STRENGTH CURVES FOR LAKE FREIGHTERS

by

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1. INTRODUCTION

The purpose of this paper is to describe the use, and development of a simplified type of loading table applicable to Great Lakes bulk ore carriers. It is a well known fact that during loading it is quite easily possible to subject the ship to undesirably high longitudinal bending moments, causing stresses that are well beyond those usually associated with good design practice.

It is for this reason that in the design of most bulk ore carriers, desired loading sequences and distributions are worked out by the shipbuilder as a guide for the owners. Such calculations are worked up in the form of standard strength curves for the ship, and include buoyancy, weight, loading, shear, and bending moment curves for the ship in various stages of loading. Due to the time and knowledge required to derive such curves, only certain recommended conditions may be investigated, and these may not cover all possibilities. Any variation from these standard conditions requires further involved calculations of a type that no ship's personnel is likely to have either the inclination or the knowledge to make.

What is therefore desired is a table that is simple enough to be useful to the ship's officers, and at the same time provide suitable accuracy with regard to dangerous bending moments, so that one could trust it while following loading sequences and distributions different from the ones recommended by the shipbuilder.

Such a table is by no means a new idea, as it was used by the American Bureau of Shipping in preparing a booklet of recommended loading procedure for T-2 Tankers (1)*. The table is based upon the use of a bending moment influence line which shows the effect upon the bending moment of the addition of a weight or weights. A short discussion of the theory of influence lines will be found in the appendix.

2. LOADING TABLE

Fig. 1 shows the final table as derived for the Steamer WILFRED SYKES, and Fig. 2 shows the sheet of instructions which would be supplied with it for the use of the ship's officers. As indicated in item 5, to insure safe loading, all that it is necessary for the ship's personnel to know is the resultant stress numeral. If the value of this numeral is under 100, either positively or negatively, the loading condition may be called safe with regard to longitudinal bending moments. A value greater than 100, either positively or negatively, indicates an unsafe condition. Also it should be pointed out that the actual value of the numeral is a reflection to the value of the bending moment; thus a numeral of 25 would be relatively safer than one of 75. An important point, which will be illustrated later in the development of the table, is that the bending moment associated with a stress numeral of 100 is by no means fixed during the preparing of the table. It is

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*Numbers in parentheses refer to references found at the conclusion of the paper.

TABLE FOR DETERMINING NUMERAL FROM LOAD DISTRIBUTION

Line No.	Compartment	Weight Long Tons/100	Bending Moment Factor	Bending Moment Numeral
1	1	(a)	(b) 3.59	(c)
2	2		4.26	
3	3		4.94	
4	4		5.65	
5	5		6.35	
6	6		7.00	
7	7		7.70	
8	8		8.41	
9	9		9.09	
10	10		9.76	
11	11		10.11	
12	12		9.41	
13	13		8.68	
14	14		8.03	
15	15		7.32	
16	16		6.68	
17	17		5.98	
18	18		5.20	
19	19		4.56	
20	Sub-total lines 1-19		X	
21	LIGHT SHIP	79.92	X	-86
22	Sub-total lines 20 + 21	Displace-ment/100	X	Line 20-21
23	Dead-wt. corr. = (6) x (Line 20-a)	X	X	(-) Dead-wt. corr.
24	Resultant Numeral Line 22-23	X	X	Numeral

Weight x factor = Numeral

Fig. 1

INSTRUCTIONS FOR USE OF LOADING TABLE

1) Enter all weights added in units of long tons divided by 100 in column (a) on the line corresponding to the compartment to which the weight was added.

2) Multiply all numbers in column (a) by the appropriate factor in column (b) and enter products in column (c).

3) Add all entries in column (c) and enter on line 20. Subtract line 21 (c) from 20 (c) and enter difference on line 22, column (c).

4) Add entries in column (a), lines 1-19, and enter sum on line 20, column (a). Multiply line 20, column (a) by 6 and enter product as minus quantity in column (c), line 23.

5) Subtract line 23, column (c), from line 22, column (c), and enter difference in column (c), line 24. This is the resultant numeral for the particular loading condition. If it is positive it indicates sagging; and if it is negative it indicates hogging. If it is over 100, either positively or negatively, the loading condition is undesirable.

Fig. 2

possible to assign the numeral 100 to any desired bending moment, and thereby assure that a chosen maximum allowable stress will not be exceeded so long as the numeral 100 is not exceeded.

To further clarify the use of the table, Fig. 3 and 4 are presented next, showing favorable and unfavorable loading conditions respectively. Both conditions represent loading that would bring the ship close to her load draft. In the condition shown in Fig. 3, the resultant stress numeral of 1.6 shows that there is practically no longitudinal bending moment, while in Fig. 4 the value of 100.9 shows that there is a bending moment slightly greater than is considered desirable.

Fig. 5 shows a small inboard profile of the ship with the locations of compartments 1 to 19 drawn in. These correspond to the longitudinal centers of each of the ship's 19 hatches. The two sloping lines, intersecting at midships, are the lines from which the factors entered in column (b) on the loading table (Fig. 1) were taken. In the event that any sizable loads were placed on board in longitudinal positions other than ones covered by one of the 19 hatches, the positions would be spotted on the profile, and the appropriate factors read off Fig. 5.

3. LIMITATIONS

In preparing the table for three ships, several important limitations were found. These will now be discussed so that the reader may fully realize where the full value of the table lies, and, more important, realize where it would be highly misleading to attempt using such a table.

First of all, the resultant stress numeral which the table produces, is a reflection of the bending moment and stress at only one longitudinal section in the ship. For the three tables prepared in conjunction with this paper, the section chosen was in each case midships. One reason for this choice was that in all strength curves investigated for Great Lakes bulk ore carriers, the largest bending moments were always found to appear either at or very close to midships. This does not mean that under all conditions the largest bending moment occurred at midships, since under several recommended loading conditions the bending moment was close to zero, but somewhat higher at other sections. In all such cases the highest bending moment was by no means a dangerous one. This means that while the table may produce a stress numeral of zero under certain conditions, there may indeed be a bending moment at some section or sections in the ship which would cause a stress equivalent to a numeral of up to about 35. This, however, is about as high as it would probably go, and based on 100 being the safe limit, it is not necessary for the crew of a ship to know about it. Conversely, in all conditions producing a bending moment equivalent to a stress numeral close to 100, this maximum bending moment, as mentioned above, was found to be very close to midships, and thus the choice of this section as the criterion for safe loading.

FAVORABLE LOADING CONDITION

Line No.	Compartment	Weight Long Tons / 100	Bending Moment Factor	Bending Moment Numeral
		(a)	(b)	(c)
1	1	28.23	3.59	101.3
2	2	16.20	4.26	69.0
3	3	10.76	4.94	53.2
4	4	6.59	5.65	37.2
5	5	4.57	6.35	29.0
6	6	9.52	7.00	66.6
7	7	9.52	7.70	73.3
8	8	9.52	8.41	80.0
9	9	9.52	9.09	86.4
10	10	9.52	9.76	92.8
11	11	9.52	10.11	96.2
12	12	9.52	9.41	89.5
13	13	9.52	8.68	82.6
14	14	9.52	8.03	76.4
15	15	3.63	7.32	26.5
16	16	6.70	6.68	44.7
17	17	12.69	5.98	76.0
18	18	17.05	5.20	88.7
19	19	20.43	4.56	93.2
20	Sub-total lines 1-19	212.40	X	1362.6
21	LIGHT SHIP	79.92	X	-86.0
22	Sub-total lines 20 + 21	292.32	X	1276.6
23	Dead-wt. corr. 6 x line 20-a	X	X	-1275.0
24	Resultant Numeral, line 22-23	X	X	+1.6

Fig. 3

UNFAVORABLE LOADING CONDITION

Line No.	Compartment	Weight Long Tons / 100	Bending Moment Factor	Bending Moment Numeral
		(a)	(b)	(c)
1	1	17.61	3.59	63.3
2	2	10.86	4.26	46.2
3	3	10.86	4.94	53.6
4	4	10.86	5.65	61.3
5	5	10.86	6.35	68.7
6	6	10.86	7.00	76.0
7	7	10.86	7.70	83.6
8	8	10.86	8.41	91.3
9	9	10.86	9.09	98.7
10	10	10.86	9.76	106.0
11	11	10.86	10.11	109.7
12	12	10.86	9.41	102.2
13	13	10.86	8.68	94.3
14	14	10.86	8.03	87.2
15	15	10.86	7.32	79.3
16	16	10.86	6.68	72.6
17	17	10.86	5.98	65.0
18	18	10.86	5.20	56.4
19	19	10.86	4.56	49.5
20	Sub-total lines 1-19	213.01		1464.9
21	LIGHT SHIP	72.92		-86.0
22	Sub-total lines 20 + 21	285.93		1378.9
23	Dead-wt. corr. 6 x (line 20-a)			-1278.0
24	Resultant Numeral, Line 22-23			+100.9

Fig. 4

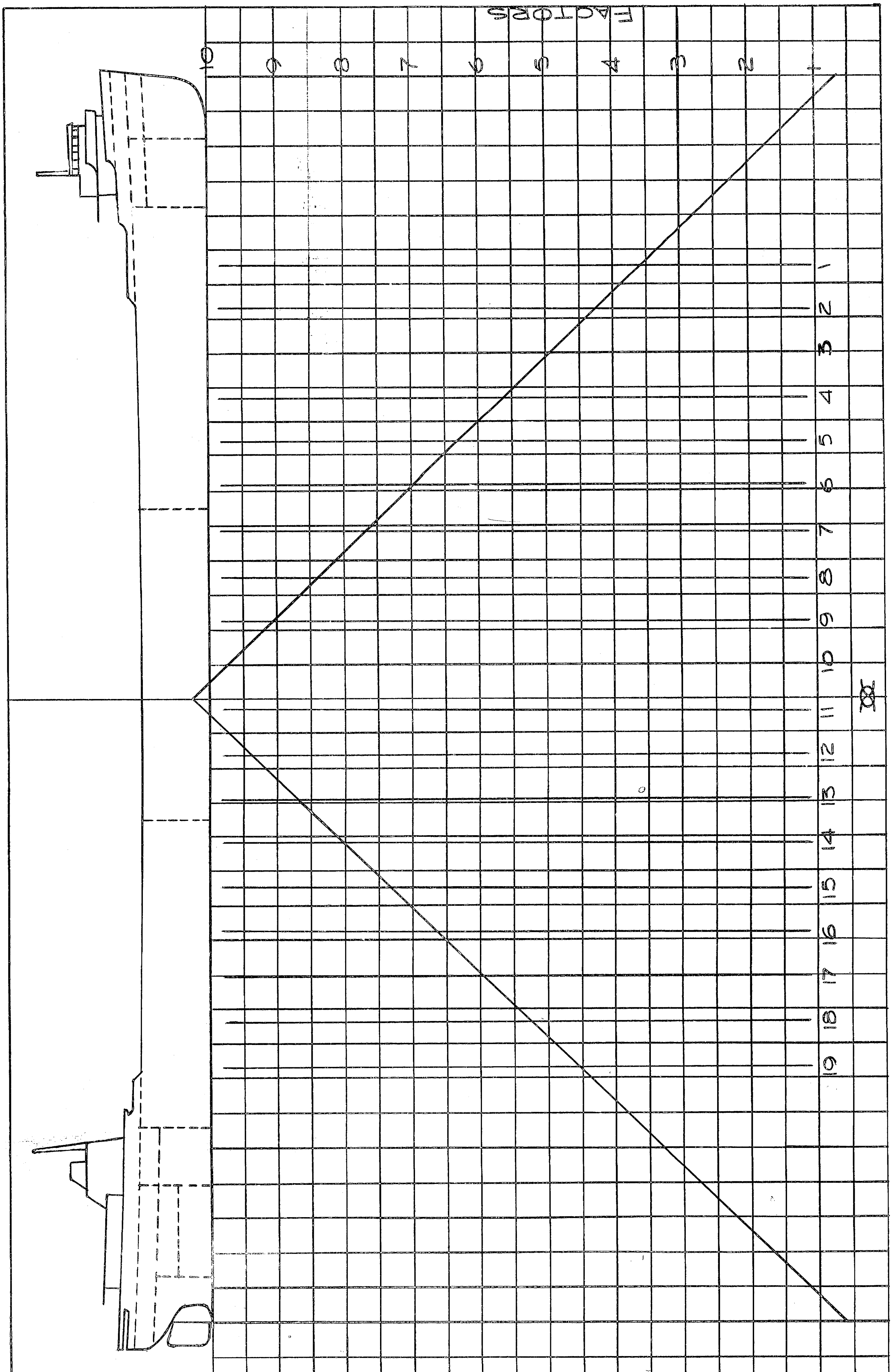

FIG. 5

As will become apparent in the derivation of the table to be presented in the appendix, the values of the factors used in the table are a function of the shape of the ship. Thus as the loading changes the draft and trim of the ship, the factors should change to be exactly accurate. However it was found that the use of a mid-draft for all calculations provided sufficient accuracy. It can be said here that the accuracy is closely dependent on the ship's conforming to a wall-sided vessel, and all Great Lakes ore carriers conform very nicely to this ideal. The actual choice of the mid-draft to be chosen will be presented in the appendix.

Another important limitation of the table is one introduced simply in the interest of simplicity in keeping the table of workable size. As will be noticed in Fig. 1 (line 21, column c) there is a lightship correction to be introduced in arriving at the final stress numeral. In choosing the lightship condition to be used for this correction, several considerations face the person preparing the table. It is possible to make this correction reflect only the actual lightship itself. This was done in the case of the USMC* ore carriers whose sample calculations are presented in the appendix. The resulting table, (Fig. 14), however, is quite cumbersome, due to the necessity of including lines for items such as stores, fresh water, fuel, crew, etc. The alternative choice is to include all such items in the lightship correction. This was done in the case of the SYKES and the JOHN G. MUNSON. It is readily admitted that while simplifying the end result, this simplification does indeed detract from the final accuracy. A good compromise is probably achieved by including all items in the lightship correction except those that come under the heading of either cargo or ballast. Sufficient lines would then be provided for each space which is to be used for either cargo or ballast.

Another consideration should be mentioned in connection with the choice of units to be used in entering weights into the table. As can be seen from Fig. 1, the units chosen for the SYKES were long tons divided by 100. This was done simply to keep the numbers involved of a workable size. It is possible, however, as will be shown in the appendix, to make the units anything that may be desired. Thus they might be carloads, or barrels or any other system of units depending on the preference of those who are actually going to use the table. It should be made clear, however, that the units chosen must be applicable to all weights that are added to the ship. Thus in a vessel which needed considerable water ballast when running light, it would be very inconvenient to have a system of units such as carloads, which does not readily lend itself to measuring the weight added, and as it happens with most bulk ore carriers, the ballast condition is usually the one causing the highest bending moment and the table should therefore be easily adaptable to this condition. Thus, the choice of long tons divided by 100 seems a good one. Short tons divided by 100 would, of course, be equally suitable so long as one is consistent.

One last limitation should be mentioned with regard to the accuracy of the table. In the form presented here, it deals only with still water bending moments. This is thought to be feasible, since general practice on the Great Lakes has been to prepare strength curves for still water only. The reasons for this are well known and need not

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*USMC - United States Maritime Commission be presented here. It should be said, however, that it would be quite possible to apply the table to bending moments caused in waves, both sagging and hogging, though the calculations become both more involved and more lengthy, and the resultant table is doubled in size since each condition must be investigated both for a sagging and a hogging wave.

4. CONCLUSIONS

With the abovementioned limitations in mind, it can readily be seen that the loading table presented is hardly a design tool. Its place is on the ship, and its function is that of a guide to steer those in charge of loading clear of dangerous loading conditions. No inference is intended that this sort of a table will provide the Naval Architect with a shortcut to the necessary laborious strength calculations which are a part of the design of any ship. It is necessary, in fact, as will be made clear in the appendix, to have on hand many strength curves with which to check the table as it is being prepared.

It is, however, felt that if a ship's personnel could be made to use such a table, a simple and safe check on all truly dangerous loading conditions would be effected. This has been the intention behind writing this paper, and preparing the appendix, in which will be found the steps involved in preparing the table for a ship.

APPENDIX: Part 1 (Influence Lines)

The influence line is a device commonly used by civil engineers to determine the effect of a live load moving across a structure, such as an automobile crossing a bridge. For the purpose of more clearly defining it, we may consider the influence line as a graphical picture of the effect upon any one section in a beam, caused by a unit weight moving across the span of the beam. By the use of different influence lines the effect of the unit weight upon the reactions, the shear, or the bending moment in the beam at any one transverse section may be ascertained. For the purposes of this paper we need only investigate the influence line with regard to the bending moment. For clarity, a simple example will first be considered.

Let us consider a simply supported beam of length L with a unit weight acting down on it at a distance x from the right end B of the beam (Fig. 6a). By statics the reaction at A, R_A is equal to $x/L \times 1\# = x/L$. Now suppose that the section that we wish to investigate be taken at XX. If the unit weight is to the right of XX, then R_A is the only force to the left of XX and the bending moment at this section being the algebraic sum of all forces times their distance from the section is therefore equal to $R_A \times a = xa/L = M_1$. Since R_A is a function of x this ordinate is plotted under the position of the unit weight as shown in Fig. 6b. Now if the unit weight is to the left of XX, the bending moment at XX is equal to $(L-x)b/L = M_2$, since $R_b = (L-x)/L$, and b is its lever. Now as the unit weight moves from

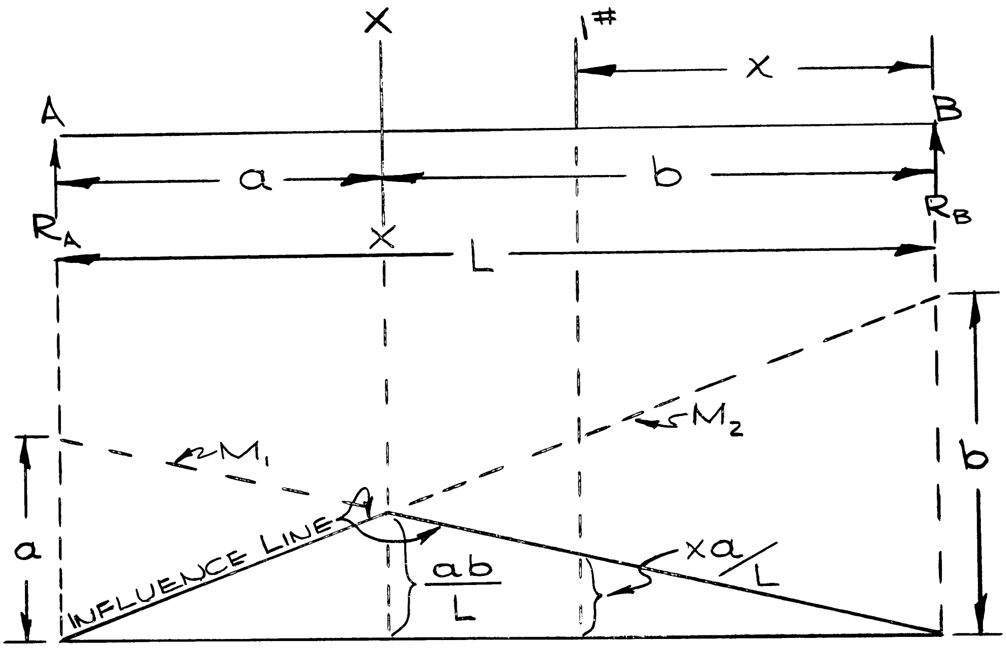


Fig. 6a

Fig. 6b

B to A we will get various values for the bending moment which will be plotted on the value of x corresponding to the position of the unit weight. Thus at $x = 0$, $M_1 = 0$, and $M_2 = 0$; and at $x = L$, $M_1 = a$, and $M_2 = 0$. Since both bending moments are expressed by linear functions, the plots of both will be straight lines as shown. Remembering that to get M_1 the unit weight had to be to the right of XX we know that only the portion of its plot to the right of XX is applicable. Similarly with M_2, only its portion to the left of XX applies. These portions of the two lines give the bending moment influence line for the section XX. This final line thus gives the effect upon the bending moment at section XX of placing the unit weight at any point on the span. Note that if the weight were doubled, all ordinates would be doubled as the reactions are doubled. However, rather than doubling the ordinates we may take the existing value of the ordinate which has the units of ft-lbs/lb and multiply by 2 lbs, thus giving ft-lbs which is the proper unit for bending moments. This shows the important point that the ordinates to the influence line are actually a function of the position of the supports and the weight rather than their actual values.

In plotting the influence line it was drawn upward from the base line since the weight downward gave a downward or positive deflection, and thus a positive bending moment. If the weight had acted upwards with a resulting minus deflection, it would then produce a negative bending moment since the reactions would have to be downward. Actually any set of conventions may be adopted so long as they are consistent. This point was only mentioned because it will later be shown that it is convenient to rely upon the influence line to settle the question of positive or negative bending moments when applying the influence line to a ship.

To further illustrate this last point, one more simple example that more nearly approaches the conditions present on a ship will be shown. It will readily be admitted that the addition of a heavy weight close to midships will cause a sagging bending moment in the midship region, due to an excess of weight over buoyancy in this region. Conversely the addition of the weight at either the very bow or stern of the ship will cause a hogging bending moment near midships due to an excess of buoyancy over weight now present in the midship region. Thus we can very roughly approximate the ship with a simply supported beam whose supports are some ways in from the ends representing the buoyancy. We then know that if a weight is added in between the supports, it will cause downward deflection and a positive or sagging bending moment (Fig. 7a). If, however, the weight is added outside the supports, the beam will then deflect upwards and the resulting bending moment near the center will be negative or hogging (Fig. 7b).

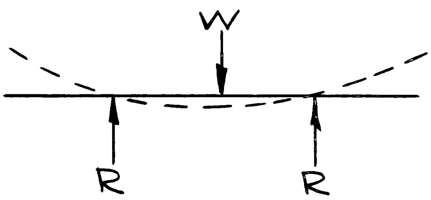


Fig. 7a

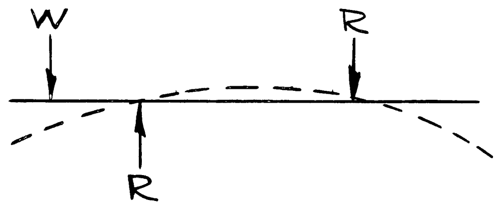


Fig. 7b

Investigating these conditions as before by moving a unit weight across the length of the beam, we once again obtain the influence line as shown in Fig. 8b. The middle of the beam was chosen as the section for which the influence line should be drawn since this corresponds to midships in our simplified example. The method used is the same as before and the work is presented below the diagram (Fig. 8a and 8b).

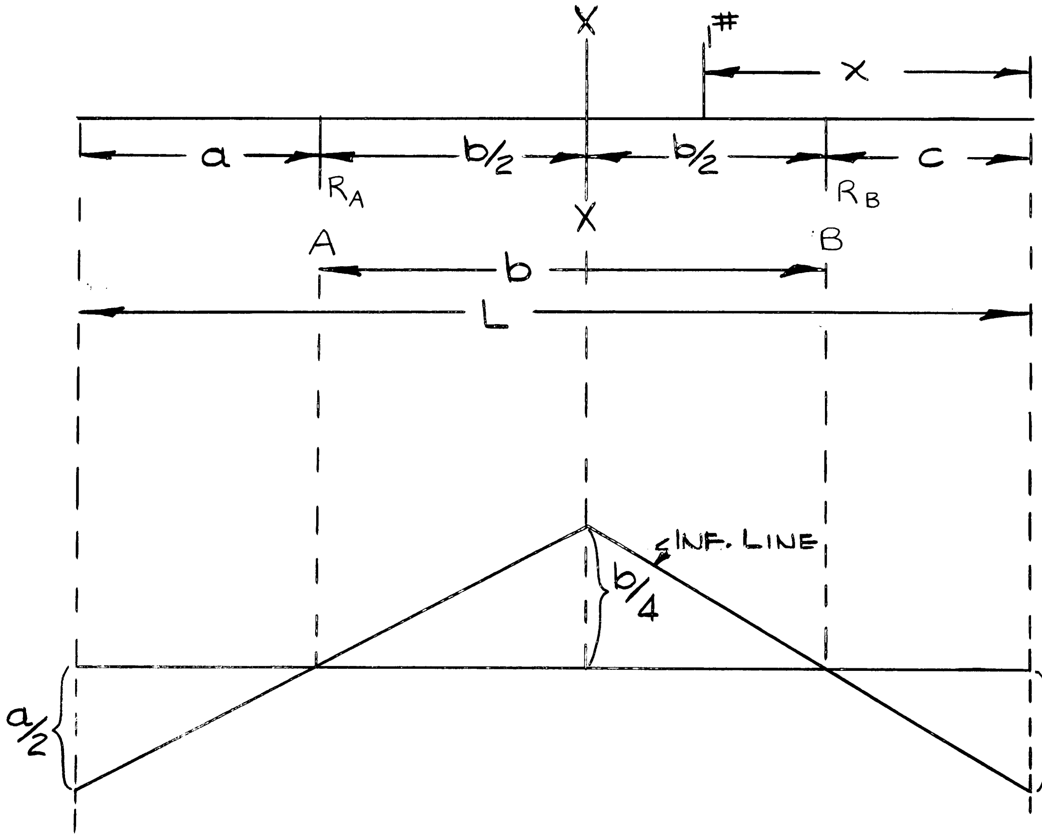


Fig. 8a

Fig. 8b

AT $x = 0$ $\Sigma M_A = 0$

$$1(b+c) - b(R_B) = 0$$

$$R_B = \frac{b+c}{b} \times 1^{\#}$$

BEND. MOM.
AT XX

$$M_1 = b/2 \; R_B - 1(b/2 + c)$$

$$= b/2 \; \frac{(b+c)}{b} - \left(\frac{b}{2} + c\right) = -c/2 \text{ (PLOT AT } x = 0)$$

AT $x = c$ $R_B = 1^{\#}$

BEND. MOM.
AT XX $M_1 = R_B \times b/2 - 1 \times b/2 = 0$

AT $x = b/2 + c$ $R_B = 1/2$

BEND. MOM.
AT XX $M_1 = 1/2 \times b/2 = b/4$

AT $x = b + c$ $R_A = 1$

BEND. MOM.
AT XX $M_2 = R_A \times b/2 - 1 \times b/2 = 0$

AT $x = b + c + a$

$$\Sigma M_B = 0$$

$$1(b+a) - R_A b = 0 \qquad R_A = \frac{b+a}{b}$$

BEND. MOM.
AT XX $M_2 = \left(\frac{b+a}{b}\right) \times \frac{b}{2} - 1\left(\frac{b}{2} + a\right) = -a/2$

Thus the influence line shows us which positions of the unit weight will result in a positive bending moment, and which will result in a negative bending moment. Again it should be mentioned that any one influence line will only show the resultant effect changes in the position of the weight have upon the bending moment at the one particular section for which the influence line was drawn.

APPENDIX: Part 2 (Considerations in Applying the Influence Line to a Ship)

In applying the influence line to a ship for use as a loading table, there are a number of important departures from its original development which should be mentioned. First, it should be noted that the influence line is designed to show the effect on bending moment of moving a unit weight across a structure. Its units are therefore force x length/unit force. In using the line to apply to the addition or subtraction of weights we multiply by force and have the resulting units of force x length, which are correct for a bending moment. But in adding or subtracting weights the reactions must necessarily change totally and this is where the largest assumptions are necessary in applying the line to a ship. A simple beam can handle this discrepancy as the position of the supports is not changed, and this, as noted before, is the only factor that affects the influence line. In the case of the ship, however, as weights are added or subtracted, the support force, buoyancy, changes position longitudinally due to both form and resultant change in trim of the vessel. Fortunately, for the purposes of an approximate loading table, however, these changes do not materially affect the influence line in most ships, even over large ranges of drafts and trim. This statement must be modified by saying that the amount by which accuracy will be retained is very definitely a function of the shape of the ship. It can be said generally that the closer an approximation the ship is to a wall-sided vessel, the better the accuracy will be over various changes in draft and trim. As will be shown later, the values of the center of flotation, the tons per inch immersion, and the moment to trim one inch enter into the calculation for the influence line, and the amount by which their values change over the range of drafts to be investigated is an indication of the amount of accuracy to be expected over the range of drafts. The smaller their change, especially that of the tons per inch, the greater the accuracy will be at drafts other than that for which the line was found. It is therefore recommended that the influence line be calculated with the ship at a draft that gives the mean value for the tons per inch, moment to trim one inch, and center of flotation favoring the draft giving the mean value of the tons per inch. It can be seen why similarity to a wall-sided vessel, as mentioned above, is desirable, since the wall-sided vessel has constant waterplane area over all drafts and thus has constant values of tons per inch and moment to trim one inch at all drafts. The length, of course, also remains constant. Also the position of the center of flotation remains fixed. As a practical matter, however, it can be said that if the ship is fairly wall-sided the accuracy will be fairly good.

Another important limitation that must be remembered when applying the influence line to the ship for a loading table is the fact that any one line only reflects the change in the bending moment upon the particular longitudinally located section for which it was calculated. It will later become evident that for a simple table, only one influence line should be used, and the choice of the section for which this line is to be calculated therefore becomes important if the table is to be of any use. In the three example ships the midship section was chosen since available bending moment curves showed that the maximum bending moment in both the lightship and fully loaded worst expected condition occurred very close to the midship section. The resultant discrepancies between the midship value and the maximum value were so small that these errors were considered to be of less importance than those arising from the ship's form not being that of the ideal wall-sided vessel. The bending moments representing the light and fully loaded conditions mentioned above were the maximum values that it was expected the ship would ever encounter. This is an important point, since there is little point in wasting the time and effort involved in calculating an influence line if it is done for a section which never experiences bending moments close to those which are the maximum for the ship. Thus if the point of maximum bending moment varies over a wide range longitudinally, one influence line will be of little or no value over a wide range of drafts. Thus, before attempting to construct the influence line it is essential to have at hand several bending moment curves for the ship representing the worst expected conditions, both light and fully loaded, so that the proper section, if indeed there is one, may be chosen. The necessity of having these curves also becomes evident at a later stage which will be discussed after the development of the influence line.

APPENDIX: Part 3 (Method of Getting Influence Line for a Ship)

The method used to determine the actual values for plotting the influence line on the example ships was outlined in a paper by Mr. Harrison T. Loesser (3). It might be informative, however, to carry through the development of the influence line by this method again, as it was found by the author that there is very little material available on this subject in the ordinary texts concerned with the strength of ships.

In introducing the development of equations for the influence line it should first be noted that the longitudinal bending moment at any transverse section in the ship is the algebraic summation of the moments of all weights and buoyancy taken either forward or aft of that section. Now, since with various conditions of loading the ship will come into a trimmed condition, the moment of buoyancy acting on a section can change appreciably. It is known that if a ship trims about the longitudinal center of gravity of the waterplane, there will be no change in the displacement. It develops that a comparable position in the waterplane may be found such that if the ship is to trim about this point, there will be no change in the moment of buoyancy about one particular section. Thus, referring to Fig. 9, we shall call point B the point about which trim causes no change in the moment of buoyancy about section A. Point B will be known as the center of moments for section A. It should be apparent from the picture and the following development that for any section there will be a forward center of moments and an aft center of moments. This point, the center of moments, is, of course, only a point over small values of trim. For clarity, the angle of trim in the figure is exaggerated.

In order for there to be no change in moment of buoyancy about section A, the moment of the immersed wedge 1 must be equal to the moment of the emerged wedge 2, both taken about section A. The method of locating point B can be shown as follows with the aid of Fig. 10.

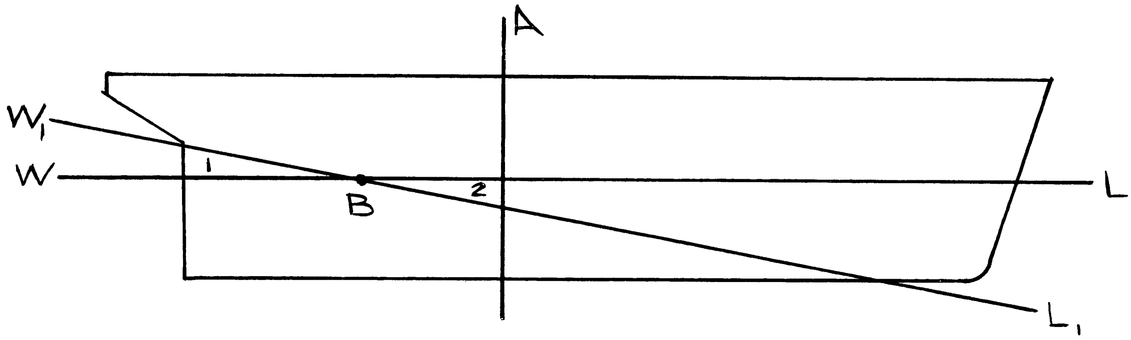


Fig. 9

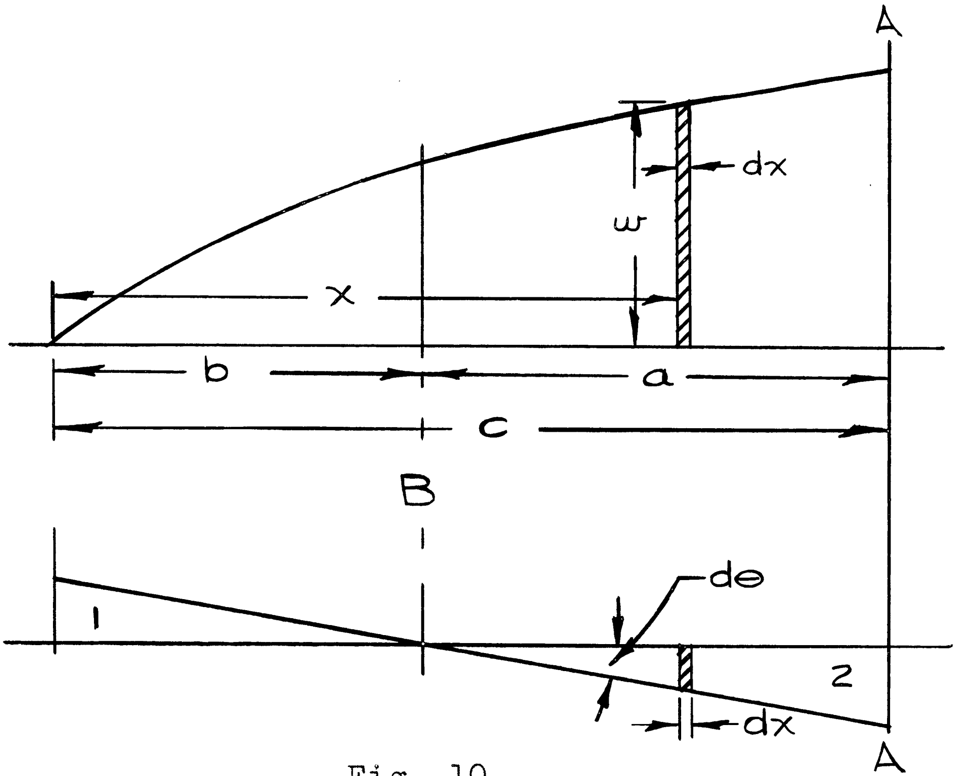


Fig. 10

$$\Sigma M_A = 0 \qquad M_{1A} - M_{2A} = 0 \tag{1}$$

$$v_1 = \int_0^b w\,dx\,d\theta\,(b-x) \tag{2}$$

$$M_{1A} = \int_0^b w\,dx\,d\theta\,(b-x)(a+b-x) \tag{3}$$

$$= -\int_0^b w\,dx\,d\theta\,(x-b)(a+b-x) \tag{3a}$$

$$U_2 = \int_b^{a+b} w \, dx \, d\theta \, (x - b) \qquad (4)$$

$$M_{2_A} = \int_b^{a+b} w \, dx \, d\theta \, (x-b)(a+b-x) \qquad (5)$$

Putting (3a) and (5) in 1

$$-\int_0^b w \, dx \, d\theta \, (x-b)(a+b-x) - \int_b^{a+b} w \, dx \, d\theta \, (x-b)(a+b-x) = 0$$

simplifying &
since $a+b = c$

$$-\int_0^c w \, (x-b)(c-x) \, dx \, d\theta = 0 \qquad (6)$$

Dividing by $d\theta$

$$-\int_0^c w \, (x-b)(c-x) \, dx = 0 \qquad (6a)$$

Expanding & solving for b

$$-\int_0^c w \, x c \, dx + \int_0^c w \, b c \, dx + \int_0^c w \, x^2 \, dx - \int_0^c w \, b x \, dx = 0$$

$$-c\int_0^c w \, x \, dx + bc\int_0^c w \, dx + \int_0^c w \, x^2 \, dx - b\int_0^c w x \, dx = 0$$

$$b\left[c\int_0^c w \, dx - \int_0^c w \, x \, dx\right] = c\int_0^c w x \, dx - \int_0^c w \, x^2 \, dx$$

$$b = \frac{c\int_0^c w \, x \, dx - \int_0^c w \, x^2 \, dx}{c\int_0^c w \, dx - \int_0^c w \, x \, dx} \qquad (7)$$

Equation 7 may be transformed for use by Simpson's first rule by using the following notation:

dx represents the station spacing over interval c = S
w represents the half-breadths B/2 at each station = B/2
y = the even no. of stations into which c is divided so c = Sy
x = lever of each station about F.P. or A.P. in feet

Thus: $$b = \frac{\frac{1}{3} S \times Sy \sum f (B/2)x - \frac{1}{3} S \sum f (B/2\ x^2)}{\frac{1}{3} S \times Sy \sum f (B/2) - \frac{1}{3} S \sum f (B/2\ x)}$$

$$b = \frac{Sy \sum f (B/2\ x) - \sum f (B/2\ x^2)}{Sy \sum f (B/2) - \sum f (B/2\ x)} \qquad (8)$$

Having now determined how the center of moments may be found both forward and aft, the method employed to calculate the actual influence line points may be developed. Again the method employed follows that outlined by Mr. H. T. Loeser (3). Referring to Fig. 11, the equations necessary for construction of the influence line will now be developed.

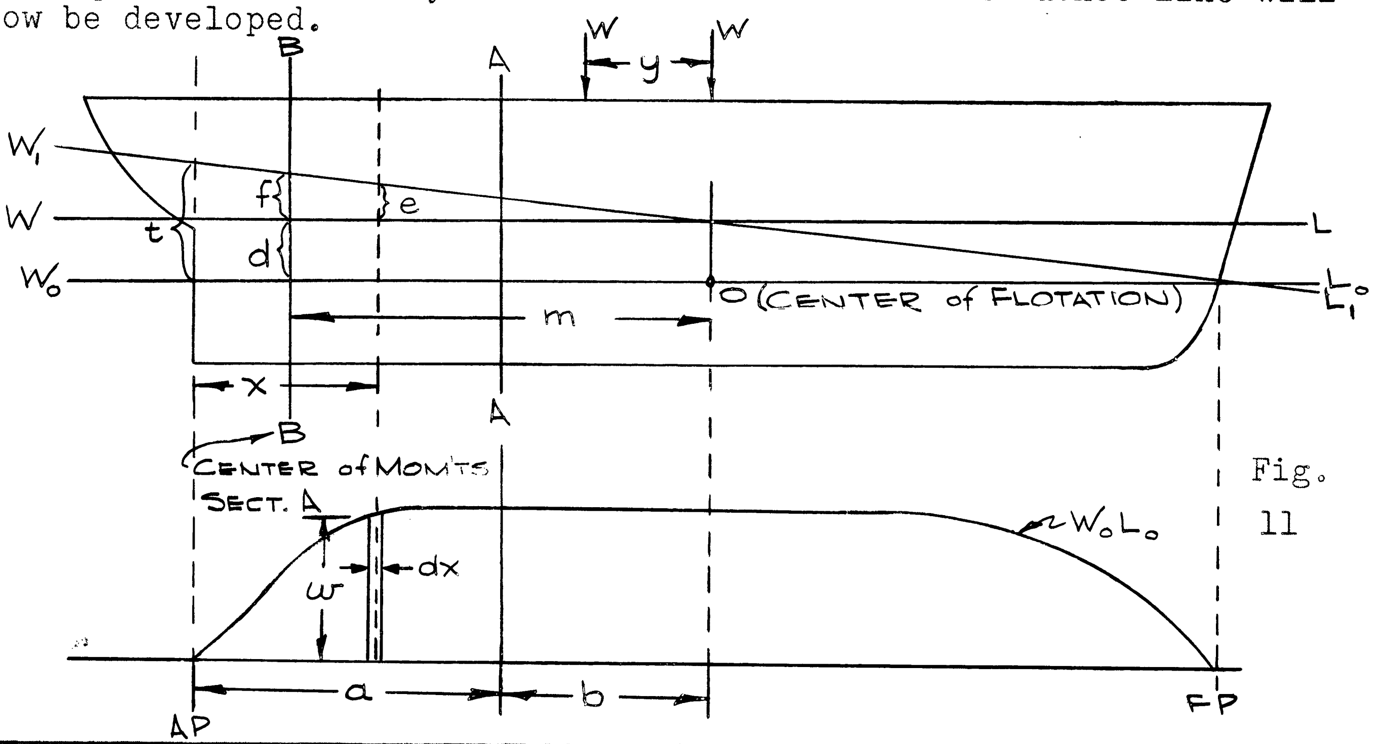


Fig. 11

*Equation (8) may be transferred to a more useful form for use with Simpson's first rule if the levers about the forward and after perpendiculars are first taken as even station spacings. Then they would run 0, 1, 2, 3, etc., up to 5 for midships. Thus x must be replaced by lvr x S, where lvr represents the numerical lever of the station about the FP or AP, and S represents the station spacing in feet. Thus (8) becomes:

$$b = \frac{S^2 y \sum f (B/2)\, lvr - S^2 \sum f (B/2 \times lvr^2)}{Sy \sum f (B/2) - S \sum f (B/2 \times lvr)}$$

$$b = \frac{Sy \sum f (B/2 \times lvr) - S \sum f (B/2\ lvr^2)}{y \sum f (B/2) - \sum f (B/2 \times lvr)} \qquad (8a)$$

This equation for b refers to Fig. 10, not Fig. 11.

Weight W is added over O (center of flotation), giving parallel sinkage.

$$d = \frac{W}{12\ TP1''} \qquad (9)$$

The increase in moment of buoyancy on section A,
ΔM_b is

$$\Delta M_B = \frac{2}{35}\int_0^a w d(a-x)\,dx = \frac{2W}{35 \times 12 \times TP1''}\int_0^a w(a-x)\,dx \qquad (10)$$

moving W aft a distance y results in a trim t which is

$$t = \frac{Wy}{12\ MT1''} \qquad (11)$$

and

$$e = t\,\frac{(b+a-x)}{L} = \frac{Wy\,(b+a-x)}{12 \times L \times MT1''} \qquad (12)$$

the additional moment of buoyancy due to trim, ΔM_{BT} acting on section A is

$$\Delta M_{BT} = \frac{2}{35}\int_0^a we\,(a-x)\,dx = \frac{2Wy}{35 \times 12 \times L \times MT1''}\int_0^a (b+a-x)\,w\,(a-x)\,dx \qquad (13)$$

the total change in moment of buoyancy is therefore the sum of the two

$$\Delta M_{TOT} = \Delta M_B + \Delta M_{BT} \qquad (14)$$

$$\Delta M_{TOT} = \frac{2W}{35 \times 12 \times TP1''}\int_0^a w(a-x)\,dx + \frac{2Wy}{35 \times 12 \times L \times MT1''}\int_0^a w(a-x)(b+a-x)\,dx \qquad (15)$$

for any one section both integrals have constant values and y is the only variable, thus,

$$\Delta M_{TOT} = c_1 + c_2 y \qquad (15a)$$

The fact that this is the equation of a straight line shows that the influence line is a straight line where it is continuous, assuming, of course, that the MT1" and TP1" stay constant as they would in a wall-sided vessel.

Now, remembering that the center of moments for section A was previously found, and again referring to Fig. 11,

$$\overline{BO} = m \qquad (16)$$

then

$$f = \frac{mt}{L} = \frac{mWy}{12 \times L \times MT1''} \qquad (17)$$

and

$$\Delta M = 2\,\frac{(d+f)}{35}\int_0^a w\,(a-x)\,dx \qquad (18)$$

results in

$$\Delta M = 2\left[\frac{W}{35 \times 12 \times TP1''} + \frac{mWy}{35 \times 12 \times L \times MT1''}\right]\int_0^a w\,(a-x)\,dx \qquad (19)$$

Simplifying (19)

$$\Delta M = \frac{2 \times W}{35 \times 12} \left[\frac{1}{TP1''} + \frac{my}{L \times MT1''} \right] \int_0^a w\,(a - x)\,dx \qquad (19a)$$

Since the maximum bending moment on a section results from placing the weight directly above it, we know ΔM will have a maximum value at $y = \overline{AO}$. Now, referring to Fig. 12, and using the notation indicated, the resulting expression is:

$$\overline{AF} = \frac{2}{35 \times 12} \left[\frac{1}{TP1''} + \frac{m\overline{AO}}{L \times MT1''} \right] \int_P^A w\,(\overline{PA} - x)\,dx \qquad (20)$$

where: MT1" = moment to trim 1" at waterline in question
TP1" = tons per 1" immersion at waterline in question
w = ship's half breadth at waterline in question (a variable)
x = a variable between limits P and A
L = LBP
$\overline{AO}$ = distance between center of flotation and Section A
m = distance between center of flotation and center of moments for section A.

Converting (20) to units useful with Simpson's rule we have the following:

w represents the half breadths at each station = (B/2)
dx represents the station spacing S

($\overline{PA}$ - x) is equal to the lvr in feet about midships of each station = $lvr_{⊕}$ x S where $lvr_{⊕}$ is the numerical lever about ⊕ for each station; i.e., 0 for station 5, 1 for stations 6 and 4, 5 for stations 0 and 10.

Thus the equation (20) becomes:

$$\overline{AF} = \frac{2S^2}{3 \times 35 \times 12} \left[\frac{1}{TP1''} + \frac{m\overline{AO}}{L \times MT1''} \right] \Sigma f\,(B/2 \times lvr_{⊕}) \qquad (20a)$$

the 2 being for both sides of the vessel and the 3 being the 1/3 for Simpson's first rule.

The distance $\overline{AO}$ is positive with the center of flotation forward of the calculation station midships, for the calculation of $\overline{AF}$ with the aft end of the ship. It is negative with the fore end. This is reversed with the center of flotation aft of the calculation station, here midships. This is because, with the center of flotation forward of midships, a shift of the weight to place it over section A (see Fig. 11) causes a trim by the stern which makes f negative with respect to d when these quantities are measured at the forward center of moments B.

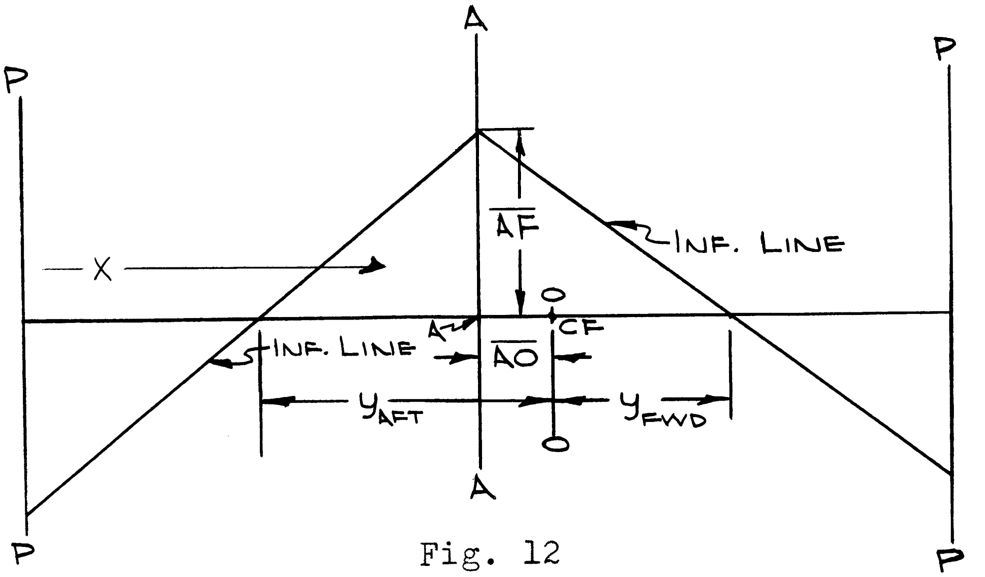


Fig. 12

In 20 and 20A above, W has been eliminated since the influence line will be calculated for a unit weight. $\overline{AF}$, however, retains the units of ft-tons/ton.

Now it remains to be shown how to get the intercepts y forward and aft, and then the influence line may be drawn. Referring once again to Fig. 11, if the weight is moved forward to such a position that -d = f, the ship will then be trimmed about section B on waterline W_oL_o, the center of moments for section A, and by previous definition ΔM must therefore be 0. Equating d and f gives:

$$-d = f \qquad (21)$$

$$-\frac{W}{12 \times TP1''} = \frac{Wym}{12 \times L \times MT1''} \qquad (22)$$

$$-y = \frac{L \times MT1''}{m \times TP1''} \qquad (23)$$

The minus sign in front of the y indicates that the weight was moved forward of the C.G. of the waterplane while the distance m was still measured to the center of moments aft of section A. Therefore numerically,

$$y = \frac{L \times MT1''}{m \times TP1''} \qquad (24)$$

This formula can now be used for finding the intercepts of the influence line with the base line, remembering that the forward intercept is obtained with value for m aft, and likewise the after intercept with the forward m. Formula 24, together with formula 20, which supplies AF (Fig. 12), and formula 15a, which shows that the influence line will be straight on either side of section A, allows the influence line to now be drawn.

It should be mentioned that the y values obtained above are measured from the center of flotation, not midships.

APPENDIX: Part 4 (Actual Calculation of Influence Line for United States Maritime Commission (USMC) Ore Carriers)

In this section, the actual calculations for the influence line are presented as carried out for the USMC ore carriers. Several important points should be noted in the interest of simplifying the work involved in calculating the line.

It is normal procedure in fairing the lines of a vessel with a large length of parallel middle body such as an ore carrier to divide the ship length into three distinct parts: the fore body, the parallel middle body, and the after body. The fore body and after body are then each divided into 10 stations and sub-stations for calculation of curves of form by Simpson's first rule. This introduces an undesirable amount of work in calculating the influence line, as was found in doing so for the SYKES. It is therefore recommended that after choosing a calculation length, this length should be divided into 10 equal parts, and after having drawn in stations on a plan view of the lines, offsets may be taken off the proper waterline. If there is no waterline corresponding to that chosen for calculation, it is simple enough to fair in one from body plan offsets taken at the desired waterline.

A word of caution with regard to the midships chosen for calculation is necessary. This, while being the point for which the influence line is being calculated, may not be the same midships as that for which the curves of form have been drawn since, in Great Lakes practice, there are liable to be several different lengths to choose from; i.e., L.B.P., L.W.L., L.O.K. and displacement length. One is, therefore, cautioned to make sure that the value for center of flotation taken from the curves of form either is measured from, or corrected to, the midships for which the line is being calculated. If there is any doubt, it is simplest just to calculate the center of flotation at the chosen waterline.

One other caution before entering upon the actual calculations. It is extremely important that the units be kept straight throughout the calculations. In the equations derived for the influence line, and in the final expression for the maximum ordinate (equation 20), the figure 35 ft^3/ton appears in the denominator. This, of course, means 35 cubic feet per long ton of 2240 lbs. If the vessel operates in salt water, and the curves of form have been calculated in long tons, this is correct. However, for fresh water and long tons this should be 35.9 ft^3/ton, and for fresh water and short tons this should be 32.0 ft^3/ton. It is necessary then to consult the curves of form to ascertain which units should be used.

The calculations follow for the USMC ore carriers and Fig. 13 is the influence line plotted as calculated, with the ordinates for various compartments recorded at their correct LCG aft of the F.P. It will be shown in the next section how this form of the influence line is useful in checking the line before converting it to the final tabular form such as that shown for the SYKES at the beginning of the paper.

Loading Diagram, USMC Ore Carriers

Light draft: 6'-4"
Freeboard draft: 23'-11½"
29'-15½" = 30'-3¼"

Mean of above: 15'-2"

Graphically from curves of form:

Draft giving average TP1": 12'-7"
Draft giving average MT1": 14'-6"

Use 13'-3" (favoring the TP1" mean draft)

Based on LOK (595'):595/2 = 297.5' from Sta. 0 & 10
(lines drawing based on LOK = 10 sta.)

$$b = \frac{Sy \sum f(B/2 \times lvr) - S \sum f(B/2 \times lvr^2)}{y \sum f(B/2) - \sum f(B/2 \times lvr)} \quad (8a)$$

b = location of center of moments for ⌀ from AP or FP
B/2 = half breadths
lvr = lever of each station about AP or FP (in stations)
S = station spacing = 59.5'
Sy = length forward or aft of ⌀ = 297.5' at 13'-3" WL

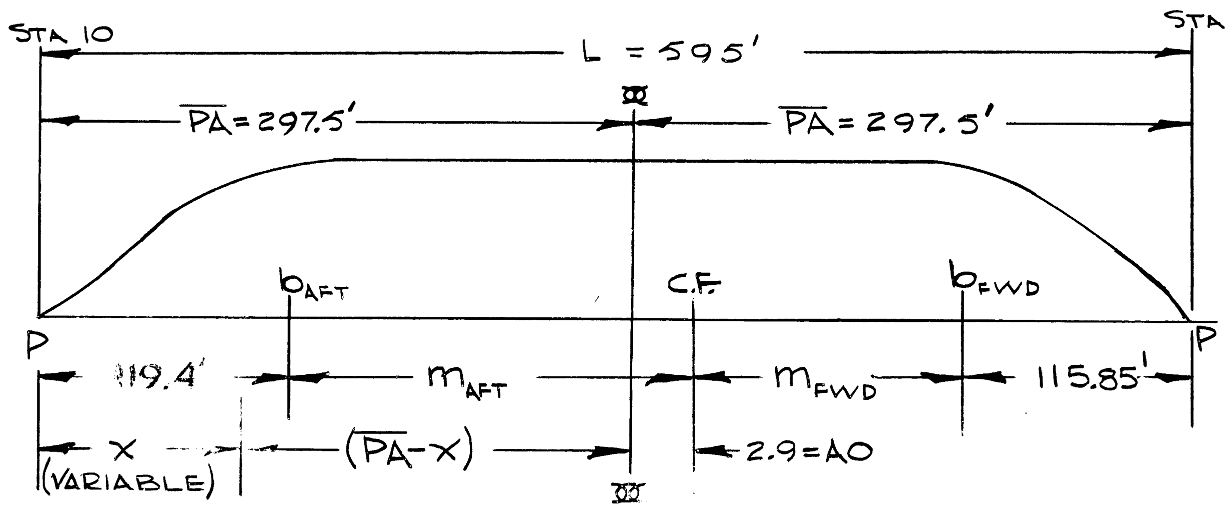
Sta	SM	B/2	f(B/2)	Lvr from Station 0 or 10	f(B/2 lvr)	f(B/2 lvr²)
0	1/2	0	0	0	0	0
1/2	2	18.54	37.08	1/2	18.54	9.27
1	1-1/2	26.75	40.12	1	40.12	40.12
2		30.00	120.00	2	240.00	480.00
3	2	30.00	60.00	3	180.00	540.00
4		30.00	120.00	4	480.00	1920.00
5	1	30.00	30.00	5	150.00	750.00
	15		407.20		1108.66	3739.39
5	1	30.00	30.00	5	150.00	750.00
6	4	30.00	120.00	4	480.00	1920.00
7	2	30.00	60.00	3	180.00	540.00
8	4	30.00	120.00	2	240.00	480.00
9	1-1/2	25.17	37.75	1	37.80	38.00
9½	2	15.17	30.34	1/2	15.20	8.00
10	1/2	0	0	0	0	0
	15		398.09		1103.00	3736.00

$$b_{fwd} = \frac{297.5 \times 1109 - 3739 \times 59.5}{5 \times 407 - 1109} = 115.85' \text{ aft of Sta 0}$$

$$b_{aft} = \frac{297.5 \times 1103 - 3736 \times 59.5}{5 \times 398 - 1103} = 119.4' \text{ fwd of Sta 10}$$

$$\overline{AF} = \frac{2}{12 \times 35.9} \left[\frac{1}{TP1''} + \frac{m(\pm \overline{AO})}{L \times MT1''} \right] \int_P^A w(\overline{PA} - x)\,dx \qquad (20)$$

$\overline{AF}$ = ordinate of influence line - ft-tons/ton
m = distance in feet from center of moments to longitudinal center of flotation
$\overline{AO}$ = distance from CF to ⊗ (or point of analysis)
L = length of ship
w = ship's half breadth at WL in question at station in question
$\overline{PA}$ = distance from FP or AP to section in question, here ⊗
x = variable fore and aft location



$m_{fwd} = (\overline{PA} - b_{fwd} - \overline{AO}) = (297.5 - 115.85 - 2.9) = 178.8$

$m_{aft} = (\overline{PA} - b_{aft} + \overline{AO}) = (297.5 - 119.4 + 2.9) = 181.0$

$$\overline{AF} = \frac{2S^2}{3 \times 12 \times 35.9} \left[\frac{1}{TP1''} + \frac{m(\pm \overline{AO})}{L \times MT1''} \right] \Sigma f(B/2 \times lvr_{⊗}) \qquad (20a)$$

Sta	SM	B/2	f(B/2)	lvr at midships	f(B/2)lvr ⦶
0	1/2	0	0	5	0
1/2	2	18.54	37.08	4-1/2	166.8
1	1-1/2	26.75	40.12	4	160.5
2	4	30.00	120.00	3	360.0
3	2	30.00	60.00	2	120.0
4	4	30.00	120.00	1	120.0
5	1	30.00	30.00	0	0
	15		407.20		927.3
5	1	30.00	30.00	0	0
6	4	30.00	120.00	1	120.0
7	2	30.00	60.00	2	120.0
8	4	30.00	120.00	3	360.0
9	1-1/2	25.17	37.75	4	151.0
9½	2	15.17	30.34	4-1/2	137.0
10	1/2	0	0	5	0
	15		398.09		888.0

$$\overline{AF} = \frac{2S^2}{12 \times 35.9}\left[\frac{1}{TP1"} + \frac{m(\pm\overline{AO})}{L \times MT1"}\right]\frac{1}{3}\sum f\left(\frac{B}{2}\right) lvr ⦶ \qquad (20a)$$

$$\text{fwd:}\ \overline{AF} = \frac{2 \times 59.5^2}{430.7}\left[\frac{1}{74.2} - \frac{178.8 \times 2.9}{595 \times 3010}\right]\frac{927.3}{3} = 67.45 \text{ ft. L.T./L.T.}$$

$$\text{aft:}\ \overline{AF} = 16.45\left[0.013475 + \frac{181 \times 2.9}{595 \times 3010}\right]\frac{888}{3} = 67.07 \text{ ft. L.T./L.T.}$$

average: $\overline{AF}$ = 67.26 ft. L.T./L.T.

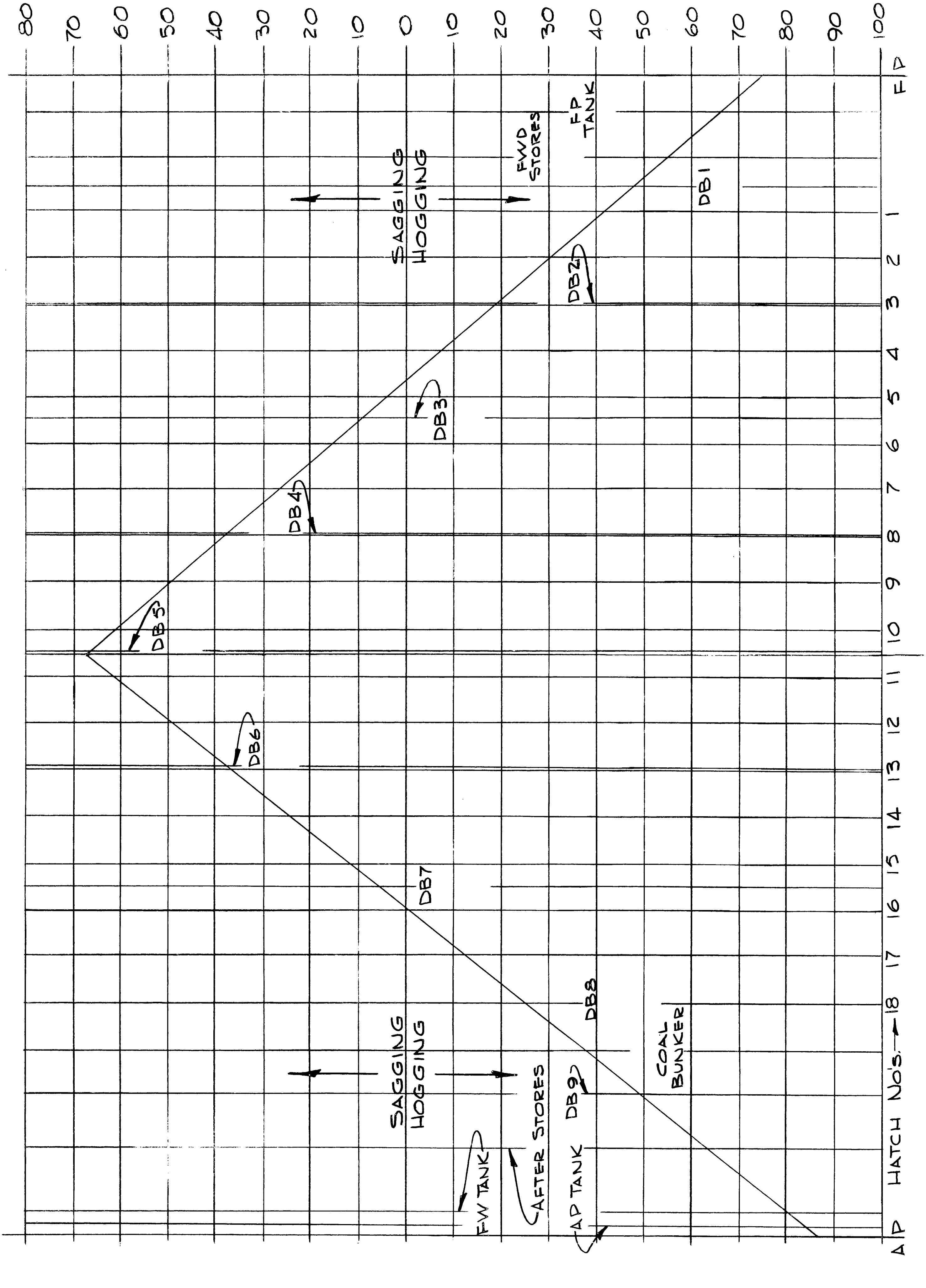
$$y = \frac{L \times MT1"}{m \times TP1"} = \frac{595 \times 3010}{m \times 74.2} = \frac{24130}{m}$$

fwd: $y_{cF} = \frac{24130}{181} = 133.3$ ft.

aft: $y_{cF} = \frac{24130}{178.8} = 135$ ft.

fwd: $y_{⦶} = y_{cF} + \overline{AO} = 133.3 + 2.9 = 136.2$ ft.

aft: $y_{⦶} = y_{cF} - \overline{AO} = 135 - 2.9 = 132.1$ ft.



80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70 80 90 100
SAGGING
HOGGING
FWD STORES
FP TANK
DB1
DB2
DB3
DB4
DB5
DB6
DB7
DB8
DB9
COAL BUNKER
SAGGING
HOGGING
AFTER STORES
FW TANK
AP TANK
FP
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
HATCH No's.
AP

FIG. 13

APPENDIX: Part 5 (Checking the Accuracy of the Influence Line)

Now that the influence line has been drawn (Fig. 13), it is necessary to check its accuracy. This was found to be necessary when certain loading conditions were found to give erroneous bending moments in both the cases of the SYKES and the MUNSON.

The first step in checking the line is to decide upon what lightship bending moment is to be used. This problem was touched upon in section 3 (page 8), and must be considered again at this time. As was explained in the section on influence lines, the line serves to show the effect on the bending moment of a change in position of a weight. We have modified its use for our purposes to show the change upon an already existing bending moment of the addition of a weight or weights. Thus, we must have an accurate idea of the bending moment in some actual condition of loading, and then use the influence line to note the changes in this existing bending moment caused by the addition of weights. The most logical condition to start from is some form of lightship bending moment at midships, since this is one of the worst conditions the ship experiences and, therefore, accuracy is desirable in this base condition. Now, by the use of the influence line any weights may be added or subtracted, and thus effect upon the base bending moment is the product of these weights times the influence line ordinate at the proper longitudinal position in the ship. Proper regard must be paid at all times as to whether the change in bending moment is either hogging or sagging. This is basically the process by which the influence line is checked; applying loading conditions with known bending moment, summing the hogging and sagging moments as found by the line, applying the lightship bending moment, and then comparing the result with the known bending moment.

Before actually going through this process, it should be said that the lightship bending moment may be modified if this is thought advisable. Thus if the lightship bending moment available is for a condition with much fuel and stores aboard, and it is desired to have a lightship bending moment with nothing on board, these weights may be taken off by use of the influence line, and the resulting bending moment used as the lightship bending moment in all further calculations. The error involved is small at most since these weights are usually quite small, and if the line is accurate no error of course will result. In all further calculations, however, including the final table, these weights, when present, will have to be added again. It is therefore thought to be advisable, as mentioned before, to include in the lightship bending moment certain average amounts of stores and fuel which will usually be on board the ship at all times.

Getting back to the checking of the line, once a lightship bending moment, and corresponding loading if any, has been decided upon, it is simply a process of checking the bending moment produced by the line against that known from strength curves. This is done for as many loading conditions as are available with known bending moments, always comparing the bending moments at the chosen section, here midships, since this is the only section for which the line applies.

If large discrepancies result, as they did in the case of the SYKES and MUNSON, the procedure for changing the line is as follows. First note which types of bending moments produced by the line are too small or too large, the hogging or the sagging, and also note by what amounts they vary from the correct value. If both hogging and sagging bending moments are too large, this means that the slope of the influence line is too great and should be reduced. Conversely if they are both too small, the slope of the line should be increased. If the hogging moments are too large, and the sagging ones too small, this means that the line is too high with regard to the base line, and should be moved down, parallel to itself. If the reverse is true, it should be moved upwards, parallel to itself.

The amount by which the line should be shifted, if this is indeed necessary, is only found by a process of trial and error combined with further checking of the line against known conditions of loading and bending moment. The following guide may be given, however, regarding parallel shifts of the line; that is, shifts dictated by hogging bending moments being too large and sagging too small or vice versa. In all conditions which show these discrepancies, take the excess or deficiency in total bending moment due to weights added, plus lightship, and divide it by the amount of weight added, and this will be the amount by which the line should be shifted. Thus, if for a certain condition, the hogging bending moment produced by weights amounting to 20,000 long tons and the lightship, was found to be 40,000 ft-long tons too large, the line should be shifted downwards, parallel to itself, 40,000/20,000, or 2 ft-LT/LT.

This is about all the advice that may be given as to checking the line other than to say that in noting discrepancies in bending moments, much more weight should be given to correcting discrepancies when the bending moment is large than when it is small, as the purpose of the table is to guard against truly dangerous loading conditions. It is not concerned with discrepancies in bending moments which produce stresses well below the maximum allowable stress.

No actual checking calculations are presented here, as they are believed to be self-explanatory and would only add unneeded bulk to the paper.

APPENDIX: Part 6 (Conversion of Influence Line to Tabular Form Loading Table)

After having corrected the influence line as mentioned in the last section, there are two remaining steps which bring the line into its final tabular form.

First of all, an appropriate allowable stress is decided upon, say 10,000 psi. Then, with the minimum section modulus (I/y) of the ship being either known or calculated, the maximum allowable bending moment may be calculated since,

$$\text{Stress} = My/I$$
$$\text{Bending Moment} = I/y \times \text{stress}$$

For the USMC ore carriers this worked out as follows:

$$\text{Stress} = 10{,}000 \text{ psi} = \frac{10{,}000}{2{,}000} = 5 \text{ short tons/sq.in.}$$

$$\text{Min. } I/y = 26{,}348 \text{ in}^2\text{ft}$$

$$\text{Max. allowable B.M.} = 26{,}348 \times 5 = 131{,}740 \text{ (s.t.-ft)}$$

We now assign to this stress the stress numeral 100, which represents the safe allowable bending moment.

Next an appropriate unit of weight is picked with due regard to the remarks on this subject in Section 3 (page 8). For the USMC vessels this unit was short tons/100. Now to convert the influence line ordinates to a stress factor, the following steps are necessary.

Since weights are going to be entered in the tabular form as short tons/100, we need this stress factor, by which the weight is multiplied to give the stress numeral, to take into account the fact that the unit weight being added is no longer of 1 short ton but one of 100 short tons. This, in effect, means that the influence line should be replotted in terms of the new unit weight of 100 short tons, and thus all ordinates are multiplied by 100. Now since the stress numeral 100 has been assigned to a definite bending moment, here 131,740 short ton-ft., it is now possible to convert all ordinates to stress factors as follows.

If an influence line ordinate had been say 50 ft-short tons/short ton, it is first changed to 5000 because of the change in unit weight, and the addition of 1 new unit weight of 100 short tons would change the B.M. moment by 1 x 5000 = 5000 short ton-ft. This bending moment is equivalent in our chosen stress numeral system to 5000 x 100 divided by 131,700 = 3.79 stress numeral. Thus, since we used a unit weight to arrive at the stress numeral, this is the stress factor for an influence line ordinate of 50 ft-short tons/short ton. Conversions of all ordinates is carried out similarly. In equation form this could be indicated as follows:

$$\text{Preliminary stress factor} = \frac{\text{(Influence ordinate)} \times 100}{\text{Max. allowable bending moment}}$$

The stress factors arrived at in this method for all compartments in the ship should be known as preliminary stress factors for the reason presented below.

In changing the influence line ordinates to stress factors, it is still necessary to keep hogging and sagging factors in mind. This, of course, results in summing hogging and sagging bending moments separately, as their signs are different. To get away from this inconvenience in the final loading table, the base line is moved either up or down until it passes the ends of the influence line and lands on an even stress factor. To keep consistent with standard beam convention, in which sagging bending moments are plus, this means that the line should be shifted downward. In the case of the USMC ore carriers, the preliminary hogging stress factors had a maximum value of 6.97; the line was, therefore, moved downwards by the amount of 7 units of stress factor. Then to arrive at the final stress factors, all hogging preliminary stress factors had 7 added to them. Thus all stress factors will now be of the same sign and the stress numerals may all be summed together. All weights added to the ship have, however, as a consequence of this change been multiplied by a stress factor equivalent 7 units sagging. Therefore, the total of all weights added must be multiplied by 7 and this product subtracted from the summation of all stress numerals to get the actual effect upon the bending moment of all weights added. This will be known as the deadweight correction.

Lastly the lightship bending moment must be applied to the resultant stress numeral from above, and it is therefore convenient to have it in terms of a stress numeral. For the USMC ore carriers the lightship bending moment was 113,663 ft-short tons, and since 131,740 ft-short tons was equivalent to a stress numeral of 100, the lightship stress numeral is equal to:

$$\frac{-113,663}{131,740} \times 100 = 86.3$$

Since the lightship bending moment was hogging, and we have made a hogging stress numeral minus in our convention, this numeral is -86.3. When applied to the resultant stress numeral, after application of the deadweight correction and with due regard to signs, the stress numeral for the particular loading condition is obtained, a plus sign indicating sagging and a minus sign hogging. Fig. 14 and 15 show the final table for the USMC ore carriers along with instruction sheet. Fig. 16 and 17 show the same for the steamer JOHN G. MUNSON. As can be noticed the table for the MUNSON is somewhat simpler than that for the USMC vessels. This is due to combining several items of stores in the lightship bending moment. The table for the SYKES (Fig. 1) is the simplest due to the combining of all items of stores in the lightship bending moment. It, of course, has no space for ballast tanks, which is a drawback.

If the table was thought to be useful by a ship operator, it could be made up in any one of the forms mentioned above, and then several blank copies could be printed and supplied for the use of the ship's personnel, along with the appropriate instruction.

For those who might be interested in constructing a table, a list is given below of the drawings that are needed:

1) Curves of form
2) Lines plan
3) Inboard profile with LCG's.
4) Any curve showing minimum I/y, or midship section so that it may be calculated
5) As many strength curves as are available, including one with lightship bending moment.

LOADING TABLE FOR USMC ORE CARRIERS

Line No.	Compartment	Weight Short Tons / 100 (a)	Bending Moment Factor (b)	Bending Moment Numeral (c)
1	Hatch #1		3.71	
2	2		4.59	
3	3		5.44	
4	4		6.32	
5	5		7.21	
6	6		8.09	
7	7		8.97	
8	8		9.85	
9	9		10.74	
10	10		11.65	
11	11		11.66	
12	12		10.76	
13	13		9.77	
14	14		8.87	
15	15		7.91	
16	16		6.97	
17	17		6.01	
18	18		5.07	
19	F.P. Tank		1.88	
20	D.B. # 1		3.23	
21	2		5.41	
22	3		7.61	
23	4		9.83	
24	5		12.06	
25	6		9.81	
26	7		7.45	
27	8		5.09	
28	9		3.28	
29	A.P. Tank		0.58	
30	Bunker		4.13	
31	Fwd stores		2.71	
32	Aft stores		2.15	
33	Fresh water tanks		0.86	
34	Sub-total lines 1-33 →		X	
35	LIGHT SHIP →		X	-86.3
36	Subtotal lines 34+35	Displ./100	X	
37	Dead-wt. corr. 7 x (line 33-a)	X	X	-(7 x line 34)
38	Resultant Numeral	X	X	Numeral

Fig. 14

INSTRUCTIONS FOR USE OF LOADING TABLE

USMC Ore Carriers

1) Enter all weights added in units of short tons divided by 100 in column (a) on the line corresponding to the compartment to which the weight was added.

2) Multiply all numbers in column (a) by the appropriate factor in column (b) and enter products in column (c).

3) Add all entries in column (c) and enter total in line 34, column (c). Subtract line 35 (c) from line 34 (c) and enter difference on line 36 (c).

4) Add all entries in column (a), lines 1-33, and enter total in line 34 (a). Multiply line 34(a) by 7 and enter product as a minus quantity in line 37(c).

5) Subtract line 37(c) from line 36(c) and enter difference in line 38(c). This is the resultant stress numeral for the particular loading condition. If it is positive, it indicates a sagging condition; if negative a hogging one. If it is over 100, either positively or negatively, it indicates an undesirable loading condition.

Fig. 15

LOADING TABLE FOR John G. Munson

Line No.	Compartment	Weight Short tons / 100	Bending Moment Factor	Bending Moment Numeral
		(a)	(b)	(c)
1	Hatch #1		3.90	
2	2		4.55	
3	3		5.21	
4	4		5.87	
5	5		6.50	
6	6		7.15	
7	7		7.75	
8	8		8.41	
9	9		9.04	
10	10		9.68	
11	11		9.17	
12	12		8.53	
13	13		7.82	
14	14		7.16	
15	15		6.45	
16	16		5.74	
17	17		5.14	
18	18		4.44	
19	F.P. Tank		1.66	
20	D.B. # 1		2.89	
21	2		4.55	
22	3		6.50	
23	4		8.41	
24	5		9.17	
25	6		7.16	
26	7		5.14	
27	8		7.28	
28	A.P. Tank		0.89	
29		(Lines 1-28a)		(Lines 1-28c)
30		+ 87.43		- 94.3
31		Displacement		Diff.
32				6 x(Lines 1-28a)
33				Resultant Stress Numeral

Fig. 16

INSTRUCTIONS FOR USE OF LOADING TABLE

STR. John G. Munson

1) Enter all weights added in units of short tons divided by 100 in column (a) on the line corresponding to the compartment to which the weight was added.

2) Multiply all numbers if column (a) by the appropriate factor on the same line in column (b) and enter the products in column (c).

3) Add all entries in column (c) and enter the sum on line 29(c). Subtract line 30(c) from line 29(c) and enter difference on line 31(c).

4) Add all entries in column (a), lines 1-28, and enter sum on line 29(a). Multiply line 29(a) by 6 and enter product as a minus quantity in column (c), line 32.

5) Subtract line 32(c) from line 31(c) and enter difference on line 33, column (c). This is the resultant stress numeral for the particular loading condition investigated. If it is positive, it indicates sagging; and if it is negative, it indicates hogging. If it is over 100, either positively or negatively, the loading condition is undesirable.

Fig. 17

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