DEEPWATER RISER VIV, FATIGUE AND MONITORING

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ABSTRACT

Vortex induced vibration is (VIV) is a major design issue for all deepwater riser systems operating in regions where severe current can be expected, such as the Gulf of Mexico and offshore Brazil. Cross-flow vibrations of a riser in severe currents can diminish the riser fatigue life, dictate the riser arrangement, fabrication details, vessel layout, installation method, and thus have significant cost impacts at all stages of the field development. The limitations of existing analytical methods and test data for predicting deepwater riser VIV response are discussed. This shows that in-service monitoring or full scale testing is essential to improve our understanding of VIV response and confidence in its predictions. A number of monitoring and test programmes are described and some of the key findings reported. Based on the experience, instrumentation requirements for monitoring VIV response are described and a design approach to deal with VIV is proposed.

INTRODUCTION

Oil and gas production in deep and ultra-deep water depths presents many challenges, one of them being the design of technical and cost effective riser systems. In almost all deepwater areas where hydrocarbons are found, severe current loading is invariably expected. High current can generate vortex-induced vibrations that give rise to high rates of riser fatigue damage accumulation. As water depth increases, riser designs become more varied and VIV behaviour presents one of the biggest uncertainties facing the riser engineers.

A great deal of experimental work, mostly on a reduced scale, has been conducted from which analytical tools to predict riser VIV response have been developed. However, as new riser configurations are developed to cope with the increasing water depths and reservoir challenges, the similarities between test models and real riser systems are diminishing rapidly. This has led to a need for more work to be conducted to understand VIV of real riser systems by full scale testing and in-service monitoring.

IMPLICATIONS OF RISER VIV

Under steady current flow conditions, cross flow vibrations of risers have two immediate consequences:

- Increased fatigue damage (Figure 1)
- Increased in-line drag (Figure 2)

These effects can influence the design and operation of riser systems in different ways, according to riser type, as described below.

Top Tensioned Risers

Top tensioned risers as used on tension leg platforms (TLP’s) and spars may require increased top tension or suppression devices to limit the fatigue damage induced by VIV. The use of suppression systems adds to cost and the difficulty of installation. Increased top tension results in increased loading on the riser base and wellhead system and increased platform loading in the case of TLP’s. For spar riser systems, an increased number of buoyancy cans may be needed. The additional buoyancy cans must be located near the base of the spar, where they are subjected to increased external hydrostatic pressure and thus are less effective than those near the water surface. On both TLP’s and spars, increased spacing between risers may be needed to avoid clashing or to accommodate the buoyancy cans needed (spar). In extreme cases, the required spacing may limit the number of top tensioned risers that can be used on these vessels.

Steel Catenary Risers (SCR’s)

Limitation of VIV induced fatigue damage in SCR’s may require the use of suppression devices or increased top tension, as for top tensioned TLP or spar risers. The SCR’s on the Auger and Mars TLP’s employ helical suppression strakes (Figure 3) over the top 500ft where current loading is most severe [1]. On the 10in SCR attached to the Petrobras XVIII in the Campos basin, the riser top angle is set at 20 degrees in order to provide a high riser tension and avoid the need for suppression devices. This approach reduces riser costs, but adds to platform loading. If large diameter SCR's or a large number of SCR's are used, this approach may not be feasible.

Drilling Risers

Joint rotation programmes may be implemented in order to distribute damage throughout the riser string rather than concentrate damage in just a few riser joints, and reduced intervals between inspections may be necessary to confirm fitness-for-purpose. However, the use of different joint types or buoyancy ratings in different parts of the riser string may limit the effectiveness of a rotation programme. Riser tension may be increased to reduce the fatigue damage incurred in the riser, but vessel tension capacity limits the feasibility of this approach on many vessels and increased VIV fatigue loading may be incurred in the wellhead and conductor system. This area is often overlooked, and though time spent on the wellhead may be a matter of a few months, the rates of fatigue damage accumulation can be considerably higher than in the riser system itself. The wellhead and conductor can therefore form the fatigue critical section of the well control system. In extreme environments, where prolonged drilling programmes are to be conducted, VIV suppression devices may be necessary to reduce the rate of fatigue damage accumulation.

Increased drag due to VIV results in increased flex-joint rotations. As flex-joint rotation dictates the limits for conducting drilling operations, increased downtime is also incurred as a result of VIV.

UNCERTAINTIES OF RISER VIV PREDICTIONS

Current design tools used to predict riser VIV such as SHEAR7 [2] and VIVA [3] are based on experimental observations. Most of the test programmes that calibrate these tools have been conducted at small-scale, in sub-critical flow with low Reynolds numbers. In most riser systems, the highest rates of fatigue damage accumulation and the greatest contribution to long term fatigue damage is obtained from extreme currents. Consequently, flow in the critical and post-critical flow regimes is of most concern for practical riser systems, for which relatively little experimental data exists.

A further limitation of small scale testing is the use of idealised riser configurations with well-defined shapes and boundary conditions. While such arrangements are necessary to further our basic understanding of VIV behaviour, quite different responses may be obtained with real riser arrangements. An overview of the areas in which risers may differ from the idealised arrangements that form the basis of VIV analytical tools are described below.

Riser orientation and shape – the response of risers inclined to current flow and risers shaped with buoyancy to accommodate large vessel motions are not well researched. Both in-plane and out-of plane VIV vibrations may be generated simultaneously and further work needs to be conducted to provide an understanding of the VIV response of different riser shapes, and the effectiveness of VIV suppression systems when used on these risers.

Riser length – in very long risers, damping over a large proportion of the riser length may result in a travelling wave type response as opposed to standing wave as assumed in SHEAR7 [2]. Predictions of fatigue damage remote from the regions of greatest excitation may therefore be greater than in practice.

Riser terminations – the end conditions of deepwater riser systems can vary considerably. In top-tensioned risers, conductor-soil interaction can affect riser response and the seabed touchdown point of SCR's bares little resemblance to the boundary conditions typically used for analytical modelling purposes. Hydro-pneumatic tensioner systems used in top tensioned TLP risers and drilling risers may also have an influence on VIV response and tension fluctuations may be generated as result of VIV. Further testing is needed in order that the influence of varying boundary conditions on riser VIV can be quantified.

Multiple riser strings – many riser systems do not consist simply of a single pipe. Top tensioned production risers have one or two casings, in addition to the tubing for transport of well fluids. Drilling risers have a large diameter central pipe, choke and kill lines, umbilical and possibly a booster line and buoyancy modules, in addition to the drill string that rotates inside and is under tension. Interaction of the different lines is likely to have an influence on VIV response that needs to be quantified for design purposes.

Riser clusters – the VIV response of a riser lying downstream of an adjacent riser is different from that of a stand-alone riser [4]. The response is further complicated when many risers are grouped together, as in the case of TLP or spar production risers.

Riser profile – variability in the outer profile of a riser is found in drilling risers where a combination of slick and buoyant joints is used. Careful arrangement of the different joint types may produce less severe VIV response [5], though confirmation of this possibility is yet to be obtained.

Current profile – widely differing current profiles are found in different deepwater locations. Highly localised currents are found in the Gulf of Mexico in the form of loop currents and eddies, whereas more severe through depth currents are experienced in West Africa and the West of Shetland. The predicted response of risers to the different flow profiles varies significantly, but further data is needed to confirm these predictions.

Current directionality – variation in current flow direction though the water depth, particularly significant in Brazil, adds further difficulty to reliable prediction of VIV fatigue damage. For design purposes it may be assumed that either the current flows in the same direction throughout the water column or the current may be resolved into a single flow direction. The two approaches can produce significantly different results and more work is needed to understand the most appropriate method to model such environments.

In each of the above areas, the riser analyst must make simplifying assumptions in order to produce estimates of VIV response. Out of necessity, such assumptions err on the side of conservatism. However, due to the lack of available data, the levels of conservatism may not be understood even when parametric analysis is conducted. Consequently, further experimental data is needed to enable calibration of VIV analytical tool for practical riser arrangements and to obtain an improved level of confidence in predicted VIV response. Such data needs to be obtained at large scale or though in-service monitoring in order that differences in behaviour between idealised analytical models and real systems can be properly quantified.

IN-SERVICE MONITORING AND FULL SCALE TESTING

The authors have been involved with a number of in-service riser monitoring programmes and test programmes conducted at full scale. Brief descriptions of these programmes and the current status are given below.

BP Schiehallion - Paul B. Loyd Jr drilling riser in 375m (1230ft) water depth, accelerometers at 3 locations along the length, monitoring over a period just longer than 1 month. Data processing completed;

NDP, BP Nyk High [6] - Ocean Alliance drilling riser in 1300m (4250ft) water depth, accelerometers at 5 locations along the length, monitoring over a period of 74 days. Data processing in progress;

STRIDE JIP, 2H Offshore Engineering Limited [7] - Tow tank test on 6in pipe to investigate the effects of inclination to flow of bare and straked pipe. Data processing completed;

STRIDE JIP, 2H Offshore Engineering Limited [7] - Open water tow test of 10-3/4in, 200m long curved riser to investigate inclination effects on bare and straked pipe, accelerometers at 40 locations (Figure 4). Data processing completed;

Chevron GoM – Glomar Explorer drilling riser in 2350m (7700ft) water depth, retrievable accelerometers at 2 locations, deployed in loop current events. Data recorded, awaiting processing;

British Borneo Allegheny – Seastar mini TLP 12in export SCR in 1005m (3300ft) water depth, retrievable accelerometers at 12 locations (Figure 5). Data recorded, awaiting logger retrieval and data processing.

Based on the data processed so far, predicted vibration amplitudes are consistently higher than those measured. This gives us confidence that riser design is erring on the side of safety. However, the processed data do not provide sufficient information to explain the reasons for the conservatism in the theoretical predictions. Explanation for the over-predictions may be the higher effective damping inherent in the real systems, due to physical interactions and complex loading conditions, than is understood theoretically.

The sources of such differences vary with riser arrangement and may consist of the following:

- Tension variations - all cases
- Environmental loading from wave action - drilling risers and full scale tests
- Multiple strings and wellhead-soil interaction - drilling riser
- Use of GRP pipe – tow tank tests

Further testing is needed to quantify the changes in VIV response that may result from the effects described above. Tow tank and current flume tests can be used to provide some of the required information, with further field monitoring and full scale tests to establish the relationships between ideal and real conditions.

IN-SERVICE MONITORING REQUIREMENTS

When conducting any riser test or monitoring programme, sufficient data must be available and measurements taken to define the following:

- Riser Physical Arrangement
- Loading Conditions
- Boundary Conditions
- Response

The riser arrangement can be simply defined in terms of riser weight and hydrodynamic diameter. Account must be taken of the pipe string, any couplings and buoyancy and internal fluids. As internal fluid weights can vary, steps must be taken to record the densities that correspond to monitored response. The weight of internal or attached lines must also be accounted for in multi-string risers together with the tension applied to each line.

Current flow speed and direction can be measured using acoustic current Doppler profilers (ACDP's). Due to limitations in the depth over which these devices can operate, they may need to be placed both near the surface and the seabed in order that the flow profile and direction can be defined throughout the entire water depth.

The boundary conditions applied to risers are often considered well defined. The tension applied to top tensioned production risers or drilling risers is dictated by the pressure in the accumulators, and can be readily recorded. However, tension fluctuations may be induced by VIV for which special monitoring devices may be needed. At the riser base, the wellhead system is often assumed to be rigid, but significant movements can occur particularly in the soft soils encountered in many deepwater locations. Care should therefore be taken to ensure that the tension applied at the top and fixity that is realised at the bottom are properly monitored.

Monitoring of riser response poses many additional difficulties to those encountered monitoring loading and boundary conditions. Some of the issues that must be addressed when determining instrumentation requirements to monitor riser response in-service are described below.

Active v Passive – In ideal circumstances, it would be possible to inspect all riser response data during testing through use of an active (on-line) monitoring system. Active devices must transmit signal back to the drilling or production vessel. This may be achieved by way of telemetry, but the power needed for such an approach would require large batteries or limit the time over which data could be recorded. Hardwiring has been used for permanent riser systems (TLP production and export risers) but is not well suited to drilling risers that are regularly disassembled. Routing of power and signal cables can add to installation time and cables may be easily damaged. Passive monitoring devices may be mounted on the riser joints either prior to or during installation using straps or clamps (Figure 6). Following riser retrieval (drilling riser) or by ROV retrieval of the monitoring devices (production and export risers, Figure 7), data can be downloaded and interpreted carefully (Figure 8). The passive approach has been successfully implemented for monitoring riser VIV response in all the monitoring programmes described above. Recently developed passive monitoring devices can record a considerable quantity of data at relatively low cost. Unless it is proposed to adjust the riser configuration in reaction to VIV response, such as may be attempted with a drilling riser, there may be little benefit in using an active monitoring system. However, when using passive devices, difficulties may arise when attempting to assess the relative motion between different points along the riser length due to drift of the monitoring clocks, which may vary from one device to the next [8]. Start and end times must therefore be carefully recorded and means of applying and recording time signatures evaluated if monitoring over a long period of time.

Strain or Displacement - Measurements may be taken from strain gauges to give riser stresses directly or from accelerometers to give displacements. Using the latter approach, riser stress variations and accumulated fatigue damage may be inferred from comparisons between analysis results and field measurements. The readings obtained from accelerometers are subject to gravitational effects that can introduce errors in results interpretation. Care must therefore be taken to ensure that such effects are properly accounted for when evaluating response.

Number of Monitoring Locations – To further our understanding of VIV response of practical riser systems the deflected shape of the riser system along its entire length should be known at any time. This would require the use of 4 or 5 monitoring points per mode of vibration, which in longer riser strings would result in the need for many 10's or 100's of monitoring devices and considerable expense. However, if the objective is simply to calibrate analysis tools, effort can be focused on monitoring critical regions where loading and fatigue damage is expected to be greatest, typically the top and bottom of the riser. This would not provide the complete response picture, but much could be inferred from observations made in this way.

Sampling Frequency and Filtering – Riser response data is often filtered prior to recording to remove response signals outside the expected frequency bands. However, it is important, particularly for practical riser systems, that as much data as possible is gathered. System responses outside the expected frequency bands of riser response, that may be generated in multi-string risers or from tension fluctuations, may have an influence on predicted vibration response. Detailed evaluation of the system being monitored must therefore be conducted in order that the sampling and filtering frequencies can be set.

Sampling Period and Interval – In tow-tank or current flume tests of VIV, response monitoring is likely to be conducted continuously for the duration of each test. When monitoring in-service, continuous monitoring of response is unnecessary, and intermittent monitoring of response may be used. The frequency at which devices are activated depends on the expected variations in the environment. One would not wish to miss monitoring a significant event, hence intervals of the order of 2 to 6 hours may be sufficient. The period for which monitoring is then conducted depends on the period of riser VIV and to some extent, the monitoring frequency selected. Sufficient data points must be accumulated to enable processing of the results, typically by fast Fourier transform, and to enable processing of individual segments of the monitoring period in order that any variations in response over the total sampling period can be defined.

DESIGN FOR VIV

When designing risers for long term service on floating production systems a factor of safety of 10 is generally applied to service life to give the required fatigue life. Due to the uncertainties in VIV predictions, a safety factor of 50 to 100 has been adopted in some instances. Coupled with the potential conservatism of VIV analytical tools based on the evidence of full-scale tests, current riser designs may be considerably more conservative than necessary. This can lead to unnecessary use of VIV suppression devices that can cost as much as $400/ft. For a Gulf of Mexico development where such devices may be used over a length of 500ft, the cost for 10 risers would be $2M. In areas where through depth currents are greater, such as West of Shetland and Brazil, suppression devices may be required over a much longer length and suppression system costs would be much greater. Furthermore, use of suppression systems can affect the installation methods used, which may further increase costs.

Where VIV fatigue life predictions for riser systems without suppression are found to be marginal, the designer may question whether VIV suppression devices need to be used. An effective, but costly, suppression system may provide almost total suppression of VIV, when only a 50% reduction of vibration amplitudes is needed to provide a 10-fold increase in fatigue life. For short term developments, or developments where the reserves are uncertain, an alternative to fitting these high cost suppression devices right from the start could be considered. It is proposed for these cases that the riser VIV response is monitored and, if necessary, VIV suppression devices are retrofitted subsequently if rates of fatigue damage accumulation are found to be high.

The monitoring system cost can be relatively small and is estimated to be $300k over 5 years as follows: capital costs of monitoring devices 10 @ $10,000, and data processing once per year at $40,000. In addition, suppression systems have been developed that may be retrofitted to the riser at relatively low cost [9].

This approach may appear complex without offering the protection afforded by suppression systems, but the capital costs of suppression devices are at worst delayed and may be completely avoided. In order to determine whether such an approach can be adopted the distribution and rate of fatigue damage accumulation from different current loading conditions must be examined. Provided the majority of long term fatigue damage does not result from just a very small number of extreme events, the use of suppression devices from day one may be avoided.

CONCLUSIONS

The analytical tools used to predict VIV and the associated fatigue damage are based on a vast amount of small scale tests. However, there are substantial gaps in the experimental data base that limits our ability to reliably predict VIV in real riser systems. This may lead to undue conservatism and increased costs at best, or under-conservatism and unsafe design at worst. Practical riser arrangements and current conditions that induce VIV can be substantially different from many of the idealised test arrangements that form the basis of existing analytical tools. Consequently, there is a need to conduct further testing and in-service monitoring of risers in order to calibrate these tools. Much has been learnt from work conducted already and low cost equipment has been developed that can ensure that future monitoring programmes are properly directed and are conducted economically. This will ultimately lead to more reliable design for riser VIV and reduced riser costs, which will assist in establishing the feasibility of future developments in deep and ultra-deep waters.

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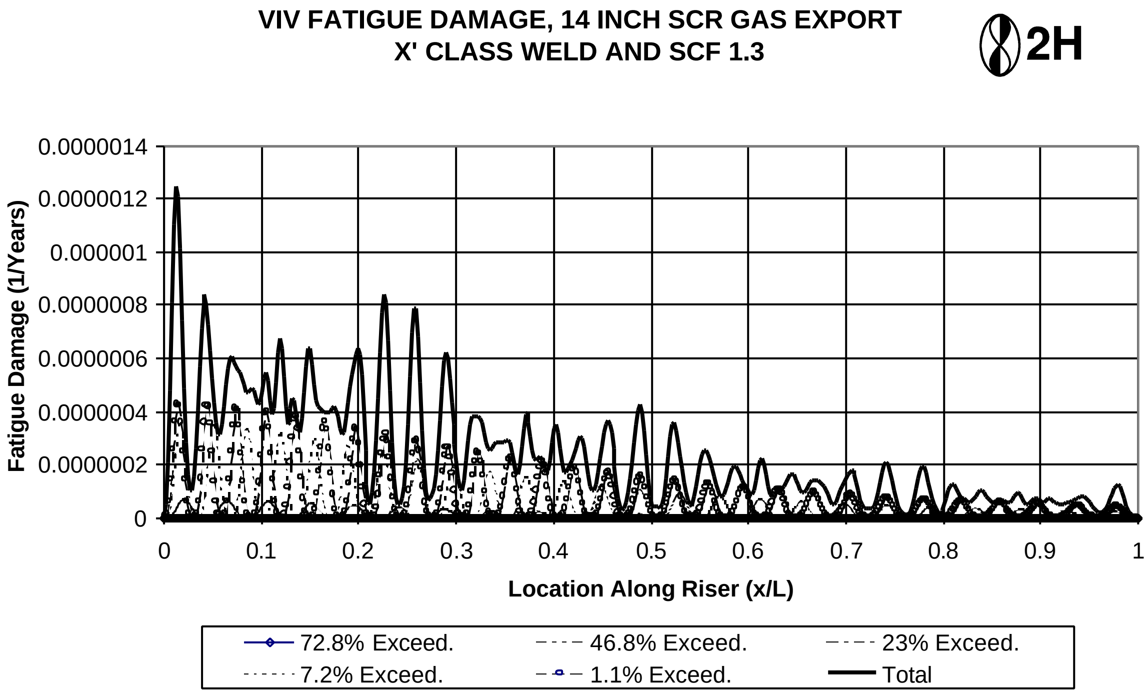

Figure 1 – Example SCR VIV Fatigue Damage Distribution

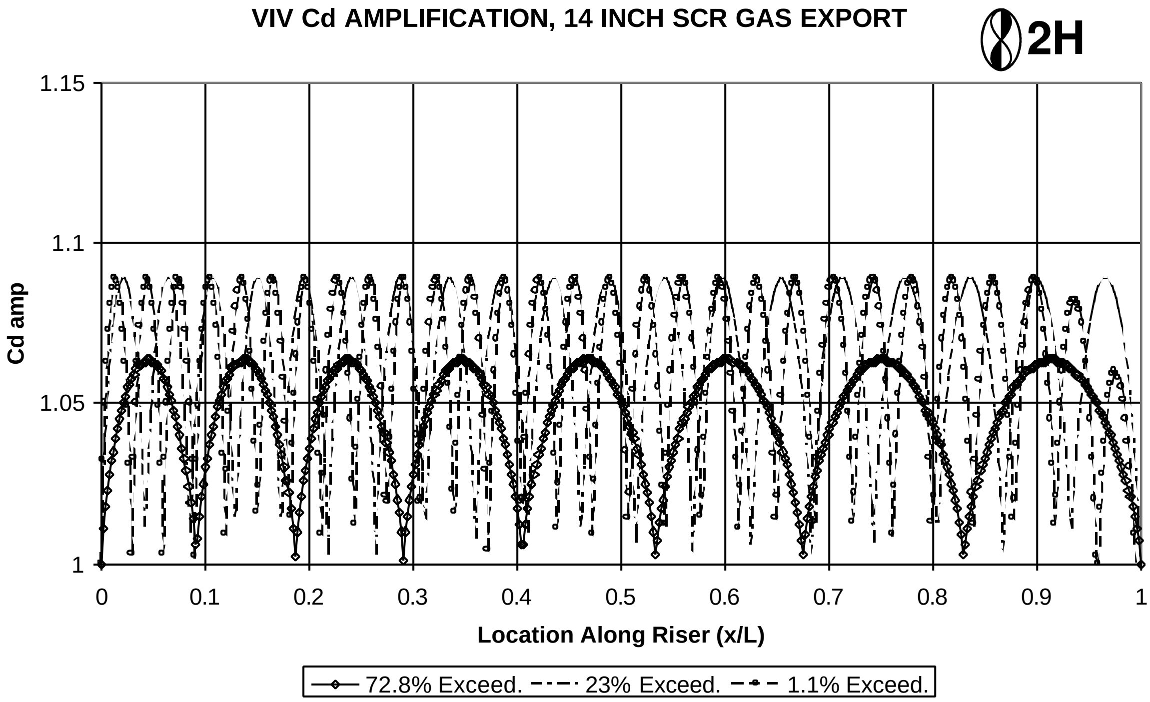

Figure 2 – Example SCR VIV Cd Amplification

Figure 3 – Helical VIV Suppression Strakes

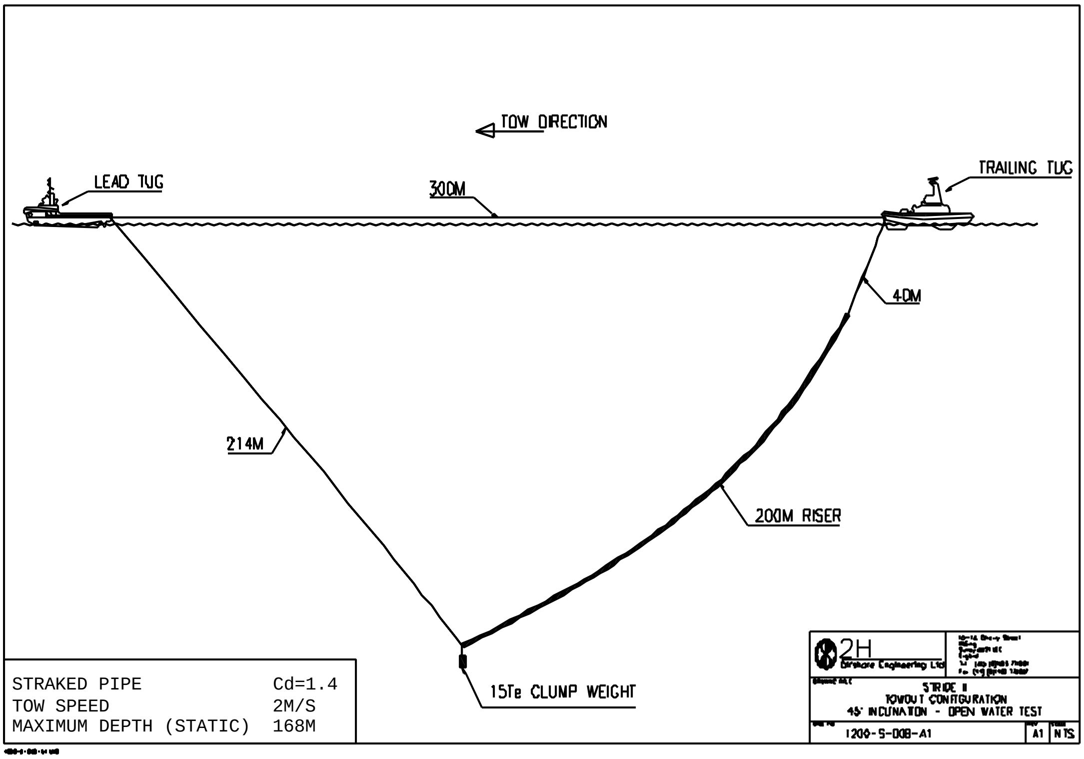

Figure 4 – STRIDE Full Scale Open Water Test Arrangement

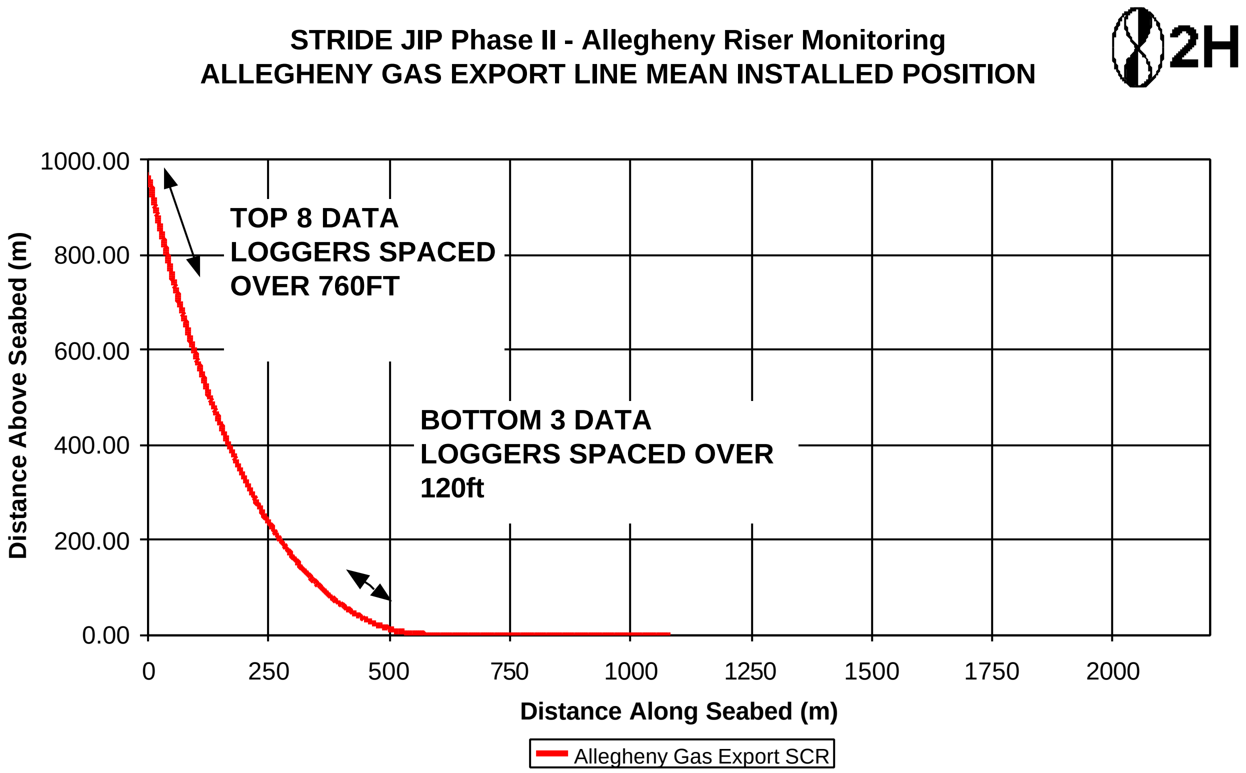

Figure 5 – Allegheny SCR Data Logging Positions

Figure 6 – Strapped on Passive Data Loggers

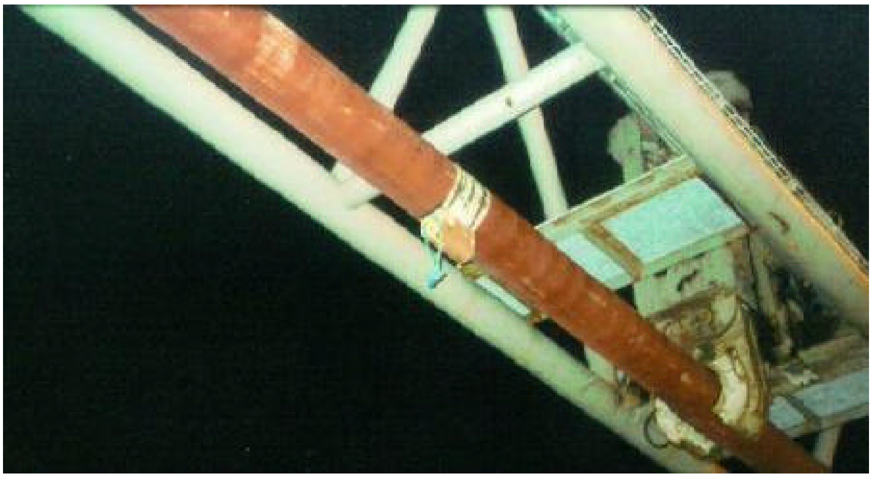

Figure 7 – ROV Retrievable Passive Data Loggers

Figure 8 – Logger Download and Processing