V393
.R46

0882

JAN 23 1956

937

MIT LIBRARIES
3 9080 02754 1868

NAVY DEPARTMENT

THE DAVID W. TAYLOR MODEL BASIN

WASHINGTON 7, D.C.

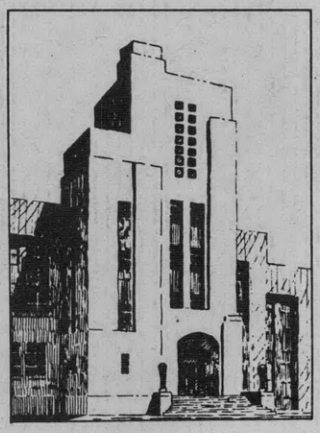
[redacted]

TEMPERATURE-INDUCED STRESSES IN BEAMS AND SHIPS

by

Norman H. Jasper

MASS. INST. OF TECHNOLOGY
JUN 21 1976
BARKER ENGINEERING LIBRARY



June 1955

Report 937

TEMPERATURE-INDUCED STRESSES IN BEAMS AND SHIPS

by

Norman H. Jasper

June 1955

Report 937

TABLE OF CONTENTS

	Page
ABSTRACT	1
I. INTRODUCTION	2
II. STRESS DISTRIBUTION IN A BOX GIRDER DUE TO AN ARBITRARY TWO-DIMENSIONAL CHANGE OF TEMPERATURE GRADIENT	5
A. Homogeneous Beams	7
B. Composite Beams	16
C. Box Beams With Transverse Restraints	17
III. PROCEDURE FOR COMPUTING THE STRESS DISTRIBUTION	18
IV. DISCUSSION	19
ACKNOWLEDGMENTS	20
APPENDIX - MEASUREMENT OF STRESSES INDUCED BY TEMPERATURE VARIATION	22
REFERENCES	24

ABSTRACT

A theoretical method is given for computing temperature-induced stresses in a nonhomogeneous or homogeneous beam or girder of uniform cross section for any temperature distribution over the cross section. It is assumed that all cross sections have the same temperature distribution.

The method is illustrated by application to a simplified model of a ship constructed of steel and aluminum and to a T-2 tanker design.

I. INTRODUCTION

It is a well-known fact that changes in the temperature distribution within a structure, such as a ship, may induce stresses even in the absence of external loads or restraints on the structure. Very few quantitative data are available which would indicate the actual stress and temperature variations that might be expected throughout a ship in service.[1, 2, 3]

Ships have broken in half while moored in still water. Mr. Arthur Gatewood of the American Bureau of Shipping has, in a private communication, called the author's attention to the observation that most, possibly all, major hull fractures in still water took place while the temperature was changing.* This, in itself, is a significant observation. Its significance is accentuated by hull-girder strains measured over a 19-month period on the T-2 tanker ESSO ASHEVILLE. These tests, which were sponsored by the S-10 Panel of the Society of Naval Architects and Marine Engineers, indicated the presence of a slow stress variation with a period of about a day which may be ascribed to the change in temperature distribution that occurs daily. These temperature-induced stress variations reached the same order of magnitude as the stresses due to the cargo loading of the ship; Figure 1 is a sample oscillogram** of temperature-induced stress variations. The appendix discusses the methods utilized to make these measurements. There is sufficient evidence to indicate that an estimate of the temperature-induced hull-girder stresses† is warranted. It would therefore be advantageous to have a reasonably simple method which could be used by the designer to estimate the magnitude and distribution of possible temperature-induced stress variations.

---

[1] References are listed on page 24.

*Examples are the fractures of the SCHENECTADY, BELLE ISLE, and PONAGANSET, all of which were afloat in still water at the time of failure.

**It is not to be inferred that the sample oscillogram is typical of everyday stress variations. Rather it illustrates fairly severe temperature-induced stress.

†Throughout this report we will be concerned with *changes* in stress corresponding to given *changes* in the distribution of temperatures. It will therefore be understood that the reference is to changes in temperature and changes in stress even though the word "change" is not specifically stated.

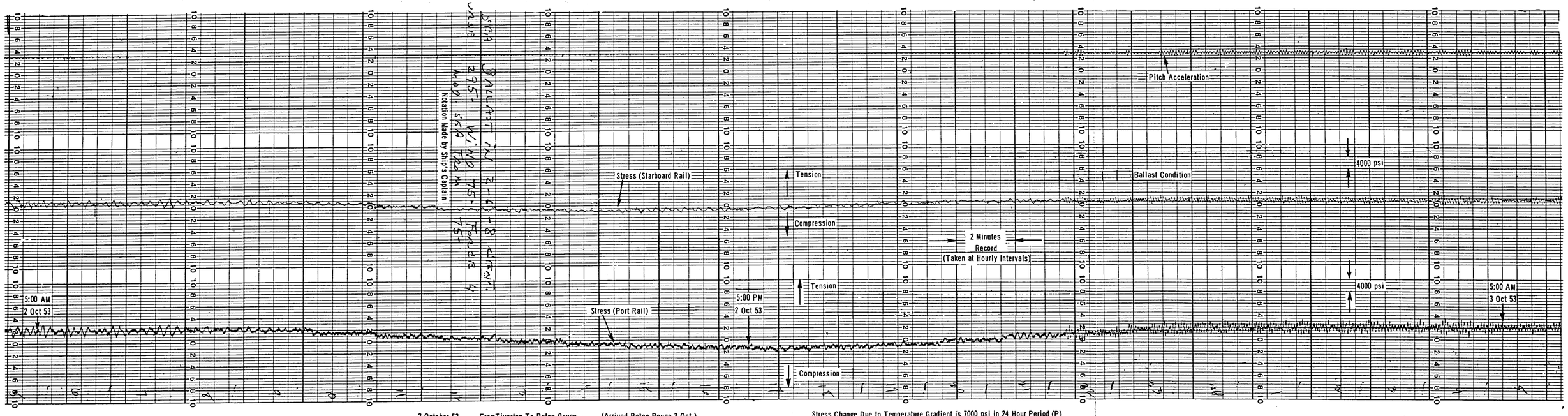
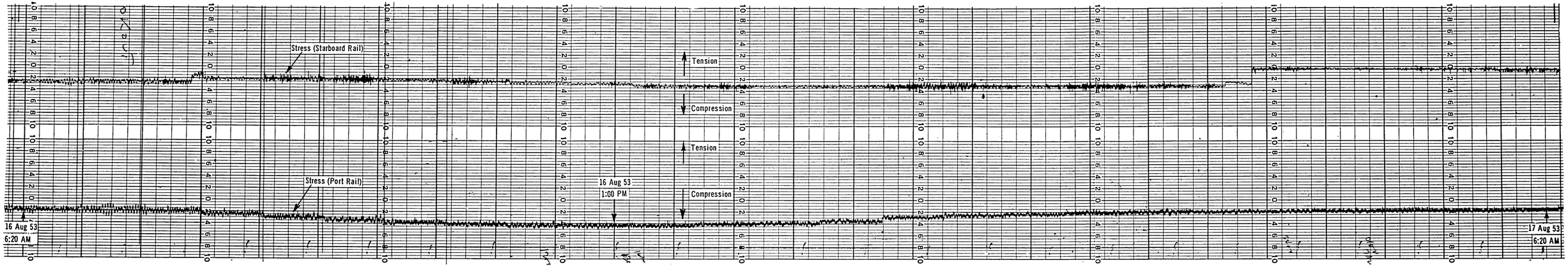


Figure 1 - Sample Oscillograms Showing Diurnal Variations in the Mean Stress Level (Incident to Temperature Changes)

The higher frequency stress variations are those incident to the passage of waves past the ship.

The scale for stress is the same on all records.



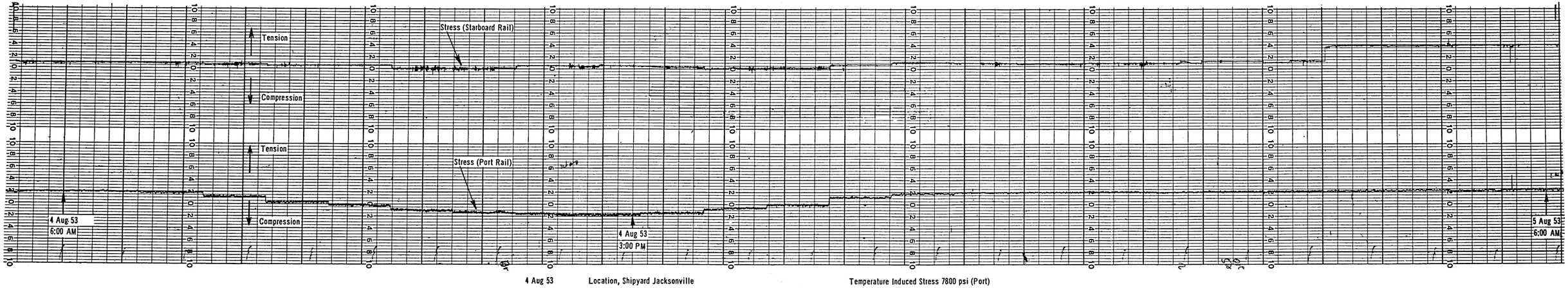
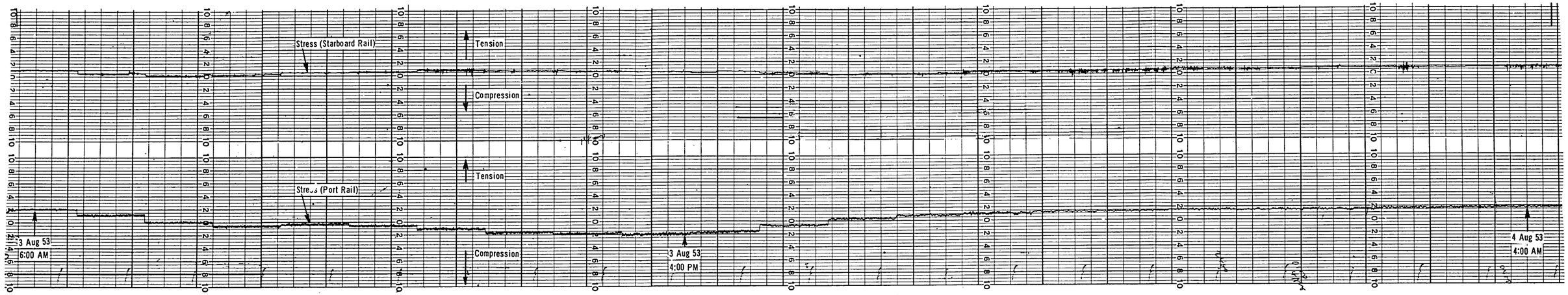


Figure 1 (continued)



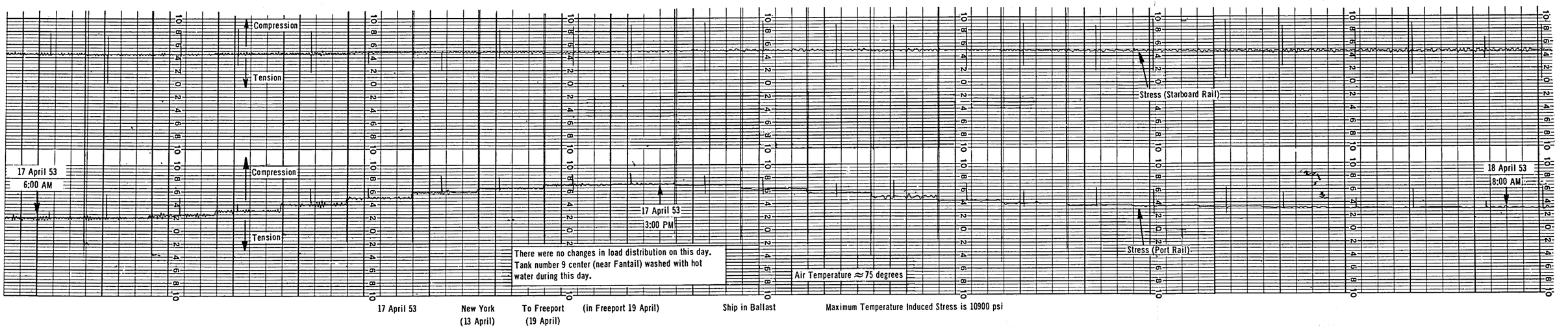


Figure 1 (continued)

It is the purpose of this report to develop and present such a method which may be readily applied to ships constructed of any combination of materials and subjected to any type of temperature distribution in the transverse section of the girder. However, all transverse sections are assumed to have the same variation in temperature distribution.

Corlett[3] developed a method for computing temperature-induced stresses which, for symmetrical temperature distributions, and for box girders without transverse restraint such as are provided by transverse bulkheads, is practically identical with the method developed here. However, the author has been unable to follow the somewhat unusual reasoning employed by Corlett in his development, and furthermore, *Corlett's method is applicable only to cases where the temperature distribution is symmetrical with respect to the midplane of the ship and where there is no transverse restraint.* The basic theory* applied in this report is straight-forward and has been given by Timoshenko.[4]

The use of the theory is illustrated by application to the ship model tests conducted by Corlett, in order to check the validity of the method. Next the theory is applied to a T-2 tanker for both an assumed symmetrical and an unsymmetrical distribution of temperature changes.

II. STRESS DISTRIBUTION IN A BOX GIRDER DUE TO AN ARBITRARY TWO-DIMENSIONAL CHANGE OF TEMPERATURE GRADIENT

Let it be required to determine the stress distribution in a transverse section of an idealized ship girder** due to an arbitrary two-dimensional (in the plane of the transverse section) temperature gradient. The following assumptions will be made: (Refer to Figure 2)

1. The usual elementary theory of the bending of beams is assumed to be applicable. Thus in the initial development it is assumed that there are no restraints which would prevent deformation in the transverse planes and that $\sigma_y = \sigma_z = 0$. Later it will be shown that if such restraints were fully effective in a thin-walled box beam, for example, by providing closely spaced rigid diaphragms, all the stresses throughout the beam will be modified in the same ratio. The actual stress variations in a box beam should lie somewhere between these two extreme assumptions of full and zero transverse restraint.

2. The change in temperature distribution is identical in every transverse cross section of the beam.

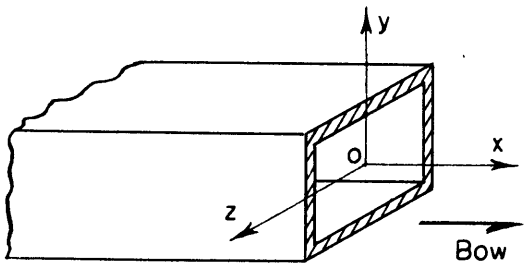
3. There are no external moments or forces acting on the beam.

4. St. Venant's principle applies.

Figure 2 illustrates the beam and gives the assumed directions and the notation. The development here will follow that given by Timoshenko[4] for a thin plate. It follows from the

*Mar and Engel[5] used the same basic theory for solving the similar, but simpler, problem of temperature-induced stresses in a rectangular cantilever box beam subjected to a symmetrical distribution of temperature changes.

**The idealized girder is assumed to have a uniform cross section throughout its length and the connections between the sides of the box are assumed to act as though they were hinged.



x, y, z are the principal centroidal axes of inertia such that
$$\int Eydx = \int Ezdx = \int Eyzdx = 0$$

x is the longitudinal axis

y is oriented in the vertical direction

α is the temperature coefficient of expansion of material

T is the temperature change, $T = f(y, z)$

A is the effective metal area of the cross section (homogeneous beam)

I_{oz} is the area moment of inertia about the axis oz

I_{oy} is the area moment of inertia about the axis oy

E is Young's modulus

e is the unit strain

σ is the normal stress in the x-direction

ν is Poisson's ratio

k is the ratio E/E_ϵ where E_ϵ is an arbitrary constant which is taken as E for steel in the illustrative examples

A_ϵ is the value of the integral $\int k dA$

$(I_{oz})_\epsilon$ is the value of the integral $\int k y^2 dA$

$(I_{oy})_\epsilon$ is the value of the integral $\int k z^2 dA$

σ_y, σ_z is the normal stress in the y and z directions, respectively

Figure 2 - Nomenclature and Schematic Sketch of Beam

The beam may be made up of different materials provided that the strain remains continuous.

assumptions that the stress distribution is the same at every transverse section sufficiently distant from the ends of the beam.

Equilibrium requires that the net moment, the total longitudinal force, and the total transverse shear force be zero in any direction at any transverse section. Since these requirements must be satisfied, the analysis of the problem may be conveniently carried out as follows for any homogeneous* beam. It is initially assumed that the girder acts as if it were made up of separate longitudinal fibers fitted together in the form of the ship girder. These elements are initially allowed to expand freely due to temperature changes. Stress fields are then imposed so as to satisfy the requirements of equilibrium, geometry, continuity, and the boundary conditions. Thus

1. A set of stresses σ_1 is determined which will prevent thermal expansion of all longitudinal fibers of the beam.**

2. A constant stress σ_2 is added which will make the total longitudinal force on the section zero.

---

*A nonhomogeneous beam may be treated as shown in Section B, page 16.

**This stress field will return all particles to the longitudinal position that they occupied before the application of the temperature changes.

3. A set of stresses σ_3 and σ_4, corresponding to pure bending in the xy and the xz planes respectively (the x axis being longitudinal), is added to the stresses σ_1 and σ_2 in such a manner that the net bending moment at the section is zero. This may readily be accomplished by choosing the oy and oz axes to coincide with the principal centroidal axes of inertia.

4. The resultant stress distribution $\sigma = \sigma_1 + \sigma_2 + \sigma_3 + \sigma_4$ is the desired solution inasmuch as it satisfies the requirements of equilibrium, continuity, beam theory, and the boundary conditions, except near the ends of the beam. By St. Venant's principle the solution will be valid at sections distant from the ends of the beam, even though the boundary conditions are not completely satisfied at the ends of the beam.

A. HOMOGENEOUS BEAMS

The four steps just described will now be carried out analytically. Let the origin of coordinates be chosen such that the oy and oz axes coincide with the principal centroidal axes of inertia.

Step 1
$$\sigma_1 = -\alpha E T$$

Step 2
$$\sigma_2 \int dA - \int \alpha E T \, dA = 0$$

Therefore
$$\sigma_2 = \frac{1}{A} \int \alpha E T \, dA$$

Step 3
$$\int (\sigma_1 + \sigma_2 + \sigma_3 + \sigma_4)\, y \, dA = 0$$

This expression is obtained by taking moments about the oz axis. Therefore
$$\sigma_3 = y \left[\frac{-\sigma_2 \int y \, dA - \int \sigma_1 y \, dA - \int \sigma_4 y \, dA}{\int y^2 \, dA} \right]$$

since $\sigma_3 = \frac{\sigma_{(y=c)}}{c} y$. Similarly
$$\sigma_4 = z \left[\frac{-\sigma_2 \int z \, dA - \int \sigma_1 z \, dA - \int \sigma_3 z \, dA}{\int z^2 \, dA} \right]$$

since $\sigma_4 = \frac{\sigma_{(z=c)}}{c} z$.

Since the oy and oz axes are chosen to coincide with the principal centroidal axes of inertia
$$\int z \, dA = \int y \, dA = \int \sigma_4 y \, dA = \int \sigma_3 z \, dA = 0$$
$$\sigma_3 = \frac{y}{I_{oz}} \int \alpha E T \, y \, dA \qquad \sigma_4 = \frac{z}{I_{oy}} \int \alpha E T \, z \, dA$$

Step 4
$$\sigma = \sigma_1 + \sigma_2 + \sigma_3 + \sigma_4$$

Thus

$$\sigma = -\alpha ET + \frac{1}{A}\int \alpha ET\, dA + \frac{y}{I_{oz}}\int \alpha ET\, y\, dA + \frac{z}{I_{oy}}\int \alpha ET\, z\, dA \qquad [1]$$

This general expression for σ gives the stress distribution for any given change in the temperature distribution $T(y, z)$ provided that the assumptions stated at the beginning of this section may be considered applicable and that the beam is made of the same material throughout. If $T(y, z)$ and dA can be approximated by analytic expressions, then the integrals may be evaluated directly. For the more general and realistic cases (for example, unequal temperature gradients on the port and starboard sides of a ship) a numerical procedure will be found convenient; see Table 1. The schedule in Table 1 will enable one to determine the stress distribution in the transverse section.

The stress distribuiton in a T-2 tanker, under assumed conditions of temperature changes which are believed to be realistic, is shown in Figures 4 and 5. The numerical work for computing these stress distributions is given in Tables 2 and 3.

Text continued on page 16.

TABLE 1

Computation of the Stress Distribution for the Steel-Aluminum Ship Model of Figure 3

All units are given in inches and pound system.

Although more than two digits are carried through in the computations, no more than two significant figures are to be inferred.

	1	2	3	4	5	6	7	8	9	10	11	12	Theoretical 13	14	15	Experimental 16
	Item No	Area (ΔA) Actual	$\bar{y}$ of ΔA	$\bar{z}$ of ΔA	T at $\bar{y},\bar{z}$	$\alpha ET = -\sigma_1$ at $\bar{y},\bar{z}$	Col 2×6 $\alpha ET(\Delta A)$	Col 7×Col 3 $\alpha ET(\Delta A)\bar{y}$	Col 7×Col 4 $\alpha ET(\Delta A)\bar{z}$	From Cols 6, 2, 7 $(\sigma_1)+(\sigma_2)$ psi	From Cols 3, 8 (σ_3) psi	From Cols 4, 9 σ_4 psi	From Cols 10, 11, 12 $\sigma = \sigma_1+\sigma_2+\sigma_3+\sigma_4$	$\Sigma f = 0$ $\sigma(\Delta A)$	$\Sigma M = 0$ $\sigma(\Delta A)\bar{y}$	Experimental Stress Value
Aluminum $k = 1/3$	1	0.75	+13.08	–	51.5	+6597	4948	$+64.72\times10^3$	–	−5805	+1678	–	−4127	−3095	-40.5×10^3	−4323
	2	0.75	13.08	–	48.2	6174	4631	60.57	–	−5382	+1678	–	−3704	−2778	−36.3	−4122
	3	0.75	13.08	–	42.0	5391	4035	52.78	–	−4599	+1678	–	−2921	−2191	−28.7	−2957
	4	0.75	13.08	–	33.0	4227	3170	41.47	–	−3435	+1678	–	−1757	−1318	−17.2	−1770
	5	0.75	12.18	–	24.0	3074	2306	28.09	–	−2282	+1563	–	− 719	− 539	− 6.6	− 874
	6	0.75	10.18	–	20.0	2562	1922	19.56	–	−1770	+1306	–	− 464	− 348	− 3.5	− 314
	7	2.95	9.08	–	17.6	2254	6651	60.39	–	−1462	+1165	–	− 297	− 876	− 8.0	− 202
	8	0.61	8.68	–	16.8	2152	1313	11.40	–	−1360	+1113	–	− 247	− 151	− 1.3	− 179
	9	0.38	7.68	–	14.9	1909	725	5.56	–	−1117	+ 985	–	− 132	− 50	− 0.4	− 112
	10	0.69	6.18	–	12.0	1537	1061	6.55	–	− 745	+ 793	–	+ 48	+ 33	+ 0.2	+ 22
Steel $k = 1$	11	0.36	5.18	–	10.3	2086	751	3.89	–	+ 290	+1994	–	+2284	+ 822	+ 4.3	+2621
	12	2.92	4.86	–	4.8	972	2837	13.79	–	+1404	+1871	–	+3275	+9563	+46.5	+2576
	13	0.85	4.41	–	7.5	1519	1291	5.69	–	+ 857	+1697	–	+2554	+2171	+ 9.5	+2554
	14	0.38	3.41	–	5.5	1114	423	1.45	–	+1262	+1313	–	+2575	+ 979	+ 3.3	+2464
	15	0.75	+ 2.01	–	3.5	709	533	+ 1.06	–	+1667	+ 774	–	+2441	+1831	+ 3.7	+2173
	16	0.75	+ 0.01	–	2.0	405	301	0	–	+1971	+ 4	–	+1975	+1481	0	+1837
	17	0.75	− 1.99	–	1.2	243	183	− 0.36	–	+2133	− 766	–	+1367	+1025	− 2.0	+1366
	18	0.75	− 3.99	–	0.8	162	121	− 0.48	–	+2214	−1536	–	+ 678	+ 509	− 2.0	+ 851
	19	0.75	− 5.99	–	0.3	61	46	− 0.28	–	+2315	−2306	–	+ 9	+ 8	0	+ 336
	20	0.75	− 7.99	–	0.3	61	46	− 0.36	–	+2315	−3075	–	− 760	− 570	+ 4.6	− 269
	21	0.75	− 9.99	–	0.3	61	46	− 0.46	–	+2315	−3845	–	−1530	−1148	+11.5	− 986
	22	3.00	−10.89	–	0.3	61	183	− 1.99	–	+2315	−4192	–	−1877	−5631	+61.3	−1254
							37,523 $=\Sigma_7$	373,040 $=\Sigma_8$						−18,695	−146.5	
														+18,422	+144.9	

$E_{\text{Steel}} = 30\times10^6$, $(E\alpha)_{AL} = 128.1$, $(E\alpha)_{ST} = 202.5$, $\frac{E_s}{E_a} = 3$, $A_\epsilon = 15.79$, $(I_{oz})_\epsilon = 969.3$, $\sigma_2 = \frac{37523}{15.79}k = 2376k$ psi, $\sigma_3 = \frac{k\bar{y}\,373040}{969.3} = 384.9\bar{y}k$, $\sigma_4 = 0$,

N. Axis is 10.99″ above B.L.

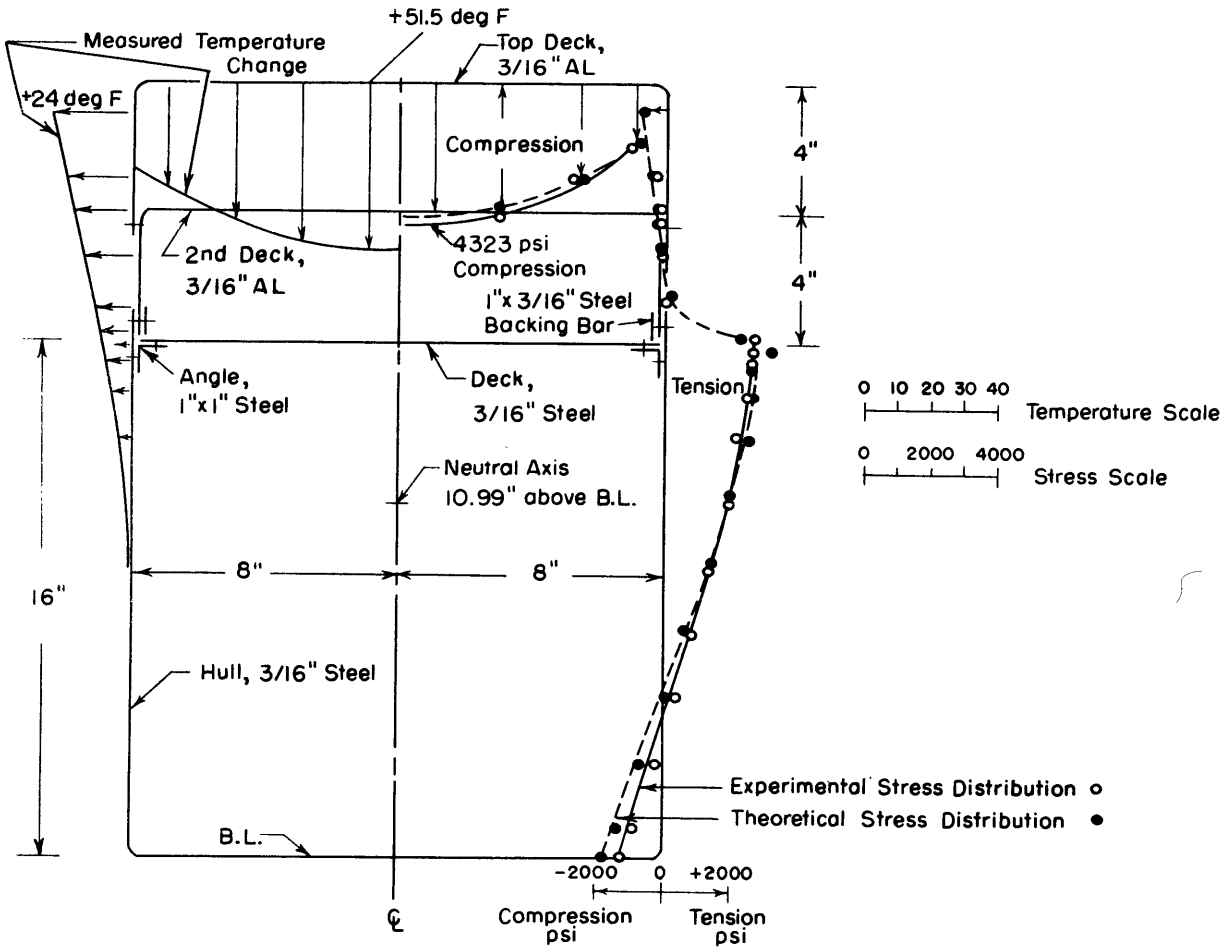


Figure 3 - Comparison of Theoretical and Experimental Stress Distribution for a Ship Model

The experimental data given here are taken from Reference 3.

The model tests were conducted in air.

The distribution of stresses and temperature variations are symmetrical with respect to the centerline of the model.

TABLE 2

Computation of Stress Distribution in a T-2 Tanker

Symmetrical distribution of temperature change. All units are given in inches and pound system. Although more than two digits are carried through in the computations, no more than two significant figures are to be inferred.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Item No	ΔA	$\bar{y}$	$\bar{z}$	T deg F	αET	$\alpha ET \times \Delta A$	$\alpha ET(\Delta A)\bar{y}$	$\alpha ET(\Delta A)\bar{z}$	$\sigma_1+\sigma_2$	σ_3	σ_4	σ	$\sigma(\Delta A)$	$\sigma(\Delta A)\bar{y}$	$\sigma(\Delta A)\bar{z}$
1	89.0	240		70	13230	1.177×10^6	2825×10^5		−8116	6816		−1300			
2	178	238		70	13230	2.355	5605		−8116	6759		−1357			
3	167.6	237		70	13230	2.217	5254		−8116	6731		−1385			
4	187.8	231		70	13230	2.485	5740		−8116	6560		−1556			
5	178.2	225		70	13230	2.358	5305		−8116	6390		−1725			
6	35.2	209		70	13230	0.466	974		−8116	5936		−2180			
7	101.4	199		70	13230	1.342	2671		−8116	5652		−2464			
8	101.4	191		70	13230	1.342	2563		−8116	5424		−2692			
9	93.0	194		35	6620	0.616	1195		−1506	5510		+4004			
10	107.6	88		0	0	0	0		5114	2499		+7613			
11	123.2	− 32		0	0	0	0		5114	− 909		+4205			
12	190.8	−169		0	0	0	0		5114	−4800		+ 314			
13	37.8	218		70	13230	0.500	1090		−8116	6191		−1925			
14	37.8	200		70	13230	0.500	1000		−8116	5680		−2436			
15	60.6	182		70	13230	0.802	1460		−8116	5169		−2947			
16	47.2	155		70	13230	0.624	967		−8116	4402		−3714			
17	57.2	128		49.7	9390	0.537	687		−4276	3635		− 641			
18	62.8	73		2.5	473	0.030	22		4641	2073		+6714			
19	213.6	21		0	0	0	0		5114	596		+5710			
20	225.6	−100		0	0	0	0		5114	−2840		+2274			
21	183.8	−196		0	0	0	0		5114	−5566		− 452			
22	148.2	−235		0	0	0	0		5114	−6674		−1560			
23	237.8	−239		0	0	0	0		5114	−6788		−1674			
24	237.8	−241		0	0	0	0		5114	−6844		−1730			
25	227.2	−243		0	0	0	0		5114	−6901		−1787			
26	62.0	−199		0	0	0	0		5114	−5652		− 538			
	3393 $= A$					$17.35\times10^6 = \sum_7$	$37.36\times10^8 = \sum_8$						−38.07 +39.24	−57.15 +57.10	

$A = \Sigma\Delta A = 3393$ in^2 $\quad \sum_7 = 17.35\times10^6$ $\quad \sum_8 = 37.36\times10^8$ $\quad I_{oz} = 1.314\times10^8$ in^4 $\quad \sigma_1 = \alpha ET$

$\sigma_2 = \frac{1}{A}\sum_7 = 5114$ psi $\quad \sigma_3 = \frac{\bar{y}}{I_{oz}}\sum_8 = 28.40\,\bar{y}$ $\quad \sigma_4 = 0$ $\quad$ Checks: $\Sigma\sigma(\Delta A) \approx 0$ $\quad \alpha E = 189$

$\Sigma(\Delta A)\bar{y} \approx 0$

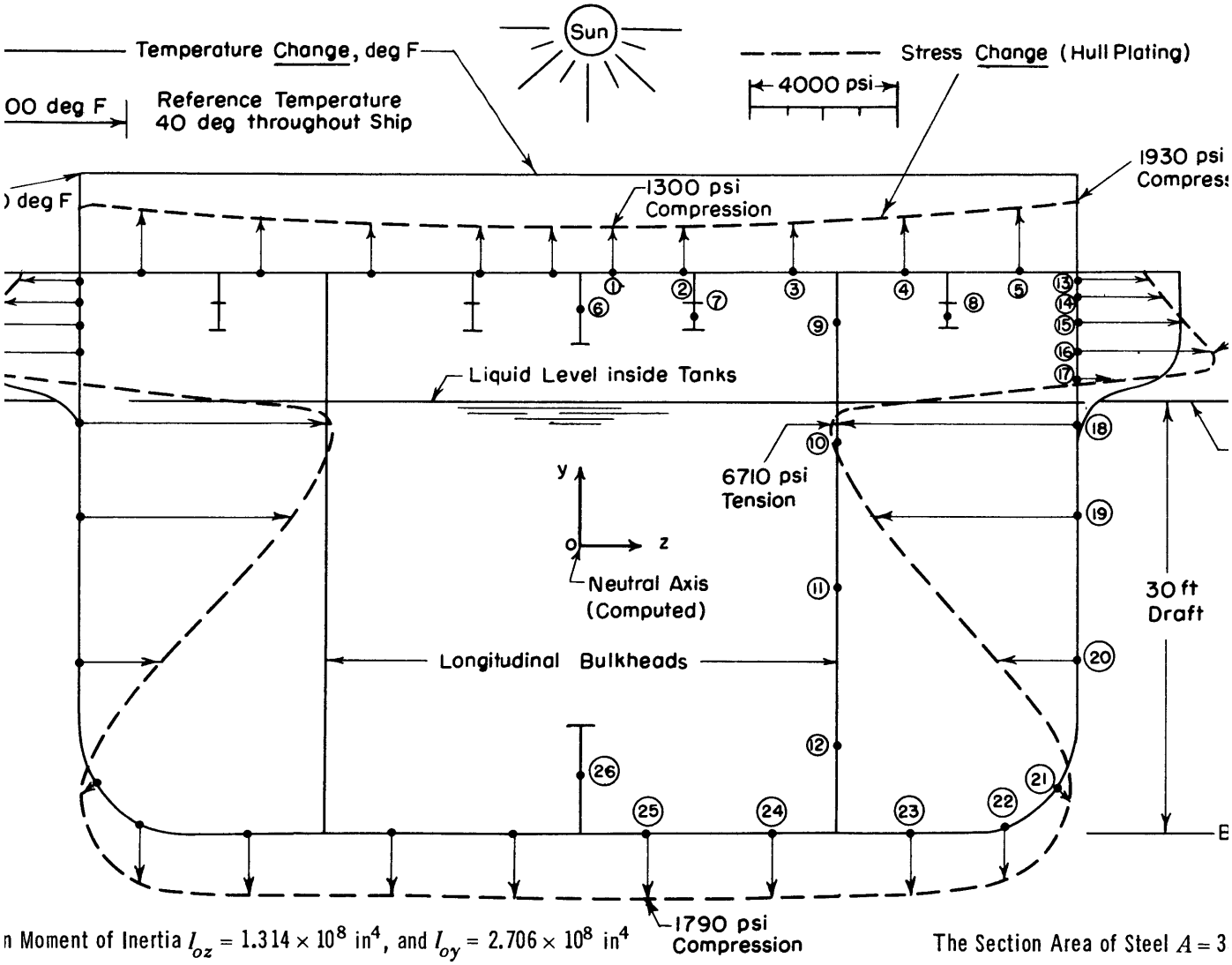


Figure 4 - Theoretical Variation in Longitudinal Hull-Girder Stresses Induced by a Symmetrical Variation in Temperature Distribution

The circled numbers denote the location of the center of gravity of the respective element of the beam.

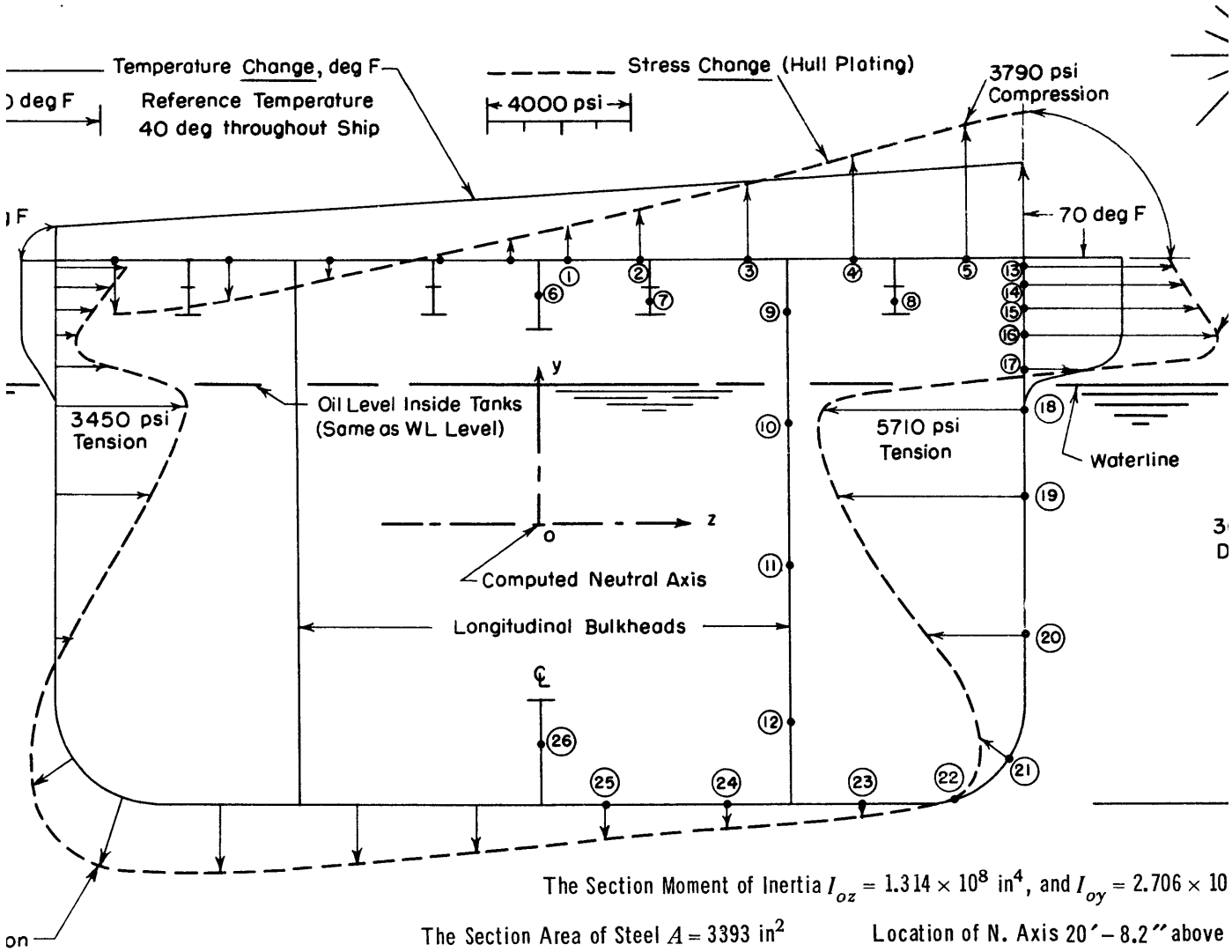


Figure 5 - Theoretical Variation in Longitudinal Hull-Girder Stresses Induced by a Non-Symmetrical Varia in Temperature Distribution

The circled numbers denote the location of the center of gravity of the respective element of the beam.

TABLE 3

Computation of Stress Distribution in a T-2 Tanker

Unsymmetric distribution of temperature changes. All units are given in inches and pound system. Although more than two digits are carried through in the computations, no more than two significant figures are to be inferred.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Item No	Area, in^2 ΔA	$\bar{y}$ in.	$\bar{z}$ in.	T deg F	αET	$\alpha ET \times \Delta A$	$\alpha ET(\Delta A)\bar{y}$	$\alpha ET(\Delta A)\bar{z}$	$\sigma_1 + \sigma_2$ psi	σ_3 psi	σ_4 psi	$\sigma = \sigma_1 + \sigma_2 + \sigma_3 + \sigma_4$ psi	$\Sigma F = 0$ $\sigma(\Delta A)$	$\Sigma M = 0$ $\sigma(\Delta A)\bar{y}$	$\Sigma M = 0$ $\sigma(\Delta A)\bar{z}$
1 Stbd	44.5	240	24	48.9	9240	4.11×10^5	987×10^5	97×10^5	−5743	+4661	+ 76	−1010			
2	89.0	238	93	52.8	9980	8.88	2114	826	−6483	+4622	+ 296	−1570			
3	83.8	237	183	57.8	10920	9.15	2169	1675	−7423	+4603	+ 582	−2240			
4	93.9	231	275	62.8	11870	11.15	2575	3065	−8373	+4486	+ 875	−3010			
5	89.1	225	364	67.8	12810	11.41	2568	4155	−9313	+4370	+1158	−3790			
6	17.6	209	0	42	7940	1.40	292	0	−4443	+4059	0	− 380			
7	50.7	199	120	42	7940	4.03	801	483	−4443	+3865	+ 382	− 200			
8	50.7	191	300	42	7940	4.03	769	1208	−4443	+3709	+ 954	+ 220			
9	46.5	194	211	42	7940	3.69	716	779	−4443	+3767	+ 671	0			
10	53.8	88	212	0	0	0	0	0	+3497	+1709	+ 674	+5880			
11	61.6	− 32	214	0	0	0	0	0	+3497	− 621	+ 681	+3560			
12	95.4	−169	215	0	0	0	0	0	+3497	−3282	+ 684	+ 900			
13	18.9	218	407	70	13230	2.50	545	1018	−9733	+4234	+1294	−4210			
14	18.9	200	407	70	13230	2.50	500	1018	−9133	+3884	+1294	−4560			
15	30.3	182	405	70	13230	4.01	730	1624	−9733	+3534	+1288	−4911			
16	23.6	155	405	70	13230	3.12	484	1624	−9733	+3010	+1288	−5440			
17	28.6	128	405	49.7	9370	2.69		1088	−5893	+2486	+1288	−2120			
18	31.4	73	405	2.5	473	0.15	11	60	+3024	+1418	+1288	+5730			
19	106.8	21	405	0	0	0	0	0	+3497	+ 408	+1288	+5190			
20	112.8	−100	405	0	0	0	0	0	+3497	−1942	+1288	+2840			
21	91.9	−196	396	0	0	0	0	0	+3497	−3806	+1259	+ 950			
22	74.1	−235	348	0	0	0	0	0	+3497	−4564	+1107	+ 40			
23	118.9	−239	265	0	0	0	0	0	+3497	−4641	+ 843	− 300			
24	118.9	−241	154	0	0	0	0	0	+3497	−4680	+ 490	− 690			
25	113.6	−243	54	0	0	0	0	0	+3497	−4719	+ 172	−1050			
26 Stbd	31.0	−199	0	0	0	0	0	0	+3497	−3865	0	− 370			

1 Port	44.5	+240	− 24	46.2	8730	3.89	932	− 93	−5233	+4661	− 76	− 650			
2	89.0	238	− 93	42.4	8010	7.13	1697	− 663	−4513	+4622	− 296	− 190			
3	83.8	237	−183	37.4	7070	5.93	1404	−1084	−3573	+4603	− 582	+ 450			
4	93.9	231	−275	32.4	6120	5.75	1328	−1580	−2623	+4486	− 875	+ 900			
5	89.1	225	−364	27.4	5180	4.62	1038	−1680	−1683	+4370	−1158	+1600			
6	17.6	209	0	42	7940	1.40	292	0	−4443	+4059	0	− 384			
7	50.7	199	−120	42	7940	4.03	801	− 483	−4443	+3865	− 382	− 960			
8	50.7	191	−300	42	7940	4.03	769	−1208	−4443	+3709	− 954	−1690			
9	46.5	194	−211	42	7940	3.69	716	− 779	−4443	+3767	− 671	−1350			
10	53.8	88	−212	0	0	0	0	0	+3497	+1709	− 674	+4530			
11	61.6	− 32	−214	0	0	0	0	0	+3497	− 621	− 681	+2200			
12	95.4	−169	−215	0	0	0	0	0	+3497	−3282	− 684	− 470			
13	18.9	218	−407	25	4730	0.89	195	− 364	−1233	+4234	−1294	+1710			
14	18.9	200	−407	25	4730	0.89	179	− 364	−1233	+3884	−1294	+1360			
15	30.3	182	−405	25	4730	1.43	261	− 580	−1233	+3534	−1288	+1010			
16	23.6	155	−405	25	4730	1.12	173	− 452	−1233	+3010	−1288	+ 490			
17	28.6	128	−405	18.1	3420	0.98	125	− 396	+ 77	+2486	−1288	+1280			
18	31.4	73	−405	1.3	246	0.08	6	− 31.3	+3251	+1418	−1288	+3380			
19	106.8	21	−405	0	0	0	0	0	+3497	+ 408	−1288	+2620			
20	112.8	−100	−405	0	0	0	0	0	+3497	−1942	−1288	+ 270			
21	91.9	−196	−396	0	0	0	0	0	+3497	−3806	−1259	−1570			
22	74.1	−235	−348	0	0	0	0	0	+3497	−4564	−1107	−2170			
23	118.9	−239	−265	0	0	0	0	0	+3497	−4641	− 843	−1990			
24	118.9	−241	−154	0	0	0	0	0	+3497	−4680	− 490	−1670			
25	113.6	−243	− 54	0	0	0	0	0	+3497	−4719	− 172	−1390			
26 Port	31.0	−199	0	0	0	0	0	0	+3497	−3865	0	− 370			
	$A=\Sigma\Delta A$ $=3393$ in^2					$\Sigma_7=118.65$ $\times 10^5$	$\Sigma_8=25521$ $\times 10^5$	$\Sigma_9=8605$ $\times 10^5$					−29.66	−45.92	−85.0
													+29.77	+44.57	+87.3

$I_{oy} = 2.706 \times 10^8$ $\quad \sigma_1 = -\alpha E T$ $\quad \sigma_2 = \frac{1}{A}\Sigma_7 = \frac{118.65 \times 10^5}{3393} = +3497$ $\quad$ Checks: $\Sigma \sigma \Delta A = 0$

$I_{oz} = 1.314 \times 10^8$ $\quad$ $\Sigma \sigma \Delta A \bar{y} = 0$

$\alpha E = 189$ $\quad \sigma_3 = \frac{y}{I_{oz}}\Sigma_8 = 19.42\,\bar{y}$ $\quad \sigma_4 = \frac{z}{I_{oy}}\Sigma_9 = 3.180\,\bar{z}$ $\quad$ $\Sigma \sigma \Delta A \bar{z} = 0$

B. COMPOSITE BEAMS

For beams constructed of more than one material the preceding development must be modified* since both α and E may vary over the cross section. The same step-by-step procedure applied to the homogeneous beam is followed.

Step 1 $$\sigma_1 = -\alpha E T$$

Step 2 Now σ_2 must vary in proportion to E in order to make the strain the same in all fibers. Hence

$$\int \sigma_2 \, dA - \int \alpha E T \, dA = 0$$

and

$$\sigma_2 = E \frac{\int \alpha E T \, dA}{\int E \, dA}$$

Step 3 In pure bending $\int \sigma_x dA = 0$. Also we locate the axes so that bending in yx and zx planes is uncoupled, and thus the strain is proportional to y or z respectively. Then

$$\int E y \, dA = \int E z \, dA = \int E y z \, dA = 0$$

This requirement may be thought of as the determination of the principal centroidal axis of an area comprised of area elements (EdA) which have the coordinates y, z of dA. Also

$$\sigma_3 = k_1 E y, \; \sigma_4 = k_2 E z$$

where k_1 and k_2 are constants.

$$\int (\sigma_1 + \sigma_2 + \sigma_3 + \sigma_4) \, y \, dA = 0$$

Therefore

$$-\int \alpha E T \, y \, dA + k_1 \int E y^2 \, dA = 0, \; -\int \alpha E T \, z \, dA + k_2 \int E z^2 dA = 0$$

$$\sigma_3 = \frac{E y}{\int E y^2 \, dA} \int \alpha E T \, y \, dA, \; \sigma_4 = \frac{E z}{\int E z^2 \, dA} \int \alpha E T \, z \, dA$$

Step 4 $$\sigma = \sigma_1 + \sigma_2 + \sigma_3 + \sigma_4$$

$$\sigma = -\alpha E T + E \frac{\int \alpha E T \, dA}{\int E \, dA} + \frac{E y}{\int E y^2 \, dA} \int \alpha E T \, y \, dA + \frac{E z}{\int E z^2 \, dA} \int \alpha E T \, z \, dA \qquad [2]$$

---

*At first this development was carried out by the use of the concept of an equivalent homogeneous beam. Both the original and present approaches give the same stress distribution.

This may also be written as

$$\sigma = -\alpha ET + \frac{k}{A_\epsilon}\int \alpha ET\, dA + \frac{ky}{(I_{oz})_\epsilon}\int \alpha ET\, y\, dA + \frac{kz}{(I_{oy})_\epsilon}\int \alpha ET\, z\, dA$$

where $k = \left(\frac{E}{E_\epsilon}\right)$, $A_\epsilon = \int \frac{E}{E_\epsilon}\, dA$, $(I_{oz})_\epsilon = \int \frac{E}{E_\epsilon}\, y^2\, dA$, $(I_{oy})_\epsilon = \int \frac{E}{E_\epsilon}\, z^2\, dA$, and E_ϵ is an arbitrary constant and is in our examples taken as E_{steel}.

This expression for σ gives the stress distribution for any given change T in temperature distribution in a nonhomogeneous beam. Equation [2] reduces to Equation [1] when the same value of E applies throughout the beam.

The stress distribution in a composite model box girder has been computed by this method utilizing the same tabular form, Table 1, as used for the homogeneous beam.

The computed stress distribution checks quite well with the experimentally determined stress distribution. The experimental model test data were taken from Reference 3.

C. BOX BEAMS WITH TRANSVERSE RESTRAINTS

Up to this point it has been assumed that the beam (box beam) is free of transverse restraint. The ship girder, however, does contain transverse constraints in the form of transverse bulkheads which do, to some extent at least, prevent the free transverse expansion of the sections when a temperature change is imposed. It might be of interest, therefore, to examine the effect on the stress distribution if this transverse constraint were complete. Actually, of course, the complete constraint is not attained. The following assumptions, in addition to those utilized thus far, will be made:

1. The walls of the box beam are thin so that there are no stresses normal to the thickness of the wall.

2.* The cross-sectional shape and dimensions are preserved by closely spaced, imaginary diaphragms which are rigid in the plane of the diaphragm and free to warp out of their plane.

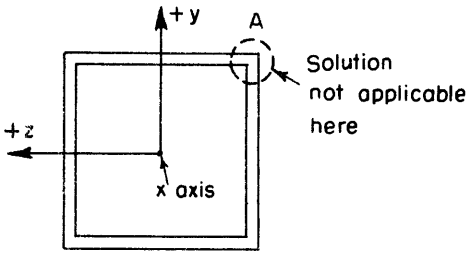
3.* The diaphragms are insulated from the box beam and the temperature of the diaphragms remains constant while the walls of the beam are subjected to temperature changes.

Let us now determine the stresses σ_1 which, as before, are required to prevent the thermal expansion of all longitudinal fibers of the beam, i.e., $\epsilon_x = 0$.

---

*This type of imaginary constraint has been used by other authors. Other types of constraints could be thought of which would serve the same purpose and give the same result.

The stress, strain, temperature relationships, are as follows:[4]



$$e_x = \frac{1}{E}[\sigma_x - \nu(\sigma_y + \sigma_z)] + \alpha T, \text{ here } e_x = 0$$

$$e_y = \frac{1}{E}[\sigma_y - \nu(\sigma_x + \sigma_z)] + \alpha T \qquad [3]$$

$$e_z = \frac{1}{E}[\sigma_z - \nu(\sigma_x + \sigma_y)] + \alpha T$$

The nomenclature is given in Figure 2. *For horizontal surfaces** (parallel to the xz plane, such as the top deck) $e_z = 0$ by Assumption 2. From Equations [3] equating e_x to e_z it is found that

$$\sigma_x = \sigma_z$$

Utilizing this result and Assumption 1 (that $\sigma_y = 0$) the first of Expressions [3] gives

$$\sigma_x = \sigma_z = -\alpha ET/(1 - \nu)$$

Similar reasoning shows that the desired normal stresses σ_1 in the axial direction and the peripheral normal stresses σ_s parallel to the yz plane are given by the expression derived above:

$$\sigma_1 = \sigma_x = \sigma_s = -\alpha ET/(1 - \nu)$$

We may therefore substitute this value of σ_1, which includes full effective lateral restraint, in place of the value $\sigma_1 = -\alpha ET$ previously used, which assumed no lateral restraint whatever. None of the remainder of the development of the theory given in the preceding sections is affected by the addition of the restraint. The net result is that the magnitudes of the stresses computed under the assumption of no restraint are multiplied by the factor $1/(1 - \nu)$ when full transverse restraint is assumed.

It is therefore evident that the stress changes induced by temperature changes are greater when transverse restraint is acting than would otherwise be the case. If, for example, Poisson's ratio $\nu = 1/3$, then the stress variations will be increased by 50 percent. The actual stresses in a box beam would be expected to lie somewhere between those obtained for the assumption of zero restraint and full transverse restraint.

III. PROCEDURE FOR COMPUTING THE STRESS DISTRIBUTION

It is convenient to arrange the necessary data and numerical work in tabular form as in Table 1.

A plan of the ship's midship section should be obtained. On this plan plot the distribution of temperature changes for which the changes in stress are to be computed. Next divide

*Note that this solution is not applicable at the corners of the box.

the cross section of the beam into a convenient number of area elements ΔA. In regions of large changes in temperature gradients, for example near the waterline, a finer subdivision should be made than elsewhere in order to define the stress distribution better.

The area of each element ΔA, its position from the principal centroidal axes, and the average temperature change T of the element are entered in Columns 2, 3, 4, and 5 of Table 1. Columns 6, 7, 8, and 9 are filled in next; the summation of these columns will give the values of the integrals which appear in Equations [1] and [2]. Columns 9 through 13 are then filled in. Column 13 gives the required stress distribution* as defined by Equations [1] or [2]. Columns 14 and 15 provide a check on the accuracy of the computation. The summation of Column 14 gives the net change in longitudinal force at the section, incident to the temperature changes which should equal zero; similarly the summation of Column 15, representing the resulting change in bending moment or couple at the section, should also equal zero. Due to the approximations and inaccuracies of numerical calculations one can only hope to approximate the requirements of zero moment and force.

IV. DISCUSSION

Application of the theory to a test of a model ship indicates fairly good agreement between computed and measured stresses. No full-scale data on the distribution of temperature variations and corresponding stress variations are available to the author for checking the applicability of this method to full-scale ships. It would seem reasonable to assume however, that this theory (which assumes that the variation in temperature distribution is the same in every transverse section) would be valid to the same degree that ordinary beam theory is applicable.

The computations given here for a T-2 oil tanker indicate that rather severe stress gradients may occur in the side shell plating due to temperature changes. It is furthermore evident that the temperature-induced stresses may be appreciably larger in the side plating (near the waterline) than in the deck plating. The assumed conditions for the T-2 tanker calculations, as well as for the model experiment, involved heating of the upper deck which induced mostly compressive stresses in the deck. It could equally well have been that the temperature of the air, and consequently of the exposed portion of the ship, had fallen below the water temperature, as in freezing weather. Inspection of Equation [2] will show that in this case the stress distribution would be identical except that compressive stresses would now be tensile stresses and vice versa, assuming the magnitudes of the temperature changes were identical.

Acker[2] has stated that "when high diurnal thermal stresses develop (stress changes) they are usually compressive and should cause no serious trouble." This statement would not appear to be justified if one considers the stresses which would be induced by low air

*If transverse restraint exists, the stress variations will be larger as discussed in Section IIc.

temperatures and relatively high water temperatures, such as would be expected during sudden freezing. Even under the more usual conditions in which the deck is heated, there will be, according to the theory, relatively large tensile stresses induced in the shell plating near the waterline provided the ship has an appreciable draft; see Figures 4 and 5. One interesting observation is that stresses of the same sign may be induced in both the deck and the bottom of the ship by the type of temperature changes expected in service; see Figure 4. Thus a cooling of the above water portion of the hull would induce tensile stresses in both the deck and the bottom structure. This could be significant from the standpoint of brittle fractures.

The temperature-induced stresses computed for the T-2 tanker by means of the theory (neglecting transverse restraints, if any) appear to be low when compared with the measured stress variations on such a vessel (Figure 1) where a variation of 7000 psi on the main deck is indicated. Presumably one could have measured even greater stresses in the side plating. It may be that the temperature changes assumed for the longitudinal deck beams were too low, that transverse bulkheads provided appreciable transverse restraints or that there existed an appreciable nonuniformity in the longitudinal temperature distribution. The only convincing way of checking the validity of the theory, as applied to ships, is to obtain simultaneous measurements of temperature and stress variations on one or more typical ships. It is *strongly recommended* that such full-scale tests be made. It is also suggested that model tests of box girders, with and without transverse restraint, with and without changes in temperature gradients in the longitudinal direction may be worthwhile in evaluating the theory.

Meanwhile it appears reasonable to assume that the temperature-induced stresses need to be considered in the strength design of the hull girder.

ACKNOWLEDGMENTS

The author's interest in this problem was aroused as a consequence of occasionally fairly large diurnal stress variations which were measured on the ESSO ASHEVILLE in connection with a program of determining service stresses in full-scale hull structures which is being carried out under the guidance of the S-10 panel of the SNAME. The possible importance of such temperature-induced stresses in connection with hull fractures was impressed on the author by Mr. Arthur R. Gatewood of the American Bureau of Shipping. This work is part of a broad study of the strength requirements of ships being carried out at the David Taylor Model Basin under the cognizance of the Bureau of Ships, Code 440. The encouragement received from Captain E.A. Wright, formerly at the Bureau of Ships, and Mr. J. Vasta of the Bureau of Ships has made this study possible.

The theoretical development has been checked by Mr. J.E. Greenspon and the numerical calculations were made by Mr. R.R. Milam, both of the Taylor Model Basin staff. Special thanks are due the Esso Company for making a tanker available for the use of the S-10 panel; without the background of these full-scale tests this particular study would probably have not been undertaken at this time. The constructive comments of the members of the S-10 panel and of Mr. Gatewood and Mr. H.G. Acker on a preprint of this report were greatly appreciated. This report was critically reviewed by Mr. R.T. McGoldrick and Dr. E.H. Kennard of the Taylor Model Basin staff. Dr. Kennard made helpful suggestions which simplified the treatment of the nonhomogeneous beam. Thanks are due the Institution of Naval Architects for permission to use Figure 16 of Reference 4, which made it possible to have one experimental check of the theory.

APPENDIX

MEASUREMENT OF STRESSES INDUCED BY TEMPERATURE VARIATION

The question frequently arises as to how one can measure the actual stress variation in a structure including those stress variations which are a consequence of a variation in temperature distribution throughout the structure. Inasmuch as the stresses induced by changes in temperature arise due to restraints which prevent the free expansion of the material, it is sometimes stated that the temperature-induced stresses are "strainless" stresses.

The relationship between stresses, strains, and temperature changes, as given in article 65 of Reference 4, have been given by Equation [3]. These relationships specify the actual strains corresponding to any actual change in stress and the corresponding change in temperature. It is immaterial whether the stresses are due to temperature changes alone, or to external loading, or to a combination of both—these relationships are valid in either case.

For the stresses in the plating of a ship girder it may be assumed that the stress σ_z normal to the thickness of the plating is zero.

Utilizing the expressions for e_x and e_z, Equations [3], the stress σ_z may be eliminated between them, and the following expression for σ_x results:

$$\sigma_x = \frac{E}{1 - \nu^2} [e_x + \nu e_z - (1 + \nu)\, \alpha T] \qquad [4]$$

where σ_x is the change in normal stress in the longitudinal direction,

e_x, e_z are the total changes in strains in longitudinal and transverse directions, respectively,

ν is Poisson's ratio,

α is the temperature coefficient of expansion, and

T is the change in temperature at the point of measurement.

If there are no variations in external loads, then the stress σ_x and the strains e_x, e_z will be due only to the changes in temperature throughout the structure, including the temperature change T at the point x, y, z at which σ_x and e_x, e_z are determined.

To determine σ_x it is then only necessary to measure the quantities e_x, e_z, and T, assuming that E, ν, and α are known constants, and substitute these values in Equation [4].

Another, more convenient method is to arrange an electrical circuit which performs the operation indicated by the right-hand side of Equation [4], thus yielding a signal which is proportional to the actual stress variation in the structure. This is the procedure which was adopted for the stress measurements on the T-2 tanker ESSO ASHEVILLE. The circuitry is shown in Figure 6, and its operation is as follows. R_1, R_2, R_3, and R_4 are 60-ohm SR4 strain gages mounted on the deck structure. B_1 and B_2 are 120-ohm SR4 strain gages mounted on steel bars which are free to expand and which are at the same temperature as is the deck. Bars B are physically located next to resistors R_1, R_2, R_3, and R_4. These gages are all

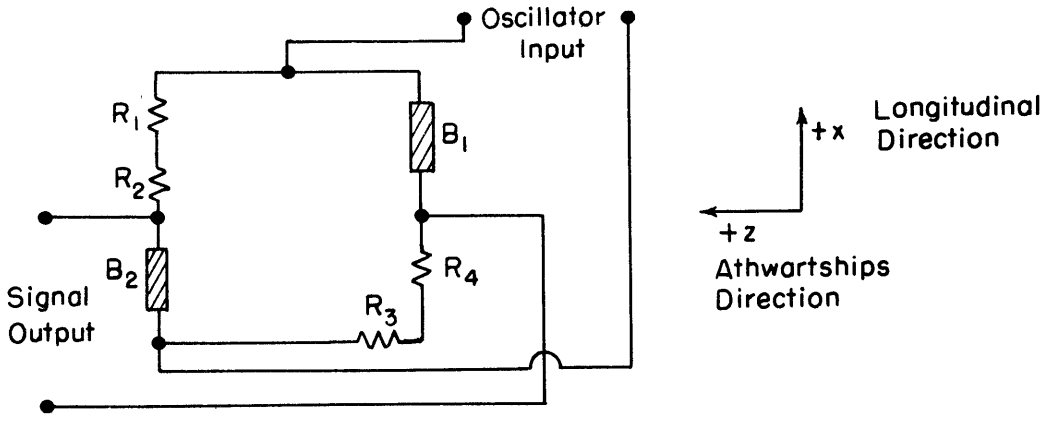


Figure 6 - Circuit for Measuring σ_x

situated close together at the location at which the stress is measured.

The resistance change of an SR4 strain gage is proportional to the strain of the metal to which it is attached and also proportional to the resistance of the gage.

Consider Equation [4] term by term and consider the component of the circuit which provides an electrical output proportional to that term.

1. A signal proportional to $+e_x$ is provided by 180 ohms of strain gage wire ($R_1 + R_2 + R_4$) physically oriented in the longitudinal x direction. Elementary electrical theory shows that the voltage changes across R_1, R_2, and R_4 are additive at the output terminals.

2. A signal proportional to $+\nu e_z$ is provided by ν times 180 ohms of strain gage wire (R_3) physically oriented in the athwartships z direction. Taking $\nu = 1/3$, it is evident that $1/3 \times 180 = 60$ ohms are required for R_3. The signal output of gage R_3 is electrically additive to that of gages R_1, R_2, and R_4.

3. A signal proportional to $-(1 + \nu)\,\alpha T = -4/3\,\alpha T$ is provided by $4/3 \times 180 = 240$ ohms of strain gage wiring attached to steel bars which are free to elongate an amount αT per unit of length where αT is the temperature induced "stress-less" strain. The electrical output of gages B_1 and B_2 is electrically subtracted from the output of R_1, R_2, R_3, and R_4.

It should be noted that any change of resistance of the strain gage wire itself, as a consequence of temperature changes, is automatically compensated by having the same amount of strain gage wire, 120 ohms in this case, in each arm of the bridge.

It has been shown, therefore, that the electrical output of the strain gage bridge is proportional to the stress σ_x at the surface of the structure (i.e., at the location of the gage).

REFERENCES

1. Osgood, W.R., "Residual Stresses in Metals and Metal Construction," Reinhold Publishing Company, New York (1954).

2. Acker, H.G., "Highlights of Welded Ship Research," Transactions Society of Naval Architects and Marine Engineers (1949), Vol 57.

3. Corlett, M.A., "Thermal Expansion in Composite Ships," Transactions Institute of Naval Architects (1950), Vol 92.

4. Timoshenko, S., "Theory of Elasticity," McGraw-Hill Book Company, Inc., New York (1934).

5. Mar, J.W., and Engel, S.J., "Experimental and Analytical Determination of the Transient Thermal Stresses in a One Cell Box Beam," Aeroelastic and Structures Research Laboratory, Massachusetts Institute of Technology Technical Report 25-13 (May 1954).

6. Melan, E., and Parkus, H., "Wärmespannungen infolge stationärer Temperaturfelder," Springer Verlag, Wien (1953). This book has an excellent bibliography on the subject of thermal stresses.

INITIAL DISTRIBUTION

Copies	
14	Chief, BuShips, Library (Code 312) 5 Tech Library 1 Chief of Bureau (Code 100) 1 Tech Asst to Chief (Code 106) 1 Applied Science (Code 370) 1 Prelim Des & Ship Protec (Code 420) 2 Hull Design (Code 440) 3 Sci-Struc & Hydro (Code 442)
1	Chief of Naval Research, Attn: Mr. Crowley (Code 438)
1	CAPT E.A. Wright, Asst Fleet Maintenance Officer, Cdr, Service Force Pacific, San Francisco, Calif.
2	CDR, Military Sea Transportation Service, Washington, D.C.
3	DIR, NACA, Washington, D.C.
1	DIR, Langley Aero Lab, Langley Field, Va.
2	COMDT, USCG Hdqtrs, Washington, D.C.
2	Administrator, U.S. Maritime Administration, Washington, D.C.
15	Sec, Ship Struc Comm, USCG Hdqtrs, Washington, D.C.
1	Engin Soc Library, New York, N.Y.
10	Sec, ASNAME, New York, N.Y.
1	Sec, Inst Nav Arch, London, England
1	Mr. F.C. Bailey, Asst Tech Dir, Comm on Ship Struc Des, Natl Acad of Sci, Washington, D.C.
1	Mr. J. Comstock, Asst Nav Arch, Newport News Shipbldg & Dry Dock Co, Newport News, Va.
1	Prof. R. Hechtman, Engin School, Univ of Washington, Seattle, Wash.
1	Dr. K.E. Davidson, DIR, ETT, SIT, Hoboken, N.J.
1	Prof. J. Ormondroyd, Dept of Engin Mech, Univ of Michigan, Ann Arbor, Mich.
1	Prof. M.M. Munk, Dept of Aero Engin, Catholic Univ, Washington, D.C.

Copies	
1	Dr. Hans Bleich, Sch of Engin, Columbia Univ, New York, N.Y.
1	Mr. A. Gatewood, Chief Engr, Amer Bureau of Shipping, New York, N.Y.
1	Mr. J.B. Letherbury, Asst to Nav Arch, N.Y. Shipbldg Co, Camden, N.J.
1	Mr. C. Ridgely Nevitt, Webb Inst of Nav Arch, Glen Cove, N.Y.
1	Mr. E.V. Lewis, ETT, SIT, Hoboken, N.J.
1	Mr. R. Krack, Washington, D.C.
1	Mr. J.H. McDonald, Nav Arch, Bethlehem Steel Co, Shipbldg Div, Quincy, Mass.
1	Mr. H.G. Acker, Bethlehem Steel Co, Shipbldg Div, Quincy, Mass.
1	Mr. E.L. Steward, Mgr, Construc & Repair Div, Marine Dept, Standard Oil Co, New York, N.Y.
1	Mr. F.L. Pavlik, Hull Tech Asst, Sun Shipbldg & Drydock Co, Chester, Pa.
1	Mr. Samuel Levy, Natl BuStand, Washington, D.C.
1	DIR, BSRA

NAVY-DPPO PRNC WASH D C

David W. Taylor Model Basin. Rept. 937.
TEMPERATURE-INDUCED STRESSES IN BEAMS AND SHIPS, by Norman H. Jasper. June 1955. ii, 25 p. incl. figs., tables, refs. UNCLASSIFIED

A theoretical method is given for computing temperature-induced stresses in a nonhomogeneous or homogeneous beam or girder of uniform cross section for any temperature distribution over the cross section. It is assumed that all cross sections have the same temperature distribution.

The method is illustrated by application to a simplified model of a ship constructed of steel and aluminum and to a T-2 tanker design.

1. Thermal stresses - Mathematical analysis
2. Girders (Marine) - Stresses - Temperature factors
3. Ships - Stresses - Measurement
4. Ship hulls - Fracture
5. Ship hulls - Stresses - Temperature factors
6. Ship plates (Stiffened) - Stress - Temperature factors

I. Jasper, Norman H.

David W. Taylor Model Basin. Rept. 937.
TEMPERATURE-INDUCED STRESSES IN BEAMS AND SHIPS, by Norman H. Jasper. June 1955. ii, 25 p. incl. figs., tables, refs. UNCLASSIFIED

A theoretical method is given for computing temperature-induced stresses in a nonhomogeneous or homogeneous beam or girder of uniform cross section for any temperature distribution over the cross section. It is assumed that all cross sections have the same temperature distribution.

The method is illustrated by application to a simplified model of a ship constructed of steel and aluminum and to a T-2 tanker design.

1. Thermal stresses - Mathematical analysis
2. Girders (Marine) - Stresses - Temperature factors
3. Ships - Stresses - Measurement
4. Ship hulls - Fracture
5. Ship hulls - Stresses - Temperature factors
6. Ship plates (Stiffened) - Stress - Temperature factors

I. Jasper, Norman H.

David W. Taylor Model Basin. Rept. 937.
TEMPERATURE-INDUCED STRESSES IN BEAMS AND SHIPS, by Norman H. Jasper. June 1955. ii, 25 p. incl. figs., tables, refs. UNCLASSIFIED

A theoretical method is given for computing temperature-induced stresses in a nonhomogeneous or homogeneous beam or girder of uniform cross section for any temperature distribution over the cross section. It is assumed that all cross sections have the same temperature distribution.

The method is illustrated by application to a simplified model of a ship constructed of steel and aluminum and to a T-2 tanker design.

1. Thermal stresses - Mathematical analysis
2. Girders (Marine) - Stresses - Temperature factors
3. Ships - Stresses - Measurement
4. Ship hulls - Fracture
5. Ship hulls - Stresses - Temperature factors
6. Ship plates (Stiffened) - Stress - Temperature factors

I. Jasper, Norman H.

David W. Taylor Model Basin. Rept. 937.
TEMPERATURE-INDUCED STRESSES IN BEAMS AND SHIPS, by Norman H. Jasper. June 1955. ii, 25 p. incl. figs., tables, refs. UNCLASSIFIED

A theoretical method is given for computing temperature-induced stresses in a nonhomogeneous or homogeneous beam or girder of uniform cross section for any temperature distribution over the cross section. It is assumed that all cross sections have the same temperature distribution.

The method is illustrated by application to a simplified model of a ship constructed of steel and aluminum and to a T-2 tanker design.

1. Thermal stresses - Mathematical analysis
2. Girders (Marine) - Stresses - Temperature factors
3. Ships - Stresses - Measurement
4. Ship hulls - Fracture
5. Ship hulls - Stresses - Temperature factors
6. Ship plates (Stiffened) - Stress - Temperature factors

I. Jasper, Norman H.

David W. Taylor Model Basin. Rept. 937.
TEMPERATURE-INDUCED STRESSES IN BEAMS AND SHIPS, by Norman H. Jasper. June 1955. ii, 25 p. incl. figs., tables, refs. UNCLASSIFIED

A theoretical method is given for computing temperature-induced stresses in a nonhomogeneous or homogeneous beam or girder of uniform cross section for any temperature distribution over the cross section. It is assumed that all cross sections have the same temperature distribution.

The method is illustrated by application to a simplified model of a ship constructed of steel and aluminum and to a T-2 tanker design.

1. Thermal stresses - Mathematical analysis
2. Girders (Marine) - Stresses - Temperature factors
3. Ships - Stresses - Measurement
4. Ship hulls - Fracture
5. Ship hulls - Stresses - Temperature factors
6. Ship plates (Stiffened) - Stress - Temperature factors

I. Jasper, Norman H.

David W. Taylor Model Basin. Rept. 937.
TEMPERATURE-INDUCED STRESSES IN BEAMS AND SHIPS, by Norman H. Jasper. June 1955. ii, 25 p. incl. figs., tables, refs. UNCLASSIFIED

A theoretical method is given for computing temperature-induced stresses in a nonhomogeneous or homogeneous beam or girder of uniform cross section for any temperature distribution over the cross section. It is assumed that all cross sections have the same temperature distribution.

The method is illustrated by application to a simplified model of a ship constructed of steel and aluminum and to a T-2 tanker design.

1. Thermal stresses - Mathematical analysis
2. Girders (Marine) - Stresses - Temperature factors
3. Ships - Stresses - Measurement
4. Ship hulls - Fracture
5. Ship hulls - Stresses - Temperature factors
6. Ship plates (Stiffened) - Stress - Temperature factors

I. Jasper, Norman H.

David W. Taylor Model Basin. Rept. 937.
TEMPERATURE-INDUCED STRESSES IN BEAMS AND SHIPS, by Norman H. Jasper. June 1955. ii, 25 p. incl. figs., tables, refs. UNCLASSIFIED

A theoretical method is given for computing temperature-induced stresses in a nonhomogeneous or homogeneous beam or girder of uniform cross section for any temperature distribution over the cross section. It is assumed that all cross sections have the same temperature distribution.

The method is illustrated by application to a simplified model of a ship constructed of steel and aluminum and to a T-2 tanker design.

1. Thermal stresses - Mathematical analysis
2. Girders (Marine) - Stresses - Temperature factors
3. Ships - Stresses - Measurement
4. Ship hulls - Fracture
5. Ship hulls - Stresses - Temperature factors
6. Ship plates (Stiffened) - Stress - Temperature factors

I. Jasper, Norman H.

David W. Taylor Model Basin. Rept. 937.
TEMPERATURE-INDUCED STRESSES IN BEAMS AND SHIPS, by Norman H. Jasper. June 1955. ii, 25 p. incl. figs., tables, refs. UNCLASSIFIED

A theoretical method is given for computing temperature-induced stresses in a nonhomogeneous or homogeneous beam or girder of uniform cross section for any temperature distribution over the cross section. It is assumed that all cross sections have the same temperature distribution.

The method is illustrated by application to a simplified model of a ship constructed of steel and aluminum and to a T-2 tanker design.

1. Thermal stresses - Mathematical analysis
2. Girders (Marine) - Stresses - Temperature factors
3. Ships - Stresses - Measurement
4. Ship hulls - Fracture
5. Ship hulls - Stresses - Temperature factors
6. Ship plates (Stiffened) - Stress - Temperature factors

I. Jasper, Norman H.

MIT LIBRARIES DUPL
3 9080 02754 1868

MAY 19 1987

JAN 23 1956