

Joint Industry Project Proposal from TTI

Develop Effective Moorings for Tanker and Gas Carrier Terminals Exposed to Waves



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Internal Distribution:

TTI Ltd.: S. Banfield, A. Ractliffe, J. Flory, R. Hobbs, J. Nichols, K. Black, N. O'Hear

Tension Technology International Ltd

36 Huggetts Lane, Eastbourne, Sussex, BN22 0LU, UK

Tel: +44 (0)1323 504167, Fax: +44 (0)1323 509770, www.tensiontech.com

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1. Introduction

Tanker and gas carrier moorings built in locations exposed to waves and swell face restrictions in order to limit vessel excursions and mooring line tensions.

There is no industry consensus, guideline or code of practice applicable to gas carrier and tanker moorings exposed to waves and swell. An OCIMF guideline states that 11m tails should be used, and many operators take this as an absolute requirement. Yet recent work has shown that longer tails are necessary to make a gas carrier mooring safe where vessel motions are significant.

There is a need to better understand the following issues that influence the mooring system

- Properties of mooring lines and tails
- Selection of tail material eg nylon, polyester pp/pet, HMPE
- Fatigue life of tails
- Inspection and retirement criteria for fiber rope mooring lines and tails
- Use of constant tension winches to supplement breasting mooring lines
- Effect of ship size, hull shape and load condition on vessel motion
- Effect of under keel clearance (UKC) on vessel motion
- Effect of double wave spectra on vessel motion

The principal focus of most of the work will be on gas carriers. Most of the results of this study will also be applicable to tankers, including the ship motion data.

1.1 Codes, Guidelines, Resources and Other Studies

Where applicable, British Standards design code (Ref 1) will be followed for the analysis examples.

Guidelines published by OCIMF (Refs 2, 3, 4) and SIGTTO will be used where appropriate. These do not specifically mention of effects of wave motions. SIGTTO gives guidance on typical wave heights, but does not mention how to do any analysis or design a mooring in an exposed location.

The Optimoor Seakeeping mooring analysis computer program will be used extensively to analyze mooring line loads and vessel motions induced by waves (Ref 5).

The industry standard AQWA™ ship motion software from Century Dynamics will be used to generate the ship motion data files.

The latest R & D studies by TTI on rope properties will be used for input on axial stiffness and fatigue life properties for the mooring lines and tails (Refs 6, 7, 8, 9, 10).

2. The JIP Proposal

2.1 Objectives

TTI propose to organize and conduct a JIP based on accomplishing the following objectives.

To identify and establish;

- a. the important environmental parameters for input to mooring analyses. These include current, wind, wave height, direction, period and how they affect the mooring response in terms of peak line loads and vessel motions
- b. how the mooring system affects the mooring response, particularly with different lengths of tails and material type
- c. if it is possible to alter the mooring response by using supplementary breasting constant tension winches or by changing the mooring system layout
- d. the effects of ship size, hull shape, load condition, and water depth on vessel motion
- e. guidelines on selection of tail material, length, and construction to optimize response and fatigue life
- f. guidelines for fibre rope and tail retirement criteria based on fatigue analysis and on examination and inspection.
- g. wear of fibre wire rope in fairleads by cyclic load testing

This JIP will achieve the aims and objectives listed above, and provide a report detailing the investigations, analysis, example studies and results.

2.2 Types of JIP Participants

It is anticipated that the participants in the JIP would include:

- a. Gas Companies
- b. Jetty design contractors/ship designers, port authorities
- c. Oil companies
- d. Ship management companies
- e. Fibre and Rope manufacturers
- f. Equipment manufacturers
- g. OCIMF/SIGTTO

2.3 Organisation and Steering Committee

TTI will be the main JIP contractor, with whom each participant will enter a JIP agreement.

TTI proposes that the sponsors of the JIP form a Steering Committee and that they elect a Chairperson to organize and manage the committee. The Steering Committee will then provide key guidance to TTI as they perform work on the project.

Three meetings are planned, one at launch, an interim meeting and a final meeting.

2.4 Deliverables

Deliverables to participants in this JIP include:

Bi-monthly (brief) status reports and a final report (text, figures and pictures) fully describing the work and results obtained on the objectives listed in 2.1.

A stand alone program to calculate ship motion for open water, piled jetty, 6 degrees freedom for any monohull.

A stand-alone program to estimate fatigue life of mooring lines.

An upgrade to the latest version of Optimoor Seakeeping together with the ship motion data files generated for the range of ships in this study (for operator tickets only). A new feature to be included in Optimoor Seakeeping will be the fatigue life calculation for the mooring line and fibre tail.

For the £1,500, £5,000 and £10,000 ticket price the stand alone fatigue calculation program will be provided, but the ship motion files will not be made available. The user will be able to enter a motion (or load range) and the program will calculate fatigue life.

Draft guideline for the selection of tail material, length, and construction to optimize vessel response and rope fatigue life.

Draft guidelines for the examination, inspection, and retirement of fiber rope mooring lines and tails.

3. TASK SUMMARY

3.1 Environmental parameters

The influences of environmental parameters - wind, wave, current - will be assessed using the Optimoor Seakeeping mooring analysis computer program. This can be based on a real berth or by developing a generic environment data set by the committee.

The main emphasis will be on studying the effect of waves and the motions they induce in the vessel. The 1st order wave-induced effect on vessel motion will be investigated, because it is especially of concern. Particular attention will be given to the influences of wave height, wave period, and wave spectra.

3.2 Mooring Lines and Tails

The 1st order vessel motions can cause high mooring line loads and fatigue in mooring lines, and although these motions cannot be reduced by the mooring system, they can be absorbed by appropriate choice of line.

However, the downside of such a change is that this increases the static component (mean wind, wave drift, current) of vessel offset. So any design must be a compromise between the two effects.

One method of increasing compliance is by using different tail materials and/or length. Another method is to move away from traditional steel wire and tails to all synthetic fibre moorings, as already carried out by some companies that have switched to all HMPE lines and tails. These options will be analysed using Optimoor Seakeeping to study how they influence peak line tension, fatigue life, vessel offset and fender loads.

3.3 Supplementary lines, shore winches

The use of shore or vessel based constant tension winches, to supplement the existing mooring system in a breasting direction only, will be studied to see how much influence they have on peak line tension, vessel offset and fender loads.

Optimoor Seakeeping analysis of one vessel and one berth will be run for a wave environment. One vessel and one berth for which high current forces are generated will also be analysed.

This activity will form part of the study in section 3.1 and 3.2.

3.4 Effect of water depth, vessel geometry, vessel load condition

The Optimoor Seakeeping program uses wave motion files to calculate 1st order wave-induced vessel motions. Three wave motion files for calculating ship motions have already been generated for Moss, Technigaz MkIII and Gaz Transport vessel hull forms.

The sensitivity of wave induced motions to variations in hull form will be investigated by plotting a superposition of analyses using the available wave motion files. Another set of wave motion results will also be generated for a simplified hull geometry, keeping the same principal dimensions, block coefficients and GM's, but without detailed modelling of bow and stern. These results will be compared with those from the more detailed representation of the hull models of specific LNG ships.

Depending on the degree of agreement** in the above comparison, a decision would be taken at this stage as to whether the subsequent ship motion analyses use a) realistically detailed hull models, or b) simplified generic hull shapes. The advantage of option b) is that it would considerably reduce the amount of work required to cover a given combination of ship types and geometries.

**A confidence fit of 10% should be applied to the hydrodynamic coefficients (added mass and damping) and not to RAOs.

If the simplified hull shape is not acceptable in the above context** and option a) is followed, we propose to examine three sizes of LNG ship, and three sizes of tanker. The following matrix of geometric parameters would be covered (non-dimensionalised wrt Breadth):

Three Length/Breadth ratios (ship geometries): 5, 6, and 7

Four Draft/Breadth ratios (load conditions): 0.2, 0.3, 0.4 and 0.5

Two Trim/Breadth ratios (load conditions): 0, and 0.1

Twelve Clearance Ratios (effect of water depth) defined as $\text{Breadth} / (\text{Breadth} + \text{Bottom Clearance})$ and 0 = deep water:

0, 0.2, 0.4, 0.5, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9 and 0.95

The full combination of parameters above will generate about 5 times the existing ship motion data for Optimoor Seakeeping for LNG and oil tankers in sea-states of any height from any direction, with wave periods from about 4 to 20 seconds.

If on the other hand option b) is acceptable in the context of the mooring parameters of the JIP, allowing the simplified hull shape, we propose to examine a wider range of ship geometries. We envisage the following:

Four Length/Breadth ratios (ship geometry): 3, 5, 7 and 9

Eight Draft/Breadth ratios (load condition): 0.07, 0.1, 0.14, 0.2, 0.28, 0.4, 0.56 and 0.8

Two Trim/Breadth ratios (load conditions): 0 and 0.1

Three Block Coefficients (ship type): 0.75, 0.85 and 0.95

Twelve Clearance Ratios (effect of water depth) defined as
Breadth / (Breadth + Bottom Clearance):
0, 0.2, 0.4, 0.5, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9 and 0.95 from deep to shallow water

The full combination of parameters above will generate about 50 times the existing ship motion data for Optimoor Seakeeping, and should cover the majority of tanker and other monohull shapes and sizes in sea-states of any height from any direction, with wave periods from about 4 to 20 seconds.

3.5 Guidelines for Tails

Tension Technology International has extensive experience with fibre ropes. This experience and the results of the above investigations will be used to prepare draft guidelines for mooring line tails. This will include guidance on the selection of fibre materials, rope constructions, and tail length.

3.6 Develop Fibre Rope Inspection and Replacement Criteria

The fibre rope inspection and replacement criteria published for marine hawsers are based on very old experience and knowledge (Ref 2, 11). They are not necessarily applicable to the rope constructions and materials now used as mooring lines and tails and for the forms of wear which mooring lines and tails experience. Other published inspection and replacement guidelines for fibre rope are based on general rope service and are not usually applicable or useful for marine hawsers. (Refs 12, 13).

A test program will be conducted to develop fibre rope inspection and replacement guidelines applicable to shipboard mooring lines and tails. It will consist of two phases:

- * Retrieval of representative examples of fibre rope mooring lines and tails from actual service, detailed examination, measurement, and documentation of the damage and wear, followed by break testing to determine the remaining rope strength.

The techniques to be used in this phase of the study are described in a recent technical presentation (Ref 14). The techniques are patterned after a successful program conducted at Exxon in the early 1980's (Ref 15).

- * Inducing external abrasion and cut damage to representative new ropes of representative materials and construction in the laboratory, measurement and documentation of the damage and wear, followed by break testing to determine the remaining rope strength.

This effort will be patterned after some of the work performed by the OCIMF in the recent OCIMF trial prototype rope test program and may employ the external abrasion test method developed in that program (ref 16). It will also be patterned after the work performed in the recent DNV (Ref 17) and MMS (Ref 18 Minerals Management Service) program to develop inspection guidelines for deepwater platform mooring lines, to which TTI were technical consultants.

The inspection and discard criteria of existing OCIMF (Ref 2) and ACI (Ref 12) documents will be reviewed and the adequacy of those techniques discussed.

Results of the testing program described in Section 3.8 will be used to supplement this work, since it will provide valuable knowledge on wear and fatigue mechanisms (flex, compression) and residual strength data.

The goal is to prepare ship-board mooring line and tail fibre rope inspection and retirement guidelines which relate remaining rope strength to:

- photographs and illustrations showing appearance of wear and damage
- quantifiable observations and measurements of wear and damage

3.7 Fatigue life of tails and mooring lines

Optimoor Seakeeping will be modified to estimate the fatigue life of the tail or mooring line, using annual wave statistics supplied by the user. Existing fatigue life coefficients will be included for steel wire rope, nylon, polyester and HMPE ropes.

This is aimed for users who either design mooring systems in accordance with codes like API or users who wish to explore the sensitivity to material (ie nylon, polyester), generic rope constructions (braid-on-braid, parallel strand, 8 strand) and tail length. This will enable better selection of the correct tail (or mooring line) parameters for a given mooring system and environment.

It is also primarily aimed at tails, which are only cycled in tension-tension fatigue. Fatigue of mooring lines that run through fairleads is beyond the scope of this fatigue module. In generic terms, any fatigue damage will be quantified in the bend shoe wear test and inspection/retirement program.

Fatigue life will be calculated using the Miners summation technique for the tails for a matrix of wave heights, periods and directions. The percentage damage will be calculated for each run and used to illustrate the requirements for developing discard criteria.

Example studies for one berth and three vessels * will be conducted to establish the sensitivity to tail material type and length for motions, peak line tension and tail fatigue life.

* Two gas carriers of sizes 135 km³ and 250 km³ (215 km³ if 250 km³ data is not available), and one tanker.

3.8 Wear in fairleads

An investigation of mooring line wear in fairleads will address the following questions:

- Is there any difference in Panama or roller
- What material should the fairlead be made from, steel or polymer?

A previous program conducted by TTI (Ref 19), cycled a fibre rope around a fixed 90 degree bend shoe. TTI developed this new technology for riser protection nets, where a large rope (up to 600 tonne break load) has to be turned 90 degrees around a bend shoe. Due to wave action on the net, there is constant motion in the bend shoe giving potential wear on both rope and bend shoe liner. The rope design was a wire rope construction with a special jacketing technique. This technology will be made available to the participants and will provide a good basis for extending this work to roller fairleads with bearings and another rope construction with a selection of materials not yet tested.

The test matrix is shown in table 1. All of the tests will use the same manufacturers 12 strand uncoated, unjacketed HMPE fibre rope.

Based on the mooring analysis, typical load ranges will be tested corresponding to cycles expected over lifetime ie large waves = small number cycles, small waves = large number cycles. The wear will be documented and then the residual strength of the fibres measured to determine the extent of wear damage. At least 20 fibres will be removed from each of the jacket and core of the rope, to gain maximum information and sufficient statistics. It is noted that it is completely pointless break-testing the whole rope, since one data point is impossible to analyse (multiple testing of ropes is cost prohibitive) and it tells you nothing about the differential in damage to the jacket and internal load bearing fibres.

Fairlead type	Rope type	Material on fairlead
Steel roller	HMPE rope	Steel surface
Panama lead	HMPE rope	Nylon or Orkot liner
Panama lead	HMPE rope	Steel surface – new condition
Panama lead	HMPE rope	Steel surface – weathered condition

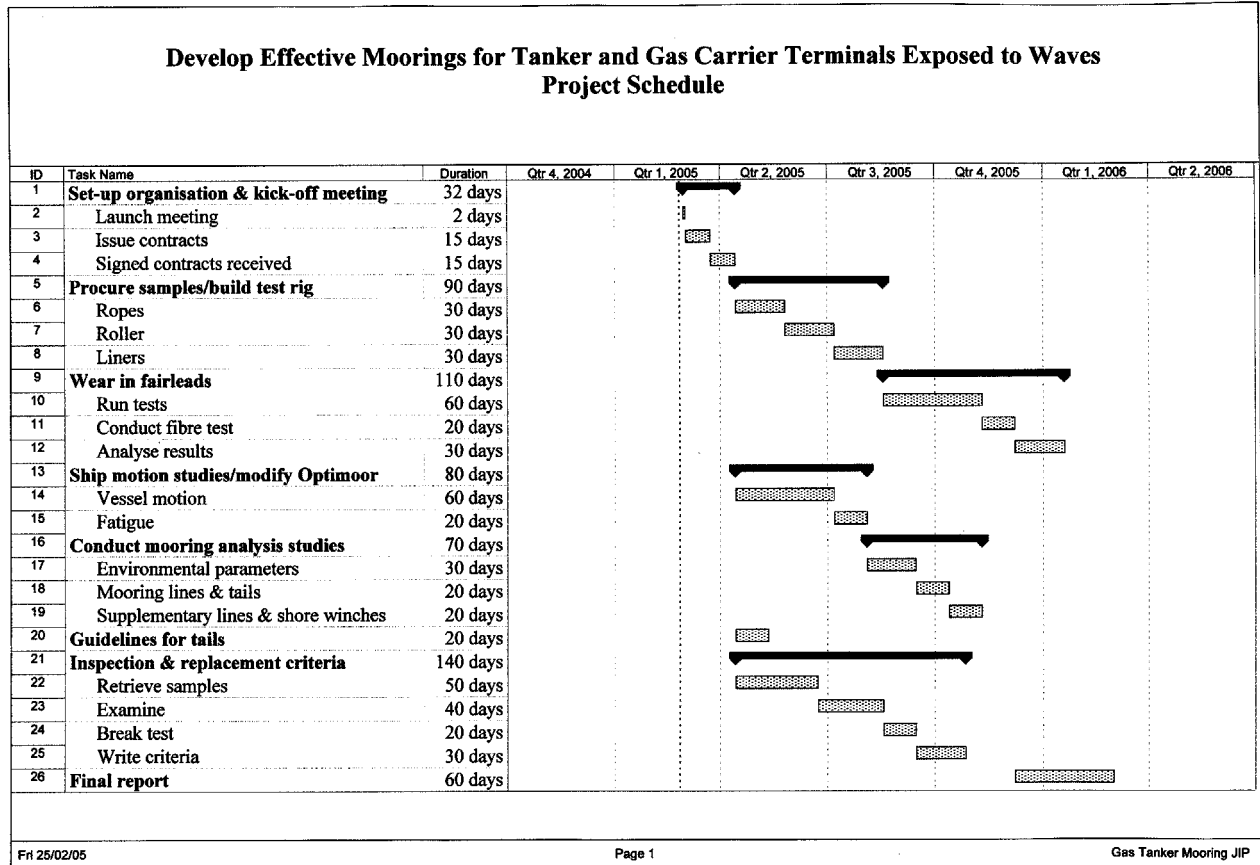
Table 1. Matrix of wear tests

Half scale ropes around 60tonne break load will be tested, based on a typical large gas/product carrier wire mooring line at 40/42mm around 124 tonne MBL.

The main aim of this test program is to establish sensitivity of roller material to wear on HMPE fibre rope. The results and measurements of damage will also be an input to the process of developing the inspection and rejection criteria.

4. JIP Schedule

The schedule is shown in the Gantt chart below, with a total duration of 12 months.



5. CONFIDENTIALITY

A 2 year confidentiality period is proposed, but the terms of the confidentiality will be decided by the committee.

6. COST/TICKET PRICE

The project costs are summarized in table 2 and detailed information is given in the CTR sheets in Appendix A.

CTR1	Mooring design/tail length	20000
CTR2	Fairlead wear/fatigue tests	48800
CTR3	Ship motion & fatigue	56600
CTR4	Fibre Rope Inspection and Replacement	37400
CTR5	Project management	16000
Grand total £GBP		178800

Table 2. Project cost summary

The ticket price is £25,000 for gas and oil companies, £10,000 for major jetty design contractors and ship designers/builders and £5,000 for ship management companies and port authorities.

Ropemakers, fiber producers, equipment manufacturers and small consultancy companies the ticket price is £1,500.

For the £1,500, £5,000 and £10,000 ticket prices the stand alone fatigue calculation program will be provided, but the ship motion files will not be made available. The user will be able to enter a motion (or load range) and the program will calculate fatigue life.

There is no charge for OCIMF and SIGTTO.

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Appendix A . CTR sheets

COST, TIME, RESOURCE (CTR) SHEET		CTR No:	1
Project: Effective Mooring JIP		Revision:	1
Client: sponsor group		Date:	27-Jun-05
Ref. No: TTI-SJB-2005-317		Approved:	KB
Task No: 1	Title:	Start:	24/10/2005
Objective:		Finish:	24/03/2006
Establish safe mooring system for exposed jetty		Duration:	110 days
Optimise tail length and fatigue life			
Scope of Work:			
Conduct mooring analysis/design for exposed jetty for:			
2 gas carriers - one 135 km ³ , one 250 km ³ (or 215 km ³) and 1 tanker			
Model ship motions			
Model peak line tensions, fender loads, motion at manifold			
Establish sensitivity to ballast/loaded condition, wave direction, sign. height and period			
Optimise mooring layout, materials, tail length			
Conduct fatigue analysis mooring lines/tails			
Analyse effect of supplementary shore lines and winches			
Inputs to Task:			
Results from ship motion analysis			
Results from fatigue module			
Rope fatigue database			
Deliverables:			
Report detailing all analysis and results			
Example design mooring system/layout for exposed jetty for 2 gas carriers and 1 tanker			
Subtotal:			£20,000

COST, TIME, RESOURCE (CTR) SHEET**Project:** Effective Mooring JIP**Client:** sponsor group**Ref. No:** TTI-SJB-2005-317**CTR No:** 2**Revision:** 1**Date:** 27-Jun-05**Approved:** KB**Task No:** 2**Title:** FAIRLEADS**Start:** 04/07/2005**Objective:****Finish:** 23/06/2006Establish roller and static fairlead design
for HMPE ropes**Duration:** 235 days**Scope of Work:**

HMPE rope, 120t BL, 50mm OD
 run fatigue tests to 40000 cycles over:
 steel rollers, D/d = 10
 and Panama fairleads, with "as-new" steel (R/d = star and two lined fairleads
 and steel fairlead lined with Orkot or nylon.
 Cycle ropes from 10 to 30% BL with 30deg offset around fairleads
 Inspect rope and fairlead wear, and measure residual rope strength.

Inputs to Task:

Standard roller and fairlead geometries for HMPE wire rope
 Fatigue database

Deliverables:

Report detailing all results, with discussion between HMPE rope and fairlead wear
 Recommended fairlead choice for HMPE and fairlead type/material
 Fatigue damage to rope
 Quantify wear damage, strength loss

Subtotal: £48,800

COST, TIME, RESOURCE (CTR) SHEET**Project:** Effective Mooring JIP**Client:** sponsor group**Ref. No:** TTI-SJB-2005-317**CTR No:** 3**Revision:** 1**Date:** 27-Jun-05**Approved:** KB**Task No:** 3**Title:** Ship motion & fatigue**Start:** 04/07/2005**Finish:** 16/12/2005**Duration:** 120 days**Objective:**

Develop ship motion program, open water, piled jetty, 6 degrees freedom for any monohull
 Develop mooring line and tail fatigue life estimation program

Scope of Work:**Inputs to Task (from data file):**

Cb (in range 0.7 - 0.9)
 LBP (in range 200 - 350 m)
 Breadth (in range 30 - 60 m)
 Draft (in range 5 - 25 m)
 Trim (in range 0 - 5 m)
 GM (fluid)
 Roll damping
 Under keel clearance (>2 m)

Output (as text readable or CSV file):

Set of 6 dof RAO data for open water for matrix of
 wave directions at 20 degree intervals
 wave periods 4 - 30 secs

Stand-alone program to estimate fatigue life of mooring lines, Input:

Positions of fairleads, dist to winch, vertical and horizontal angles of mooring lines
 Length and dynamic stiffness properties of lines and tails, T-N fatigue curves, mean tensions
 RAO data file generated from above program (or provided independently by any other means)
 Wave statistics (assuming Pierson-Moskowitz spectrum) data tables giving % time for a matrix combination of:
 Sig wave heights (0 - 10 m)
 Wave periods (4 to 20 secs mean)
 Wave directions (all available)

Output:

Fatigue life of each line based on Miner's Rule

Deliverables:

Report within 2 months on the extent to which detailed hull shapes can be simplified without sacrificing accuracy
 Standalone program to calculate ship motions using data pre-calculated from AQWALINE, only for £25,000 ticket
 Optimoor will be upgraded to incorporate the features of the above programs, only for £25,000 ticket
 Fatigue program for HMPE, nylon wet and dry, polyester, polypropylene, steel wire, chain

Subtotal: £56,600

COST, TIME, RESOURCE (CTR) SHEET

Project: Effective Mooring JIP
Client: sponsor group
Ref. No: TTI-SJB-2005-317

CTR No:	4
Revision:	1
Date:	27-Jun-05
Approved:	KB

Task No: 4**Title:** Develop Fibre Rope Inspection and Replacement Criteria**Objective:**

Develop inspection and retirement guidelines for fibre rope mooring lines and tails, including:

- * Photographs and illustrations showing appearance of wear and damage
- * Quantifiable observations and measurements of wear and damage
- * Relation of wear and damage to retained strength

Start:	12/04/2005
Finish:	30/06/2006
Duration:	389 days

Scope of Work:

4.1 Gather information on fibre rope now uses as mooring lines and tails, how they are used and what types of damage

they experience

4.2 Collect samples of ropes used tails and mooring lines

4.3 Examine used ropes to quantify wear and damage and break test to determine residual strength

4.4 Procure and prepare samples of new ropes, induce artificial damage, and break test to determine residual strength

4.5 Based on results of above, prepare guidelines relating degree of wear and damage to remaining rope strength

Inputs to Task:

Used fiber rope mooring lines and tails from vessel operators, with known history, hours use

say 200, 400 and 600 hours

Results from roller wear test

Deliverables:

Report within 3-4 months on what samples are available so that a test program can be agreed.

Inspection and retirement guidelines for fibre rope mooring lines and tails.

Relationship hours usage and strength loss

Subtotal: £37,400

COST, TIME, RESOURCE (CTR) SHEET	
Project: Effective Mooring JIP	CTR No: 5
Client: sponsor group	Revision: 1
Ref. No: TTI-SJB-2005-317	Date: 27-Jun-05
	Approved: KB
Task No: 5	Title: Project management
Objective: Manage, conduct study, reporting results JIP	Start: 11/04/2005
	Finish: 11/08/2006
	Duration: 345 days
Scope of Work: Organise steering committee meetings Write minutes meetings Setup and manage contracts Report to steering committee General liason with steering committee and industry	
Deliverables: Contract agreement with participants and any sub-contracts Paperwork, interim reports, final reports	
	Subtotal: £16,000