4)} + \frac{q a^2 g_2}{4 C_s E_s \Delta} \left(\frac{\sigma_{yf}}{\alpha} \right)^{-3G/2\Delta} = \text{constant}$$

$$\tau_{opt} = \frac{q a^2 (g_3 + \nu_f g_4)}{\sigma_{yf} c_{opt}} = \text{constant}$$

In running this program, the three failure modes considered above will be compared with each other to determine the overall minimum weight design.

It is noted that the stiffness-core shearing failure mode is not included in this program because it ends up with an impractically large core thickness.

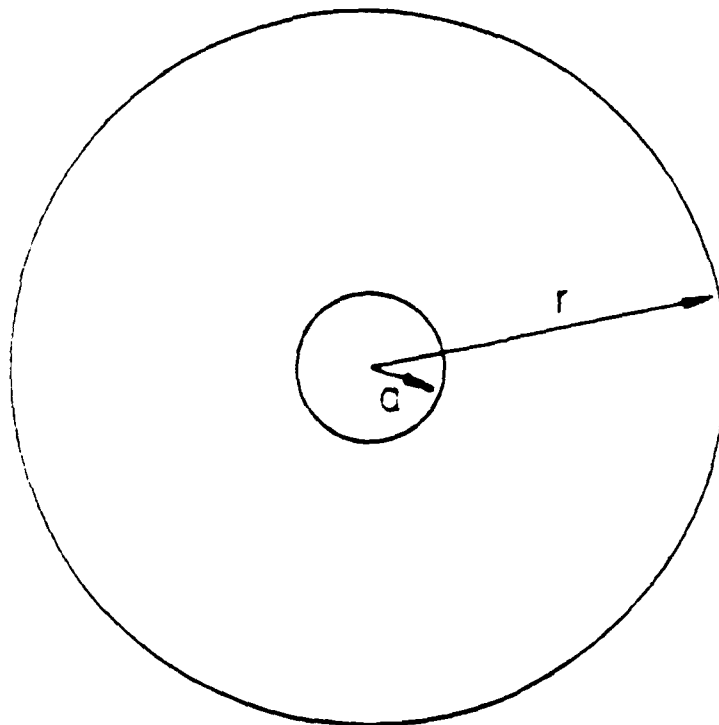
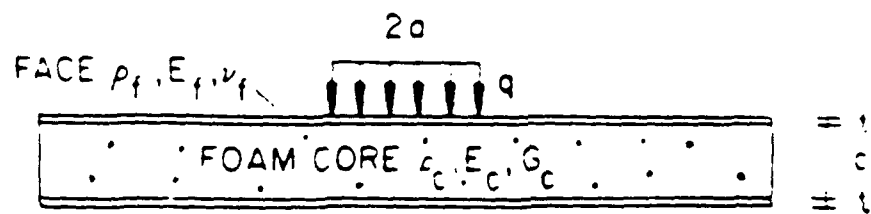


Figure 4. The geometry of a circular sandwich plate.

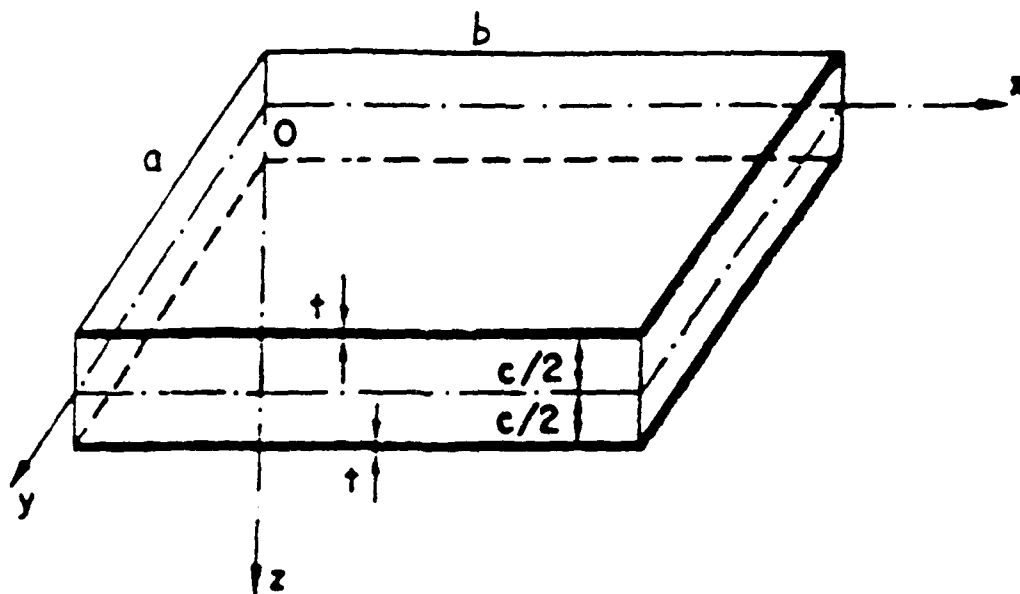


Figure 5. The geometry of a rectangular sandwich plate.

Appendix

Simply supported circular sandwich plate :

$$g_1 = \frac{3+\nu_f}{1+\nu_f} (r/a)^2 + \ln(a/r) - \frac{7+3\nu_f}{4(1+\nu_f)}$$

$$g_2 = 1 + 2\ln(r/a)$$

$$g_3 = 1/2 + \frac{1}{2}\ln(r/a) - \frac{a^2}{8r^2}$$

$$g_4 = \frac{1}{2}\ln(r/a) + \frac{a^2}{8r^2}$$

$$g_5 = \frac{1}{2} + \frac{1}{2}\ln(r/a) - \frac{a^2}{8r^2}$$

$$g_6 = \frac{1}{2}\ln(r/a) + \frac{a^2}{8r^2}$$

$$g_7 = 0$$

$$g_8 = 1/2$$

$$g_9 = 1/2$$

Clamped circular sandwich plate :

(1) $a > 0.588r$

$$g_1 = (r/a)^2 - \ln(r/a) - \frac{3}{4}$$

$$g_2 = 1 + 2\ln(r/a)$$

$$g_3 = g_6 = \frac{1}{2} - \frac{a^2}{4r^2}$$

$$g_4 = g_5 = 0$$

$$g_7 = 0$$

$$g_8 = g_9 = 1/2$$

$$(2) \ a < 0.588r$$

$$g_1 = (r/a)^2 - \ln(r/a) - \frac{3}{4}$$

$$g_2 = 1 + 2\ln(r/a)$$

$$g_3 = g_4 = g_5 = g_6 = \frac{1}{2}\ln(r/a) + \frac{a^2}{8r^2}$$

$$g_7 = 0$$

$$g_8 = g_9 = 1/2$$

Simply supported rectangular sandwich plate :

$$g_1 = \frac{(16)^2}{\pi^6} \sum \sum \frac{(-1)^{(m-1)/2} (-1)^{(n-1)/2}}{mn\Omega^2}$$

$$g_2 = \frac{64}{\pi^4} \sum \sum \frac{(-1)^{(m-1)/2} (-1)^{(n-1)/2}}{mn\Omega}$$

$$g_3 = g_6 = \frac{16}{\pi^4} \sum \sum \frac{(-1)^{(m-1)/2} (-1)^{(n-1)/2}}{\Omega^2} \frac{\pi a^2}{nb^2}$$

$$g_4 = g_5 = \frac{16}{\pi^4} \sum \sum \frac{(-1)^{(m-1)/2} (-1)^{(n-1)/2}}{\Omega^2} \frac{n}{m}$$

$$g_7 = \frac{16}{\pi^4} \sum \sum \frac{a}{b\Omega^2}$$

$$g_8 = \frac{16}{\pi^3} \sum \sum \frac{(-1)^{(n-1)/2}}{n\Omega} \frac{a}{b}$$

$$g_9 = \frac{16}{\pi^3} \sum \sum \frac{(-1)^{(m-1)/2}}{m\Omega}$$

$$\text{where } \Omega = \frac{m^2 a^2}{b^2} + n^2$$

$$m, n = 1, 3, 5, 7, \dots, 23$$

PROGRAM SWP

```

*****
*****
***
*** THIS PROGRAM WAS CREATED BY JONG-SHIN HUANG ***
*** IN AUGUST 1988 FOR OPTIMUM DESIGN METHODS OF ***
*** STRUCTURAL SANDWICH PANELS ***
***
*****
*****
INTEGER TY,CONF1,FAIL
REAL C5(10),C6(10),EF,EC,GC,WS,SS,UDL,MCL,LCL,M,SD,D,YF,YS,C3,A,G8
REAL STEP,2,SIGMAC,TAUC,SIGMAF,TAUF,AREA,DEFL,ES,ROS,CG,ROF,G,B,G9
REAL STIFF,WEIGHT,THETA,AL,RCP,NUF,G1,G2,AA,BB,P,C4,Q,PP,TL,CRIT
REAL OMEGA,S,C1(10),C2(10),RCS,DELTA,STR1,STR2,STR3,G3,G4,G5,G6,G7
DOUBLE PRECISION TF,TC,ROC,COEFF,STREN,AFA
OPEN(UNIT=7,FILE='SWP.OUT',STATUS='NEW')
WRITE(*,1)
1 FORMAT(T2,'WHAT KIND OF PROBLEM DO YOU WANT TO RUN?',/,T10,
$' 1 - ANALYSIS OF SANDWICH BEAMS',/,T10,
$' 2 - MINIMUM WEIGHT DESIGN FOR STIFFNESS IN SANDWICH BEAMS',/,
$T10,' 3 - MINIMUM WEIGHT DESIGN FOR STRENGTH IN SANDWICH BEAMS',
$/,T10,' 4 - MINIMUM WEIGHT DESIGN FOR STIFFNESS AND STRENGTH IN SA
$NDWICH BEAMS',
$/,T10,' 5 - ANALYSIS OF SANDWICH PLATES',/,T10,
$' 6 - MINIMUM WEIGHT DESIGN FOR STIFFNESS IN SANDWICH PLATES',/,
$T10,' 7 - MINIMUM WEIGHT DESIGN FOR STRENGTH IN SANDWICH PLATES',
$/,T10,' 8 - MINIMUM WEIGHT DESIGN FOR STIFFNESS AND STRENGTH IN SA
$NDWICH PLATES')
READ(*,*)TY
IF (TY.EQ.1) WRITE(7,51)
IF (TY.EQ.2) WRITE(7,52)
IF (TY.EQ.3) WRITE(7,53)
IF (TY.EQ.4) WRITE(7,54)
IF (TY.EQ.5) WRITE(7,55)
IF (TY.EQ.6) WRITE(7,56)
IF (TY.EQ.7) WRITE(7,57)
IF (TY.EQ.8) WRITE(7,58)
51 FORMAT(//,T10,'ANALYSIS OF SANDWICH BEAMS',/)
52 FORMAT(//,T10,'MINIMUM WEIGHT DESIGN FOR STIFFNESS IN SANDWICH BEA
$MS',/)
53 FORMAT(//,T10,'MINIMUM WEIGHT DESIGN FOR STRENGTH IN SANDWICH BEAM
$S',/)
54 FORMAT(//,T10,'MINIMUM WEIGHT DESIGN FOR STIFFNESS AND STRENGTH IN
$ SANDWICH BEAMS',/)
55 FORMAT(//,T10,'ANALYSIS OF SANDWICH PLATES',/)
56 FORMAT(//,T10,'MINIMUM WEIGHT DESIGN FOR STIFFNESS IN SANDWICH PLA
$TES',/)
57 FORMAT(//,T10,'MINIMUM WEIGHT DESIGN FOR STRENGTH IN SANDWICH PLAT
$ES',/)
58 FORMAT(//,T10,'MINIMUM WEIGHT DESIGN FOR STIFFNESS AND STRENGTH IN
$ SANDWICH PLATES',/)

*****
** INPUT THE MATERIAL PROPERTIES **
*****
WRITE(*,*)'INPUT THE ELASTIC MODULUS OF FACE MATERIAL ( ksi )'
READ(*,*)EF
WRITE(*,*)'INPUT THE YIELD STRENGTH OF FACE MATERIAL ( ksi )'
READ(*,*)YF

```

```

WRITE(*,*)'INPUT THE MASS DENSITY OF FACE MATERIAL ( pcf )'
READ(*,*)ROF
WRITE(*,*)'INPUT THE ELASTIC MODULUS OF SOLID FOAM ( ksi )'
READ(*,*)ES
WRITE(*,*)'INPUT THE YIELD STRENGTH OF SOLID FOAM ( ksi )'
READ(*,*)YS
WRITE(*,*)'INPUT THE MASS DENSITY OF SOLID FOAM ( pcf )'
READ(*,*)ROS
WRITE(*,*)'INPUT THE PROPORTIONALITY CONSTANT FOR ELASTIC MODULUS
$OF FOAM CORE'
READ(*,*)C3
WRITE(*,*)'INPUT THE POWER CONSTANT FOR ELASTIC MODULUS OF FOAM.CO
$RE'
READ(*,*)A
WRITE(*,*)'INPUT THE PROPORTIONALITY CONSTANT FOR SHEAR MODULUS OF
$ FOAM CORE'
READ(*,*)CG
WRITE(*,*)'INPUT THE POWER CONSTANT FOR SHEAR MODULUS OF FOAM CORE
$'
READ(*,*)G
WRITE(*,*)'INPUT THE PROPORTIONALITY CONSTANT FOR SHEAR STRENGTH O
$F FOAM CORE'
READ(*,*)C4
WRITE(*,*)'INPUT THE POWER CONSTANT FOR SHEAR STRENGTH OF FOAM COR
$E'
READ(*,*)B
WRITE(7,75)EF,YF,ROF,ES,YS,ROS,C3,A,CG,G,C4,B
75 FORMAT(T10,'THE ELASTIC MODULUS OF FACE MATERIAL =',T50,F12.3,T65,
$'( ksi )',//,T10,'THE YIELD STRENGTH OF FACE MATERIAL =',T50,F12.3
$,T65,'( ksi )',//,T10,'THE MASS DENSITY OF FACE MATERIAL =',T50,F1
$2.3,T65,'( pcf )',//,T10,'THE ELASTIC MODULUS OF SOLID FOAM =',T50
$,F12.3,T65,'( ksi )',//,T10,'THE YIELD STRENGTH OF SOLID FOAM =',
$,T50,F12.3,T65,'( ksi )',//,T10,'THE MASS DENSITY OF SOLID FOAM =',
$,T50,F12.3,T65,'( pcf )',//,T10,'THE PROPORTIONALITY CONSTANT',/,
$,T10,'FOR ELASTIC MODULUS OF FOAM CORE =',T50,F12.3,/,T10,
$'THE POWER CONSTANT',/,T10,'FOR ELASTIC MODULUS OF FOAM CORE =',
$,T50,F12.3,/,T10,'THE PROPORTIONALITY CONSTANT',/,T10,
$'FOR SHEAR MODULUS OF FOAM CORE =',T50,F12.3,/,T10,
$'THE POWER CONSTANT',/,T10,'FOR SEAR MODULUS OF FOAM CORE =',
$,T50,F12.3,/,T10,'THE PROPORTIONALITY CONSTANT',/,T10,
$'FOR SHEAR STRENGTH OF FOAM CORE =',T50,F12.3,/,T10,
$'THE POWER CONSTANT',/,T10,'FOR SHEAR STRENGTH OF FOAM CORE =',
$,T50,F12.3,/)
AFA=0.57*C3**(2./3.)*EF**(1./3.)*ES**(2./3.)
GO TO (100,100,100,100,300,300,300,300),TY

```

```

*****
*****
***      A. ANALYSIS AND DESIGN OF SANDWICH BEAMS      ***
*****
*****

```

```

*****
***      INPUT THE CONFIGURATION AND LOADING GEOMETRY      ***
*****

```

```

100 DATA C1(1),C1(2),C1(3),C1(4),C1(5),C1(6)/4,1,8,8,2,12/
DATA C2(1),C2(2),C2(3),C2(4),C2(5),C2(6)/2,1,2,2,1,2/
DATA C5(1),C5(2),C5(3),C5(4),C5(5),C5(6)/48,3,192,76.8,8,384/
DATA C6(1),C6(2),C6(3),C6(4),C6(5),C6(6)/4,1,4,8,2,8/
WRITE(*,101)

```

```

101 FORMAT(T2,' WHAT IS THE CONFIGURATION AND LOADING GEOMETRY ?',/)
$T15,' 1 - SIMPLY-SUPPORTED UNDER CONCENTRATED LOAD',/,
$T15,' 2 - CANTILEVER UNDER CONCENTRATED LOAD',/,
$T15,' 3 - FIXED ENDS UNDER CONCENTRATED LOAD',/,
$T15,' 4 - SIMPLY-SUPPORTED UNDER UNIFORM DISTRIBUTED LOAD',/,
$T15,' 5 - CANTILEVER UNDER UNIFORM DISTRIBUTED LOAD',/,
$T15,' 6 - FIXED ENDS UNDER UNIFORM DISTRIBUTED LOAD')
  READ(*,*)CONFI
  IF (CONFI.EQ.1) WRITE(7,111)
  IF (CONFI.EQ.2) WRITE(7,112)
  IF (CONFI.EQ.3) WRITE(7,113)
  IF (CONFI.EQ.4) WRITE(7,114)
  IF (CONFI.EQ.5) WRITE(7,115)
  IF (CONFI.EQ.6) WRITE(7,116)
111 FORMAT(T10,'SIMPLY-SUPPORTED UNDER CONCENTRATED LOAD',/)
112 FORMAT(T10,'CANTILEVER UNDER CONCENTRATED LOAD',/)
113 FORMAT(T10,'FIXED ENDS UNDER CONCENTRATED LOAD',/)
114 FORMAT(T10,'SIMPLY-SUPPORTED UNDER UNIFORM DISTRIBUTED LOAD',/)
115 FORMAT(T10,'CANTILEVER UNDER UNIFORM DISTRIBUTED LOAD',/)
116 FORMAT(T10,'FIXED ENDS UNDER UNIFORM DISTRIBUTED LOAD',/)
  WRITE(*,*)'INPUT THE WIDTH OF THE SANDWICH BEAM ( in. )'
  READ(*,*)WS
  WRITE(*,*)'INPUT THE SPAN OF THE SANDWICH BEAM ( in. )'
  READ(*,*)SS
  WRITE(7,117)WS,SS
117 FORMAT(T10,'THE WIDTH OF THE SANDWICH BEAM =',T50,F10.3,T65,'( in.
$ )',/,T10,'THE SPAN OF THE SANDWICH BEAM =',T50,F10.3,T65,'( in.
$ )',/)
  IF (TY.EQ.2) GO TO 200
  IF (TY.EQ.3) GO TO 250
  IF (TY.EQ.4) GO TO 270

```

```

*****
*****
***      1. ANALYSIS OF SANDWICH BEAMS      ***
*****
*****

```

```

  WRITE(*,*)'INPUT THE MASS DENSITY OF FOAM CORE ( pcf )'
  READ(*,*)ROC
  WRITE(*,*)'INPUT THE THICKNESS OF FACE MATERIAL ( in. )'
  READ(*,*)TF
  WRITE(*,*)'INPUT THE THICKNESS OF FOAM CORE ( in. )'
  READ(*,*)TC
  WRITE(7,125)ROC,TF,TC
  EC=C3*(ROC/ROS)**A*ES
  GC=CG*(ROC/ROS)**G*ES
  IF (CONFI.GE.4) THEN
    WRITE(*,*)'INPUT THE MAGNITUDE OF UNIFORM LOAD ( kips/in )'
    READ(*,*)UDL
    WRITE(7,126)UDL
  ELSE IF (CONFI.LT.4) THEN
    WRITE(*,*)'INPUT THE MAGNITUDE OF THE CONCENTRATED LOAD ( kip
$s )'
    READ(*,*)MCL
    WRITE(*,*)'INPUT THE LOCATION OF THE CONCENTRATED LOAD ( in.
$ )'
    WRITE(*,*)'*** THE LOCATION IS MEASURED FROM THE FREE END FOR
$CANTILEVER BEAM ***'
    READ(*,*)LCL
    WRITE(7,127)MCL,LCL

```

```

      AL=(SS-LCL)/SS
      IF (AL.LT.0.01) WRITE(*,*) '** CHECK THE LOCATION OF LOAD **'
      END IF
125  FORMAT(T10,'THE MASS DENSITY OF CORE MATERIAL =',T50,F12.3,T65,
      '$ (pcf )',/,T10,'THE THICKNESS OF FACE MATERIAL =',T50,F12.3,
      $T65,' ( in. )',/,T10,'THE THICKNESS OF FOAM CORE =',T50,F12.3,
      $T65,' ( in. )',/)
126  FORMAT(T10,'THE MAGNITUDE OF UNIFORM      LOAD      =',T50,F12.3,
      $T65,' ( kips/in. )',/)
127  FORMAT(T10,'THE MAGNITUDE OF CONCENTRATED LOAD =',T50,F12.3,
      $T65,' ( kips )',/,
      $T10,'THE LOCATION OF CONCENTRATED LOAD =',T50,F12.3,
      $T65,' ( in. )',/)

```

```

*****
***      CALCULATE THE CRITICAL BENDING AND SHEAR STRESSES      ***
*****

```

```

      IF (CONFI.EQ.1) THEN
        IF (AL.LT.0.5) AL=1-AL
        C1(1)=1./(AL*(1-AL))
        C2(1)=1./AL
        C5(1)=27./(AL*(1-AL)*(2-AL)*(3*AL*(2-AL))**0.5)
        C6(1)=1./(AL*(1-AL))
      ELSE IF (CONFI.EQ.2) THEN
        C1(2)=1./AL
        C2(2)=1.
        C5(2)=6./(3*AL*AL-AL**3)
        C6(2)=1./AL
      ELSE IF (CONFI.EQ.3) THEN
        IF (AL.GT.0.5) AL=1-AL
        C1(3)=1./(AL*(1-AL)**2)
        C2(3)=1./((1-AL)**2*(1+2*AL))
        C5(3)=3*(3-2*AL)**2/(2*AL**2*(1-AL)**3)
        C6(3)=1./(AL*(1-AL)**2*(1+2*AL))
      END IF
      SD=TF+TC
      D=EF*WS*TF**3/6.+EF*WS*TF*SD**2/2.+EC*WS*TC**3/12.
      IF (CONFI.GE.4) THEN
        M=UDL*SS**2/C1(CONFI)
        Q=UDL*SS/C2(CONFI)
      ELSE IF (CONFI.LT.4) THEN
        M=MCL*SS/C1(CONFI)
        Q=MCL/C2(CONFI)
      END IF
      WRITE(*,130)
      WRITE(7,130)
130  FORMAT(/,T5,'THE CRITICAL BENDING AND SHEAR STRESSES :',/,T10,
      '$ Z ( in )',T25,'SIGMAC ( ksi )',T40,'TAUC ( ksi )',/)
      STEP=TC/40.
      Z=0.0
      DO 140 I=1,21
        SIGMAC=M*Z*EC/D
        TAUC=(EF*TF*SD/2.+EC*(TC**2/4.-Z*Z)/2.)*Q/D
        WRITE(*,135)Z,SIGMAC,TAUC
        WRITE(7,135)Z,SIGMAC,TAUC
135  FORMAT(T5,F7.3,T20,F12.6,T35,F12.6)
      Z=Z+STEP
140  CONTINUE
      WRITE(*,145)
      WRITE(7,145)

```

```

145 FORMAT(/,T10,'Z ( in )',T25,'SIGMAF ( ksi )',T40,'TAUF ( ksi )',/)
STEP=TF/20.
Z=TC/2.
DO 150 I=1,21
SIGMAF=M*Z*EF/D
TAUF=Q*EF*(((TC/2.+TF)**2-Z*Z)/2.)/D
WRITE(*,135)Z,SIGMAF,TAUF
WRITE(7,135)Z,SIGMAF,TAUF
Z=Z+STEP
150 CONTINUE

```

```

*****
***      CALCULATE THE MAXIMUM DEFLECTION      ***
*****

```

```

AREA=WS*SD**2/TC
IF (CONFI.GE.4) THEN
    DEFL=UDL*SS**4/(C5(CONFI)*D)+UDL*SS**2/(AREA*GC*C6(CONFI))
ELSE IF (CONFI.LT.4) THEN
    DEFL=MCL*SS**3/(C5(CONFI)*D)+MCL*SS/(C6(CONFI)*AREA*GC)
END IF
WRITE(*,160)DEFL
WRITE(7,160)DEFL
160 FORMAT(/,T10,'THE MAXIMUM DEFLECTION =',T35,F12.6,T50,'( in. )')

```

```

*****
***      JUDGE THE STRENGTH FAILURE MODE      ***
*****

```

```

PFY=C1(CONFI)*YF*WS*TC*TF/SS
PFW=AFA*C1(CONFI)*(ROC/ROS)**(2.*A/3.)*WS*TC*TF/SS
COEFF=(C3*(ROC/ROS)**A*ES*SS/(2.*C1(CONFI)*TF*EF))**2.
COEFF=COEFF+(1./C2(CONFI))**2
PCS=C4*(ROC/ROS)**B*YS*WS*TC*(1./COEFF)**0.5
FAIL=3
IF(PFY.LT.PFW) THEN
    IF (PFY.LT.PCS) FAIL=1
ELSE IF (PFW.LE.PFY) THEN
    IF (PFW.LT.PCS) FAIL=2
END IF
IF (CONFI.GE.4) PP=UDL*SS
IF (CONFI.LT.4) PP=MCL
IF (FAIL.EQ.1) THEN
    WRITE(*,163)
    WRITE(7,163)
    IF ((PFY-PP).GT.0) THEN
        WRITE(*,161)
        WRITE(7,161)
    ELSE IF ((PFY-PP).LE.0) THEN
        WRITE(*,162)
        WRITE(7,162)
    END IF
ELSE IF (FAIL.EQ.2) THEN
    WRITE(*,164)
    WRITE(7,164)
    IF ((PFW-PP).GT.0) THEN
        WRITE(*,161)
        WRITE(7,161)
    ELSE IF ((PFW-PP).LE.0) THEN
        WRITE(*,162)
        WRITE(7,162)
    END IF
END IF

```

```

ELSE IF (FAIL.EQ.3) THEN
  WRITE(*,165)
  WRITE(7,165)
  IF ((PCS-PP).GT.0) THEN
    WRITE(*,161)
    WRITE(7,161)
  ELSE IF ((PCS-PP).LE.0) THEN
    WRITE(*,162)
    WRITE(7,162)
  END IF
END IF

```

```

END IF
GO TO 1000

```

```

161 FORMAT(T10,'THE SANDWICH BEAM UNDER LOADING IS SAFE',/)
162 FORMAT(T10,'THE SANDWICH BEAM UNDER LOADING IS NOT SAFE',/)
163 FORMAT(/,T10,'THE FAILURE MODE IS FACE YIELDING',/)
164 FORMAT(/,T10,'THE FAILURE MODE IS FACE WRINKLING',/)
165 FORMAT(/,T10,'THE FAILURE MODE IS CORE SHEAR YIELDING',/)

```

```

*****
*****
***      2. MINIMUM WEIGHT DESIGN FOR STIFFNESS IN SANDWICH BEAMS      ***
*****
*****

```

```

*****
***      INPUT THE REQUIRED DESIGN STIFFNESS      ***
*****

```

```

200 WRITE(*,*)'INPUT THE REQUIRED DESIGN STIFFNESS ( kips/in )'
    READ(*,*)STIFF
    WRITE(7,201)STIFF
201 FORMAT(T10,'THE REQUIRED DESIGN STIFFNESS =',T50,
  $F12.5,T65,'( kips/in )',/)

```

```

*****
***      CALCULATE THE OPTIMAL DESIGN VALUES      ***
*****

```

```

COEFF=4*(G*(4./(G-1))**((1./G)/(G-1))*((2+2*G)/(G-1))**((1-1./G)
COEFF=COEFF*(SS*C5(CONFI)*EF/(CG*C6(CONFI)*ES))**(-1./G)
COEFF=COEFF*(STIFF/(C5(CONFI)*WS*EF))**((1-1./G)
TC=(COEFF*ROF*SS**3/ROS)**(G/(3*G-1))
TF=2*(1+G)*STIFF*SS**3/((G-1)*C5(CONFI)*EF*WS*TC**2)
COEFF=SS*C5(CONFI)*STIFF*EF*TC*TF/(CG*C6(CONFI)*ES)
ROC=(COEFF/(C5(CONFI)*EF*WS*TF*TC**2-2*STIFF*SS**3))**((1./G)*ROS
WEIGHT=(2.*ROF*WS*TF*SS+ROC*WS*TC*SS)/1728000.
SD=TF+TC
COEFF=(CG*(ROC/ROS)**G*ES*TC*(1+3*(SD/TF)**2)/(2*EF*TF))**0.5
THETA=COEFF*SS/TC
WRITE(*,215)TC,TF,ROC,WEIGHT,THETA
WRITE(7,215)TC,TF,ROC,WEIGHT,THETA
215 FORMAT(/,T10,'THE OPTIMAL DESIGN VALUES :',//
  $,T15,'THE OPTIMAL CORE THICKNESS =',T55,F12.4,T70,'in.',//,
  $T15,'THE OPTIMAL FACE THICKNESS =',T55,F12.4,T70,'in.',//,T15,
  $'THE OPTIMAL MASS DENSITY OF FOAM =',T55,F12.4,T70,'pcf',//,T15,
  $'THE MINIMUM WEIGHT OF SANDWICH BEAM =',T55,F12.4,T70,'kips',//,
  $T15,'THETA OF THE SHEAR LAG CRITERION =',T55,F12.4)
GO TO 1000

```

```

*****
*****
**      3. MINIMUM WEIGHT DESIGN FOR STRENGTH IN SANDWICH BEAMS      ***

```


*** INPUT THE REQUIRED DESIGN STRENGTH ***

```
250 WRITE(*,*)'INPUT THE REQUIRED DESIGN STRENGTH PER UNIT WIDTH AND L
    $LENGTH ( psi )'
    READ(*,*)STREN
    WRITE(7,251)STREN
    STREN=STREN/1000.
251 FORMAT(T10,'THE REQUIRED DESIGN STRENGTH ',/,T10,
    $'PER UNIT WIDTH AND LENGTH =',T50,F12.4,T65,'psi',/)
```

*** CALCULATE THE OPTIMAL DESIGN VALUES ***

***** FY/FW/CS FAILURE DESIGN *****

```
TC=STREN*SS*(YF/AFA)**(-1.5*B/A)/(YS*C4*C2(CONFI))
TF=STREN*SS**2./(C1(CONFI)*YF*TC)
ROC=(YF/AFA)**(1.5/A)*ROS
WEIGHT=(2.*ROF*WS*TF*SS+ROC*WS*TC*SS)/1728000.
FAIL=4
COEFF=(YF/AFA)**((6*B-3)/(2.*A))*2*ROF*YS**2*C4**2*C2(CONFI)**2
STR1=COEFF/(C1(CONFI)*ROS*YF)
COEFF=(YF/AFA)**((6*B-2*A-3)/(2.*A))*(C2(CONFI)*C4*YS)**2*ROF*2
STR2=COEFF*(2*A-3*B)/(ROS*(3.-3.*B)*C1(CONFI)*AFA)
COEFF=(YF/AFA)**((6*B-3)/(2.*A))*(C2(CONFI)*C4*YS)**2*B*2*ROF
STR3=COEFF/(ROS*(B-1)*C1(CONFI)*YF)
```

***** FW/FY FAILURE DESIGN *****

```
IF (STREN.LE.STR1) THEN
    COEFF=2*ROF*STREN*SS**2*AFA**((1.5/A)/(C1(CONFI)*ROS)
    TC1=(COEFF/(YF**((1+(1.5/A))))**0.5
    TF1=STREN*SS**2/(C1(CONFI)*YF*TC1)
    ROC1=(YF/AFA)**(1.5/A)*ROS
    W1=(2*TF1*WS*SS*ROF+TC1*WS*SS*ROC1)/1728000.
    IF (W1.LT.WEIGHT) THEN
        TF=TF1
        TC=TC1
        ROC=ROC1
        WEIGHT=W1
        FAIL=1
```

END IF

END IF

***** FW/CS FAILURE DESIGN *****

```
IF (STREN.LE.STR2) THEN
    COEFF=(STREN*SS/(C2(CONFI)*C4*YS))**((2*A+3)/(3.*B))*AFA
    COEFF=COEFF*C1(CONFI)*ROS*(3-3*B)/(2.*ROF*(2*A-3*B))
    TC1=(COEFF/(STREN*SS**2))**((3*B)/(2.*A-6.*B+3.))
    ROC1=(STREN*SS/(C2(CONFI)*C4*YS*TC1))**((1./B)*ROS
    TF1=STREN*SS**2/(C1(CONFI)*AFA*(ROC1/ROS)**(2*A/3.))*TC1
    W1=(2*TF1*WS*SS*ROF+TC1*WS*SS*ROC1)/1728000.
    IF (W1.LT.WEIGHT) THEN
        TF=TF1
        TC=TC1
        ROC=ROC1
        WEIGHT=W1
        FAIL=2
```

END IF

```

END IF
*****  FY/CS FAILURE DESIGN  *****
IF (STREN.GE.STR3) THEN
  COEFF=2*B*ROF*(STREN*SS)**((B-1)/B)*SS/(C1(CONFI)*YF)
  COEFF=(C2(CONFI)*C4*YS)**(1./B)*COEFF/(ROS*(B-1))
  TC1=COEFF**B/(2.*B-1.)
  TF1=STREN*SS**2/(C1(CONFI)*YF*TC1)
  ROC1=(STREN*SS/(C2(CONFI)*C4*YS*TC1))**((1./B)*ROS
  W1=(2*TF1*WS*SS*ROF+TC1*WS*SS*ROC1)/1728000.
  IF (W1.LT.WEIGHT) THEN
    TF=TF1
    TC=TC1
    ROC=ROC1
    WEIGHT=W1
    FAIL=3
  END IF
END IF
WRITE(*,260)TC,TF,ROC,WEIGHT
WRITE(7,260)TC,TF,ROC,WEIGHT
IF (FAIL.EQ.1) WRITE(7,261)
IF (FAIL.EQ.2) WRITE(7,262)
IF (FAIL.EQ.3) WRITE(7,263)
IF (FAIL.EQ.4) WRITE(7,264)
GO TO 1000
260 FORMAT(/,T10,'THE OPTIMAL DESIGN VALUES :',/,T15,
$'THE OPTIMAL CORE THICKNESS =',T55,F12.4,T70,'in.',/,T15,
$'THE OPTIMAL FACE THICKNESS =',T55,F12.4,T70,'in.',/,T15,
$'THE OPTIMAL MASS DENSITY OF FOAM =',T55,F12.4,T70,'pcf',/,T15,
$'THE MINIMUM WEIGHT OF SANDWICH BEAM =',T55,F12.4,T70,'kips',/)
261 FORMAT(T15,'FY/FW FAILURE DESIGN',/)
262 FORMAT(T15,'FW/CS FAILURE DESIGN',/)
263 FORMAT(T15,'FY/CS FAILURE DESIGN',/)
264 FORMAT(T15,'FY/FW/CS FAILURE DESIGN',/)

*****
*****
***      4. MINIMUM WEIGHT DESIGN FOR STIFFNESS      ***
***      AND STRENGTH IN SANDWICH BEAMS              ***
*****
*****

*****
***      INPUT THE DESIGN PARAMETERS                  ***
*****
270 WRITE(*,*)'INPUT THE REQUIRED DESIGN LOAD ( kips )'
  READ(*,*)P
  WRITE(*,*)'INPUT THE REQUIRED DESIGN DEFLECTION ( in )'
  READ(*,*)DELTA
  WRITE(7,271)P,DELTA
271 FORMAT(T10,'THE REQUIRED DESIGN LOAD =',T50,F12.4,T65,'kips',/,
$T10,'THE REQUIRED DESIGN DEFLECTION =',T50,F12.4,T65,'in.',/)

*****
***      CALCULATE THE OPTIMAL DESIGN VALUES        ***
*****

***      S+FY FAILURE DESIGN                          ***
RCS=(YF/AFA)**(1.5/A)*ROS
CRIT=DELTA*C5(CONFI)*EF*P/(2*C1(CONFI)**2*YF**2*WS*SS*1000.)
TF1=CRIT

```

WEIGHT=1000000.

FAIL=1

WRITE(*,*)'THE PROGRAM IS RUNNING. PLEASE WAIT!'

DO 273 I=1,999

TC1=P*SS/(C1(CONFI)*YF*WS*TF1)

COEFF=C5(CONFI)*EF*P*SS*TF1*TC1/(CG*C6(CONFI)*ES)

COEFF=COEFF/(C5(CONFI)*DELTA*WS*TF1*TC1**2*EF-2*P*SS**3)

ROC1=COEFF**(.1./G)*ROS

W1=(2*ROF*WS*SS*TF1+ROC1*WS*SS*TC1)/1728000.

IF (ROC1.GE.RCS) THEN

IF (W1.LE.WEIGHT) THEN

TC=TC1

TF=TF1

ROC=ROC1

WEIGHT=W1

END IF

END IF

TF1=TF1+CRIT

273 CONTINUE

*** S+FW FAILURE DESIGN ***

CRIT=RCS/1000.

ROC1=CRIT

DO 274 I=1,999

COEFF=2*SS**2*AFA*C1(CONFI)*(ROC1/ROS)**(2*A/3.)/C5(CONFI)

TC1=COEFF/(DELTA*EF)+P*SS/(CG*C6(CONFI)*ES*WS*DELTA*

\$ (ROC1/ROS)**G)

TF1=P*SS*(ROC1/ROS)**(-2*A/3.)/(AFA*C1(CONFI)*WS*TC1)

W1=(2*ROF*WS*SS*TF1+ROC1*WS*SS*TC1)/1728000.

TL=C2(CONFI)*C4*YS*(ROC1/ROS)**(B-2*A/3.)/(AFA*C1(CONFI))

IF ((TF1/SS).LE.TL) THEN

IF (W1.LE.WEIGHT) THEN

TC=TC1

TF=TF1

ROC=ROC1

WEIGHT=W1

FAIL=2

END IF

END IF

ROC1=ROC1+CRIT

274 CONTINUE

*** S+FY+FW FAILURE DESIGN ***

ROC1=(YF/AFA)**(1.5/A)*ROS

COEFF=2*SS**2*C1(CONFI)*YF/(C5(CONFI)*DELTA*EF)

TC1=COEFF+P*SS*(YF/AFA)**(-1.5*G/A)/(CG*C6(CONFI)*ES*WS*DELTA)

TF1=P*SS/(C1(CONFI)*YF*WS*TC1)

W1=(2*ROF*WS*SS*TF1+ROC1*WS*SS*TC1)/1728000.

IF (W1.LE.WEIGHT) THEN

TC=TC1

TF=TF1

ROC=ROC1

WEIGHT=W1

FAIL=3

END IF

WRITE(*,280)TC,TF,ROC,WEIGHT

WRITE(7,280)TC,TF,ROC,WEIGHT

IF (FAIL.EQ.1) WRITE(7,281)

IF (FAIL.EQ.2) WRITE(7,282)

```

      IF (FAIL.EQ.3) WRITE(7,283)
      GO TO 1000
280  FORMAT(/,T10,'THE OPTIMAL DESIGN VALUE :',//,T15,
      $'THE OPTIMAL CORE THICKNESS =',T55,F12.4,T70,'in.',//,T15,
      $'THE OPTIMAL FACE THICKNESS =',T55,F12.4,T70,'in.',//,T15,
      $'THE OPTIMAL MASS DENSITY OF FOAM =',T55,F12.4,T70,'pcf',//,T15,
      $'THE MINIMUM WEIGHT OF SANDWICH BEAM =',T55,F12.4,T70,'kips',/)
281  FORMAT(T15,'STIFFNESS/FY FAILURE DESIGN',/)
282  FORMAT(T15,'STIFFNESS/FW FAILURE DESIGN',/)
283  FORMAT(T15,'STIFFNESS/FY/FW FAILURE DESIGN',/)

```

```

*****
*****
***      B. ANALYSIS AND DESIGN OF SANDWICH PLATES      ***
*****
*****

```

```

*****
***      INPUT THE CONFIGURATION AND LOADING GEOMETRY      ***
***      AND CALCULATE G1---G9 COEFFICIENTS                ***
*****

```

```

300  WRITE(*,301)
301  FORMAT(T2,'WHAT IS THE CONFIGURATION AND LOADING GEOMETRY?',/,
      $T15,'1 - CIRCULAR PLATE, SIMPLY-SUPPORTED UNDER UNIFORM LOAD.',/,
      $T15,'2 - CIRCULAR PLATE, CLAMPED UNDER UNIFORM LOAD.',/,
      $T15,'3 - RECTANGULAR PLATE, SIMPLY-SUPPORTED UNDER UNIFORM LOAD.')
      READ(*,*)CONFI
      IF (CONFI.EQ.1) WRITE(7,311)
      IF (CONFI.EQ.2) WRITE(7,312)
      IF (CONFI.EQ.3) WRITE(7,313)
311  FORMAT(T10,'CIRCULAR PLATE, SIMPLY-SUPPORTED UNDER UNIFORM LOAD',
      $/)
312  FORMAT(T10,'CIRCULAR PLATE, CLAMPED UNDER UNIFORM LOAD',/)
313  FORMAT(T10,'RECTANGULAR PLATE, SIMPLY-SUPPORTED UNDER UNIFORM LOAD
      $',/)
      WRITE(*,*)'INPUT THE POISSON'S RATIO OF THE FACE MATERIAL'
      READ(*,*)NUF
      WRITE(7,323)NUF
      IF (CONFI.LE.2) THEN
          WRITE(*,*)'INPUT THE RADIUS OF THE CIRCULAR PLATE ( in. )'
          READ(*,*)RCP
          WRITE(7,321)RCP
          WRITE(*,*)'INPUT THE RADIUS OF THE UNIFORM LOAD ( in. )'
          READ(*,*)AA
          WRITE(7,322)AA
321  FORMAT(T10,'THE RADIUS OF THE CIRCULAR PLATE =',T50,F12.3,T65,
      $'( in. )',/)
322  FORMAT(T10,'THE RADIUS OF THE UNIFORM LOAD =',T50,F12.3,T65,
      $'( in. )',/)
323  FORMAT(T10,'THE POISSON'S RATIO OF THE FACE MATERIAL =',T50,
      $F12.3,/)
      IF (CONFI.EQ.1) THEN
          G1=(3+NUF)*(RCP/AA)**2/(1+NUF)+LOG(AA/RCP)
          G2=(7+3*NUF)/(4*(1+NUF))
          G3=0.5+0.5*LOG(RCP/AA)-AA**2/(8*RCP**2)
          G4=0.5*LOG(RCP/AA)+AA**2/(8*RCP**2)
          G5=G3
          G6=G4

```

```

ELSE IF (CONFI.EQ.2) THEN
  G1=(RCP/AA)**2-LOG(RCP/AA)-0.75
  IF ((AA-0.588*RCP).GE.0) THEN
    G3=0.5-AA**2/(4*RCP**2)
    G4=0.
    G5=0.
    G6=G3
  ELSE IF ((AA-0.588*RCP).LT.0) THEN
    G3=0.5*LOG(RCP/AA)+AA**2/(8*RCP**2)
    G4=G3
    G5=G3
    G6=G3
  END IF
END IF
G2=1+2*LOG(RCP/AA)
G7=0.
G8=0.5
G9=0.5
ELSE IF (CONFI.GE.3) THEN
  WRITE(*,*)'INPUT THE LENGTH ( X DIRECTION ) OF THE RECTANGULA
$R PLATE ( in. )'
  READ(*,*)BB
  WRITE(7,324)BB
  WRITE(*,*)'INPUT THE WIDTH ( Y DIRECTION ) OF THE RECTANGULAR
$PLATE ( in. )'
  READ(*,*)AA
  WRITE(7,325)AA
324 FORMAT(T10,'THE LENGTH ( X DIRECTION ) OF',/,T15,
$'THE RECTANGULAR PLATE -',T50,F12.3,T65,'( in. )',/,)
325 FORMAT(T10,'THE WIDTH ( Y DIRECTION ) OF',/,T15,
$'THE RECTANGULAR PLATE -',T50,F12.3,T65,'( in. )',/,)
  DO 330 I=0,11
    M=2*I+1
    DO 330 J=0,11
      N=2*J+1
      OMEGA=(M*AA/BB)**2+N**2
      G1=G1+16**2*(-1)**I*(-1)**J/(3.14159**6*M*N*OMEGA**2)
      G2=G2+64*(-1)**I*(-1)**J/(3.14159**4*M*N*OMEGA)
      G3=G3+16*(-1)**I*(-1)**J*M*AA**2/(3.14159**4*OMEGA**2*N*
$      BB**2)
      G4=G4+16*(-1)**I*(-1)**J*N/(3.14159**4*OMEGA**2*M)
      G7=G7+16*AA/(3.14159**4*BB*OMEGA**2)
      G8=G8+16*(-1)**J*AA/(3.14159**3*N*OMEGA*BB)
      G9=G9+16*(-1)**I/(3.14159**3*M*OMEGA)
330    CONTINUE
      G5=G4
      G6=G3
END IF
IF (TY.EQ.6) GO TO 400
IF (TY.EQ.7) GO TO 500
IF (TY.EQ.8) GO TO 600

```

```

*****
*****
***      1. ANALYSIS OF SANDWICH PLATES      ***
*****
*****

```

```

WRITE(*,*)'INPUT THE MAGNITUDE OF THE UNIFORM LOAD ( ksi )'
READ(*,*)UDL
WRITE(*,*)'INPUT THE THICKNESS OF FACE MATERIAL ( in. )'

```

```

READ(*,*)TF
WRITE(*,*)'INPUT THE THICKNESS OF FOAM CORE ( in. )'
READ(*,*)TC
WRITE(*,*)'INPUT THE MASS DENSITY OF FOAM CORE ( pcf )'
READ(*,*)ROC
WRITE(7,341)UDL,TF,TC,ROC
341 FORMAT(T10,'THE MAGNITUDE OF THE UNIFORM LOAD =',T50,F12.5,T65,
$( ' ksi ' ),',',T10,'THE THICKNESS OF FACE MATERIAL =',T50,F12.3,T65,
$( ' in. ' ),',',T10,'THE THICKNESS OF FOAM CORE =',T50,F12.3,T65,
$( ' in. ' ),',',T10,'THE MASS DENSITY OF FOAM CORE =',T50,F12.3,T65,
$( ' pcf ' ),',')

```

```

*****
***      CALCULATE THE MAXIMUM STRESSES AND DEFLECTION      ***
*****

```

```

SD=TC+TF
D=EF*TF*SD**2/(2.*(1.-NUF**2))
GC=CG*(ROC/ROS)**G*ES
S=SD*GC
DEFL=UDL*AA**4*G1/(16*D)+UDL*AA**2*G2/(4*S)
SIGMAX=UDL*AA**2*(G3+NUF*G4)/(SD*TF)
SIGMAY=UDL*AA**2*(G5+NUF*G6)/(SD*TF)
TAUXY=UDL*AA**2*(1-NUF)*G7/(SD*TF)
TAUZX=UDL*AA*G8/SD
TAUYZ=UDL*AA*G9/SD
WRITE(*,346)SIGMAX,SIGMAY,TAUXY,TAUZX,TAUYZ,DEFL
WRITE(7,346)SIGMAX,SIGMAY,TAUXY,TAUZX,TAUYZ,DEFL
346 FORMAT(T10,'THE MAXIMUM STRESSES IN THE FACE MATERIAL :',',',,
$T15,'THE MAXIMUM STRESS SIGMAX (SIGMAR) =',T50,F12.4,T65,'ksi',',',,
$T15,'THE MAXIMUM STRESS SIGMAY (SIGMAT) =',T50,F12.4,T65,'ksi',',',,
$T15,'THE MAXIMUM STRESS TAUXY (TAURT) =',T50,F12.4,T65,'ksi',',',,
$T10,'THE MAXIMUM STRESSES IN THE FOAM CORE :',',',,
$T15,'THE MAXIMUM STRESS TAUZX (TAUZR) =',T50,F12.4,T65,'ksi',',',,
$T15,'THE MAXIMUM STRESS TAUYZ (TAUTZ) =',T50,F12.4,T65,'ksi',',',,
$T10,'THE MAXIMUM DEFLECTION =',T50,F12.4,T65,'in. ')

```

```

*****
***      JUDGE THE STRENGTH FAILURE MODE      ***
*****

```

```

PFY=YF*TC*TF/(AA**2*(G3+NUF*G4))
PFW=AFA*TC*TF*(ROC/ROS)**(2*A/3.)/(AA**2*(G3+NUF*G4))
PCS=C4*(ROC/ROS)**B*YS*TC/(AA*G8)
FAIL=3
IF(PFY.LT.PFW) THEN
  IF (PFY.LT.PCS) FAIL=1
ELSE IF (PFW.LE.PFY) THEN
  IF (PFW.LT.PCS) FAIL=2
END IF
IF (FAIL.EQ.1) THEN
  WRITE(*,363)
  WRITE(7,363)
  IF ((PFY-UDL).GT.0) THEN
    WRITE(*,361)
    WRITE(7,361)
  ELSE IF ((PFY-UDL).LE.0) THEN
    WRITE(*,362)
    WRITE(7,362)
  END IF
ELSE IF (FAIL.EQ.2) THEN
  WRITE(*,364)

```

```

WRITE(7,364)
IF ((PFW-UDL).GT.0) THEN
    WRITE(*,361)
    WRITE(7,361)
ELSE IF ((PFW-UDL).LE.0) THEN
    WRITE(*,362)
    WRITE(7,362)
END IF
ELSE IF (FAIL.EQ.3) THEN
    WRITE(*,365)
    WRITE(7,365)
    IF ((PCS-UDL).GT.0) THEN
        WRITE(*,361)
        WRITE(7,361)
    ELSE IF ((PCS-UDL).LE.0) THEN
        WRITE(*,362)
        WRITE(7,362)
    END IF
END IF
GO TO 1000
361 FORMAT(T10,'THE SANDWICH PLATE UNDER LOADING IS SAFE',/)
362 FORMAT(T10,'THE SANDWICH PLATE UNDER LOADING IS NOT SAFE',/)
363 FORMAT(/,T10,'THE FAILURE MODE IS FACE YIELDING',/)
364 FORMAT(/,T10,'THE FAILURE MODE IS FACE WRINKLING',/)
365 FORMAT(/,T10,'THE FAILURE MODE IS CORE SHEAR YIELDING',/)

```

```

*****
*****
***      2. MINIMUM WEIGHT DESIGN FOR STIFFNESS IN SANDWICH PLATE      ***
*****
*****

```

```

*****
**      INPUT THE REQUIRED DESIGN STIFFNESS      ***
*****
400 WRITE(*,*)'INPUT THE REQUIRED DESIGN STIFFNESS ( ksi/in )'
    READ(*,*)STIFF
    WRITE(7,401)STIFF
401 FORMAT(T10,'THE REQUIRED DESIGN STIFFNESS -',T50,F12.5,T65,
    $( ksi/in ),/)

```

```

*****
*      CALCULATE THE OPTIMAL DESIGN VALUES      ***
*****
ROC=((G+1)**2*(G-1)**2*G2**3*ROS*EF*(STIFF*AA)**2/
$(256*CG**3*G*(1-NUF**2)*G1*ROF*ES**3))**(1./(3*G-1.))*ROS
TC=(4***(G+1)*CG*G**G*(G+1)**(G-1)*(1-NUF**2)**G*G1**G*ROF**G*ES*
$(STIFF*AA)**(G-1)/((G-1)**(2*G)*G2*ROS**G*EF**G))**(1./(3*G-1.))
$*AA/2.
TF=((G**2-1)**(G+1)*(1-NUF**2)**(G-1)*G1***(G-1)*G2**2*ROS***(2*G)*
$EF***(1-G)*(STIFF*AA)**(G+1)/(2***(13*G+1)*CG**2*G***(2*G)*ROF***(2*G)
$*ES**2))**(1./(3*G-1.))*4*AA
IF (CONFI.LT.3) WEIGHT=(2*TF*ROF+TC*ROC)*3.14*RCP**2/1728000.
IF (CONFI.GE.3) WEIGHT=(2*TF*ROF+TC*ROC)*AA*BB/1728000.
WRITE(*,402)TF,TC,ROC,WEIGHT
WRITE(7,402)TF,TC,ROC,WEIGHT
.02 FORMAT(/,T10,'THE OPTIMAL DESIGN VALUES :',/,
    $T15,'THE OPTIMAL THICKNESS OF FACE MATERIAL -',T55,F12.4,
    $T70,'in.',/,T15,'THE OPTIMAL THICKNESS OF CORE MATERIAL -',T55,
    $F12.4,T70,'in.',/,T15,'THE OPTIMAL MASS DENSITY OF FOAM -',T55,

```

```

$F12.4,T70,'pcf',/,/,T15,'THE MINIMUM WEIGHT OF SANDWICH PLATE -',
$T55,F12.4,T70,'kips',/,/
GO TO 1000

```

```

*****
***      3. MINIMUM WEIGHT DESIGN FOR STRENGTH IN SANDWICH BEAMS      ***
*****

```

```

*****
***      INPUT THE REQUIRED DESIGN STRENGTH      ***
*****

```

```

500 WRITE(*,*)'INPUT THE REQUIRED UNIFORM LOADING ( psi )'
    READ(*,*)STREN
    WRITE(7,551)STREN
    STREN=STREN/1000.
551 FORMAT(T10,'THE REQUIRED UNIFORM LOADING -',T50,F12.4,T65,'psi',/,/

```

```

*****
***      CALCULATE THE OPTIMAL DESIGN VALUES      ***
*****

```

```

*****      FY/FW/CS FAILURE DESIGN      *****

```

```

TC=STREN*AA*G8*(YF/AFA)**(-1.5*B/A)/(YS*C4)
TF=STREN*AA**2*(G3+NUF*G4)/(YF*TC)
ROC=(YF/AFA)**(1.5/A)*ROS
IF (CONFI.LT.3) WEIGHT=(2*ROF*TF+ROC*TC)*3.14*RCP**2/1728000.
IF (CONFI.GE.3) WEIGHT=(2*ROF*TF+ROC*TC)*AA*BB/1728000.
FAIL=4
COEFF=(YF/AFA)**((6*B-3)/(2.*A))*2*ROF*YS**2*C4**2*(G3+NUF*G4)
STR1=COEFF/(G8**2*ROS*YF)
COEFF=(YF/AFA)**((6*B-2*A-3)/(2.*A))*(C4*YS)**2*ROF*2*(G3+NUF*G4)
STR2=COEFF*(2*A-3*B)/(ROS*(3.-3.*B)*G8**2*AFA)
COEFF=(YF/AFA)**((6*B-3)/(2.*A))*(C4*YS)**2*B*2*ROF*(G3+NUF*G4)
STR3=COEFF/(ROS*(B-1)*G8**2*YF)

```

```

*****      FW/FY FAILURE DESIGN      *****

```

```

IF (STREN.LE.STR1) THEN
    COEFF=2*ROF*STREN*AA**2*AFA**((1.5/A)*(G3+NUF*G4)/ROS
    TC1=(COEFF/(YF**((1+(1.5/A))))**0.5
    TF1=STREN*AA**2*(G3+NUF*G4)/(YF*TC1)
    ROC1=(YF/AFA)**(1.5/A)*ROS
    IF (CONFI.LT.3) W1=(2*TF1*ROF+TC1*ROC1)*3.14*RCP**2/1728000.
    IF (CONFI.GE.3) W1=(2*ROF*TF1+ROC1*TC1)*AA*BB/1728000.
    IF (W1.LT.WEIGHT) THEN
        TF=TF1
        TC=TC1
        ROC=ROC1
        WEIGHT=W1
        FAIL=1
    END IF
END IF

```

```

*****      FW/CS FAILURE DESIGN      *****

```

```

IF (STREN.LE.STR2) THEN
    COEFF=(STREN*AA*G8/(C4*YS))**((2*A+3)/(3.*B))*AFA
    COEFF=COEFF*ROS*(3-3*B)/(2.*ROF*(2*A-3*B))
    TC1=(COEFF/(STREN*AA**2*(G3+NUF*G4)))*(3*B/(2.*A-6.*B+3.))
    ROC1=(STREN*AA*G8/(C4*YS*TC1))**((1./B)*ROS
    TF1=STREN*AA**2*(G3+NUF*G4)/(AFA*(ROC1/ROS)**(2*A/3.)*TC1)
    IF (CONFI.LT.3) W1=(2*TF1*ROF+TC1*ROC1)*3.14*RCP**2/1728000.
    IF (CONFI.GE.3) W1=(2*TF1*ROF+TC1*ROC1)*AA*BB/1728000.
    IF (W1.LT.WEIGHT) THEN

```

TF-TF1
TC-TC1
ROC-ROC1
WEIGHT-W1
FAIL-2

END IF

END IF

***** FY/CS FAILURE DESIGN *****

IF (STREN.GE.STR3) THEN

COEFF=2*B*ROF*(STREN*AA)**((B-1)/B)*AA*(G3+NUF*G4)/YF
TC1=((C4*YS/G8)**(1./B)*COEFF/(ROS*(B-1)))** (B/(2.*B-1.))
TF1=STREN*AA**2*(G3+NUF*G4)/(YF*TC1)
ROC1=(STREN*AA*G8/(C4*YS*TC1))** (1./B)*ROS
IF (CONF1.LT.3) W1=(2*TF1*ROF+TC1*ROC1)*3.14*RCP**2/1728000.
IF (CONF1.GE.3) W1=(2*TF1*ROF+TC1*ROC1)*AA*BB/1728000.
IF (W1.LT.WEIGHT) THEN

TF-TF1
TC-TC1
ROC-ROC1
WEIGHT-W1
FAIL-3

END IF

END IF

WRITE(*,560)TC,TF,ROC,WEIGHT

WRITE(7,560)TC,TF,ROC,WEIGHT

IF (FAIL.EQ.1) WRITE(7,561)

IF (FAIL.EQ.2) WRITE(7,562)

IF (FAIL.EQ.3) WRITE(7,563)

IF (FAIL.EQ.4) WRITE(7,564)

GO TO 1000

560 FORMAT(/,T10,'THE OPTIMAL DESIGN VALUES :',//,T15,
\$'THE OPTIMAL CORE THICKNESS -',T55,F12.4,T70,'in.',//,T15,
\$'THE OPTIMAL FACE THICKNESS -',T55,F12.4,T70,'in.',//,T15,
\$'THE OPTIMAL MASS DENSITY OF FOAM -',T55,F12.4,T70,'pcf',//,T15,
\$'THE MINIMUM WEIGHT OF SANDWICH PLATE -',T55,F12.4,T70,'kips',/)

561 FORMAT(T15,'FY/FW FAILURE DESIGN',/)

562 FORMAT(T15,'FW/CS FAILURE DESIGN',/)

563 FORMAT(T15,'FY/CS FAILURE DESIGN',/)

564 FORMAT(T15,'FY/FW/CS FAILURE DESIGN',/)

*** 4. MINIMUM WEIGHT DESIGN FOR STIFFNESS ***

*** AND STRENGTH IN SANDWICH PLATES ***

*** INPUT THE DESIGN PARAMETERS ***

600 WRITE(*,*)'INPUT THE REQUIRED UNIFORM LOADING (ksi)'

READ(*,*)P

WRITE(*,*)'INPUT THE DESIGN DEFLECTION (in)'

READ(*,*)DELTA

WRITE(7,671)P,DELTA

671 FORMAT(T10,'THE REQUIRED UNIFORM LOADING -',T50,F12.4,T65,'kips',

\$//,T10,'THE DESIGN DEFLECTION -',T50,F12.4,T65,'in.',/)

** CALCULATE THE OPTIMAL DESIGN VALUES ***

```
***      S+FY FAILURE DESIGN      ***
RCS=(YF/AFA)**(1.5/A)*ROS
CRIT=8*DELTA*EF*P*(G3+NUF*G4)**2/((1-NUF**2)*G1*YF**2*1000.)
TF1=CRIT
WEIGHT=1000000.
FAIL=1
WRITE(*,*)'THE PROGRAM IS RUNNING. PLEASE WAIT!'
DO 673 I=1,999
    TC1=P*AA**2*(G3+NUF*G4)/(YF*TF1)
    COEFF=((DELTA/P)-AA**4*(1-NUF**2)*G1/(8*EF*TF1*TC1**2))**(-1)
    ROC1=(COEFF*AA**2*G2/(4*CG*TC1*ES))**((1./G)*ROS
    IF (CONFI.LT.3) W1=(2*ROF*TF1+ROC1*TC1)*3.14*RCP**2/1728000.
    IF (CONFI.GE.3) W1=(2*ROF*TF1+ROC1*TC1)*AA*BB/1728000.
    IF (ROC1.GE.RCS) THEN
        IF (W1.LE.WEIGHT) THEN
            TC=TC1
            TF=TF1
            ROC=ROC1
            WEIGHT=W1
        END IF
    END IF
    TF1=TF1+CRIT
673 CONTINUE
```

```
***      S+FW FAILURE DESIGN      ***
CRIT=RCS/1000.
ROC1=CRIT
DO 674 I=1,999
    COEFF=(ROC1/ROS)**(2*A/3.)*AA**2*AFA*G1*(1-NUF**2)/8.
    TC1=COEFF/(DELTA*EF*(G3+NUF*G4))+P*AA**2*G2/(CG*4.*ES*DELTA*
$    (ROC1/ROS)**G)
    TF1=P*AA**2*(G3+NUF*G4)*(ROC1/ROS)**(-2*A/3.)/(AFA*TC1)
    IF (CONFI.LT.3) W1=(2*ROF*TF1+ROC1*TC1)*3.14*RCP**2/1728000.
    IF (CONFI.GE.3) W1=(2*ROF*TF1+ROC1*TC1)*AA*BB/1728000.
    TL=C4*YS*(G3+NUF*G4)*(ROC1/ROS)**(B-2*A/3.)/(AFA*G8)
    IF ((TF1/AA).LE.TL) THEN
        IF (W1.LE.WEIGHT) THEN
            TC=TC1
            TF=TF1
            ROC=ROC1
            WEIGHT=W1
            FAIL=2
        END IF
    END IF
    ROC1=ROC1+CRIT
674 CONTINUE
```

```
***      S+FY+FW FAILURE DESIGN      ***
ROC1=(YF/AFA)**(1.5/A)*ROS
COEFF=AA**2*YF*G1*(1-NUF**2)/(8*DELTA*EF*(G3+NUF*G4))
TC1=COEFF+P*AA**2*G2*(YF/AFA)**(-1.5*G/A)/(4*CG*ES*DELTA)
TF1=P*AA**2*(G3+NUF*G4)/(YF*TC1)
IF (CONFI.LT.3) W1=(2*ROF*TF1+ROC1*TC1)*3.14*RCP**2/1728000.
IF (CONFI.GE.3) W1=(2*ROF*TF1+ROC1*TC1)*AA*BB/1728000.
IF (W1.LE.WEIGHT) THEN
    TC=TC1
    TF=TF1
    ROC=ROC1
```

WEIGHT-W1
FAIL-3
END IF

WRITE(*,680)TC,TF,ROC,WEIGHT
WRITE(7,680)TC,TF,ROC,WEIGHT
IF (FAIL.EQ.1) WRITE(7,681)
IF (FAIL.EQ.2) WRITE(7,682)
IF (FAIL.EQ.3) WRITE(7,683)
680 FORMAT(/,T10,'THE OPTIMAL DESIGN VALUE :',//,T15,
\$'THE OPTIMAL CORE THICKNESS -',T55,F12.4,T70,'in.',//,T15,
\$'THE OPTIMAL FACE THICKNESS -',T55,F12.4,T70,'in.',//,T15,
\$'THE OPTIMAL MASS DENSITY OF FOAM -',T55,F12.4,T70,'pcf',//,T15,
\$'THE MINIMUM WEIGHT OF SANDWICH PLATE -',T55,F12.4,T70,'kips',/)
681 FORMAT(T15,'STIFFNESS/FY FAILURE DESIGN',/)
682 FORMAT(T15,'STIFFNESS/FW FAILURE DESIGN',/)
683 FORMAT(T15,'STIFFNESS/FY/FW FAILURE DESIGN',/)
1000 STOP
END

ANALYSIS OF SANDWICH BEAMS

THE ELASTIC MODULUS OF FACE MATERIAL = 10150.000 (ksi)

THE YIELD STRENGTH OF FACE MATERIAL = 12.470 (ksi)

THE MASS DENSITY OF FACE MATERIAL = 168.570 (pcf)

THE ELASTIC MODULUS OF SOLID FOAM = 232.000 (ksi)

THE YIELD STRENGTH OF SOLID FOAM = 18.415 (ksi)

THE MASS DENSITY OF SOLID FOAM = 75.000 (pcf)

THE PROPORTIONALITY CONSTANT
FOR ELASTIC MODULUS OF FOAM CORE = 1.130

THE POWER CONSTANT
FOR ELASTIC MODULUS OF FOAM CORE = 1.710

THE PROPORTIONALITY CONSTANT
FOR SHEAR MODULUS OF FOAM CORE = 1.400

THE POWER CONSTANT
FOR SHEAR MODULUS OF FOAM CORE = 2.000

THE PROPORTIONALITY CONSTANT
FOR SHEAR STRENGTH OF FOAM CORE = 1.310

THE POWER CONSTANT
FOR SHEAR STRENGTH OF FOAM CORE = 1.520

SIMPLY-SUPPORTED UNDER CONCENTRATED LOAD

THE WIDTH OF THE SANDWICH BEAM = 2.000 (in.)

THE SPAN OF THE SANDWICH BEAM = 30.000 (in.)

THE MASS DENSITY OF CORE MATERIAL = 4.000 (pcf)

THE THICKNESS OF FACE MATERIAL = .050 (in.)

THE THICKNESS OF FOAM CORE = 4.000 (in.)

THE MAGNITUDE OF CONCENTRATED LOAD = .010 (kips)

THE LOCATION OF CONCENTRATED LOAD = 15.000 (in.)

THE CRITICAL BENDING AND SHEAR STRESSES :

Z (in)	SIGMAC (ksi)	TAUC (ksi)
.000	.000000	.000518
.100	.000002	.000518
.200	.000003	.000518
.300	.000005	.000518
.400	.000005	.000518
.500	.000007	.000518

.600	.000007	.000616
.700	.000011	.000618
.800	.000013	.000618
.900	.000014	.000618
1.000	.000016	.000617
1.100	.000017	.000617
1.200	.000019	.000617
1.300	.000020	.000617
1.400	.000022	.000617
1.500	.000024	.000617
1.600	.000025	.000617
1.700	.000027	.000616
1.800	.000028	.000616
1.900	.000030	.000616
2.000	.000031	.000616

Z (in)	SIGMAF (Ksi)	VALUE (Ksi)
2.000	.182482	.000616
2.003	.182710	.000525
2.005	.182568	.000555
2.008	.183166	.000524
2.010	.183394	.000494
2.013	.183622	.000463
2.015	.183850	.000433
2.018	.184078	.000402
2.020	.184307	.000371
2.023	.184535	.000341
2.025	.184763	.000310
2.028	.184991	.000279
2.030	.185219	.000248
2.033	.185447	.000217
2.035	.185675	.000186
2.038	.185903	.000155
2.040	.186131	.000124
2.043	.186359	.000093
2.045	.186588	.000062
2.048	.186816	.000031
2.050	.187044	.000000

THE MAXIMUM DEFLECTION = .035319 (in.)

THE FAILURE MODE IS FACE YIELDING

THE SANDWICH BEAM UNDER LOADING IS SAFE

MINIMUM WEIGHT DESIGN FOR STRENGTH IN SANDWICH BEAMS

THE ELASTIC MODULUS OF FACE MATERIAL = 10150.000 (ksi)

THE YIELD STRENGTH OF FACE MATERIAL = 12.470 (ksi)

THE MASS DENSITY OF FACE MATERIAL = 168.570 (pcf)

THE ELASTIC MODULUS OF SOLID FOAM = 232.000 (ksi)

THE YIELD STRENGTH OF SOLID FOAM = 18.415 (ksi)

THE MASS DENSITY OF SOLID FOAM = 75.000 (pcf)

THE PROPORTIONALITY CONSTANT
FOR ELASTIC MODULUS OF FOAM CORE = 1.130

THE POWER CONSTANT
FOR ELASTIC MODULUS OF FOAM CORE = 1.710

THE PROPORTIONALITY CONSTANT
FOR SHEAR MODULUS OF FOAM CORE = .400

THE POWER CONSTANT
FOR SEAR MODULUS OF FOAM CORE = 2.000

THE PROPORTIONALITY CONSTANT
FOR SHEAR STRENGTH OF FOAM CORE = .310

THE POWER CONSTANT
FOR SHEAR STRENGTH OF FOAM CORE = 1.520

SIMPLY-SUPPORTED UNDER CONCENTRATED LOAD

THE WIDTH OF THE SANDWICH BEAM = 2.000 (in.)

THE SPAN OF THE SANDWICH BEAM = 30.000 (in.)

THE REQUIRED DESIGN STRENGTH
PER UNIT WIDTH AND LENGTH = 4.0000 psi

THE OPTIMAL DESIGN VALUES :

THE OPTIMAL CORE THICKNESS = 2.8892 in.

THE OPTIMAL FACE THICKNESS = .0250 in.

THE OPTIMAL MASS DENSITY OF FOAM = 2.9150 pcf

THE MINIMUM WEIGHT OF SANDWICH BEAM = .0006 kips

FY/FW FAILURE DESIGN

MINIMUM WEIGHT DESIGN FOR STIFFNESS IN SANDWICH BEAMS

THE ELASTIC MODULUS OF FACE MATERIAL = 10150.000 (ksi)

THE YIELD STRENGTH OF FACE MATERIAL = 12.470 (ksi)

THE MASS DENSITY OF FACE MATERIAL = 168.570 (pcf)

THE ELASTIC MODULUS OF SOLID FOAM = 232.000 (ksi)

THE YIELD STRENGTH OF SOLID FOAM = 18.415 (ksi)

THE MASS DENSITY OF SOLID FOAM = 75.000 (pcf)

THE PROPORTIONALITY CONSTANT
FOR ELASTIC MODULUS OF FOAM CORE = 1.130

THE POWER CONSTANT
FOR ELASTIC MODULUS OF FOAM CORE = 1.710

THE PROPORTIONALITY CONSTANT
FOR SHEAR MODULUS OF FOAM CORE = .400

THE POWER CONSTANT
FOR SEAR MODULUS OF FOAM CORE = 2.000

THE PROPORTIONALITY CONSTANT
FOR SHEAR STRENGTH OF FOAM CORE = .310

THE POWER CONSTANT
FOR SHEAR STRENGTH OF FOAM CORE = 1.520

SIMPLY-SUPPORTED UNDER CONCENTRATED LOAD

THE WIDTH OF THE SANDWICH BEAM = 2.000 (in.)

THE SPAN OF THE SANDWICH BEAM = 30.000 (in.)

THE REQUIRED DESIGN STIFFNESS = .50000 (kips/in)

THE OPTIMAL DESIGN VALUES :

THE OPTIMAL CORE THICKNESS = 2.3633 in.

THE OPTIMAL FACE THICKNESS = .0149 in.

THE OPTIMAL MASS DENSITY OF FOAM = 8.4933 pcf

THE MINIMUM WEIGHT OF SANDWICH BEAM = .0009 kips

THETA OF THE SHEAR LAG CRITERION = 338.9451

MINIMUM WEIGHT DESIGN FOR STIFFNESS AND STRENGTH IN SANDWICH BEAMS

THE ELASTIC MODULUS OF FACE MATERIAL = 10150.000 (ksi)

THE YIELD STRENGTH OF FACE MATERIAL = 12.470 (ksi)

THE MASS DENSITY OF FACE MATERIAL = 168.570 (pcf)

THE ELASTIC MODULUS OF SOLID FOAM = 232.000 (ksi)

THE YIELD STRENGTH OF SOLID FOAM = 18.415 (ksi)

THE MASS DENSITY OF SOLID FOAM = 75.000 (pcf)

THE PROPORTIONALITY CONSTANT
FOR ELASTIC MODULUS OF FOAM CORE = 1.130

THE POWER CONSTANT
FOR ELASTIC MODULUS OF FOAM CORE = 1.710

THE PROPORTIONALITY CONSTANT
FOR SHEAR MODULUS OF FOAM CORE = .400

THE POWER CONSTANT
FOR SEAR MODULUS OF FOAM CORE = 2.000

THE PROPORTIONALITY CONSTANT
FOR SHEAR STRENGTH OF FOAM CORE = .310

THE POWER CONSTANT
FOR SHEAR STRENGTH OF FOAM CORE = 1.520

SIMPLY-SUPPORTED UNDER CONCENTRATED LOAD

THE WIDTH OF THE SANDWICH BEAM = 2.000 (in.)

THE SPAN OF THE SANDWICH BEAM = 30.000 (in.)

THE REQUIRED DESIGN LOAD = .2500 kips

THE REQUIRED DESIGN DEFLECTION = .5000 in.

THE OPTIMAL DESIGN VALUE :

THE OPTIMAL CORE THICKNESS = 2.9965 in.

THE OPTIMAL FACE THICKNESS = .0251 in.

THE OPTIMAL MASS DENSITY OF FOAM = 6.5763 pcf

THE MINIMUM WEIGHT OF SANDWICH BEAM = .0010 kips

STIFFNESS/F, FAILURE DESIGN

ANALYSIS OF SANDWICH PLATES

THE ELASTIC MODULUS OF FACE MATERIAL = 10150.000 (ksi)

THE YIELD STRENGTH OF FACE MATERIAL = 12.470 (ksi)

THE MASS DENSITY OF FACE MATERIAL = 168.570 (pcf)

THE ELASTIC MODULUS OF SOLID FOAM = 232.000 (ksi)

THE YIELD STRENGTH OF SOLID FOAM = 18.415 (ksi)

THE MASS DENSITY OF SOLID FOAM = 75.000 (pcf)

THE PROPORTIONALITY CONSTANT
FOR ELASTIC MODULUS OF FOAM CORE = 1.130

THE POWER CONSTANT
FOR ELASTIC MODULUS OF FOAM CORE = 1.710

THE PROPORTIONALITY CONSTANT
FOR SHEAR MODULUS OF FOAM CORE = .400

THE POWER CONSTANT
FOR SEAR MODULUS OF FOAM CORE = 2.000

THE PROPORTIONALITY CONSTANT
FOR SHEAR STRENGTH OF FOAM CORE = .310

THE POWER CONSTANT
FOR SHEAR STRENGTH OF FOAM CORE = 1.520

RECTANGULAR PLATE, SIMPLY-SUPPORTED UNDER UNIFORM LOAD

THE POISSON'S RATIO OF THE FACE MATERIAL .300

THE LENGTH (X DIRECTION) OF
THE RECTANGULAR PLATE = 200.000 (in.)

THE .WIDTH (Y DIRECTION) OF
THE RECTANGULAR PLATE = 100.000 (in.)

THE MAGNITUDE OF THE UNIFORM LOAD = .00100 (ksi)

THE THICKNESS OF FACE MATERIAL = .100 (in.)

THE THICKNESS OF FOAM CORE = 4.000 (in.)

THE MASS DENSITY OF FOAM CORE = 4.000 (pcf)

THE MAXIMUM STRESSES IN THE FACE MATERIAL :

THE MAXIMUM STRESS SIGMAX (SIGMAR) 1.1300 ksi

THE MAXIMUM STRESS SIGMAY (SIGMAT) 2.4798 ksi

THE MAXIMUM STRESS TAUXY (TAURT) = 1.1264 ksi

THE MAXIMUM STRESSES IN THE FOAM CORE :

THE MAXIMUM STRESS TAUCY (TAUCY) = .0065 ksi

THE MAXIMUM STRESS TAUCZ (TAUCZ) = .0111 ksi

THE MAXIMUM DEFLECTION = 1.1600 in.

THE FAILURE MODE IS CORE SHEAR YIELDING

THE SANDWICH PLATE UNDER LOADING IS SAFE

MINIMUM WEIGHT DESIGN FOR STIFFNESS IN SANDWICH PLATES

THE ELASTIC MODULUS OF FACE MATERIAL = 10150.000 (ksi)

THE YIELD STRENGTH OF FACE MATERIAL = 12.470 (ksi)

THE MASS DENSITY OF FACE MATERIAL = 168.570 (pcf)

THE ELASTIC MODULUS OF SOLID FOAM = 232.000 (ksi)

THE YIELD STRENGTH OF SOLID FOAM = 18.415 (ksi)

THE MASS DENSITY OF SOLID FOAM = 75.000 (pcf)

THE PROPORTIONALITY CONSTANT
FOR ELASTIC MODULUS OF FOAM CORE = 1.130

THE POWER CONSTANT
FOR ELASTIC MODULUS OF FOAM CORE = 1.710

THE PROPORTIONALITY CONSTANT
FOR SHEAR MODULUS OF FOAM CORE = .400

THE POWER CONSTANT
FOR SEAR MODULUS OF FOAM CORE = 2.000

THE PROPORTIONALITY CONSTANT
FOR SHEAR STRENGTH OF FOAM CORE = .310

THE POWER CONSTANT
FOR SHEAR STRENGTH OF FOAM CORE = 1.520

RECTANGULAR PLATE, SIMPLY-SUPPORTED UNDER UNIFORM LOAD

THE POISSON'S RATIO OF THE FACE MATERIAL .300

THE LENGTH (X DIRECTION) OF
THE RECTANGULAR PLATE = 200.000 (in.)

THE WIDTH (Y DIRECTION) OF
THE RECTANGULAR PLATE = 100.000 (in.)

THE REQUIRED DESIGN STIFFNESS = .00100 (ksi/in)

THE OPTIMAL DESIGN VALUES :

THE OPTIMAL THICKNESS OF FACE MATERIAL = .0178 in.

THE OPTIMAL THICKNESS OF CORE MATERIAL = 5.5394 in.

THE OPTIMAL MASS DENSITY OF FOAM = 4.3228 pcf

THE MINIMUM WEIGHT OF SANDWICH PLATE = .3464 kips

MINIMUM WEIGHT DESIGN FOR STRENGTH IN SANDWICH PLATES

THE ELASTIC MODULUS OF FACE MATERIAL =	10150.000	(ksi)
THE YIELD STRENGTH OF FACE MATERIAL =	12.470	(ksi)
THE MASS DENSITY OF FACE MATERIAL =	168.570	(pcf)
THE ELASTIC MODULUS OF SOLID FOAM =	232.000	(ksi)
THE YIELD STRENGTH OF SOLID FOAM =	18.415	(ksi)
THE MASS DENSITY OF SOLID FOAM =	75.000	(pcf)
THE PROPORTIONALITY CONSTANT FOR ELASTIC MODULUS OF FOAM CORE =	1.130	
THE POWER CONSTANT FOR ELASTIC MODULUS OF FOAM CORE =	1.710	
THE PROPORTIONALITY CONSTANT FOR SHEAR MODULUS OF FOAM CORE =	.400	
THE POWER CONSTANT FOR SEAR MODULUS OF FOAM CORE =	2.000	
THE PROPORTIONALITY CONSTANT FOR SHEAR STRENGTH OF FOAM CORE =	.310	
THE POWER CONSTANT FOR SHEAR STRENGTH OF FOAM CORE =	1.520	

RECTANGULAR PLATE, SIMPLY-SUPPORTED UNDER UNIFORM LOAD

THE POISSON'S RATIO OF THE FACE MATERIAL	.300	
THE LENGTH (X DIRECTION) OF THE RECTANGULAR PLATE =	200.000	(in.)
THE WIDTH (Y DIRECTION) OF THE RECTANGULAR PLATE =	100.000	(in.)
THE REQUIRED UNIFORM LOADING =	1.0000	psi

THE OPTIMAL DESIGN VALUES :

THE OPTIMAL CORE THICKNESS =	2.0729	in.
THE OPTIMAL FACE THICKNESS =	.0179	in.
THE OPTIMAL MASS DENSITY OF FOAM =	2.9150	pcf
THE MINIMUM WEIGHT OF SANDWICH PLATE =	.1399	kips

FY/FW FAILURE DESIGN

MINIMUM WEIGHT DESIGN FOR STIFFNESS AND STRENGTH IN SANDWICH PLATES

THE ELASTIC MODULUS OF FACE MATERIAL = 10150.000 (ksi)

THE YIELD STRENGTH OF FACE MATERIAL = 12.470 (ksi)

THE MASS DENSITY OF FACE MATERIAL = 168.570 (pcf)

THE ELASTIC MODULUS OF SOLID FOAM = 232.000 (ksi)

THE YIELD STRENGTH OF SOLID FOAM = 18.415 (ksi)

THE MASS DENSITY OF SOLID FOAM = 75.000 (pcf)

THE PROPORTIONALITY CONSTANT
FOR ELASTIC MODULUS OF FOAM CORE = 1.130

THE POWER CONSTANT
FOR ELASTIC MODULUS OF FOAM CORE = 1.710

THE PROPORTIONALITY CONSTANT
FOR SHEAR MODULUS OF FOAM CORE = .400

THE POWER CONSTANT
FOR SEAR MODULUS OF FOAM CORE = 2.000

THE PROPORTIONALITY CONSTANT
FOR SHEAR STRENGTH OF FOAM CORE = .310

THE POWER CONSTANT
FOR SHEAR STRENGTH OF FOAM CORE = 1.520

RECTANGULAR PLATE, SIMPLY-SUPPORTED UNDER UNIFORM LOAD

THE POISSON'S RATIO OF THE FACE MATERIAL = .300

THE LENGTH (X DIRECTION) OF
THE RECTANGULAR PLATE = 200.000 (in.)

THE WIDTH (Y DIRECTION) OF
THE RECTANGULAR PLATE = 100.000 (in.)

THE REQUIRED UNIFORM LOADING = .0010 ksi

THE DESIGN DEFLECTION = 1.0000 in.

THE OPTIMAL DESIGN VALUE :

THE OPTIMAL CORE THICKNESS = 10.1207 in.

THE OPTIMAL FACE THICKNESS = .0037 in.

THE OPTIMAL MASS DENSITY OF FOAM = 3.6316 pcf

THE MINIMUM WEIGHT OF SANDWICH PLATE = .4397 kips

STIFFNESS/FY FAILURE DESIGN

