

DEVELOPMENTS IN RISER VORTEX INDUCED VIBRATION ANALYSIS

by

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INTRODUCTION

Cross-flow vibration of risers in steady current flow is an important factor in the design of all rigid riser systems for deep water, including drilling, production and export risers. High levels of VIV fatigue damage can be accumulated in relatively short periods of time in the severe currents encountered in most of the deep water development areas worldwide. Suppression devices, such as helical strakes or fairings may be needed to prevent unacceptable levels of fatigue damage. These devices can have a significant influence on riser cost both in terms of materials and installation time. Reliable predictions of VIV response are needed to ensure that premature failures do not occur and that undue expense in specification of suppression devices is not incurred.

A considerable amount of experimental work and analytical development has been conducted in recent years to improve predictions of VIV response. This paper gives a designer's perspective of the available methods for VIV analysis, current developments and the requirements for further work to rationalise riser design for VIV's.

CURRENT ANALYSIS METHODS

A detailed review of current VIV analysis methods is given in reference [1]. Of these methods, only a few are commercially available to the riser designer, including the DnV Rules [2] and the analysis programs SHEAR7 [3] and VIVA both developed at MIT under separate JIP's. The guidance provided by DnV enables prediction of the response of uniform risers in uniform current flows. This approach is unsuitable for many developments where highly sheared current profiles are experienced. The program SHEAR7 accounts for variation in current speed through the depth and enables prediction of multi-mode VIV response of a uniform riser in sheared or uniform current and has been extensively validated using model tests. While SHEAR7 was developed for analysis of nominally straight, top-tensioned risers, such as drilling risers and TLP production risers, it is also considered applicable to steel catenary risers. Though some inaccuracies may exist at low modes of vibration, the program is considered suitable for prediction of higher mode response which generally produce the greatest contribution to fatigue damage. The most recent technique to become commercially available is the programme VIVA, also developed at MIT. This can account for the effects of varying riser section along the length, drilling riser choke and kill lines and is currently being validated using tank test data.

In order to obtain estimates of long term VIV fatigue damage, analysis must be conducted with a number of current profiles of varying severity, typically based on exceedence level. The fatigue damage obtained assuming continuous application of each profile is then factored according to the assumed duration of the profile, and the total long term damage is given by the sum of the factored damage from each profile. As the more severe current profiles generally produce greater rates of fatigue damage, a more refined selection of profiles is required amongst the low exceedence levels.

VIV fatigue damage is sensitive to the selection of analysis parameters [4], particularly Strouhal number, and the bandwidth parameter which governs the length of the riser over which VIV excitation occurs for a given mode of vibration. Sensitivity analyses must be conducted to evaluate the influence of changes in such parameters on predicted fatigue life and provide lower bound estimates of fatigue

life for design purposes.

LIMITATIONS OF EXISTING TOOLS FOR NEW RISER APPLICATIONS

The operating conditions of risers in deep water is continually changing and extending the requirements of the available VIV analysis methods. Some of the main changes in riser operating parameters and the associated changes in analytical requirements are described below. As SHEAR7 is widely used in the industry, the development requirements are identified largely with respect to the current capabilities of SHEAR7.

Water depth - the depths in which risers are to be deployed are increasing at a considerable rate with a number of developments planned for water depths of 2000-3000m in the Gulf of Mexico and West Africa. VIV analysis needs to take account of the long lengths over which excitation may be damped. The standing wave solution, as employed in SHEAR7, may be unsuitable for some of these very long risers, in particular steel catenary risers with suspended lengths of up to 1.5 times the water depth. For such depths, an earlier incarnation of the program, SHEAR6 (SHEARINF), which uses a Greens function approach to determining response may be more applicable than the standing wave solution employed by SHEAR7.

Environments - the environments in which risers are to be used have widely differing current profiles. The ultra-deep water Gulf of Mexico has the submerged eddies to contend with, not found in the current deep water developments in the same location. West Africa and West of Shetland have large through depth current speeds which place a high degree of importance on excitation velocity bandwidths in the determination of VIV fatigue damage. Variation in current flow direction through the water depth, particularly significant in Brazil, adds further difficulty to reliable prediction of VIV fatigue damage. For analysis purposes, it may be assumed that the current flows in the same direction throughout the water column. This is considered conservative, as variation in flow direction will reduce the degree of excitation in a given plane and result in more even distribution of fatigue damage around the riser circumference. Where current direction is well defined throughout the water depth a suitable profile for VIV analysis may be obtained by resolving current into a single plane, though the effects of such an assumption must be evaluated by parametric analyses.

Extended drilling programmes - for short term drilling programmes in deep water, high rates of VIV fatigue damage accumulation may not be considered problematic. For a number of existing drilling vessels and many of the deepwater drilling vessels currently under construction drilling programmes of the order of 5 years or more are planned. The levels of riser fatigue damage that may be accumulated over these extended duration programmes by VIV may warrant the use of suppression devices such as strakes or fairings [5-9]. As such devices are expensive, both in terms of materials and running time, reliable predictions of VIV response are needed to rationalise the extent to which such devices are used.

Riser buoyancy - the drag diameter used for VIV analysis should take account of choke and kill lines and buoyancy modules. For a slick drilling riser, the effective drag diameter varies according to current direction. To account for uncertainties in flow direction sensitivity analysis should be conducted using drag diameters that account for flow both normal to and in the plane of the choke and kill lines. A further difficulty arises when selecting the drag diameter to model a riser arrangement that uses a combination of buoyant and slick joints. It may not be satisfactory to simply average the diameter over the whole riser length as the extent and degree of VIV excitation and damping may not be satisfactorily determined. Until more rigorous analysis methods are developed, sensitivity analysis, accounting for the change in drag diameter along the riser length need to be conducted.

Riser shapes - for semi-submersible production vessels and FPSO's, where the severity of vessel motions precludes the use of simple catenary risers, steel risers shaped with buoyancy, giving lazy wave riser arrangements may be used. The use of buoyancy over part of the length has the same analytical complications as for the drilling riser, described above. In addition, the shape of the riser further complicates VIV response. Under in-plane flow, the riser inclination varies along the length and under flow normal to the plane of the riser the riser will tend to roll over in the arch. Further information on the effect of inclination on VIV excitation is needed to enable reliable predictions of VIV response of these configurations.

In each of the above areas, the riser designer must make simplifying assumptions in order to produce estimates of VIV response. Out of necessity, such assumptions must 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, and enhancements to analytical tools are needed in order that these uncertainties can be quantified and undue conservatism avoided.

TEST PROGRAMMES

Ongoing development of VIV analysis tools is dependent to a significant extent on the availability of experimental data to verify predictions and refine analysis techniques. As yet, rigorous theoretical analysis of VIV response, accounting for three dimensional, non-linear fluid-structure interaction response, such as potentially provided by computational fluid dynamics, is not available for practical design purposes. As the riser arrangements being implemented are changing, so further experimental data is needed for reliable prediction of VIV response.

A number of test programmes have recently been conducted or are being started to assist in the verification of VIV analysis methods. A brief summary of some of these the programmes and areas of investigation are given below:

STRIDE JIP - 2H Offshore Engineering

- tow tank test on 6in pipe to investigate the effects of inclination to flow of bare and straked pipe;
- open water tow test of 10-3/4in curved riser to investigate inclination effects on bare and straked pipe.

Shell Oil [10, 11]

- tow tank and flume to investigate VIV in sheared current, effectiveness of suppression devices wave interference effects and influence of VIV on wake interference;

Marintek, Norway

- rotating arm tank experiments on riser with staggered buoyancy to investigate suppression effects of variable cross-section.

Norwegian University of Science and Technology (NTNU) [12]

- tow tank tests on a 2.0m section of 10mm diameter pipe to determine the the interaction effects of multiple frequency components on lock-on.

Norsk Hydro, Hanoytangen Fjord, Norway [13]

- large scale tests on a 90m long 30mm diameter pipe to examine VIV in sheared current and influence of variation in axial tension on VIV response and wake interference effects between adjacent risers

The areas of investigation listed above cover a number of the previously identified uncertainties in current analytical methods. Many more are needed, however, particular those which can provide information on response at high Reynold's number, for which there is a relatively small amount of available experimental data.

FIELD MONITORING OF VIV

To complement the data provided by VIV laboratory experiments and further enhance VIV analysis tools, data is needed from riser arrangements which closely resemble real riser systems and conditions which simulate in-service environments. The extensive drilling activity in progress in many deep water locations provides an opportunity for providing valuable data at relatively little cost. Data has been provided from two such drilling programmes, as described below:

BP Schiehallion

- Paul B. Lloyd drilling riser in 375m water depth, accelerometers at 3 locations along the length monitoring over a period just longer than 1 month;

BP Nyk High [14]

- Ocean Alliance drilling riser in 1300m water depth, accelerometers at 5 locations along the length monitoring over a period of 74 days.

The data from both the above field experiments is currently being processed with the objective of calibrating analysis tools and required inputs such as Strouhal number and excitation bandwidths. The data from the Schiehallion work is also assisting in calibrating input assumptions for the riser tension contribution from drill string tension that is shown to have a significant influence on analysis results.

The data obtained from exploratory drilling programmes can be used to assist in predicting the response of production and export riser systems to be used in the same locations at a later stage. Further monitoring of in-service production and export risers is also needed, particularly steel catenary risers, where uncertainties in response adjacent to the touch-down point on the seabed are significant and the effects of varying flow direction on riser response need to be better understood.

A major decision affecting the equipment required for VIV monitoring in the field is whether on-line or passive monitoring is required. The former provides output directly to the surface vessel in real time, whereas the latter approach requires retrieval of monitoring devices for data processing.

On-line devices must be hardwired to transmit signal back to the vessel. Signal can be transmitted by way of telemetry, but the power requirements 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 so well-suited to drilling risers that are regularly disassembled. Routing of power and signal cables can add to installation time and cables may be damaged.

Passive monitoring systems typically consist of a number of autonomous monitoring devices which are strapped or clamped to the riser during running and removed following riser retrieval (drilling risers) or attached and retrieved by ROV (production and export risers). Processing of data can only be conducted following retrieval. However, unless an in-service programme of adjusting riser configuration to react to VIV is planned there are few benefits in adopting active monitoring devices. A possible concern with this type of approach is that the devices cannot be checked to ensure they are operating correctly. However, for long term programmes, malfunctions can be detected following retrieval and devices re-installed. The passive approach has been successfully implemented for monitoring VIV response of drilling risers both West of Shetland and in the Voring Basin, this approach will be used for the tow tests to be conducted as part of the STRIDE Phase II test programme.

FUTURE DEVELOPMENTS

Improved confidence in VIV analysis methods to reliably predict the response of real riser in real environments requires the ongoing accumulation of experimental data with which theoretical algorithms can be validated. Current and planned test programmes will significantly assist in these objectives, but there is still a considerable amount of further work needed to improve predictions of VIV fatigue damage for many planned riser systems.

The extensive drilling activity being conducted in deep water high current environments provides an ideal opportunity for collecting data on riser VIV response and assessing the effectiveness of suppression devices at high Reynold's number. It is important that this opportunity is not lost, and that the data is processed in a timely manner in order that VIV design of future drilling, production and export risers can be rationalised.

Some evidence is available to suggest that current predictions of VIV fatigue damage are conservative. As the application of suppression devices can be costly, possibly affecting feasibility, alternative design approaches may need to be considered for some production and export riser applications where VIV fatigue lives are marginal. A typical approach may consist of installing bare

risers and monitoring response in-service. Where fatigue life predictions are found to be conservative the use of suppression devices can be avoided. If predictions are unconservative, then suppression devices may need to be retrofitted or the riser replaced prior to expiry of the service life. Such approaches may prove extremely cost effective with the advent of low cost monitoring devices and recently developed suppression systems [8].

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