DET NORSKE VERITAS

Proposal for:

Syrope JIP - Global Performance of Synthetic Rope Mooring systems

DNV Reg. No.: 1-3I287D-NTANO713-2
Rev. 0, 2011-11-04

MANAGING RISK

Proposal title: Syrope JIP - Global Performance of Synthetic Rope Mooring systems		DET NORSKE VERITAS AS P.O.Box 300 1322 Høvik, Norway Tel: +47 67 57 99 00 Fax: +47 67 57 99 11 http://www.dnv.com Org. No: NO 945 748 931 MVA
Customer:	Multiple	
Customer Address:		
Customer Reference:		
Contact Person:		
DNV Legal Entity:	Det Norske Veritas AS	
DNV Reference:	1-3I287D-NTANO713-2	
Date of Issue:	2011-11-04	
Validity of Proposal:	3 months from date of issue	
Terms and Conditions:	See section 8, Contractual	
Prepared by/Contact Person: Erik Falkenberg	*Position:* Principal Engineer	*Signature:* Erik Falkenberg
Reviewed by: for Srinivas Vishnubhotla	*Position:* Senior Engineer	*Signature:* Oddan [illegible]
Approved by: Turid Storhaug	*Position:* Business Developer	*Signature:* Turid Storhaug

This proposal is business sensitive to DNV and is being transmitted as confidential. No part of the proposal may be duplicated or used, or disclosed for any other purpose.

Table of Contents

1 INTRODUCTION

1.1 Background

There is a growing interest in using fiber ropes for both permanently moored floaters and drilling rigs. For deep and ultra-deep water applications, synthetic fiber ropes are considered an enabling technology due to their higher strength-to-weight ratio as compared to steel wire ropes and chains and due to the superior station-keeping performance. In shallow water the lower elastic stiffness of synthetic fiber ropes compared to steel systems may drive the selection of material for the mooring lines.

Synthetic fiber ropes have visco-elastic stiffness and stretch characteristics. The change-in-length response of a fiber rope is non-linear, load path dependent (different unload-reload stiffness), and varies with the rate as well as the duration of loading (creep and retraction).

The current design practice is to use a simplified and conservative approach wherein a lower or an upper bound stiffness is used depending on the type of expected response (quasi-static post installation, cyclic storm loading). This simplification is primarily due to two factors:

1. The industry at large does not have a common, well-defined understanding of fiber-rope change-in-length performance.
2. There is a lack of commercially available mooring analysis programs with the capability to simulate the non-linear change-in-length response of the synthetic fiber rope.

1.2 Pilot study

DNV has run a pilot study for developing analysis methods for fiber rope mooring systems. The study was performed under contract with Statoil and a part of the work was sub-contracted to Marintek andJohn Flory of Tension Technology International was used as an advisor. The work that was performed has covered:

- Analysis of previous tests and new tests based on recommendations from the “Improving Fiber-Mooring Design Practices” JIP. The rope samples were exposed to prescribed tension variations and the resulting strain was measured. Rope parameters were identified based on spring-dashpot models and valuable insight into the behavior of a polyester rope was obtained.
- A model for analysis of fiber rope systems in the frequency domain was proposed and a case study was performed showing that the conservatism in traditional design can be reduced. More information is presented in Ref. /1/.
- A finite element program (Riflex) was modified in order to include a ratchet mechanism which was found important for modeling of fiber ropes. Robustness of the implementation was demonstrated.

In order to bring the analysis models to a mature level, more work is needed, and will be sought financed through the new JIP proposed herein.

1.3 Motivation

In recent years, there have been significant advances in the synthetic fiber rope technology, in particular with polyester fiber. However, there is a lack in consensus among the designers on the interpretation of change-in-length properties, and hence selection of appropriate stiffness values and rope stretch. Testing techniques developed on fiber rope mechanical stiffness properties in the "Improving Fiber-Mooring Design Practices" JIP must be supplemented with proper analysis methods to get reliable global performance response. The motivation for DNV to launch this Joint Industry Project (JIP) is to provide the industry with improved methods for a safe and reliable design of synthetic fiber rope mooring systems that utilize the new knowledge from the recent JIP project and the pilot study.

1.4 Benefits

The JIP will seek to improve the design methods for synthetic fiber rope systems. The benefits for the participants in the JIP include:

- Access to high quality test data for fiber ropes.
- Detailed insight into the change-in-length behavior of synthetic rope and thereby also the conservatism of the present design approach.
- Utilizaton the new knowledge to refine the design methodology and thereby enable optimization of mooring systems. A smaller dimension of the synthetic rope will reduce dynamic tensions and thereby also the fatigue loads on the steel components in the mooring lines.
- Algorithms for developed methods which can be implemented into mooring analysis software.
- Method to determine accurate length of polyester rope for manufacturing, installation and in-service.

1.5 Joint Industry Project

The proposed JIP will be based on the "Improving Fiber-Mooring Design Practices" JIP and the pilot study carried out for Statoil. These projects have proposed new ways forward both for rope testing and for analyses. Additional development is however still required. The objective of the JIP is to provide the industry with improved methods for analysis of synthetic fiber rope mooring systems both for long-term and mobile mooring. The final delivery will be a guideline for the analysis of such systems.

This JIP will focus on:

- Testing of fiber ropes, using recommendations from the previous JIP and experience from the pilot study.
- Development and validation of a method for implementation into concept and early design stage tools (i.e. frequency domain programs).
- Development and validation of a method for implementation into final design and verification tools (i.e. time domain programs).
- Case studies.
- Development of a guideline for analysis of fiber rope mooring systems.

2 SCOPE OF WORK

2.1 Rope testing

Figure 1 Rope testing machine “Bristle Worm”.

Rope testing will take place in DNV’s laboratory, and will be performed on sub-ropes. Experience gained in the previous JIP will be applied to maintain the considerably higher accuracy of measurements compared to traditional testing.

From the pilot study a set of 4 documentation tests and 3 model improvement tests have been proposed. These tests include rapid loading and unloading as well as cycling with regular tension variation and irregular tension variation. An example of the latter is presented in Figure 2.

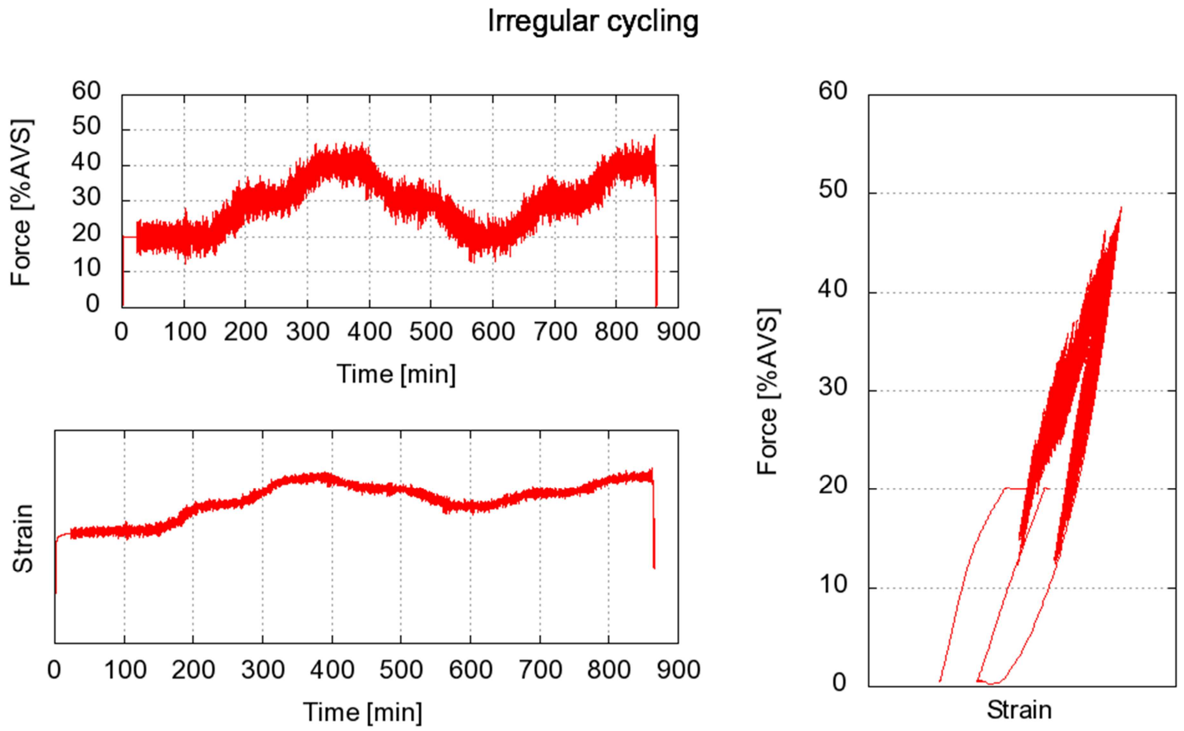

Figure 2 Example of irregular cycling test

In the pilot study only one type of polyester rope was tested. It is proposed to perform these tests for ropes from different manufacturers, including both polyester and other fibers. The number of ropes to be tested will depend on the available funding.

2.2 Method development

2.2.1 General

The work will include method development for both frequency domain and time domain analyses. The rope specification will as far as possible apply the same material model for both cases. The models must cover the properties of irreversible stretching.

The model may comprise different 'levels' of specification:

- Advanced, including known, quantified parameters based on the spring-dashpot model.
- Simplified, replacing the most uncertain features by approximations (e.g. representing lower and upper bounds of some response, such as creep).

New material models may pose new requirements to specifications of environment, vessels, winches and/or anchors. This will be evaluated.

The assumption of stationary conditions is a challenge when synthetic rope is part of the mooring system. It is known from previous testing that the short-term properties of synthetic rope will depend upon its tension history. In a frequency domain model, the notion of history (or time or chronology) is not defined. To specify the condition of a synthetic rope in order to distinguish it from a new rope, it is necessary to have a *condition* parameter. Together with the data for a brand-new rope, the condition parameter will uniquely describe the present properties of the rope. One simple candidate for the condition parameter could be the highest tension level the rope's fibers have previously been subjected to.

A frequency domain approach can compute the responses of motion and mooring tensions under given stationary metocean conditions. This gives the statistical parameters of the responses directly. These include standard deviations, expected maxima and average periods. This is in contrast to time-domain simulation, which gives time history samples of the responses that must be processed to give *estimates* for the statistics.

In a time domain approach, it is relatively simple to implement the change of material properties during a short-term period. Once a common material model has been developed, the results from a time domain approach can be used to calibrate the frequency domain model.

The methods developed will be of a general nature that is suited towards implementation in most mooring analysis software.

2.2.2 Frequency-domain model

The frequency domain model developed during the pilot study is based on the assumption that each line operates on a non-linear working curve that depends on the previous maximum tension the line has experienced. An example is presented in Figure 3.

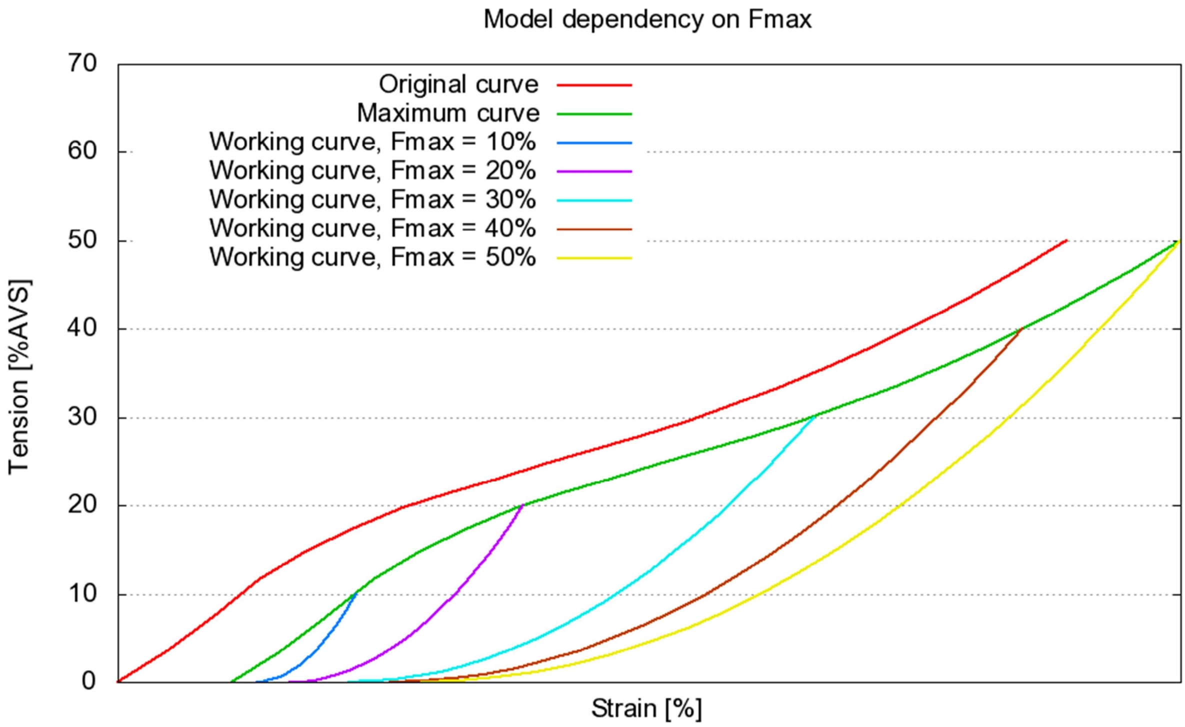

Figure 3 Working curves – dependency on previous maximum tension

Improvements to the frequency domain model will be developed based on the results from the new tests. The working curve may not only depend on the maximum mean tension but also on minimum tension after the maximum tension. Alternatively, contraction of the rope can be modeled by decreasing the apparent maximum tension as time elapses with the rope at a lower tension level.

The frequency domain approach separates the response in three parts:

1. Mean response (displacements and tensions) caused by the mean environmental loads
2. Low frequency (LF) response
3. Wave frequency (WF) response

Appropriate modeling will be established for all of these parts.

2.2.3 Time domain model

The time domain model will be based on a finite element model of each mooring line. Based on the spring-dashpot model in Ref. /2/, various model formulations will be evaluated and parameters in the models will be estimated. This will challenge the usefulness of simple linear components in the model. The ability to capture the effect of rope elongation when exceeding the previous maximum tension will be particularly considered.

The present method for calculating the expected maximum tension during a storm may require modification. If the storm is of such severity that it will alter the rope's condition, the response model will no longer be stationary. This is a complicated case in that the expected minimum safety margin for the rope during the storm will not only depend on the number and the distribution of the LF and WF motion cycles, but also of their succession.

2.3 Case studies

Frequency domain response calculations are relatively fast, and it is therefore possible to perform a large number of calculations for different environmental conditions within a reasonable time.

When the environment can be described as a sequence of states with a natural development, either observed or hindcast, the calculation can be performed as follows:

- Basis is working curve for previous max tension.

1. Calculate stressfree length based on previous tension and dynamic stiffness.
2. Equilibrium mooring calculation.
3. Repeat from 1 until convergence.

- Begin from start with new working curve if previuos max tension is exceeded.
- Dynamic calculation when all iterations are completed

For time domain case studies it will be of particular interest to study how the system behaves as a storm builds up, and how the statistical distribution of tension peaks depend on large waves and wave groups occurring early or late in a short-term seastate of duration 3 hours.

For frequency domain studies it will be of interest to study how the status (previous maximum tension) develops for a sequence of seastates,and how the mooring lines should be initialized for an ULS condition. It will also be investigated whether the load-limiting feature when exceeding the original curve is important to account for in such analyses.

It will also be investigated with basis in the results from the advanced analyses how more simple design analyses can be performed.

Case studies will be defined in discussion with the Steering Committee.

2.4 Recommended practice

After a confidentiality period the guideline delivered by this project will be implemented as an update to the Recommended Practice DNV-RP-E306 'Design, Testing & Analysis with Offshore Fibre Ropes'. This RP is due in its first version when the confidentiality period of the previous JIP expires in April 2013. The document will include the following:

- Specification of test procedures
- Estimation of parameters from tests
- Method descriptions for advanced time domain and frequency domain analyses
- Recommended methods for simplified analyses

The DNV recommended practices are stand-alone documents that summarize best industry practices in the opinion of DNV, and as such do not form basis for DNVs services per se.

3 DELIVERABLES

Table 3-1 JIP Activities

CTR	Task	Deliverable
0	Administration	
1	Rope testing	Report, test data
2	Frequency-domain model	Report
3	Time domain model	Report
4	Case studies	Report
5	Guideline	Report

4 SCHEDULE

The JIP is planned to be completed in 24 months. The proposed schedule for the project is presented below. Final commitment to the project schedule and delivery dates is pending agreement of the actual project scope of work and project milestones.

5 ORGANISATION

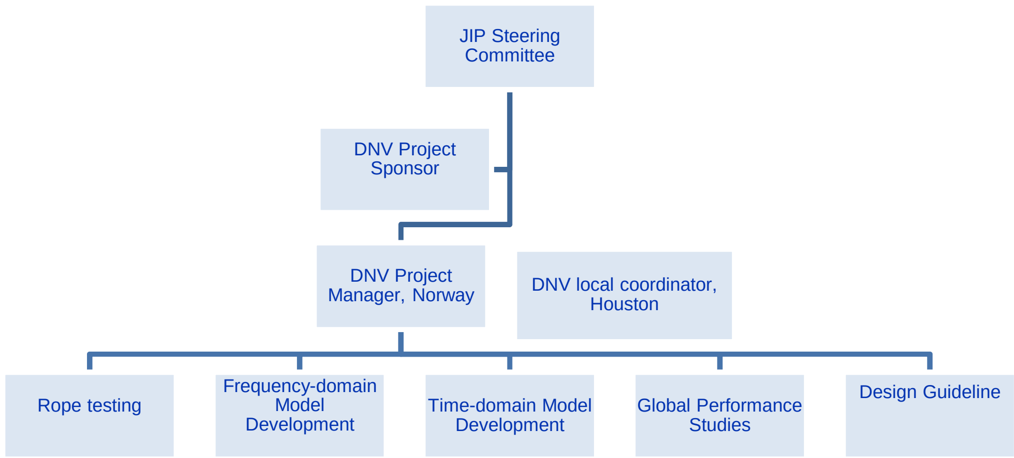

Figure 4 Project organisation chart

The project will be managed by DNV and will report to the JIP Steering Committee with 1 vote for each participating company. The chairman will be elected by the Steering Committee.

Parts of the work may be sub-contracted to organizations such as MARINTEK which has participated in the pilot study, and Tension Technology International (John Flory) who was used as a discussion partner in the pilot study and a subcontractor in the previous JIP. DNV has leading laboratory facilities and in-depth knowledge on fiber rope behavior and development and use of codes for mooring system analyses.

6 LIST OF JIP REFERENCES

DNV has a comprehensive reference list of successfully managing Joint Industry Projects. Most of the DNV-Recommended Practices have been developed by Joint Industry Projects. We have currently three ongoing or recently completed JIPs within fiber rope mooring-related activities. These are listed below in Table **6-1**.

Table 6-1 Completed and ongoing JIPs on fiber ropes and mooring managed by DNV

Name	Participants	Result
Fiber Rope Damage Assessment and Acceptance Criteria	Petrobras, BP, Chevron, ConocoPhillips, Shell, ExxonMobil, Statoil, Marathon Oil, Texaco, Norsk Hydro.	DNV-RP-304, “Damage Assessment of Fiber Ropes for Offshore Mooring”
Improving Fiber-Mooring Design Practices	Statoil, BP, Shell, Chevron, Atlantia, APL, Petrobras, Sevan Marine, Viking Moorings, Exxon.	DNV-RP-306, “Design, Testing and Analysis of Offshore Fiber Ropes” – to be issued

Name	Participants	Result
Managing the Safe Service Life of Fiber Ropes for Mooring	BP, Statoil, Anadarko, Shell, Chevron, Atlantia, APL, Sevan Marine, Petrobras, Performance Fibers, Exxon	DNV-RP-304 – to be issued The SSA[1] method.
Certification of Deepwater Installation Systems	30 companies; operators, installation contractors, manufacturers.	Ongoing JIP. DNV-OS-E407 'Offshore Installation Systems'. Phase 1 project report issued 2011.
NorMoor	BP, Statoil, GDF Suez, Det Norske Oljeselskap, Total, BG, Petrobras, APL Delmar, SBM, Vryhof Anchors, PSA, Vicinay Cadenas, Moorlink	Ongoing JIP. Aims at recommending improvements to design standards for mooring lines using reliability-based calibration.

7 COMPENSATION

The estimated cost for each task is presented in Table **7-1**. The scope may be adjusted in case the target budget is exceeded. In such case there will probably be room for more case studies.

Table 7-1 Estimated cost of minimum scope

CTR	Task	Cost (NOK)
0	Administration	500.000,-
1	Rope testing	500.000,-
2	Frequency-domain model	500.000,-
3	Time domain model	1.000.000,-
4	Case studies	750.000,-
5	Guideline	250.000,-
	Total	3.500.000,-

Operators, engineering companies and rope manufacturers are invited to sponsor this JIP. The participation fee for each category is provided in Table **7-2**.

Governmental bodies can apply for participation free of cost, but will in such case not have any vote in the Steering Committee.

[1] The Safe Service Assessment method has been developed by DNV in the Managing the Safe Service Life of Fiber Ropes for Mooring JIP, which has established a design-curve approach to rope endurance under high sustained tension. This method is based on the Time-To-Rupture theory and is currently being applied by operators (participating in that JIP) in place of an insert-retrieval based condition-monitoring program. This method has already proved its value to the industry, with the first FPSO classed by DNV in 2004, and with several more to date.

Table 7-2 Participation Fee

Category	Continuing Participants from the "Improving Fiber-Mooring Design Practices" JIP	New participants
Oil company, Statoil	NOK 0,-[2]	
Oil companies, other	NOK 800.000,-	NOK 1.100.000,-
Other companies	NOK 400.000,-	NOK 700.000,-
Governmental bodies (e.g. PSA, NMD, HSE, BSEE, Coast Guard, etc)		Free

Suppliers of fiber ropes may be accepted based on in-kind contribution in the form of rope samples for testing. The conditions for such participation will be decided by the steering committee when the project has been established.

8 CONTRACTUAL

A contract between DNV and each of the participants will be signed. Our proposed terms and conditions can be provided upon request.

DNV is presently running the NorMoor JIP. That project aims at recommending improvements to design standards for mooring lines using reliability-based calibration. These objectives are formulated relative to the ultimate limit state for mooring line design.
DNV will use experience obtained in this JIP within the limits of the confidentiality requirements to enhance the results of the NoorMoor JIP as relevant.

9 REFERENCES

/1/ Falkenberg, E., Åhjem, V, Larsen, K, Lie, H and Kaasen, K.E.: "Global Performance of Synthetic Rope Mooring Systems – Frequency Domain Analysis", OMAE2011-49723

/2/ Flory, J.F., Åhjem, V. and Banfield, S.J, "A New Method of Testing for Change-in-Length Properties Of Large Fiber Rope Deepwater Mooring Lines", OTC 18770, May 2007.

[2] Statoil will contribute in-kind with results from the Syrope Pilot study with a value exceeding NOK 800.000,-

Det Norske Veritas:

Det Norske Veritas (DNV) is a leading, independent provider of services for managing risk with a global presence and a network of 300 offices in 100 different countries. DNV's objective is to safeguard life, property and the environment.

DNV assists its customers in managing risk by providing three categories of service: classification, certification and consultancy. Since establishment as an independent foundation in 1864, DNV has become an internationally recognised provider of technical and managerial consultancy services and one of the world's leading classification societies. This means continuously developing new approaches to health, safety, quality and environmental management, so businesses can run smoothly in a world full of surprises.

Global impact for a safe and sustainable future:

More on www.dnv.com