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MEASURED AND PREDICTED VIBRATIONAL BEHAVIOR OF GULF OF MEXICO PLATFORMS.

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ABSTRACT

This paper discusses the scope and results of two recently completed joint-industry research projects which investigated the feasibility of using ambient surface vibrational measurements to evaluate the structural integrity of steel template platforms in the Gulf of Mexico. Specifically, the projects sought to establish whether the vibrational behavior of the platforms remained stable under varying environmental and operating conditions but changed due to structural modification.

The first project was primarily a data gathering effort. During a 7-month period, over 4,000 hours of vibrational and wave height data were recorded on three typical Gulf of Mexico platforms with varied structural configurations, operating conditions and environmental loadings. On one platform, Ship Shoal 274A (SS274A), major repairs on two legs and the replacement of three braces took place during the monitoring period. Measurements were obtained before, during and after the construction activity on this platform. To a limited extent, data from the three platforms was then evaluated using autospectral techniques.

The second project was an analytical study of the SS274A platform. Selected data was analyzed using both autospectral and cross-spectral analysis methods. A new analysis technique, the response shape vector method, was also utilized. Results of the data analyses were then correlated to the results of a series of structural analyses using a detailed dynamic model of the platform.

The projects concluded that state of the art ambient surface vibrational monitoring techniques failed to detect the removal of jacket bracing members on the SS274A platform.

References and illustrations at end of paper

INTRODUCTION

The concept of using vibrational monitoring to assess the structural integrity of offshore platforms has been the subject of considerable interest over the past five years. This concept is based on the premise that the loss of, or major damage to, one or more structural members causes measurable changes in the vibrational behavior of a platform which are distinguishable from any changes that normally occur due to variations in operating and environmental conditions. If vibrational monitoring can be shown to be a reliable technique, then significant savings may be achieved by reducing the frequency and extent of conventional underwater inspections. This is particularly true in OCS areas with deep water or perennially rough seas. Further, if ambient vibrational monitoring from the surface provides adequate data, then the cost of instrumentation can be greatly reduced. For the technique to be operationally successful, it is necessary to be able to predict vibrational behavior by structural analysis in order to interpret the meaning of changes in the measured vibrational response. This paper summarizes the scope and results of two recently completed joint-industry research projects which were intended to evaluate the feasibility of using ambient surface vibrational monitoring to assess the structural integrity of offshore platforms.

The first project, the Offshore Structural Assessment (OSA) Program, was conducted during 1978. It was primarily a data gathering effort. During a 7-month period, over 4,000 hours of acceleration and wave height data were collected on three typical Gulf of Mexico steel template platforms. On one platform, Ship Shoal 274A (SS274A), the replacement of three bracing members took place during the repair period. One of these members was observed to be severely damaged when it was removed from the platform. Measurements were obtained before the repairs, during the periods when the members were removed, and following the installation of new members. A limited amount of autospectral data analysis was performed on the data from all three platforms.

The second project, the Platform Vibrational Assessment (PVA) Program, was conducted during 1979. This project was concerned solely with the evaluation of the measured and predicted vibrational behavior of the SS274A Platform. The analysis of the data included both autospectral and cross-spectral methods. A new analysis technique, the response shape vector method, was also utilized. The development and detailed description of the method is given in Reference 1. The structural analysis included parameter studies to establish the influence of various structural parameters on the predicted vibrational behavior. The analysis results were calibrated to fit the data using the results of the parameter studies. Structural analyses of the platform with various bracing members removed were then performed. Finally, the results of the data analysis and structural analysis studies were correlated to assess the viability of the monitoring techniques employed.

DATA GATHERING

Platform Descriptions

The three platforms included in the OSA Program were selected to provide a variation in age, water depth, operational mode and foundation characteristics. The objective was to achieve a representative sample of Gulf of Mexico platforms. The platforms selected were Conoco Main Pass 296A (MP296A), Gulf South Pass 62B (SP62B) and Shell Ship Shoal 274A (SS274A). An additional factor influencing the selection of SS274A was that repair work had been scheduled for the platform.

MP296A is an eight leg jacketed structure with grouted piles situated in 212 ft. of water. At the time of the OSA recordings, it was approximately eight years old and was in a fully automatic production mode. SP62B, by contrast, was three years old and in a drilling mode throughout the recording period. It is an eight leg structure with four skirt piles standing in 375 ft. of water. SS274A is an eight leg jacket structure situated in 213 ft. of water. Two of the eight piles are grouted into the legs. Platform equipment includes a large oil storage tank which is located eccentrically on the uppermost deck. The jacket configuration is shown in Figure 1. The platform was approximately fourteen years old at the time of the recordings and was in a production mode throughout the recording period.

Data Gathering Procedures

Accelerometers were normally deployed such that accelerations at seven different locations were recorded simultaneously. A typical accelerometer configuration is shown in Figure 2. Four different configurations were used on each platform. For each configuration, recordings were taken with signal conditioning filters set at 5 Hz, 15 Hz and 30 Hz, successively, for periods of time which allowed sufficient data to be gathered for analysis purposes. Signal conditioning amplifiers were adjusted such that the full dynamic range of the tape recorder was utilized. In addition, recordings were made with accelerometers attached to vibrating equipment in order to identify machine-induced vibration.

Data was recorded on each platform during 3 to 5-day visits. SS274A was visited four times, the others three times. The first three visits were in February, April and July, 1978. The fourth visit to SS274A took place in August, 1978. This visit was required to obtain recordings on the platform following completion of the repair activities which were conducted during Visit 3. The distribution of the visits enabled vibrational recordings to be taken in a variety of sea states and enabled an assessment of the stability of vibrational behavior over a period of six months.

DATA ANALYSIS

Preliminary Analysis of All Three Platforms (OSA) Program

The OSA Program was primarily a data gathering effort. A limited amount of data analysis was conducted as described here.

The analog vibration recordings from all three platforms were digitized and subsequently transformed to the frequency domain using conventional Fast Fourier Transform (FFT) routines. The FFT routines used 2048 points per transform with approximately 60 FFT transforms averaged for each record. The quality of the data was checked by comparing standard deviations of each 2048 point segment of the digitized data with the average standard deviation for the entire record. Segments which departed significantly from the average were dropped from further processing. Autospectral density plots were produced for all records processed.

By comparing the plots of autospectral density with available machinery data and vibrational recordings taken on the supporting structures of the machinery, it was possible to identify significant machinery peaks. The data taken on SP62B was completely dominated by noise in the region 2.5 Hz to 30 Hz. The majority of the noise was due to drilling activity. The data from SS274A appeared to be dominated by machinery from 5 Hz to 30 Hz. The gas compressor and diesel generators were responsible for the peaks of greatest amplitude. The data from MP296A was, by comparison, relatively free of machinery noise in the region from 0 Hz to 15 Hz.

The spectral peaks which were thought to represent the natural modes of vibration of the structures were examined for stability between tests and between visits. MP296A exhibited excellent stability of nineteen spectral peaks which were repeated at constant frequencies for all tests. The response of SS274A was apparently not as stable. The peaks at the lower frequencies (assumed to be the fundamentals) varied in frequency by as much as 10%. Only four higher peaks were repeated consistently from test to test. No noticeable changes were apparently caused by the repair activity. The dominance of drilling noise in SP62B precluded any conclusions concerning the stability of the data base.

The preliminary data analysis undertaken in the OSA Program failed to reach definite conclusions as to the feasibility of monitoring. The more detailed data analysis conducted in the PVA Program was limited to the analysis of SS274A.

Detailed Analysis of SS274A (PVA Program)

For the detailed analysis of the data recorded on SS274A, a further data quality check was performed, a stationarity run test. This was performed on the standard deviation of the 2048-point segments of the digitized data to give a statistical estimate of the probability of stationarity. The results were mixed - several records were indicated to be nonstationary. Subsequent analysis revealed that the indications of nonstationarity were generally caused by the presence of "bad" segments which were later dropped following the results of the previously described data quality test.

The vibrational data were analyzed using auto and cross-spectral techniques and by use of the response shape vector method as discussed below. A total of 33 tests comprising 231 records were analyzed. A plot of autospectral density for one of the records, 3S47A1Y, is presented in Figure 3. 3S47 is the test number (visit 3, test 47); A1Y refers to the location and direction of the accelerometer (leg A1, Y-direction). All accelerometers were at the boat deck level (L) unless stated to be at the cellar deck level (U). The figure clearly shows the peaks in response. The peak at around 0.2 Hz corresponds with the peak in the wave energy forcing function. The peak at 4.9 Hz corresponds to the fundamental vibrations of the gas compressor. The identity of several of the other peaks, in terms of structural mode, was established by further analysis.

Figures 4 and 5 contain plots of the phase angle between records 3S47A1Y and 3S47B4YL, and between 3S47B4YU and 3S47B4YL, respectively. The absolute value of phase is plotted to avoid rapid cross-overs between +180° and -180°. Figure 4 gives an indication of torsional response whenever the phase is 180°, and of sway response when the phase is 0°. By reading Figure 4 in conjunction with Figure 3, the torsional peaks can be identified. The fundamental torsional mode at 0.85 Hz is apparent. Figure 5 gives the phase angle between motion at the lower (boat) deck and motion at the upper (cellar) deck. The motion can be clearly seen to be in phase until approximately 1.2 Hz, and then out of phase until 2.2 Hz. The fundamental modes which are expected to result in an in-phase motion of the decks have frequencies below 1.2 Hz. the second order modes have frequencies between 1.2 Hz and 2.2 Hz.

It should be emphasized that the plots discussed here are a very small sample of the data which was analyzed using cross-spectral techniques. The conclusions which were drawn from this analysis were that there are two fundamental sway modes between 0.65 Hz and 0.71 Hz and a fundamental torsional mode varying from 0.82 Hz to 0.93 Hz. The second order modes lie between 1.5 Hz and 2.2 Hz with the torsional mode at around 2.1 Hz, although phase angle indications of the existence of torsion at that frequency were only found in some of the tests. In order to obtain a clearer indication of mode shape, the Response Shape Vector (RSV) method was utilized.

The RSV method, described in detail in Reference 1, consolidates all the spectral information contained in a test into a vector, $\underline{r}\ (\omega)$, which describes the relative motion of each accelerometer (seven, in this case) at each FFT frequency increment, $\Delta\omega$ (.00977 Hz, in this case). The vector is calculated such that:

$$\underline{r}^T.\underline{r} = [S] \quad \ldots\ldots\ldots\ldots (1)$$

where: $\underline{r}$ is the row vector $r_i(\omega)$, i=1,N
$\underline{N}$ is the number of sensors
$[S]$ is the symmetrical 7x7 matrix whose diagonal is G_{ii}, i=1,N and whose off-diagonal terms are C_{ij}, i,j=1,7
$G_{ii}(\omega)$ is the autospectral density of record i at frequency ω
$C_{ij}(\omega)$ is the co-spectral density of records i and j at frequency ω
T denotes transpose

Note that the imaginary parts of the cross-spectral density are neglected. This corresponds with the assumption that for pure structural vibration the motions will be either in phase or out of phase. There are 28 equations and seven unknowns. A best-fit, least squares iterative routine is used to estimate $r_i(\omega)$. Using the convergence option generally applied, equations involving the diagonal terms are weighted with a factor of 1 for the least squares error minimization and equations involving the off-diagonal terms are weighted with the coherence of the corresponding pair of sensors. The converged vectors are listed for each frequency increment.

In order to identify which of the response vectors correspond to structural modes, several functions of the vectors can be calculated and plotted. The response norm is defined as follows:

$$R(\omega) = \sum_{i=1}^{N} r_i^2(\omega) \quad \ldots\ldots\ldots\ldots (2)$$

The norm has the same units as spectral density and represents the consolidation of all 28 autospectral and co-spectral values. Peaks in the plot of norm against frequency correspond to peaks in the response of the platform. Other terms give a quantitative appraisal of how well the converged vector fits the vibrational behavior of the sensors. Their formulation is covered in detail in Reference 1.

Plots of the response norm for tests 3S87 and 4S11 are presented in Figures 6 and 7. The letter following the test number on the Figure refers to the accelerometer configuration. Thus 3S87 and 4S11 are both configuration D (all accelerometers at the boat deck level). The most significant output of the RSV method is the listing of the vectors at each frequency. The response shape of the platform decks can thus be plotted throughout the frequency range. The adequacy with which the vector describes the response shape of the platform is limited only by the number of terms in the vector, that is, the number of accelerometers recorded simultaneously.

By studying the response shapes at peaks, the changes of shape across frequency bands, and the stability of shape from one test to another, it was possible to obtain a more confident description of mode shape. Notably, it was possible to identify two distinct sway modes in the region 0.6 to 0.75 Hz. Also, two distinct sway modes which had a coincident peak at 1.8 Hz were postulated after detailed interpretation of RSV results. Their existence was not confirmed absolutely, but is strongly suggested by the available data. Further, the second order torsional mode at 2.1 Hz was confirmed. The phase angle plots in some tests failed to indicate this mode because it was superimposed on the sway modes which covered broad frequency bands.

The Visit 4 tests were evaluated to give the following structural frequencies and mode shapes:

0.65 to 0.66 Hz	Diagonal sway
0.69 to 0.70 Hz	Diagonal sway
0.85 to 0.92 Hz	Torsion
1.79 to 1.81 Hz	x-sway (2nd order)
1.80 to 1.83 Hz	y-sway (2nd order)
2.02 to 2.09 Hz	Torsion and sway (2nd order)
2.68 to 2.70 Hz	Torsion and sway
2.79 to 2.80 Hz	x-sway
3.08 to 3.10 Hz	Boat deck bowing mode
4.57 to 4.60 Hz	Vertical mode

STRUCTURAL ANALYSIS

Procedures

The program used to perform the dynamic structural analysis calculates frequencies and mode shapes based upon linear, lumped mass, eigenvalue analysis techniques. Six-by-six boundary element stiffness matrices were used to represent the stiffness of the piles at the mudline. They were calculated using a static analysis program for offshore structures. Pile-soil interaction was accounted for in terms of piecewise-linear lateral, axial and torsional behavior. The boundary element stiffness matrices were developed using applied loads which were estimated to represent the ambient conditions experienced over the recording period. Each pile was analyzed using a model containing 68 nodes. Pile-soil interaction curves were initially based on API-RP2A criteria.

The structure was modeled using nodes only at structural joints, mid-member nodes were not included. Subsequent analysis indicated that global platform vibrational mode shapes and frequencies below 3 Hz would not be significantly affected by the omission of mid-member nodes. Conductors were not assumed to contribute to the structural stiffness, except as a parameter as discussed below. The pile-jacket centralizers were modeled such that rotations and axial translations were permitted, but non-axial translations of jacket and pile were linked. Two of the legs were grouted and were modeled as composite members.

Hydrodynamic added mass, assumed to be equal to the displaced mass of seawater acting normal to the member only and lumped at the member ends, was included for all submerged members except the piles. The legs were considered flooded and the bracing members dry (except as a parameter). The conductor mass together with its associated hydrodynamic added mass and flooded water mass were assumed to act horizontally only at each guide level. The mass of deck equipment was estimated and distributed to the leg nodes. The mass of the oil storage tank compartments was modeled such that the significant sloshing frequencies of each compartment in each horizontal direction were included. Vandiver's formulation (Reference 2) was used. The effect of the tank model was to introduce five new natural modes of vibration into the structural model. All the new modes had frequencies lower than the fundamental structural frequencies. Variations in the oil level were modeled by varying the masses and frequencies of the system. The total weight of the full oil tank was 2100^K, a substantial portion of the deck weight.

Parameter Studies

The purpose of the parameter studies was twofold: to investigate the effects of operational changes, such as tank mass, on the vibrational characteristics of the platform; and to investigate the effects of parameters whose values are uncertain, such as foundation stiffness, so that the values could be adjusted to calibrate the model to the data. The results of the parameter studies are listed in Table 1. A discussion of their significance follows. It should be noted that the frequency changes due to a parameter variation were based on the effects of the parameter change on a particular base structure. Because the parameter studies were part of a calibration effort, the base structure for each parameter variation was not necessarily the same.

The mode shape numbers given in Table 1 correspond to the following modes.

1	Fundamental diagonal sway
2	Fundamental diagonal sway
3	Fundamental torsion
4	Second order y-sway
5	Second order x-sway
6	Second order torsion
7	Third order y-sway
8	Third order x-sway
9	Third order torsion
10	x-sway
11	Diagonal sway
12	Bowing deformations of boat deck
13	Bowing deformations of boat deck

Modes corresponding to oil tank sloshing or localized member bending are omitted from the table.

The variation in soil-pile stiffness is seen to have a noticeable effect on the frequencies. The justification for the possible increase in stiffness is based primarily on arguments developed by Stevens and Audibert (Reference 3). The base framing level of the platform is shown on the design drawings to lie 4 ft. below the mudline. No mudmats are shown on the drawings. It is probable, nevertheless, that the mud provides support to the jacket at this elevation. The spring stiffnesses used as a parameter to model this extra boundary condition were calculated using the approach outlined in Reference 3.

It was not known how many, if any, jacket bracing members were flooded. The variation used in Table 1 represents bounding values. The margin for error in estimating frequencies, especially of higher modes, is therefore apparent.

The true influence of the conductors in terms of mass and stiffness is also unknown. The effect of neglecting the horizontal component of mass is shown. It is also possible that the conductors contribute significant horizontal stiffness between the deck structure and the jacket and that they add to the horizontal support of the structure at the mudline. These stiffness contributions are probably nonlinear due to the gaps between the conductors and their guides. The inclusion of conductor stiffness, therefore, marks an upper bound, the omission a lower bound. The effect, particularly on the second order modes, is considerable.

The behavior of the pile-jacket centralizers under the low-level cyclic forces they experience during ambient vibrations is also unknown. It is possible that the centralizers "freeze" and transmit small axial forces. The effect of the assumption is shown.

Member Removal Analysis

The results of individually removing the members shown in Figure 1 are given in Table 2. The case number refers to the number of the member which was removed. Case 10 refers to members 7 and 8 removed simultaneously. Cases 7 through 10 correspond to actual repair phases during which vibrational recordings were taken. Cases 1 through 6 represent further theoretical studies to evaluate the effects of removing horizontals and members remote from the waterline.

Examination of Table 2 gives an indication of the type of vibrational changes which monitoring must be able to detect and to distinguish from nonfailure changes in order to be viable. The comparison with observed behavioral changes is given in the next section. It should be noted that all structural modes are included in Table 2, including the modes at 2.20 Hz and 2.30 Hz which correspond to localized bending and are unlikely to be detected by surface monitoring. These modes were omitted from Table 1.

It is significant that the structural analysis predictions of the effects of member removal show that the frequency shifts of the fundamental and second order modes are not larger than the shifts caused by nonfailure changes, such as oil storage tank mass fluctuations. There are, however, potentially measurable second order mode shape changes. (It was not possible to detect the mode shape changes in the OSA data due to the limited distribution of sensors.) The really significant frequency changes are in the higher modes. New modes of vibration corresponding to localized motion, appear at 2.07 Hz for Case 1 and 2.64 Hz for Case 7. It is unlikely that either of the new modes would be detected by surface monitoring. The changes for Cases 3, 5, 7 and 10 are more likely to be detected at the surface. Tracking of modes of vibration by mode shape demonstrates that for Case 3, mode 9 (2.80 Hz) shifts to 2.31 Hz; for Case 5, mode 13 (3.08 Hz) shifts to 2.43 Hz; for Case 7, mode 13 shifts to 2.76 Hz; and for Case 10, mode 13 shifts to 2.72 Hz. If these frequency shifts were identified in the data, they would appear as peaks disappearing from one location and reappearing in another. Therefore, it is necessary to be able to identify mode shapes accurately in the data such that the modes of vibration indicated in the data can be correlated with modes predicted by structural analysis. Such accurate correlation is necessary before any conclusions can be drawn concerning the appearance, disappearance or shifting of any peak in the data.

CORRELATION OF STRUCTURAL ANALYSIS AND DATA

The structural model was calibrated to the recorded data such that the three fundamental modes corresponded in terms of frequency and mode shape. Calibration to the second order modes was not attempted because of the nonlinear nature of conductor behavior. The results of calibration are presented in Table 3. In order to achieve the calibration, it was necessary to increase the pilehead stiffness from the API-based values by a factor of 2.5. Horizontal and vertical mudline jacket springs were also necessary. For the final calibrated model, bracing members were not considered flooded; horizontal conductor mass was included at the guides but conductor stiffness effects were neglected; the centralizers were assumed free to slide axially.

The correlation of the structural analysis results to the data for the fundamental modes is excellent in terms of mode shape and frequency. The calibration of the second order modes is poor in terms of frequency, but excellent in terms of mode shape (at least at the deck level where measurements were made). It should be noted that the second order modes were only identified in the data after detailed analysis and this identification is still possibly open to question. Modes higher than second order are more complex. Positive identification is generally not possible due to the limited number of accelerometers. The correlations given in Table 3 are based on response shapes at the boat deck.

The parameter studies indicated that the frequencies of the fundamental modes would be changed by variations in mass of the oil storage tank. It was possible to correlate observed fundamental frequencies with observed variations in tank mass. Larger changes were observed than could be predicted by analysis. There was no apparent correlation between observed fundamental frequencies and the magnitude of platform response (corresponding to forcing function energy, e.g. wave height), but testing of this relationship was confused by uncertain oil tank mass variations.

The structural analysis predictions of the effects of member removal indicated that the frequency shifts of the fundamental and second order modes were not greater than the shifts observed due to nonfailure changes prior to the member repairs. Second order mode shape changes were predicted by structural analysis, however, but such changes could not have been detected in the recorded data even if they had occurred.

The structural analysis indicated that, of the bracing members actually repaired, the removal of member 7 would cause the most noticeable effect. Case 10 is merely a combination of Cases 7 and 8.

The analysis predictions for Case 7 indicated that mode 13 (3.08 Hz) would disappear and a new mode, whose mode shape is similar to mode 13, would reappear at around 2.7 Hz. The 3.08 Hz mode would correspond to the undamaged platform. As shown in Table 3, mode 13 is thought to correspond to the Visit 4 peak at 3.10 Hz. The mode shapes are similar, but the peak could also correspond to mode 12, which has a similar mode shape. The data peak is clearly visible in Figure 7, the response norm of 4S11. It is missing in Figure 6, the response norm of 3S87. Test 3S87 was recorded after members 7 and 8 had been removed. The peak is missing in all but one of the twenty-four tests prior to the replacement of member 7, including those tests recorded with the damaged member 7 in place. It is present in six out of nine tests following the replacement. The damage to member 7 would therefore seem to have caused an effect similar to the member's removal. The structural analysis predicted that a peak should appear at around 2.7 Hz for the damaged case. This did not occur. A study of the response vectors in this area did not indicate any changes during the repair period. A similar study of response vectors in the region of 3.1 Hz indicated that the mode shape was not affected by the member removals. These two facts, along with the inconsistencies in the appearance and disappearance of the peaks, refute the suggestion that the analysis predictions were reflected in the data. Although the changes observed in the data over the repair period bear a resemblance to the analysis predictions, the inconsistencies in the data make it impossible to claim that the removal or subsequent repair of the damaged members was detected.

CONCLUSIONS

The results reported in this paper are based largely on the analysis of the data obtained from SS274A and the structural analysis of that platform. The results of the structural analysis are believed to be generally relevant to the analysis of other similar platforms; the vibrational data which was analyzed in detail is unique to SS274A. Although the conclusions are relevant to platforms with similar structural configurations, mechanical equipment and operating procedures, direct extrapolation of the conclusions to other Gulf of Mexico platforms is not, in general, valid.

1. The limited autospectral analysis of vibrational data recorded on the Gulf of Mexico platforms indicated that the amount of structural information available in the data and the repeatability of that information from test to test and from visit to visit varied considerably. On one platform, drilling noise drawned out almost all of the structural response. On another, nineteen peaks thought to correspond to natural modes of vibration were observed to be stable throughout the visits. On the third, structural information in the recorded data indicated that only the fundamental modes could be clearly identified, and these modes varied in frequency by as much as 10% between tests.

2. Use of the response shape vector method enabled the recognition of modes which would not have been recognized using conventional cross-spectral techniques given the same amount of data analysis effort. Calculation of response shapes permitted the correlation of the structural analysis results and the field data in terms of mode shape. It was shown that the positive identification of mode shapes in the data is essential to detection of member removal.

3. In the analytical study of SS274A, it was necessary to increase foundation stiffness values generally used in design practice by a factor of 2.5 in order to achieve calibration of the fundamental modes. It was also necessary to take account of the support given to the jacket at the base framing level below the mudline. These changes to accepted foundation modeling practice were necessary to model the low amplitude, ambient behavior of the platform accurately. The validity of accepted modeling techniques for worst case design purposes was not questioned.

4. The true behavior of conductor tubes restrained in guides is unknown. They may contribute to both the mass and stiffness of the platform. Different assumptions of conductor behavior resulted in very different frequencies of the second and higher order modes.

5. Different assumptions of the extent of flooding in bracing members caused significant changes to frequencies of modes higher than the second order.

6. The frequency variation of the fundamental modes of SS274A could be partially attributed to changes in the mass of the oil storage tank. The observed variation was greater than that predicted by structural analysis.

7. Structural analysis of SS274A showed that the removal of bracing members caused frequency shifts in the first six modes which would not be distinguishable from shifts caused by normal operational changes.

8. The structural analysis of SS274A indicated that the structural function of a bracing member, and not its location relative to the surface, determines the effect of its removal on the dynamic response of the platform as measured at the surface.

9. The structural analysis of SS274A showed that certain member removals would result in a "jump" of a higher mode from one position to another relative to the frequencies of neighboring modes of vibration. If monitoring is going to be based on the detection of these jumps, then there is a possibility for confusion caused by the existence of peaks which cannot be correlated with modes predicted by structural analysis. The need for positive identification of higher order modes in the recorded data is therefore emphasized.

10. The overall conclusion is that, based upon state of the art random data analysis techniques, ambient surface vibrational monitoring failed to detect the removal of the bracing members which were repaired on SS274A. Apparent indications of member damage in the data were called into question by inconsistencies in the data, and lack of positive identification of mode shapes.

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TABLE I
STRUCTURAL ANALYSIS - PARAMETER STUDIES
FREQUENCY CHANGE IN Hz FOR "GLOBAL" MODES

PARAMETER	MODE NO. AND FREQUENCY (Hz) IN FINAL CALIBRATED MODEL												
	1	2	3	4	5	6	7	8	9	10	11	12	13
	.66	.69	.91	1.46	1.65	1.67	2.52	2.68	2.80	2.89	2.96	3.01	3.08
Soil-Pile Stiffness 1.0 API to 3.5 API	+.13	+.11	+.18	+.19	+.14	+.17	+.08	+.19	+.04	+.03	+.04	+.06	+.02
Vertical Mudline Springs Absent to Present	+.01	+.02	--	--	--	--	+.04	+.02	+.01	--	+.01	+.01	+.01
Horizontal Mudline Springs Absent to Present	+.08	+.10	+.11	+.16	+.14	+.16	+.21	+.06	+.08	+.04	+.06	+.03	+.05
Oil Storage Tank Empty to Full	-.01	-.02	-.06	-.08	-.06	-.09	-.02	-.25	-.05	-.06	-.10	-.10	-.03
Bracing Members Empty to Flooded	-.02	-.02	-.03	-.06	-.09	-.08	-.35	-.54	-.54	-.48	-.39	-.30	-.25
Conductor Mass Absent to Present	-.05	-.05	--	-.10	-.09	-.05	-.15	-.03	--	-.02	-.15	-.16	-.15
Conductor Stiffness and Pile Effect Absent to Present	+.05	+.06	+.10	+.45	+.55	+.41	+.12	+.12	+.03	+.12	+.05	+.15	+.28
Centralizers Free to Frozen	+.08	+.10	+.02	+.01	--	+.01	+.17	+.05	+.08	+.04	+.03	+.02	+.05

TABLE 2
LIST OF REMOVED MEMBER ANALYSIS FREQUENCIES SORTED BY MODE

MODE NO.	CASE 0	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8	CASE 9	CASE 10 (7+8)
1	.66	.66	.65	.66	.64	.66	.66	.65	.66	.65	.65
2	.69	.69	.69	.68	.69	.69	.69	.69	.69	.69	.68
3	.91	.91	.91	.90	.86	.91	.91	.91	.91	.91	.90
4	1.46	1.46	1.45	1.46	1.39*	1.46	1.46	1.46	1.46	1.43	1.46
5	1.65	1.61*	1.65	1.62*	1.62*	1.63	1.65	1.62*	1.60*	1.65	1.57*
6	1.67	1.66	1.66	1.66	1.65*	1.66	1.67	1.66	1.66	1.66	1.66
		2.07									
	2.20	2.20	2.20	2.20	2.20	2.19	2.20	2.20	2.20	2.20	2.20
	2.30	2.30	2.30	2.29	2.30	2.28	2.30	2.29	2.29	2.30	2.29
				2.31							
						2.43					
7	2.52	2.52	2.51	2.60	2.48	2.52	2.52	2.51	2.52	2.52	2.52
			2.64								
8	2.68	2.69	2.71*	2.68	2.67	2.69	2.68	2.68	2.68	2.68	2.67*
								2.76			2.72
9	2.80	2.81	2.82		2.79*	2.80	2.80	2.80	2.80	2.80	2.80
10	2.89	2.93	2.94	2.81	2.81	2.91**	2.89	2.92*	2.88	2.88	2.92*
11	2.96	2.98	2.97	2.91	2.92	2.96	2.96	2.97*	2.94*	2.95	2.97*
12	3.01	3.02	3.02	2.98	2.98	3.02**	3.01	3.03*	2.98	3.00	3.03*
13	3.08	3.08	3.09	3.06	3.05		3.08		3.03	3.06	
	3.36	3.38	3.46	3.35	3.35*	3.36	3.36	3.36	3.36	3.36	3.35
	3.48	3.49	3.48	3.47	3.47	3.47	3.47	3.44	3.46	3.44	3.43
	3.57	3.61	3.62	3.56	3.57	3.51	3.57	3.53	3.54*	3.56	3.51*
	3.74	3.74	3.75	3.73	3.69	3.73	3.74	3.74	3.74	3.73	3.73
	3.77	3.77	3.77	3.77	3.76	3.77	3.77	3.77	3.77	3.77	3.77
	3.97	3.97	3.97	3.97	3.97	3.97	3.97	3.97	3.97	3.97	3.97
	4.06	4.06	4.06	4.06	4.06	4.06	4.06	4.06	4.06	4.06	4.06

*Noticeable change in mode shape at Boat Deck and Cellar Deck.
**Mode unrecognizable at the Boat Deck and Cellar Deck.

TABLE 3
CORRELATION OF STRUCTURAL ANALYSIS AND FIELD DATA

Mode No.	Analysis Frequencies (Hz)	Visit 4 Peaks (Hz)
1	.66	0.65 to 0.66
2	.69	0.69 to 0.70
3	.91	0.85 to 0.92
4	1.46	1.79 to 1.81
5	1.65	1.80 to 1.83
6	1.67	2.02 to 2.09
7	2.52	
8	2.68	
9	2.80	2.68 to 2.70
10	2.89	2.79 to 2.80
11	2.96	
12	3.01	
13	3.08	3.08 to 3.10

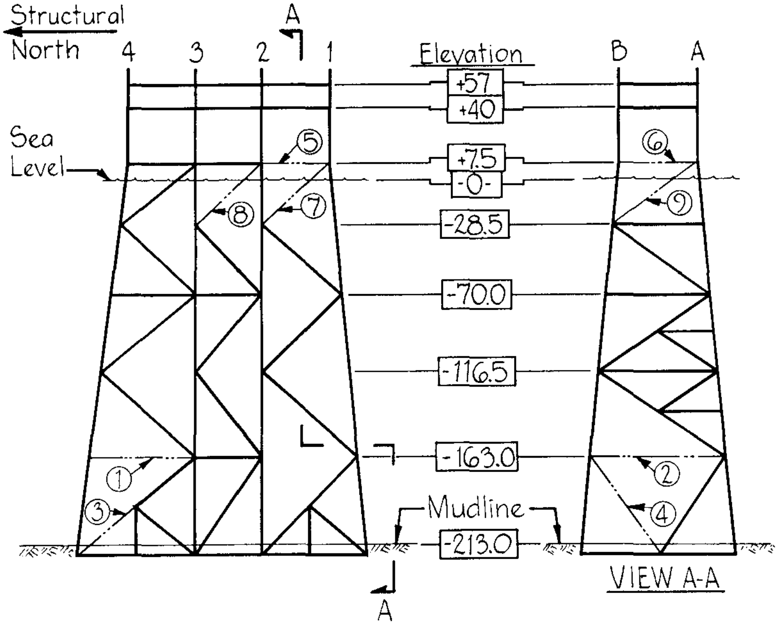


Fig. 1 - Platform SS274A - Identification of removed members.

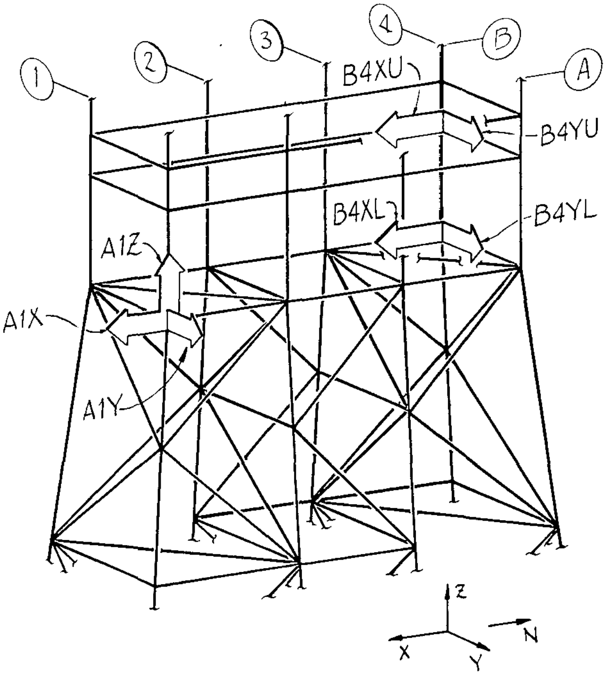


Fig. 2 - Platform SS274A - Accelerometer configuration A.

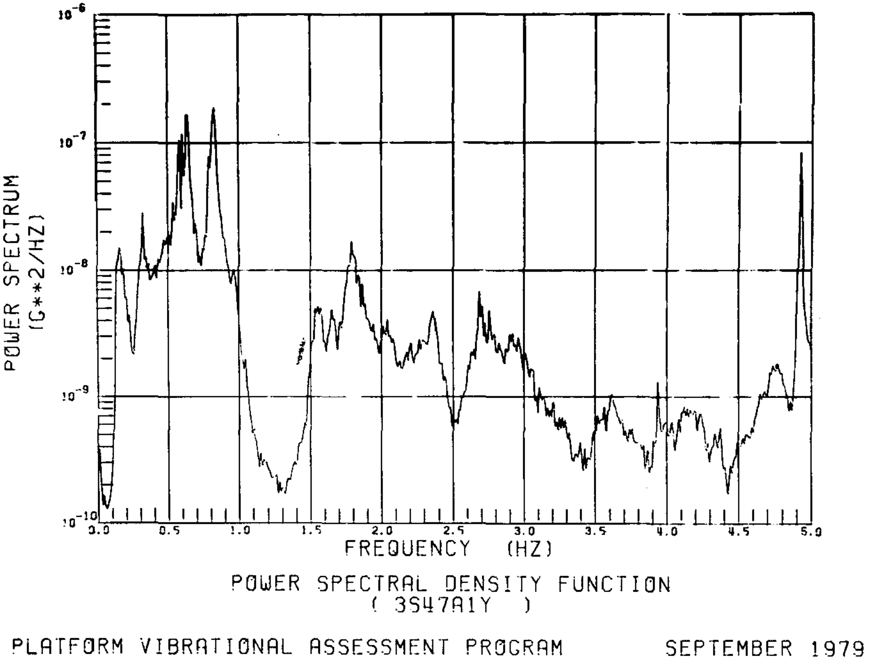
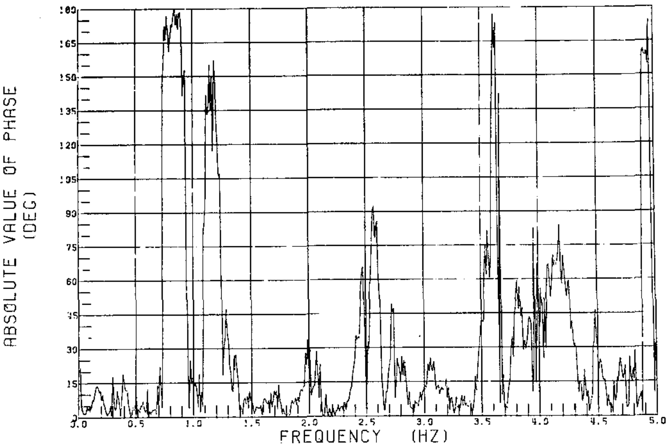


Fig. 3 - Platform SS274A - Autospectral density plot.



PHASE OF THE CROSS SPECTRAL DENSITY FUNCTION
(3S47A1Y AND 3S47B4YL)
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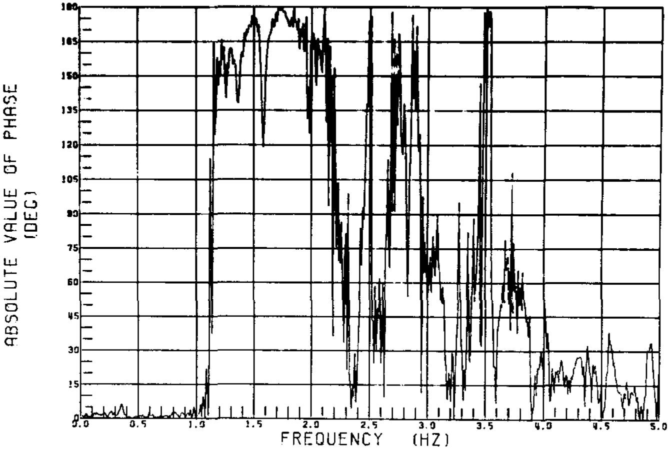
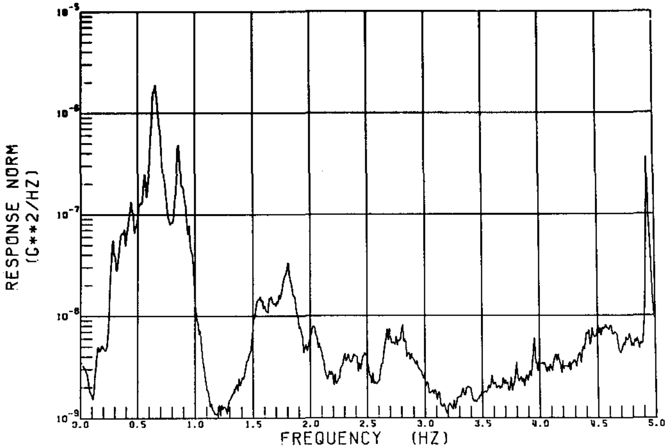
Fig. 4 - Platform SS274A - Phase angle plot.



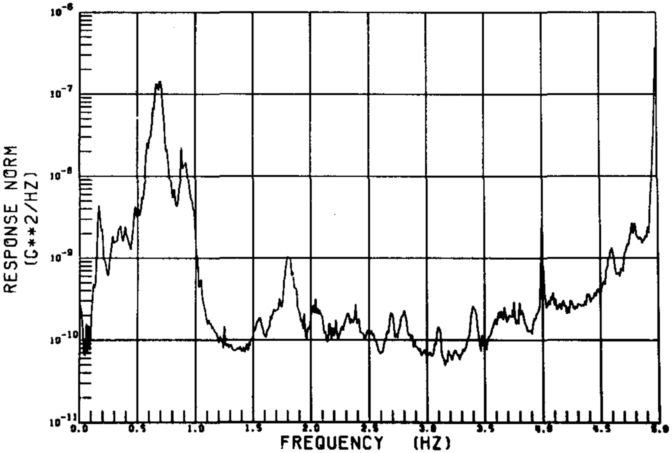
PHASE OF THE CROSS SPECTRAL DENSITY FUNCTION
(3S47B4YU AND 3S47B4YL)
PLATFORM VIBRATIONAL ASSESSMENT PROGRAM SEPTEMBER 1979

Fig. 5 - Platform SS274A - Phase angle plot.



RESPONSE NORM FUNCTION
(3S87D)
PLATFORM VIBRATIONAL ASSESSMENT PROGRAM SEPTEMBER 1979

Fig. 6 - Platform SS274A - Response norm plot.



RESPONSE NORM FUNCTION
(4S11D)
PLATFORM VIBRATIONAL ASSESSMENT PROGRAM SEPTEMBER 1979

Fig. 7 - Platform SS274A - Response norm plot.