

Acoustics and Vibration Group

Bureau Veritas HS&E Ref: NSOX0277/1/JRB/CEN

17th October 2006

Re: Flow Induced Pulsation in Flexible Risers - JIP Phase 3 Proposal from Bureau Veritas HS&E Ltd and OTM Consulting

Executive Summary

Bureau Veritas HS&E (BV) and OTM Consulting (OTM) are pleased to present this proposal for a Phase 3 Joint Industry Project (JIP), for the assessment of flow induced pulsation in flexible risers. This document outlines the background to the Phase 3 project, the objectives, deliverables and benefits, then presents the proposed scope of work, JIP structure and participation details.

The JIP Phase 3 workscope is intended to continue on from, and extend the work of, the JIP Phase 2, by:

- Completing the High Pressure testing of actual 6" carcass sections, started in Phase 2, and evaluating the effect of the introduction of liquids into a "singing" riser;
- Extending the High Pressure testing to include representative prefabricated test sections that have been previously tested at low and medium pressures, and to evaluate the effect of the introduction of liquids into a "singing" riser;
- At low and medium pressures, obtaining quantitative test data for the assessment of the influence of the boundary reflection coefficients.
- Extending the Low and Medium pressure tests to include larger diameter corrugated pipe, and longer pipe lengths;
- Producing Source strength and Pressure Drop models, to then enable a executable Evaluation tool to be developed for submission to the JIP participants, i.e. which with carcass geometry and process conditions as input data, it will predict the static pressure drop, the onset velocity, and the frequency and maximum amplitude of the pressured pulsations;
- Should additional on-site data become available, then detailed analysis would be undertaken for inclusion in measurement database.

This CTRs will allow the critical process conditions and carcass profile characteristics to be determined for onset of the phenomenon, and hence help in the development of guidelines and procedures to avoid the problem, both for existing and future dry gas riser users.

Operators, flexible riser vendors and regulatory / verification organisations are all invited to participate.

A general "Information Day" for Phase 3 of the project is planned for October 23rd 2006 at the TNO facilities in Delft, The Netherlands.

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Subject to sufficient funds becoming available, the JIP Phase 3 would last 18 months. The total cost of the JIP is £225,000, with participation cost of £75,000 for Phase 1 & 2 members, £85,000 for Phase 1 only participants, and £95,000 for new participants to include access to the Phase I and 2 deliverables.

Please contact the OTM project manager with any queries about the proposal.

Yours sincerely

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1. Background

In the last 10 years, up to 8 offshore assets that utilise flexible risers for gas export are known to have experienced high levels of piping noise and vibration. This has resulted in at least two piping failures, and significant reductions in gas export rate to avoid the problem. The problem has been attributed to the vortex shedding phenomena within the flexible risers. The flexible riser carcass (innermost layer) has a corrugated profile. Vortex shedding from these corrugations, combined with feedback effects from associated piping acoustics, can lead to very high internal dynamic pressure levels. The excitation can be so extreme as to cause piping fatigue failures of small-bore connections on both topside and subsea piping.

The problem has been seen to occur for riser velocities as low as 1.5 m/s, which is potentially a severe limiting factor to the assets' production capabilities. To date the phenomenon has affected risers from both Wellstream and Coflexip. Bureau Veritas is currently unaware of an NKT riser experiencing the phenomena, however, the internal profiles of risers from all three manufacturers are very similar.

As the demand for gas export from deepwater fields is increasing, the likelihood of many more assets experiencing this phenomenon is high. Currently the problem is being handled by:

Improving piping integrity (bracing or removing potentially weak connections);
Modifying the topsides and subsea pipework design to the pressure pulsation magnification effects

Although these techniques are effective, they are very specific to each individual asset, so a more general solution is required. As this phenomenon is likely to affect many offshore operators, the most appropriate way of increasing the level of understanding and developing remedial solutions was deemed to be via a Joint Industry Project.

1.1 JIP Phase 2

Phase 2 of the JIP is currently coming to an end (October 2006) and the deliverables include:

- further increasing awareness of the problem (knowledge gained in addition to Phase 1);
- reporting on the results of testing of a broad range of prefabricated corrugated profiles in air at low and medium pressures (atmospheric to 16 bar), under laboratory conditions, to get a better understanding of:
 - the effective Strouhal Number;
 - the pressure loss associated with the onset of the phenomenon;
 - identification of the critical corrugation parameter – the “characteristic dimension”;
 - the effect of flow direction (relative to the corrugation profile)
 - the effect of pressure and flow velocity on the above;
 - prediction of the maximum pulsation amplitude and what factors influence it;
 - determination of the system damping.
- reporting of the results of testing of the limited number of actual riser carcass sections at low to medium pressures (2" diameter with air), and high pressures (6", 64 bar with Nitrogen), for comparison and contrast with the prefabricated test data.

1.2 Proposed JIP Phase 3

The “singing riser” phenomenon has been reproduced in scale testing with 2” diameter machined corrugations and various profiles in air, at both low and medium pressures (up to 16 bar). The impact of the corrugation profile, i.e. gap width, gap depth, pitch, and upstream and downstream edge radius, on the onset velocity and the vortex shedding frequency has been investigated, and their contribution is now considered to be understood. It is becoming increasingly clear however that the pipe diameter, the number of corrugations per unit length, and hence the carcass length are also significant factors, especially with regard to the pressure pulsation amplitudes and onset velocities. Similarly it has become apparent that the carcass acoustic boundary conditions, i.e. the detailed upstream and downstream pipework configuration, are critical for the phenomenon to occur.

To help quantify these effects in more detail, it is therefore proposed to significantly extend the testing of both the prefabricated and actual carcass sections, for example at LP and MP to include 3” and 4” diameter pipes and longer pipe lengths.

On completion of this additional testing, it is hoped that sufficiently rugged models can be developed to enable a prediction tool to be supplied as a project deliverable, i.e. with process, carcass and upstream/downstream pipework detail inputs, an onset velocity can be predicted, along with pressure pulsation amplitudes and frequencies, and static pressure droops.

2. Objectives and Deliverables

2.1. Objectives

The objectives of Phase 3 of the JIP are:

- (i) To complete the High Pressure tests in Nitrogen gas of actual 6” carcass sections using the revised test loop configuration, to enable a comprehensive analysis report to be written, comparing the results with LP and MP tests data, and test data from offshore investigations;
- (ii) To carry out High Pressure testing of a number of representative, prefabricated test sections that had previously been tested at low and medium pressures, to extend the previous evaluation to significantly higher pressures and test specimen lengths, and enable comparison with actual carcass sections;
- (iii) When a carcass of prefabricated test piece is found to “sing”, to determine the effect of the introduction of a liquid flow;
- (iv) To quantify the effect of various acoustic boundary conditions, (representing attached pipework configurations), ultimately to determine the susceptibility to this phenomenon of different topsides/subsea pipework designs;
- (v) To evaluate the use of “tuned absorbers”, i.e. additional pipe section attachments that could be used either retrospectively or at the design stage to reduce the impact of the “singing” riser phenomenon;
- (vi) Evaluate the effect of larger diameter or longer riser sections;
- (vii) From the results of the above and already completed work items, to develop both a source and a pressure drop model, which could then be used to develop a prediction tool, i.e. with carcass and process data inputs, to predict the frequency and amplitude of the pressure pulsations, the onset velocity, and the pressure drop;

2.2. Deliverables

The major deliverables are proposed as follows:

- (i) A comprehensive technical report detailing the results of the high Pressure testing measurements in Nitrogen, on three actual 6" riser carcasses, and the effect of flow direction, corrugation profile, flowrate and pressure on the onset velocity, Strouhal Number, and pressure pulsation amplitudes.
- (ii) A technical report detailing the results of the high Pressure testing measurements in Nitrogen, on up to five (5) prefabricated profiles comparable, ten chosen to extend the LP and MP measurements previously undertaken as part of Phase 2 of the JIP, i.e. to extend the frequency range. This would include the effect of flow direction, corrugation profile, flowrate and pressure on the onset velocity, Strouhal Number, and pressure pulsation amplitudes.
- (iii) A technical report detailing the results of LP tests on one prefabricated and one actual carcass test piece with varying upstream and downstream boundary conditions (acoustic reflection effects).
- (iv) A technical report detailing the results of LP and MP tests on existing prefabricated profiles, but with larger pipe diameters and longer test piece lengths.
- (v) Based on the results of the Phase 2 and Phase 3 testing, to develop:
 - a. A Source model tool (to predict pulsation frequency, amplitudes and onset velocities);
 - b. A Pressure Drop tool (to predict pressure drop down a "singing" riser carcass);
 - c. An Evaluation tool (an executable program implementing the above tools).
- (vi) Should additional field data become available, a summary report comparing the results with previous analysed offshore installations, and the JIP test data.

3. Benefits of Participation

Operators and Flexible Riser vendors are invited to participate in this JIP. The benefits of participating will include:

3.1. For Operators

Access to a fully developed theoretical understanding of the concern, validated by scale and full scale tests;

Opportunity to be involved in the development of generic guidelines on how to overcome the problem, and help define the optimum means of minimising the risk of a vibration induced fatigue failure

Guidelines for the measurement and assessment of the concern for both topsides and subsea pipework;

Dialogue with the Flexible Riser vendors, and the opportunity to influence the design of their products to your specifications;

An international focus for knowledge sharing.

3.2. For vendors

Knowledge sharing with both operators and other vendors;

Dialogue with operators, leading to better understanding of their requirements in the area of flexible risers;

Guidance on potential long terms modifications to risers.

3.3. For both operators & vendors

Leveraged funding - for a relatively small outlay, members will benefit from a full scale research and testing programme;

Access to all JIP deliverables;

Facilitated technology transfer into participating companies;

An opportunity for leadership within the JIP – members will be able to influence JIP workscope and priorities to ensure that the JIP results meet *your* needs.

4. Scope of Work

The scope of work for Phase 3 of the JIP, and associated budget estimate costs, are summarised in the attached CTRs. Note that these CTRs are provisional and their content and inclusion in Phase 3 are intended for discussion and agreement. Additional work items can be included based on the agreement of the Phase 3 participants.

5. JIP Organisation

Detailed JIP planning meetings held at least once between each steering group meeting.

Attended at least by OTM, the chairman and active contractors.

Minutes distributed by OTM.

All meetings will be open to all participants.

5.1. Structure

Bureau Veritas will be the main JIP contractor, with whom each participant will enter into a participation agreement. Overall JIP project management will be provided by OTM under subcontract to BV.

The JIP will be coordinated by a steering group, consisting of one representative from each participating operator and vendor organisation, a project manager from BV, and a chairman elected at the first meeting. OTM will provide secretarial services to the steering group.

For Phase 3 it is suggested that steering group meetings are held no more frequently than once every three months. This is open to discussion at the kick-off meeting as desired by JIP participants.

The steering group will be responsible for making all decisions regarding early termination and changes to the budget, work program for JIP procedure (see Participation Agreement). Working groups may be set up by the chairman as necessary to address specific issues, and hence occur at more frequent intervals than the steering group meetings, and can then be dissolved once the need has been met or withdrawn. Working groups may be assisted by OTM who will be responsible for regular progress reporting.

5.2. Participation

Participation is open to operators, flexible riser vendors, engineering contractors and regulatory /verification organisations. Each participant will contract directly with BV, and the contractual basis will be the Participation Agreement.

The total cost of Phase 3 is £225,000, with the participation fee of £75,000 for Phase 1 and 2 Participants, £85,000 for Phase 1 only operators, and £95,000 for new participants looking to join the JIP – these additional funds will give them access to all the Phase 2 deliverables. Three full (former) participants are required to progress the study and carry out the entire workscope. The steering group will make decisions regarding the disbursement of any additional JIP funds beyond the planned workscope.

All JIP participants will be entitled to one vote at steering committee meetings, and have the power of veto on external disclosure of background information brought by them to the study.

If fewer participants join than forecast, the JIP can still continue with a reduced, prioritised workscope and this is allowed for in the Participation Agreement.

Phase 3 invoices will be issued for full payment upon signature of the agreement.

Subject to the agreement of the steering group, late participants will be able to join the project upon payment of the full participation fee, whereupon they shall be entitled to the full deliverables.

5.3. Project Management

Overall project management for Phase 3 of the Flow Induced Pulsation in Flexible Risers JIP will be provided by OTM, working closely with BV. One of the main emphases of the project management task will be to add value to the JIP by promoting optimum technology transfer and learning between BV and the JIP participants, and between participants themselves. Specific project management activities will include:

Expediting of project kick-off, including discussion of any requested amendments to the JIP participation agreement with relevant participants and main contractor, and providing a central focus and assistance with ongoing contractual queries and issues.

Organisation of project progress meetings/ technical workshops, including planning, pre-meeting mail outs, development and management of all issues relating to venue, catering, accommodation, local travel, agenda, AV facilities, provision of meeting secretariat, facilitation, recording of minutes and subsequent drafting and circulation. It is anticipated that JIP meetings will take place approximately every 3 months after project kick-off.

Management of documentation, including receipt of all project reports (from main and subcontractors/others), updating of document register, uploading of reports to JIP website participant's area, and e-mail notification/ distribution of electronic report copies to all participants. Production of master CD-ROM comprising all JIP documentary deliverables at end of phase I (and subsequent phases) and distribution to all participants.

Management of project website, including ongoing site design, pass wording, site updating, responding to queries received, resolution of I.T. queries received from users. This website will have a restricted access participants area where participants will be able to download JIP deliverables, network with one another and access JIP progress information.

Teleconference calls will take place either every month or on completion of agreed milestone activities.

6. About the Contractors

6.1. Bureau Veritas

Bureau Veritas HS&E (BV) is a service company specialising in QHSE management, (quality, health, safety and environment) and social accountability, with a network that covers 140 countries and includes 550 offices and laboratories. It offers an extensive range of technical services and solutions in the field of certification, conformity assessment, consulting and outsourcing.

The workscope described in this document would be carried out / managed by the BV Acoustics & Vibration. This multidisciplinary engineering group has extensive experience of solving noise and vibration related problems in process piping systems, both on operational assets and at the conceptual, detailed design and commissioning stages of a new facility.

6.2. OTM Consulting Ltd

OTM is a firm of technology management consultants which assists its clients in the areas of technology commercialisation (market analyses, technology audits, finance raising, joint industry projects - Jip), knowledge sharing (lessons learnt, benchmarking, technology networks), technology strategy development, and market development (market/ economic studies, supply chain development). OTM has launched and managed more than 45 Jip in the last few years, with budgets ranging from \$20,000 to \$5mn, and has gained unparalleled expertise in this area. These projects include:

Cowes (configurable subset water separation system)
STRIDE (steel risers for deepwater environments)
SLOOP (deepwater production strategies simulation tool)
PEA (Production Engineering Association) Technology Transfer JIP
DOSI (database of Separator Internals)
Sea sense (a DTI LINK programme with many characteristics akin to that of a JIP)
SPEED (subsea power distribution)
HELIPS (advanced electrical submersible pump)
COREL (Corrosion resistant liners)

Clients include more than 30 oil companies worldwide, the DTI, HSE, contractors and technology suppliers. OTM strongly believes that the JIP service offered enables clients to focus upon the all-important technical issues, and ensures that programmes remain on course

in terms of meeting participants' quality, budget and timing expectations.

7. Contacts

Queries regarding this proposal should be addressed as follows:

For queries relating to JIP participation, organisation and management:

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Activity (CTR) Sheet	
Activity no.: 1	Description: Completion of NEL “improved piping design” tests
Objectives:	To complete the High Pressure testing of actual 6” carcass sections, so that a comprehensive set of measurement and analysis data is available for review against LP/MP measurements undertaken by TNO as part of Phase 1 and 2, and field data. Also to evaluate effect of liquid, and what concentration affects “singing”.
Activities:	HP tests using Nitrogen gas using: <ul style="list-style-type: none">• NKT (2 directions), 40 and 60 bar• FlexiFrance (1 direction) risers, 40 and 60 bar• with introduction of liquid into “singing” riser For flow velocities between 1.5 and 25 m/s.
Deliverables:	Technical report, including all measurement data, and including full comparison with previous NEL test data.
Budget cost:	£31k
Time scale:	3 months

Activity (CTR) Sheet

Activity no.: 2 **Description: Additional NEL High Pressure tests using manufactured-to-suit corrugated pipe sections.**

Objectives: To extend the previous NEL high pressure testing to include representative (but not actual carcass) sections, e.g. similar to previous TNO LP/MP tests, so that the effect of 10 metres long corrugation profiles can be more fully evaluated at high pressures. Also to evaluate the effect of introduction of liquid, and what concentration affects "singing".

Activities: HP tests using Nitrogen gas using up to five, 10 metre long, representative (to be agreed) prefabricated profiles, for at least 2 pressures (40 and 60 bar), and for a range of flow velocities (minimum of 1.5 to 25 m/s).

Deliverables: Technical report, including all measurement data, and comparison with LP and MP test data.

Budget cost: £46k

Time scale: 4 months

Activity (CTR) Sheet	
Activity no.: 3	Description: Influence of boundary conditions
Objectives:	Using experimental measurements and subsequent analysis, the effect of the test section end conditions on the onset and characteristics of “singing” carcass/test specimens will be evaluated, to help determine the influence of topsides/subsea pipework acoustic characteristics. Also to evaluate the effect of the introduction of tuned absorbers and how they might be used to affect the concern.
Activities:	Using representative test sections (minimum of 1 fabricated + 1 actual carcass section) both the upstream and downstream boundary condition will be varied (orifices, volumes, side branches). The standard parameters (frequency, amplitude) will be measured to obtain the influence of the boundary reflection coefficients. The base measurements will be done for a range of low pressures. Some high pressure validation tests may also be performed. In this series of experiments the tests can include the introduction of controlled liquid volumes into a “singing” system.
Deliverables:	Technical report, including all measurement data. Input data for developing an evaluation tool. Engineering guidelines for evaluating the influence of boundary conditions, (pipework at either end of a flexible riser).
Budget cost:	£21k
Time scale:	4 months

Activity (CTR) Sheet	
Activity no.: 4	Description: Scaling effects/rules
Objectives:	From LP and MP tests, the effect of corrugation volume appears to be significant and hence it is proposed to evaluate this factor, through measurements of longer test section lengths, and large diameters.
Activities:	In almost all the experiments (at 2") the effect of the corrugation volume is seen. To validate this behavior it is proposed to extend the measurements to larger scales. The frequencies, amplitudes and onset velocities will be measured for different tubes sizes with (near) identical corrugations. The experiments will be done with tube sizes of 2", 3" and 4" at different lengths. The base idea is to use long lengths of readily available corrugated tubes
Deliverables:	Technical report, including all measurement data. Scaling rule
Budget cost:	£24k
Time scale:	3 months

Activity (CTR) Sheet	
Activity no.: 5	Description: Prediction tool development
Objectives:	To produce a series of prediction tools which can be used in combination to determine the gas riser operating envelop with the minimum risk of flow induced pulsation.
Activities:	To develop: <ol style="list-style-type: none">1. A Source model: combining the results of the LP/MP and damping experiments it should be possible to develop a "source model" for a range of different test geometries. Used with an acoustic analysis of the measurement systems, the model should then be able to be used to predict the pulsation frequency, amplitudes and the onset velocities.2. a Pressure drop model: through detailed analysis of previously recorded pressure drop data, develop pressure drop models for all the test geometries, so that a generic pressure drop model can then be used for corrugated tubes.3. An evaluation tool (executable): A software tool will be developed for submission to the JIP participants, which with carcass geometry and process conditions as input data, will calculate the static pressure drop, and the frequency and maximum amplitude of the pressured pulsations as output data, (As noted in our previous meeting, we will have to discuss and agree the Intellectual rights associated with this item).
Deliverables:	Tools as described above
Budget cost:	£53k
Time scale:	3 months

Activity (CTR) Sheet	
Activity no.: 6	Description: Field data analysis
Objectives:	Should additional on-site data become available, then detailed analysis would be undertaken (subject to information supplied) to identify onset velocity, Strouhal Number, etc.
Activities:	Review and analyse field data, including detailed process conditions.
Deliverables:	Technical report detailing results and conclusions, and comparison with previous field data.
Budget cost:	£5k per system.
Time scale:	1 month per system.

Activity (CTR) Sheet	
Activity no.: 7	Description:
Objectives:	JIP management services.
Activities:	<ul style="list-style-type: none">• Facilitation of Phase 3 launch meeting & subsequent minutes• Identification of potential additional participants• Secretariat role acting as a single point of contact and coordination• Responsible for progress reports etc• Workshop / meeting organisation and facilitation• Updating and maintenance of the JIP website• Management of project documentation• Responsible for project publicity
Deliverables:	As above.
Budget cost:	£35k, (or 16%)
Time scale:	Duration of project.

Activity (CTR) Sheet	
Activity no.: 8	Description: BV Technical management fee
Objectives:	Technical management fee
Activities:	<ul style="list-style-type: none">• Hosting project contracts• Overall responsibility for technical aspects of projects• Setting up project• Control and review of project deliverables• Assimilation of final deliverables for delivery to project sponsors.
Deliverables:	As above.
Budget cost:	£10k, (or 5%)
Time scale:	Duration of project.