THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
One World Trade Center, Suite 1369, New York, N.Y. 10048
Paper to be presented at the Ship Vibration Symposium
Arlington, Va., October 16–17, 1978

Cost Considerations in Ship Vibration and Noise Problems

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ABSTRACT

A distillation of views is offered with independent contributions relating to the pragmatic aspects of cost implications of both structure borne vibrations and airborne noise. Attention is focused on cost factors that are attributable to vibratory driving forces to encourage the development of improved technical/economic assessments of ship systems and proposed improvements thereon. Problems in the accumulation and allocation of the costs of damage that are attributable to vibratory forces are discussed with the view of promoting improved methods of identifying and displaying the cost consequences.

INTRODUCTION

Cost, habitability, and safety considerations are the main driving forces for the elimination or reduction of vibration and noise problems. Little has been published on the cost implications of vibration and/or noise. For example, the ISSC Report of Committee II.4 VIBRATIONS (consisting of ten members) covering the work accomplished during the previous 3-4 years reports nothing on the aspects of cost, as shown in the Proceedings of the Sixth International Ship Structures Congress. In fact, this committee report is the smallest (19 pages of text) of the 12 committee reports and the only committee report of the 12 that is double-spaced. This suggests a low level of attention to a problem area that is progressively increasing in severity and cost. This condition in the industry is attributed to the somewhat varying nature and characteristics of both vibration between ship types and the practices for the accumulation and disclosure of the attendant costs, much of which goes unreported for various reasons. For example, the cost of such premature failure of starters in fluorescent lights, light bulbs, and electrical components are probably not allocated in any way to vibratory forces. Also, certain types of vibration problems are unique to particular ship types and the detailed knowledge of such problems often resides only with the personnel directly involved. Hence, attempts to accumulate costs of damage that result, at least in part, from vibration and noise would no doubt fall far short of the true mark. Also, little specific benefit would be gained beyond the correction of those specific problems that would be costed-out except for the global impressions that could be gained on the problem area as illustrated in the report entitled "Cost of Ship Vibration Problems" which was prepared for the Maritime Administration by the Center of Maritime Studies of Webb Institute of Naval Architecture and Marine Engineering. That report, with its display of costs of vibration conditions, helped to justify MarAd's support of the successful highly skewed propeller program to alleviate propeller/wake induced vibration problems.

The following discussion of many vibration and noise problems as related to the author may be helpful to the reader in reducing costs. The author has discussed vibration and noise problems with many personnel in both government and industry. Hence, the author is primarily acting as a conduit for the accumulation, arrangement, and presentation of the material. None of the names of the personnel or their affiliations are given. This sanitized approach permits condensation of the results, and avoids identification with individuals or firms of the instances discussed.

COST OF VIBRATION AND NOISE

Areas of Cost

Some of the general areas of costs that are assignable to vibration and noise considerations are identified in the following as an effort to focus more clearly on the problems:

A. Testing to determine actual vibration and noise levels.
B. Repairs and replacements of premature and recurring failures of ship components.
C. Corrections, redesign, and rebuilding to correct problems.

D. Curtailed personnel efficiency and performance.
E. Out of service and/or reduced service capacity of ships.
F. Diversion of management and engineering skills from other duties.
G. Additional fees to regulatory bodies.
H. Disputes and attendant legal services.
I. Design efforts to mitigate anticipated vibration problems.
J. Propensity for accidents.

Cost of Testing

The cost of testing to determine the levels of vibration and noise varies widely with ship type, nature of problem, conditions for testing, etc. Based on MarAd records, the cost of the vibration generator tests of the 3C-S-38a in 1961 was $15,280 per ship. That cost in 1978 would be about $34,200 per ship. The cost for vibration tests on the SAVANNAH was $29,000 in 1962. That cost would be approximately $65,000 in 1978.

Premature and Recurring Failures

Vibration forces that occur in ships are blamed by some authorities as a primary or major contributory cause of many occurrences of structural and equipment damage ranging from major damage to hull strength and safety to the premature failure of light bulbs. Recent analyses of "springing" type vibrations combined with normal wave induced loads cause some researchers to expect that one particular ship will begin showing hull damage in about 3 1/2 years. A partial list of reported damage that has been, in some cases, attributed to vibration forces includes: (1) cracking of waste-water tanks, ballast tanks, aft peak tanks, aft bulkheads, welds of plating to frames, welded floors (at abrupt changes in structure section), pipe hanger welds (in one case it was reported that one man was assigned nearly full time to the rewelding of pipe hangers), and general nuisance cracking; (2) failures of piping, couplings, stern tube bearings, line shafting, brickwork in boilers, and suspended ceilings; (3) loss of service of electrical and electronic equipment including rotating radar antennae, radar masts, electrical cables (wearing insulation off wires in conduits results in electrical shorts, etc.), controllers for fans, alarms and other equipment, and radio equipment (cost for one particular ship was reported as $20,000 per year). The loss of operation of radio equipment has forced delays in departure of ships and loss of communication at sea. Virtually all electrical or electronic equipment can be affected; however, such equipment located in a forward deckhouse are reported to experience many fewer problems than that for such equipment located in the aft deck house. One can easily envision the varnish being rubbed off of electrical windings of motors, etc., by vibration forces; (4) Miscellaneous and unique failures, such as safety valves on waste heat boilers "flopping around" and salt water cooling pipes to air conditioners breaking, which in one know case resulted in salt water being sprayed on electrical equipment in a main propulsion control center. Occurrences of some costly disasters and casualties in which vibratory forces most likely contributed in a major way.

Structural Correction

The cost of attempts to correct serious vibration problems through structural modifications after a ship is built can be quite high and likely range up to 3 or 4 times the cost per ton for the original construction in that area of the ship. In some cases, corrective attempts have been dismal failures. In the case of one known deckhouse problem, such a structural correction is not reasonably possible. The only viable alternative in the latter case (before the advent of the highly skewed propeller) was to reduce the ship speed to bring the vibration to tolerable levels at the cost of reduced ship productivity.

The breaking in half of one vessel has been attributed to cracks initiated in the strength deck at the base of king posts by the cyclic forces imposed by the environment with other contributory factors. The cost of repair was $2.2 million. This condition was corrected by structural changes upon rebuilding. According to MarAd records, a reduction in machinery vibration was successfully accomplished by a structural fix in the 100 b's. In the case of LASH ships, the correction of the foundation, known as the "Filbare Fix" cost $400,000 per ship; however, not all of the 11 ships were "fixed." In the case of the C4-5-69b ships, the cost to fix excessive hull vibration was $82,650 for each of five ships in 1970. Today that cost would be approximately $129,926 per ship. The correction involved the installing of 8 tons of steel stiffening in each shaft alley among other delays and costs. This fix is not considered to be completely satisfactory. Acoustic tile was used to correct the noise problem in the 85 b's at the cost of $80,000 per ship; however, that fix is still not considered to be satisfactory.

Noise

Unlike structure-borne vibration, which contributes to later fatigue damage because of its time and frequency dependence, air-borne noise can be troublesome immediately and often demands immediate correction or treatment such as the case of a loud whistle generated by an improperly designed steam valve. In one known case, the control room and crew quarters had to be insulated and the crew had to wear ear muffs at an annual cost of approximately $6,000 per year. In another case the propulsion shafting emitted a highly distrubing 22-33 hertz noise in the aft quarters. Metal perforated tiles sequeaking, loose access doors rattling, and noise from other poorly fastened or secured items contribute to noise levels.

Variability of Cost

The extent of the cost implications varies widely from operator to operator, ship to ship, and the extent of both the vibration and noise levels generated. In one type of a high-powered tug, it is reported that the vibration and noise problems cost the owner over one million dollars for repairs, model tests, redesigns, dry dockings, lost revenue, and other factors. The stern plating was vibrated loose from the framing with enormous amount of other damage. The propeller blades were cropped to increase the tip clearance (not sufficient to solve the problem) and the scantlings nearly doubled in the stern area among other changes. Speed was reduced in this and other cases to avoid vibration damage with an attendant decrease in ship productivity, the cost of which can also vary widely.

The development and test of the highly-skewed propeller has demonstrated a viable, low cost solution for many propeller/wake induced vibration problems. The cost of a cast, highly-skewed propeller should be increased only in proportion to the cost of the increase in weight (approximately 8 percent) over that of a propeller of conventional design. The additional cost of the highly-skewed propeller was more than made up in savings from fewer radio (shack) repairs.

Personnel Performance

The efficiency and capacity of personnel to perform is severely affected in some reported cases to the extent that personnel either will not or cannot perform ordinary maintenance work because of the high noise and vibration levels. It is reported in one case that operating crew fatique prevented personnel from standing four-hour watches without doubling of the number of personnel on watch which resulted in an increase in operating costs. Notwithstanding personnel limitations, a considerable amount of vibration damage is repaired by crews. Some operators regard this as "free" repairs in the sense that the crews would have to be paid anyway.

The effect on habitability from vibration and noise is considered by some to contribute significantly to the propensity for accidents. Vibration and noise levels are known to be disturbing to sleep and other functions. In fact, the sudden cessation of such conditions are said to be equally disturbing once the crew had gotten used to the conditions in some cases. The cost impact of the wide variety of accidents that could be assigned, at least in part, to crew fatigue from vibration and noise would be highly speculative. It was conjectured by one regulatory body official that "more than half of the accidents may be attributed to vibration, at least in a major part."

Vibration Damage; Economic Analyses

An economic analysis was performed on data from both the report entitled "Cost of Ship Vibration Problems" (prepared in 1972 by the Center of Maritime Studies of Webb Institute of Naval Architecture for the Maritime Administration) and information drawn from other documents and private communications. The year 1972 was used as the base year. The results are shown in Table 1. The following assumptions are made for purposes of this analysis.

A. The direct cost of vibration damage repairs, as reported, are lumped as a ten-year set of costs and assumed to be uniformly spread out.
B. The future predicted costs are treated on the basis of equal annual increments.
C. Annual interest rate of 10 percent is arbitrarily assumed for both prior year expenditures and predicted future costs for present value computations; however, some analysts regard this assumption as being too conservative.
D. An annual rate of inflation on costs is assumed to be 5 percent.

The direct cost data was adjusted by accepted averaging techniques used in analysis of variance techniques to cover refusals to provide data and lack of data for new ships. The direct data were also adjusted for crew-made repairs, etc., which normally equal the direct port repair charges according to a given rule of thumb that is used by some

TABLE I

	Number of Bad Vibrator Ships Total Examined*	Reported Cost of Vibration Damage* 10 yr. Average Period X $1,000	Cost Adjusted for Lack of Data and Refusals 10 yr. Average Period X $1,000	Cost Adjusted for Crew Made Corrections and Repairs 10 yr. Average Period X $1,000	Present Value Cost of Prior Built Ships Past 10 yr. Period X $1,000	Present Value Cost of Prior Built Ships Next 15 yrs. X $1,000	Total Present Value Cost for Prior Build Ships 25 Years Life X $1,000
UNITIZED CARGO CONTAINER SHIPS	12/19 (63.2%)**	$2,652	$2,652	$5,304	$8,700	$6,300	$15,000 (1,250)[A]
MEDIUM VALUE BULK CARGO SHIPS - BARGE CARRIERS - GENERAL PURPOSE	10/81 (12.35%)**	$2,800	$2,800	$5,600	$9,130	$6,590	$15,720 (1,592)[A]
LOW VALUE BULK CARGO - LARGE SINGLE SCREW CRUDE TANKERS SINGLE SCREW OBO's	12/114 (10.52%)**	$2,674	$3,754	$7,508	$12,240	$8,800	$21,040 (1,750)[A]
TOTAL	34/214 (15.88%)**	$8,126	$9,206	$18,412	$30,070	$21,690	$51,760 ($4,592)[A]

* Based on Webb Institute of Naval Architecture Report entitled "Cost of Ship Vibration Problems," January 17, 1972. (Which is considered to be Highly Conservative Estimate).

** Percent considered to be Bad Vibrators by Operators.

A - Per Ship Cost.

operators and which is not otherwise taken into account. The data were also arbitrarily adjusted for a ship life of 25 years on a linear (straight line) basis. The data provided is only on ships built since 1950, some of which are relatively new. The linear assumption is that the cost of vibration damage is in equal annual amounts. Actual vibration damage costs often increased as the ship got older, but an early component of high costs exists where improvements (or attempted improvements) in conditions are sometimes necessary. Hence, a linear assumption appears somewhat reasonable.

The column for Present Value Cost for Prior Built Ships, Past 10 Year Period, represents the average lumped cost for the data on the ships studied that were built since 1950 (average age taken as 10 years old) multiplied by a single compound amount factor $(1+i)^{10}$ to yield the estimate of present value cost. The column for the present value cost for these ships for the next 15 years simply takes the present value of the historical data for the past 10 years multiplied by 1.5 and by $1/(1-i)^{15}$ to yield a conservative present value of future expected costs on the prior built ships.

Using the total present value cost for each ship of the three types, a uniform annual cost for a ship of each type is determined. Using the capital recovery factor, the present value cost of vibration damage is determined for a hypothetical new 300-ship fleet assuming that the ships are built the first year. The Total Present Value of the calculated future costs of vibration damage is a sum of the estimated future cost of vibration damage for the prior built ships studied and that for the new fleet, the sum for all three of the ship types is identified as the Total Expected Savings.

The probability of technical achievement is set at 90 percent based in part on the encouraging results of the highly-skewed propeller work accomplished under MarAd sponsorship. The probability of implementation is set at 95 percent because some of the existing bad-vibrator-ships would not be corrected under any circumstances.

Approaches to Cost Reductions of Vibration and Noise

Based on a review of typical problems, it appears that a reduction of the future costs of vibration and noise damage should be approached, in part, through improved design procedures with a special eye on allowing only low levels for the forces that drive vibration. This approach is of prime importance regardless of whether or not one blames any of a number of factors as the "cause" in any particular case; such as, propeller/wake interactions (which are generally considered to be the most prevalent driving force in most vibration problems), unbalanced propeller(s), cavitation, inadequate tip clearance, ship components not supported properly, wave-induced loads, marginal or inadequate design or selection of components and their proper support (long, slender bridge was cited as one example), loading conditions of ship (reports show that changes in loading may change patterns of vibration with attendant changes in problems), and inadequate propulsion machinery specifications.

In general it is felt that the cost of sharply reducing potentially damaging vibratory driving forces is very much less than after the fact attempts to accommodate the vibratory loads by beefing up the structure or by other means. The design and use of a highly-skewed propeller is one such approach that is attractive for some cases in which vibration problems are anticipated in advance and/or are corrected after the fact. The cost of the energy lost for useful purposes through vibration and noise was not evaluated.

One colleague strongly suggested that, "the achievable economic benefits of automated engine rooms may be elusive or seriously diluted because of dangerous failures, especially those that may be compounded with alarm failures, if everything is not well thought out."

Some of the energy emitted from vibratory driving forces is dissipated through the generation and absorption of noise from components that are inadequately mounted or supported for the imposed conditions. The cost of proper mounting or support of equipment is expected to be relatively small if done during ship construction. The cost of corrective work such as installing insulation to absorb noise energy, securing rattling and improperly mounted items, rearranging funiture in quarters, and making other hopefully corrective measures, can vary widely.

CONCLUSIONS AND RECOMMENDATIONS

(1) The time cost of damage from vibration and noise is felt to be significantly under-reported. Vibration damage is often repaired without allocation of such costs to vibration as a contributory cause.

(2) Some ship operators have little or no vibration problems as compared with the serious problems of others.

(3) The occurrence of damage from vibratory forces acting either alone or as a contributor with other applied loads is usually time dependent and may not be assessed and reported as such unlike noise problems.

(4) The suggestion that damage from vibratory forces has been a major contributor to some ship casualties make any exclusive cost assessment highly conservative.

(5) The costly correction of vibration problems after ship construction is often difficult to impossible with the possible exception of reducing the vibratory driving forces from propeller/wake interaction by the installation of a highly-skewed propeller, as demonstrated to date.

(6) It is felt that failure analyses of critical ship systems from a vibration standpoint would be productive and promote improved ship reliability leading to cost reductions.

(7) A study of human fatigue and efficiency under shipboard type vibration conditions may be helpful in improving overall reliability and costs.

(8) The given net present value of vibration damage is considered highly conservative. The value of the costs is a large sum of money which suggests that research efforts to further reduce the costs beyond the development of the highly-skewed propeller would be rewarding.

ACKNOWLEDGEMENTS

This paper would never have been written were it not for the many contributors who gave willingly of their time and knowledge and for those who, seeing the need, gave so much encouragement to the author.