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THE DAVID W. TAYLOR MODEL BASIN

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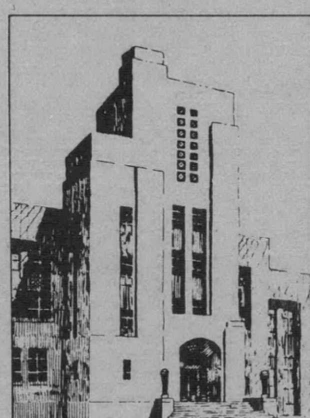
A REPORT ON HULL VIBRATION MEASUREMENTS MADE ON THE SS BETHLEHEM AND VIBRATION GENERATOR TESTS MADE ON THE SS C.A. PAUL AND THE SS PERE MARQUETTE 21 WHILE IN SERVICE ON THE GREAT LAKES

by

Edward Kapiloff and John T. Birmingham



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ABSTRACT

As part of the general program of extension of hull vibration theory to all classes of ships, this report describes tests made on three Great Lakes vessels and compares the experimental results with the computed values made according to the methods presently considered to be most satisfactory.

INTRODUCTION

In a commentary appearing in the July and August 1951 issues of "Marine Engineering and Shipping Review" the economic inducement and justification to repowering a number of cargo ships in service on the Great Lakes is well presented. What does not appear, however, is that repowering some of these ships, some as much as forty years old, could result in severe hull vibration which could definitely shorten the expected twenty years of service after conversion. Alert to recognize that possibility with a new installation, the interested parties, aware of the facilities available and the precedent already established,[1] requested the David Taylor Model Basin to determine the critical frequencies of vertical hull vibration for several ships.

As part of a broad program of mutual interest to private shipbuilders as well as to the Navy, the Taylor Model Basin has been compiling, for some time, experimental data on the flexural and torsional vibration of ship hulls. These experimental data are then compared with the data resulting from an analysis of an electrical network analogous to a vibrating beam, whose structure is similar, in general, to the hull of a ship. The ultimate purpose of this program, of course, is to refine the analytical method so that it will reliably predict the vibration characteristics of a hull in the early stages of design. A general discussion of the background, theoretical concepts, and present trends in the problem of evaluating hull vibration is given in TMB Report 739.[2]

It is felt that at least for vertical flexural vibration the analytical method is now rather well established. Since it is intended that the method be generally applicable, its validity will continue to be checked against the experimental results from as many different types of hulls as is possible while at the same time data will be obtained for analysis of other types of hull vibration.

In this report are discussed the flexural vibration measurements made by the Taylor Model Basin on the Great Lakes steamers SS BETHLEHEM, an ore carrier owned by the Bethlehem Steel Company, SS C.A. PAUL, an ore carrier owned by the Wilson Transit Company, and SS PERE MARQUETTE 21, a railway car ferry owned by the Chesapeake and Ohio Railway Company. All of these are existing vessels so that the element of prediction for design

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[1]References are listed on page 4.

purposes is not present. However, the proposal to lengthen one of the hulls did offer an opportunity for such a prediction.

TEST PROCEDURE

The experimental methods for obtaining the desired hull characteristics are usually full-scale vibration generator tests. Vibration generator tests were made on the SS C.A. PAUL and the SS PERE MARQUETTE 21, only. For the SS BETHLEHEM, the scope of interest was such that it was felt that measurement of the induced vibration while maneuvering or underway would give the desired information. As a result the test on the SS BETHLEHEM consisted of making several deck surveys while the vessel was underway.

The tests on the SS C.A. PAUL and the SS PERE MARQUETTE 21 required the installation of a vibration generator[3] powered by a 60-kw diesel-driven d-c generator. On both vessels the installation was made as close as was feasible to the after perpendicular on the main deck, and the instrumentation for measurement of the resultant vibration was installed in a space provided at the bow. On all three vessels the distance between the forward and after perpendiculars was divided into at least twenty parts, and these points were chosen for measurement. General Radio Type 761-A vibration meters with crystal pickups and Brush recorders were used to detect and record the vibrations.

Tests on the SS BETHLEHEM and the SS C.A. PAUL were made at the request of the Great Lakes Engineering Works, then under contract to repower these two ships, and several of the company's engineers were on hand to assist the test party from the Model Basin. For the tests on the SS C.A. PAUL this permitted a scheme of operation wherein one man at the forward end could remain with the recording instruments, monitoring stationary pickups at the forward and after ends and recording, on signal, the response from a pickup that was moved from station to station along the deck by a second man. The third member of the party operated the vibration generator and a monitoring pickup and recorder indicating the motion at his location. This procedure assisted the operator of the vibration generator in maintaining a fixed speed during the deck surveys and in varying the speed of the generator more effectively when examining for resonances during speed runs.

Inasmuch as the main recording equipment was in the pilot house whereas the vibration generator was installed on the main deck just aft of the engine room, intercommunication between those two points was achieved simply by use of the ship's telephone. The man with the moving pickup could be seen readily from the pilot house, and simple hand signals were adopted for his use.

On the SS PERE MARQUETTE 21, a car ferry, the open main deck simplified the problem of communication except when cars were on board, because one could see from the after end to the bulkhead about 7 ft from the forward perpendicular, at which point the recording equipment was located. When the car ferry was loaded, sound-power telephones were used. A three-man crew from the Model Basin conducted these tests.

Since all of these ships operate in both deep and shallow water, vibration generator tests were made with the ship anchored in both depths, and in each case both when light and when loaded. Because the requesting agency was chiefly apprehensive of vertical vibration, most of the time was given to making measurements under vertical excitation, and when time permitted the vibration generator was so oriented or adjusted as to excite horizontal and torsional vibration.

TEST RESULTS

Tables 1, 2, and 3 summarize the test results for the three ships, arranged in the order of the tests.

Figure 1 shows amplitude measurements of the vertical hull vibration on the BETHLEHEM while the ship was traveling in deep water. For the most part these measurements were made while the ship speed was maintained at the number of turns at which resonance occurred, so that the normal run of the ship was not unduly delayed. Since the C.A. PAUL and the PERE MARQUETTE 21 were required to remain dead in the water during the vibration generator tests the number of deck surveys possible without unduly delaying the vessels was limited. As a result only those amplitude measurements were made that were deemed necessary to define the mode of vibration and the sequence of the various resonances. Several of these normal-mode curves are shown in Figures 2 and 3.

GENERAL DISCUSSION

For the most part, the original request for vibration studies included only the experimental determination of the vertical flexural resonance frequencies of the ships discussed. The Taylor Model Basin is interested, however, in seeing how well the experimental values compare with theoretical values obtained by the method of calculation that is now considered most satisfactory. Because of the uncertainty as to the effect of shallow water on the virtual mass of a given hull, it is preferable at the present time to confine comparisons of calculated and experimental hull frequencies to data obtained in deep water only.

In Table 4 are shown the theoretical results obtained with the electrical analog in comparison with the experimentally determined results for the SS BETHLEHEM. There is good correlation between experimental and theoretical results.

Since considerably more data were obtained on the C.A. PAUL and the PERE MARQUETTE 21 by virtue of the vibration generator tests, they offer a better basis for comparison. The results for vertical and transverse vibration of these ships, for both light and loaded conditions in deep water, are compared in Tables 5 and 6. In general there is good agreement for the first three modes. Beyond that the calculated frequencies have a greater divergence and as a result run higher than the experimental frequencies, mode for mode.

It is believed that the present method of evaluating shear rigidity in the calculations yields too high a value for that parameter. Since in the higher modes shear rigidity plays a larger role than bending rigidity, a general study of improved methods of evaluating the shear rigidity is now under way at the Taylor Model Basin.

Shortly after the tests were run on the SS PERE MARQUETTE 21, the Chesapeake and Ohio Railway Company informed the Taylor Model Basin of its intent to lengthen the PERE MARQUETTE 21 and its sister ship the PERE MARQUETTE 22 by 40 ft and requested that this activity make a calculation of the probable critical frequencies for the modified hulls. The probable hull criticals as computed on the TMB A-C Network Analyzer are given in Table 7. As a matter of academic interest, the owners have indicated that they will attempt to obtain by vibration measurements while under way any hull criticals that may be apparent in the operating speed range of the vessels. The ships are expected to be back in service in the spring of 1953.

REFERENCES

1. McGoldrick, R.T., "Determination of Hull Critical Frequencies on the Ore Carrier SS E.J. KULAS by Means of a Vibration Generator," TMB Report 762, June 1951.

2. McGoldrick, R.T., Gleyzal, A.N., Hess, R.L., and Hess, G.K., Jr., "Recent Developments in the Theory of Ship Vibration," TMB Report 739, February 1951.

3. Berdahl, E.O., "Construction and Operation of the Taylor Model Basin 5,000-Pound Vibration Generator," TMB Report 524, April 1944.

PRINCIPAL DATA FOR THE THREE VESSELS

SS BETHLEHEM

LBP	580 ft - 0 in.		
Beam-Moulded	60 ft - 0 in.		
Depth-Moulded	32 ft - 0 in.		
Normal Drafts and Displacements			
Light Condition	3 ft - 0 in. fwd.	17 ft - 0 in. aft	9,100 short tons
Loaded Condition	21 ft - 7 in. fwd.	22 ft - 0 in. aft	20,920 short tons

SS C.A. PAUL

LBP	520 ft - 0 in.		
Beam-Moulded	54 ft - 0 in.		
Depth-Moulded	31 ft - 0 in.		
Normal Drafts and Displacements			
Light Condition	7 ft - 6 in. fwd.	15 ft - 9 in. aft	5,200 short tons
Loaded Condition	21 ft - 3 in. fwd.	21 ft - 6 in. aft	16,200 short tons

SS PERE MARQUETTE 21

LBP	348 ft - 0 in.		
Beam-Moulded	56 ft - 0 in.		
Depth-Moulded	21 ft - 6 in.		
Normal Drafts and Displacements			
Light Condition	9 ft - 0 in. fwd.	15 ft - 6 in. aft	4,470 short tons
Loaded Condition	12 ft - 8 in. fwd.	16 ft - 6 in. aft	5,900 short tons

TABLE 1

Vertical Hull Resonances Obtained from Vibration Measurements on the SS BETHLEHEM

Mode	Vertical* Hull Resonances in cpm			
	Light Condition		Loaded Condition	
	Deep Water	Shallow Water	Deep Water	Shallow Water
1st	44	37	**	**
2nd	112	103	92	86

*What is assumed to be the fundamental transverse critical frequency for the loaded shallow-water condition was recorded as 58 cpm. This frequency was excited by a dock-side bump.

**There was no apparent excitation of these modes.

TABLE 2

Critical Hull Frequencies Obtained from Vibration Generator Tests on the SS C.A. PAUL

Mode	Critical Hull Frequencies in cpm							
	Vertical Modes				Transverse Modes			
	Light Condition		Loaded Condition		Light Condition		Loaded Condition	
	Deep Water	Shallow Water	Deep Water	Shallow Water	Deep Water	Shallow Water	Deep Water	Shallow Water
1st	50	47	45	44		116		90
2nd	117	120	106	114		260	180	174
3rd	283	256	168	151		405	300	281
4th	325	300	210	202				
5th	430	405	312	297				
6th	489	450	354	345				
7th	555	535	432	405				

TABLE 3

Critical Hull Frequencies Obtained from Vibration Generator Tests on the SS PERE MARQUETTE 21

Mode	Critical Hull Frequencies in cpm							
	Vertical Modes				Transverse Modes			
	Light Condition		Loaded Condition		Light Condition		Loaded Condition	
	Deep Water	Shallow Water	Deep Water	Shallow Water	Deep Water	Shallow Water	Deep Water	Shallow Water
1st	130		112				220	
2nd	253		224				390	
3rd	388		346	320				
4th	562		512					

TABLE 4

Comparison of the Vertical Resonances Found for the SS BETHLEHEM with Theoretically Computed Resonances

Mode	Vertical Resonances in cpm			
	Light Condition		Loaded Condition	
	Experimental	Theoretical	Experimental	Theoretical
1st	44	43		34
2nd	112	103	92	84
3rd		176		144
4th		248		204
5th		320		263
6th		391		319
7th		455		372

TABLE 5

Comparison of Experimental Flexural Resonances Found for the SS C.A. PAUL with Theoretically Computed Resonances

Mode	Flexural Vibration Resonances in cpm							
	Vertical Modes				Transverse Modes			
	Light Condition		Loaded Condition		Light Condition		Loaded Condition	
	Experimental	Theoretical	Experimental	Theoretical	Experimental	Theoretical	Experimental	Theoretical
1st	50	46	45	37		98		64
2nd	117	118	106	94		248	180	148
3rd	183	206	168	163		422	300	243
4th	288	301	210	235		590		340
5th	363	397	312	307		760		435
6th	430	488	354	380		925		518
7th	555	577	432	448		1090		608
8th		662		514				693

TABLE 6

Comparison of Experimental Flexural Resonances Found for the SS PERE MARQUETTE 21 with Theoretically Computed Resonances

Mode	Flexural Vibration Resonances in cpm							
	Vertical Modes				Transverse Modes			
	Light Condition		Loaded Condition		Light Condition		Loaded Condition	
	Experimental	Theoretical	Experimental	Theoretical	Experimental	Theoretical	Experimental	Theoretical
1st	130	120	112	110		227	220	201
2nd	253	267	224	243		489	390	423
3rd	388	413	346	376		712		622
4th	562	561	512	511		950		832
5th		705		641		1175		1022
6th		836		762				
7th		962		880				

TABLE 7

Probable Flexural Resonances for the SS PERE MARQUETTE 21 with 40 Foot Length Added at the Ship's Midsection

Mode	Computed Resonances in cpm			
	Vertical Modes		Transverse Modes	
	Light Condition	Loaded Condition	Light Condition	Loaded Condition
1st	90	82	164	147
2nd	212	192	395	344
3rd	334	305	575	504
4th	468	429	793	701
5th	594	546	983	875
6th	721	656	1174	1030

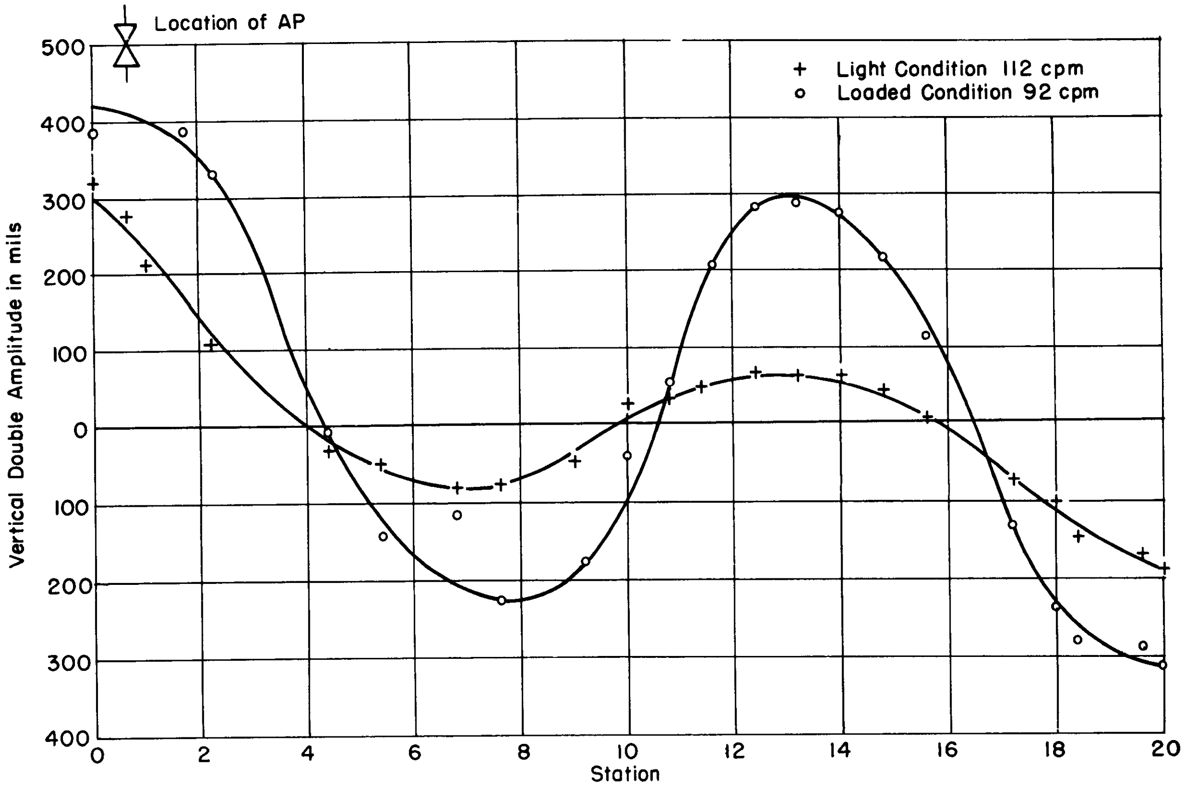

Figure 1 - Amplitude Profiles for the Second Mode Resonance of the SS BETHLEHEM for Light and Loaded Conditions in Deep Water

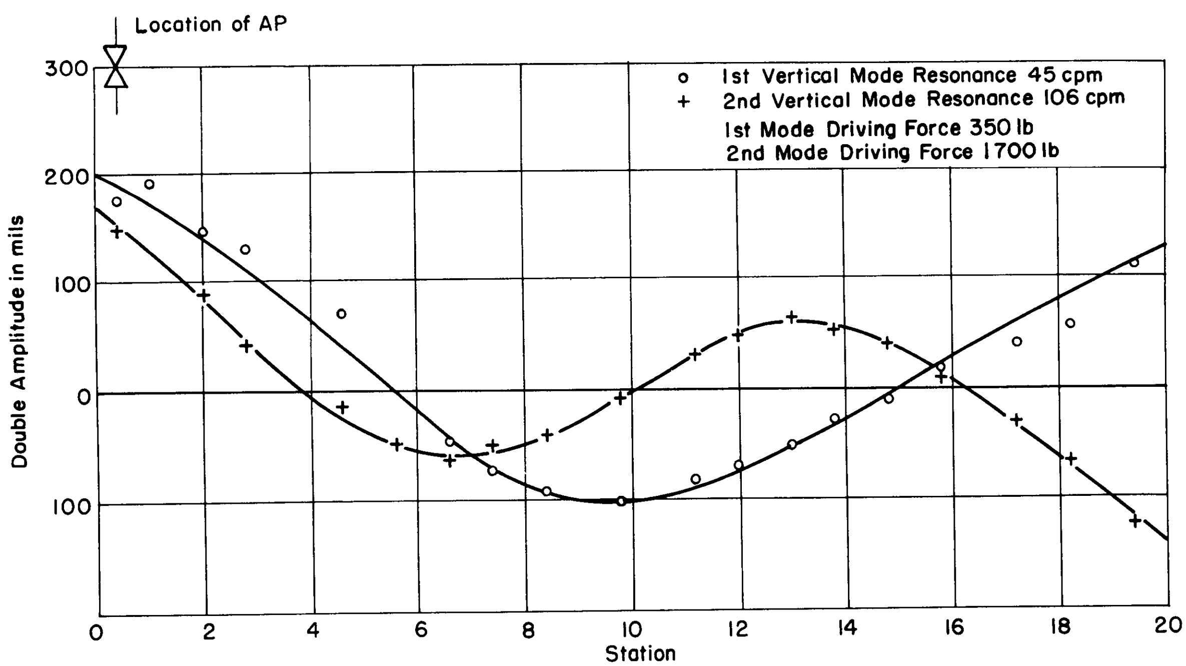

Figure 2 - Amplitude Profiles for the First and Second Vertical Hull Resonances of the SS C.A. PAUL for the Deep-Water Loaded Condition

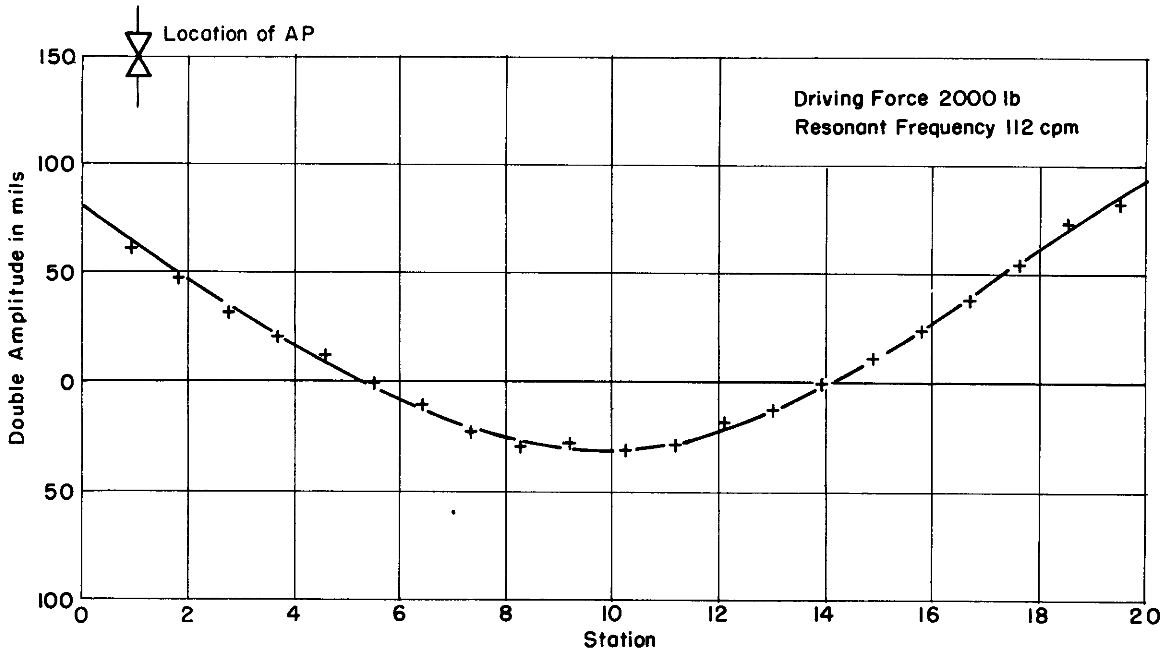

Figure 3 - Amplitude Profile for the Fundamental Vertical Hull Resonance of the SS PERE MARQUETTE 21 for the Deep-Water Loaded Condition

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