Effects of sea motion on the crew of the Petro Canada Terra Nova FPSO (Floating, Production, Storage and Offloading) vessel

Bob Cheung
DRDC Toronto

Chris J. Brooks
Survival Systems Inc.

Antonio Simoes-Re
National Research Council

Kevin Hofer
DRDC Toronto

Defence R&D Canada – Toronto

Technical Report

DRDC Toronto TR 2004-117

October 2004

Report Documentation Page			*Form Approved* *OMB No. 0704-0188*
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.			
1. REPORT DATE **30 NOV 2004**	2. REPORT TYPE		3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Effects of Sea Motion on the Crew of the Petro Canada Terra Nova FPSO (Floating, Production, Storage and Offloading) Vessel**			5a. CONTRACT NUMBER
			5b. GRANT NUMBER
			5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)			5d. PROJECT NUMBER
			5e. TASK NUMBER
			5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Defence R&D Canada -Ottawa,National Defence Headquarters,Ottawa,CA,K1A OK2**			8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSOR/MONITOR'S ACRONYM(S)
			11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**			
13. SUPPLEMENTARY NOTES **The original document contains color images.**			
14. ABSTRACT **see report**			
15. SUBJECT TERMS			

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**79**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Author

B. Cheung, PhD

Approved by

L.S. Goodman, PhD

Acting Head, Aerospace Life Support Section

Approved for release by

K.M. Sutton

Chair, Document Review and Library Committee

Abstract

Current oil and gas exploration requirements to exploit resources in both deep and shallow water have changed the method of oil extraction. Floating Production Storage and Offloading (FPSO) vessels are increasingly being used to operate in deep water where the operating environment can be very extreme. The Terra Nova FPSO vessel is the first of its kind built for operations on the Grand Banks in Newfoundland at the Terra Nova field and is the first to operate in Canadian waters. The crew on this vessel must often work under extreme weather conditions, in shifts throughout the day and night for up to three weeks at a time, or even longer if the weather prevents crew changes. Seasickness and its after-effects, motion-induced fatigue and motion-induced interruptions are a potential problem for the safety and health of crewmembers at sea. Understanding the incidence, severity and the effects of seasickness on performance can improve effective scheduling, task assignment, and reduce the likelihood of personal injury both on- and off-duty. In extreme circumstances, this understanding may prevent major injury, loss of life and even loss of the FPSO itself. The previous questionnaire-based survey (Cheung, Brooks & Hofer 2002) results revealed that crew complained of a variety of problems including sleep disturbance, task completion, task performance, loss-of-concentration, decision-making and memory disorders. These problems were correlated with increasing ship motion, however, in the previous study, the ship motion data were obtained indirectly through the radio operator from the FPSO Offshore Installation. This new survey attempts to (1) confirm the incidence and severity of the symptom complex of seasickness, motion-induced fatigue and task performance problems encountered on the Terra Nova FPSO vessel, (2) to examine correlations (if any) between real time direct recordings of fore and aft FPSO vessel motion, seasickness, motion-induced fatigue and task performance, and (3) use the results to develop recommendations to ameliorate seasickness and improve comfort and performance in the environment described above. A questionnaire-based survey of motion effects including sleep problems, symptoms and severity of seasickness and task performance was administered at various times during 3-week offshore shifts. Ship motion data provided for this analysis was gathered from two accelerometers mounted on the FPSO in the forward and aft switch rooms on the same deck. The FPSO crew responded well and 1344 questionnaires were received. Data analyses revealed only a small number of complaints of sea sickness, but as was expected there was a much higher number of complaints of sleep problems, decision making and memory disorders. The correlation between sleep disturbance and ship motion was relatively high. Task performance problems such as loss of concentration, decision-making and memory disorders and task completion problems were observed. Between November 2002 and April 2003, the number of significant correlations between ship motion and symptoms/performance increased with the severity of average sea state. There appeared to be no apparent habituation among subjects who participated in more than 2 shifts offshore. It is apparent that the number of safety, health and performance issues increases with the deterioration of weather conditions. It is recommended that an identification system should be implemented by the OIM to signify when the ship's company is at risk of injury and potential task degradation.

Résumé

Le fait qu'on doive actuellement exploiter les ressources pétrolières et gazières en eaux tant profondes que peu profondes a entraîné des changements dans les méthodes d'extraction. On utilise de plus en plus des unités flottantes de production, stockage et déchargement (FPSO) pour l'exploitation en haute mer, où les conditions environnementales peuvent être extrêmes. Le navire Terra Nova est le premier du genre construit pour l'exploitation du gisement Terra Nova sur les Grands Bancs de Terre-Neuve et est le premier en opération dans les eaux canadiennes. L'équipage de ce navire doit souvent travailler dans des conditions météorologiques extrêmes par postes diurnes et nocturnes pour des périodes de trois semaines ou même plus si la météo empêche les changements d'équipage. Le mal de mer et ses répercussions ainsi que la fatigue et les interruptions de travail induites par le mouvement présentent des risques potentiels pour la sécurité et la santé des membres d'équipage en mer. Une meilleure connaissance de l'incidence et de la sévérité du mal de mer chez les membres d'équipage ainsi que de ses effets sur la performance permettrait d'améliorer les calendriers de travail et les assignations de tâches et de réduire les risques de problèmes de santé tant durant les périodes de travail qu'en dehors de ces périodes. Dans des conditions extrêmes, cette connaissance pourrait prévenir des traumatismes importants, des mortalités et même la perte du navire FPSO. Selon les résultats de l'enquête par questionnaire précédente (Cheung, Brooks et Hofer, 2002), les membres d'équipage souffrent de problèmes divers : troubles du sommeil, difficulté de terminer leurs tâches, perte d'efficacité, perte de concentration, difficulté à prendre des décisions et troubles de la mémoire. Ces problèmes étaient corrélés avec l'intensité des mouvements du navire; cependant, dans cette étude antérieure, les données sur les mouvements du navire ont été obtenues indirectement par l'entremise de l'opérateur radio du navire FPSO. Les objectifs de la présente étude étaient les suivants : 1) remesurer l'incidence et la sévérité du complexe de symptômes du mal de mer, de la fatigue induite par le mouvement et des problèmes de performance au travail observé chez les membres d'équipage du FPSO Terra Nova; 2) établir les corrélations éventuelles entre les enregistrements directs des mouvements du navire en temps réel avec le mal de mer, la fatigue induite par le mouvement et la performance au travail; 3) à partir des résultats, élaborer des recommandations visant à réduire le mal de mer et améliorer le confort et la performance dans ce type d'environnement. Un questionnaire sur les effets du mouvement – troubles du sommeil, symptômes et sévérité du mal de mer et performance au travail – a été soumis à différents moments durant des périodes de travail en mer de trois semaines. Les données de mouvement du navire utilisées dans cette analyse ont été obtenues au moyen de deux accéléromètres installés sur le même pont dans des salles d'équipement avant et arrière du FPSO. L'équipage du FPSO a bien répondu, 1344 questionnaires ayant été reçus. Les analyses des données ont montré que les cas de mal de mer étaient peu nombreux, mais, comme prévu, les cas de troubles du sommeil, de la prise de décision et de la mémoire étaient beaucoup plus fréquents. La corrélation entre la perturbation du sommeil et les mouvements du navire était relativement élevée. Nous avons noté que l'équipage montrait des problèmes de performance au travail, comme la perte de concentration et des troubles de la prise de décision et de la mémoire, ainsi que de la difficulté à terminer leurs tâches. Entre novembre 2002 et avril 2003, le nombre de corrélations significatives entre les mouvements du navire et les symptômes et problèmes de performance augmentait avec la détérioration de l'état de la mer moyen. Il n'y avait apparemment pas habituation chez les sujets qui ont connu plus de deux périodes de travail en mer. Il appert que le nombre de problèmes de sécurité, de santé et de performance

s'accroît avec la détérioration des conditions météorologiques. Nous recommandons que les responsables des installations de forage en mer mettent en œuvre un système de repérage des problèmes permettant d'établir quand l'ampleur des mouvements du navire risque d'affecter l'équipage et la performance au travail.

Executive summary

The Petro Canada Terra Nova Floating, Production, Storage, Offshore (FPSO) vessel is the first of its kind built for operations on the Grand Banks of Newfoundland at the Terra Nova field in Canadian waters. Unlike fixed installation oil drilling platforms, a common feature of FPSO vessel operation is that the ship will be subjected to severe wave motion at sea, and consequently it needs to be able to operate for as long as possible in severe conditions. As a result, it is expected that crewmembers living and working aboard the FPSO vessel will be exposed to severe weather and motion (especially during the winter months) than those on conventional fixed installation platforms. This survey study is a continued effort in assessing motion effects on the crew working on the FPSO vessel during the winter months from November 2002 to April 2003. State-of-the-art motion sensors mounted on the same deck in the fore and aft switch rooms were used to monitor ship motion in the heave, longitudinal and lateral axes as well as roll, pitch and yaw angular motion. Based on a series of questions we attempt to investigate if seasickness is a problem and whether certain ship motions affect sleep, mental and physical performance on board. Fifty-nine out of an average of 80 personnel participated in the study and 1344 returned questionnaires were collected from the 59 participants during the study period. In agreement with our first survey, from this excellent response rate, it was found that the incidence and severity of seasickness and performance degradation ranged from slight to moderate. The correlation between ship motion and complaints of discomfort increases when the average monthly sea state is higher. The number of safety, health and performance issues increase with the deterioration of weather conditions. Experienced Offshore Installation Managers (OIMs) know this and have procedures to manage these issues. This scientific study has confirmed their observations and has provided OIMs with the justification to amend and improve their ability to manage under worsening conditions. Guidelines using a colour coded warning system are proposed to identify when the ship's company is at risk from injury due to provocative ship motion.

Cheung, B., Brooks, C.J., Simoes-Re, A., Hofer, K. 2002. Effects of sea motion on the crew of the Petro Canada Terra Nova FPSO (Floating, Production, Storage and Offloading) vessel. DRDC Toronto TR 2004-117. Defence R&D Canada – Toronto.

Sommaire

L'unité flottante de production, stockage et déchargement (FPSO) Terra Nova de Petro-Canada est le premier navire du genre construit pour l'exploitation du gisement Terra Nova sur les Grands Bancs de Terre-Neuve, dans les eaux canadiennes. À la différence des plates-formes de forage pétrolier fixes, les navires FPSO sont mis en mouvement par les vagues et doivent pouvoir demeurer en opération le plus longtemps possible dans ces conditions difficiles. Les membres d'équipage vivant et travaillant sur un navire FPSO peuvent être exposés à des conditions de mauvais temps et de forts mouvements (particulièrement durant l'hiver) plus difficiles que celles auxquelles sont exposés les travailleurs des plates-formes traditionnelles fixes. La présente étude poursuit l'évaluation des effets du mouvement sur l'équipage du FPSO Terra Nova durant l'hiver, ici pour la période allant de novembre 2002 à avril 2003. Des senseurs de mouvement des plus perfectionnés installés sur le même pont dans des salles d'équipement avant et arrière ont été utilisés pour enregistrer les mouvements verticaux, longitudinaux et latéraux du navire ainsi que les mouvements de roulis, de tangage et de lacet. À partir d'un questionnaire, nous avons cherché à savoir si le mal de mer constitue un problème et si certains mouvements du navire affectent le sommeil et les performances mentales et physiques à bord. Sur une moyenne de 80 membres d'équipage, 59 personnes ont participé à l'étude et nous ont remis 1344 questionnaires remplis. Tout comme dans notre première étude, et avec cet excellent taux de réponse, nous avons trouvé que l'incidence et la sévérité du mal de mer et de la dégradation de la performance variaient de légères à modérées. La corrélation entre les mouvements du navire et les cas d'inconfort s'accroissait avec l'augmentation de la moyenne mensuelle de l'état de la mer. Le nombre de problèmes de sécurité, de santé et de performance augmentait avec la détérioration des conditions météorologiques. Les responsables des installations de forage en mer expérimentés connaissent cette problématique et appliquent des procédures pour gérer ces problèmes. La présente étude scientifique a confirmé leurs observations et leur fournit des raisons d'améliorer les moyens dont ils disposent pour gérer les installations quand les conditions sont difficiles. Nous proposons des lignes directrices utilisant un système d'avertissement, fondé sur un code de couleurs, qui permettent d'établir quand l'ampleur des mouvements du navire risque d'affecter l'équipage.

Cheung, B., Brooks, C.J., Simoes-Re, A., Hofer, K. 2002. Effects of sea motion on the crew of the Petro Canada Terra Nova FPSO (Floating, Production, Storage and Offloading) vessel. DRDC Toronto TR 2004-117. Defence R&D Canada – Toronto.

Table of contents

List of figures

List of tables

Acknowledgements

This project could not have started without the assistance of Mr. Ian Denness, Mr. Stewart Strong, Dr. Ciaran O'Shea, Ms. Margaret Harris and Mr. Frank Martin from Pertro Canada and Terra Nova. Further, the data collection could not have been done without the hard work of both the Operation Health Advisors and the cooperation of all the workers of Terra Nova, especially the support of the Offshore Installation Managers (OIMs). The authors also wish to thank Ms. Raquel Heskin and Mr. Andrew Smith from DRDC Toronto for their assistance in data reduction and analysis from the questionnaires; and Mr. Mike Sullivan, Mr. Ennis for the installation of hardware, Mr. Greg Janes for data acquisition software development and the data analysis by Mr. Bradley Elliot, Mr. Timothy Hopkins and Mr. Stephen Mulrooney all from NRC.

Introduction

This study is a continued project in assessing the motion effects on the personnel working on the Petro Canada Terra Nova FPSO (Floating, Production, Storage, Offloading) vessel. The FPSO is exposed to wind and waves, and it is stabilized and positioned by a complex controlled system of trimming and thrusting. Unlike semi-submersible or fixed installation oil drilling platforms, a common aspect of FPSO vessel operation is that the crew are subjected to all extremes of wave motion at sea. Thus, crewmembers living and working aboard the FPSO vessel will be exposed to more severe motions (especially during the winter months) than those on conventional fixed installation platforms. Literature suggests that motion-induced fatigue, motion-induced interruption (Baitis et al. 1995), seasickness and its after-effects remain potential threats to crewmembers at sea. Understanding the incidence, severity and the effects of these motion-induced phenomena on performance can improve safety, effective scheduling, task assignment, and productivity. It should be noted that terminology of motion-induced fatigue is non-specific, since some of the symptoms of motion-induced fatigue, such as lack of motivation, excessive tiredness and disinclination for work are similar to some of the symptoms associated with motion sickness and the after-effects of motion sickness such as the Sopite syndrome (irresistible drowsiness after succumbing to one or more bouts of motion sickness). This suggested that there is a central nervous system influence to motion-induced fatigue. The term, motion-induced interruptions, refers specifically to the effects on physical performance tasks, such as standing, walking, turning and minor lifting. In the current and previous study, we avoid the ambiguity and limitation of using these two terms by using a questionnaire that solicits subjects' response on sleep problems, specific symptoms of motion sickness, problems related to task performance, the ability to complete tasks and other problems that may contribute to the crew's discomfort.

Our previous questionnaire-based survey (Cheung, Brooks & Hofer 2002) had a very good response rate of 82.7%, and revealed that the crew complained of a variety of problems related to sleep disturbance, task completion, task performance, loss of concentration, decision-making and memory disorders. However there were few complaints of frank seasickness. Specifically, there were high correlations between complaints of sleep disturbance and vessel motion. Task performance problems such as concentration, decision-making, and memory disorder were noted in December, January, February, and May when weather conditions were poor. The percentage of subjects who experienced problems ranged from 5.8-69.2%. Although there were relatively few incidences of severe motion sickness, the correlations between complaints of sickness and the roll, pitch and heave motion of the FPSO vessel were high. In the previous study, the ship motion data were obtained indirectly through the radio operator from the FPSO Offshore Installation Office. The frequencies of ship motion that cause these disturbances were unknown. In this new study, we attempt to investigate if there are correlations between the motion effects observed and a direct measurement of the FPSO motion in six axes (roll, pitch, yaw angular accelerations and vertical, longitudinal, lateral linear acceleration) recorded by motion sensors from 2 designated positions on the FPSO vessel during severe weather. Data obtained from this study also serve to increase our database on the effects of ship motion on the FPSO crew and validate our previous findings that the number of safety, health and performance issues increases with the deterioration of weather conditions.

This page intentionally left blank.

Methods

Subjects

The subjects are employees of the Petro Canada Terra Nova project including tradespeople, technical personnel, project engineers and project managers. Approval of this survey study was obtained from the DRDC Toronto (formerly DCIEM) Human Ethics Committee. All participants met the medical requirements as offshore employees and went through the medical screening provided by Atlantic Offshore Medical Services. All participants in this study were volunteers. Participants from the previous study were also invited to participate in the current study. Subjects were free to withdraw at any time without specifying a reason. The Terra Nova project enforces strict prohibition of alcohol consumption immediately prior to departure and during time spent on the FPSO vessel. Therefore, the survey was conducted away from the influence of alcohol. The questionnaire and ship motion/acceleration data were collected by the duty Operation Health Advisors (OHA) on a daily basis and were brought ashore at the end of each three-week shift offshore. The questionnaire was sent directly to the principal investigator, and the Institute of Marine Dynamics. In St John's Newfoundland analyzed the ship motion acceleration data.

Experimental design

The study duration was a period of 6 months from November 2002 to April 2003. Each employee on board the FPSO vessel was assigned a numerical code by the OHA and was responsible for distributing and collecting the questionnaires. The questionnaire data remained anonymous and are treated as confidential. Prior to the commencement of the study, crewmembers were given a briefing on the objectives of the study by the OHA.

Procedure

Acquisition of ship motion in six axes

The FPSO moves in six axes, 3 angular accelerations (roll, pitch, yaw) and 3 linear accelerations (surge, sway, heave). Movements in these axes were measured at two designated locations on board, (the forward switch room and aft switch room on the same deck) by two independent accelerometers and data acquisition systems. The highly sophisticated data acquisition system consists of 4 main components:

1. MotionPak – an accelerometer unit that detects ship motion.

2. Signal Conditioning Unit – provides filtering and amplification of the analog signals from the MotionPak, and also provides DC power to the MotionPak.

3. Industrial Computer – records and process the motion data

4. UPS (Uninterruptible Power Supply) – provides temporary backup power for the entire system when it is necessary.

The motion sensor provides outputs for seven channels of analog data – roll, pitch, yaw, surge, sway, and heave; and one designated channel that monitors the internal temperature of the sensors. These data channels were acquired at 10 Hz and stored in binary files every 24 hours at 1200 GMT. The maximum duration of recording was 24 hours including a 12-hour day shift and 12-hour night shift. The major indicator of vessel motion was the root-mean-square average acceleration magnitude, at the designated position, calculated over each measurement period.

Questionnaire-based assessment of motion effects on the crew

Two questionnaire-based surveys of the crewmembers including a motion sickness susceptibility questionnaire, a survey on past motion sickness susceptibility (Golding, 1998) and a motion effects assessment questionnaire were administered at various times as described below. The motion effects assessment questionnaire was based on the NATO Performance Assessment Questionnaire (Colwell 2000) and modified for use in the civilian community. A copy of the Motion Effects Assessment is attached at Annex 1.

The one-page motion sickness history questionnaire was administered by the OHA to each of the crewmembers before reporting for duty on board the FPSO vessel. During a 3-week rotation offshore, participants were encouraged to answer the questionnaire one half hour before shift end every day of the first week at sea and on designated days of the second and third week as determined by the marine weather forecast. Ideally, in the second and third week, data were collected during mild sea (sea state 3-4) and rough sea state (sea state 5 and above). In addition, on any other day during rough weather when participants wished to use anti-motion sickness drugs, they were encouraged to answer an additional questionnaire prior to receiving medication from the OHA. In the event that a transfer vessel was required to transport the crew to the FPSO vessel, all passengers were encouraged to answer a separate Motion Effects Assessment upon arrival on the FPSO. The questionnaire and ship motion/acceleration data were collected by the duty OHA on a daily basis and were brought ashore at the end of a three-week shift offshore.

Data analysis

Measurement and Analysis of FPSO vessel motion

A state-of-the-art motion sensing and analysis method was used to measure the ship motion. The motions of the FPSO vessel in the three rotational (roll, pitch and yaw) and the three translational (x, y and z) axes were computed from accelerations measured on the forward and aft switch room on the same deck. When the data were transferred ashore they were converted from raw binary format to full-scale units by a corresponding calibration factor and then stored in files of ASCII columns. Upon processing, each data channel was divided into two halves, the first half covered 1200 to 2400 hours GMT for the first day, the second half covered 2400 to 1200 hours for the next day. The power spectral density (PSD) plots were calculated by partitioning each channel into 106 segments of 8192 points. Each segment overlapped the adjoining segment by 4096, i.e., half of its length. Prior to undertaking Fast Fourier Transformation (FFT) each segment was multiplied by a Hanning window to reduce leakage from adjacent frequency components. As a result, 106 periodograms were averaged together to obtain the PSD estimate (Oppenheim & Schafer, 1975). The low frequency bins were discarded; the first bin is 0.2001953 Hz and the rest are equally spaced at 0.0012207 Hz intervals (1/(0.1 x 8192)). In addition, daily average wave data for the Terra Nova field such as significant wave height (metres), zero up-crossing period (seconds), peak frequency (Hz), and peak period (seconds) were used to determine the sea state for the particular day. A program called ZCA (zero crossing analysis) was used to compute the parameters described above for each of the time series. The definitions of these ship motion parameters are defined as follows:

Significant wave height ($H_{sig.}$): The average wave height of the waves that comprise the top 33% of wave heights.

> Zero up-crossing analysis: A wave cycle is defined as the portion of the record between three successive zero crossings. After the mean is removed from the time series, the peak and trough of each wave cycle in the time series is measured and the wave height is calculated as the difference between the peak and trough. The wave heights for the complete time series are then ranked.
>
> Mean Zero up-crossing period (Tz): The mean value of many measurements of the time between two upward zero crossings
>
> Mean Peak Period (Tp): The mean value of many measurements of the time between two successive peaks.
>
> Mean Peak Frequency (Fp): 1/Tp
>
> Sea state: The minimum, average, and maximum for every 12 hours, and 24 hours for each day of the month were calculated. Using the average wave

height, and significant range of periods, a sea state was given for each 12 and 24 hour interval. The definitions for each sea state are attached in Annex 4.

Motion Sickness Susceptibility Questionnaire (MSSQ)

A modified motion sickness susceptibility questionnaire (MSSQ, Golding 1998) was used to elucidate motion sickness history from the participating subjects. The MSSQ uses simplified scoring to produce adult reference norms. The test-retest reliability may be assumed to be better than 0.8. The predictive validity of the MSSQ for motion sickness tolerance using laboratory motion devices averaged at a correlation of r = 0.45 (a correlation of 1 suggests that there is a linear relationship). Thus, from a scientific point of view, we can be confident that the data acquired provided reliable information.

Scoring subject input

The data were analyzed on fixed 12-hour intervals, based on the FPSO crew's 12-hour shift schedule. The majority of the motion effects assessments were scored on a four-point scale from zero through three; corresponding to none through severe. The seasickness rating was scored on an eleven-point scale (0 through 10). The higher score corresponds to a greater severity of the specific category of symptoms; a score of zero indicates the described condition as "not present". Most of the other parameters were scored on a two-point score (i.e. yes/no), where no is scored as zero, and yes is scored as one. There are a total of 44 parameters listed under 6 major categories: sleep problems, symptoms of sickness, severity of sickness, performance problems, task completion problems, and other problems experienced during the scheduled period.

Null responses

For the analyses reported in this study, all null responses were counted as a response of zero (i.e. no problem). The effects of scoring null responses as zero, versus their omission from the analysis, were small for those parameters considered.

Weighted Severity Score

A weighted severity (WS) score, expressed as a percent of maximum possible score, was used to quantity the severity of each of the problems listed under each category in the Motion Effects Assessment questionnaire (Colwell 2000).

The general form of weighted severity is:

$$WS = \frac{100\sum_{i=1}^{\mathrm{Im}ax} iN_i}{\mathrm{Im}\,ax\sum_{i=0}^{\mathrm{Im}ax} Ni}$$

where i denotes the response score, I_{max} is the maximum score in the response scale, and Ni is the number of subjects reporting score i.

For the four-point scale, $Imax$ =3, and WS is calculated as follows:

$$WS = \frac{100(N_1 + 2N_2 + 3N_3)}{3N_{subjects}}, \; N_{subjects} = N_0 + N_1 + N_2 + N_3$$

where N_0 is the number of subjects scoring “0” (no problem), N_1 is the number of subjects scoring “1” (mild problem), N_2 is the number of subjects scoring “2” and N_3 is the number of subjects scoring “3”.

For parameters with the two-point “yes/no” scale, WS reduces to percent of subjects responding yes (i.e. 100 $N_1/ N_{subjects}$) and for the eleven-point seasickness scale; the WS summation expands to the maximum score of 10.

Correlation analysis

Correlation is defined as the specific measure of association between two variables. In this study, variables from the questionnaire under consideration were measured on an ordinal (rank order) scale. As a conservative measure, Spearman’s rho correlation analysis was employed. The Spearman correlation between two variables is calculated by first reducing the sample values of each variable, separately, to ranks. A correlation coefficient indicates the degree of linear relationship between two variables. A positive correlation suggests that, as the observed values on one variable increase or decrease, the observed values on the other variable increase or decrease proportionately. A correlation of 0 suggests that there is not a linear relationship between the two variables. On the other hand, a correlation of 1 suggests that there is a linear relationship between the two variables. In this study, the correlation analysis discusses only those cases with sufficiently high statistical significance to reject the associated null hypotheses. Since $N_{subjects}$ is relatively high (a total of 59 participants), a critical ratio z test was employed (Colwell, 2000). A p level of 0.01, which defines a 1% chance that the correlation is random, is accepted as the level denoting statistical significance. Accordingly, p-levels lower than 0.01 are significant (less likely to be random) and p-levels values higher than 0.01 are not statistically significant (more likely to be random).

Reliability of responses

Relative reliability of responses were based on the participation rate from the crew, i.e., percent of crew returning the Motion Effects Assessment questionnaire and that it was completed according to the instructions given.

This page intentionally left blank.

Results

Participation rate

Between November 2002 and April 2003, a cumulative total of 1344 Motion Effects Assessment questionnaires were returned from a total of 59 subjects. The mean number of crew on board of the FPSO vessel during this period is about 80. Therefore the participation rate is approximately 74%. There were 56 male and 3 female, ranging in age from 24 to 50 years. The mean age was 37.9 years ± 5.6 S.D. In addition to the 38 returns from participants from phase 1 of this study (Cheung, Brooks and Hofer 2002), there were 21 new participants. Forty-one subjects responded to the survey during multiple (more than 2) shifts offshore, while 18 subjects responded to the survey during one shift. The distribution of participants relative to the total number of offshore shifts worked is tabulated in Table 1.

Table 1. *Participation rate*

NUMBER OF SUBJECTS	TOTAL # OF OFFSHORE SHIFTS
1	5
16	4
15	3
9	2
18	1

General responses

The average number of questionnaires filled out by the participants is 22 within a range of 7 to 42. The distribution of the returned surveys across the six-month period is listed in Table 2. Four participants who completed three or more shifts offshore reported no symptoms and encountered no problems related to task performance. Two other participants who completed only one tour each also reported no symptoms and encountered no problems. For the remainder of the participants, the majority of the complaints were related to the following:

Quality and length of sleep

Poor concentration

Problems in carrying or moving objects

Taking longer than normal to complete a task

In general, the severity of the reported problems ranged from slight to moderate, however, 19 subjects reported having experienced severe symptoms at least once during their shifts offshore. Examples of severe symptoms included poor quality of sleep, physical and mental fatigue, headaches and severe nausea. The participants rated the hindrance in task performance or task completion problems as slight to moderate.

Motion Sickness History Questionnaire

Cumulative distribution (percentile) of Motion Sickness Susceptibility Questionnaire (MSSQ) scores based on Golding (1998) ranged from 0% to 96% with a mean of 33.2% ± 33.6. The higher the score, the more susceptible the individual is to motion sickness. Our results suggest that very few of the participants are highly susceptible to motion sickness.

Table 2. *Distribution of returned surveys*

MONTH	TOTAL # OF SURVEYS	TOTAL # OF SUBJECTS
November 2002	105	17 (16 continued into December)
December 2002	338	52 (20 continued into February)
January 2003	302	46 (17 continued into March)
February 2003	190	36 (13 continued into April)
March 2003	199	31 (10 continued into May)
April 2003	210	30

FPSO motion

The mean monthly averages of the power spectral densities of translational accelerations, in the x (longitudinal), y (lateral) and z (heave) axes at the two recorded locations for the months of November 2002 to April 2003 are illustrated in Annex 2. The x-axis, y-axis and z-axis translational accelerations were dominated by narrow-band motion centred on 008 to 0.1 Hz (i.e. an oscillation having a period of approximately 10 seconds). Similarly, PSD plots of roll and pitch angular accelerations (illustrated at Annex 2) show that the dominant frequency of the motion in the roll and pitch axes were centred on 0.08 to 0.1 Hz. Upon close examination, the z-axis (heave) deck motion was primarily caused by the pitching of the vessel about the centre of rotation of the FPSO. Therefore, the vertical motion was largest at the extreme end of the vessel. The dominant frequency of the roll angular motion was similar to that of the y-axis acceleration suggesting that the rolling of the deck relative to the gravitational vector primarily caused the y-axis translational acceleration. Based on the various ship motion parameters described under Data Analysis, the average sea state ranged from sea state 3 to sea state 7. Due to the inclement weather experienced in the Terra Nova Field region during the winter months of 2002-2003, the monthly average sea states between November and March were very similar. Nevertheless, the higher the mean sea state, the higher the number of significant correlations between ship motion and symptom/performance problems from November to April. The mean sea state and other ship motion parameters between November and April are illustrated in Table 3.

Table 3. *Mean values of ship motion parameters by each month*

SHIP MOTION	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
Hs - significant wave height	4.18 ±1.2	3.99 ±1.3	4.46 ±1.14	4.49 ± 1.76	3.99 ±1.37	2.61 ±0.11
Tz – zero up-crossing	7.89 ±0.76	7.62 ±0.71	7.82 ±0.80	7.59 ±1.01	7.53 ±0.79	9.48 ±0.98
Fp – peak frequency	0.10 ±0.01	0.10 ±0.01	0.10 ±0.01	0.11 ±0.02	0.10 ±0.01	0.11 ±0.01
Tp – peak period	10.37 ±1.14	9.86 ±0.92	10.14 ±1.02	9.84 ±1.129	10.13 ±1.36	7.53 ±0.79
SS – sea state	5.45 ±0.73	5.39 ±0.83	5.71 ±0.64	5.64 ± 1.01	5.50 ±0.69	3.99 ±1.37
No of significant correlations between motion and symptoms/performance	21	32	42	39	15	11

Correlations between motion effects and ship motion

The relationships between ship motion (significant wave height, zero up-crossing period, peak frequency, peak period and sea state) and the motion effect assessment parameters for each of the months from November to April are tabulated in Tables 12-17 at Annex 3. Only correlation coefficients with a statistical significance of $p < 0.01$ are presented.

Sleep problems

Between November and April, 41-64% of respondents complained about poor quality of sleep. Over the same period, 47-67% of respondents complained of insufficient sleep. The percentage of participants who experienced sleep problems is listed in Table 4. This was a parameter correlated with sea state, specifically, significant wave height, zero up-crossing period, and peak period in some cases. For example, in November, the correlation between sleep problems and peak frequency of ship motion is 0.5. In January and March, the correlation between sleep problems and significant wave height is 0.49 and 0.73 respectively. In April the correlation between sleep problem due to seasickness and significant wave height is 0.41.

Table 4. *Percentage of participants experiencing sleep problems by each month*

SLEEP PROBLEMS	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
Poor quality of sleep	41.2%	59.6%	56.5%	63.9%	54.8%	43.3%
Insufficient sleep	47.0%	67.3%	60.9%	66.7%	61.3%	50.0%

Motion-induced sickness

In general, 89% of respondents experienced seasickness at least once. The percentage of respondents who complained about sickness induced mental fatigue was 30 to 46%, physical fatigue was 41 to 52% and sleepy/drowsiness was 44 to 63%. Other prevalent motion sickness symptoms also included headache and nausea. The percentage of participants who experienced vomiting/retching is relatively small as compared to those experienced sleepiness, mental and physical fatigue. The percentages of participants experiencing various motion sickness symptoms by month are illustrated in Table 5. Significant wave height was most frequently correlated with motion sickness symptoms. However, zero up-crossing and sea state and to a lesser extent peak frequency and peak period also had significant correlations with motion-sickness symptoms.

Table 5. *Percentage of participants experiencing motion sickness symptoms by each month*

SYMPTOMS OF MOTION SICKNESS	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
Dizziness	13.4%	14.8%	14.9%	13.2%	11.8%	9.4%
Mental fatigue	34.8%	46.3%	38.3%	36.8%	29.4%	40.6%
Physical-fatigue	47.8%	51.9%	49.0%	50.0%	41.2%	40.6%
Sleepy	43.5%	51.9%	59.6%	63.2%	44.1%	46.9%
Headache	34.8%	33.3%	44.7%	47.4%	23.3%	32.2%
Apathy	8.7%	22.2%	21.3%	34.2%	17.6%	18.8%
Tension/anxiety	8.7%	24.1%	17.0%	29.0%	23.5%	15.6%
Vomiting or retching	-	1.8%	2.2%	-	2.9%	31.3%
Nausea	8.7%	13.0%	6.4%	5.3%	5.9%	31.3%
Stomach awareness	17.4%	16.7%	10.6%	13.2%	8.8%	31.3%
Cold sweating	4.3%	5.6%	6.4%	5.3%	8.8%	313%
Unmotivated	17.4%	22.2%	23.4%	29%	23.5%	12.5%
Depressed	8.7%	20.4%	10.6%	15.8%	11.8%	9.4%

Task performance

The percentage of the number of subjects who experienced various task performance problems from November to April is listed in Table 6. The problems encountered include decision-making, loss of concentration and loss of memory. Between 12-28% participants complained about problems in decision making, 12 to 26% complained about memory problems, 36-44% complained about concentration problems and 20-46% complained about problems in maintaining body motion/balance and 10-33% complained about problems in carrying and moving heavy objects.

Table 6. *Percentage of participants experiencing task performance problems by each month*

TASK PERFORMANCE PROBLEMS	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
Decision making	11.8	19.2%	23.9%	27.8%	22.6%	20.0%
Concentration	41.2%	44.2%	39.1%	41.7%	35.5%	36.7%
Memory	11.8%	26.9%	19.6%	25.0%	19.4%	20.0%
Simple tasks	5.9%	26.9%	15.2%	22.2%	12.9%	13.3%
Body motion/balance	35.3%	46.2%	32.6%	38.9%	25.8%	20.0%
Carrying/moving heavy objects	11.8%	32.7%	19.6%	33.3%	22.6%	16.7%
Eye-hand coordination	11.8%	15.4%	10.9%	16.7%	9.7%	6.7%
Vision	11.8%	15.4%	6.5%	11.1%	6.4%	6.7%

Significant correlations among task performance problems and ship motion parameters were observed in each month, November to April. The correlation coefficient ranged from 0.29 to as high as 0.75 with a significance of $p < 0.01$. Among the physical performance parameters, there were decrements in body motion/balance and carrying/moving objects. For example, the correlation between performance affected by unstable body motion/balance and significant wave height is 0.75 in January and 0.71 in March. Significant correlations with ship motion are most apparent in January and February. The most notable difficulties encountered in January are those of maintaining balance (as mentioned above), carrying or moving objects, decision-making, and simple tasks such as mental arithmetic. The correlation coefficient between these variables and significant wave height are 0.75, 0.58, 0.56 and 0.58, respectively (see Table 14). The correlation coefficient between significant wave height and balance in March is 0.71 (see Table 16). The above finding is not surprising. It has been established by previous investigators in the laboratory (Baitis et al. 1995, Wertheim 1996, Wertheim & Kistemaker 1997) that motion-induced interruptions occur when standing on a moving surface that emulates movement on the deck of moving vessels. Under these circumstances, the effort in stabilizing oneself, such as grasping for handrails, interrupts the task being undertaken and also has significant implications for safety in the workplace.

Task completion

The percentages of participants who experienced problems in completing tasks are listed in Table 7. The two most common complaints were "made more mistakes" (6-23% of participants) and "took longer to complete task" (12-35% of participants) with the highest percentage occurring in December, January and February in both cases. Specifically, in December, "not allowed to attempt" tasks were correlated with significant wave height, zero up-crossing, peak period and sea-state. In addition, significant correlations between ship motion parameters and even "abandoning some tasks", were evident in the months of January to April. These problems encountered in task completion have correlation coefficients ranging from 0.29 to 0.52.

Table 7. *Percentage of participants experiencing task completion problems by each month*

COMPLETION PROBLEMS	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
Made more mistakes	5.9%	23.1%	15.2%	16.7%	9.8%	13.3%
Took longer to complete task	11.8%	30.8%	34.8%	22.2%	22.6%	20%
Task not completed in time available		9.6%	13.0%	11.1%	9.7%	6.7%
Forced to abandon task			8.7%	5.6%	12.9%	
Not allowed to attempt task		3.8%	4.3%	2.8%	6.4%	

The general feeling of good health deteriorated significantly in December through March. December and January had the highest percentage of subjects who reported deterioration of well-being, 51 (86%) and 54 (91%) participants, respectively. Table 8 shows the number of subjects that responded with a rating of 1 or greater on the subjective well being (0 to 10 scale) question of the symptoms section of the MSSQ as well as the resulting mean score.

Table 8. *Number of participants rate 1 or higher on the subjective well being scale by each month*

PERFORMANCE PROBLEMS	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
Number of subjects	5	51	54	23	18	8
Mean well-being score	6.11 ±	3.88 ±	2.92 ±	4.56 ±	3.85 ±	1.58 ±

Table 9 shows the correlations between task performance and task completioproblems and subjective well being by month. There is a high correlation between concentration, decision-making, eye hand coordination, vision and “not allowed to attempt task” with subjective well-being.

Table 9. *Correlations between task performance/completion with subjective well being by month.*

PERFORMANCE PROBLEMS	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
Making decisions		0.39	0.37	0.29	0.38	0.50
Concentration	0.32	0.56	0.54			0.29
Memory	0.35	0.40		0.30		
Body motion					0.38	
Carrying/moving things					0.34	
Eye-hand coordination				0.60		
Vision				0.50		
Abandon task					0.38	
Not allowed to attempt task					0.59	

Other problems

Other problems that participants reported are illustrated in Table 10 below as a percentage. Air quality, vibration and lighting were correlated with ship motion parameters in December (Table 12, Annex 3). No other problems were correlated with ship motion in January. In November February, March and April, noise, vibration, lighting and temperature were all observed to correlate with several ship motion parameters (Tables 12, 15, 16, 17, Annex 3). It is not surprising to note, with the ship pitching, heaving and rolling, that there was a strong correlation between problems with noise and vibration. Temperature is known to influence motion sickness susceptibility, however, the strong correlation between lighting with ship motion cannot be explained easily.

Table 10. *Percentage of participants experiencing other problems by each month*

OTHER PROBLEMS	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
Cold flu or other illness	9.5%	21.0%	21.2%	8.1%	9.0%	18.8%
Air quality	4.8%	7.7%	12.7%	10.8%	12.1%	12.5%
Noise	19.0%	25.0%	21.2%	24.3%	21.2%	21.9%
Vibration	28.6%	19.2%	19.1%	18.9%	21.2%	15.6%
Lighting	19.0%	21.0%	19.1%	21.6%	21.2%	3.1%
Temperature	19.0%	19.2%	29.7%	21.6%	24.3%	12.5%

Other correlations of statistical significance

Of particular interest in this phase of the study is the prominence of significant correlations involving mental fatigue, physical fatigue, and concentration (see Table 11 at Annex 3). These three parameters are correlated with 13, 14 and 27 different parameters in the motion sickness assessment questionnaire respectively, and suggest that the interplay between ship motion, quality of sleep, and fatigue may be critical in employee productivity.

Discussion

Seventy-four percent of the crew participated in the study, which is lower than the 82.7% participation rate in the initial study; but it is still a high response rate, and provides an indication of how strongly the crew believe that motion does affect their performance on board when sea conditions deteriorate. Crew members provided conscientious replies concerning their well-being, mental and physical state during their shifts on board the FPSO for a period of six months. Each crewmember was given the choice to participate. Why one quarter of the crew did not participate is open to speculation and beyond the scope of this study. Considering the poor weather during this study period, it is likely that they too had symptoms of varying degrees and were affected in some way, but for whatever reason, did not wish to admit to them.

Acceleration measurement of the FPSO vessel made at the two designated locations on the same deck was used to compute the motions of the vessel in the three rotational and three translational axes. The accuracy of the acceleration in all six axes (x, y, z, roll, pitch and yaw) was calibrated in the laboratory against the manufacturer's standards. The frequencies of oscillation recorded in all axes were between 0.08 and 0.1 Hz and the incidences of frank vomiting were low. These frequencies are below 0.167 Hz, the frequency that O'Hanlon and McCauley (1974) found to cause the greatest vomitory incidence. Our data were also consistent with previous findings by Haward et al. (2000) that the x axis, z axis, pitch and roll acceleration were dominated by a narrow-band motion centred on 0.1 Hz and that the y axis acceleration was slightly lower at 0.09 Hz.

This acceleration data were analysed in conjunction with 1344 subjective questionnaire assessments. Problems encountered relative to the sea state were then broken down into three classic categories of motion illness: symptoms of motion sickness sleep problems and performance degradation. Each category was investigated to see whether the FPSO acceleration contributed to these symptoms. There was a very high correlation between the degrees of ship motion in the majority of these categories.

In fact, our analysis demonstrates that the correlation between ship motion and some of the parameters of motion effects are significant, often with a p value much less than 0.01 (the probability that these findings happened by chance is less than one in one hundred). In many cases, it is highly significant with $p < 0.0001$ (the probability that these findings happened by chance is less than one in ten thousand). Compared to the percentage of crew-members that complained about poor performance during the months of bad weather in December, January, and February (decision making 23.2-43.8%; concentration 50-69.2%; memory 29.2-37.5%; body motion/balance 50-64.1%; and moving/carrying heavy objects 29.2-58.9), the percentage of complaints in May and June when the weather was relatively calm was much less (5.9%, 35.3%, 11.85%; 29.41%, and 11.8, respectively). Poor sleep quality was reported by 79.5% in January, the worst month for weather; compared to 38.5% in June, the best month for weather. Furthermore, insufficient sleep was reported by 82.1% in January and 46.2% in June. The results of this study confirm the findings in our previous study that physical and mental aspects of task performance appear to be equally affected by vessel motion. There is a strong association between the motions measured in all six axes.

Motion sickness affects the workforce in various ways. At one extreme, if the person is particularly sensitive to the provocative frequencies of ship motion, the affected individual becomes very ill with nausea, vomiting, lassitude and a complete disinterest in work and group activities. From our data, not unexpectedly, no one was seriously affected, although 19 subjects (30.5%) reported severe symptoms at least once during their shifts offshore at sea. The relatively low percentage of seriously affected individuals and low frequency of occurrence would suggest that in the sea-going trades such as the coxswains, those who had previous problems were naturally selected out, and for the oil producers, there could have been some habituation to motion sickness. For the latter group, there may also have been some self-selection (i.e., a person who knew s/he suffered from sea sickness might have taken an alternate job with the company on land rather than on the FPSO).

The severe symptoms include poor quality of sleep, physical and mental fatigue, headaches and severe nausea (as described under Results). More importantly, our data demonstrated that what has been often suspected and partially proven (Colwell 2000) is the more subtle and potentially more dangerous effect of motion sickness on sleep disturbance, mental and physical fatigue (motion induced fatigue and job performance, motion induced interruptions).

Analysis of the vertical acceleration data indicated that there were significant ship motion effects on balance, moving, lifting and transporting objects. This is apparent as illustrated by the following examples. It requires more physical effort walking to and from bunk space to galley, to workspace, up and down ladders or stairwells while maintaining one's balance when the deck is pitching and rolling severely. There is also the chance of bumps and bruises when walking in confined spaces and sprains if caught off balance by violent ship motion. There is also the chance of trapping hands, arms and legs when passing through bulkheads with unsecured doors. The wet or icy open deck conditions can pose additional problems. The potential for slips, trips and falls intensifies with increase in wetness, wind, and snow. Therefore, it may be difficult for all crews to perform effectively irrespective of their duties.

It takes additional physical effort to carry out one's duties in a safe manner while the FPSO vessel is affected by fore-and-aft and lateral accelerations associated with pitch and roll. Depending on the tasks being undertaken, roll and pitch motion might have greater effect than a vertical motion disturbance. Our data indicated that there was a good correlation between significant wave height and balance (with a correlation coefficient of 0.75) and carrying/moving objects (with a correlation coefficient of 0.58). For instance, lifting heavy of pumps and compressors must be done with extreme caution to avoid muscular skeletal injury. Transferring boiling water from one cooking vessel to another in the galley must be done equally with extreme caution to avoid serious scalding, and the soldering of a very fine connection on a computer board requires much more effort when the ship is moving violently. This means the efficiency of the work is reduced by these motion induced interruptions and 22–34 crew reported that it took longer to complete tasks, 15–17% made more mistakes, and 5-6% abandoned their task. These problems were highly correlated with the severe weather.

In addition, there were significant problems with memory and decision making in task performance. These were reported by 30% of participants and lack of concentration appears to be prominent, reported by 35 to 46% of participants at various times. It is not confined to one trade, but was reported across the entire crew from supervisor to technician. The Offshore Installation Managers (OIMs) must be aware of this effect. The mental state of physically and mentally exhausted personnel can cause strain in interpersonal relationships. Personnel can be short tempered and intolerant of each other and may take a short cut to complete a task, which might pose unnecessary danger to themselves, their colleagues, and the FPSO.

The relentless motion also affects the off duty personnel (paradoxically just when they have the only chance to rest and recuperate) at the recreational space and in the bunk space. In the recreational area, cans of pop and juice slither across the tables, games are usually abandoned, galley services are reduced to a bare minimum due to safety, the majority of people have lost their appetite, and there is a general gloomy atmosphere among the workers who are simply hanging on until the storm abates. At this stage, most of those off duty turn into their bunks. However, sleep in any reasonable quantity and quality is impossible as shown by our data. At any one time, between 47 and 67% of participants reported insufficient and poor quality of sleep. The body, depending on the orientation of the bunk, will be constantly rolled from side to side, or being moved head or feet wise if the bunk is in line with the bow and stern of the ship, and there is the noise and vibration of the banging and crashing of the ship as it meets each wave. Accumulation of this additional physical effort, constant noise and poor sleep leads to mental and physical exhaustion. When the weather was at its worst in December and January, 86% and 91% of participants reported deterioration of well-being.

It may seem obvious that the worse the weather conditions (evoking provocative ship motion), the more crew will fall casualties to motion sickness. However, we have been able to show that there are significant correlations between various reported symptoms and performance problems with ship motion. These data provides an opportunity to investigate possible amelioration.

It is recommended that an identification system be implemented. The objective of this system is to identify when the ship's company is at risk from injuring themselves or other people, and attempt to identify when they may be making poor decisions, which ultimately may put the FPSO at risk. It is recommended that the OIM introduce a three colour code system into the duty roster with the following guidelines for the FPSO operation:

Code Green:
Sea state 4
Normal operations – no restrictions on any duties or operations

Code Yellow:
Sea state 5
Proceed with normal operations under caution
Provide additional time for decision making and technical work
Provide additional workers to change out heavy equipment.
All moveable items should be secured ("lash things down")
Everyone must take extra care when in the gallery, when moving to and from and in and around their work and accommodation spaces.
Care must be taken climbing in and out of the bunk and security straps may be used.

Code Red:
Sea State 6 and higher.
Proceed with only the most urgent, essential work.
Postpone routine maintenance that can wait until the storm has abated.
Extreme caution should be taken in operating on heavy equipment, general duties in workspaces and the galley.
Security straps in the bunks must be used.
Routine meetings, except for the most urgent ones, must be postponed until the storm has abated.
Secure all doors, hatches and vents.
At the beginning of this code, coxswains to:
Recheck all TEMPSCs.
Recheck lifejackets and survival suits.

The status of the code should be posted in the control room at the beginning of the shift and changed at any time to anticipate poorer weather conditions. If this matrix of operation is implemented, then the likelihood of personal injury during on and off duty hours will be minimized; the safety of the FPSO will be maintained. The worker and the supervisor will understand that they are working as a team, that everyone's health and safety depends to a high degree on the weather conditions, and that there is no shame in accepting that under extreme conditions some people will not be feeling well, and struggling to keep up. And indeed, there is no shame in admitting that one feels worn out, tired or unwell. A scientific study has confirmed that increasingly poor sea conditions will impact the health, safety, and performance of crew-members in varying degrees. The OIMs have guidelines, which they can now justifiably apply to their operators under such conditions. For example, at their discretion OIMs can implement guidelines into their operating procedures in whatever manner they wish. A coloured coded system, outlined above, that is posted in the control room is the suggested approach.

Conclusion

Approximately 74% of the crew responded to our survey. This was a very good response rate and provides a high indication how strongly the crew believe that motion does affect their mental and physical performance on board when sea conditions deteriorate. The data presented confirm our previous findings that crewmembers exposed to severe FPSO vessel motion in the winter months were found to experience symptoms of motion sickness, insufficient and poor quality of sleep and performance degradation. These were directly associated with ship motions. Over 90% of the participants were negatively affected in some form between November and April; only six respondents reported no problems. This was not an unexpected finding and is consistent with previous findings by Haward et al (2000). Although there was a low incidence of vomiting or frank sickness, a positive correlation between the signs and symptoms of motion sickness, sleep disturbance and vessel motion were frequently observed. Although the wave motion did not produce frank vomiting, this does not mean that the person was not affected by one of the more subtle aspects of motion induced illness. On average, 50% of the respondents freely admitted that they generally did not feel well during the weeks of severe weather, and this significant finding among several others demonstrates that great care should be taken when conducting various tasks in such a sophisticated and complex vessel like the FPSO.

Many of the participants complained of different types of performance degradation. The most important ones were: 20-46% complained of loss of body balance and 12-33% complained of difficulty in carrying heavy objects. Between 22-34% took longer to complete their tasks. 15-17% made more mistakes and 5-6% abandoned their tasks completely. High correlation was observed between physical and mental fatigue and concentration with various parameters in the motion sickness assessment. Some 41-52% of respondents complained of physical fatigue, 29-46% complained of mental fatigue, 12-29% reported feeling unmotivated and 36-41% complained of loss of concentration. January has the highest correlations between pitch, roll and heave motion with complaints of seasickness. The average sea state was the worst during this month. Significant correlations between task performance, task completion and ship motion were noted in January, February and March when weather conditions were poor. The correlation coefficient is as high as 0.6 with $p < 0.01$. There was no evidence of habituation to motion sickness among subjects who participated in more than 2 shifts offshore.

The OIM can expect that over 30% of the crew will not be operating at peak performance during severe weather conditions. This is not meant in any way to be a criticism; this is a hard fact of life of the effect of motion sickness on the body. We have clearly shown that the ship motion makes the crew ill. Some become violently ill, which was very rare in this study (likely because those individuals have already been self-selected out). The majority of the respondents were subtly affected and were simply coping with the problem in the hope that the storm would abate soon. The effects of chronic exposure to such conditions over several years need to be investigated.

The effectiveness of any ship at sea is degraded by rough weather. Excessive ship motion may prevent crewmembers from performing their duties or, in the worst case, failing to complete the tasks altogether. From an occupational aspect this study clearly document the physiological and psychological effects on the FPSO crew of operating under severe weather conditions. It is essential that appropriate operating procedures should be developed that will recognise the range of seasickness during which operations on board may be safely undertaken. A performance colour code system has been developed for the OIM that recognises that these problems will occur. The code provides guidance for the OIM when and when not to conduct critical mental and physical tasks. For example, personnel should use caution when scheduling major physical work when sea conditions deteriorate, and to be aware that after several days of poor weather, relationships can become strained, major decision making that involves group effort perhaps should be re-scheduled when the storm abates, and when the weather worsens, only the most urgent of tasks should be undertaken. The end result of these efforts may be a safer operation, and from the company's standpoint, shows a keen interest in the morale and well being of the crew of the FPSO.

References

1. Baitis, AE, Holcombe FD, Conwell SL, Crossland P, Colwell, J, Pattison JH, Strong R. 1995 1991-1992 Motion Induced Interruption (MII) and Motion Induced Fatigue (MIF) Experiments at the Naval Biodynamics Laboratory. CRDKNSWC-HD-1423-01 December 1995 Hydromechanics Directorate Research and Development Report

2. Cheung, B., Brooks C.J., Hofer K. Assessments of Motion Effects on the FPSO (Floating, Production, Storage and Offloading) Vessel. DRDC Report TR 2002-144

3. Haward BM, Lewis CH, Griffin MJ. 2000 Crew Response to Motions of An Offshore Oil Production and Storage Vessel. Human Factors in Ship Design and Operation. RINA.

4. Golding, JF. 1998. Motion Sickness Susceptibility Questionnaire Revised and its Relationship to other Forms of Sickness. Brain Research Bulletin, 47, 507-516.

5. Colwell JL 2000. NATO Performance Assessment Questionnaire (PAQ): PAQ Project, Questionnaire Design and Reliability of Responses (DREA TM 2000-141 Defence Research Establishment Atlantic, Canada.

6. Colwell JL. 2000. NATO Performance Assessment Questionnaire (PAQ): Problem Severity and Correlation for Ship Motions, Fatigue, Seasickness and Task Performance. DREA TM 2000-142 December 2000. Defence Research Establishment Atlantic, Canada.

7. O'Hanlon JG, McCauley 1974 Motion sickness incidence as a function of the frequency and acceleration of vertical sinusoidal motion. Aerospace Medicine 48, 366-369

8. Oppenheim AV, Schafer, RW 1975 Digital Signal Processing Prentice-Hall, Englewood Cliffs, NJ, 1975.

9. Wertheim AH, Kistemaker JA. 1997. Task Performance During Simulated Ship Movements. TNO-report TM-97-A014 TNO Human Factors Research Institute.

10. Wertheim AH. 1996 Human Performance in a Moving Environment. TNO-report TM-96-A063 TNO Human Factors Research Institute

Annex 1

Symptoms

ID Number________________________
Mode of transportation to FPSO ☐ Helicopter ☐ Boat ☐
Date________________Shift start time________ Shift end time _______
Location____
Occupation____

Sleeping problems before this shift 0 = none; 3 = severe:	0	1	2	3
Quality of sleep was poor	☐	☐	☐	☐
Amount of time sleeping was short	☐	☐	☐	☐
Sleep problems caused by:				
ship motions (bouncing around)	☐	☐	☐	☐
seasickness	☐	☐	☐	☐
other:______________________________	☐	☐	☐	☐

Symptoms experienced during this shift 0 = none; 3 = severe:	0	1	2	3
Dizziness	☐	☐	☐	☐
Mental fatigue	☐	☐	☐	☐
Physical fatigue	☐	☐	☐	☐
Sleepy	☐	☐	☐	☐
Headache	☐	☐	☐	☐
Apathy (just don't care)	☐	☐	☐	☐
Tension/anxiety	☐	☐	☐	☐
Vomiting or retching	☐	☐	☐	☐
Nausea (not vomiting, yet)	☐	☐	☐	☐
Stomach awareness	☐	☐	☐	☐
Cold sweating	☐	☐	☐	☐
Unmotivated (don't feel like doing anything)	☐	☐	☐	☐
Depressed	☐	☐	☐	☐
Other: ______________________________	☐	☐	☐	☐

How sick are you? 0=feel fine; 10 = feel awful

0	1	2	3	4	5	6	7	8	9	10
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Are you taking seasickness medicine? Yes ☐ No ☐

Did you vomit before/during this shift? Yes ☐ No ☐
If yes, at about what time?____________
How did you feel after? Better ☐ Same ☐ Worse ☐

Performance

Task *performance* problems during this shift

0 = none; 3 = severe:	0	1	2	3	n/a
Making decisions	☐	☐	☐	☐	☐
Concentration/attentions	☐	☐	☐	☐	☐
Memory	☐	☐	☐	☐	☐
Simple tasks (adding, spelling)	☐	☐	☐	☐	☐
Body motion (balance)	☐	☐	☐	☐	☐
Carrying or moving things	☐	☐	☐	☐	☐
Eye hand coordination	☐	☐	☐	☐	☐
Vision	☐	☐	☐	☐	☐
Other:____________________	☐	☐	☐	☐	☐

Task *completion* problems during this shift

Made more mistakes than usual	Yes ☐	No ☐
Tasks took longer than usual	Yes ☐	No ☐
Tasks not completed in time available	Yes ☐	No ☐
Had to abandon task	Yes ☐	No ☐
Not allowed to attempt tasks	Yes ☐	No ☐
Other:____________________	Yes ☐	No ☐

Other problems during this shift

0 = none; 3 = severe:	0	1	2	3
Cold, flu, or other illness	☐	☐	☐	☐
Air quality (bad smells)	☐	☐	☐	☐
Noise	☐	☐	☐	☐
Vibration	☐	☐	☐	☐
Lighting (bright ☐, dark ☐)	☐	☐	☐	☐
Temperature (hot ☐, cold ☐)	☐	☐	☐	☐
Other:____________________	☐	☐	☐	☐

Comments____
____
____
____
Seasickness drugs taken: ____________________________

Annex 2

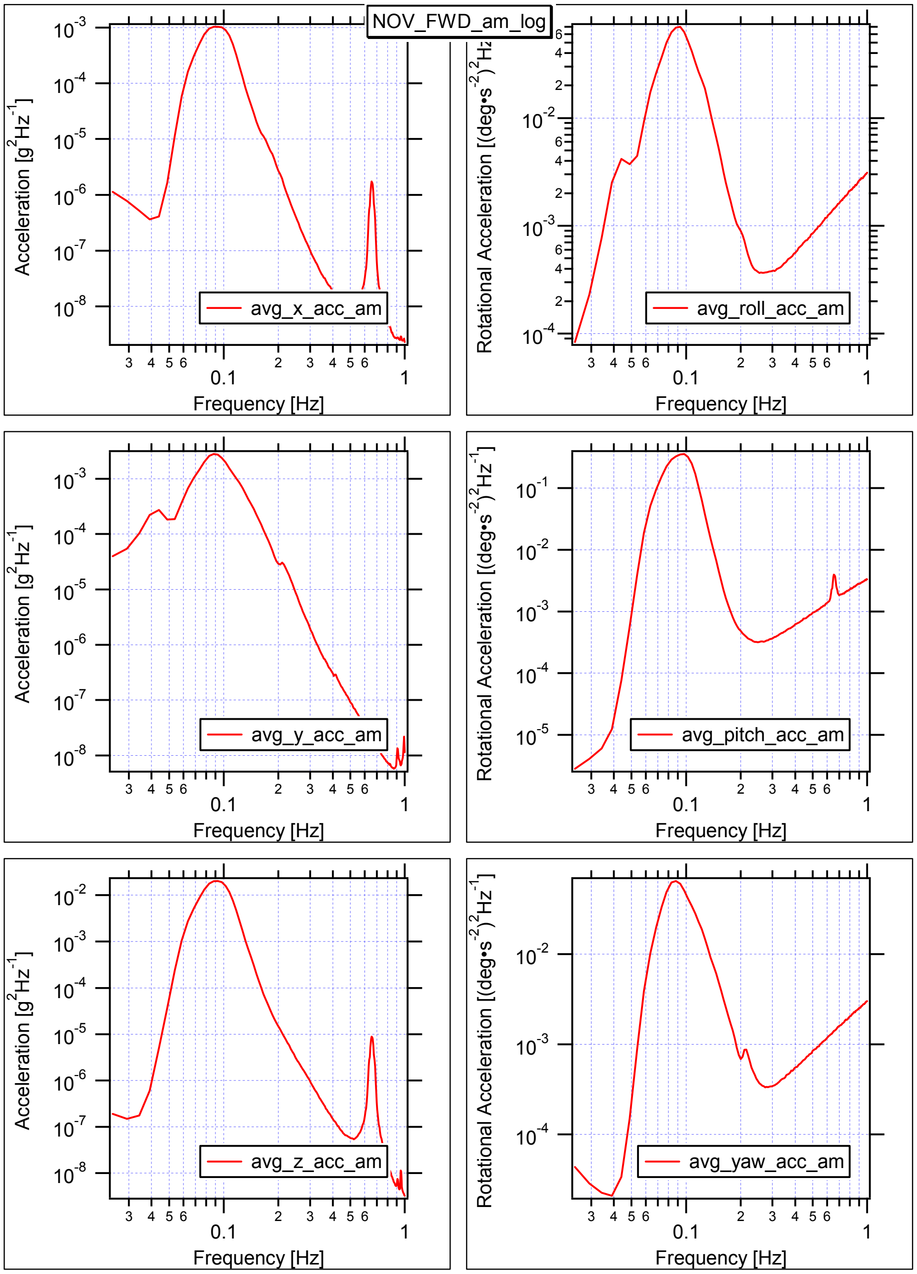

Figure 1. *November morning average logarithmic bow data*

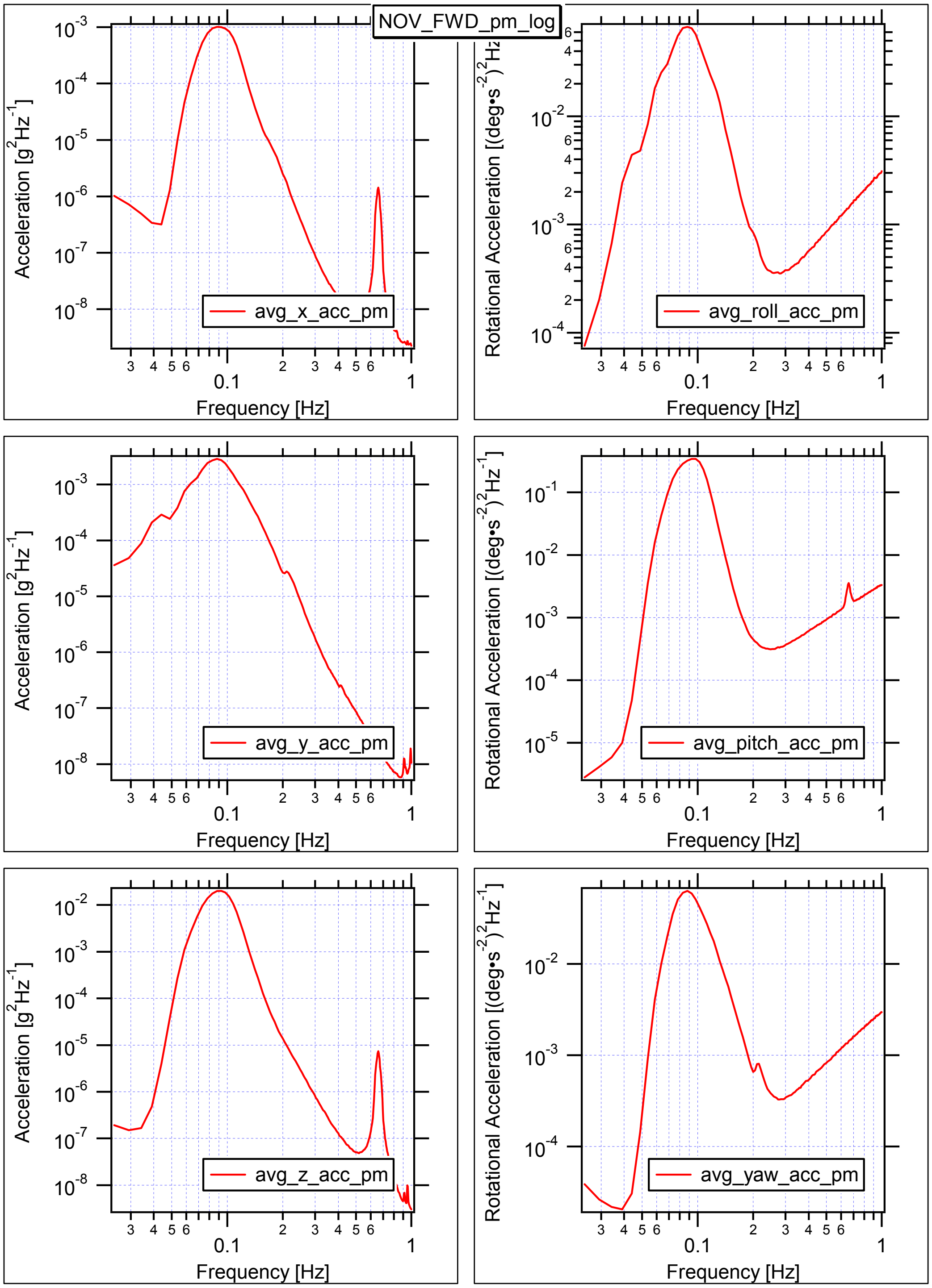

Figure 2. *November evening average logarithmic bow data*

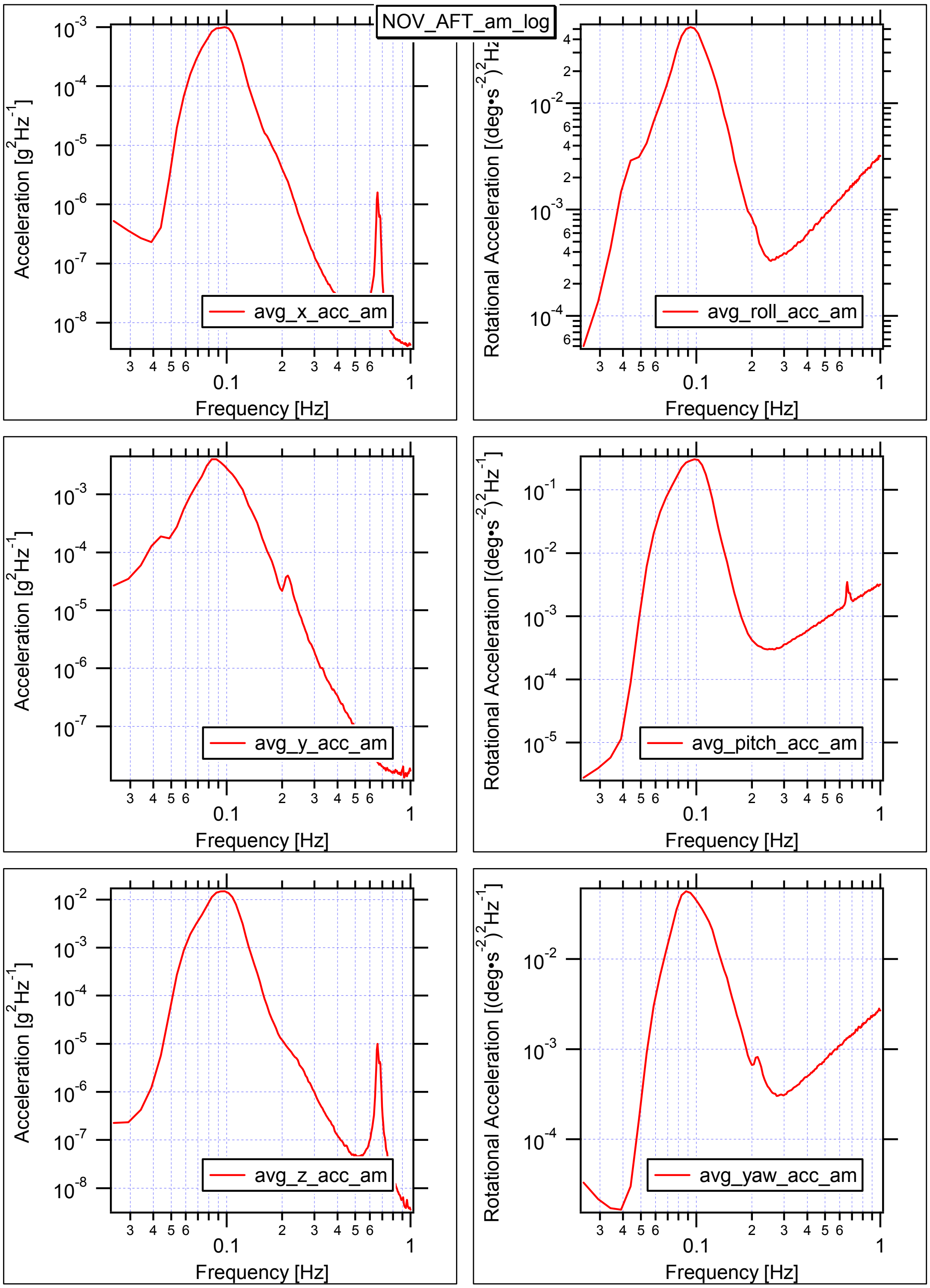

***Figure 3.** November morning average logarithmic stern data*

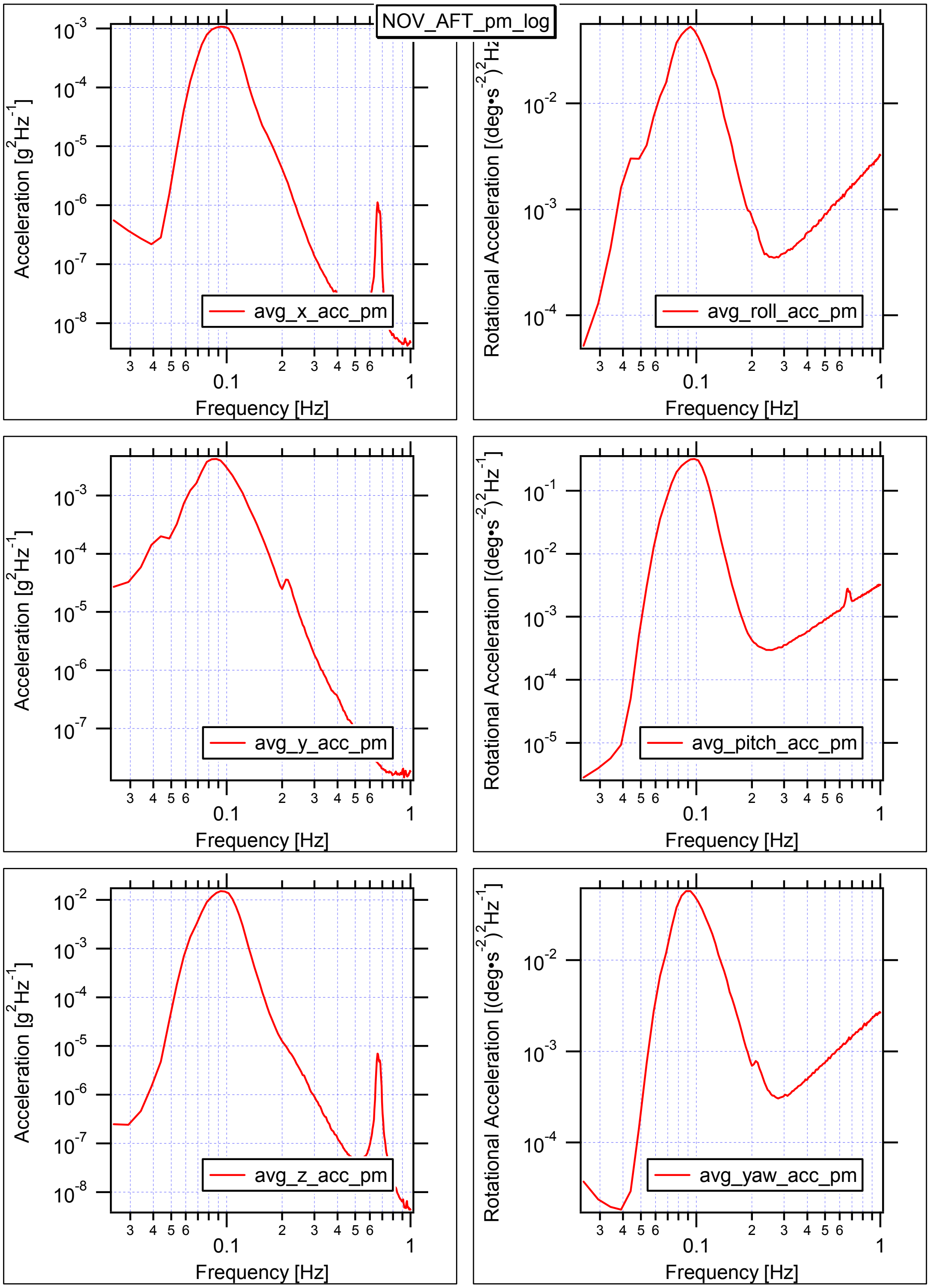

Figure 4. *November evening average logarithmic stern data*

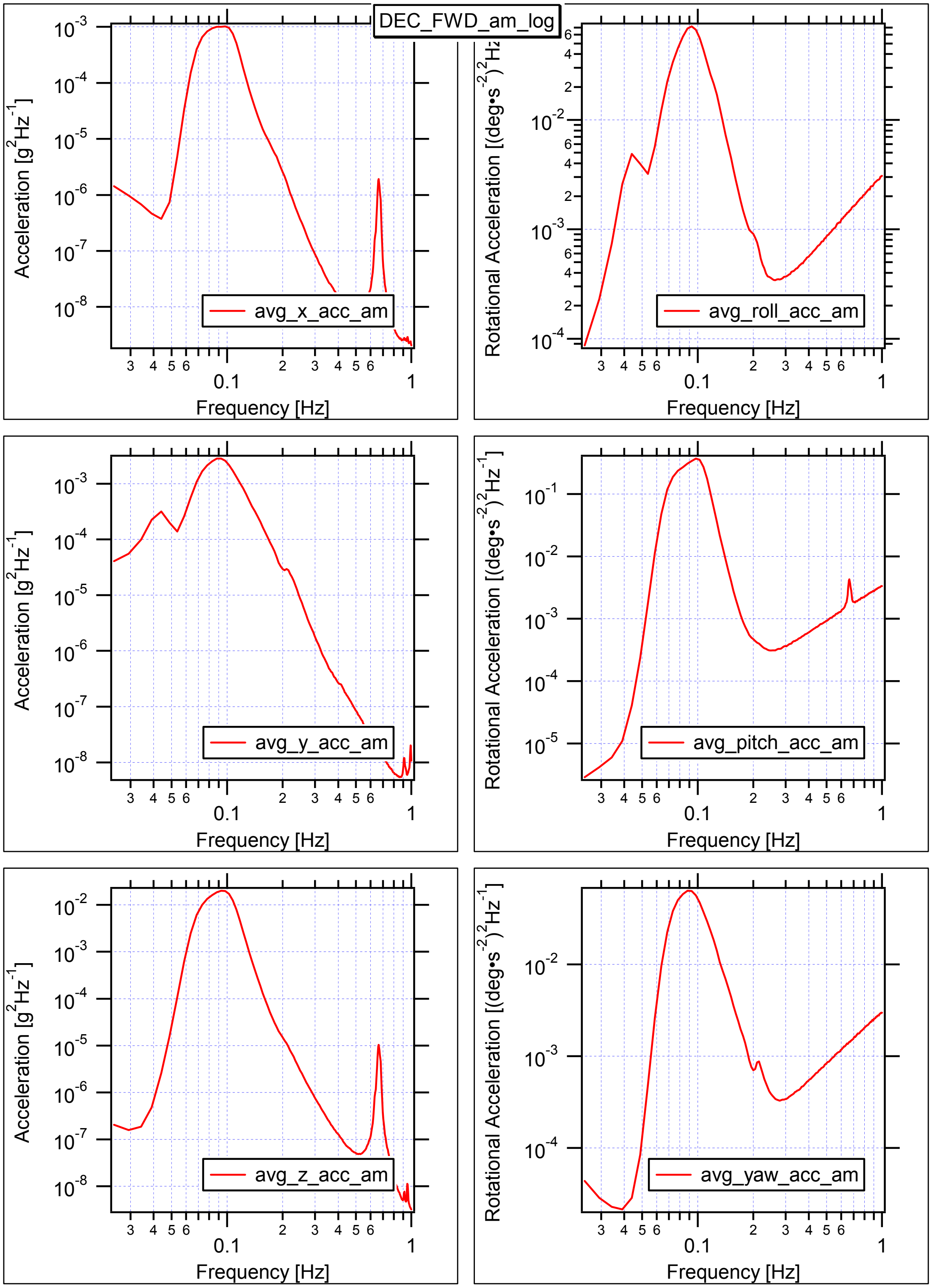

Figure 5. *December morning average logarithmic bow data*

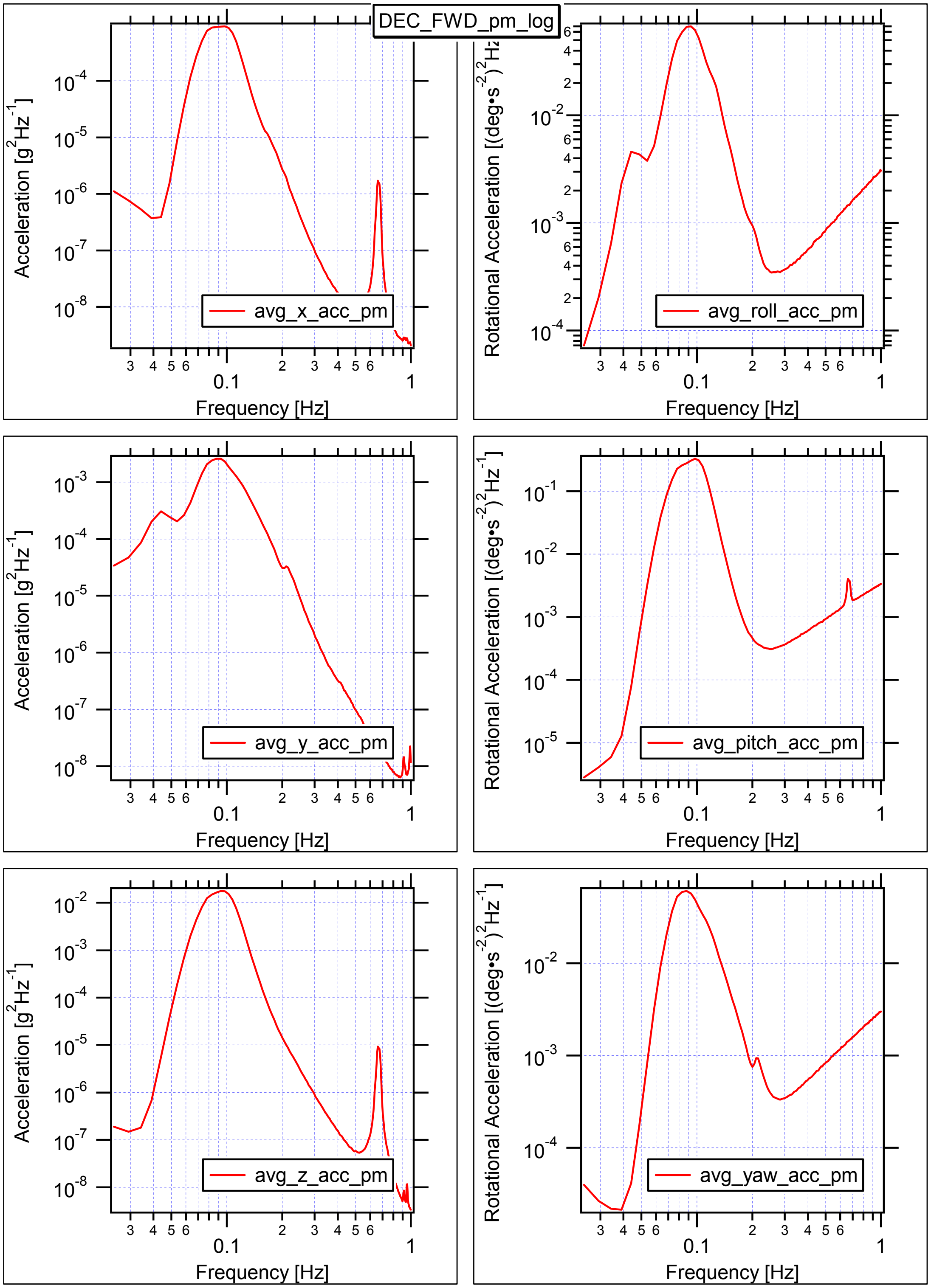

Figure 6. *December evening average logarithmic bow data*

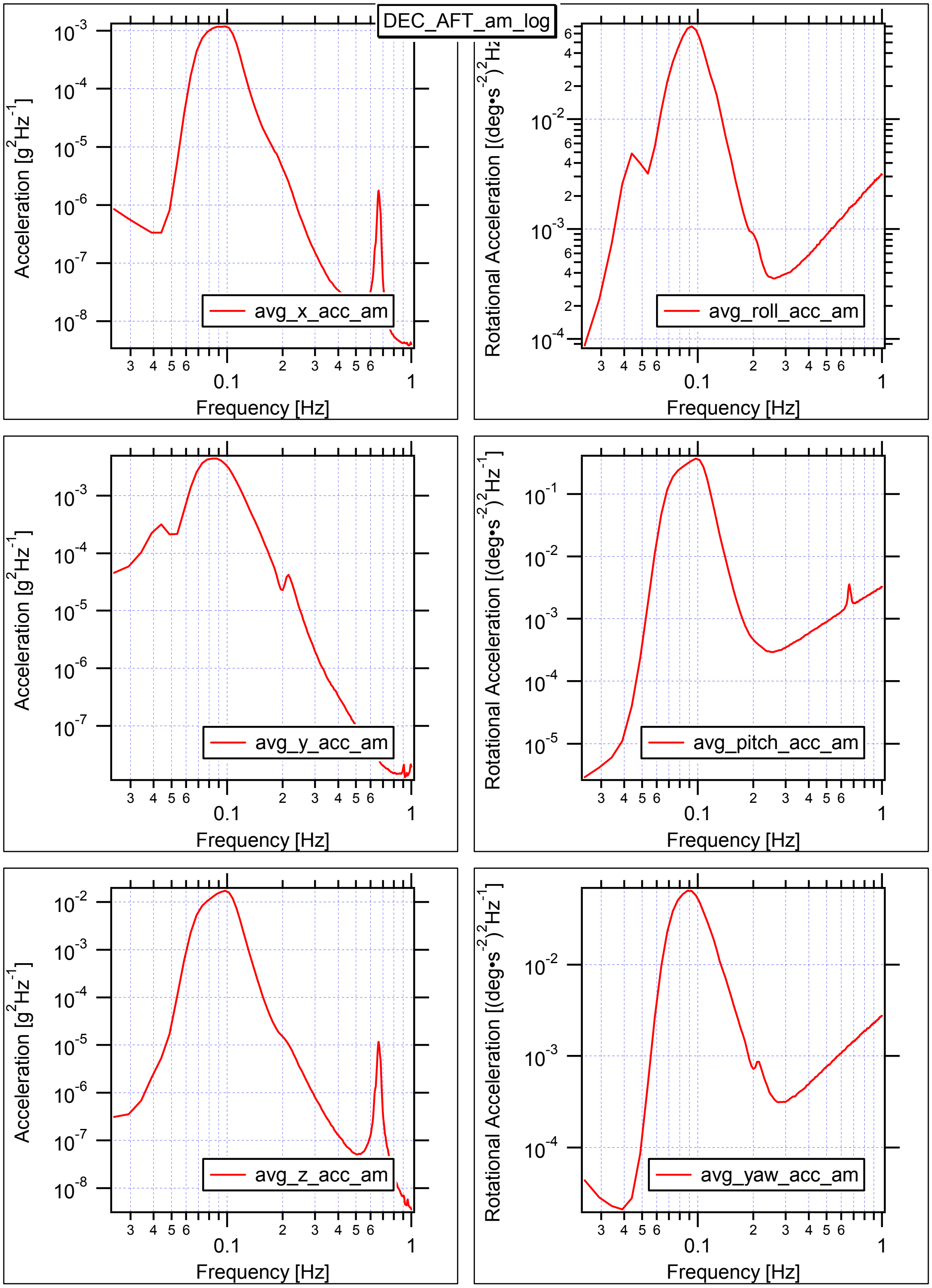

Figure 7. *December morning average logarithmic stern data*

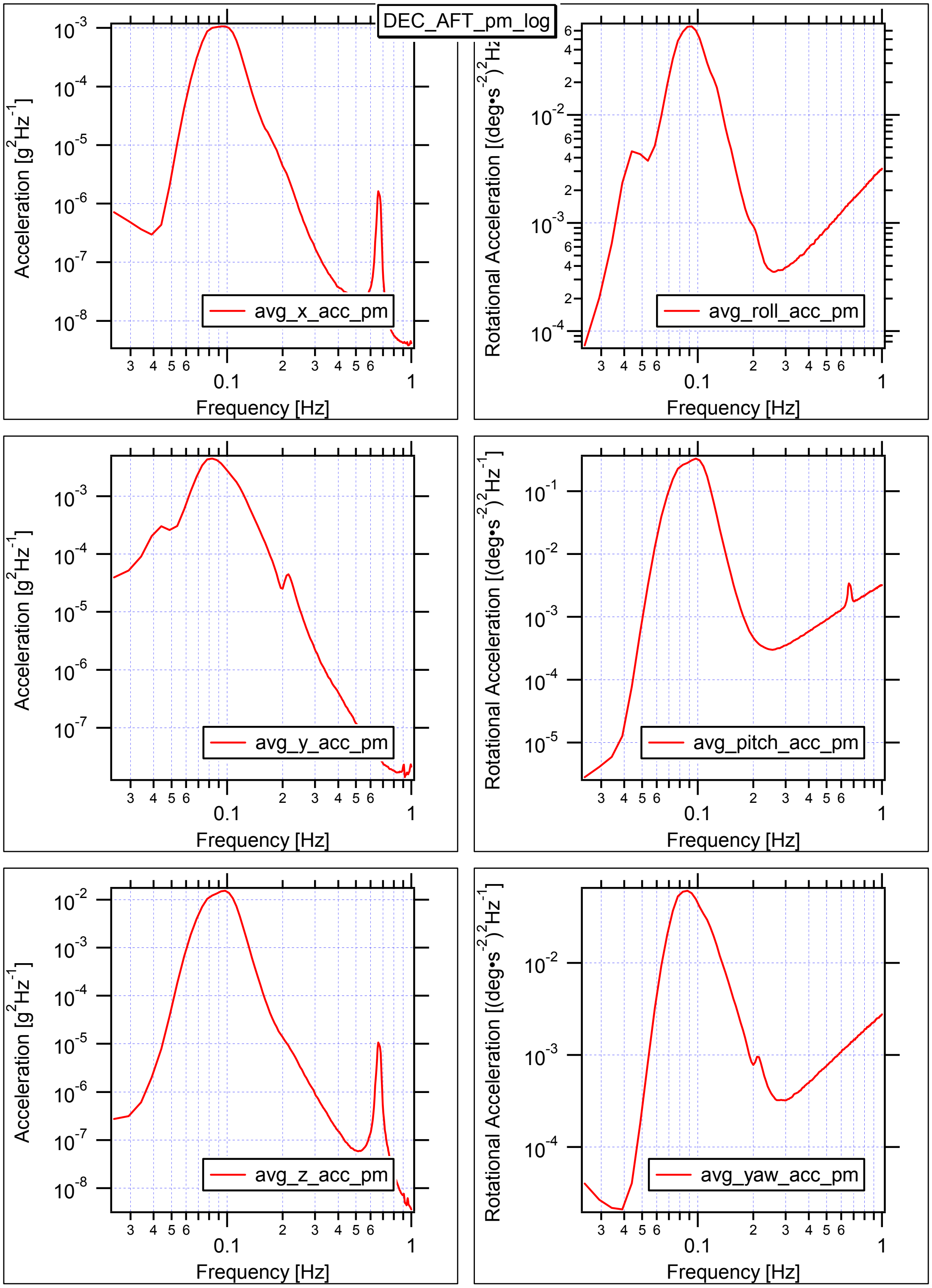

Figure 8. *December evening average logarithmic stern data*

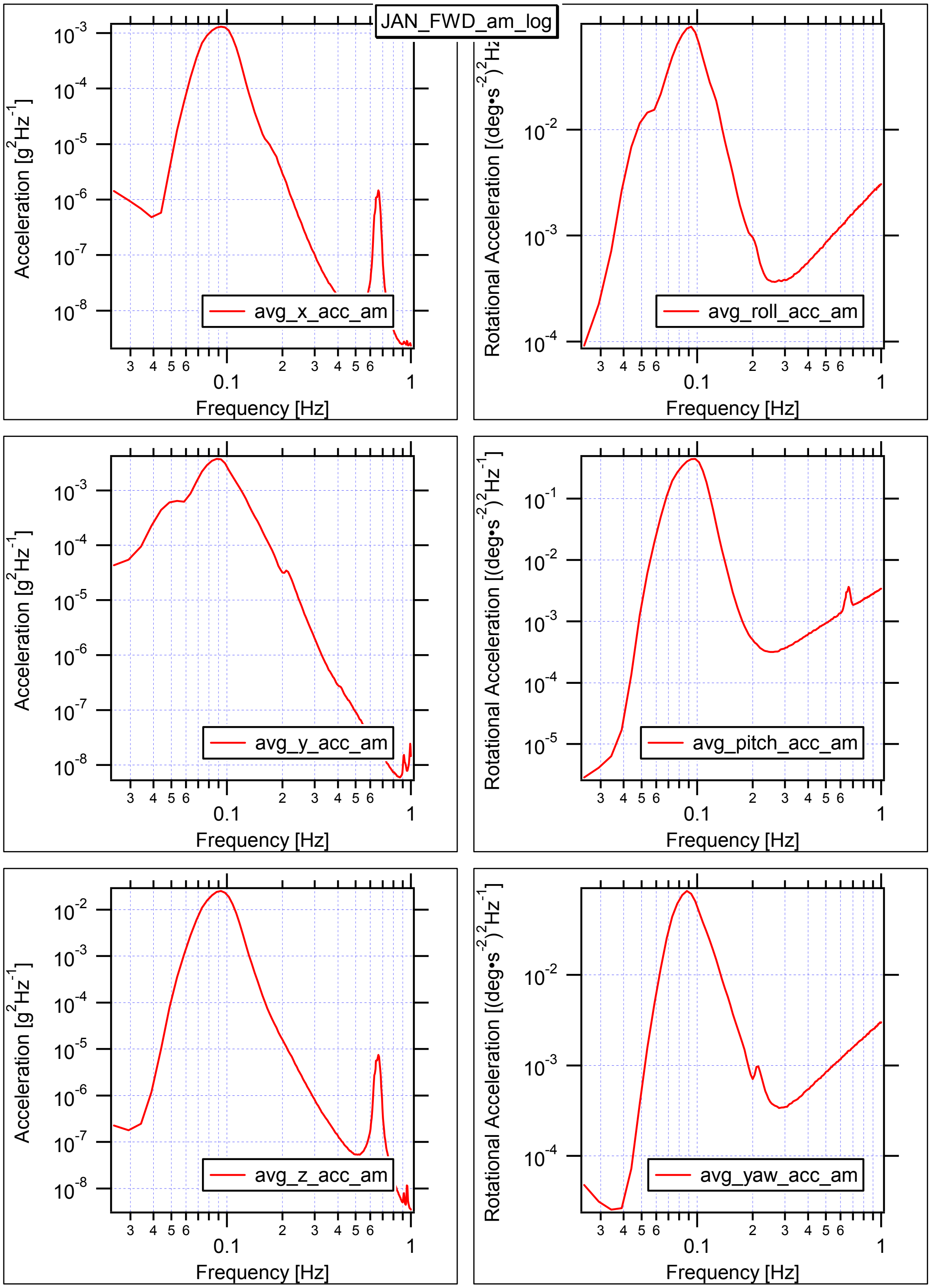

Figure 9. *January morning average logarithmic bow data*

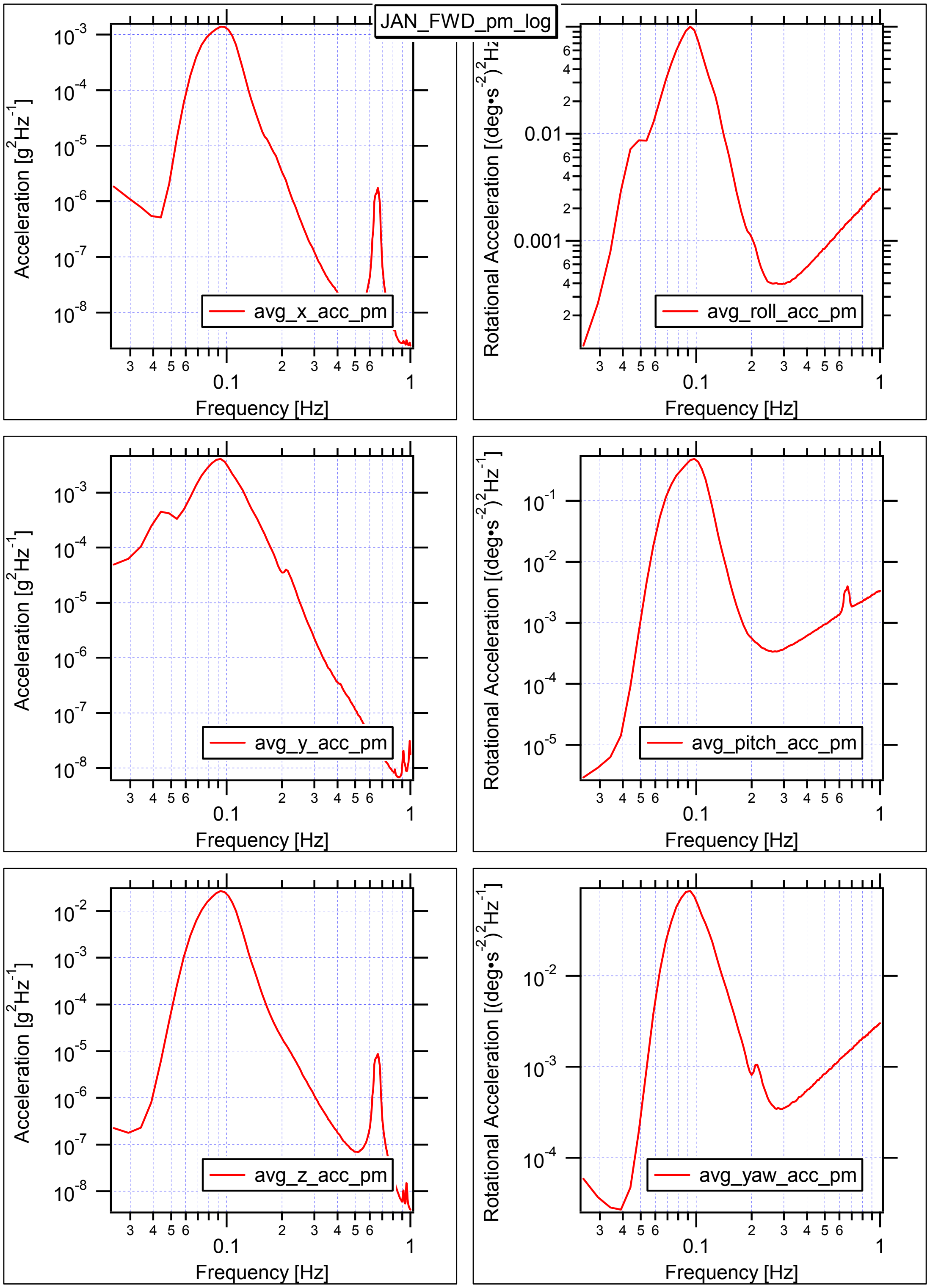

Figure 10. *January evening average logarithmic bow data*

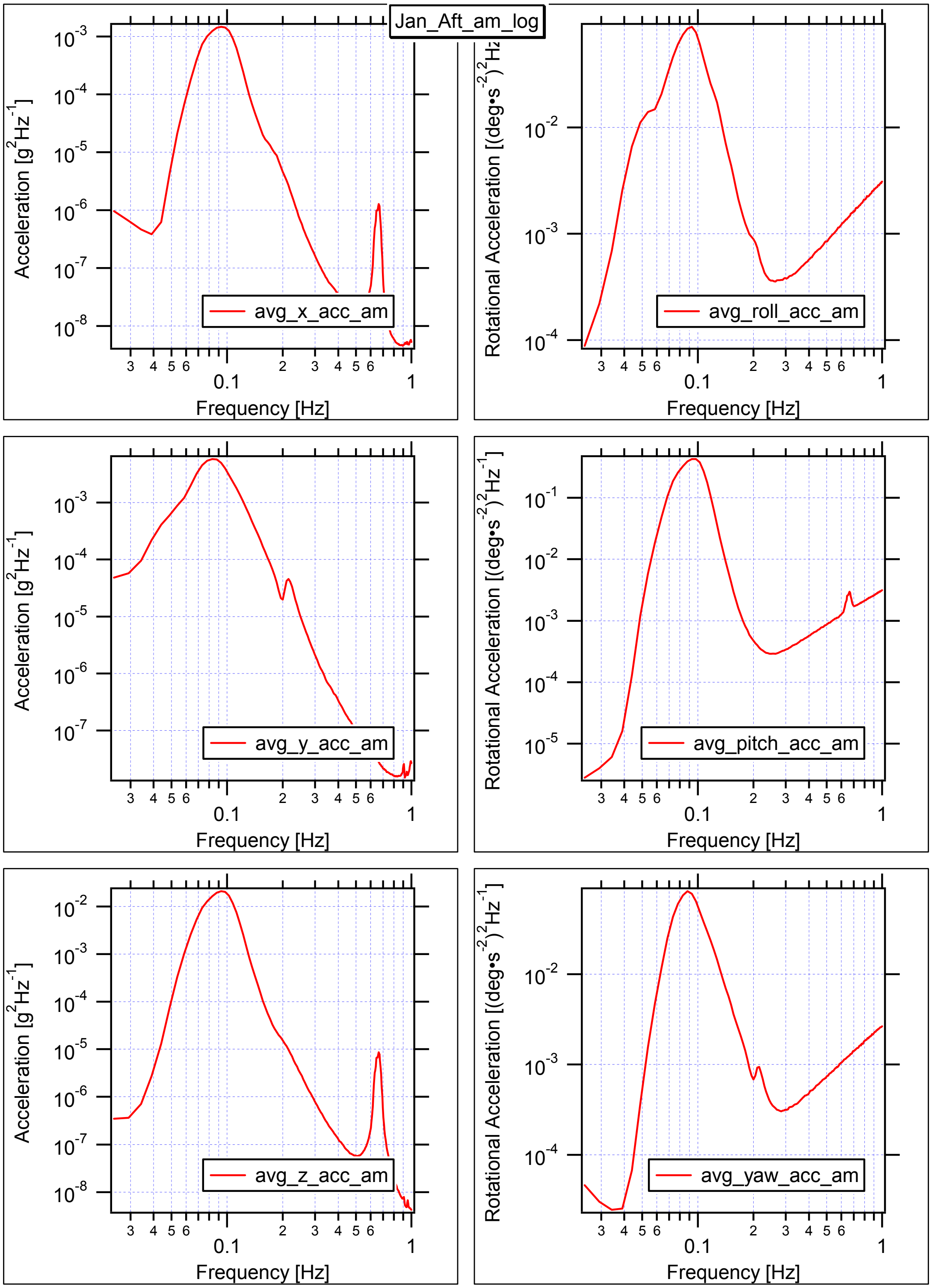

Figure 11. *January morning average logarithmic stern data*

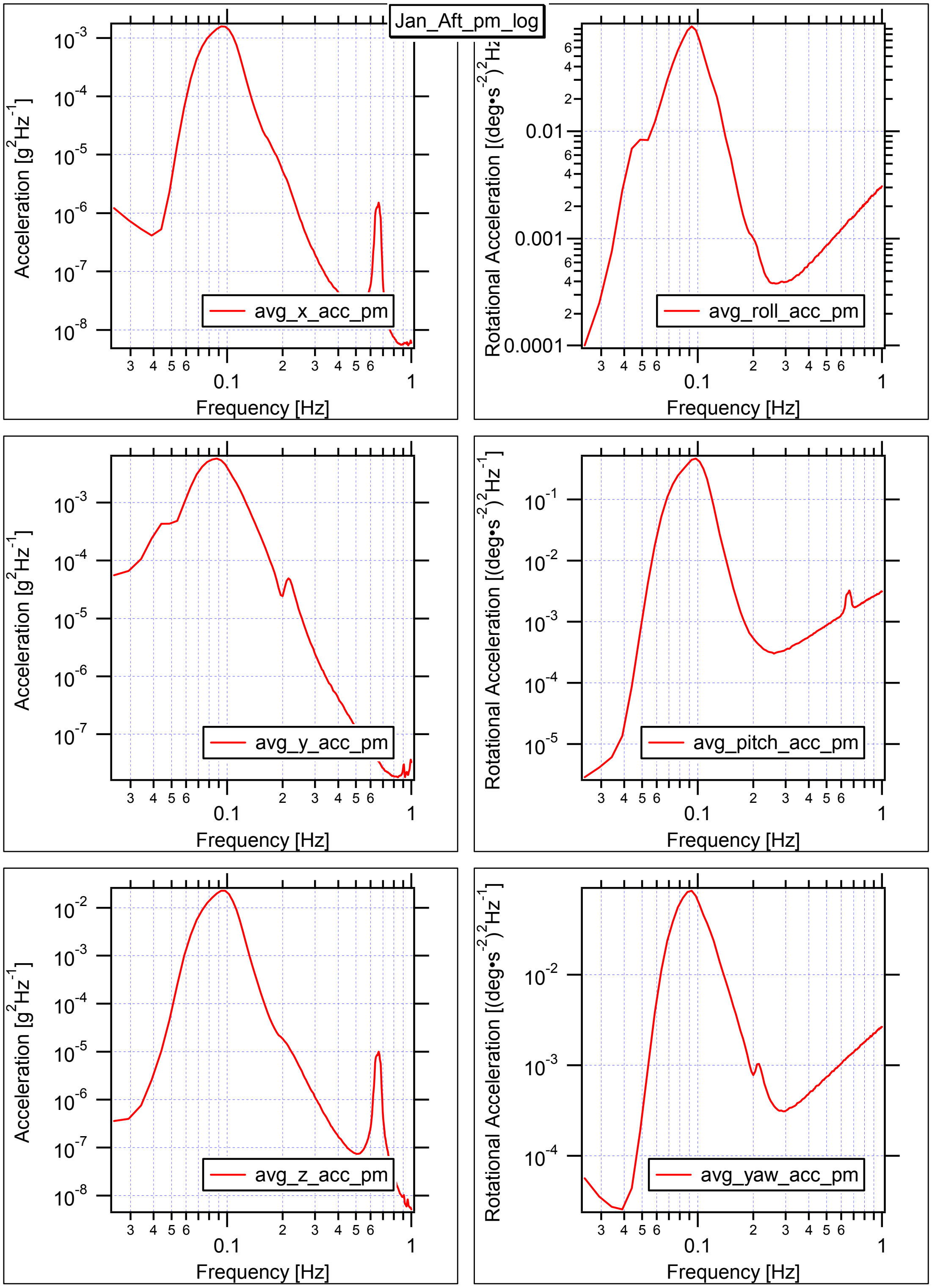

Figure 12. *January evening average logarithmic stern data*

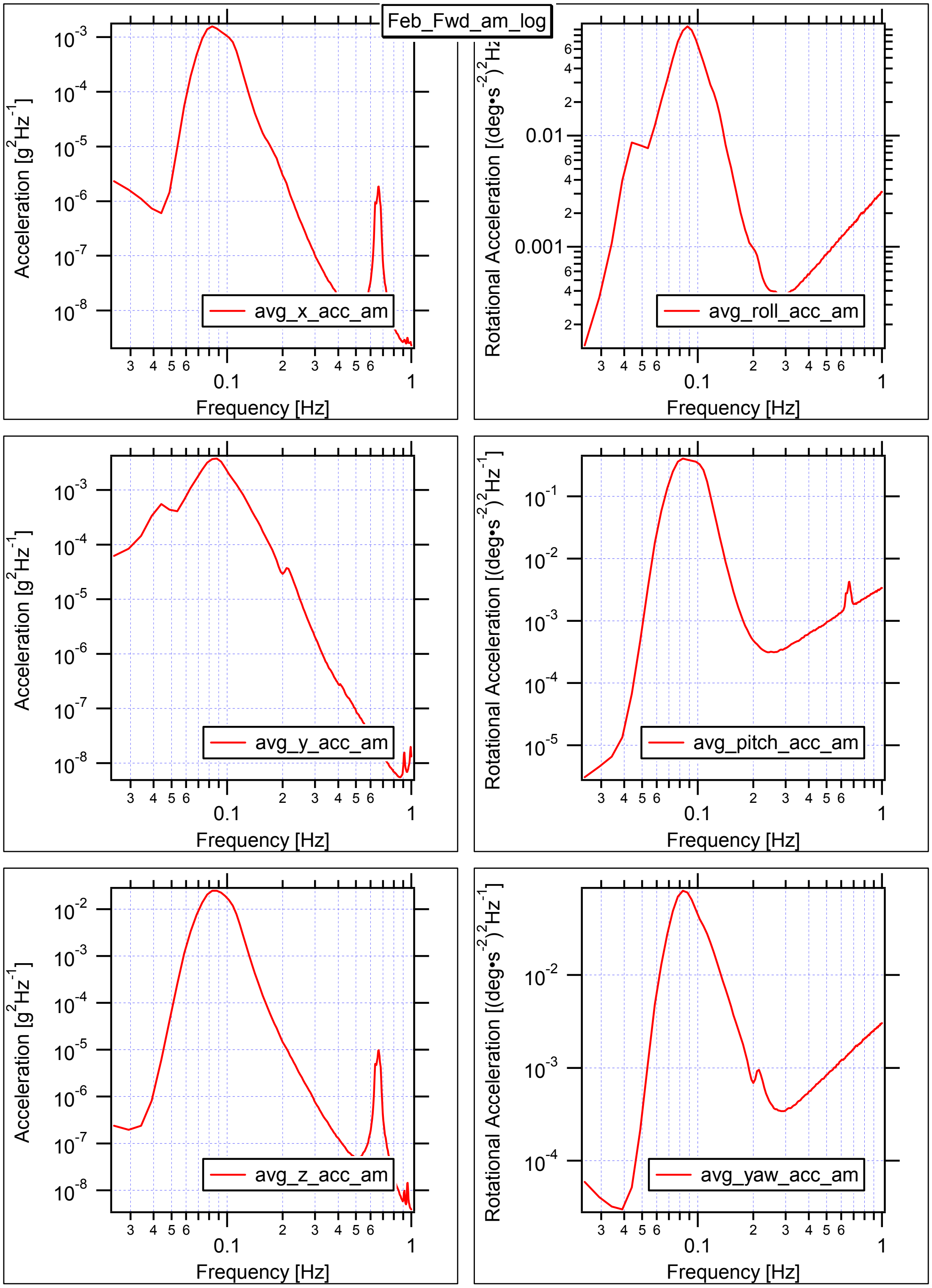

Figure 13. *February morning average logarithmic bow data*

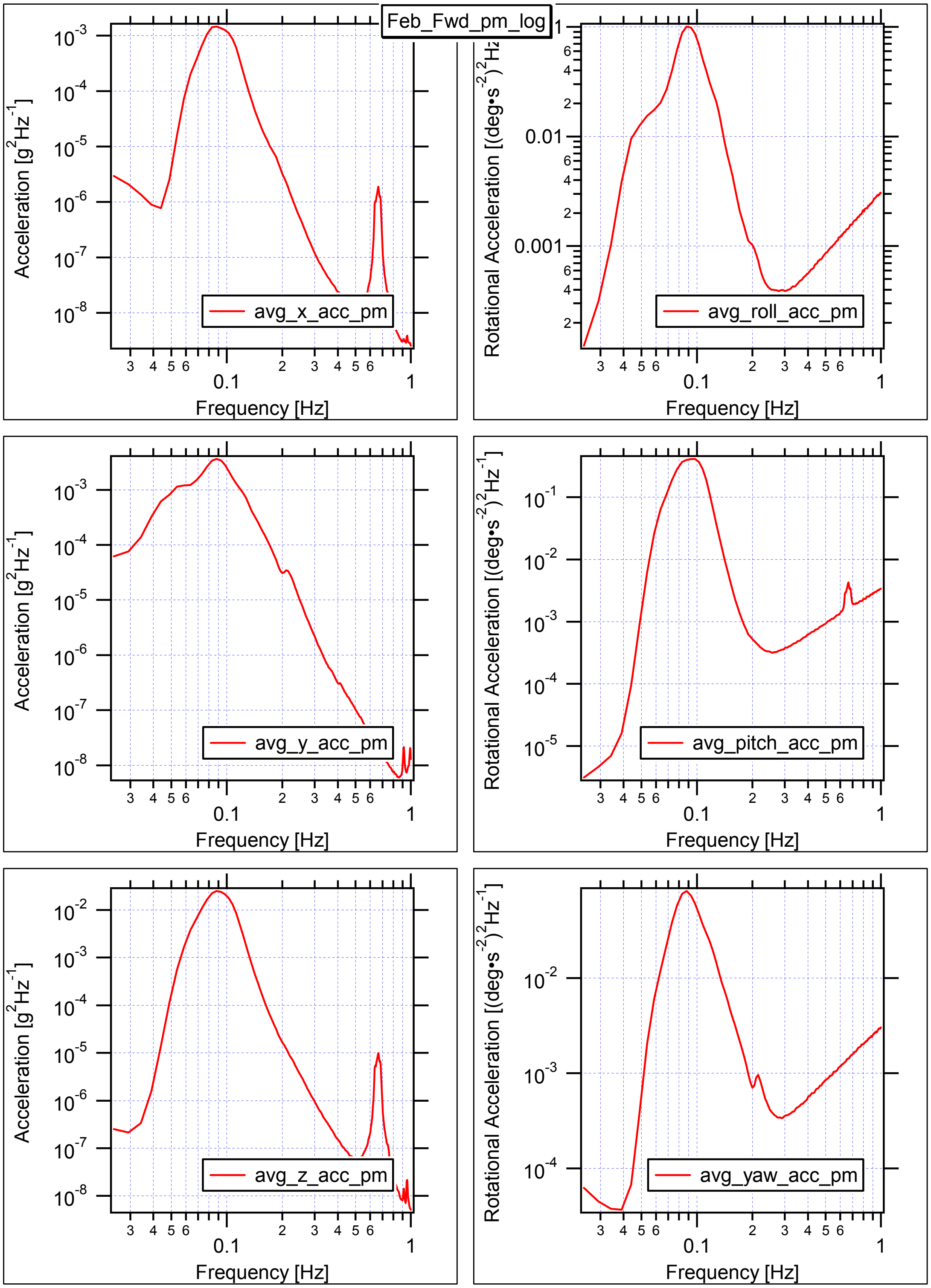

Figure 14. *February evening average logarithmic bow data*

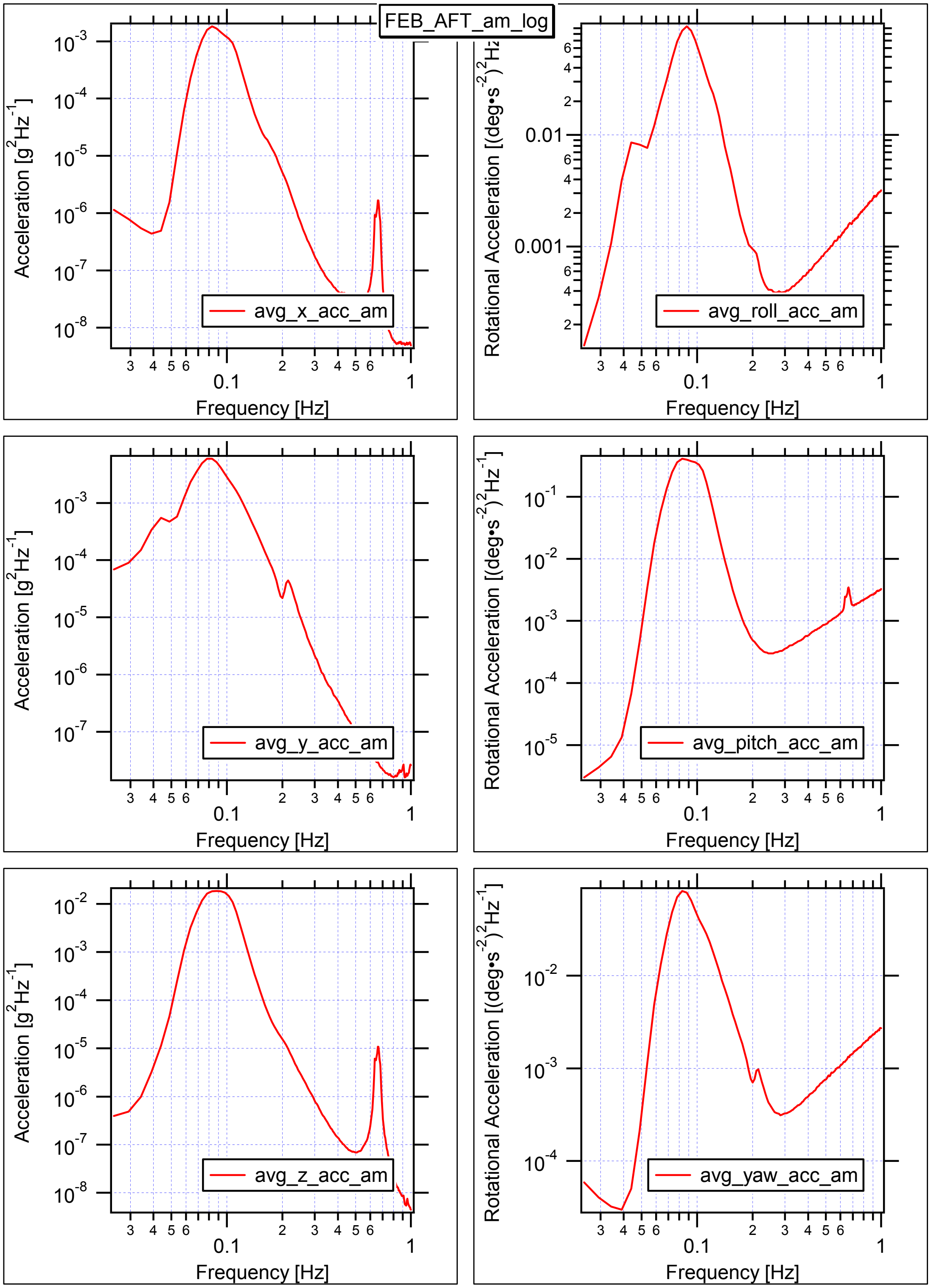

Figure 15. *February morning average logarithmic stern data*

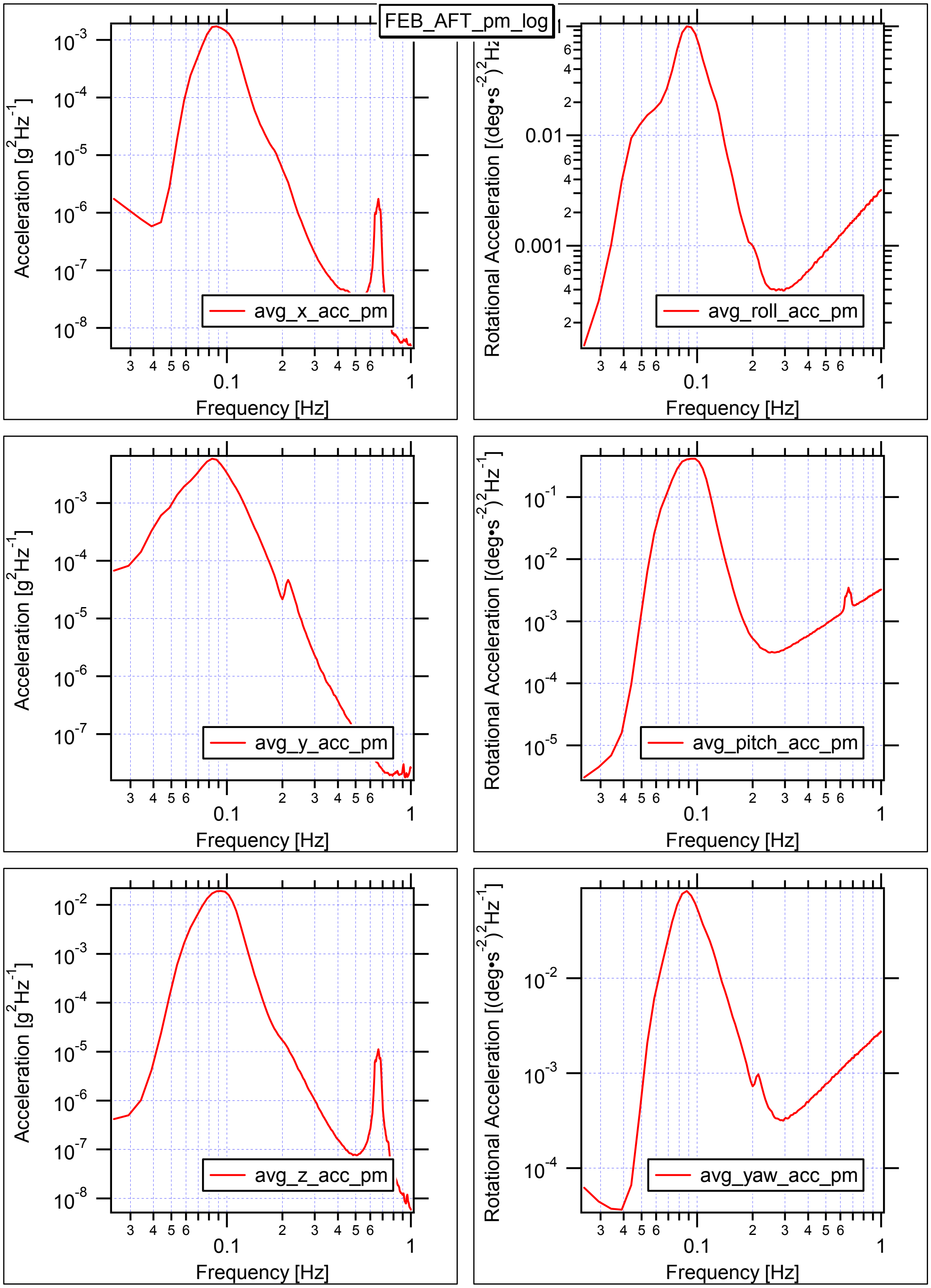

Figure 16. *February evening average logarithmic stern data*

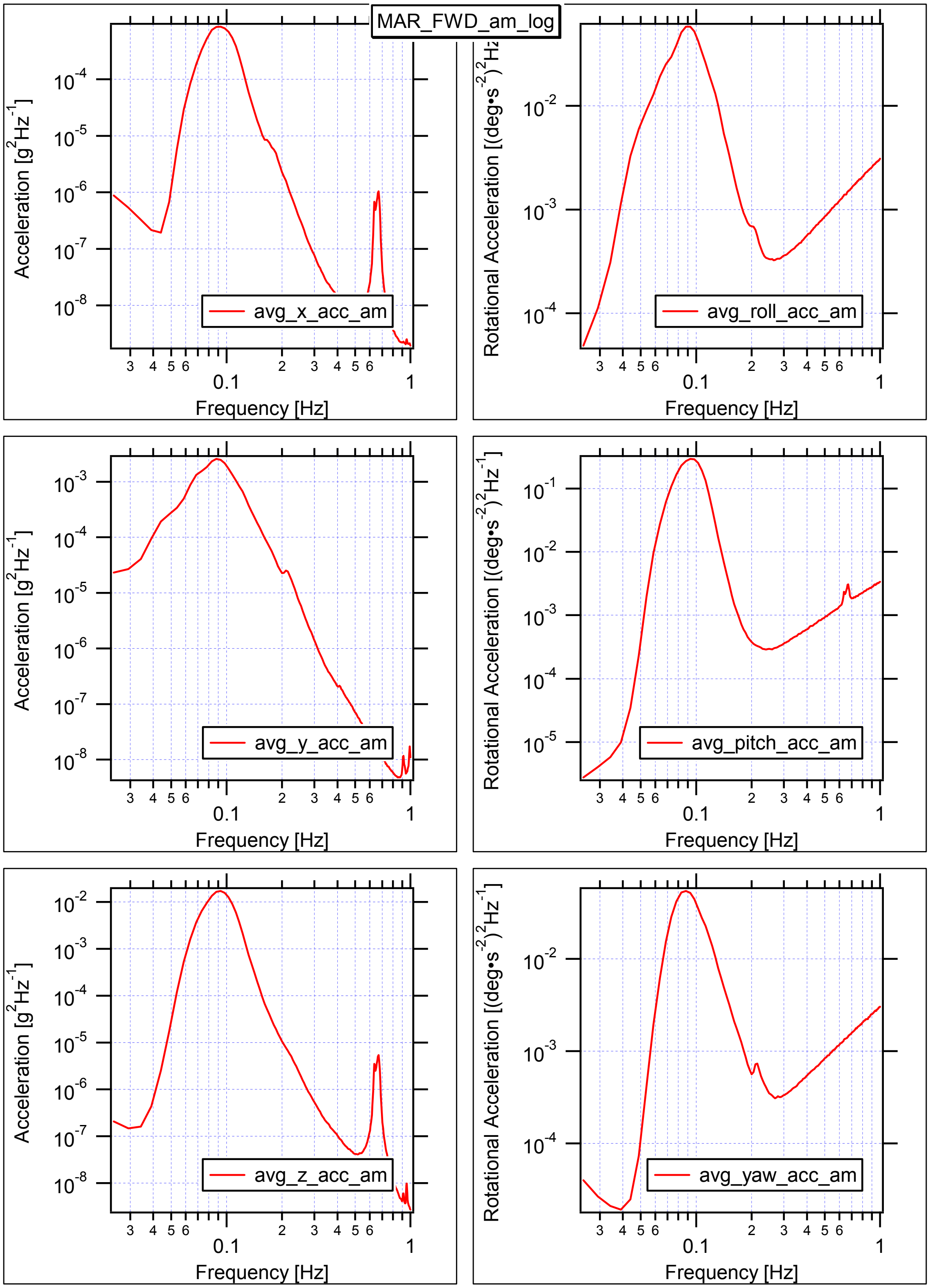

***Figure 17.** March morning average logarithmic bow data*

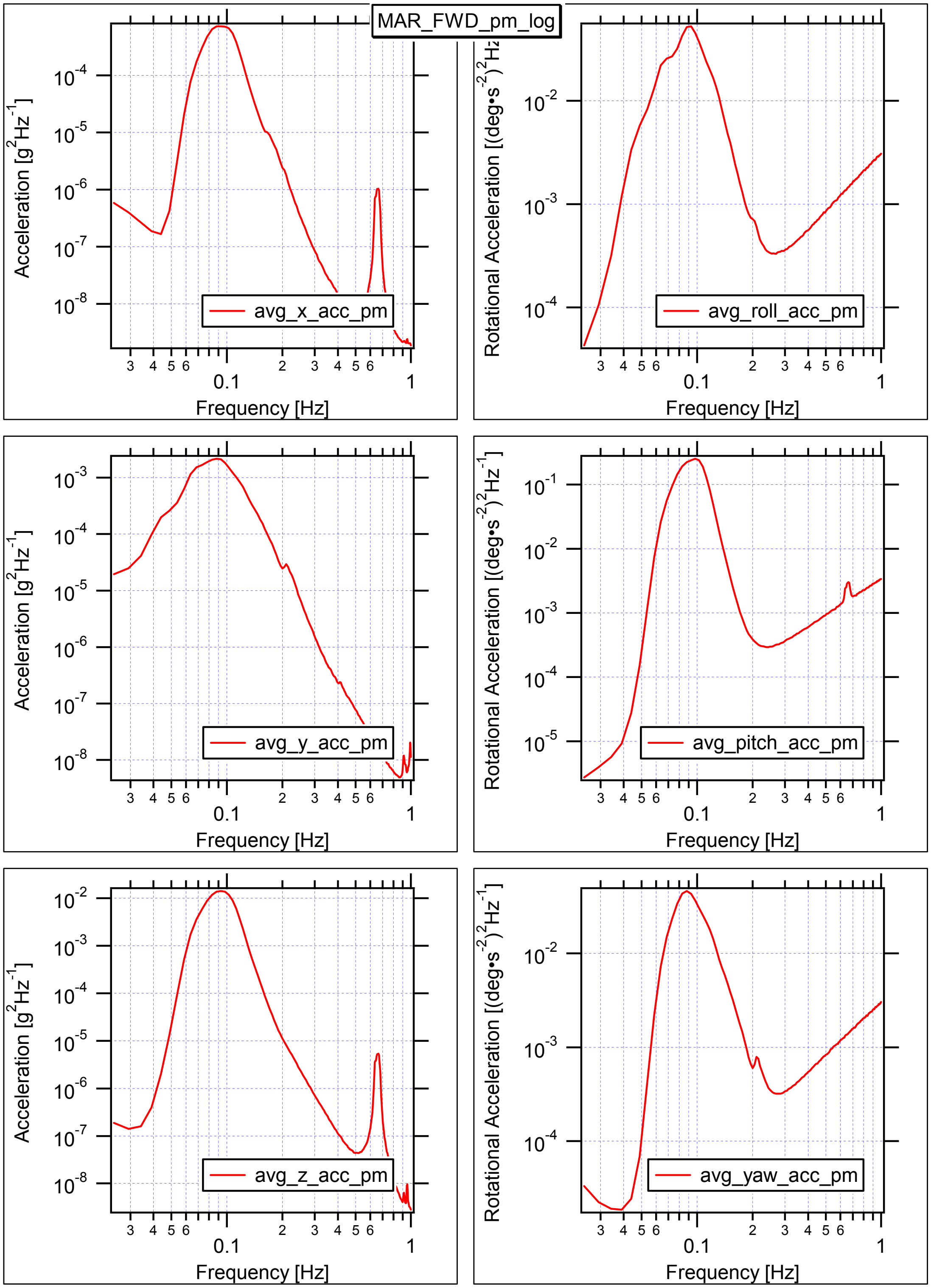

Figure 18. *March evening average logarithmic bow data*

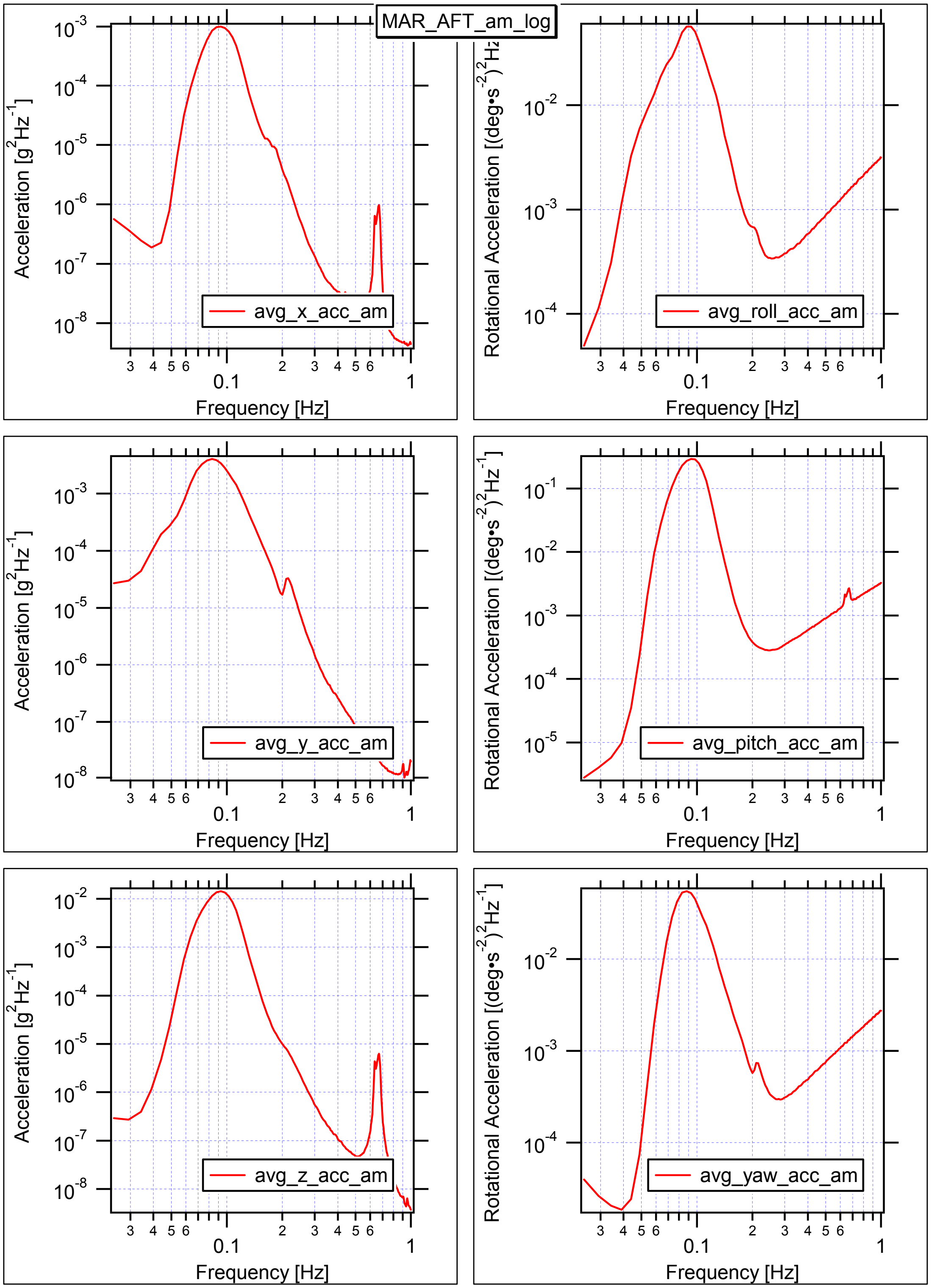

Figure 19. *March morning average logarithmic stern data*

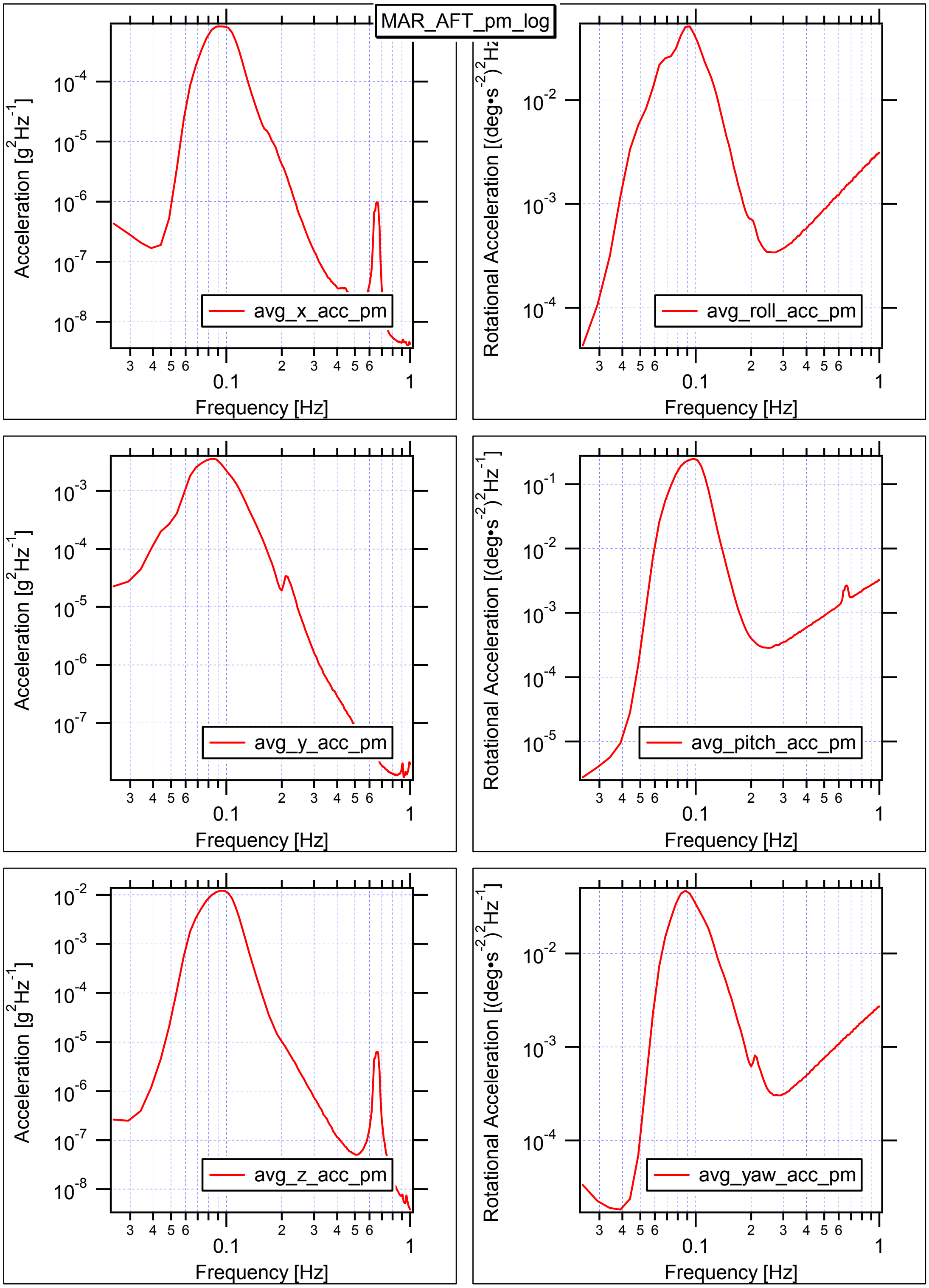

Figure 20. *March evening average logarithmic stern data*

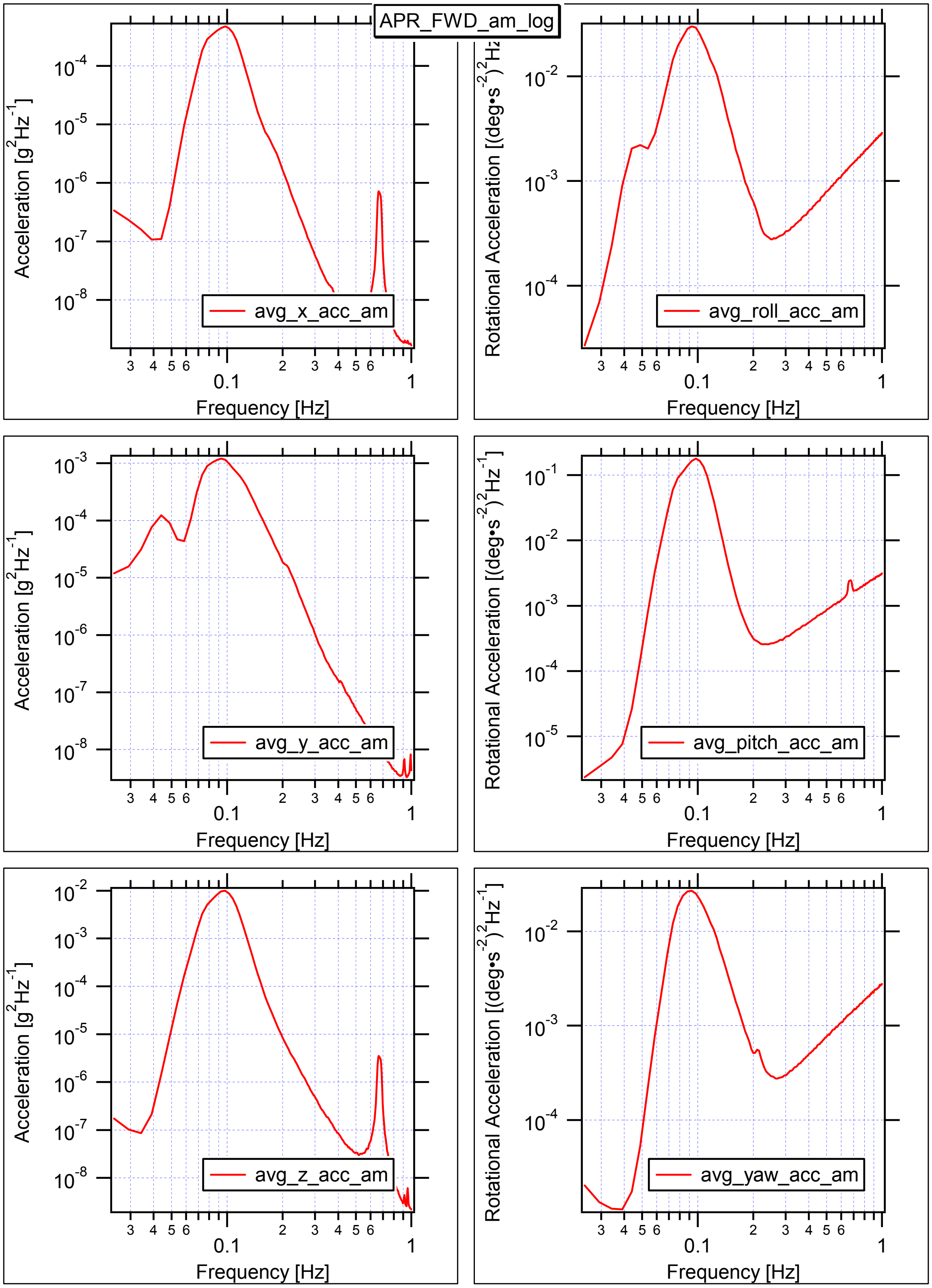

Figure 21. *April morning average logarithmic bow data*

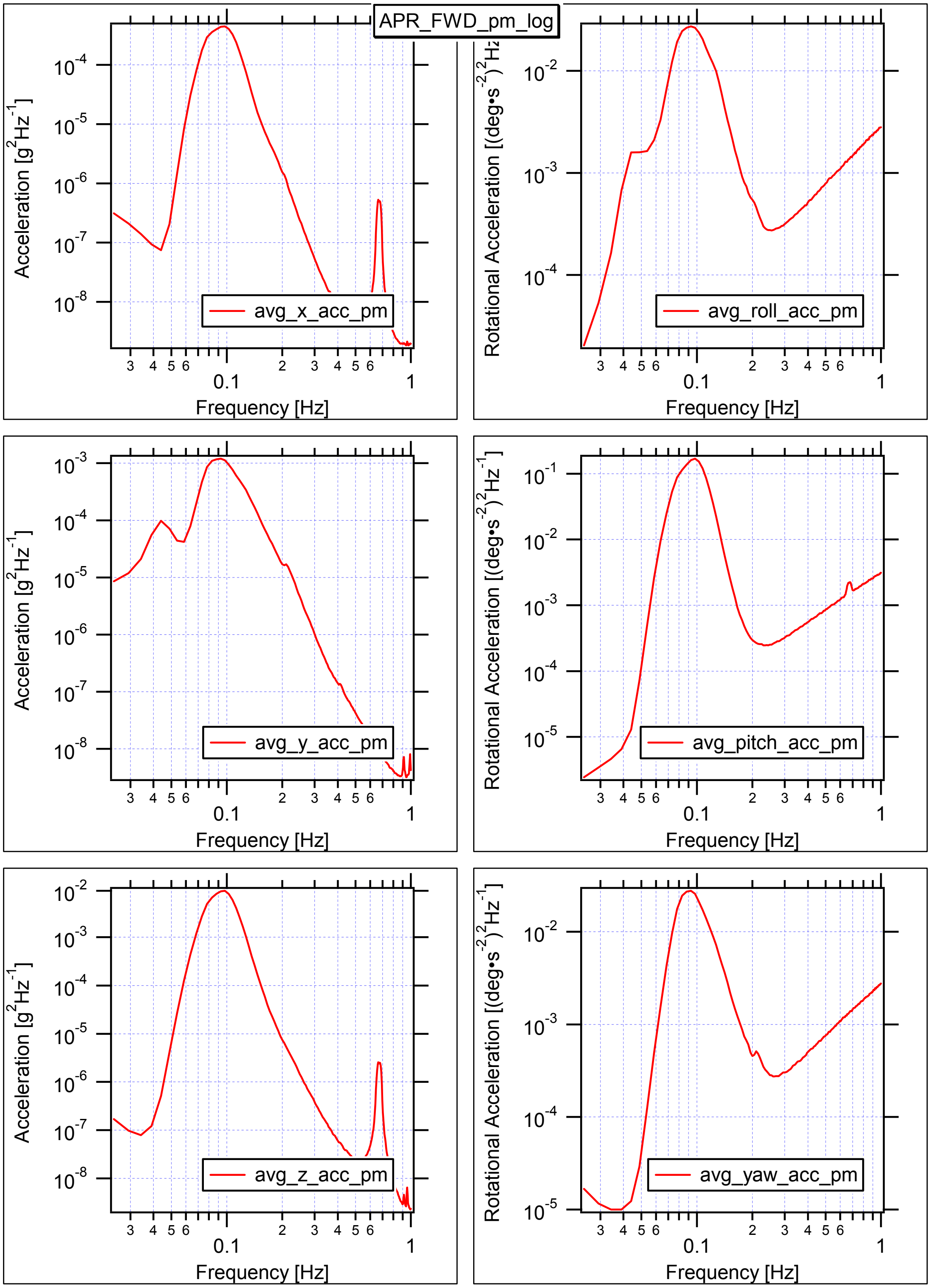

Figure 22. *April evening average logarithmic bow data*

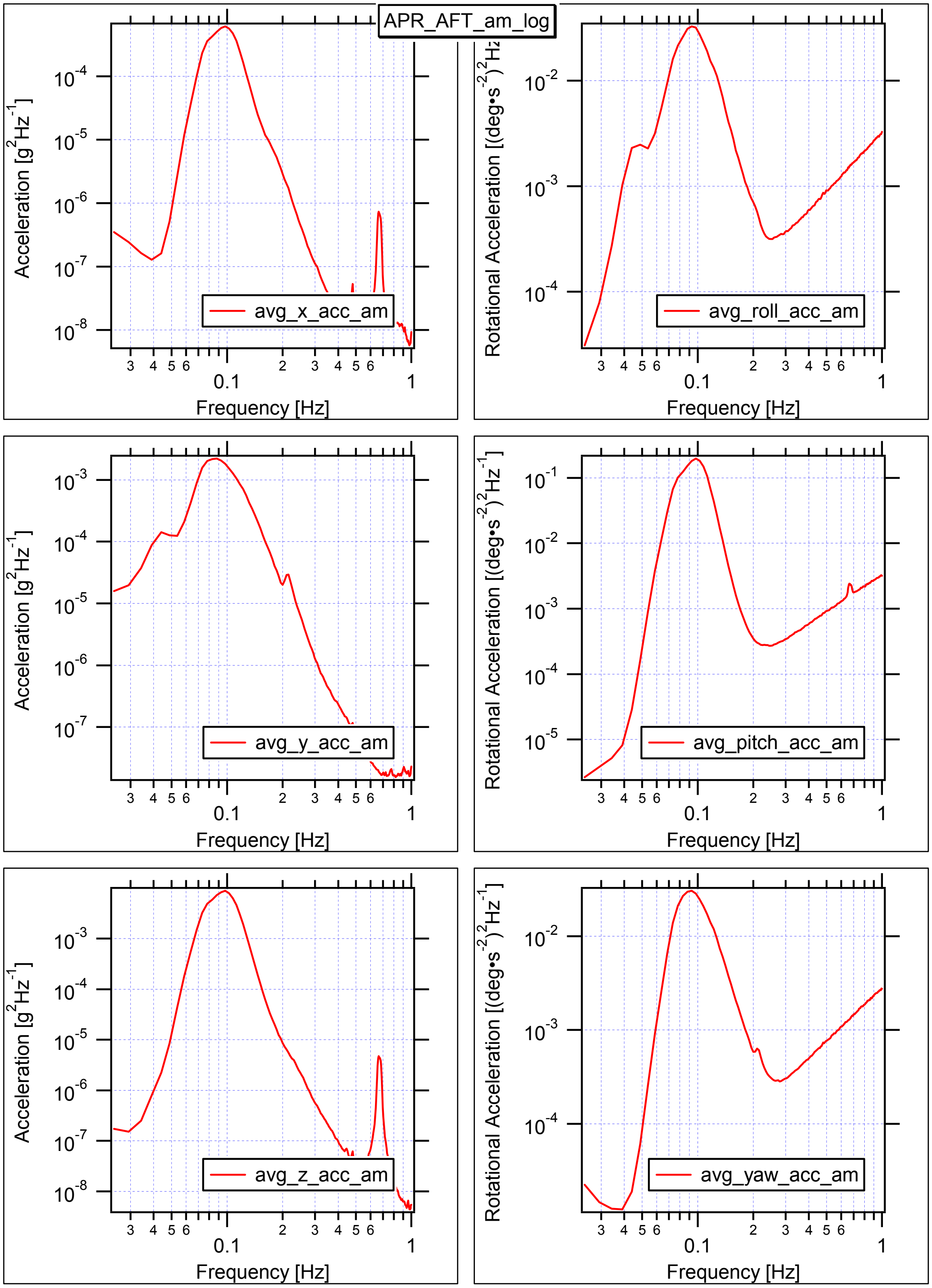

Figure 23. *April morning average logarithmic stern data*

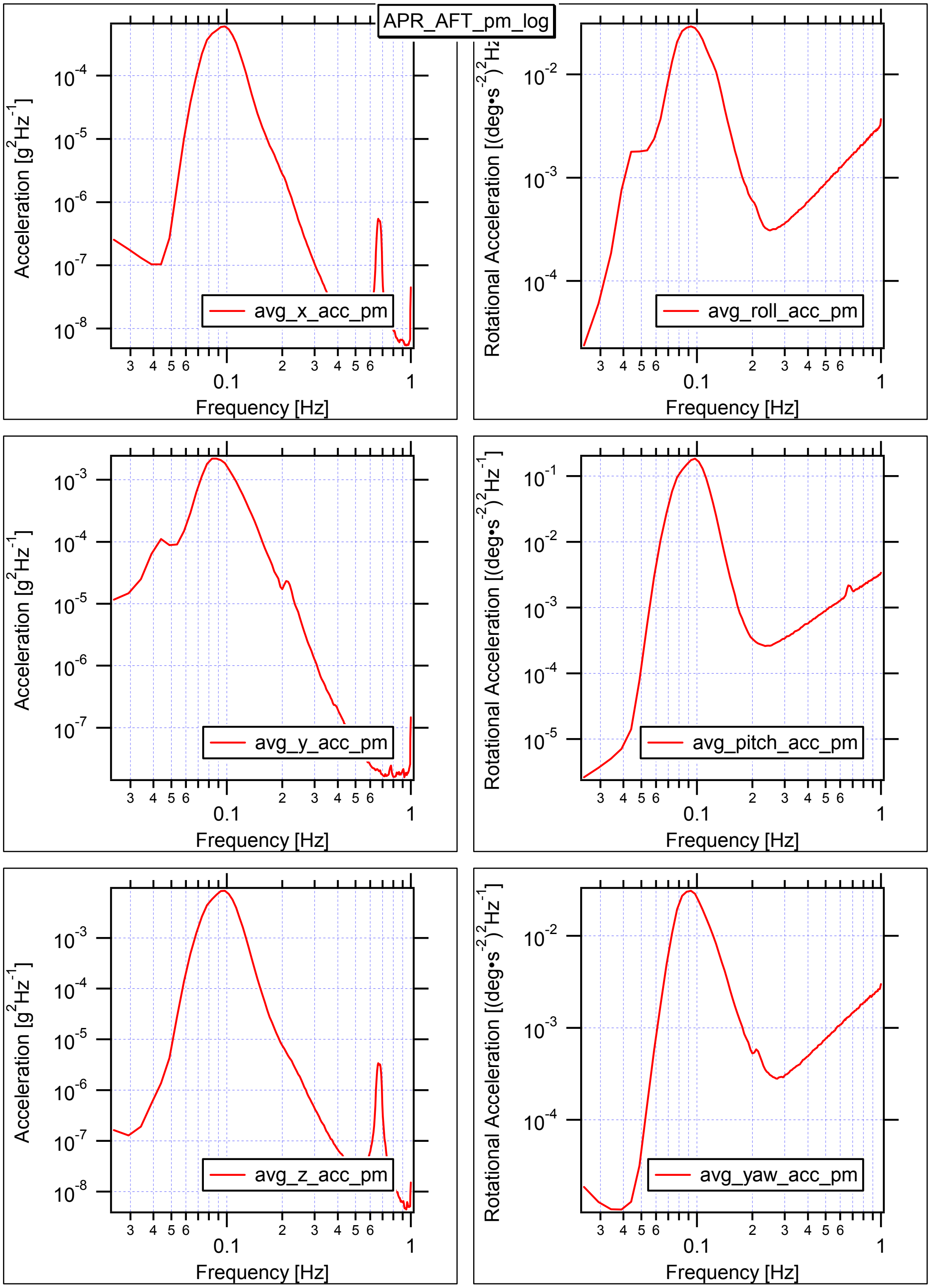

Figure 24. *April evening average logarithmic stern data*

Annex 3

Table 11. continued. *Correlations between mental and physical fatigue, concentration and environmental factors, p value less than 0.01 is considered to be highly significant*	
COGNITIVE PERFORMANCE	**CORRELATION COEFFICIENT**
Concentration deficit & poor sleep quality	0.48, p<0.0001
Concentration deficit & short sleep time	0.48, p<0.0001
Concentration deficit & dizziness	0.33, p<0.0001
Concentration deficit & mental fatigue	0.62, p<0.0001
Concentration deficit & physical fatigue	0.66, p<0.0001
Concentration deficit & sleepiness	0.62, p<0.0001
Concentration deficit & headache	0.26, p<0.0001
Concentration deficit & apathy	0.43, p<0.0001
Concentration deficit & anxiety	0.54, p<0.0001
Concentration deficit & nausea	0.22, p<0.0001
Concentration deficit & stomach awareness	0.32, p<0.0001
Concentration deficit & no motivation	0.55, p<0.0001
Concentration deficit & depression	0.41, p<0.0001
Concentration deficit & decision making problems	0.63, p<0.0001
Concentration deficit & memory deficit	0.65, p<0.0001
Concentration deficit & simple task problems	0.57, p<0.0001
Concentration deficit & balance problems	0.50, p<0.0001
Concentration deficit & carrying problems	0.39, p<0.0001
Concentration deficit & eye hand coordination	0.36, p<0.0001
Concentration deficit & vision	0.42, p<0.0001
Concentration deficit & made more mistakes	0.54, p<0.0001
Concentration deficit & tasks took longer	0.57, p<0.0001
Concentration deficit & tasks not completed in time	0.32, p<0.0001
Concentration deficit & cold/flu symptoms	0.26, p<0.0001
Concentration deficit & air quality	0.17, p<0.0001
Concentration deficit & noise	0.38, p<0.0001
Concentration deficit & vibration	0.37, p<0.0001
Concentration deficit & temperature	0.17, p<0.0001

Table 11. *Correlations between mental and physical fatigue, concentration and environmental factors, p value less than 0.01 is considered to be highly significant*

FATIGUE	CORRELATION COEFFICIENT
Mental fatigue & poor sleep quality	0.47, p<0.0001
Mental fatigue & insufficient sleep	0.46, p<0.0001
Mental fatigue & decision-making problems	0.59, p<0.0001
Mental fatigue & concentration deficit	0.62, p<0.0001
Mental fatigue & memory deficit	0.47, p<0.0001
Mental fatigue & simple task problems	0.43, p<0.0001
Mental fatigue & balance problems	0.46, p<0.0001
Mental fatigue & carrying problems	0.36, p<0.0001
Mental fatigue & eye hand coordination	0.26, p<0.0001
Mental fatigue & vision	0.35, p<0.0001
Mental fatigue & made more mistakes	0.47, p<0.0001
Mental fatigue & tasks took longer	0.36, p<0.0001
Mental fatigue & tasks not completed in time	0.18, p<0.0001
Physical fatigue & poor sleep quality	0.59, p<0.0001
Physical fatigue & insufficient sleep	0.54, p<0.0001
Physical fatigue & decision-making problems	0.58, p<0.0001
Physical fatigue & concentration deficit	0.66, p<0.0001
Physical fatigue & memory deficit	0.50, p<0.0001
Physical fatigue & simple task problems	0.51, p<0.0001
Physical fatigue & balance problems	0.60, p<0.0001
Physical fatigue & carrying problems	0.48, p<0.0001
Physical fatigue & eye hand coordination	0.42, p<0.0001
Physical fatigue & vision	0.38, p<0.0001
Physical fatigue & made more mistakes	0.41, p<0.0001
Physical fatigue & tasks took longer	0.46, p<0.0001
Physical fatigue & tasks not completed in time	0.39, p<0.0001
Physical fatigue & tasks abandoned	0.20, p<0.0001

Table 12. *November - symptom and motion parameter correlations*

SIGNIFICANT WAVE HEIGHT		
Parameter	***Definition***	***Correlation***
Symp1	Dizziness	0.40
ZERO UP-CROSSING PERIOD		
Parameter	***Definition***	***Correlation***
Other3	Noise	0.43
Other4	Vibration	0.34
Other5	Lighting	0.35
Other6	Temperature	0.45
PEAK FREQUENCY		
Parameter	***Parameter***	***Parameter***
Sleep1	Quality of sleep poor	0.29
Sleep2	Time sleeping was short	0.38
Sleep3	Ship motions	0.50
Symp6	Apathy	0.30
Symp7	Tension/anxiety	0.46
Symp9	Nausea	0.41
Symp11	Cold sweat	0.39
Symp12	Unmotivated	0.36
Symp13	Depressed	0.40
Per1	Making decisions	0.30

Table 12 continued. *November - symptom and motion parameter correlations*

PEAK FREQUENCY CONTINUED		
Parameter	***Definition***	***Correlation***
Per4	Simple tasks	0.30
Per6	Carrying or moving things	0.43
Comp2	Tasks took longer than usual	0.30
PEAK PERIOD		
Parameter	***Definition***	***Correlation***
Other3	Noise	0.47
Other5	Lighting	0.37
Other6	Temperature	0.39

Table 13. *December - symptom and motion parameter correlations*

SIGNIFICANT WAVE HEIGHT		
Parameter	***Definition***	***Correlation***
Sleep3	Ship motions	0.43
Symp5	Headache	0.36
Symp9	Nausea (not vomiting yet)	0.35
Symp10	Stomach awareness	0.44
Perf5	Body motion	0.31
Comp5	Not allowed to attempt tasks	0.52
Other2	Air quality	0.32
Other4	Vibration	0.32
Other5	Lighting	0.37
ZERO UP-CROSSING PERIOD		
Parameter	***Definition***	***Correlation***
Sleep3	Ship motions	0.40
Symp5	Headache	0.37
Symp9	Nausea (not vomiting yet)	0.43
Symp10	Stomach awareness	0.39
Per5	Body motion	0.29
Comp5	Not allowed to attempt tasks	0.37
Other2	Air quality	0.30
Other4	Vibration	0.34
Other5	Lighting	0.35

Table 13 continued. *December - symptom and motion parameter correlations*

PEAK FREQUENCY		
Parameter	***Definition***	***Correlation***
Symp7	Tension/anxiety	0.34
Per7	Eye hand coordination	0.34
PEAK PERIOD		
Parameter	***Definition***	***Correlation***
Sleep3	Ship motions	0.35
Symp5	Headache	0.48
Symp9	Nausea (not vomiting yet)	0.39
Symp10	Stomach awareness	0.31
Comp5	Not allowed to attempt tasks	0.37
Other5	Lighting	0.42
SEA STATE		
Parameter	***Definition***	***Correlation***
Sleep3	Ship motions	0.33
Symp5	Headache	0.38
Symp9	Nausea (not vomiting yet)	0.31
Comp5	Not allowed to attempt tasks	0.38
Other2	Air quality	0.28

Table 14. *January - symptom and motion parameter correlations*

SIGNIFICANT WAVE HEIGHT		
Parameter	***Definition***	***Correlation***
Sleep1	Sleep quality poor	0.34
Sleep2	Sleeping was short	0.29
Sleep3	Ship motions	0.49
Symp2	Mental fatigue	0.31
Symp5	Headache	0.38
Symp7	Tension/anxiety	0.42
Symp12	Unmotivated	0.46
Per1	Making decisions	0.56
Per2	Concentration/attention	0.36
Per3	Memory	0.47
Per4	Simple tasks	0.58
Per5	Body motion	0.75
Per6	Carrying or moving things	0.58
Comp1	More mistakes than usual	0.40
Comp2	Task took longer than usual	0.29
ZERO UP-CROSSING PERIOD		
Parameter	***Definition***	***Correlation***
Sleep3	Ship motions	0.40
Symp1	Dizziness	0.29
Per1	Making decisions	0.32
Per2	Concentration/attention	0.48
Per3	Memory	0.50
Per4	Simple tasks	0.45
Per5	Body motion	0.53
Per6	Carrying or moving things	0.49
Comp1	More mistakes than usual	0.43

Table 14 continued. *January - symptom and motion parameter correlations*

PEAK PERIOD		
Parameter	***Definition***	***Correlation***
Per2	Concentration/attention	0.36
Per3	Memory	0.36
Per4	Simple tasks	0.30
Per5	Body motion	0.35
Per6	Carrying or moving things	0.29
Comp1	More mistakes than usual	0.38
SEA STATE		
Parameter	***Definition***	***Correlation***
Sleep3	Ship motions	0.35
Symp2	Mental fatigue	0.29
Symp5	Headache	0.32
Per1	Making decisions	0.35
Per2	Concentration/attention	0.39
Per3	Memory	0.41
Per4	Simple tasks	0.49
Per5	Body motion	0.57
Per6	Carrying or moving things	0.47
Comp1	More mistakes than usual	0.38
Comp2	Tasks took longer than usual	0.37
Comp4	Had to abandon task	0.37

Table 15. *February - symptom and motion parameter correlations*

SIGNIFICANT WAVE HEIGHT		
Parameter	***Definition***	***Correlation***
Sleep3	Ship motions	0.35
Symp2	Mental fatigue	0.42
Symp12	Umotivated	0.49
Per1	Making decisions	0.37
Per2	Concentration	0.32
Per3	Memory	0.34
Per4	Simple tasks	0.36
Per5	Body motion	0.57
Per6	Carrying or moving 7things	0.42
Comp1	More mistakes than usual	0.36
Comp2	Tasks took longer than usual	0.48
Other3	Noise	0.38
Other4	Vibration	0.39
ZERO UP-CROSSING PERIOD		
Parameter	***Definition***	***Correlation***
Symp2	Mental fatigue	0.36
Symp5	Headache	0.34
Symp12	Unmotivated	0.29
Per5	Body motion	0.37
Comp1	More mistakes than usual	0.29
Other2	Air quality	0.37
Other3	Noise	0.31
Other4	Vibration	0.34
Other5	Lighting	0.44

Table 15 continued. *February - symptom and motion parameter correlations*

PEAK FREQUENCY		
Parameter	***Definition***	***Correlation***
Comp3	Tasks not completed in time available	0.32
PEAK PERIOD		
Parameter	***Definition***	***Correlation***
Other2	Air quality	0.52
Other3	Noise	0.29
Other4	Vibration	0.38
Other5	Lighting	0.59
Other6	Temperature	0.38
SEA-STATE		
Parameter	***Definition***	***Correlation***
Symp12	Unmotivated	0.43
Per1	Making decisions	0.48
Per2	Concentration/attention	0.30
Per4	Simple tasks	0.42
Per5	Body motion	0.57
Per6	Carrying or moving things	0.41
Comp1	More mistakes than usual	0.38
Comp2	Tasks took longer than usual	0.37
Other3	Noise	0.38
Other4	Vibration	0.38
Other5	Lighting	0.34

Table 16. *March - symptom and motion parameter correlations*

SIGNIFICANT WAVE HEIGHT		
Parameter	***Definition***	***Correlation***
Sleep1	Sleep quality poor	0.38
Sleep3	Ship motions	0.73
Symp3	Physical fatigue	0.36
Symp12	Umotivated	0.30
Per5	Body motion	0.71
Other6	Temperature	0.33
ZERO UP-CROSSING PERIOD		
Parameter	***Definition***	***Correlation***
Sleep1	Sleep quality poor	0.39
Sleep3	Ship motions	0.30
Per5	Body motion	0.52
PEAK FREQUENCY		
Parameter	***Definition***	***Correlation***
Symp8	Vomiting	0.35
Comp5	Not allowed to attempt task	0.35
PEAK PERIOD		
Parameter	***Definition***	***Correlation***
Symp7	Tension/anxiety	0.40
Per3	Memory	0.29
Other4	Vibration	0.41
Other5	Lighting	0.32

Table 17. *April - symptom and motion parameter correlations*

PEAK FREQUENCY		
Parameter	***Definition***	***Correlation***
Sleep4	Ship motion	0.41
Symp2	Mental fatigue	0.42
Symp11	Cold sweating	0.43
Per1	Making decisions	0.50
Per3	Memory	0.33
Per4	Simple tasks	0.34
Per5	Body motion	0.33
Comp1	More mistakes than usual	0.36
Comp2	Took longer than usual	0.44
Other3	Noise	0.38
Other4	Vibration	0.34

Annex 4

Table 18. *NATO – Sea state definitions*

SEA STATE	SIGNIFICANT WAVE HEIGHT	
	Range (m)	***Mean (m)***
0	-	-
1	0.0 – 0.1	-
2	0.1 – 0.5	0.30
3	0.5 – 1.25	0.88
4	1.25 – 2.5	1.88
5	2.5 – 4.0	3.25
6	4.0 – 6.0	5.0
7	6.0 – 9.0	7.5
8	9.0 – 14.0	11.5
9	14.0+	-

DOCUMENT CONTROL DATA SHEET

1a. PERFORMING AGENCY DRDC Toronto	2. SECURITY CLASSIFICATION UNCLASSIFIED −
1b. PUBLISHING AGENCY DRDC Toronto	

3. TITLE

Effects of Sea Motion on the Crew of the Petro Canada Terra Nova FPSO (Floating, Production, Storage and Offloading) Vessel

4. AUTHORS

Bob Cheung, Chris J. Brooks, Antonio Simoes−Re, Kevin Hofer

5. DATE OF PUBLICATION November 30 , 2004	6. NO. OF PAGES 59

7. DESCRIPTIVE NOTES

8. SPONSORING/MONITORING/CONTRACTING/TASKING AGENCY
Sponsoring Agency:
Monitoring Agency:
Contracting Agency :
Tasking Agency:

9. ORIGINATORS DOCUMENT NO. Technical Report TR 2004−117	10. CONTRACT GRANT AND/OR PROJECT NO.	11. OTHER DOCUMENT NOS.

12. DOCUMENT RELEASABILITY

Unlimited distribution

13. DOCUMENT ANNOUNCEMENT

Unlimited announcement

14. ABSTRACT

(U) Current oil and gas exploration requirements to exploit resources in both deep and shallow water have changed the method of oil extraction. Floating Production Storage and Offloading (FPSO) vessels are increasingly being used to operate in deep water where the operating environment can be very extreme. The Terra Nova FPSO vessel is the first of its kind built for operations on the Grand Banks at the Terra Nova field and is the first to operate in Canadian waters. The crew on this vessel must often work under extreme weather conditions, in shifts throughout the day and night for up to three weeks at a time, or even longer if the weather prevents crew changes. Seasickness and its after−effects, motion−induced fatigue and motion−induced interruptions are a potential problem for the safety and health of crewmembers at sea. Understanding the incidence, severity and the effects of seasickness on performance can improve effective scheduling, task assignment, and reduce the likelihood of personal injury both on− and off−duty. In extreme circumstances, this understanding may prevent major injury, loss of life and even loss of the FPSO itself. The previous questionnaire−based survey results revealed that crew complained of a variety of problems including sleep disturbance, task completion, task performance, loss−of−concentration, decision−making and memory disorders. These problems were correlated with increasing ship motion, however, in the previous study, the ship motion data was obtained indirectly through the radio operator from the FPSO Offshore Installation. This new survey attempts to (1) confirm the incidence and severity of the symptom complex of seasickness, motion−induced fatigue and task performance problems encountered on the Terra Nova FPSO vessel, (2) to examine correlations (if any) between real time direct recordings of fore and aft FPSO vessel motion, seasickness, motion−induced fatigue and task performance, and (3) use the results to develop recommendations to ameliorate seasickness and improve comfort and performance in the environment described above. A questionnaire−based survey of motion effects including sleep problems, symptoms and severity of seasickness and task performance was administered at various times during 3−week offshore shifts. Ship motion data provided for this analysis was gathered from two accelerometers mounted on the FPSO in the forward and aft switch rooms on the same deck. The FPSO crew responded well and 1344 questionnaires were received. Data analyses revealed only a small number of complaints of sea sickness, but as was expected there was a much higher number of complaints of sleep problems, decision making and memory disorders. The correlation between sleep disturbance and ship motion was relatively high. Task performance problems such as loss of concentration, decision−making and memory disorders and task completion problems were observed. Between November and April, the number of significant correlations between ship motion and symptoms/performance increased with the severity of average sea state. There appeared to be no apparent habituation among subjects who participated in more than 2 shifts offshore. It is apparent that the number of safety, health and performance issues increases with the deterioration of weather conditions. It is recommended that an identification system should be implemented by the OIM to signify when the ship’s company is at risk of injury and potential task degradation.

(U) Le fait qu’on doive actuellement exploiter les ressources pétrolières et gazières en eaux tant profondes que peu profondes a entraîné des changements dans les méthodes d’extraction. On utilise de plus en plus des unités flottantes de production, stockage et déchargement (FPSO) pour l’exploitation en haute mer, où les conditions environnementales peuvent être extrêmes. Le navire Terra Nova est le premier du genre construit pour l’exploitation du gisement Terra Nova sur les Grands Bancs de Terre?Neuve et est le premier en opération dans les eaux canadiennes. L’équipage de ce navire doit souvent travailler dans des conditions météorologiques extrêmes par postes diurnes et nocturnes pour des périodes de trois semaines ou même plus si la météo empêche les changements d’équipage. Le mal de mer et ses répercussions ainsi que la fatigue et les interruptions de travail induites par le mouvement présentent des risques potentiels pour la sécurité et la santé des membres d’équipage en mer. Une meilleure connaissance de l’incidence et de la sévérité du mal de mer chez les membres d’équipage ainsi que de ses effets sur la performance permettrait d’améliorer les calendriers de travail et les assignations de tâches et de réduire les risques de problèmes de santé tant durant les périodes de travail qu’en dehors de ces périodes. Dans des conditions extrêmes, cette connaissance pourrait prévenir des traumatismes importants, des mortalités et même la perte du navire FPSO. Selon les résultats de l’enquête par questionnaire précédente (Cheung, Brooks et Hofer, 2002), les membres d’équipage souffrent de problèmes divers : troubles du sommeil, difficulté de terminer leurs tâches, perte d’efficacité, perte de concentration, difficulté à prendre des décisions et troubles de la mémoire. Ces problèmes étaient corrélés avec l’intensité des mouvements du navire; cependant, dans cette étude antérieure, les données sur les mouvements du navire ont été obtenues indirectement par l’entremise de l’opérateur radio du navire FPSO. Les objectifs de la présente étude étaient les suivants : 1) remesurer l’incidence et la sévérité du complexe de symptômes du mal de mer, de la fatigue induite par le mouvement et des problèmes de performance au travail observé chez les membres d’équipage du FPSO Terra Nova; 2) établir les corrélations éventuelles entre les enregistrements directs des mouvements du navire en temps réel avec le mal de mer, la fatigue induite par le mouvement et la performance au travail; 3) à partir des résultats, élaborer des recommandations visant à réduire le mal de mer et améliorer le confort et la performance dans ce type d’environnement. Un questionnaire sur les effets du mouvement – troubles du sommeil, symptômes et sévérité du mal de mer et performance au travail – a été soumis à différents moments durant des périodes de travail en mer de trois semaines. Les données de mouvement du navire utilisées dans cette analyse ont été obtenues au moyen de deux accéléromètres installés sur le même pont dans des salles d’équipement avant et arrière du FPSO. L’équipage du FPSO a bien répondu, 1344 questionnaires ayant été reçus. Les analyses des données ont montré que les cas de mal de mer étaient peu nombreux, mais, comme prévu, les cas de troubles du sommeil, de la prise de décision et de la mémoire étaient beaucoup plus fréquents. La corrélation entre la perturbation du sommeil et les mouvements du navire était relativement élevée. Nous avons noté que l’équipage montrait des problèmes de performance au travail, comme la perte de concentration et des troubles de la prise de décision et de la mémoire, ainsi que de la difficulté à terminer leurs tâches. Entre novembre 2002 et avril 2003, le nombre de corrélations significatives entre les mouvements du navire et les symptômes et problèmes de performance augmentait avec la détérioration de l’état de la mer moyen. Il n’y avait apparemment pas habituation chez les sujets qui ont connu plus de deux périodes de travail en mer. Il appert que le nombre de problèmes de sécurité, de santé et de performance s’accroît avec la détérioration des conditions météorologiques. Nous recommandons que les responsables des installations de forage en mer mettent en œuvre un système de repérage des problèmes permettant d’établir quand l’ampleur des mouvements du navire risque d’affecter l’équipage et la performance au travail.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) Sea Sickness; oil exploration; performance