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MODAL DAMPING FACTORS
for a
RING-STIFFENED CYLINDER

by

Layton E. Gilroy

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Approved by:
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Abstract

Defence Research Establishment Atlantic (DREA) conducted experiments involving the measurement of radiated noise from a ring-stiffened cylinder subjected to a harmonic load applied at the cylinder's resonant frequencies. Three sets of trials have been performed with the cylinder either floating, submerged, or in-air. These experiments were performed to provide validation data for structural acoustics computer codes being developed in-house and under contract. For the numerical analyses, it was necessary to use measured modal damping ratios to determine the radiated noise levels. This is seen as a deficiency in DREA's predictive capability in radiated noise. This report examined the measured damping ratios and attempted to draw general conclusions based on the data. It was determined that the lowest damping ratios were measured during the submerged tests followed by the in-air then floating tests; however, given the differences in experimental methods, it was not possible to isolate the mechanisms which determined the levels of damping.

Résumé

Le Centre de recherches pour la Défense (Atlantique) (CRDA) a récemment mené une expérience visant à mesurer le bruit rayonné par un cylindre rendu rigide par des anneaux sous l'effet d'une charge harmonique appliqué à la fréquence de résonance du cylindre. L'expérience comportait trois parties; au cours de la première partie, le cylindre flottait, au cours de la deuxième, le cylindre était immergé et au cours de la troisième il était dans l'air. Cette expérience a été effectuée dans le but de recueillir des données pour valider des programmes informatiques d'acoustique qui ont été élaborés sur place et à contrat. Pour ce qui est des analyses numérique, ila été nécessaire d'utiliser des rapports d'amortissement acoustique modaux mesurés pour déterminer les niveaux du bruit émis par rayonnement. On estime qu'une des lacunes du CRDA a trait à sa capacité de prévoir le bruit émis par rayonnement. Dans le présent document, on procéde à une analyse des rapports d'amortissement acoustique mesurés et on tente de tirer des conclusions générales d'après les données. On a déterminé que les rapports d'amortissement acoustique les plus faibles sont ceux obtenus lorsque le cylindre est immergé; viennent ensuite ceux obtenus lorsque le cylindre est dans l'air, puis lorsque le cylindre flotte. Toutefois, étant donné les différences inhérentes à chaque méthode expérimentale, il est impossible de déterminer avec précision les principes qui régissent les niveaux d'amortissement.

DREA TM/97/237

Modal Damping Factors for a Ring-Stiffened Cylinder

by

L. E. Gilroy

Executive Summary

Introduction

Suites of computer codes have been developed at Defence Research Establishment Atlantic (DREA) to predict the radiated noise from submerged or floating elastic structures. These codes have been developed in support of the Ship Noise Project whose objective is to provide DND with the expertise and tools necessary to deal with issues related to underwater noise from naval vessels. Such computer programs may be used to either optimize the structural arrangement to minimize radiated noise or to examine existing structures to isolate noise-producing structures. DREA has conducted several sets of experiments at DREA's Acoustic Calibration Barge in Halifax, Nova Scotia, and Health Canada's anechoic chamber in Ottawa, Ontario, to measure the natural frequencies and radiated noise from a submerged ring-stiffened cylinder subjected to a harmonic load in order to provide validation data for the computer codes. Analysis of these trials indicated a deficiency in our predictive capability in the area of structural damping. During these trials, the natural frequencies and mode shapes of the cylinder and directivity patterns of radiated noise were measured while the cylinder was excited with an electromagnetic shaker. The measured radiated sound was compared to predictions made using the DREA suites of computer codes which require as input the modal damping factors for the structural resonances. As there are no standard theoretical or empirical values for these damping factors for such a structure, it was necessary to use measured modal damping factors for the numerical predictions of radiated noise. While this technique was sufficient for these studies, it does not allow for the ability to make predictions if the structure is not available for modal testing. Given this limitation, it was decided to collate the experimental data from this cylinder to determine if this data set could be used to assist in predicting future modal damping factors for similar steel structures and to determine if general conclusions could be drawn by comparing the modal factors from the cylinder in a submerged, semi-submerged, or in-air state.

Principal Results

This report discusses the three sets of experiments performed and compares the measured modal damping ratios. Over the resonant modes examined, while a definite pattern did not emerge, it was apparent that the submerged cylinder trials resulted in the lowest measured damping ratios, followed by the in-air trials and the floating trials. Given that the three sets of trials involved suspension of the cylinder by three separate methods, it was not possible to determine the primary mechanism for the differences in the damping ratios. The data collected is still of use in determining approximate damping ratios which could be used for similar structures in future analyses, although it may be necessary to insure that similar suspensions and similar modes are being considered.

Future Plans

Further work in this area would be of use in determining the correlation between fluid loading and measured damping ratios. Similar sets of trials in which the suspension systems and models were identical should clarify the picture. As well, the existing results should be compared to other measured damping ratios for similar structures to identify whether ratios may be specified based on structural aspects alone.

Contents

1 Introduction

Suites of computer codes have been developed at Defence Research Establishment Atlantic (DREA) to predict the radiated noise from submerged or floating elastic structures [1, 2, 3, 4]. These codes have been developed in support of the Ship Noise Project whose objective is to provide DND with the expertise and tools necessary to deal with issues related to underwater noise from naval vessels. Such computer programs may be used to either optimize the structural arrangement to minimize radiated noise or to examine existing structures to isolate noise-producing structures. DREA has conducted several sets of experiments [5, 6, 7] at DREA's Acoustic Calibration Barge [8, 9] in Halifax, Nova Scotia, and Health Canada's anechoic chamber in Ottawa, Ontario, to measure the natural frequencies and radiated noise from a submerged ring-stiffened cylinder subjected to a harmonic load in order to provide validation data for the computer codes.

Analysis of these trials [10, 11, 12] indicated a deficiency in our predictive capability in the area of structural damping. During these trials, the natural frequencies and mode shapes of the cylinder were measured using either strain gauges or accelerometers placed throughout the cylinder with excitation provided by an electromagnetic shaker. Directivity patterns of radiated noise were also measured with a hydrophone while the cylinder was excited with the shaker. The measured radiated sound was compared to predictions made using the DREA suites of computer codes. As the cylinder was typically excited at a structural resonance for the radiated noise tests, modal damping factors were required in the numerical analysis. As there are no standard theoretical values for these damping factors for a generic structure in the literature and as there were no empirical values available for such a structure, it was necessary to use measured modal damping factors for the numerical predictions of radiated noise. While this technique was sufficient for these studies, it does not allow for the ability to make predictions if the structure is not available for modal testing (which is likely to be the general case for large scale analyses). Given this limitation, it was decided to collate the experimental data from this cylinder to determine if this data set could be used to assist in predicting future modal damping factors for similar steel structures and to determine if general conclusions could be drawn by comparing the modal factors from the cylinder in a submerged, semi-submerged, or in-air state.

This technical memorandum discusses the construction of the cylinder, the various experimental set-ups and compares the results of the modal damping factor measurements from the various experiments.

2 Experimental Procedures

2.1 Cylinder Construction

The ring-stiffened right cylinder was manufactured at the Ship Repair Unit (Atlantic) machine shops with material provided by DREA. The cylindrical part itself was purchased as a 9.5mm thick tube with a nominal diameter of 762mm (30in), with a weld seam running longitudinally

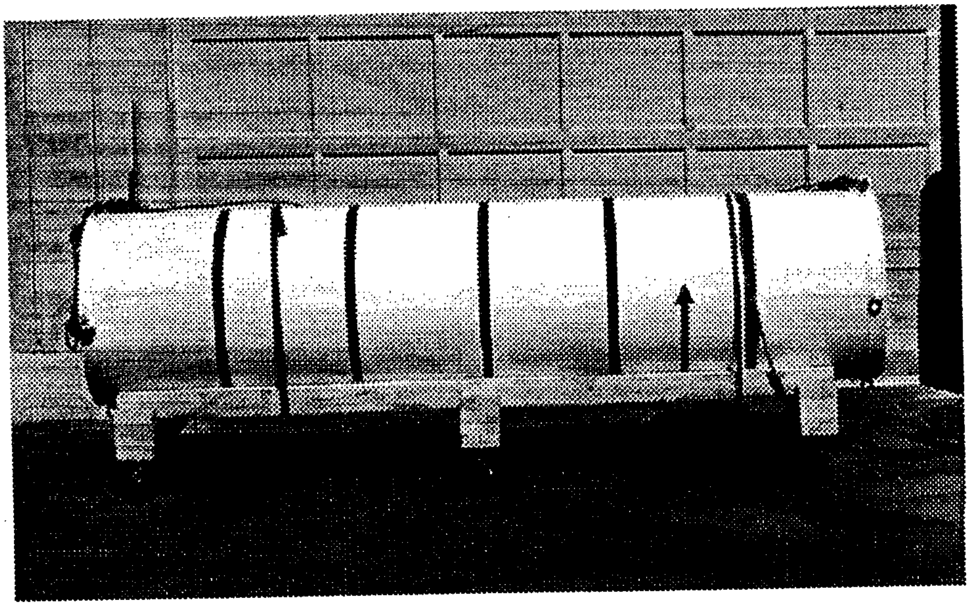

Figure 1: Test Cylinder

along the entire length. Five circumferential stiffeners were welded into the tube (continuous welds) at equal intervals of 0.5m. These stiffeners had a square 38.1mm × 38.1mm cross-section. Threaded 9.5mm radial holes facing inwards were also provided at 45° intervals on every ring stiffener to allow for the attachment of various pieces of equipment [13].

Removable endcaps 76.2mm thick were constructed of nominal 3in plate and welded to the tube. The endcaps were of two pieces with a central 'hatch' roughly 600mm in diameter, which was bolted to the remainder of the endcap and sealed with an O-ring. Ring bolts were welded to the endcaps at various positions to allow for handling of the cylinder and the endcaps.

Four 24-pin Envirocon marine connectors penetrated one endcap (called the *front* endcap) to allow for the wiring of the strain gauges and force transducers. A 4-pin Marsh Marine connector was used to provide power for the electromagnetic shaker. An air fitting was also provided in the front end to allow for pressure testing of the cylinder. A photograph of the cylinder on its transport carriage is shown in Figure 1.

Overall, the cylinder was of solid construction with only continuous welds to avoid any possibility of structural 'chatter' when excited. The entire structure was mild steel with the exception of the two O-ring seals, the instrumentation plugs, and any attached equipment. Handling of the cylinder was always performed with steel cables attached at the various ring bolts.

2.2 Physical Layout

The first set of trials took place at the DREA Acoustics Calibration Barge located in Halifax Harbour. Figure 2 shows the interior of the barge and the cylinder suspended for transport. These trials involved submerging the cylinder with the axis of the cylinder normal to the surface of the water. The cylinder was attached to a rotating station fixed at one end of the barge's moon pool (see Figure 2). The cylinder was attached to the station using 3m long rods which can be connected in series with pin-jointed connections between each rod. The uppermost rod fit into a sleeve in the rotating station and was pinned at the top. The lowermost rod was bolted to the end of the cylinder. The lower end of the cylinder housed the instrumentation cable which was allowed to have significant slack before rising to the surface. A schematic of the layout is shown in Figure 3.

The second set of trials, involving the floating cylinder, also took place at the DREA Acoustics Barge but, to avoid reflections from the moon pool walls, the cylinder was floated outside of the barge at the extreme reach of the barge's swivel crane. As the cylinder was close to neutrally buoyant, it was necessary to suspend the cylinder from the crane so that the waterline would bisect the cylinder as desired. The cylinder was hung in the horizontal position from two steel sling cables attached to ring bolts at either end of the cylinder. A guide line was attached to each end of the cylinder to allow for positioning but, during any tests, the guidelines were allowed to lay slack. The schematic for this experiment is shown in Figure 4.

The in-air trials of the cylinder took place at Health Canada's anechoic chamber in Ottawa. The chamber measured 12m × 16m × 11m high. The cylinder was supported on an aluminum turntable which was mounted on bayonet mounts in the chamber floor. The cylinder was lifted to this turntable using a winch attached to the roof of the chamber and, for safety reasons, several hundred pounds of tension were supported by the winch cable during the trial. The cylinder was supported from the winch by two steel sling cables which were attached to two of the cylinders ring bolts. The instrumentation cable was supported by a sling from the chamber roof as well. This resulted in a torque applied to the cylinder as it was rotated during the tests due to the tension on the cable. The schematic for this layout is shown in Figure 5.

2.3 Damping Measurements

For all three sets of trials, measurements of modal damping were made in much the same way. The cylinder was excited using an electromagnetic shaker attached to the inside of the cylinder on the centre stiffener such that the force was applied in a radial direction. For modes which were not excited well with the shaker, the cylinder was excited using an underwater sound projector for the submerged case and a set of speakers for the in-air case. Due to the difficulties of maintaining proximity to the cylinder during the floating tests, these modes were not excited and no measurements were taken.

In general, broadband random noise excitation was provided initially and the resulting vibrations were examined using accelerometers placed throughout the cylinder. The resonant peaks were recorded and the mode shape identified where possible. In most cases, a limited

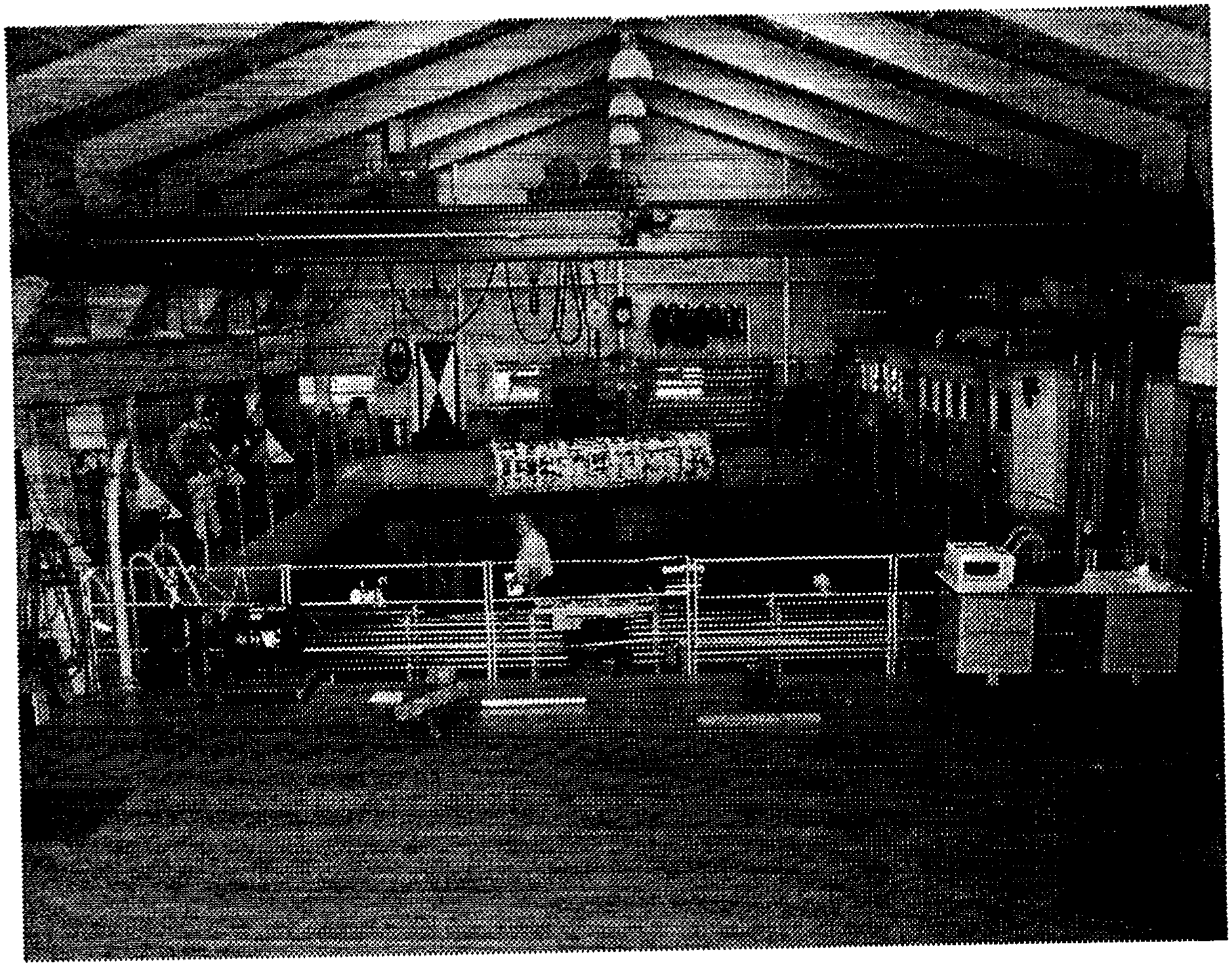

Figure 2: Interior of DREA Acoustic Calibration Barge

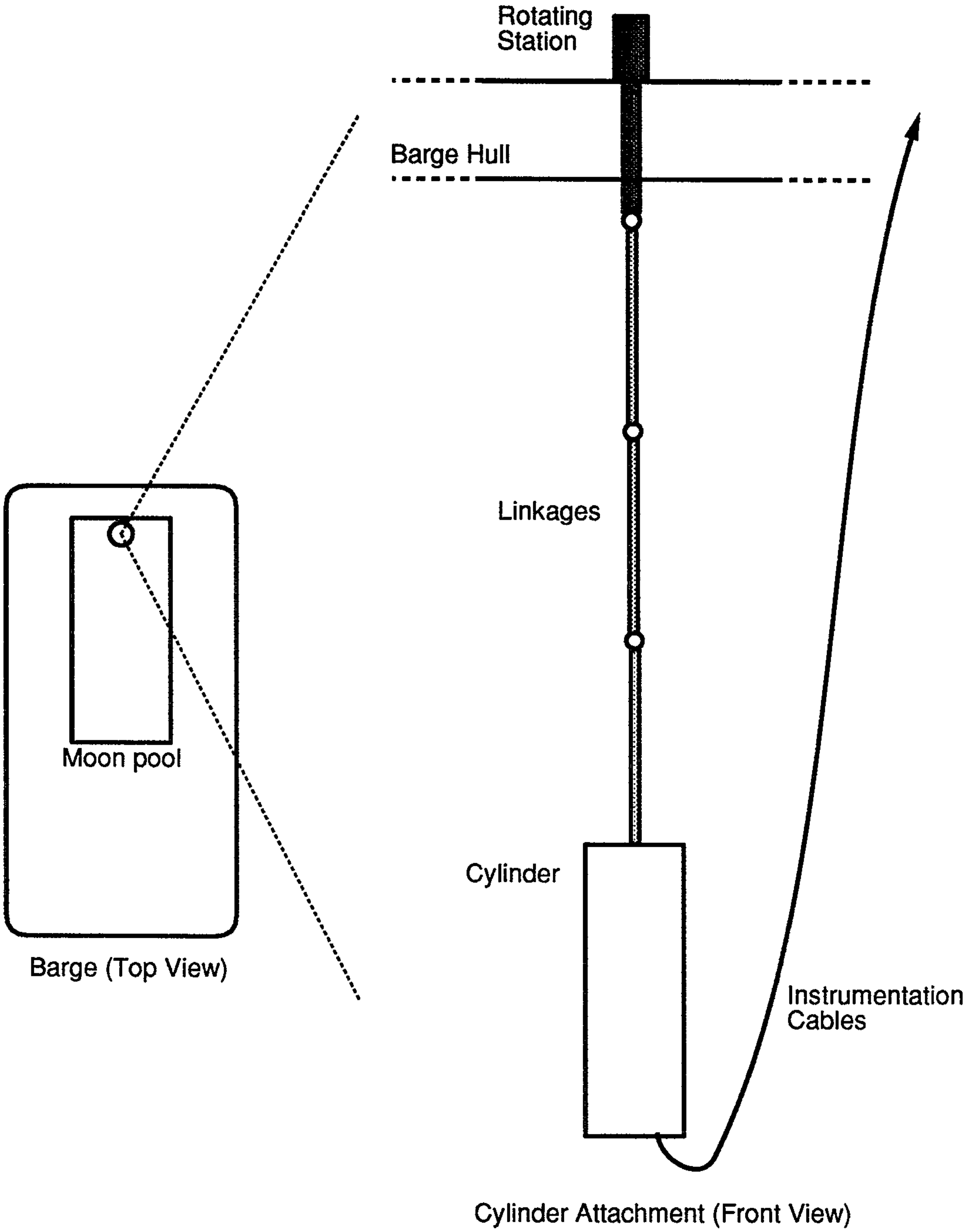

Figure 3: Schematic of Submerged Cylinder Experiment

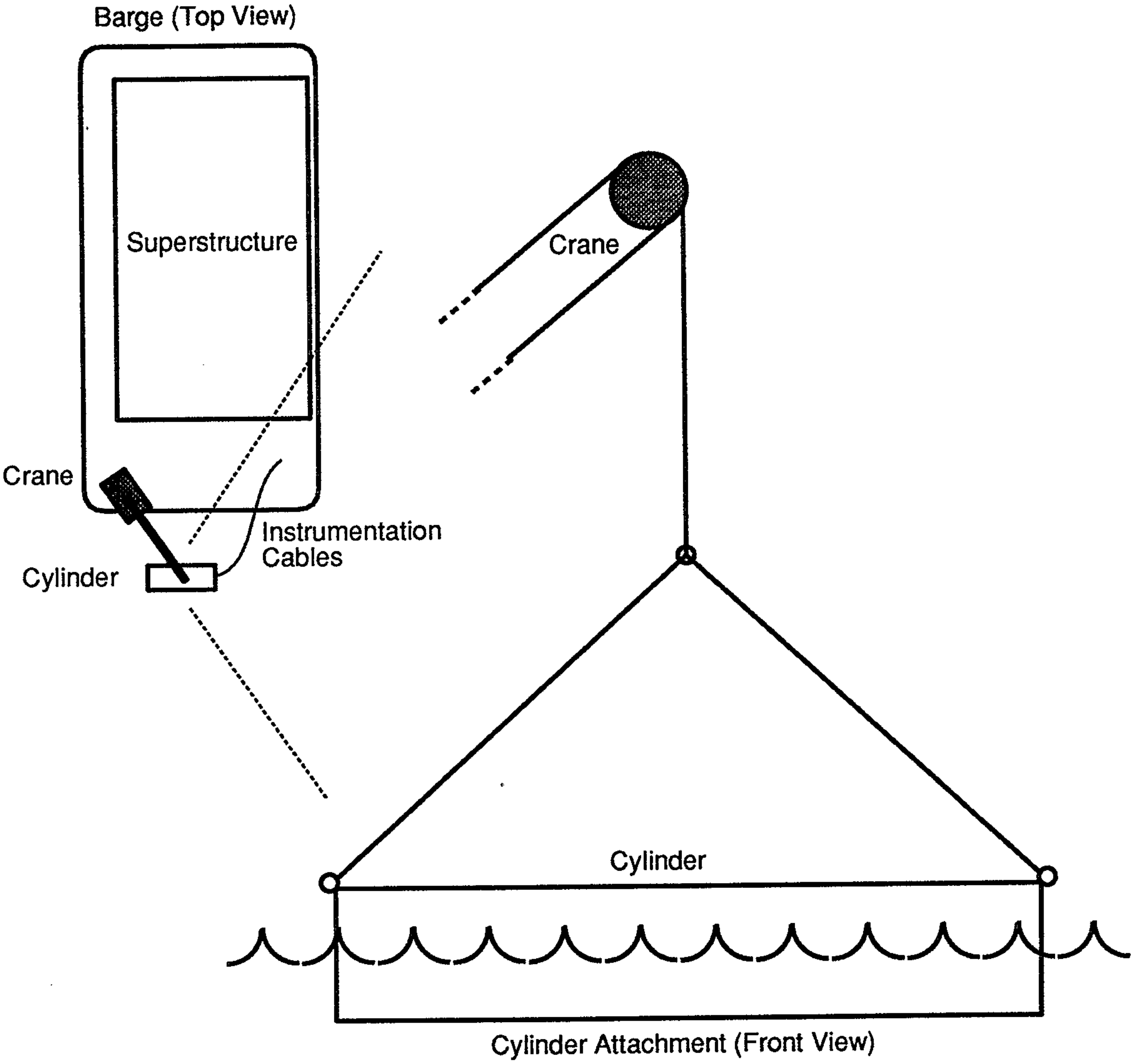

Figure 4: Schematic of Floating Cylinder Experiment

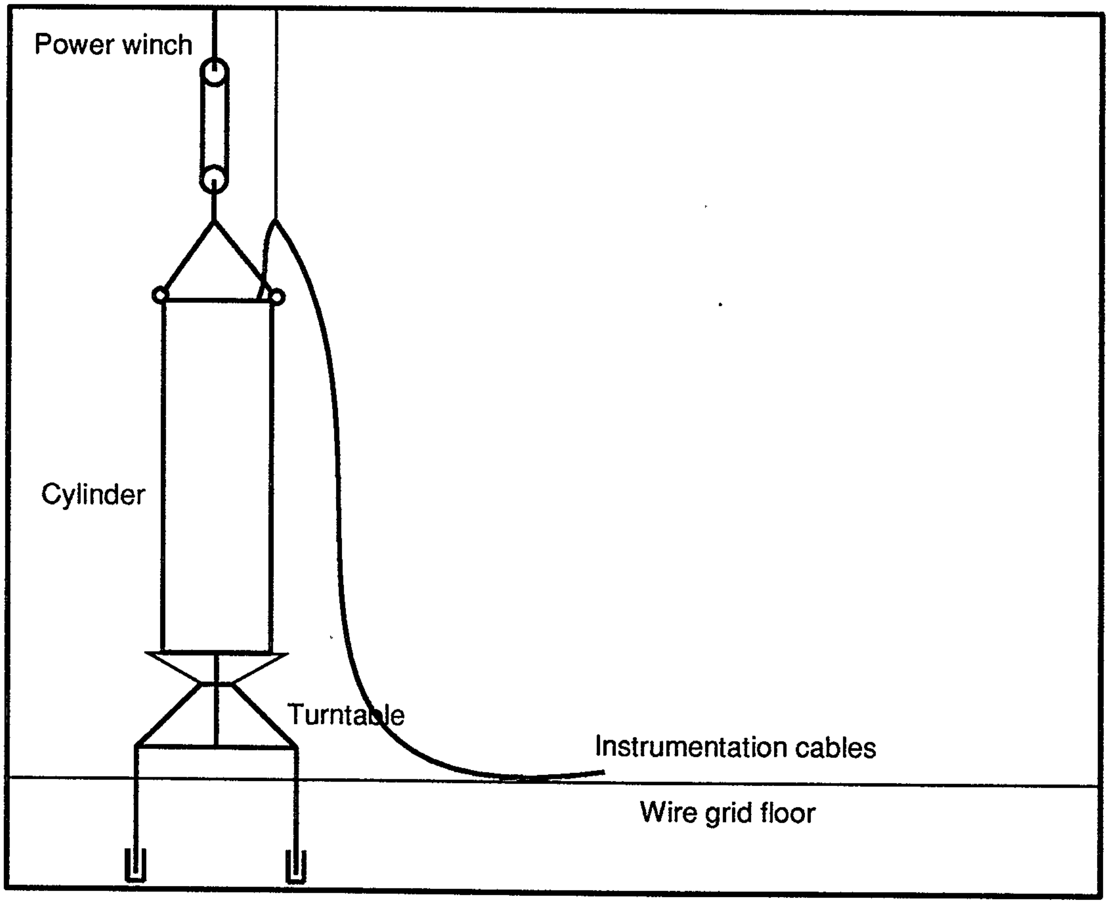

Figure 5: Schematic of In-Air Cylinder Experiment

frequency band random noise signal centred on a specific resonant frequency was then used as excitation. The response was plotted and the damping factor was calculated by measuring the width of the resonant peak at the 3dB down point (half-power point). The damping factor, η, was found using the following:

$$\eta = \frac{\Delta\omega}{2\omega} \tag{1}$$

where $\Delta\omega$ is the width of the resonant peak (in rad/s) and ω is the resonant frequency (in rad/s). Where multiple measurements were made, the results were simply averaged, unless the divergence was extreme. In that case, the multiple values were recorded.

3 Results

The results of the modal damping ratio experiments are combined in Table 1. They are listed according to the mode with which they are associated. In the table, the letter N indicates the order of the circumferential mode (number of full sine waves) of the cylinder and M the longitudinal (number of half sine waves).

As can be seen from the table, there were significant variations in the damping ratios varying with mode type and with the physical circumstances. The lack of entries under the 'Floating' heading (indicated by N/A) can be attributed to the difficulty in exciting those particular mode shapes as discussed in the previous section. The missing entries under the 'In-Air' heading were also not measured during the trial, again due to difficulties in exciting that resonance.

For the majority of the modes for the submerged and in-air cases, a single reasonably consistent damping ratio was measured for each mode, as expected. In some cases, significantly different values were measured during different trials (e.g., modes 3,1 and 4,1) and both were listed here. It was not clear what caused such a large variation in the results; however, damping ratios can be sensitive to small changes in the experimemtal setup. It is also not clear why, for the submerged system, there was such a large variation in the various bending mode values, which range from 1.24% to .043%. The values for the 1,1 and 1,2 modes were not comparable at all to any other measured values and the other systems did not show such wide variations.

For the floating case, there were two values for most of the measured modes. In a symmetric cylinder, predicted resonant modes (except those such as torsion and breathing modes) appear as orthogonal pairs which have different axes of motion perpendicular to the cylinder axis. Thus, for the floating cylinder, which did not have a symmetric fluid loading, these pairs occur at slightly different frequencies depending on the significance of the fluid loading with respect to that mode shape and orientation. This would lead to different damping ratios for the same reason.

The damping ratios are plotted in Figure 6 versus mode number (not sorted by frequency). The y-axis was truncated so that the submerged 1,1 and 1,2 modes were not visible. This was necessary to be able to differentiate the lower values. As can be seen from the figure, over the majority of the range, the lowest damping ratios occurred in the submerged case. With the exception of the bending modes (N=1), the damping ratios for the floating cylinder were

Mode	Damping Ratios		
(N,M)	Submerged	Floating	In-Air
1,1	0.01040	0.00088	0.00277
1,2	0.01240	N/A	N/A
1,3	0.00072	N/A	N/A
1,4	0.00043	N/A	N/A
2,1	0.00112	0.00109	0.00168
		0.00224	
2,2	0.00052	N/A	0.00086
		N/A	0.00297
2,3	0.00053	0.00088	0.00097
		0.00246	0.00156
2,4	0.00156	N/A	0.00120
2,5	0.00100	N/A	N/A
3,1	0.00053	0.00176	0.00125
		0.00346	0.00140
3,2	0.00040	0.00439	0.00183
3,3	0.00036	0.00168	0.00114
		0.00356	
3,4	0.00062	N/A	0.00050
		N/A	0.00079
3,5	0.00052	N/A	0.00087
		N/A	0.00097
4,1	0.00039	0.00089	0.00151
	0.00028	0.00124	0.00134
4,2	0.00039	N/A	0.00128
4,3	0.00041	N/A	N/A
5,1	0.00033	N/A	0.00095
	0.00060	N/A	

Table 1: Modal Damping Ratios of Test Cylinder

the highest of those measured, although there were several overlaps between the floating and in-air values. The two sets of values for each mode for the floating case also seem to inhabit separate regions except for the 3,2 mode. Ignoring the 1,2 and 1,2 modes in all cases, the average damping ratios were 0.00060 (submerged), 0.00215 (floating), and 0.00128 (in-air).

Some of these differences between the measured damping ratios during the different trials may be explained by the variations in the experimental setups. In the submerged cylinder case, the cylinder was rigidly attached to the metal poles which provided rigid connections (although pin-jointed) up to the large supporting station. Supporting damping would only have come from the instrument cable hanging freely from the lower end of the cylinder. For the in-air testing, while the cylinder was placed on a rigid aluminum turntable, several hundred pounds of tension were maintained on the lifting cable resulting in a source of damping. As well, the instrument cable may have contributed due to its applied torque to the system as described in the previous section. In the floating case, the cylinder was suspended from the crane by two wires which supported a significant fraction of the cylinder's weight. These support cables may have contributed to the damping.

4 Conclusions

Suites of computer codes have been developed at DREA to predict the radiated noise from submerged or floating elastic structures. To help validate these codes, DREA has conducted several sets of experiments at DREA's Acoustic Calibration Barge in Halifax, Nova Scotia, and Health Canada's anechoic chamber in Ottawa, Ontario, to measure the natural frequencies and radiated noise from a ring-stiffened cylinder subjected to a harmonic load. Analysis of these trials indicated a deficiency in our predictive capability in the area of structural damping. For the numerical analyses performed, it was necessary to use measured modal damping ratios as no empirical or theoretical values were available.

This report discussed the experiments performed and compared the measured modal damping ratios. Over the resonant modes examined, while a definite pattern did not emerge, it was apparent that the submerged cylinder trials resulted in the lowest measured damping ratios, followed by the in-air trials and the floating trials. Given that the three sets of trials involved suspension of the cylinder by three separate methods, it was not possible to determine the primary mechanism for the differences in the damping ratios. The data collected is still of use in determining approximate damping ratios which could be used for similar structures in future analyses, although it may be necessary to insure that similar suspensions and similar modes are being considered.

Further work in this area would be of use in determining the correlation between fluid loading and measured damping ratios. Similar sets of trials in which the suspension systems and models were identical should clarify the picture. As well, the existing results should be compared to other measured damping ratios for similar structures to identify whether ratios may be specified based on structural aspects alone.

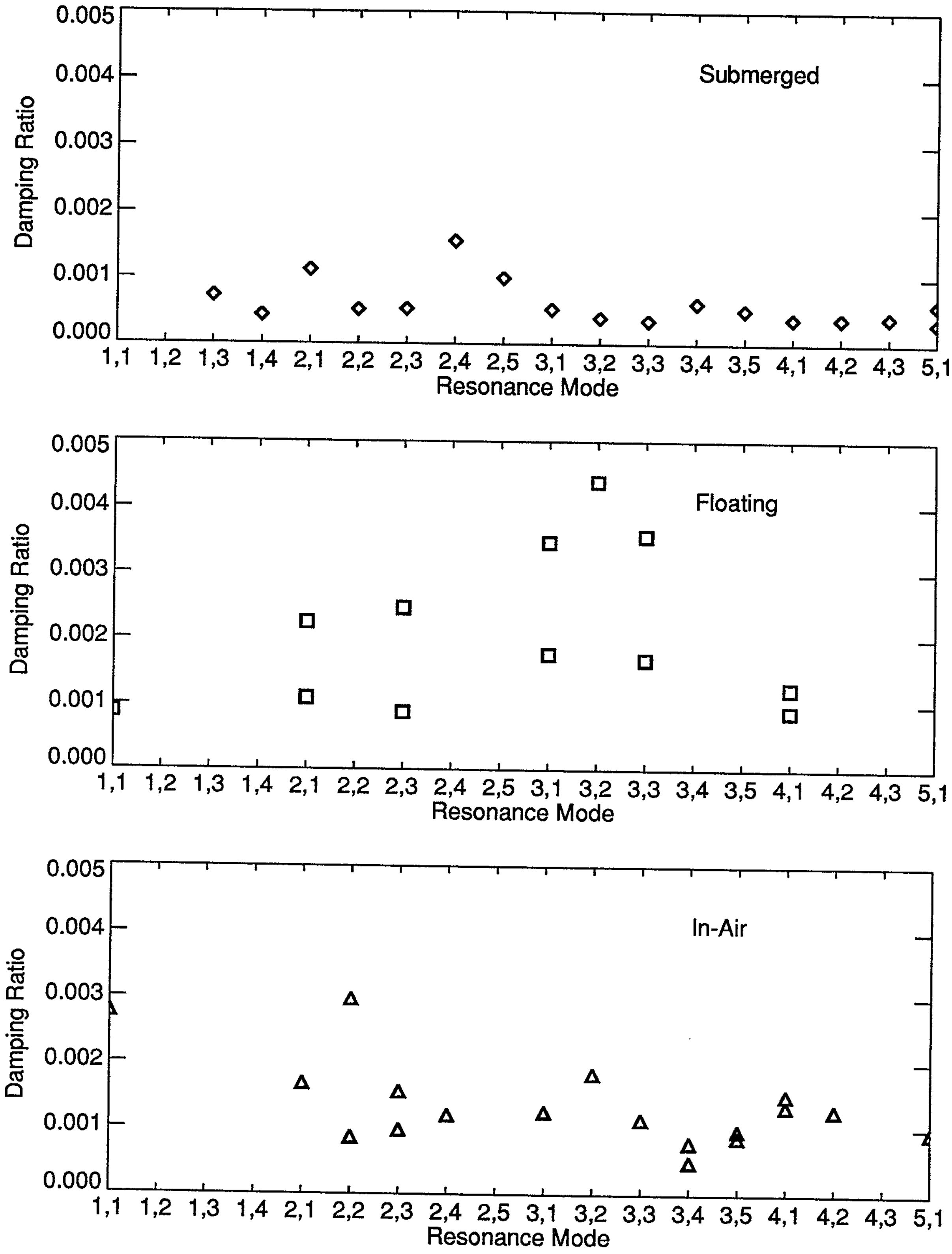

Figure 6: Cylinder Damping Ratios

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