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The Long Ships into the Seventies

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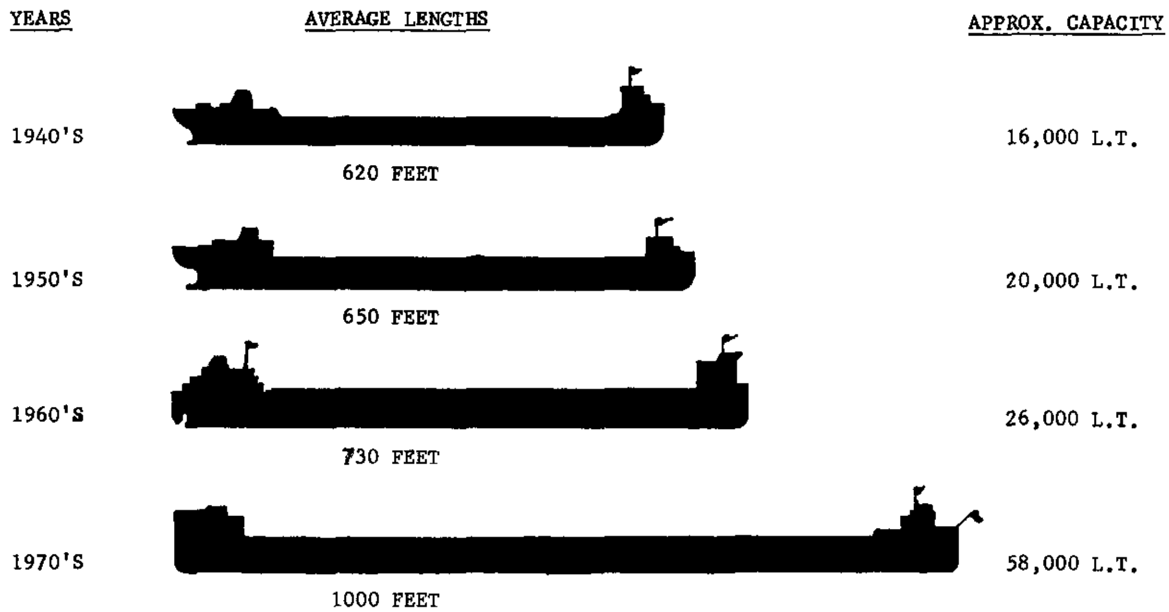


THE EVOLUTION OF GREAT LAKES VESSELS

ABSTRACT

In 1969, with the opening of the new Poe Lock connecting Lake Superior to its four sisters, a resurgence of shipbuilding on the Great Lakes began with a quantum jump in the allowable size of vessel. New design criteria were needed and the marine community, research organizations, governmental groups, and the regulatory bodies entered into a cooperative venture to develop and assess these criteria.

This paper outlines, from an operator's viewpoint, what should be considered in developing new strength standards and, in addition, outlines the history of the research effort to define the ship environment and its loads. It also presents a summary of some of the full scale data and provides a starting point for those interested in further research.

PART I

In developing the general topic of "Yesterday's Technology, Today's Ships", the authors intend to first present the thoughts of the ship operator and then pursue a more technical review of regulatory criteria. From a Great Lakes ship operator's view, it is submitted that the term "technology" in the past few years has been given an interpretation that is far too limited. It has in the eyes of many simply become a section modulus calculation.

In stepping back in lake history to the period of 1900 to 1930 when a great many steel hulled vessels were built, one can observe that the design and operation of this type of vessel has been successful. This basic design has served well in many different adaptations and it was the transportation mainstay for the delivery of iron ore to the nation's steel mills all during World War II.

A historic and most valuable source of information pertaining to load lines, bulkheads and strength of Great Lakes vessels is contained in a General Committee Report prepared in 1921 and submitted to the United States Government Committee by Rear Admiral D. W. Taylor, U.S.N., Chairman. This report traces in great detail the background of the Great Lakes vessel and its unique design needs. The criteria today is the same as yesteryear and can be simply stated as the necessity of lifting the greatest amount of bulk cargo within the dimensional confines of docks, channel depths and lock size.

This report picked up lake history at the point where the wooden ship had been replaced by the steel hulled vessel. As it would be expected, the steel vessel was shown to be clearly superior in every respect, yet there were losses. In the three-day great storm of 1913, nineteen vessels were lost of which eight were of the then modern steel design and two were of the ocean tramp type. Little is known about the exact details of these casualties because of the lack of survivors. One of the vessels, however, the Str. CHARLES S. PRICE was observed in the lower end of Lake Huron floating intact but upside down. During the last few years scuba diving and wreck exploration have become very popular on the lakes and many sunken hulls have been discovered. To the best of our knowledge, none of these ships, built prior to 1921, were lost due to hull structural failure. For the most part, it appears that the cause of sinking was from collision or foundering. Of the ships built since then, only two are known to have been lost due to structural failure. As a matter of interest both of these vessels were in ballast when the loss occurred. The point of this is that the designers of 1920 based their calculations on an assumed maximum wave length of 350 feet where modern data indicates that, on occasion, it is possible to encounter a wave length approaching 700 feet. This is a 100 percent discrepancy on the dilemma side of a most important design factor.

Now the question is - how is it that these hundreds of ships have had so successful a service record, many in excess of sixty years? It is felt that the answer lies among the following four factors. Only the first one is a true design consideration. The other three are of an environmental or operational nature.

The first factor of design is that the permissible stress in tons per square inch used in the 1921 strength calculations was assumed to vary as the one-third power of length expressed in feet. This assumption would appear by the record to be on the conservative side and thus has allowed for occasional peaks in low frequency wave stress as well as the newly discovered but always present high frequency springing stress.

The second factor of environment is that these vessels are in fresh water service. Corrosion is not normally very harmful to strength even after sixty years. The only areas that show wastage are poorly drained pockets or those subject to flexing. The flexing and thinning action usually occurs in the inner bottom structure where there is at the same time an offsetting factor of lower stress. The upper or spar deck along with the sheer strake is most generally subjected to the highest stress and by like token the least corrosion and/or physical damage. The vessels now regularly operating in the seaway are, of course, in brackish water when beyond Quebec. This exposure would usually run less than 10 percent of their time and to date has not appeared to be a problem.

The third factor of operation is that through all the years up to the recent times, the lake vessels have been laid up from late December until April. During this annual period the vessels are inspected and there is ample time to carry out a complete topside maintenance program. This annual and thorough preventive maintenance along with a United States Coast Guard recertification inspection at fitout undoubtedly contributes to keeping the vessels truly shipshape.

The fourth factor, also operational, has probably the most bearing on the success of these vessels and is the least recognized. This factor is prudent ship handling on the part of well-experienced Masters. This all-important trait has been in existence for over seventy years as evidenced by THE NEW YORK TIMES' article written in 1905 after a casualty on Lake Superior: "Salt water sailors are apt to speak with derision not always mild of their brothers on the Great Lakes and, of course, the two branches of the nautical family do differ in many respects. The men of the ocean should remember, however, that the navigators of the Lakes have not in some storms, but in every one they encounter, a lee shore close at hand, a circumstance well calculated to develop seamanship of no little skill and courage." A typical lake Captain will have sailed over thirty seasons and traveled the 1500 miles round trip from the lower lakes to upper lakes some 1,000 times. He, therefore, is totally familiar with the courses, aids to navigation, traffic patterns, harbors of refuge, pecularities of the weather and sea patterns, and the responses of his vessel. He is constantly aware of the lee and weather shores and strives to adjust his ship's speed, course, and ballast water to eliminate heavy going or excessive springing.

The opening of the Poe Lock at Sault Ste. Marie in June of 1969 made it possible to utilize vessels 1,000 feet in length. The seventies have already produced two 1,000 footers, three 800 footers and a number of vessels just under 800 feet. There are in addition to this at least eight more 1,000 footers on order so that Long Ships Into The Seventies is not a design dream but a real design challenge.

As with any truly successful design, we find that it is made up of good basic ingredients and a multitude of delicately balanced compromises. It would seem that we are in a most opportune position to develop new designs through technology. This technology should extend well beyond the old one-two punch of load line and section modulus. It should also give meaningful consideration to the use of high quality materials, details eliminating stress concentrations and a realistic corrosion allowance. Two other areas of technology that are relatively untapped are operational limitation of bending moment and the use of weather forecasting.

A reliable twenty-four hour forecast is all that is needed as this is the longest period of time in open water on the Great Lakes. There is at the present time an active and basic research program being carried out at the Naval Research and Development Center and at Webb Institute to unravel the mechanism of how the dynamic forces produced by waves and springing combine to form a resultant stress. There is also work being done to improve weather forecasting. All of the foregoing properly blended with prudent ship handling should result in the design of a safe, economical and productive ship. This is the ship that the industry and the nation needs and the one that a full application of technology can supply.

PART II

INTRODUCTION

The Great Lakes and St. Lawrence Seaway bulkers have been dubbed the "Long Ships". Even though they have been equaled and surpassed in length by salt water vessels they still retain the title for the simple reason that they appear extraordinarily long. And for good reason. Their trade routes impose dimensional restrictions that make their depths and beams small in relation to their length giving the lakers the appearance of an expensive cigar.

The primary cargo moving in these bulkers on the Great Lakes is iron ore. The ore is loaded into and out of these vessels by what once was very efficient materials handling equipment developed for older, narrower vessels with less of a depth than is necessary with today's lengths. They travel through connecting waterways that limit their drafts and through locks that limit their lengths and beam.

Boundary conditions controlling design are not unusual in naval architecture. Seldom however, do they result in such unique ship proportions and seldom are the demands for economic transportation more severe. The steel industry, faced with a need to develop domestic sources in the national interest, the instability of South American ore sources and high demand are investing heavily in the development of domestic sources and need to move larger tonnages. The operators, faced with ballooning fuel costs, increasing labor cost, and the growing cost of domestically built vessels need to be ever alert to means of increasing carrying capacity with minimal cost increases.

Table 1 Summary Table Of Peak Wave Lengths (Feet)

	Median Value Of Peak Wave Lengths					1% - Value Of Peak Wave Lengths					Peak L To Be Expected Once A Year
	Up To Sept.15	Sept. 16-30	Oct. 1-31	Nov. 1 To End	Entire Season	Up To Sept.15	Sept. 16-30	Oct. 1-31	Nov. 1 To End	Entire Season	
North Superior	57	125	130	130	66	200	300	450	450	300	700
Battle Island	56	75	75	60	70	200	350	350	350	260	500
Grand Marais	56	100	100	100	80	250	425	425	425	320	600
Eagle Harbour	60	70	80	110	85	225	250	350	400	370	625
Cap Chat	80	100	100	100	90	275	400	400	400	330	625
Cap d'Espoir	100	120	120	120	100	350	400	400	400	380	700
Sept Isles	100	120	90	120	100	315	480	480	480	410	825
West Point	115	160	160	140	120	315	500	560	560	410	825
North Point	60	90	120	120	100	300	230	400	500	450	925
East Point	100	100	100	140	100	350	400	400	500	375	600
Bird Rocks	150	180	180	250	180	450	650	650	800	600	1100
Heath Point	140	-	200	200	150	600	-	525	525	550	1250
Cape Whittle	160	150	150	230	160	410	315	315	750	525	1100
Cape North	200	375	280	-	225	800	1250	580	-	1000	1250

Composite of Data for 1965, 1966, 1967.

The societies and governmental agencies must try to meet these needs with rational and reasonable classification criteria and assurance that safety of life at sea is maintained. The designer must attempt to consolidate these demands into an efficient, safe product at a reasonable price.

The industry has attempted to meet its requirements in three ways: vessel size increase, draft improvements and longer seasons. All four groups-industry, the classification societies, governmental agencies, and the designer have attempted to evaluate the desired changes in an intelligent manner. Thus, the urgent need for research on the Great Lakes was established.

RESEARCH AND THE GREAT LAKES ENVIRONMENT

Load Line Revisions

Study of the Great Lakes and Gulf of St. Lawrence wave environment was initiated in 1961, under the impetus of requests to sail lakers in the Gulf. The first approach was to determine the similarity between the Gulf and Lake Superior environments. Wave hind casting studies were followed by the gathering of data from submerged pressure cells and floating accelerometer wave recorders. The results of these studies were published in Reference (1). Tables 1 and 2 and Figures 1 and 2 are reproduced from a review of that report (2) showing the summaries of significant wave heights and lengths and the locations of the measurements.

Table 2 Summary Table Of Significant Wave Heights (Feet)

	Median Significant Wave Heights					1% - Significant Wave Heights					Signif. Wave Hgt. To Be Expected Once A Year	Maximum Observed Individual Wave Height
	Up To Sept. 15	Sept. 16-30	Oct. 1-31	Nov.1 To End	Entire Season	Up To Sept. 15	Sept. 16-30	Oct. 1-31	Nov.1 To End	Entire Season		
North Superior	1.0	1.8	1.6	2.4	1.3	4.5	5.4	8.8	10.0	7.0	15	18
Battle Island	1.4	2.0	2.2	2.4	1.5	4.4	5.3	11.0	9.0	7.8	15	22
Grand Marais	1.2	2.6	2.8	2.5	1.9	7.0	11.5	16.0	13.0	12.8	25	35
Eagle Harbour	1.5	3.5	3.2	3.7	2.0	6.5	10.0	16.0	21.0	14.0	29	34
Cap Chat	1.6	2.7	2.5	2.8	2.0	6.0	7.5	12.0	10.0	9.0	17	26
Cap d'Espoir	2.1	3.0	2.7	2.6	2.5	8.1	13.0	10.0	13.0	11.0	21	34
Sept Iles	1.8	3.0	2.3	2.5	2.2	7.2	12.0	8.0	10.0	9.0	16	25
West Point	2.6	4.0	4.0	3.7	3.0	8.0	17.0	15.0	17.0	13.0	26	40
North Point	1.9	3.0	3.7	3.6	3.0	7.0	6.4	9.4	12.5	10.0	18	24
East Point	2.5	2.7	3.8	4.2	3.0	8.5	9.0	11.0	13.0	11.0	19	24
Bird Rocks	3.5	4.5	5.0	6.2	4.5	11.0	14.0	14.0	18.5	15.0	25	38
Heath Point	3.0	---	4.0	5.2	3.5	8.5	---	13.0	18.0	12.0	20	30
Cape Whittle	3.5	3.8	3.8	4.7	3.6	8.4	9.2	10.0	16.0	11.5	19	30
Cape North	4.0	5.5	5.5	10.5	4.7	11.0	16.0	14.0	25.0	15.0	25	38

Composite Of Date For 1965, 1966, 1967

The direct result of these studies was the rational analysis of the 1966 International Load Line Regulations by the U. S. and Canadian Joint Technical Committee on the Great Lakes Load Lines and their adoption for vessels in 1968 of the international freeboard standards for B Class vessels. The regulations resulted in the extension of the load lines to the new lengths of vessels, up to 1,000 feet, where formally no standards existed, and the initiation of a lengthening program that only proved economic under the new rules for freeboard. Seven of these lengthenings have been completed, in time spans approximating the winter layup period, with deadweight increases of between 28 and 30 percent.

For the unlengthened vessels the results were equally satisfying; added draft that permitted a deadweight increase of up to 700 L.T. for seaway sized vessels (730 feet by 75 feet). Since the Great Lakes is in a cycle of high water this additional draft means additional usable deadweight.

In addition to the adoption of a new standard, knowledge of the wave environment permitted a review of the seasonal load line periods to determine whether the cut off dates were reasonable in relation to the expectable sea states. This review led to a two-week extension of the period during which the deepest (midsummer) load line could be used. The extension can be interpreted as adding 2½ percent to the summer draft for two more trips a season. For a 730 footer this amounts to an additional 1500 L.T. deadweight for the season; not much, but a step in the right direction to combat increasing operational costs.

The background for these changes to the freeboard requirements are detailed in Reference (3).

Winter Operations

On the premise that a capital investment as large as that represented by a fleet of ships cannot economically be left idle, the Maritime Administration, the U. S. Coast Guard, and lake operators have participated in a program initiated by Congress for extending the Great Lakes season of operation into the winter. The University of Michigan Department of Naval Architecture developed a mathematical model, the Extended Season Program (ESP) reported in Reference (4) to allow parametric studies of variations of ship proportions, trip times, speed, power, operational costs, capital costs and stockpile costs; all as affected by longer operations into the normally dormant winter season.

Ice coverage studies under the auspices of the U. S. Coast Guard and National Oceanic and Atmospheric Administration (NOAA) have been conducted.

Studies of ship bow configurations for ice operations have been made and reported in Reference (5).

The feasibility of using newly developed navigational aids capable of withstanding the rigors of ice and winter weather has been studied by the U. S. Coast Guard and Maritime Administration with the cooperation of operators.

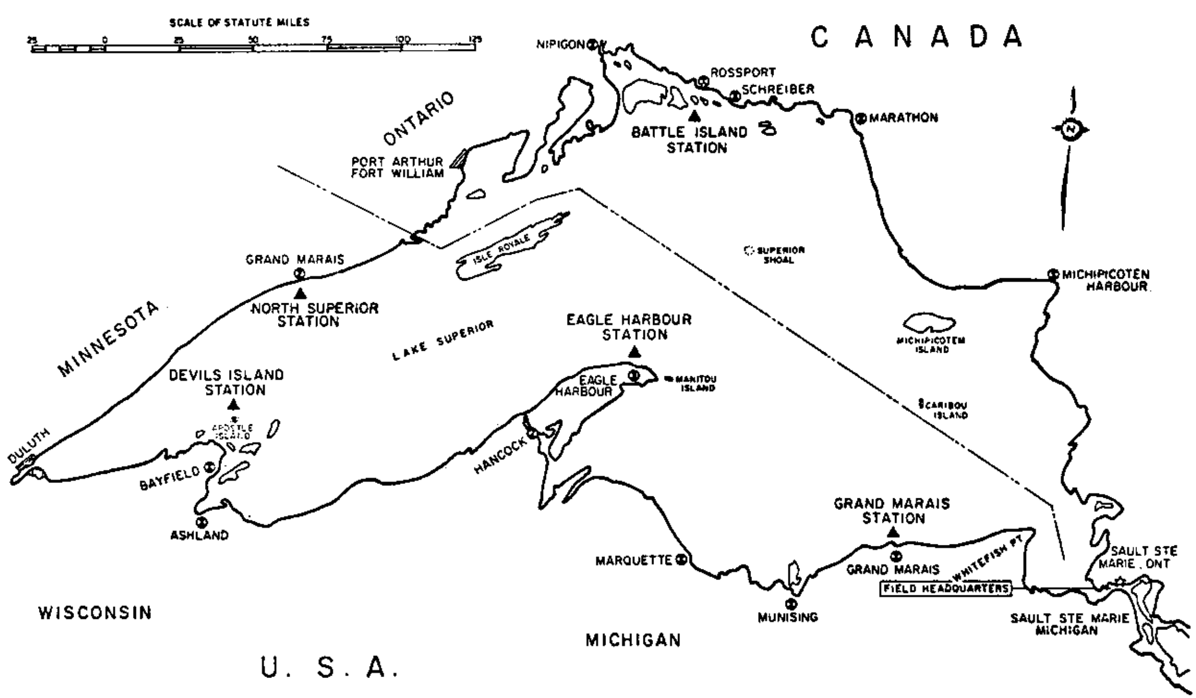


FIG. 1 LAKE SUPERIOR WAVE RECORDING STATIONS

The U. S. Coast Guard has conducted operational tests of survival gear capable of being used in sub-zero winter environments.

Operators have run vessels for progressively longer periods into January, February, March and April for seven winter season to assess the problems and capabilities of ships and men in this environment.

The information developed over the last seven years can only be alluded to here. Synthesizing the large volume of data gathered on this subject into a unified and rational whole could be the subject of an extensive paper in itself. Suffice it to report that, pending the completion of these studies and their environmental and societal impact, improved economy of operation through winter operations seems to offer promise.

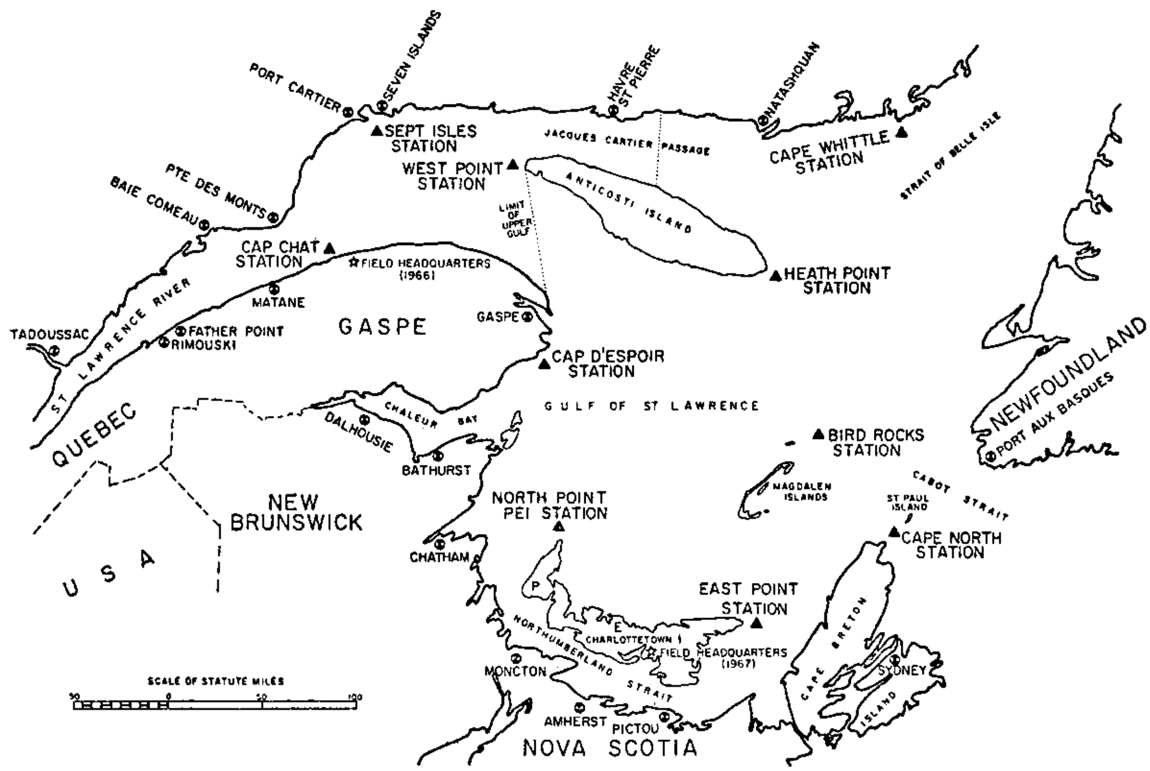


FIG. 2 GULF OF ST LAWRENCE WAVE RECORDING STATIONS

Strength Standards

When the Corps of Engineers announced their plans in 1959 to construct a new lock at Sault Ste. Marie connecting Lake Superior with the four lower Great Lakes there were no plans for designs of vessels to take advantage of the increased dimensions. When it was opened and christened the "Poe" in 1969 there were two vessels nearing completion, the ROGER BLOUGH and the STEWART J. CORT, that required the lock in order to transit between the lakes. One of these the CORT, utilized its permissible dimensions, 1,000 foot by 105 foot beam, to their fullest.

Today there is a fleet of ten in operation and eight more under construction or planned, all in the 800 to 1,000 foot range, requiring the lock in order to move their cargo.

It had taken from 1943 to 1960 to reach the 730 x 75 limiting dimensions of the MacArthur Lock. Within two years of the Poe Lock completion in 1969 the 1,000 x 105 foot limits were reached and again limiting design.

Design had previously progressed at a leisurely pace with time for review and assessment of relatively small changes. Now there was a quantum jump in size, over 35 percent in length and practically 100 percent in deadweight, that raised questions about the extension of previously developed design criteria.

The industry, faced with extrapolation of existing empirical strength standards or the development of rational standards using the technology and environmental knowledge that was now available took the only course available. An organized research program was carried out, a strength standard developed, and a design assessment procedure instituted.

Through the 1965, '66, '67 and '68 seasons the EDWARD L. RYERSON, instrumented with strain gauges, engaged in maneuvering tests and measured sea states with wave riding buoys concurrently with strain measurements. These data are documented in Reference (6).

The SEAWAY QUEEN, ONTARIO POWER and SAGUENAY were instrumented in a similar manner from 1964 through 1966 gathering strain gauge data.

The information from the ONTARIO POWER, advance data from the '65-'66 RYERSON season and sea spectra data from the '65-'66 season of the Canadian Wave Climate Study along with unpublished information were synthesized to develop the 1968 Interim Strength Standard adopted by the Canadian-U.S. Great Lakes Load Line Joint Technical Committee. The standard was recommended to the two governments for acceptance on an interim basis.

The background and development of this standard and all of the associated research was reported in a SNAME symposium in Ottawa in 1971, "Hull Stresses in Bulk Carriers in the Great Lakes and Gulf of St. Lawrence Wave Environment", Reference (7). A survey of the data acquisition and assessment since that time will be the subject of the remainder of this discussion.

EVALUATION OF THE STRENGTH STANDARD

Background

After the data gathered from the full scale strain gauge recordings on the ONTARIO POWER was assessed in Reference (8) there was very little doubt that the primary loads on the ship's hull girder arose from three sources: a bending moment created because of the static vessel loading (still water), the bending moment arising out of the change in support of the hull girder due to wave action (wave or low frequency bending), and an additional bending moment resulting from the hull vibrating in its first frequency mode (springing or high-frequency bending).

Obviously there are other loads entering into the straining of the hull girder: torsion, slamming and the vibratory motions set up by this action, hydrostatic and local loadings and many more. The establishment of a basic hull girder strength however had previously been based on wave and still water bending moment assessments with recognition that springing existed but with a tacit assumption that it was taken care of implicitly in the requirements by the safety factor and the experience of safe operation. The cause and magnitude of springing strains were unknown, unstudied and apparently inconsequential.

The RYERSON studies provided quantitative data on the magnitude of springing stresses, stresses that could at times exceed those arising from wave action and provided a clue to their source.

Springing was, to quote Reference (6), "the result of wave energy at such wave lengths and wave frequencies that its combination with vessel speed produces an encounter frequency very close to. . .the natural first mode frequency of vibration".

It was apparently a function of the ship's speed and the wave frequency or, combined, the encounter frequency, the first mode hull natural frequency, and the energy in the wave spectrum. It was affected by the ship's heading since this changed the encounter frequency and the damping effect of the water surrounding the ship's vibrating hull.

It built and receded from resonance at reasonably regular intervals apparently as a result of changing wave conditions and the energy in the wave spectrum.

It, likewise, raised a host of questions about increasing severity with longer, more flexible ships, fatigue life, how wave and springing combine, etc., all of which could be answered only through a comprehensive full scale vessel study.

The Program

The Ottawa Symposium, Reference (7), presented the background, the thoughts and research of the marine and research community that led to the development of the new load line and strength standard. The conclusions were based on the largest lakes' vehicles then available for research, 730 footers. Since that time the purpose of the whole exercise, the 1,000 footer, has come into being, two in the 1,000-foot class and eight in the 800- to 900-foot class are sailing and some have gone through as many as three successful seasons.

Table 3 Principal Characteristics Of Instrumented Great Lakes Vessels

	EDWARD L. RYERSON	ARMCO, CALLAWAY	CHARLES M. BEEGHLY	ROGER BLOUGH	STEWART J. CORT
	New	Lengthened	Lengthened	New	New
L. O. A.	730	767	806	858	1,000
L. B. P.	712	749.25	786	833	988.5
Breadth	75	70	75	105	104.6
Depth	39	36	37.5	41.5	49
L. B. P./D.	18.26	20.81	20.96	20.07	20.17
Load Line, Extreme:					
Summer	27-8 1/8	26.33	27.81	----	----
All Season	----	----	----	27.92	27.96
Displacement*	34,900	33,880	41,250	60,400	74,400
Higher Strength Steel	No	No	No	Yes-Deck	Yes-Deck & Bottom
Inertia - $In.^2$ $Ft.^2$	883,913	760,256	932,522	1,761,247	2,401,741
Section Modulus - $In.^2$ $Ft.^2$	42,455	41,408	49,734	67,082	92,162
First Mode - Period-Seconds	1.84	2.13	2.0	2.4	2.88-3.15

* Displacement At The Quoted Draft

The marine community saw the need to assess and substantiate the strength standards and it was carried out under the auspices of the HS-1-2 SNAME Task Group on Wave Loads - Great Lakes Vessels and sponsored by industry, the Coast Guard, the American Bureau of Shipping and the Maritime Administration. The STEWART J. CORT at 1,000 feet has been strain instrumented since its departure from the fitting out pier for trials in 1971. The BEEGHLY started out from its conversion berth in 1972 where it had been stretched from 710 feet to 806 feet, similarly, but not quite so extensively instrumented. The ROGER BLOUGH at 858 feet was instrumented in 1973 with strain gauges, and the ARMCO and CALLAWAY both operating at a new stretched length of 767 feet, were also instrumented to acquire bending stress data.

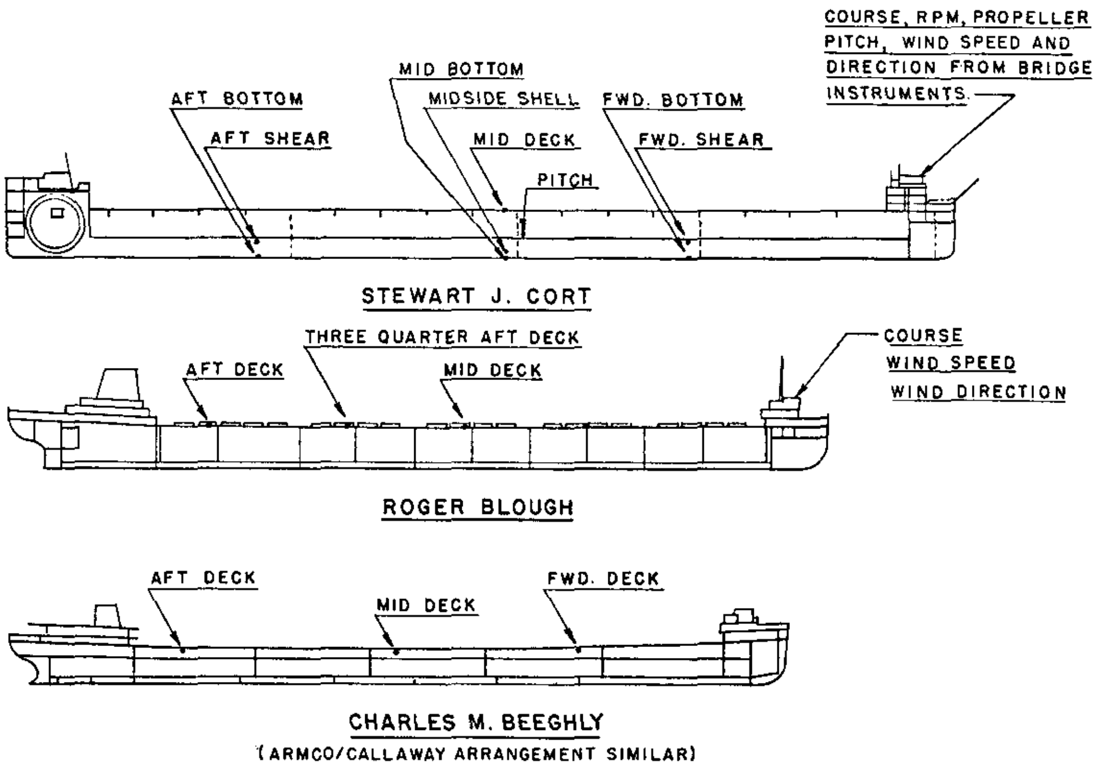
The group has attempted to span the range between the RYERSON at 730 feet and the CORT at 1,000 feet, so that inferences drawn from the data would have support at all vessel lengths. The principal characteristics of these vessels are shown in table 3. Figure 3 is a composite showing diagrammatically the instrumentation on each.

Instrumentation

Each of the vessels is equipped with temperature compensated strain gauges located approximately amidships port and starboard and arranged to provide a signal initiated by vertical bending strains and connected to remove the effects of horizontal bending. This arrangement is common to all. The CORT is more extensively instrumented than this to determine bending stress other than at the extreme fibers, shear stresses, frame bending, pitch, bow and stern accelerations and to record the associated ship operating conditions. The BLOUGH and BEEGHLY also have additional weather deck strain gauges but the data of principal interest here is that recorded from the midship gauges common to all three.

In pursuing the small amount of data presented here, and in making a further detailed review of the reference material, three items must be kept in mind:

1. The strain gauge data represents dynamic changes only from a static baseline. The strains caused by ballast or cargo are the baseline, or zero point, from which the gauges measure the tension and compression variations due to wave action and springing.
2. The type of material upon which the strain gauge is mounted; whether it is a normal mild steel or higher strength steel.
3. The data is normally, unless qualified, double amplitude, i.e., the stresses are from the peak of tension to the trough of compression in the same cycle. Where the combined, and



INSTRUMENTATION
ON
GREAT LAKES VESSELS

FIGURE 3

the component wave and springing stresses are separately reported the components are not necessarily from the same cycle as the combined value.

STEWART J. CORT, 1973 Season

The presentation of CORT data is begun with the 1973 season despite the fact that data was collected during the '72 season. The '72 data, Reference (9), although statistically valuable, was not dramatic, and the '73 season was, by far, the more interesting.

An interesting incident from the 1972 season is described in Reference (10), however. In an attempt to determine the damping effect of the water surrounding the hull on the hull natural frequency, anchor drop tests were conducted to institute a vibration from a known source and measure its attenuation with time. The tests were unsuccessful. The vessel was springing in a relatively calm sea, while at rest, with sufficient amplitude to make the forced vibration and its attenuation indistinguishable from the motion caused by the seaway.

The data collected during the '73 season is summarized in Reference (11). The information throughout this season is as interesting as the first season is commonplace.

Nine hundred and eighty-three, one-half hour data intervals were collected. Of these 188 were in port and the remaining 795 were underway. Included in these, were data collected during four storms that developed significant stress data.

A summary of the storm and operation conditions and the most outstanding stress data is shown in tables 4 and 5 taken from Reference (11). The single amplitude dynamic stresses vary between 8,650 and 14,700 psi combined wave and springing.

The effect of a loading change on the springing period is relatively small. All of the ballast conditions average a springing period of 2.88 $\pm$ .03 seconds. The one loaded condition has a period of 3.03 seconds, a 5 percent increase.

During this season five maneuvering tests were made on the CORT with wave buoys launched to give an accurate assessment of the sea state. The wave data from two of these tests was unusable due to signal transmission difficulties. The remaining three tests provided data on the combined wave and springing stresses and the individual components for various ship heading, speeds, loadings, and the observed sea.

The value of varying heading and speed to mitigate springing was not fully conclusive from the maneuvering data.

Less than 5 percent of the data collected in the 1973 season showed bending stresses exceeding single amplitude values of 3,800 psi. During storm conditions, however, the single amplitude combined dynamic stresses occasionally exceeded 10,000 psi with a single peak value of 14,700 psi in association with 15 foot waves on the starboard bow with periods of about 7.5 seconds. During this same interval, but not simultaneously, the springing and wave values reached single amplitude values of 8,200 psi and 8,300 psi respectively.

Data was collected through the 1974 season and has not yet been published. Inquiries to Teledyne Materials Research indicate the data gathered was statistically valuable but reasonably routine with no new discoveries.

CHARLES M. BEEGHLY

The BEEGHLY was instrumented in 1960 as a 710 footer when its name was the SHENANGO II. Its instrumentation in 1972 as a lengthened 806 footer is of particular interest because of this previous data and because it is intermediate between the CORT's 1,000 feet and the RYERSON's 730 feet. Some data was gathered during the 1972 season and a maximum combined dynamic stress, single amplitude of 11,350 psi was recorded. The 1973 season (12) is, like the CORT season, the more interesting.

The recording equipment on the BEEGHLY is started by two means, manual switching by the mate on watch or by a signal indicating high stresses. Thus the data gathered tends to show

Table 4 STEWART J. CORT Storm & Operating Description 1973

	May 2, 1973	November 8, 1973	December 10, 1973	December 13, 1973
Wave				
Height-Ft. (Visual)	15	12	7-8	10-15
Length-Ft.	--	--	--	--
Visual Direction	Starboard Bow	Bow	Starboard Bow	Bow
Wind				
Direction	N.E. x N.	W.N.W.	N.	N.E.
Velocity-Knots	42	35	36	35
Vessel				
Crs.	325	289	310	Just Prior To Anchoring
Speed-M.P.H.	15.3	9	13	" " " " "
Draft-Ft.	17.96 FP	16.75 FP	17.00 FP	27.00 FP
Condition	Ballast	Ballast	Ballast	Loaded
Location	Eastern Lake Superior	Lake Superior Caribou Island To Stannard Rock	Lake Superior N.E. Manitou Island	Lake Michigan Outside Burns Harbor

Table 5 STEWART J. CORT Summary Of Storm Data 1973

		Frequency Hz.	Period	Stress P.S.I.-Peak To Trough	*
May 2, 1973	Combined	--	--	29,400	
	Springing	0.343	2.91	16,400	
	Wave Induced	0.134	7.48	16,600	
November 8, 1973	Combined	--	--	23,600	17,677
	Springing	0.346	2.89	22,400	14,800
	Wave Induced	0.150	6.68	5,200	7,225
December 10, 1973	Combined	--	--	17,300	19,100
	Springing	0.351	2.85	15,500	15,700
	Wave Induced	0.162	6.18	5,600	5,700
December 13, 1973	Combined	--	--	19,200	
	Springing	0.331	3.03	12,700	
	Wave Induced	0.158	6.31	10,660	

* Additional Values During The Same Storm

a bias toward the higher, more interesting stresses and cannot be considered a statistical sampling of the ship's exposure throughout the season. The CORT equipment samples data at set intervals for 30 minutes or more regardless of the intensity of the stress (or, in addition, when a stress threshold is exceeded) giving a statistical sample of the entire season.

One hundred thirty-six usable one-half hour data samples were collected during 1973. During this season the BEEGHLY experienced a single occurrence of combined wave and springing single amplitude stress variation of 15,000 psi. The wave components of the combined stress were generally less than 5,000 psi single amplitude except for one storm occurrence where the wave induced stress exceeded 8,000 psi single amplitude.

The data indicates that high springing stresses are generally associated with the higher wave induced stresses and that the largest peak to trough springing values occurred within 45 degrees of head seas. When the springing data is compared against its associated Beaufort number, the maximum springing stresses occur at the higher numbers as might be expected.

When the data is ordered according to the date it was collected, it confirms a common sense surmise, that the highest stresses are concentrated in the last three months of the season, October, November and December, with the possibility of April entering the group at the beginning

The BEEGHLY data includes eight storms that generated combined single amplitude stresses in excess of 9,000 psi summarized in tables 6 and 7 (but shown in the tables as peak to trough values) taken from Reference (12).

Maneuvering tests were conducted with the BEEGHLY in an attempt to gain quantitative information on the sea state and direction concurrently with stress data. The wave buoys were not cooperative, however, due to poor signals or insufficient power and only one 2½ minute section of sea data was of value from the four experiments. This test was 8 hours after the data given in tables 6 and 7 for the November 8 storm when the wave height was estimated visually at 7 feet from 285° (283° during the maneuvering test) and the single amplitude stress maximums were 9,200 psi combined, 8,200 springing and 1,400 wave. The wave buoy information showed a concentration of energy in the 4 to 6 second periods.

The BEEGHLY is continuing to collect data during the 1974 season but this information is not yet available.

ROGER BLOUGH

The BLOUGH at 858 feet is the second longest vessel on the lakes and was instrumented at the end of the 1973 season (13). The usual midship gauges were installed but, in addition, gauges were placed at two locations aft of the midship location spanning the locations where the largest static bending moments are experienced on this vessel and on most of the longer vessels.

The data collected between November 18, 1973 and January 30, 1974, all that has been published thus far, has been routine. Only one interval had a double amplitude combined stress of significance, 16,350 psi (8,170 single amplitude), when the sea state was estimated at 7 to 8 feet with 40 knots winds, 5° off the starboard bow and a speed of 10 M.P.H. Seventy-five percent of the recorded intervals showed stresses less than 1,500 psi and 98 percent were below 5,000 psi combined single amplitude.

The data collected during the 1974 season has not been fully reviewed yet but a preliminary review of the information seems to indicate data similar to that discussed above.

This latter 1974 data was to be gathered without re-zeroing the equipment after loading and unloading. When this information becomes available it should show the variation in the dynamic baseline due to the static loads for the three gauge locations. It is possible some conclusions can be drawn regarding the superposition of the dynamic loads on the static at the three locations and possibly about stress variation during loading, underway ballasting and unloading.

Table 6 CHARLES M. BEEGHLY Storm & Operating Description 1973

	April 8, 1973	September 5, 1973	October 15, 1973	November 1, 1973
Wave				
Height-Ft. (Visual)	12	10	12	10-15
Length-Ft.	--	--	--	--
Visual Direction	026	257	310	248
Wind				
Direction	026	252	304	263
Velocity-Knots	40	31	30	35-40
Vessel				
Crs.	341	257	294	248
Speed-M.P.H.	15	14	14	12
Draft-Ft.	--	--	--	--
Condition	Ballast	Ballast	Ballast	Ballast
Location	Lake Huron Harbor Beach	Lake Superior Manitou Island	Lake Superior N.W. Whitefish Point	Lake Erie Buffalo

	November 8, 1973	November 21, 1973	December 10, 1973	December 28, 1973
Wave				
Height-Ft. (Visual)	7	8-10	8-12	6-8
Length-Ft.	--	--	--	--
Visual Direction	235	225	023	247
Wind				
Direction	285	235	025	247
Velocity-Knots	32	40	36	28
Vessel				
Crs.	280	270	350	292
Speed-M.P.H.	13	15	15	16
Draft-Ft.	--	--	--	--
Condition	Ballast	Ballast	Ballast	Ballast
Location	Lake Michigan Ludington	Lake Superior Keweenaw Peninsula	Lake Superior Whitefish Point	Lake Superior S. E. Portion

SUMMARY

The information available is voluminous and that presented here is only a sampling. The statistical analyses, model and mathematical simulation are in process with conclusions yet to be propounded.

Mathematical simulation and experimental reproduction has been and is under continuing study at Webb Institute. Reference (14) has been published documenting these studies and a final report, not yet available to the author, is being readied for publication.

The collected stress data for Great Lakes Vessels and for the BEEGHLY in particular, has been subjected to computer and theoretical analysis at the National Ship Research and Development Center (NSRDC) in Reference (15) and (16). The information presented and its impact on the evaluation of the strength standard is not known to the author at this writing. All branches of the research community are, by rational analysis, bringing to a conclusion the Great Lakes Strength Standard.

But even though the last nail has not yet been set some general observations are in order.

It seems an inescapable conclusion that the Master, by judicious navigation and routing, can affect the loads on his vessel and apparently does so.

In at least one test the data gathering would have been truncated by the Master's desire to limit his vessel's exposure had it not been completed at the same time that he came to this conclusion. In the CORT's first season the Master's conservatism and his desire to learn about his vessel before venturing into full exposure may have reduced the magnitude of stress excursion. Quantitative data is not available to support this but severe springing is obvious to the Master and data log entries indicate mitigating action on his part.

In all the data gathered and available so far there is no situation where the maximum combined stress is a direct summation or superposition of the maximum springing and maximum wave components. Whether this is accidental or the result of a paucity of extreme data must be answered by further analysis. The data reduction method is such that matching the extreme combined value with the simultaneous springing and wave components is difficult. What we see are the extremes of each in a given data period. When the extreme components are added directly they exceed at times, the maximum combined value during the interval. Perhaps there is a reason other than coincidence for lack of direct summation in the data so far collected.

We have not yet experienced the wave or the stress assumed in the strength standard. This could be an accident of time, since design criteria may never come together simultaneously in the life of a structure. The closest we have come to this is 57 percent of the standard in head seas and waves visually observed to be 10 to 15 feet high. Obviously these values could be amplified by discontinuities and built-in stresses. Perhaps our best tack is a greater concern for good practice in details of construction.

There are many questions still without definitive answers. The two most pressing seem to be:

1. By what law do springing and wave stresses combine: superposition or the root square law assumed in the standard?
2. Throughout the vessel's lifetime do the stress magnitudes and number of cycles approach the criteria set for fatigue limits such that they should be considered in the design decisions?

Perhaps the bank of data now available and the investigators now working will provide rational, practical answers to these questions based on the knowledge that Great Lakes operations have been and hope to remain among the safest ship operations in the world.

Table 7 CHARLES M. BEEGHLY Summary Of Storm Data 1973

Date		Frequency Hertz	Period Seconds	Stress P.S.I. Peak To Trough
April 8, 1973	Combined	--	--	20,800
	Springing	0.48	2.1	15,000
	Wave Induced	0.17	5.8	6,200
September 5, 1973	Combined	--	--	18,000
	Springing	0.50	2.0	15,900
	Wave Induced	0.25	4.0	2,000
October 15, 1973	Combined	--	--	27,000
	Springing	0.48	2.09	16,500
	Wave Induced	0.13	7.8	16,500
November 1, 1973	Combined	--	--	22,500
	Springing	0.48	2.09	19,100
	Wave Induced	0.18	5.7	3,450
November 8, 1973	Combined	--	--	18,400
	Springing	0.50	2.0	16,400
	Wave Induced	--	--	2,750
November 21, 1973	Combined	--	--	29,600
	Springing	0.50	2.0	26,500
	Wave Induced	0.18	5.6	3,050
December 10, 1973	Combined	--	--	18,900
	Springing	0.51	2.0	14,950
	Wave Induced	0.18	5.5	3,950
December 28, 1973	Combined	--	--	19,250
	Springing	0.50	2.0	17,300
	Wave Induced	--	--	1,800

ACKNOWLEDGEMENTS

The information reviewed here is a bare scraping of the surface of the research efforts on Great Lakes design. We have neglected completely the ancillary studies in the tanks and on the computer to duplicate and predict the real life conditions. For this we apologize but space and time are the culprits.

This review would not have been possible without the published and private information of many researchers. We hope the long list of reference citations adequately puts the credit where it is due and provides others with the starting points for research that will eventually answer our questions.

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* To be published for public use by the Department of Transportation, U. S. Coast Guard in the near future.