draft summary of 3rd CA-OE Workshop

17 October 2006

From: Peter Scheijgrond, Ecofys, NL
To: Kim Nielsen, CA-OE Core Group

Introduction to 3rd CA-OE Workshop

The 3rd CA-OE Workshop was held on 30-31st March 2006 at the Lloyd Hotel in Amsterdam and was organised by Ecofys. The topic of the Workshop was System design, Construction, Reliability & Safety. Over 50 participants attended the workshop.

During two days, 27 presentations were given while the break-out sessions provided a way of interacting, sharing and learning amongst the participants. The topics of the break out sessions were:

- Speed dating using "NEEDS and OFFERS" of each participant related to construction and production of ocean energy systems
- Discussion groups on Guidelines (3 groups)
- Exercise in Failure Modes Effects Analysis (FMEA) (5 groups)
- Plenary Workshop Evaluation

There were 5 invited speakers: Diederik Samsom (PvdA) from the Dutch government, Claudio Bittencourt Ferreira from DNV, Kimon Argyriadis from Germanische Lloyd, Rod Hacker from Halcrow and Jan van der Tempel from TU Delft.

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Figure 1 Break-out sessions provided a way to interact and share experience.

Below a summary is given for each task by the the task leaders.

1 Task 3.1 Verification of design codes and structural reliability

Task leader Chalmers University of Technology

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1.1 Task 3.1 work program description

Evaluation methods need be able to compare the different technologies with a standardised set of tests focused on commercial viability. For ocean energy this may be a different set of criteria for each device, but there will be generic specifications such as fatigue life of components, extreme loads etc.

1.2 Verification, reliability and safety

The purpose of creating standards, guidelines or recommended practices for ocean energy converters is to have a common basis for design and independent verification by third parties of the design work. This independent verification or certification would then be used to show financiers, partners, utility companies, insurers and the public that the converters will perform adequately within acceptable levels of safety, availability and reliability. The certification process is also a good way to obtain access to knowledgeable expertise with a different perspective.

Presently there are no special standards for Ocean Energy Converters. However, DnV has recently developed a guideline for the design and operation of Wave Energy Converters on behalf of the Carbon trust[1]. DnV is also developing an Offshore Service Specification (OSS-312 yet not available late Aug 2006) dedicated to Wave Energy Converters. Germanischer Lloyd are developing a “Guideline for the Certification of Ocean Energy Converters” and has published “Part 1: Ocean Current Turbines”[2].

1.2.1 Verification

The standards, guidelines and recommended practices form a “certification basis”, which is used to verify that the used design procedures and design calculations give correct results and can form the basis for evaluation of reliability and safety. Task 3.1 was formulated as “Verification of design codes and structural reliability”, which would imply a verification of the design codes but is interpreted here as an evaluation by developers of the design codes (standards, guidelines and recommended practices) as to their feasibility for ocean energy converters. Ocean Power Delivery’s Methodology for the Pelamis Wave-Energy-Converter verification[3] is given in the appendix as an example of application of present certification basis.

1.2.2 Reliability

Reliability is the ability of a system to perform and maintain its functions in routine circumstances, as well as hostile or unexpected circumstances. Reliability may especially refer to reliability engineering ensuring a system will be reliable when operated in a specified manner

1.2.3 Safety

Safety is the state of being safe, the condition of being protected against physical, social, spiritual, financial, political, emotional, occupational, psychological or other types or consequences of failure,

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[1] Guidelines on design and operation of wave energy converters, Commissioned by the Carbon Trust and carried out by Det norske Veritas, May 2005

[2] Guideline for the Certification of Ocean Energy Converters, Part 1: Ocean Current Turbines, Germanischer Lloyd, 2005

[3] Chris Retzler: Pelamis Certification Methodology, Power Point Presentation given at CAOE third workshop in Amsterdam 30-31 March 2006.

damage, error, accidents, harm or any other event which could be considered dangerous. Protection is from both the cause and from exposure to something that is not safe. It can include physical protection or that of possessions. Safety is often in relation to some guarantee of a standard of insurance to the quality and unharmful function of a thing or organization. It is used in order to ensure that the thing or organization will do only what it is wanted to do.

1.3 Guidelines for Ocean Energy Converters

1.3.1 The Carbon Trust Guidelines for Wave Energy Converters

The Carbon Trust guideline provides interpretation and guidance on the application of existing codes and standards (mainly from industries such as offshore and maritime) to wave energy conversion devices and should be read in conjunction with the Standards, Recommended Practices and other referred documents. However, the Carbon Trust guideline highlights whenever possible "the differences between system design philosophies reflected in offshore codes and wave device design. It must be recognised that failure mechanisms that govern the normal design in an offshore installation may change in the case of WEC devices for the following reasons:

- Although the probability of failure may be the same in both offshore and wave device applications, the consequence of failure is much smaller for a wave device that is normally unmanned, since different and less hazardous conditions may exist and further escalation of failure is less likely. This may happen without affecting the reliability of the equipment.
- Standard equipment in a WEC device may be subject to different loads and thus consideration of dominant failure modes should be made. For example, design for resonance with wave conditions makes fatigue a governing failure mechanism which in turn affects reliability."

1.3.2 Germanischer Lloyd's Guidelines for Ocean Current Turbines

The Germanischer Lloyds Guidelines for Certification of Ocean Turbines are founded on certification procedure and requirements described in the GL "Guideline for the Certification of Offshore Wind Turbines"[4], but also standards for other related technologies –such as oil and gas, maritime – have been collected, reviewed and the most appropriate compiled in order to serve as a first basis for design and safety of ocean current turbines.

1.3.3 New and unproven technology

Ocean energy converters are developed using new or unproven technology or using well-established technology in a new context. To speed up the development process DnV refers to their RP-A203: Qualification procedures for New Technology, and defines qualification as "the process of providing the evidence that the technology will function reliably within specific limits". The aim of the qualification

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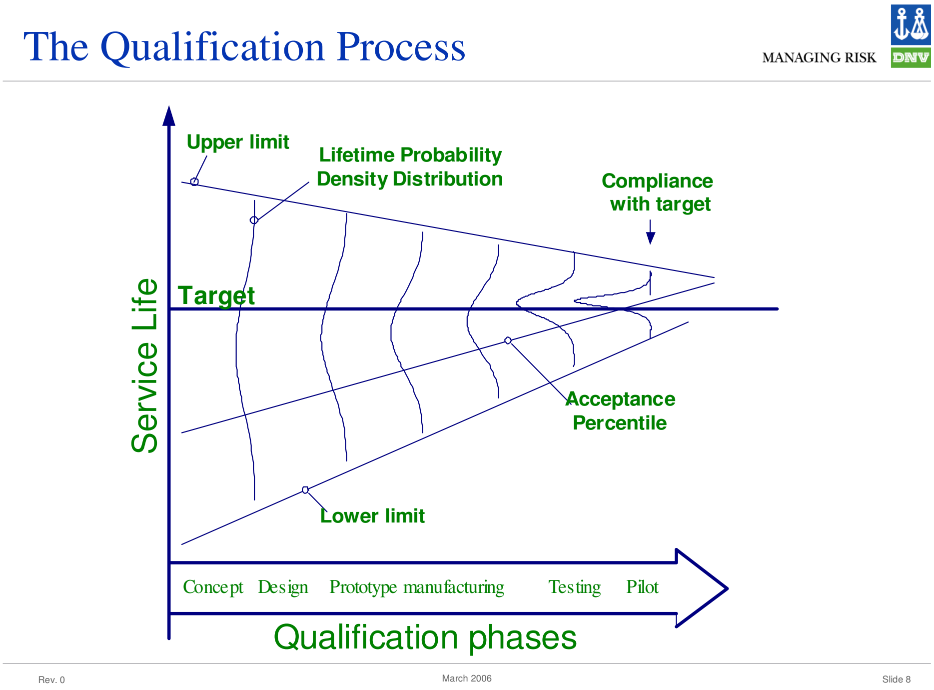
[4] Guideline for the certification of Offshore Wind Turbines, Edition 2005, Germanischer Lloyd WindEnergie Gmbh

process is to reduce the uncertainty to an acceptable level and includes a Risk Ranking (See DnV slides below)



The Qualification Process

MANAGING RISK

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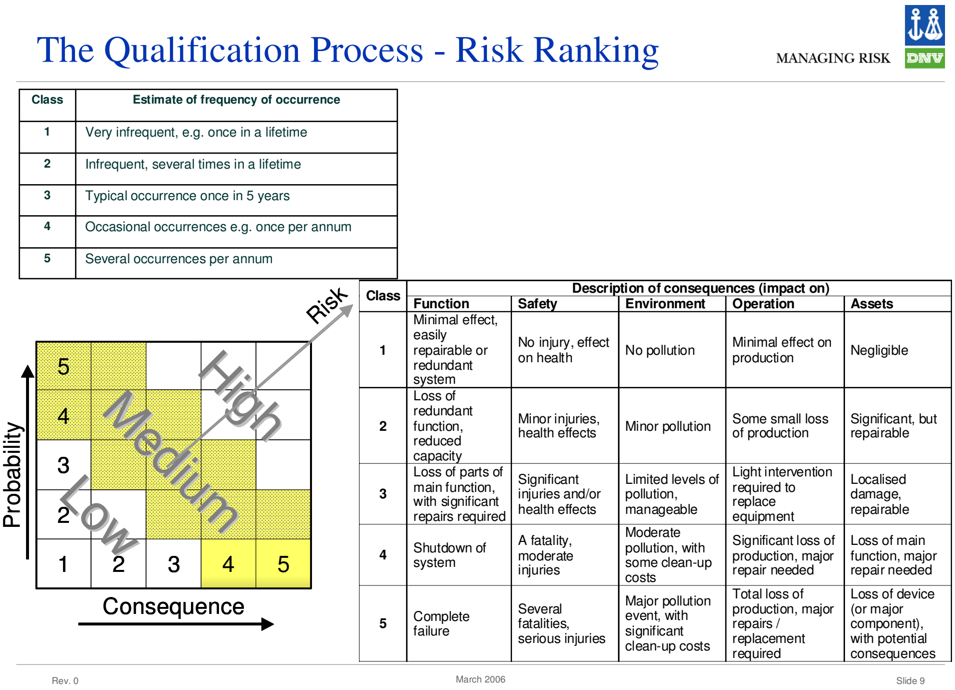
Figure 2 The Qualification process



The Qualification Process - Risk Ranking

MANAGING RISK

Class	Estimate of frequency of occurrence
1	Very infrequent, e.g. once in a lifetime
2	Infrequent, several times in a lifetime
3	Typical occurrence once in 5 years
4	Occasional occurrences e.g. once per annum
5	Several occurrences per annum

Class	Description of consequences (impact on)				
	Function	Safety	Environment	Operation	Assets
1	Minimal effect, easily repairable or redundant system	No injury, effect on health	No pollution	Minimal effect on production	Negligible
2	Loss of redundant function, reduced capacity	Minor injuries, health effects	Minor pollution	Some small loss of production	Significant, but repairable
3	Loss of parts of main function, with significant repairs required	Significant injuries and/or health effects	Limited levels of pollution, manageable	Light intervention required to replace equipment	Localised damage, repairable
4	Shutdown of system	A fatality, moderate injuries	Moderate pollution, with some clean-up costs	Significant loss of production, major repair needed	Loss of main function, major repair needed
5	Complete failure	Several fatalities, serious injuries	Major pollution event, with significant clean-up costs	Total loss of production, major repairs / replacement required	Loss of device (or major component), with potential consequences

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Figure 3 Risk Ranking according to DnV

1.4 Group sessions: FMEA exercise

One point of the agenda in Workshop 3 was to exercise Failure Mode and Effect Analysis on some selected vital components in ocean energy converters, in order to acquaint the participants to the technique. The participants were divided into five groups, which started the exercise by selecting a vital component in some devices:

1. Power take off in an OWC device (Wells Turbine – Stop valve)
2. Tidal device (Rotor blades)
3. Moorings (Mooring cable)
4. Offshore floating devices (Floater)
5. Buoy with hydraulic ram (Ram seal)

The appendix contains a standard form for a FMEA excersise which was used by all five groups to go through each stages.

1.5 Group sessions: Learning from Experience, Consensus on Guidelines, Component reliability

One point of the agenda in Workshop 3 was to discuss Design Codes:

- Coordinating guideline development
- Failure mode identification and risk ranking (make generic lists for a hypothetical floating wave device)
- Life Cycle Analysis
- Safety philosophy
- Corrosion protection, exchange experience
- Mooring system analysis, tools, methods

The participants split into three groups treating the following subjects which engaged the participants the most:

- Consensus on guidelines
- Learning from experience
- Reliability of components - Existing component

1.6 Conclusion for Task 3.1

It is acknowledged by developers that the ocean energy industry can only expand if it creates a reputation for reliability and safe operation. It is therefore also acknowledged that the early development of safety codes and design practises are gradually developed to include experience from ongoing developments. This will make the developed practises better adapted to the various types of ocean energy devices without threatening the safety of the ocean energy industry.

2 Task 3.2 Production and construction methods

Task leader Forrschungzentrum Küste of University Hanover & Technical University Braunsweig

To be added asap by J. Grune

2.1 Task 3.2 WP description

Wave and tidal energy devices often involve large construction work and the price of the civil engineering and construction work will be a major part of the total cost. Based on the first wave and tidal prototypes and the offshore wind energy experience recommendations will be given.

3 Task 3.3 Deployment and maintenance procedures

Task leader Bulgarian Ship Hydrodynamics Centre

3.1 Task 3.3 Deployment and maintenance procedures

As ocean energy technology is in its infancy, experience regarding safety procedures implemented when undertaking technology deployment and maintenance must be collected and evaluated. The appropriateness of these measures for wave and tidal technologies needs to ensure that maintenance and servicing schedules are developed which satisfy appropriate legislation in the operating environment without being an economic burden that is a barrier to the technology commercialization. Evaluation must address the economic reality of maintenance issues related to projects.

The main goal of Task 3.3 was to contribute to improve installation/deployment methods and technologies, and the maintenance of wave and tidal energy devices, this way to assist to decrease operational expenses, to preserve people and environment.

The objectives of the Session 3.3 at the Workshop 3 were:

- Review available knowledge and experience

- Discuss main challenges, best practices, and bad experience; present advanced approaches and alternatives options.
- Summarize expertise, discuss and recommend actions, procedures and documents

Six presentations were delivered during Session 3.3 of the workshop. Developers from the UK (*Halcrow*, and *ITPower*), from the US (*Aqua Buoy*), from Netherlands (*Teamwork Technology*), from Sweden (*Upsala University*), and from Denmark (*Sterndorff Engineering*), presented their experience in the field of deployment and maintenance of various wave and tidal energy converter devices. Titles of all presentations can be found in the Workshop Program.

3.2 Main topics discussed during presentations and group session, challenges and recommendations.

Most of the presentations within Session 3.3 were focused on the experience in deployment of various wave energy devices (linear buoy, *AWS* wave energy converter, *Seaflow* current turbine, wave hub, some offshore constructions). Various aspects on transportation of the devices, and their installation on-site (including influence of local conditions - wind, waves, tides, currents) were presented in details, and discussed.

Topics related to the operation, maintenance, and reliability, were addressed. Problems of in-situ service, and repair, were outlined and discussed. Special attention was paid on proprietary component failure, including considerations on materials and corrosion.

The difficulties to access the offshore machines were also discussed, and it was recommended that reliable remote operation, remote fault diagnostic, and condition monitoring will be essential in a production device.

The installation and maintenance procedures have to be planned according to local conditions. Special logistic effort has to be made for the installation of the wave energy devices, including special guidelines and preparation for transportation to the site of deployment, for evaluation of interaction with waves, tides and currents, as well as for underwater operations.

Periodic monitoring should be performed to assure that performance of the wave and tidal energy devices is performed according to the design requirements, and that the overall conditions of the device enable safe operations. It includes main components, the electrical installation, the moorings (or support system) the safety and control system.

Recommendations on procedures and documents related to installation and retrieval, commissioning and handover, operations and maintenance of wave energy devices, are presented in *Guidelines on design and operation of wave energy converters* (*Der Norske Veritas, May 2005*), reported at Session 3.1.

4 Workshop Evaluation

On the last day of the workshop a plenary evaluation was held. Everybody was asked to write down some positive points and points for improvement on POST-ITs. The results are listed in the graphs below. Most positive points were made about the nice location, the good organisation of the workshop, the break out sessions and the pleasant atmosphere. Points for improvement were to reduce the number of presentations on the last day and to improve the audio/visual facilities.

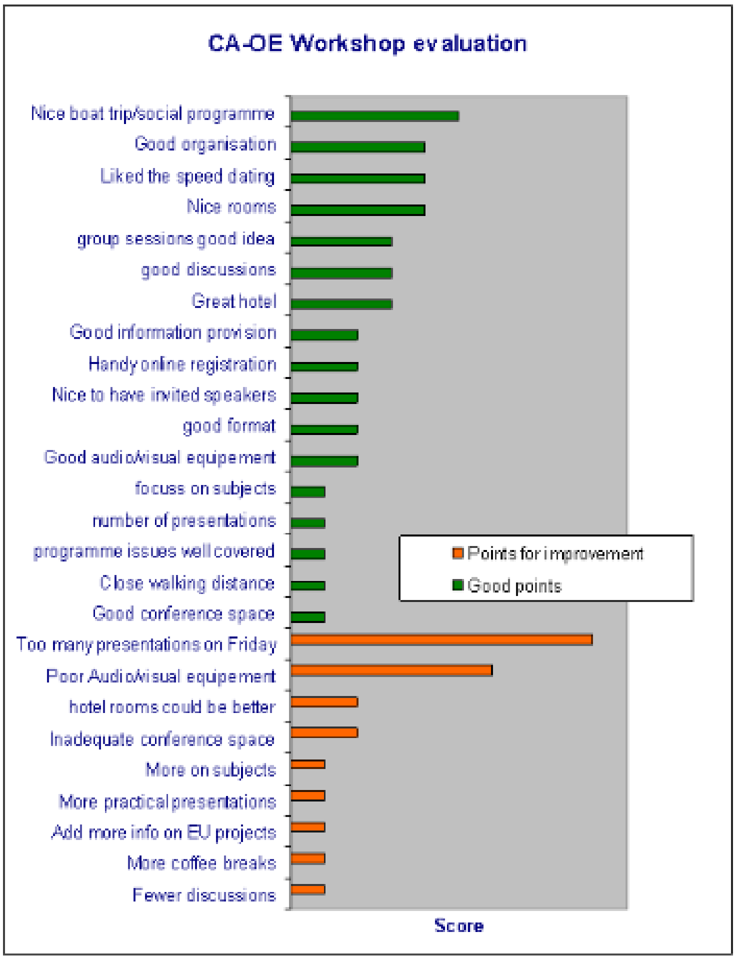


Figure 4 Workshop evaluation.

Appendix I Pelamis Verification Methodology

Chris Retzler at Ocean Power Delivery Ltd presented their methodology for the verification of the Pelamis wave energy converter at the third workshop of CA/OE in Amsterdam March 2006. This will be referred here as an example of how verification or rather qualification of a new device can be performed. In this paragraph the wording of Chris Retzler is used.

Verification

The independent confirmation of design, analysis, testing and procedure, so as to…

- avoid death or injury to people and loss or damage of assets
- meet statutory and insurance requirements

Comprises Formal Methods:

- Qualification Basis
- Technical assessment
- FMEA (Failure Mode and Effects Analysis)
- Procedure Analysis

Qualification Basis

For each system specify…• System Description

- Operation
- Fabrication
- Transport
- Operation and Maintenance (O&M)
- Disposal
- Manufacture and Quality Assurance (QA)
- Health, Safety and Environment (HS&E)

Technical Assessment

For each component specify:

- Function
- Application, and whether-
  - – Known
  - – New
- Technology, and whether-
  - – Proven
  - – Limited field history
  - – New or unproven

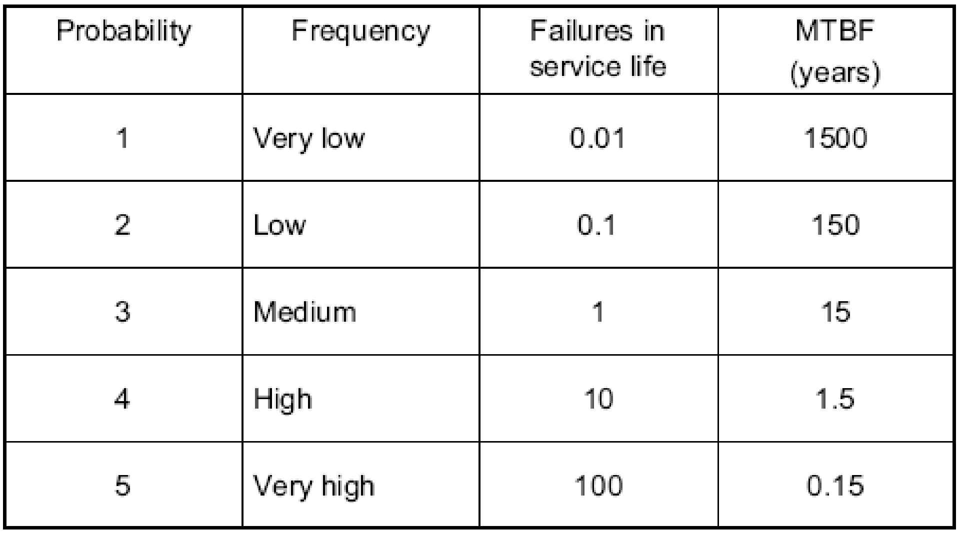
FMEA

Failure Mode and Effect Analysis, FMEA, is a methodology for analyzing potential reliability problems early in development, is used to identify potential failure modes and to determine their effect, and identify actions to mitigate the failures. It has a ‘tree’ structure: starting from large scale. Systems can be examined along branches to finer and finer detail

FMEA Guide Words

- Survivability events
  - Break-up; sinking; foundering
- Root Causes
  - Fatigue; overload, accident; fixing failure; corrosion and wear
- Components
  - Tubes; power modules; PTO; yoke; moorings
- Operating modes
  - Installation; operation; maintenance; retrieval

FMEA Probability Categories (Compare DnV slide above)



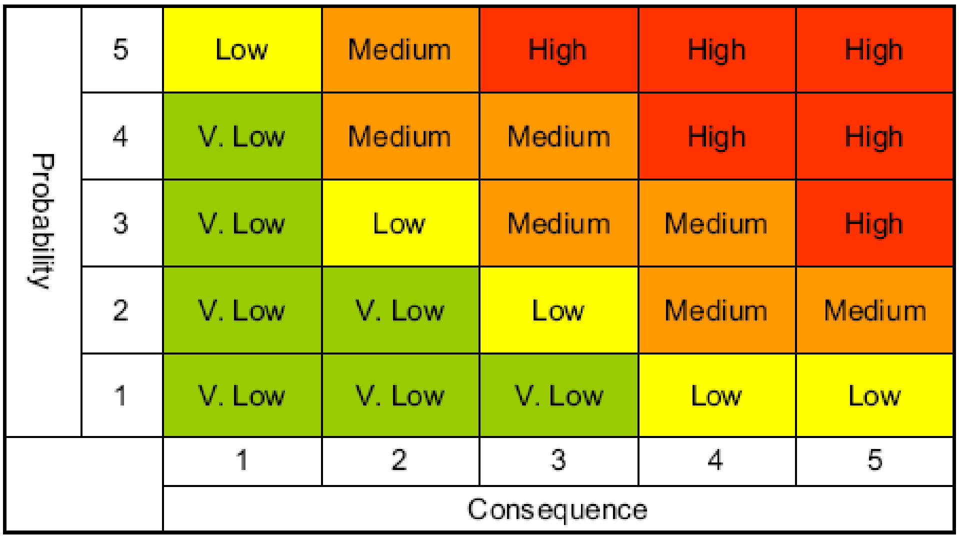
Probability	Frequency	Failures in service life	MTBF (years)
1	Very low	0.01	1500
2	Low	0.1	150
3	Medium	1	15
4	High	10	1.5
5	Very high	100	0.15

MTBF = mean time to failure

FMEA Consequence Categories

Consequence level	Production loss	Potential asset loss	Intervention
1	0 days	none	none
2	Reduced output	none	Next routine visit
3	2-3 weeks	remote	Next opportunity
4	3 months	possible	immediate
5	Permanent	total	salvage

FMEA Risk Values (Compare DnV slide above)



Probability	5	Low	Medium	High	High	High
	4	V. Low	Medium	Medium	High	High
	3	V. Low	Low	Medium	Medium	High
	2	V. Low	V. Low	Low	Medium	Medium
	1	V. Low	V. Low	V. Low	Low	Low
		1	2	3	4	5
		Consequence				

Avalanche Failures

a small failure

can have…

very…

large…

consequences!

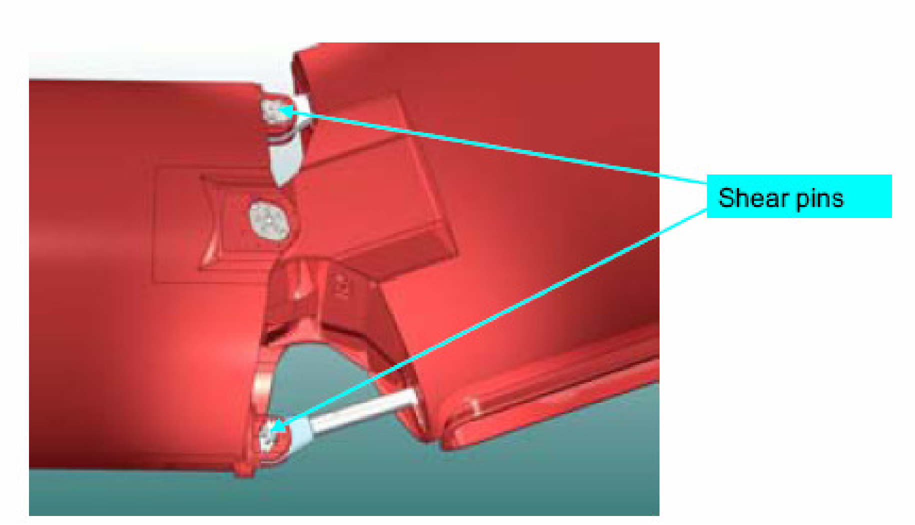
Intervention cost increases the later the intervention (and so does the cost of not intervening!) Early detection of faults is invaluable!

Fault Mitigation

Faults can be mitigated in a number of ways…

- Detection
  - Monitoring and routine preventive maintenance
- Design
  - Anticipate problems and either prevent them or ensure a path of controlled degradation
- Intervention
  - Fix problems as they arise

Module/Tube joint

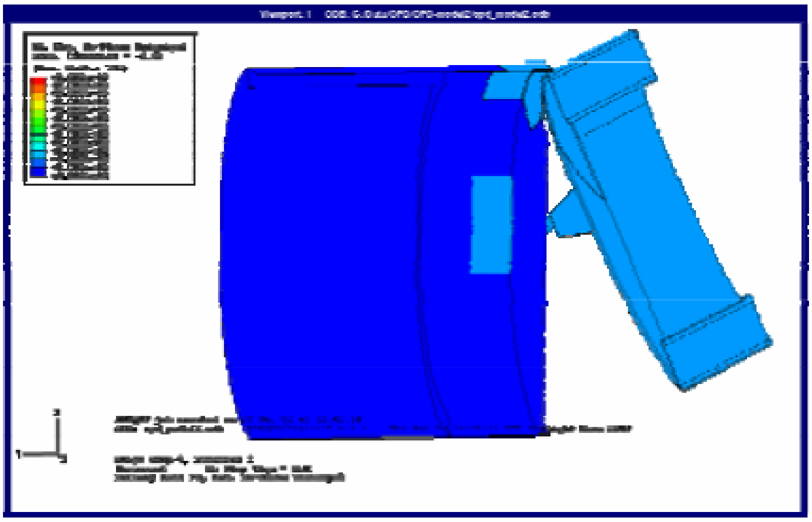


Controlled Degradation

Module/tube joints are designed so the rams never reach their end-stops.
BUT if all oil is lost in the primary circuit and in the secondary circuit then the rod end pins are designed to shear in a sacrificial failure, freeing the rams and leaving clearance between them and the structure.
If there is then contact between the module and tube, the energy is absorbed in crumple zones.

Structure

Non-linear impact analysis between the module and tube



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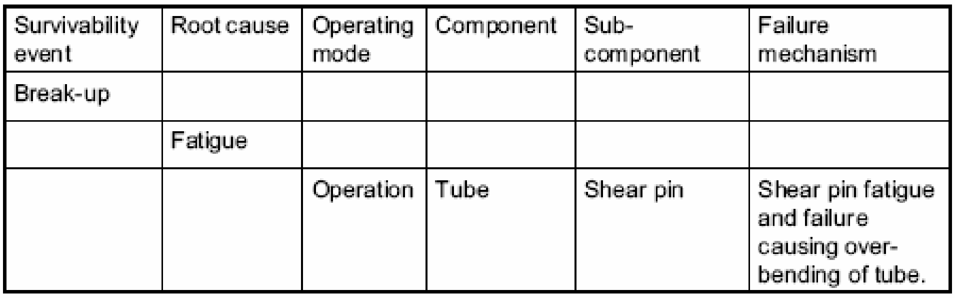
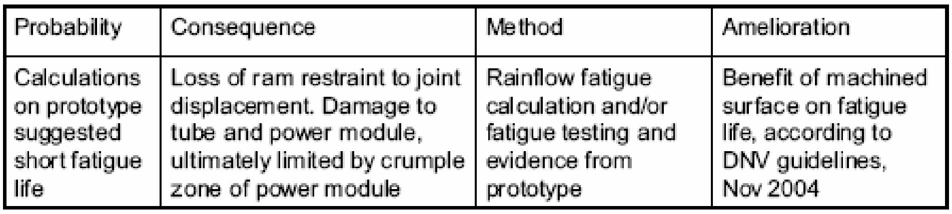
FMEA Example 1 – shear pin

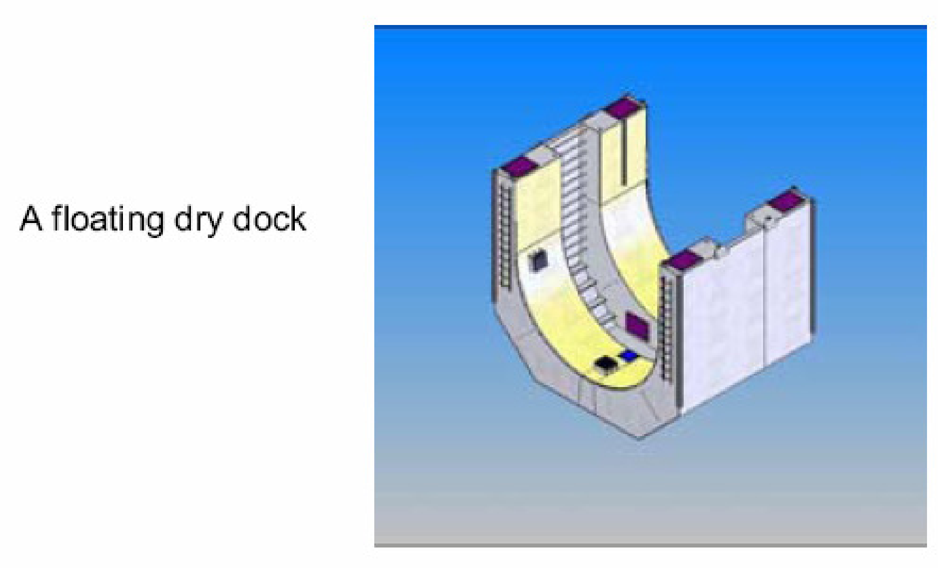


Survivability event	Root cause	Operating mode	Component	Sub-component	Failure mechanism
Break-up					
	Fatigue				
		Operation	Tube	Shear pin	Shear pin fatigue and failure causing over-bending of tube.



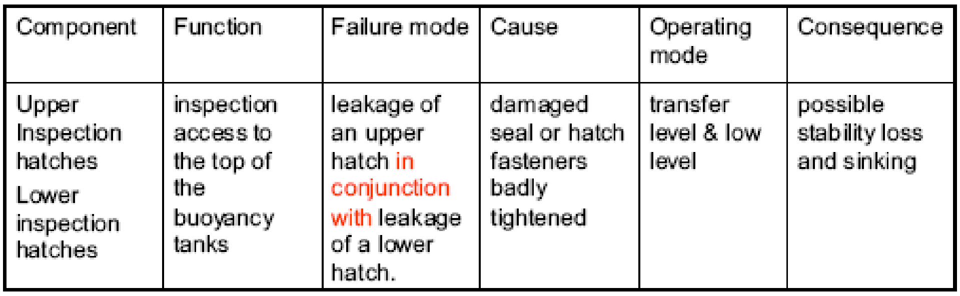
Probability	Consequence	Method	Amelioration
Calculations on prototype suggested short fatigue life	Loss of ram restraint to joint displacement. Damage to tube and power module, ultimately limited by crumple zone of power module	Rainflow fatigue calculation and/or fatigue testing and evidence from prototype	Benefit of machined surface on fatigue life, according to DNV guidelines, Nov 2004

The Habitat

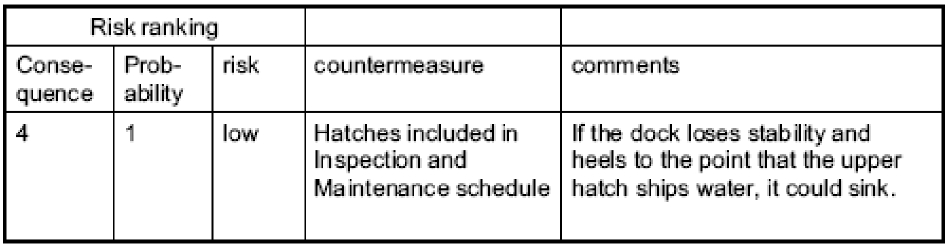


A floating dry dock

FMEA Example 2 – habitat leaks



Component	Function	Failure mode	Cause	Operating mode	Consequence
Upper Inspection hatches Lower inspection hatches	inspection access to the top of the buoyancy tanks	leakage of an upper hatch in conjunction with leakage of a lower hatch.	damaged seal or hatch fasteners badly tightened	transfer level & low level	possible stability loss and sinking



Risk ranking				
Conse-quence	Prob-ability	risk	countermeasure	comments
4	1	low	Hatches included in Inspection and Maintenance schedule	If the dock loses stability and heels to the point that the upper hatch ships water, it could sink.

Procedure Analysis

- Can follow a similar assessment to that of technology assessment or FMEA, applied to the operating procedures for the use of a system.•
- The output of the PA can be used for Risk Analyses required for Health and Safety Regulations.

Practicl Experience

- The prototype build and test programme has provided OPD with invaluable experience of real-world failures.
- It has confirmed that forward-thinking design can avoid or mitigate asset damage or loss…
- and that vigilance is essential in both build and operation!

Prototype Trials

- Sea trials 1
  - Fibre optic failure (operator error)
  - Transformer fill level trip (build QA)
  - Software instability (software QA)
  - Minor internal oil drips (build QA)

- Sea trials 2
  - Oil leak from LP relief valve (build QA)
  - Minor software glitches

- Sea trials 3
  - 1 x electronic card failure (build QA)
  - Fiber optic failure #2 (operator error)… but WiFi backup

- Sea trials 4
  - Gas leak past accumulator piston on return to dock (poor component)
  - • Back-up installed in 7 days at quayside

- Onsite trials
  - Oil leak due to extruded 'O'ring in hard pipe on ram (build QA)
    - Failed after 700 hours at pressure
    - Dual circuit automatically isolated problem
    - SCADA[5] allowed diagnosis to be made
    - Continued to operate & generate for 5 days
    - Fault rectified in 1 day at quayside

Summary

- Verification involves the systematic assessment of design and procedures. By examining causes and consequences, it can show where and how to mitigate faults.

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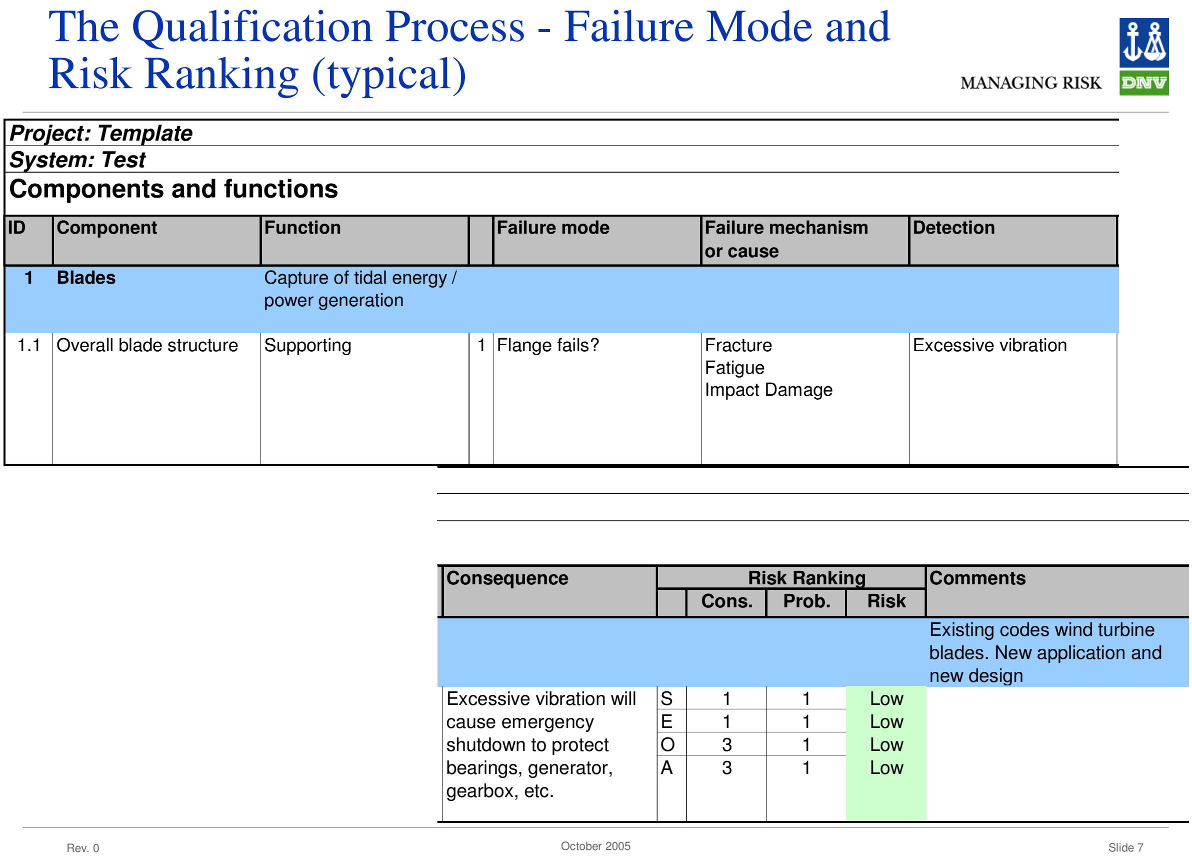
[5] Acronym for *supervisory* ***c****ontrol* ***a****nd* ***d****ata* ***a****cquisition*, a computer system for gathering and analysing real time data. SCADA systems are used to monitor and control a plant or equipment in industries such as telecommunications, water and waste control, energy, oil and gas refining and transportation. A SCADA system gathers information, such as where a leak on a pipeline has occurred, transfers the information back to a central site, alerting the home station that the leak has occurred, carrying out necessary analysis and control, such as determining if the leak is critical, and displaying the information in a logical and organized fashion. SCADA systems can be relatively simple, such as one that monitors environmental conditions of a small office building, or incredibly complex, such as a system that monitors all the activity in a nuclear power plant or the activity of a municipal water system.

SCADA systems were first used in the 1960s.

- It supports the early interception of faults, addressing them as early as possible in the range of responses from monitoring (an integral part of SCADA), through routine and preventive maintenance, to emergency repair.
- Most faults are detectable and correctable at an early stage, and contribute to learning, innovation and improvement of the product.
- The most serious consequences can be avoided by conservative design. As experience grows this can be relaxed, helping to drive down costs.

Appendix II FMEA Workshop



The Qualification Process - Failure Mode and Risk Ranking (typical)

MANAGING RISK

Project: Template

System: Test

Components and functions

ID	Component	Function		Failure mode	Failure mechanism or cause	Detection
1	**Blades**	Capture of tidal energy / power generation				
1.1	Overall blade structure	Supporting	1	Flange fails?	Fracture Fatigue Impact Damage	Excessive vibration

Consequence	Risk Ranking				Comments
		Cons.	Prob.	Risk	
					Existing codes wind turbine blades. New application and new design
Excessive vibration will cause emergency shutdown to protect bearings, generator, gearbox, etc.	S	1	1	Low	
	E	1	1	Low	
	O	3	1	Low	
	A	3	1	Low	

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