Measurement of Wellhead Fatigue

H. Howells, R. Baker, A. Rimmer

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Abstract

Fatigue loading on subsea wellheads has been increasing in recent years through the use of larger and heavier BOP stacks and the longer drilling durations needed for deeper wells and to extend production lives. This challenge has prompted the widespread implementation of monitoring systems to confirm predictions of wellhead fatigue and ensure well operations are conducted safely. Monitoring system design requirements, data processing and evaluation of field measurements from a number of wells are described.

Monitoring systems for measurement of wellhead fatigue require careful planning. Considerations include what to measure, instrument accuracy, power, data transmission, methods of attachment, data processing and data storage. The evaluation will determine the suitability of off-the-shelf equipment or the need for application specific devices. An example assessment of the requirements of measurement devices from which wellhead fatigue can be derived is given that demonstrates the importance of integrated consideration of instruments, resolution and data processing methods in the selection and design of the system. The assessment presented here has widespread application across subsea wellhead systems worldwide.

A variety of different approaches to monitoring wellhead system fatigue have been attempted. These include motion measurement, using devices located in varying positions along the wellhead and BOP, to strain measurement of the conductor pipe. Examples of real systems used in different geographical locations and the wellhead system fatigue damage derived from the data are presented. The improved understanding of wellhead behaviour and modelling improvements that can be made from the use of the data obtained are demonstrated. Finally, comparisons of response measurements from different devices demonstrate the importance of instrument positioning. This finding provides a driver for the design of future instrumentation systems and an important pointer for verification of wellhead fatigue damage derived from previous monitoring programs.

The work presented here provides a systematic basis for design and implementation of wellhead fatigue monitoring systems. Furthermore, the field measurements obtained demonstrate some potential pitfalls to be avoided and how to get maximum value from the data obtained.

Introduction

Extending the design life of subsea wells to maximize production is becoming increasingly common. Many subsea wells approaching or past their design lives of 20 or so years are being reworked to enable production for many years to come. This additional work results in further accumulation of fatigue damage to that already incurred during previous drilling and workover operations. A further design challenge is the use of newer vessels than those used in the earlier operations. These vessels have taller and heavier BOP and LMRP stacks which have the effect of increasing the rate of fatigue damage accumulation. Even on new wells, where steps can be taken to accommodate the potentially severe cyclic fatigue loading imposed from newer vessels and their riser systems through fatigue optimization of the wellhead system design arrangement, meeting fatigue life targets can be challenging.

The decision to measure response is often driven by the criticality of calculated results, possibly not meeting target safety factors. Analytical models used to calculate wellhead fatigue typically err on the side of conservatism in terms of weather
inputs, vessel orientation, directionality of loading and soil properties [1]. The use of monitoring offers the opportunity to determine the fatigue life of the wellhead system with most of the analytical conservatisms removed, hence it is expected that measured response will generally be better than predicted response.

The challenges of monitoring dynamic response in deep water include the hydrostatic pressure, power, volume of data collected and methods to satisfactorily process the data. Instrumentation systems have progressed a long way since the early systems deployed on the P18 steel catenary riser [2] and the field tow test conducted for the STRIDE joint industry project [3]. There is now a wide range of equipment available on the market for rental or purchase that may be used to assist in measurement of wellhead fatigue response. Ideally, systems for measurement of wellhead system response would be integrated into the BOP where power and data transmission could be provided by the BOP control system. However, unless designed to be integrated from new, there is an understandable reluctance on the part of drilling contractors to modify their complex mission critical systems to include wellhead fatigue monitoring equipment. The implication is that there is a wide variety of potential options for monitoring wellhead system response, and equipment specification and data processing methods must be carefully evaluated and selected.

**Instrumentation System Specification**

Instrumentation for measurement of wellhead fatigue must be specified and selected with the same level of attention as any other piece of equipment used offshore. The design requirements of this type of equipment are often inadequately defined which can lead to gathering of data that is incomplete and from which response is difficult to interpret. Measurement systems for derivation of wellhead equipment fatigue, as for any other field measurement system, require complete evaluation of the expected response through to the methods by which the data will be processed. The steps involved are as follows:

- Define objectives
- Define target fatigue life
- Set threshold measurement target
- Select measurement system – e.g. strain, displacement, angle
- Define response corresponding to threshold fatigue life
- Assess implications of instrument noise on threshold measurements
- Define data processing requirements

Explanations of the issues to be addressed in each step are given below.

**Define Objectives** – Instrumentation used for assessment of wellhead fatigue can be used in a wide variety of ways from simply identifying whether wellhead motions are unacceptably severe, to calculation of fatigue damage accumulation throughout the life of the well and calibration of analysis tools. Definition of which of these objectives is required greatly assists in ensuring that the instrumentation is appropriately specified.

**Target Fatigue Life** – A target fatigue life should be defined that represents the expected duration of all drilling operations on the well with a suitable safety factor applied. Typical values may be 6 months drilling with a safety factor of 10 giving a 5 year target fatigue life.

**Fatigue Life Measurement Threshold** – Instruments used in the measurement of structural response have a limited range of sensitivity and hence have limited ability to measure very small dynamic responses. It is therefore necessary to set a target low level of response below which fatigue damage accumulation may not be reliably captured and which would make little difference to the total calculated fatigue damage. This threshold may be taken as the target fatigue life or 50% of the target fatigue life.

**Measurement System Selection** – The instrumentation system selected will depend on many factors including equipment availability and method of deployment. Ideally, measurements will be recorded locally to the region of concern, namely, the conductor pipe adjacent to the wellhead housings. However, there is a danger that any equipment placed in this region may be damaged during installation. As a result, many wellhead fatigue monitoring systems use motion measurements devices placed on the BOP, LMRP or guidebase. Some success has been had with direct monitoring of conductor strains which is discussed below.

**Threshold Response** – In order to assess the suitability of the selected measurement devices, the threshold response corresponding to the fatigue life threshold needs to be determined. This can be achieved through conducting analysis of the riser and wellhead system and determining the response levels at the measurement device locations which, when applied continuously, generate the threshold fatigue life at the most fatigue critical location on the wellhead system. An example
assessment of the threshold measurement requirements for determining wellhead fatigue from monitoring of accelerations or angular rates on a BOP and LMRP are given in Figure 1 to Figure 3. These figures show two important effects:

- More precision is required for worse fatigue details
- More precision is required for measurements made nearer the mudline

![Figure 1](image1.png)
**Figure 1 – LMRP Accelerometer Sensor Threshold assessment**

![Figure 2](image2.png)
**Figure 2 – BOP Accelerometer Sensor Threshold Assessment**

![Figure 3](image3.png)
**Figure 3 – BOP Angular Rate Sensor Threshold Assessment**

**Sensitivity and Instrumentation Noise** – All instrumentation exhibits noise that is seen as a near constant measurement. It is necessary to make an assessment of the threshold measurements, corresponding to the threshold fatigue lives, in relation to the
instrumentation noise, in order to ensure that the threshold measurements are clearly detectable. Ideally, the noise will be small (say less than 10%) of the threshold measurement, such that any measurements at around threshold response are little affected. For the example considered here, a comparison of the threshold measurements and noise levels is given in Table 1. This comparison shows that threshold angular rate measurements are less affected by noise than acceleration measurements, due to their higher signal to noise ratio. However, it should not be inferred from this that the acceleration measurements will be unacceptably distorted. Through the process of filtering the measured signal, a considerable portion of the noise can be removed, improving the residual signal to noise ratio, as illustrated in Figure 4 and explained below.

<table>
<thead>
<tr>
<th>Logger</th>
<th>Parameter</th>
<th>Threshold Values</th>
<th>Signal to Noise Ratio @ Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Logger</td>
<td>G- Cont Acceleration RMS (m/s²)</td>
<td>0.017</td>
<td>0.0098</td>
</tr>
<tr>
<td></td>
<td>Angular Rate RMS (deg/s)</td>
<td>0.036</td>
<td>0.0100</td>
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<tr>
<td>Bottom Logger</td>
<td>G- Cont Acceleration RMS (m/s²)</td>
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<td>0.0098</td>
</tr>
<tr>
<td></td>
<td>Angular Rate RMS (deg/s)</td>
<td>0.036</td>
<td>0.0100</td>
</tr>
</tbody>
</table>

Table 1 – Assessment of Signal to Noise Ratios at Signal Thresholds

Processing and Filtering Requirements – It is good practice to define objectives for the use of the data and how it is to be processed as part of monitoring system design. For dealing with measurements of acceleration and angular rates, integration is required. The methods used, whether frequency domain or time domain should be established together with the filtering that may be used at each integration step. Further, the resolution of orthogonal measurements to different orientations needs to be defined and steps for correction of g-contamination in accelerations made. Further filtering of data may also be needed on the resolved displacement or angle measurements in order to limit frequency content and remove noise. An example of this is shown in Figure 4. Band pass filters are applied such that only frequencies of interest are processed. However, this raises an issue as to what fatigue may be generated by other effects such as drift (low frequency) or drilling induced vibrations (high frequency). Filters need to be clearly defined, and adjustable, so that any extraneous effects can be evaluated through variation of the filter settings. A noise filter may also be applied to ensure that very low measurements of response are not substantially overestimated, as shown in Figure 4.
Instrumentation Implementation Considerations

Deployment of the instrumentation system forms an integral part of the instrument system design. Key issues to consider are discussed below.

**Power** – Stand-alone and acoustic devices must have adequate battery power for the target deployment life. Contingency plans may include redeployable battery packs or in-service retrieval and redeployment for use on long duration wells. Alternatively, multiple devices with delayed start times may be used so that the target duration is captured by serial recording on different devices, or intermittent logging used to gather snapshots of data at regular intervals, between which the device is dormant. On-line systems that require cables run to surface need to provide for cable clamping and ensure adequate cable protection through the wave zone.

**Memory** – Stand-alone and some acoustic measurement devices must have sufficient memory capacity to store the recorded data. This may require a balance to be struck between frequency of recording, and the number of instruments deployed in each device.

**Attachment** – For measurement systems attached prior to riser deployment, care must be taken to ensure damage does not occur during deployment. In the case of instruments attachment during riser deployment the devices and methods of attachment must be streamlined to avoid delays to running operations. A number of ROV deployable measurement systems have been implemented, for which a key challenge can be accurate positioning and orientation of the devices. Application of paint markings to indicate the exact location of the equipment following installation can be helpful in this respect. Receptacles that receive the equipment can aid with repeatability of positioning and orientation when in-service retrieval and deployment is planned. ROV access should be carefully considered in any regions around the BOP. Attempts to attach devices near the seabed may be difficult due to seabed disturbance from the ROV.

**Vessel Data** – Verification of the gathered data and evaluation of measurements can be simplified through the acquisition of measurements from the vessel. These may consist of vessel heading, current and wave data, logs of drilling operations being conducted, top tension, mud weight and drill string hook weights. Provision for recording this data should be agreed with the drilling contractor prior to monitoring system deployment.

**Time** – Correlation between measurements from different devices and measurements on the vessel can be helpful in interpreting measured response. Understanding of the data timestamp conventions (whether a sample starts or ends at the timestamp) and the potential drift in stand-alone and acoustic devices is needed for this purpose. Also, an agreed reference time is needed to ensure satisfactory correlation can be achieved between data obtained from recording systems managed by different organizations.

Data Review, Verification and Manipulation

Before embarking on detailed data processing, some basic checks should be conducted to assess the validity of gathered data. Data may be gathered periodically in “events” of typically 10 to 30 minute durations or continuously. For data recorded continuously, an event duration should be selected in order that the data can be processed in meaningful chunks. For each event, summary statistics should be produced that give event summary time histories. Checks should be conducted on both event summary time histories, representing the data from the entire monitoring program, and on individual timetraces (data gathered within single events). Data should also be processed and plotted in the form of spectra and the frequency content inspected. Some examples of the checks that can be conducted to assess the validity of recorded data are described below.

**Basic Checks**

Some basic checks that should be conducted are listed below.

- **Data calibration** – acceleration with a magnitude of g is a useful indication of accelerometer calibration. Generally the channel that is orientated vertically should have a mean acceleration of ±9.81m/s².
- **File format** – consistency of the data file formats and completeness throughout the file should be confirmed.
- **Data units** – accelerations may be recorded in units of g, m/s², mm/s² and rotations in radians or degrees, which can be confirmed by sense checking the magnitude of the responses obtained.
- **Battery power** – battery power timetraces can be reviewed to confirm that the battery power during data capture is within the calibration power limits.

**Mean Values** – Mean values should remain more or less constant subject to gradual drift in signal due to instrument warm-up or variations in global geometry. The actual values may indicate misalignment of instruments from vertical and step changes may indicate that instruments are not securely attached to the structure. Checks can be conducted on both event summary time histories and timetraces.
**Standard Deviation, Maximums and Minimums** – Variations in the magnitude of dynamic response with time as indicated by standard deviation, should correlate to the excitation input. Where wave and current measurements are obtained it may be expected that response measurements vary in accordance with changes in the environment. Alternative sources of response excitation may include drilling or flow induced motions. When reviewing the responses it should be attempted to obtain some form of general correlation between the measurements and potential sources of excitation, from records or measurements of environmental conditions, operations logs and/or daily drilling reports. It should also be checked that maximum and minimum values are within the design range of the instrumentation.

**Consistency Between Recording Devices** – Measurement devices placed in similar locations are expected to have similar responses. E.g. the motions obtained from instruments on the bottom of a BOP are expected to be smaller than those on the top of a BOP. Furthermore, the relative magnitude of the measured responses may be compared to the response derived from global riser and wellhead system analysis. Checks should be conducted to ensure that data is consistent in direction (sign), by evaluation of measurement timetraces, and in magnitude, by comparison of both timetraces and event summary time histories.

**Consistency Between Instruments** – Instruments in the same measurement device should produce a signal of consistent magnitude and sign. E.g. changes in angles should be consistent with changes in translation and hence, measurements of acceleration and angular rate should follow consistent trends. Furthermore, the sign of the motion should be checked to ensure that all instruments are orientated as expected and that any combination of measurements that may be required, such as to correct for G-contamination, will be calculated correctly. Examples of things to look out for include:

- Devices mounted upside down
- x,y,z axes within a data logger may not be arranged according to either a right or left hand rule
- Angular rates may be defined as positive clockwise or anticlockwise about the x and y axes

Information regarding instrumentation orientation will be obtained from the vendor prior to equipment installation. Even so, checks on the data should be conducted to ensure orientation is as intended.

**G-Contamination of Nominally Horizontal Motion Data**

Measurements of displacement are generally obtained through the use of accelerometers. When such instruments are orientated to capture vertical movement, they measure gravity when at rest. Vertical motions therefore introduce changes in the measured signal about the nominal measurement of g.

For accelerometers orientated to measure horizontal movements, the measurement when at rest is zero and lateral movements produce changes in the signal. However, lateral motions are often accompanied by rotation or inclination of the riser or wellhead to which the monitoring device is attached and the associated tilt of the accelerometer results in a component of gravity being included in the measurement. Figure 5. This gravitational component is referred to as G-contamination and can result in increase or decrease in measured acceleration, depending on the deflected shape of the equipment to which the accelerometer is installed. The magnitude of the resultant signal can be a small fraction or many multiples of the target measurement. Correction of this effect can be conducted using measurements of angle (or angular rate), or interpretation of response can be conducted using G-contaminated data.

![Figure 5 – Effect of Gravity on Measured Acceleration](https://www.2hoffshore.com)
**Instrumentation Noise**
The effects of instrumentation noise are not expected to be significant if the process of instrument selection using threshold measurements is conducted as described above. However, in the absence of such an assessment prior to measurement system deployment, an evaluation of response should be conducted to determine suitable means of processing the data. The noise measurements are not generally a concern when considering response peaks, as the instruments are typically selected such that peaks in response are much larger than the noise levels. However, when considering response time histories or statistics over a period of time, such as used in fatigue calculations, the additional variability in measured response resulting from background noise can lead to large errors in response statistics or calculated fatigue damage and filtering to minimize the effects of noise should be implemented.

**Calculation of Stress Transfer Functions**
Most of the wellhead fatigue measurement programs conducted to date rely on measurements of acceleration and/or angular rate that are converted to displacements and angles respectively, from which bending loads in the wellhead system are derived. The inputs and steps involved to convert motion measurements to fatigue damage are shown in Figure 6. One of the critical aspects of this approach is the derivation of the stress transfer function. A simple approach to derive the stress transfer function is to use a cut down model of the LMRP, BOP and wellhead system and apply the equivalent riser tension and lateral displacements at the location of the lower flex-joint. The displacements should be representative of those expected in service and may be applied statically. Application of varying displacement amplitudes will enable assessment of the non-linearity of response expected from soil behaviour, and harmonic application of displacements will enable frequency dependent response to be determined. Alternatively, dynamic analysis may be performed in which the complete riser and wellhead system model is subjected to loading from expected seastates or simulated VIV excitation. For many systems the statically derived transfer functions have been found to be in good agreement with the values derived from dynamic application of load.

Regardless of the method of calculation used, a number of uncertainties and operational variables may exist in the model used to calculate the transfer function. These include the following:

- Top tension and mud weight
- Soil strength and modelling approach
- BOP inertial mass
- External cement shortfall/scour
- BOP/Frame stiffness
- Wellhead housing interaction
- Internal cement shortfall

All these parameters lead to uncertainty in calculated fatigue lives. Without measurements of response, little is known about the degree of conservatism in the analytical methods. However, steps can be taken using measured data to calibrate transfer functions such that the potential errors in interpretation of fatigue damage are minimized. This process of calibration can be used to produce modelling improvements that can then be fed back into analysis models, to provide improved long term fatigue life predictions.

Three potential steps for transfer function calibration are as follows:

**Global Frequency** – Spectrograms or spectra plots of measured response can be used to identify modal response frequencies. The measured frequencies may be compared to the modal frequencies derived from the analysis models and any differences identified. The analysis models can be adjusted, within reasonable bounds based on available data, to improve agreement with the measured data, as for example shown in Figure 7. It is not expected that changes to the model will be large as top tensions and mud weights are generally well defined, but drill string tension (hook load) has been shown to have a significant influence on response frequencies in some shallow water applications, and adjustments for its influence may be warranted.

**BOP/Wellhead Natural Frequency** – This is generally the most critical aspect of transfer function calibration as it determines whether the BOP natural period coincides with wave or VIV excitation frequencies. While matching most of the response frequencies can be achieved with the step described above, differences may still be seen in the frequency corresponding to the BOP and wellhead system first natural frequency. Uncertainties in soil strength and modelling, BOP inertial mass and scour can all contribute to differences between predictions and measurements. Perhaps the most significant of these is soil strength and stiffness. Modelling is typically conducted using the guidance provided by API [4]. However, more recent work conducted by Jeanjean suggests that the API approach may underestimate stiffness, and modifications to that approach are suggested [5]. Nonetheless, big differences are often seen between specified upper bound and lower bound soil strength profiles and analysis models typically adopt the worst case, out of the need for conservatism. By varying the modelled soil stiffness, the natural
period of the wellhead and BOP system can be adjusted to match observed response, with little influence on other riser natural periods. Discussion of the effects of inappropriate modelling of soil stiffness is given in the case studies below.

**Local Amplitude** – The stiffness of the BOP or BOP frame to which monitoring devices are attached may be evaluated by comparing the relative motions measured at different locations. The approach should account for potential misalignment of the instrument axes and consider response in different directions. The analysis model should be evaluated to confirm that it provides a relationship that is consistent with that reported by the instruments and appropriate changes made to the model to account for any disparities prior to developing the transfer functions. Examples of how measured data is assessed are given in the case studies below.

![Diagram](https://via.placeholder.com/150)

**Figure 6 Interpretation of Fatigue Damage from Motion Measurements**

![Spectrogram](https://via.placeholder.com/150)

**Figure 7 – Example Spectrogram with Modal Response Periods**

**Lessons Learnt from Field Measurements**

**Case Study 1 – VIV Monitoring Database**

Vortex induced vibration has been identified as a key driver of wellhead fatigue in harsh and deep-water environments and a number of monitoring programs have been conducted with the objective of calibrating analytical predictions of response. An example output from this type of work is given in Figure 8, [6]. Response data from wells West of Shetland [6], offshore North Africa [7] and many other geographical locations have been used to calibrate predictions of VIV fatigue damage. The data gathered from these monitoring programs forms a substantial database of drilling riser response, which shows that VIV fatigue damage estimates may by an order of magnitude or more greater than that determined from measured response [8]. The monitoring systems adopted for obtaining this data generally consisted of a number of motion measurement devices along the length of the riser with one or more devices on the LMRP and BOP. However, a limitation with the data gathered from these monitoring programs is that while the driver for instigation of the field measurements was wellhead fatigue, the focus of the
data assessment was global VIV response rather than local BOP and wellhead system response. Consequently, little insight can be gained from this work as to the characteristics of and parameters driving wellhead fatigue response.

Figure 8 – Typical Measured v Calculated Fatigue Damage Comparison

Case Study 2 – Western Australia
More recent field measurement programs have focused on the detailed response of the wellhead system. Work conducted on a drilling program offshore Australia in a water depth of 800m gives an interesting insight into the potential difficulties of deriving stress transfer functions from BOP and LMRP motions measurements [9]. The riser, BOP and wellhead system was extensively instrumented enabling calibration of modelled response along the entire length of the riser. An example comparison of measured and predicted response, shown in Figure 9, demonstrates the inconsistency in measurements and predicted motions along the BOP and LMRP. With a small degree of analysis model calibration, the calculated motion response of the BOP and guidebase were in good agreement with the measured response, but differences between measurements and analysis of motions at the LMRP and lower flex-joint were still evident. This suggests that the BOP and LMRP response was considerably stiffer than that assumed in the model and demonstrates the potential uncertainties in calculation of wellhead system loading from measurements remote from the wellhead location.

Figure 9 – WA Riser – Comparison of Riser and Wellhead System Motion Analysis and Measurements

Case Study 3 – Caspian
Concerns regarding wellhead fatigue on a drilling programme being conducted in the Caspian Sea in water depths between 100 and 500m led to the introduction of monitoring of all drilling operations. Motion measurement devices were implemented at two elevations along the BOP frame and calculation of cumulative fatigue damage conducted using the measurements obtained. Initial findings from this work seemed to indicate that analysis was substantially underpredicting fatigue damage measured in the field. The reason behind this discrepancy can be determined the motion measurements shown in Figure 10. Acceleration measurements were being used to calculate fatigue damage and all events were being processed. On inspection of the measurements it could be seen that much of the response was well below the threshold fatigue damage rates that could

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reasonably be measured and that the effect of instrument noise was driving interpreted fatigue damage accumulation. Subsequent interpretation of response using angular rate measurements, in which signal to noise ratios at the measurement thresholds are much greater, resulted in much lower estimates of measured fatigue damage, more in keeping with analysis output. Applying the methodology described above, in which only measurements above the threshold were used in calculating measured response would have yielded even lower levels of measured damage. However, as the noise levels in the angular rate sensors were small, and had little influence on accumulated fatigue, it was decided to process all events when deriving fatigue from field measurements.

A further finding from this monitoring program was the implication of variation of BOP stiffness on response measurements obtained along the BOP. A comparison of measured angular motions on the BOP and LMRP was assessed for a number of different wells in different water depths, as shown in Figure 11. This shows a difference between measurements along the length of the BOP stack which is due to the structural flexibility between points of motion measurement. The magnitude of the difference in motion depends on the vessel (BOP stack). Between the most stiff and least stiff configuration, a difference in motion measurement of 10-15% exists, which may equate to a difference in calculated fatigue damage or 30 to 60%. However, it is difficult to accurately assess this stiffness, which may be affected by BOP frame/stack interaction and the connections between components along the length of the BOP, without the use of response measurements. It is expected that the closer the measurement is to the wellhead, the more representative it is likely to be, and hence that interpretation of wellhead behaviour from motion measurements on the LMRP alone will be subject to some uncertainty due to the uncertainty in effective bending stiffness of the BOP stack and its interaction with the frame.

Figure 10 – BOP Response Measurements from Caspian Monitoring Program

Figure 11 – Comparison of Motion measurement Along the BOP and LMRP

Case Study 4 - West of Shetland

One of the major findings of the wellhead monitoring programs reported above is the uncertainty in calculating transfer functions to derive wellhead fatigue damage from measurements of motion along the LMRP and BOP. A wellhead monitoring program has been conducted offshore West of Shetland that aids assessment of this issue through the provision of both motion measurements on the BOP and strain measurements on the conductor. The wells, located in a water depth of 450m, were subjected to some severe wave loading and current induced VIV.
A comparison of cumulative fatigue damage obtained from analysis, strain and motion measurements has been developed. This shows that the fatigue damage obtained from analysis is approximately twice that obtained from strain measurements. In addition, the general trends of fatigue damage accumulation from analysis and strain are different. The analysis indicates accumulation of fatigue damage where there is little damage derived from strain measurements and where fatigue damage is shown to increase rapidly by the strain measurements, the rate of increase in fatigue damage accord to analysis is lower. Investigation of the frequency content of the response provides an insight as to likely reasons for these differences. Figure 12 shows response frequency content in three different seastates: 1) 11/9 Hs = 3m Tp = 6sec, 2) 16/9 Hs = 6m Tp = 11sec and 3) 01/10 Hs = 5m Tp = 8sec. In each of these events, a high frequency component of response can be seen at frequencies of between 0.4 to 0.6 Hz (1.6 to 2.5 sec), which is typical of the modal response frequency of the BOP and wellhead system. However, the calculated modal frequency of the BOP and wellhead system is 0.21 Hz (4.8 sec), based on the actual riser configuration, top tension, mud weight and specified soil properties. This difference between observed and calculated frequencies suggests that the true soil stiffness is considerably greater than that modelled.

The implication of the potentially under-estimated soil stiffness used in the analysis is that the natural period of the BOP and wellhead system is high enough to enable excitation of the BOP stack by wave action, whereas, the measured BOP and wellhead system natural period of around 2 seconds is below the wave excitation period range. As a consequence, we see growth in fatigue damage in the calculated response during small seastates which we do not see in the measured behaviour. Increasing soil stiffness in the analysis would result in improved correlation between calculated and measured fatigue damage by avoiding the significant accrual of fatigue damage caused by wellhead system modal response excitation in the smaller seastates. In addition, an increase in bending loading in the wellhead system would be expected, due to the stiffer soil, that would increase the rate of calculated fatigue damage accumulation in the larger seastates to be more in keeping with that observed.

A further consequence of the apparent disparity between actual and specified soil properties is the higher fatigue damage accumulation derived from strain measurements compared to those from accelerations. For the same riser excitation, the displacements generated at the location of the accelerometers on the BOP are smaller in stiffer soil. However, the transfer function used to derive wellhead bending loads from the measured motions is based on the less stiff, specified soil properties. Consequently, fatigue damage accumulation in the wellhead system is underestimated. This further demonstrates the importance of close inspection of measured data and model calibration prior to generation of transfer functions as described above, in order to obtain reliable estimates of fatigue damage accumulation from response measurements.

![Figure 12 – Frequency Content of Strain and Motion Measurements from Different Events](https://www.2hoffshore.com)
Conclusions

Monitoring provides a useful tool for validating and calibrating analytical predictions of wellhead fatigue. The instrumentation systems require design and engineering in the same manner as any other piece of equipment deployed offshore in order that they are properly specified and meet functional requirements. Provision should be made for redundancy to maximize the opportunity for success and enable data validation through measurement comparison. Measurement of very small fatigue damage rates is extremely challenging and probably unnecessary. A good understanding of threshold measurement requirements should be established that forms the basis of instrument specification and defines expectations for data processing.

Uncertainties exist in deriving wellhead system fatigue damage from measurements. The stress transfer functions used in these calculations depend on the modelling methods used, and uncertainties in soil properties and BOP stiffness which can lead to errors in interpretation of measurements. Measurement of response as close as reasonably possible to the wellhead system is preferable, but it must be remembered that improved sensitivity measurement devices are needed to provide suitable measurements at the lower elevations.

Much can be learned about the limitations of our analytical models and use of stress transfer functions to derive fatigue damage from measurements, from scrutinizing the measured response data. Data from the case studies presented here suggests that automated fatigue monitoring systems require extensive robustness checks to ensure that critical parameters such as soil strength/stiffness are properly modelled and that fatigue damage is correctly derived from response measurements.

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References


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