DDS 130-4

DECK CAMBER AND SHEER
FOR
USN SURFACE SHIPS

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
WASHINGTON, DC 20362-5101

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DESIGN DATA SHEET
DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND

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FIGURES

130-4-a. References

(a) Deck Camber Requirements and Design Guidance for USN Surface Ships, NAVSEA Report No. 3213-80-20, September 1980.

(b) DDS 079-2, Minimum required Freeboard for U. S. Naval Surface Ships, 1 March 1982.

(c) Masubuchi, K., et al, "Analysis of Thermal Stresses and Metal Movements of Weldments: A Basic Study Toward Computer-Aided Analysis and Control of Welded Structures," Transactions SNAME, Vol. 83, 1975.

(d) MIL-STD-1689, Fabrication, Welding, and Inspection of Ships Structure.

130-4-b. Purpose and Scope

The purpose of this design data sheet is to present a procedure to determine the sheer and camber (longitudinal and transverse slope of the deck) required to effectively drain the weather decks of USN surface ships. The selection of sheer and camber type, extent and transition is presented. The calculation procedure is applicable to all weather deck surfaces such as exposed portions of the uppermost hull deck, exposed portions of the superstructure decks, housetops, and flight decks of air-capable ships, except CV-types.

130-4-c. Symbols

c = Subscript referring to camber

$C_{c,s}$ = Angular rigidity coefficients, inch-pounds/inch

C_D = Camber required for deck plate distortion, inches per foot

C_L = Camber required for ship list, inches per foot

C_{TOT} = Total minimum required slope of camber, inches per foot

D_E = Plate bending rigidity, inch-pounds

D_W = Weld size (depth), inches

E = Modulus of elasticity, pounds per square inch

L_C = Stiffener or girder spacing in the transverse direction, inches

L_S = Web or frame spacing in the longitudinal direction, inches

s = Subscript referring to sheer

t = Plate thickness, inches

W = Weight of weld electrode consumed, pounds/inch

ϕ = Restrained angle of weld distortion, degrees

$\phi_{c,s}$ = Unrestrained angle of weld distortion, degrees

ρ = Weld material density, pounds per cubic inch

η_D = Weld material deposition efficiency

ζ = Poisson's ratio

130-4-d. Camber and Sheer Type and Selection

To ensure the maximum military effectiveness and minimum maintenance of Navy ships, all exposed deck areas require adequate positive drainage while at sea and in port. Adequate drainage can be provided by either parabolic or straight-line sheer and camber, or alternatively by deck drains. The approach is selected by consideration of the effects of the alternatives on exposed deck drainage characteristics, ship design and construction costs, and ship weight and vertical center of gravity.

The traditional type of deck camber and sheer is approximately parabolic. This is a continuation of the practice of bending wooden deck beams for added strength and drainage. A simpler alternative is straight-line camber and sheer. Straight-line camber may be configured with one knuckle on the ship centerline or with two knuckles outboard of the centerline, which are typically located at the edge of the superstructure. Parabolic camber and straight-line camber are illustrated in Figure 1.

While parabolic camber and sheer are considered to provide adequate drainage, the constant slope of straight-line camber provides better drainage near the centerline of the ship. For one half of the distance outboard of the centerline the slope of parabolic camber is less than the slope of straight-line camber for the same centerline camber height. Thus, only half of the deck with parabolic camber would have continuous positive drainage while water tends to collect near the ship centerline. Straight-line camber and sheer are generally preferred for providing the maximum extent of weather deck drainage.

Most Navy ship decks are constructed of metal plating supported by a grillwork of transverse and longitudinal frames. The construction of decks with straight-line camber and sheer requires sloping of the plating and frames, which increases construction complexity and labor costs. The construction of decks with parabolic camber and sheer requires bending of the plating and frames to the parabolic curve, as well as transition areas with compound curvature, which further increases construction complexity and labor costs. For ships built of wood or fiberglass parabolic camber and sheer are generally recommended because the increase in deck strength and stiffness compensates for the relatively smaller increase in construction complexity and labor costs. For metal ships straight-line camber and sheer are generally less costly.

The effects of camber and sheer on ship weight and vertical center of gravity (VCG) are similar for parabolic and straight-line camber. Up to six inches of deck camber can be generally accommodated by reducing the overhead space of the deck below, without increasing the centerline deck height, which lowers the VCG slightly. Camber in excess of six inches generally requires a corresponding increase in the centerline deck height, which raises the VCG slightly. This increase in VCG is additive for each deck with camber in excess of six inches. Straight-line camber will have slightly less effect unless the increased strength of parabolic camber allows the use of thinner structure.

Additional discussion of camber and sheer types and selection considerations is contained in Reference (a).

130-4-e. Extent and Transition of Camber and Sheer

Deck camber and/or sheer are provided on all weather deck areas to ensure adequate drainage at sea and in port. These areas include exposed portions of the uppermost continuous hull deck, exposed portions of the superstructure decks, housetops, and flight decks of air-capable ships. The amount of sheer is usually determined by the freeboard requirements of Reference (b).

On those exposed portions of the uppermost continuous hull deck which incorporate sufficient sheer, camber may not be required. However, any transverse vertical obstruction such as a weapon foundation, deck house front, or helicopter hangar door presents a drainage problem when camber is not provided. This problem can be solved by providing camber in addition to the sheer, a local section of camber, a triangular transverse frontal shape to the obstruction, or similarly shaped coaming, to direct the water outboard as it follows the sheer, or a system of deck drains.

Where the exposed portions of the hull or superstructure decks are only a small part of the deck outboard of the deckhouse, only the outboard portion needs camber with a transition to the flat portion.

The camber on flight decks must be compatible with the aircraft operational requirements. Helicopter flight decks should have camber, which begins at the centerline or outboard of the Recovery Assist, Securing and Traversing (RAST) System, if provided. Aircraft carrier flight deck camber practice, from the CV 59 Class on, has been to provide 4 inches of camber.

The transition between flat deck areas, or deck areas having sheer only, with cambered deck areas must be designed to minimize disruptions to arrangements, deck handling, and other ship systems, to avoid stress concentations, and to ensure the structural integrity of the ship.

The transition between the portion of a deck having camber only and a portion having sheer only is the intersection of the two surfaces. If both the camber and sheer are straight-line, the intersection is a straight line; otherwise, the intersection is a curve, as shown in Figure 2.

The transition between a straight-line cambered deck and a flat deck without sheer is a flat triangular surface. The transition between a parabolic cambered deck and a flat deck requires plating with compound curvature. The length of the transition area should be approximately equal to the transverse distance of the cambered area, or approximately a 45 degree triangle. This type of transition is shown in Figure 3.

An example of deck camber extent and transition for improved weather deck drainage of the DD 963 Class ships is shown in Figure 4. Single-knuckle straight-line camber is shown on the main deck and the 02, 03 and 04 levels. Double-knuckle straight-line camber is shown on the 01 level outboard of the superstructure. Additional examples of deck camber are shown in Reference (a).

130-4-f. Camber and Sheer Calculations - All Surface Ships Except CV-Types

The minimum amount of deck camber or sheer required for adequate drainage of weather decks while at sea and in port can be expressed as the sum of the camber or sheer required to compensate for deck plate distortion and the camber required to compensate for ship list, as follows:

$$C_{TOT} = C_D + C_L \qquad (1)$$

Calculation of Camber or Sheer for Deck Plate Distortion The minimum camber required to ensure drainage of dished deck plating resulting from welding stresses, based on the method of Reference (c), as shown in Figure 5, is determined by the following relation:

$$C_D = 12 \left(\text{Tangent} \left[\frac{\phi_c / 4}{1 + \left(\frac{2 D_E}{L_c C_c} \right)} \right] \right) \text{ inches per foot} \qquad (2)$$

where:

ϕ_c = the unrestrained angle of weld distortion in the transverse direction, degrees

D_E = Plate bending rigidity, inch pounds, equation (4)

L_c = Stiffener or girder spacing in the transverse direction, inches

C_c = Angular rigidity coefficient, inch-pounds/inch

The value of ϕ_c is determined from Figures 6 and 7 for steel and aluminum, respectively. The value of C_c is determined from Figures 8 and 9 for steel and aluminum, respectively. These values are determined on the basis of the deck plating thickness, t, and the weld size or depth, D_w, which are shown in Figure 5. The value of D_w is determined from the materials to be welded, the thickness of the thinner member (either the deck plating or the web of the stiffener), and the type of welding electrode. Applicable values are contained in tables in Reference (d). Typical values of D_w are 0.75 t and 1.0 t. The data in Figures 6 through 9 indicate that plating distortion due to welds is decreasing for plating thicknesses either thicker than the maximum or thinner than the minimum values shown in the figures. The data for plating distortion in Figures 6 through 9 for the maximum thickness is used for thicknesses greater than the maximum; data for the minimum thickness is used for thicknesses thinner than the minimum.

If the weight of weld electrode consumed W, in pounds per inch, is known, rather than the weld size, the weld size is determined using the following expression:

$$D_W = (2 W \eta_D / \rho)^{1/2} \quad \text{inches} \qquad (3)$$

where:

η_D = Weld material deposition efficiency
= 0.657 for steel
= 0.950 for aluminum

ρ = Weld material density, pounds per cubic inch
= 0.2836 lb/in^3 for steel
= 0.0960 lb/in^3 for aluminum

The value of D_E, the plate bending rigidity, is calculated as follows:

$$D_E = \frac{E\, t^3}{12\,(1 - \varsigma^2)} \quad \text{inch-pounds} \qquad (4)$$

where:

E = Modulus of elasticity, pounds per square inch
= 30.0 x 10^6 lb/in^2 for steel
= 10.3 x 10^6 lb/in^2 for aluminum

ς = Poisson's ratio
= 0.30 for steel
= 0.33 for aluminum

On weather deck areas having sheer, drainage of dished deck plating is adequate providing that the angle of sheer exceeds that determined by the following relation:

$$\phi = \frac{\phi_s}{1 + \left(\frac{2\, D_E}{L_s C_s}\right)} \quad \text{degrees} \qquad (5)$$

where:

ϕ_s = Unrestrained angle of weld distortion in the longitudinal direction, degrees

D_E = Plate bending rigidity, inch pounds, equation (4)

L_s = Web or frame spacing in the longitudinal direction, inches

C_s = Angular rigidity coefficient, inch pounds/inch

The value of ϕ_s is determined from Figures 6 and 7 for steel and aluminum, respectively. The value of C_s is determined from Figures 8 and 9 for steel and aluminum, respectively. These values are determined on the basis of the deck plating thickness, t, and the weld size or depth, D_w, which are shown in Figure 5. If the weight of weld electrode consumed is known, rather than the weld size, the weld size is determined using equation (3).

The equations above require input data that is not normally available until later in the design. However, reasonable preliminary estimates of plate and stiffener sizes, stiffener spacing, weld size, and material type can be used to develop preliminary estimates of required camber. Instead of the above calculation procedure, a value of plate distortion camber of 0.10 inches per foot may be assumed as a reasonable maximum.

The equations above will often indicate as many variations in required deck camber as there are variations in deck plating thicknesses, stiffener spacings, and materials. Ship construction will be less complex and expensive if the variations in deck camber are minimized. Different amounts of deck camber for hull and superstructure decks should be considered for steel hull ships with aluminum superstructure. The camber of the house top may well be different from the rest of the superstructure.

130-4-g. Example of Camber for Deck Plate Distortion

The equations above are used to calculate the amount of camber required for drainage of the weather decks of the DD 963 Class ships allowing for deck plate distortion.

01 Level: Steel plating, t = 0.562 in., L_c = 26 in., $D_w = t$

From Figure 6, by interpolation, ϕ_c = 4.0 degrees

From Figure 8, by interpolation, C_c = 35000. in-lb/in.

By equation (4), $$D_E = \frac{30000000\ (.562)^3}{12\ [\ 1 - (.3)^2\ ]} = 488000.\ \text{in-lb.}$$

By eqn. (2), $$C_D = 12\left(\text{Tan}\left[\frac{4.0\ /\ 4}{1 + \left(\frac{2\ (488000)}{26\ (35000)}\right)}\right]\right) = 0.10\ \text{in/ft}$$

02 Level: Aluminum plating, $t = 0.875$ in., $L_c = 21$ in., $D_w = t$

Because the plating thickness exceeds the largest values in Figures 7 and 9, assume that $t = 0.75$ in. for this calculation. The data in Figures 6 through 9 indicate that plating distortion due to welds is decreasing for plating thicknesses either thicker than the maximum or thinner than the minimum values shown in the figures.

From Figure 7, $\phi_c = 1.7$ degrees

From Figure 9, $C_c = 20500.$ in-lb/in.

By equation (4), $D_E = \dfrac{10300000\ (.75)^3}{12\ [\ 1 - (.33)^2\ ]} = 406000.$ in-lb.

By eqn. (2), $C_D = 12\ \left(\text{Tan}\left[\dfrac{1.7\ /\ 4}{1 + \left(\dfrac{2\ (406000)}{21\ (20500)}\right)}\right]\right) = 0.03$ in/ft

04 Level: Aluminum plating, $t = 0.375$ in., $L_c = 21$ in., $D_w = t$

From Figure 7, $\phi_c = 1.8$ degrees

From Figure 9, $C_c = 30000.$ in-lb/in.

By equation (4), $D_E = \dfrac{10300000\ (.375)^3}{12\ [\ 1 - (.33)^2\ ]} = 50800.$ in-lb.

By eqn. (2), $C_D = 12\ \left(\text{Tan}\left[\dfrac{1.8\ /\ 4}{1 + \left(\dfrac{2\ (50800)}{21\ (30000)}\right)}\right]\right) = 0.08$ in/ft

Based on the above calculations, the required deck camber for the DD 963 for plating distortion is 0.10 inches per foot for all decks or alternatively reduced to 0.08 inches per foot for decks above the 01 level.

130-4-h. Camber for Ship List

The list of the ship will hinder drainage of the deck on the higher side of the ship where camber has been provided to drain dished plating. Normal ship operational practice is to correct list when it exceeds one degree. Camber in the amount of 0.20 inches per foot is required to compensate for one degree of list. A lesser amount of camber, such as 0.10 inches per foot, will necessitate more frequent corrections of list to avoid the accumulation of standing water on deck. The lesser amount of camber may be desirable from arrangement or weight considerations.

130-4-i. Camber Practice - Aircraft Carriers (CV-Type)

In accordance with current aircraft carrier design practices used on all aircraft carrier classes beginning with the CV 59 Class, four inches of straight-line camber is provided on the flight deck. This amount of camber is compatible with the operations of existing aircraft. However, new types of aircraft under development, such as V/STOL aircraft, may have substantially different aircraft/flight deck interface requirements.

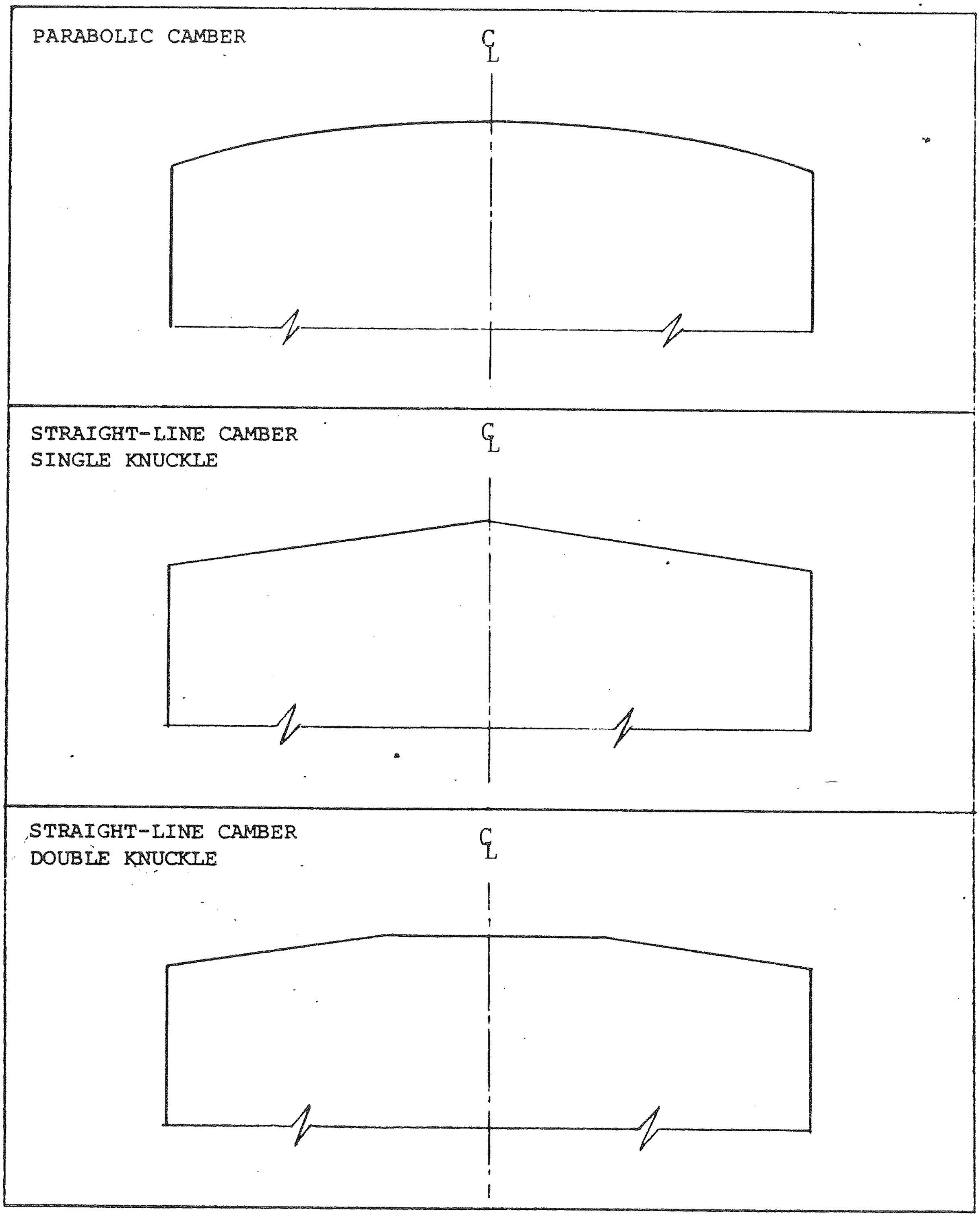


FIGURE 1

TYPES OF DECK CAMBER

FIGURE 2

TRANSITION FROM CAMBERED DECK AREAS TO DECK AREAS WITH SHEER

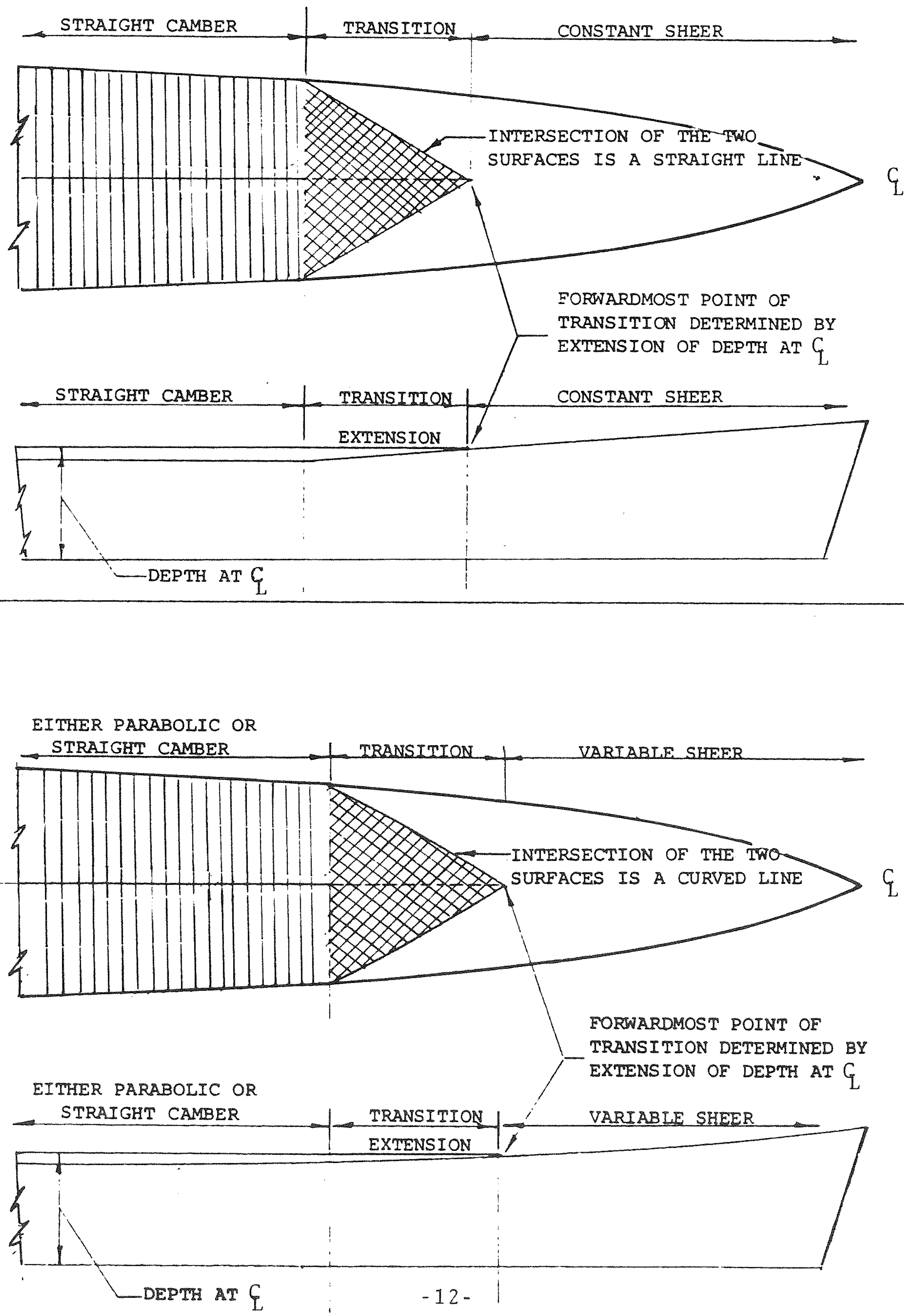
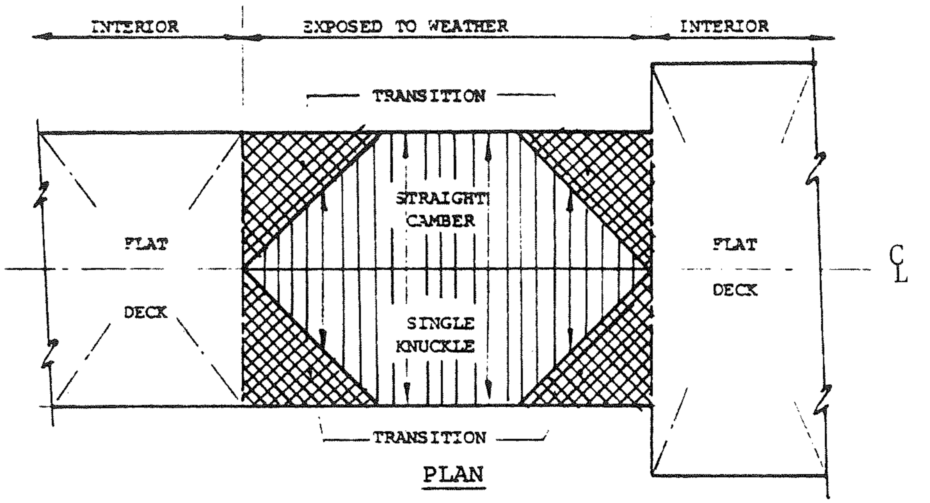


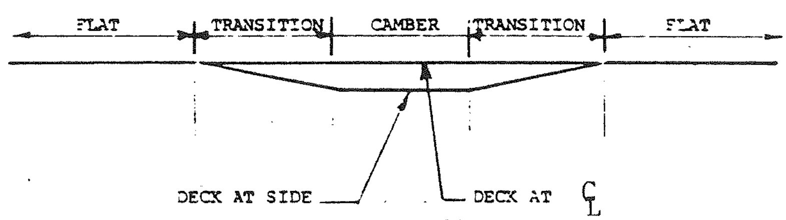
FIGURE 3

TRANSITION OF CAMBERED DECK AREAS TO FLAT DECK AREAS WITHOUT SHEER

TYPICAL SUPERSTRUCTURE DECK:

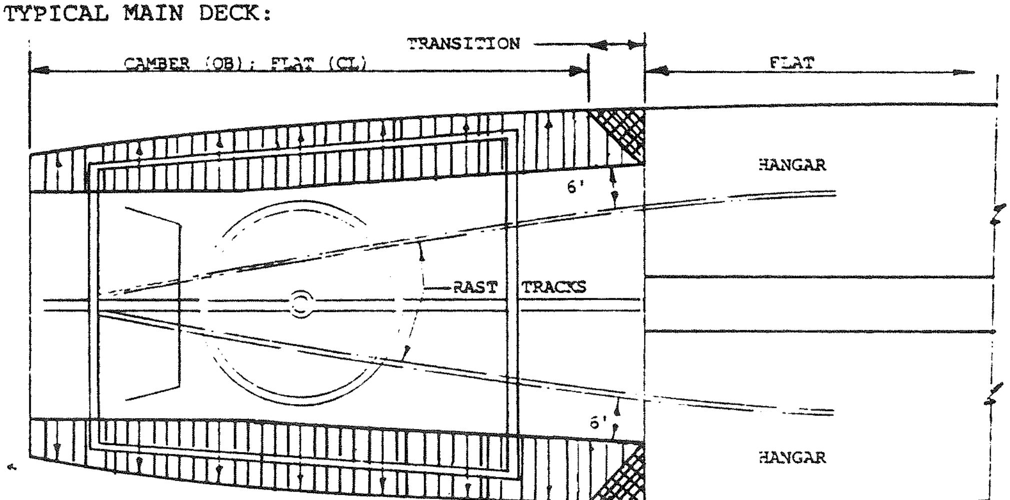


PLAN

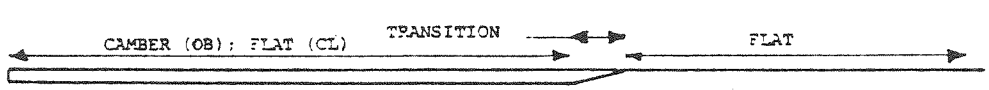


ELEVATION

TYPICAL MAIN DECK:



PLAN



ELEVATION

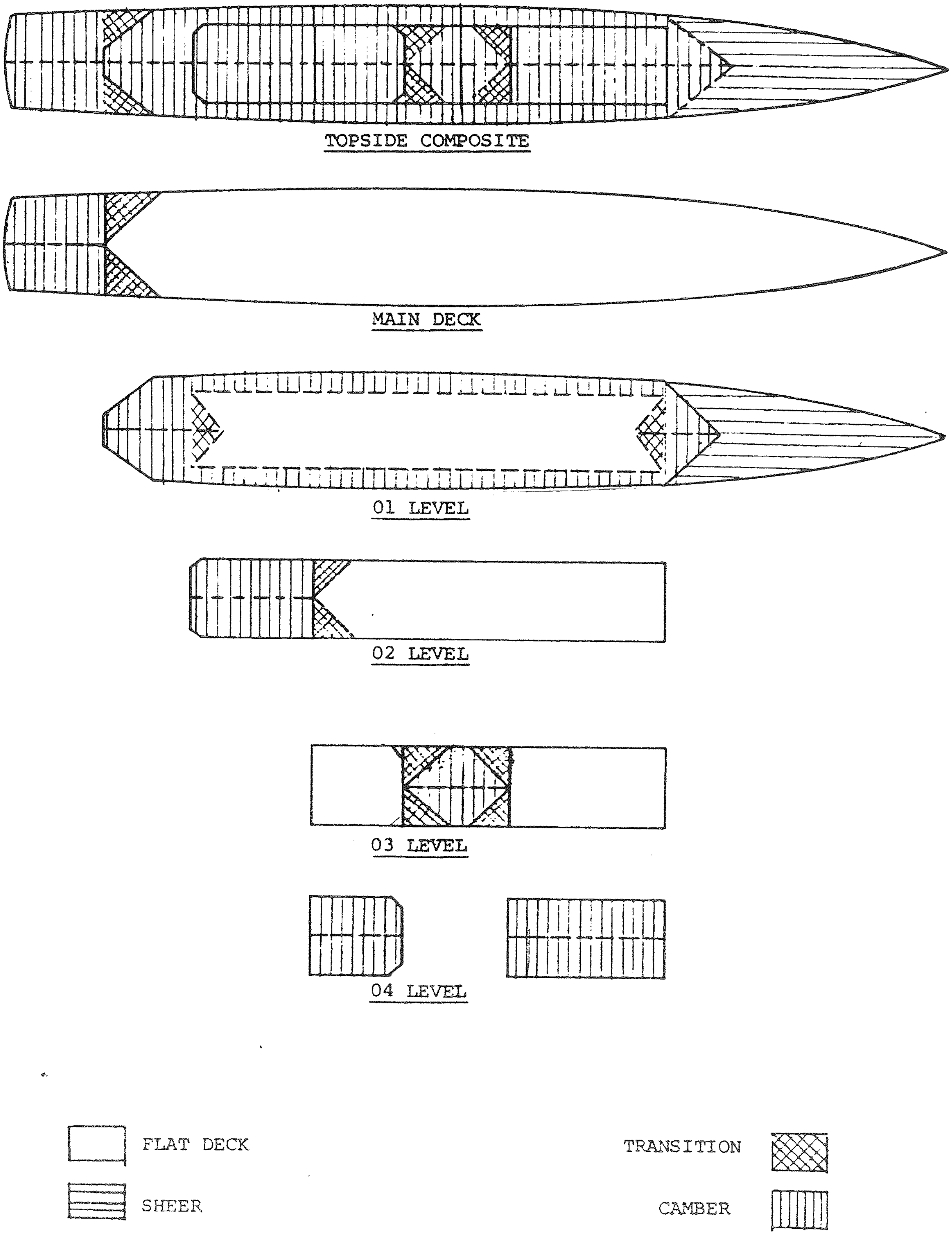


FIGURE 4

CAMBER PLAN FOR DD-963 USING BOTH SINGLE AND DOUBLE KNUCKLE STRAIGHT-LINE CAMBER

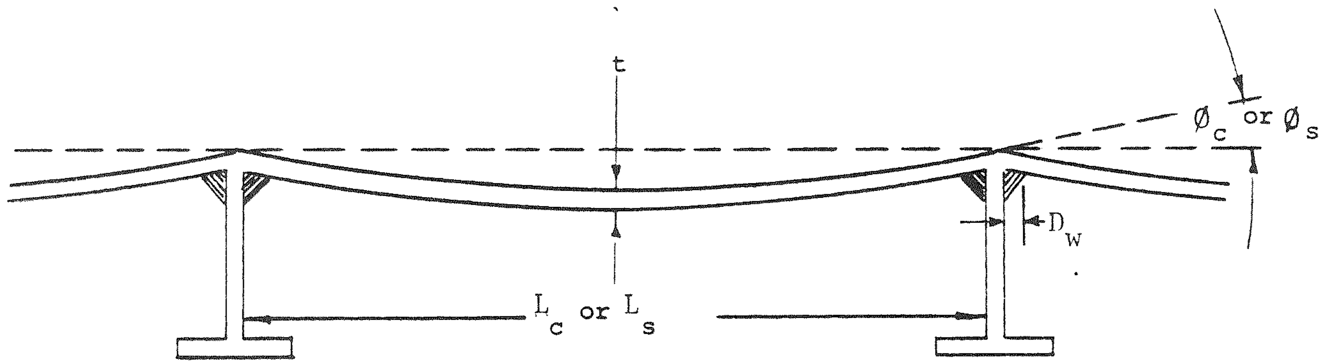


FIGURE 5

PLATE DISTORTION GEOMETRY

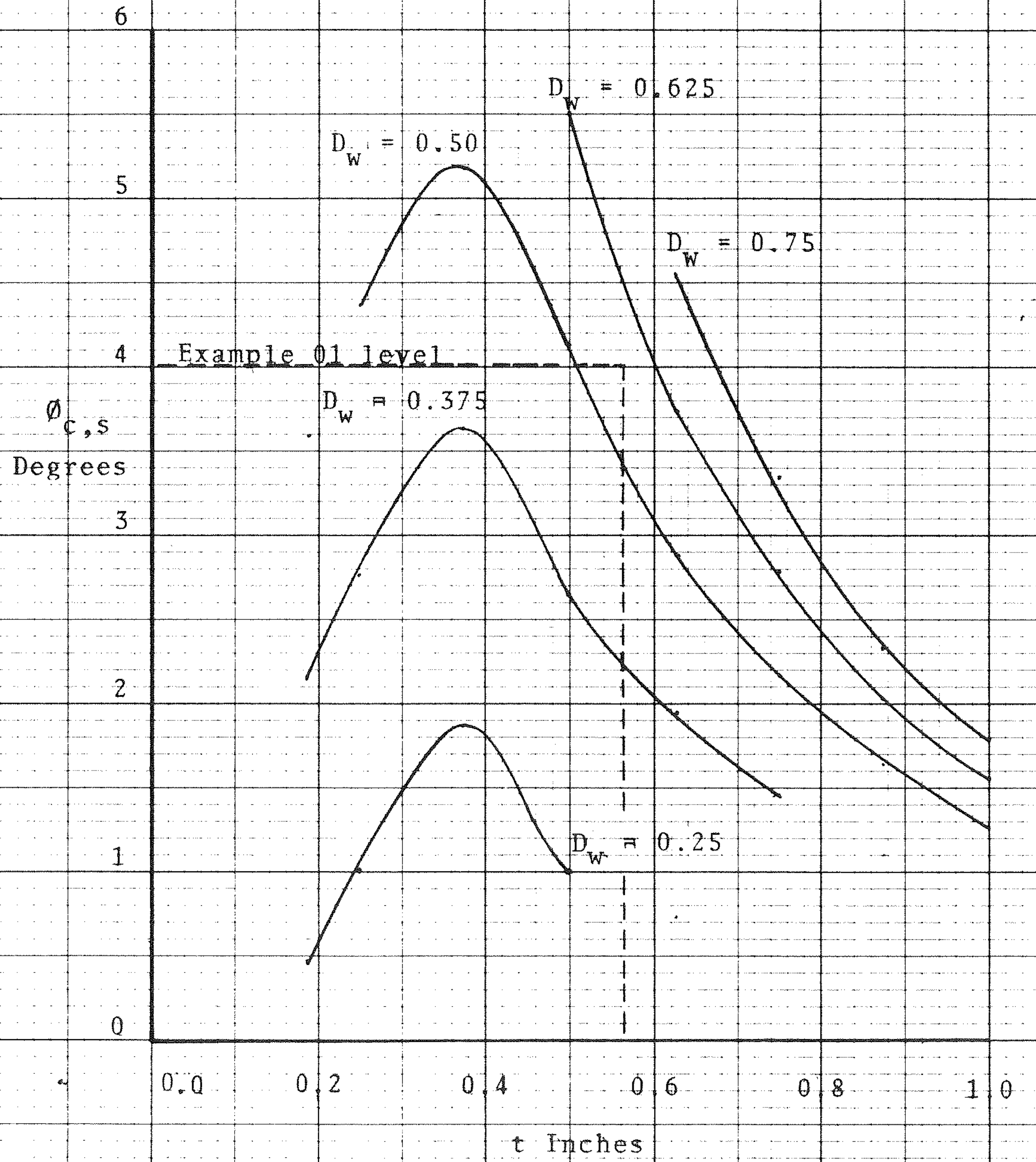


Figure 6

Unrestrained Angle of Weld Distortion, Steel

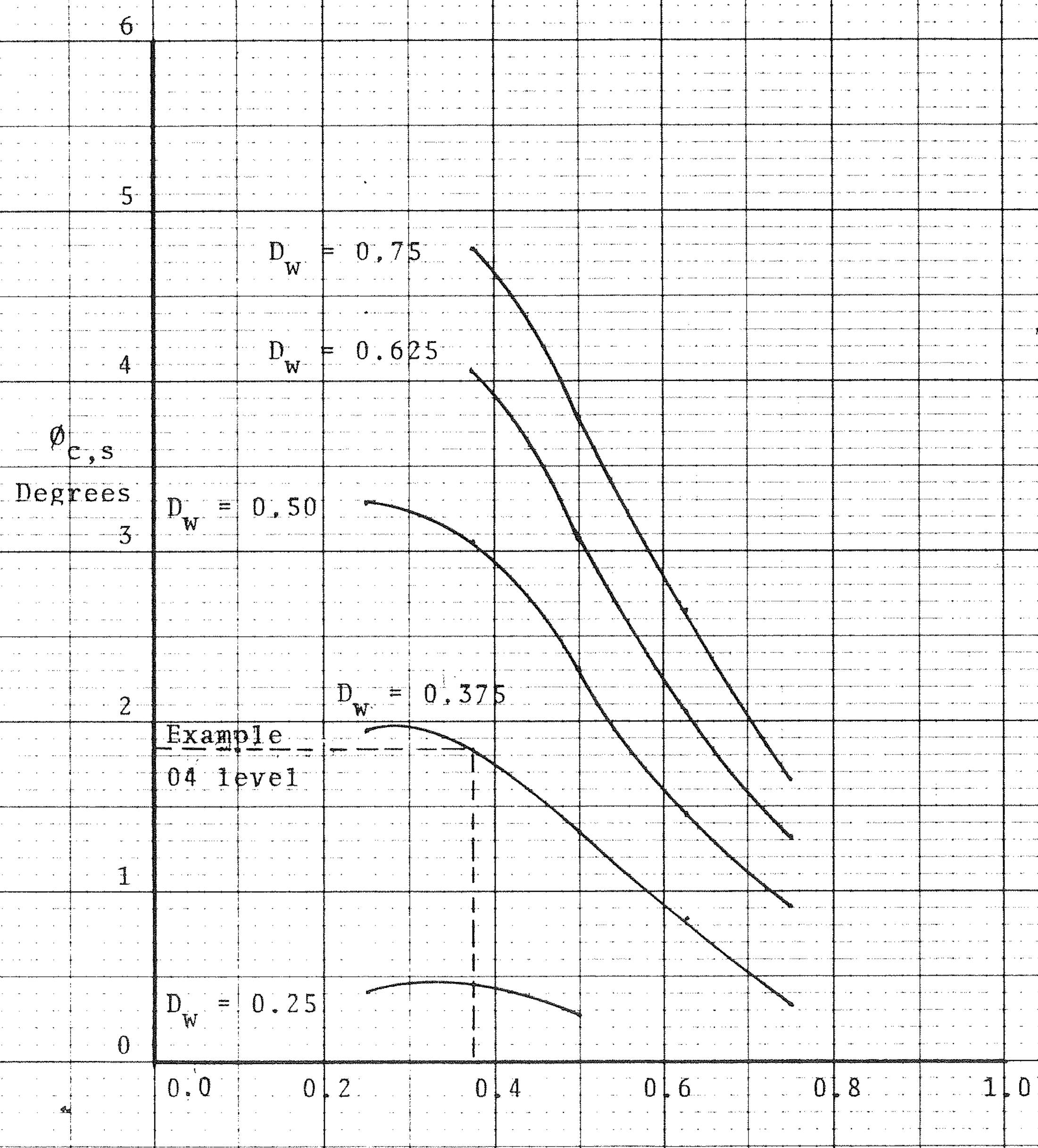


Figure 7

Unrestrained Angle of Weld Distortion, Aluminum

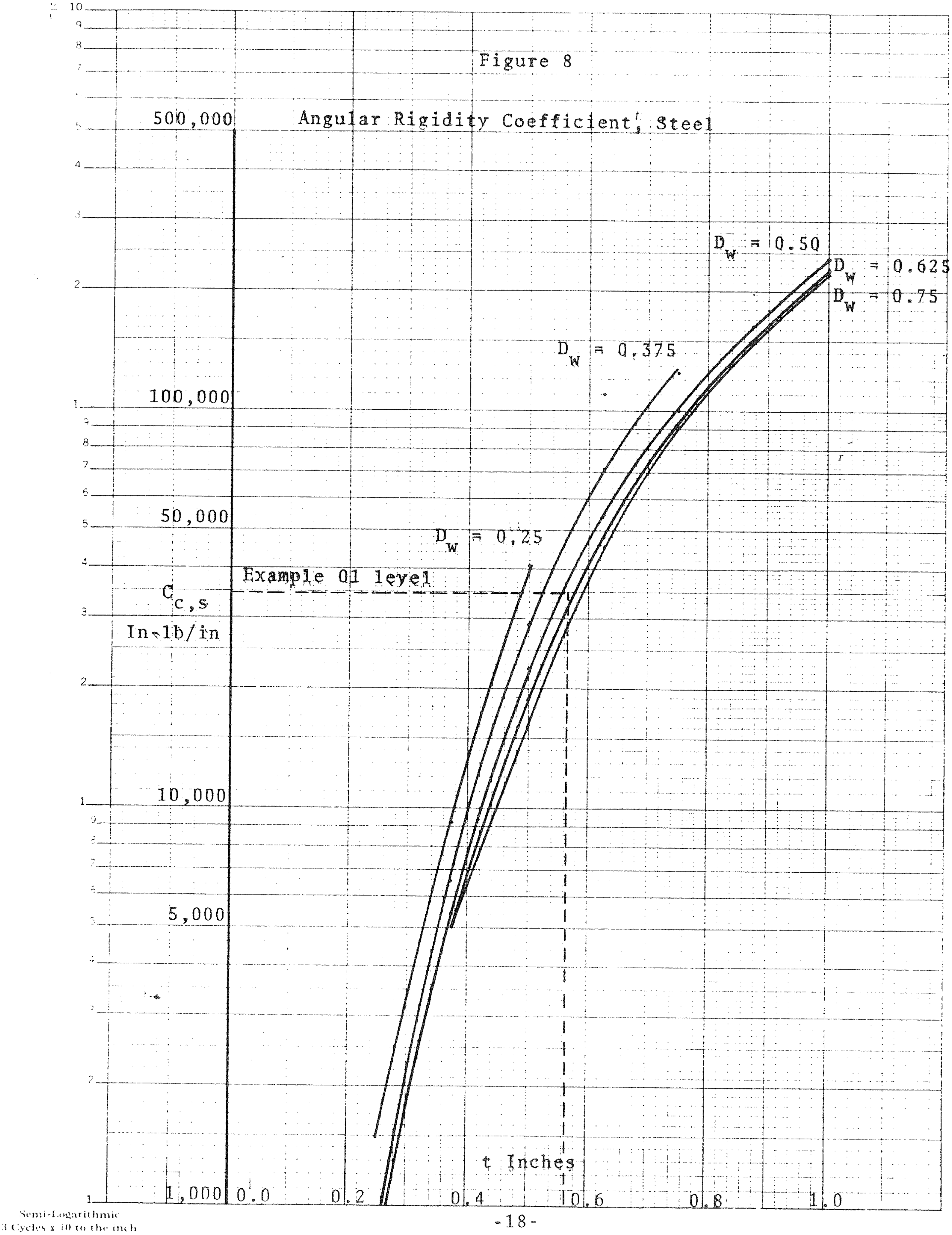
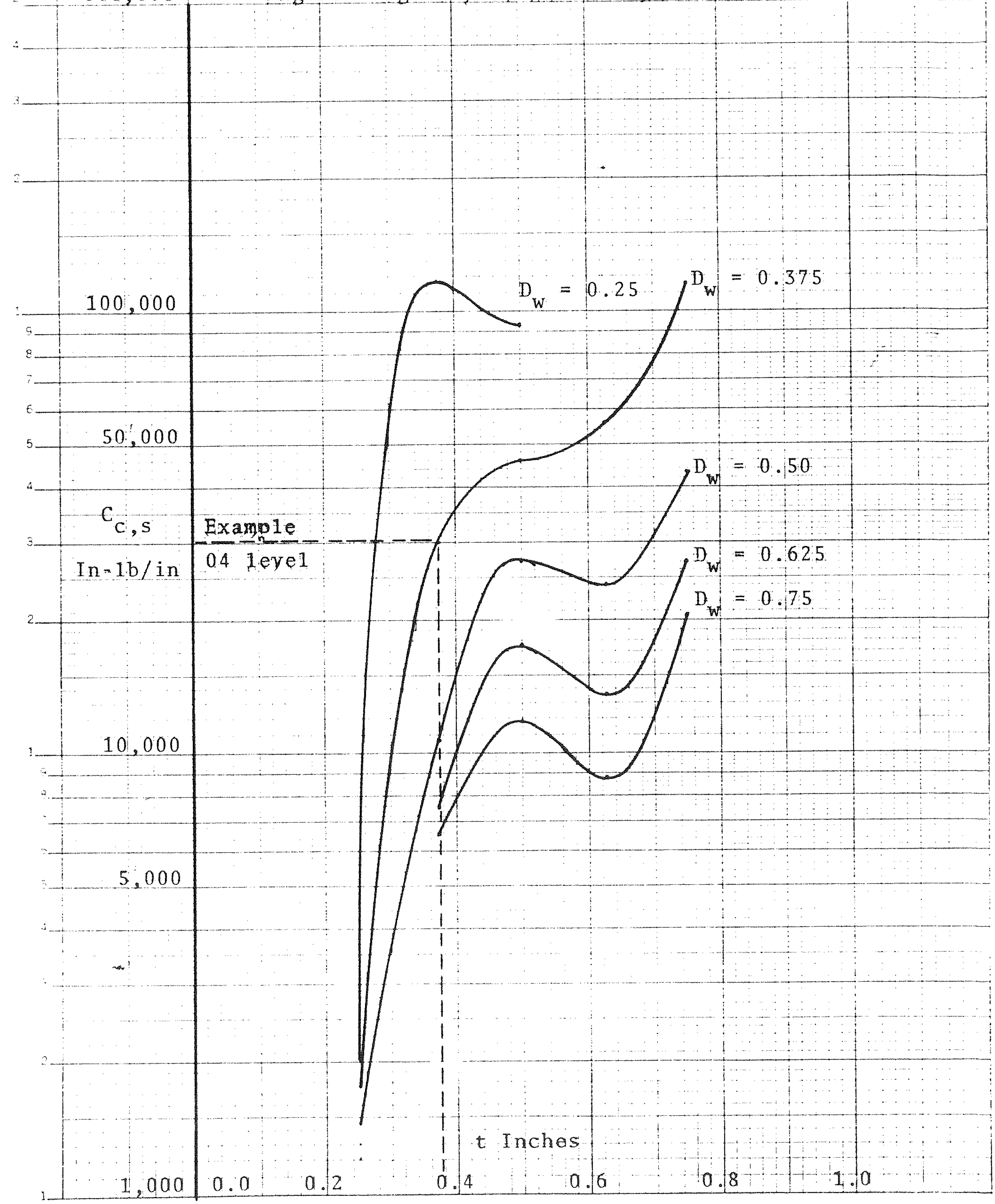


Figure 8
Angular Rigidity Coefficient, Steel
500,000
100,000
50,000
10,000
5,000
1,000
$C_{c,s}$
In-lb/in
Example 01 level
D_w = 0.50
D_w = 0.625
D_w = 0.75
D_w = 0.375
D_w = 0.25
t Inches
0.0
0.2
0.4
0.6
0.8
1.0
Semi-Logarithmic
3 Cycles x 10 to the inch

Figure 9

Angular Rigidity Coefficient, Aluminum



Semi-Logarithmic
3 Cycles x 10 to the inch