Reliability/availability methods for subsea risers and deepwater systems design and optimization

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Abstract: The restriction of construction licenses for onshore oil/gas treatment plants and regasification units along with energy demand growth has increased the development of offshore installations. Furthermore the discover of new offshore deep water fields enhance the engineering efforts towards the development of engineering of submarine systems and plants. Due to the complexity of these submarine systems, the severe environment where they operate and the difficulty or the impossibility to repair a component, a high system availability is becoming a key requirement. In this framework, to have a system architecture verified also from the reliability and availability point of view, the RAM analysis are becoming an essential part of the design. This paper describes the application of reliability/availability methods (RBD, Montecarlo method, FMEA risk assessment) to support the design of subsea deep water systems. In particular, two case studies are presented, the first aiming at the definition of the optimum configuration of retrievable and permanent deep water modules, the second addressing the verification of design configurations and the suggestion of tests and inspection plans to guarantee system integrity along operating life. Moreover the paper summarizes also difficulties to find subsea equipment reliability data and proposes solutions for reliability components characterization.

Keywords: Reliability, Availability, Deep water systems, Subsea systems, Risers.

1. INTRODUCTION

In the frame of the oil and gas industry, the improvement of offshore installation, more and more competitive, complex and challenging is becoming the rule. The reasons for the development of new offshore technologies, as subsea plants, are mainly two: the optimization of the resources and the discover of new offshore fields in harsh and severe environment and/or in deep and ultra-deep water.
Due to the nature and the location of these new subsea installations, an high system availability is a mandatory requirement for the remunerativeness of the investment. The causes of this strict requirement are various: the complex system architecture, the severe environment where they operate, the difficulty or the impossibility to repair the components.

In this framework the reliability methods are an essential tool to verify and validate the design. They also represent an effective method to individuate the system weakness and criticality, aiming at the design optimization. Notwithstanding, differently from the standard oil and gas industry, the subsea installations are often characterized by Non Reparable components (due to the onerous operations needed for repair or substitute an item) and by the difficulty to retrieve reliability data, mainly due to the new techniques employed.

In this paper two RAM analysis approaches are presented and applied to two case studies to support the design of subsea deep water systems.

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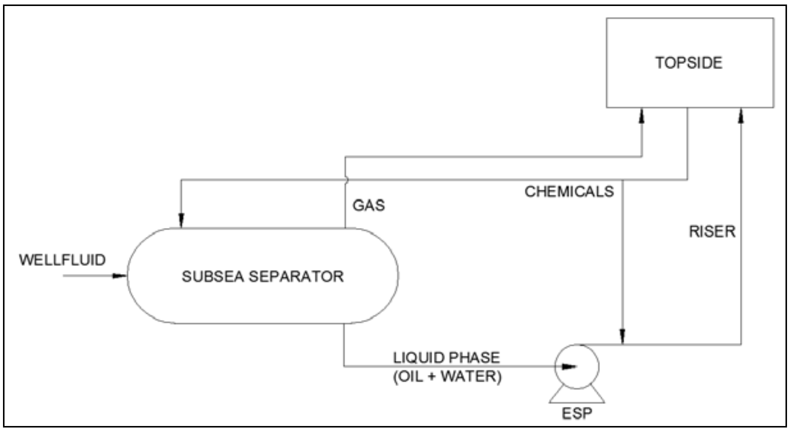
2. CASE-STUDY 1

2.1. Description

Case-study 1 concerns a subsea system for deep-water application.
This subsea system (Figure 1) consists of subsea separation of the well fluids, boosting of the liquid phase to topside and dumping of the gas phase at sea or at topside.

RAM analysis has been applied to this subsea system in order to verify and validate the design and to provide, if necessary and applicable, input and recommendations to the engineering design team in order to improve and enhance the availability of facilities and to reach the availability target.

Figure 1: Case-study 1 - simplified scheme.

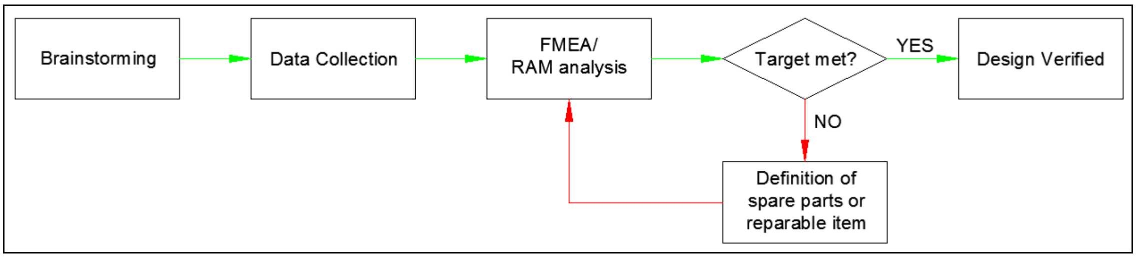


The design life of this subsea system is 30 years but the operating life is very short, 6 months; in this period the system availability shall be at least 90%.
The maintenance and repair activities shall be minimized or, if possible, eliminated.

2.2. Methodology

The analysis has been developed as for the scheme in Figure 2.

Figure 2: Flow diagram adopted for the Case-study 1 assessment.



<u>Brainstorming</u>
The brainstorming has been conducted as a multi-disciplinary meeting aiming at the sharing of all the information regarding the analyzed system, with the following objectives:

- collection of information concerning the system under analysis;
- identification of system components and main sub components, and relevant specific functionality and roles;
- definition of the main assumption and hypothesis.

Data Collection

The second step consists of the preparation of the Data Collection Table, aiming at associating a Main Equipment Type to each item of the analyzed system, together with the relevant failure modes and related failure rates.

The Data Collection Table collects the failure modes (FMs), the Main Time To Failure (MTTF) and related Active Repair Times (ARTs, only for reparable components) to be modeled in a Reliability Block Diagram (RBD) model.

Due to the particular architecture of this subsea system, very few data are present in literature and belongs to different data bases. The data collection has been mainly based on OREDA Handbook [2], OGP Database [3], Exida Handbook [4], OTRC report [8] and SINTEF report [9].

FRs have been assumed to be constant on time and mainly characterized by their mean value, and the probabilities of failures have been characterized by the use of a negative exponential distribution over time.

For some components failure rates have been characterized by their upper value (95^{th} percentile) due to their particular operative conditions. As for several publications from scientific literature ([5]), this option represents a reasonable and appropriate solution for technological complex systems, especially when availability modelling is conducted at high level and elements represent complete items rather than individual failure modes. No additional consideration about wear-in and wear-out impact is done, considering the equipment under study in the reliability optimal range of its lifetime when failures can be considered characterized only on a random basis.

Active Repair Times are values directly extracted from reference databases. The related Repair Rates assumed to be constant and related probabilities of repair are well characterized by a log-normal distribution, officially recognized by the scientific literature as appropriated to characterize human interventions([2], [6], [5].

FMEA/RAM Analysis

The RAM analysis have been performed in three steps:

1) all the components have been considered “not repairable”, in order to evaluate the reliability and to establish the most critical components;
2) for the most critical components a sensitivity analysis has been performed, setting the hypothesis of “repairable items” as a recommendation and the availability has been evaluated;
3) if the availability target is not met, the implementation of the possible mitigation (i.e. additional redundancies, further components set to “repairable”) is evaluated.

It is to be noted that due to installation constraint the use of redundant components shall be minimized, therefore, if the availability target is not met, preference is done to the recommendation of "repairable" components.

2.3. Results

Brainstorming

Table 1 shows the identified main components and sub-components of the analyzed systems.

Table 1: Main components and sub-components of the analyzed system.

Main Component	Sub-component type	Sub-component Tag
Subsea Separator	Separator	VA-001
	Gate Valve	V-S1, V-S2
	Choke Valve	V-S4
	Gate valve	V-S3
	Lines	Line V-S3, Line V-S4
	Differential Pressure Transducer	DP-1, DP-2
	Density meter	DM-1
	Temperature and Pressure Transducer	APT-1

Main Component	Sub-component type	Sub-component Tag
	Radar Level Meter	RD-1
	Linear Displacement Transducer	LD-1
	Temperature Transducer	TT-1/2/3/4/5/6
	Level Gauge	LG-1
Subsea Riser Base	Gate Valve	V-Cl4, V-Cl5, V-Cl6
	Riser	Riser
Subsea Submergible Pump	ESP	PS-001
	ESP Motor	PS-001 Motor
	Gate Valve	V-PI, V-BF, V-PB, V-II, V-AI, V-EX, V-Cl1, V-Cl2, V-Cl3
	Choke Valve	V-PR
	Linear Displacement Transducer	LD-2
	Differential Pressure Transducer	DP-3
	Absolute Pressure transducer	AP-3, AP-2
	Check Valve	V-CHECK1/2/3
Umbilical system reel	Umbilical	U-003 (Power Supply) U-004 (Chemical/hydraulic) U-006 (Chemical/optical)

Data Collection
The following Table 2 reports a portion of the data collection used for the case-study 1.
It includes only the Critical FMs and the relevant FRs as per section 2.2.

Table 2: Extract of the Data Collection ([2], [3], [4])
(NOTE: If not stated the FRs refer to the mean value)

Main Equipment Type	Modelled Items	Failure Mode	Failure Rate (h^{-1})	MTTF (h)	ART (h)	Dispersion
Valve check	Check Valves	Critical Failure	7.0E-08	14285714	-	1.4
Risers	Riser	External leakage	1.7E-07	5882353	-	1.4
		No immediate effect	1.7E-07	5882353	-	1.4
		Structural deficiency	5.0E-07	2000000	-	1.4
V-S3 Valve (FRs refer to the upper value, 95th percentile)	V-S3	Delayed operation	1.2E-06	847458	-	1.4
		External Leakage	1.9E-06	512821	-	1.4
		Fail to close on demand	1.0E-05	98522	-	1.4
		Fail to open on demand	1.8E-06	540541	-	1.4
		Spurious operation	1.6E-06	641026	-	1.4
		Structural deficiency	1.5E-06	675676	-	1.4
		Valve leakage in closed position	1.2E-06	819672	-	1.4
		Other	1.5E-06	671141	-	1.4

RAM Analysis Results
The analysis shows a Reliability of the system equal to **77.35%**. This result means that the system has a probability of 77.35% to fully perform its function, at the 100% of its capacity, continuously and without interruption over the defined mission time (6 operational months).
Table 3 reports the main items that contribute to the system un-reliability.

Table 3: Reliability Results

Item	Un-Reliability
ESP	7.9%
V-S3	4.3%
Subsea Separator (VA-001)	4.1%
V-S4	2.2%
ESP Motor	2%
V-Cl6	1.2%

The Table 3 shows that the major contribution to system un-reliability is given by the ESP.
Considering the results of Table 3, in order to achieve the availability target, it has been decided to allow the ESP repair, in particular it has been foreseen to install the ESP on the riser base and the module "riser base - ESP" has been made retrievable. Replace times are assumed to be equal to 24 hours.

The availability analysis has been carried out considering the system model described above and the module "riser base - ESP" reparable. The expected Availability of the system is equal to **87.422**%. This means that the system is expected to run on average 3766 hours over six months at full capacity.
As an additional contribution to the final results, the main critical components referred to the expected Availability are summarized in the Table 4. For each item the related criticality index is shown. This index represents for each component its direct quantitative contribution to the overall Unavailability of the system.

Table 4: Availability Results

Element	Description	Criticality Index (%)
V-S3 (all FMs)	Fast Gas Release Valve	4.0
880VA001 (all FMs)	Separator	3.7
V-S4 (all FMs)	Proportional Gas Release Valve	1.8
V-CI 6	Oil Soluble Chemical Injection Valve	1.0
V-CI 4	Methanol Injection Valve	1.0
Overall residual criticality due to all other items with CI less than 1		*1.1*
NOTE: (all FMs) = all FMs considered critical on FMECA.		

As it can be seen, main contributors on unavailability of the system are the not reparable items placed on Subsea Separator. In particular:

- **VS-3 Valve**. This component has a MTTF=47893 hours. It is obtained summing all failure rates of all failure modes of a generic "gate valve" taken from OREDA 2009. As this valve is characterized by an high number of operation per day, the "upper" value of failure rate (95^{th} percentile of statistic distribution) has been considered to be more realistic knowing the high number of operation per day of this item. Moreover, this item is not reparable.
- **Subsea Separator** (MTTF = 54025 hours). This value is obtained summing all failure rates of generic Vessel Separator (10-1000 m^3) taken from OREDA 2009
- **VS-4 Valve**: This item is modelled as Choke Valve, and related failure rate (referred to "external leakage") is taken from OREDA 2009. It has a MTTF of 102881 hours.
- **V-CI 6** and **V-CI 4**, that are valves not reparable associated to chemical injection system. Their MTTF is equal to 194175 hours because they are modelled as "gate valve" (mean value of statistic distribution of failure rate).

On the basis of previous results, the methodological approach allowed to define a set of possible improvement of system availability:

- insertion of a redundancy of V-S3/V-S4 valves;

- requirements to the vendors for the reliability parameters of V-S3/V-S4, that must be characterized by a MTTF equal or better than 30 years (with related failure rate corresponding to 3.8E-06 failures per hour).

The main issue, related to case-study 1, is the lack of reliability data, due to the new technology employed and the not common use of some widely diffused items (such as ESP, valves, etc…). Anyway, following the methodology described in section 2.2, a suitable data collection have been developed. Despite this issue, the obtained results have highlighted the system criticalities, suggesting some design improvement and contributing to achieve the availability target.

3. CASE-STUDY 2

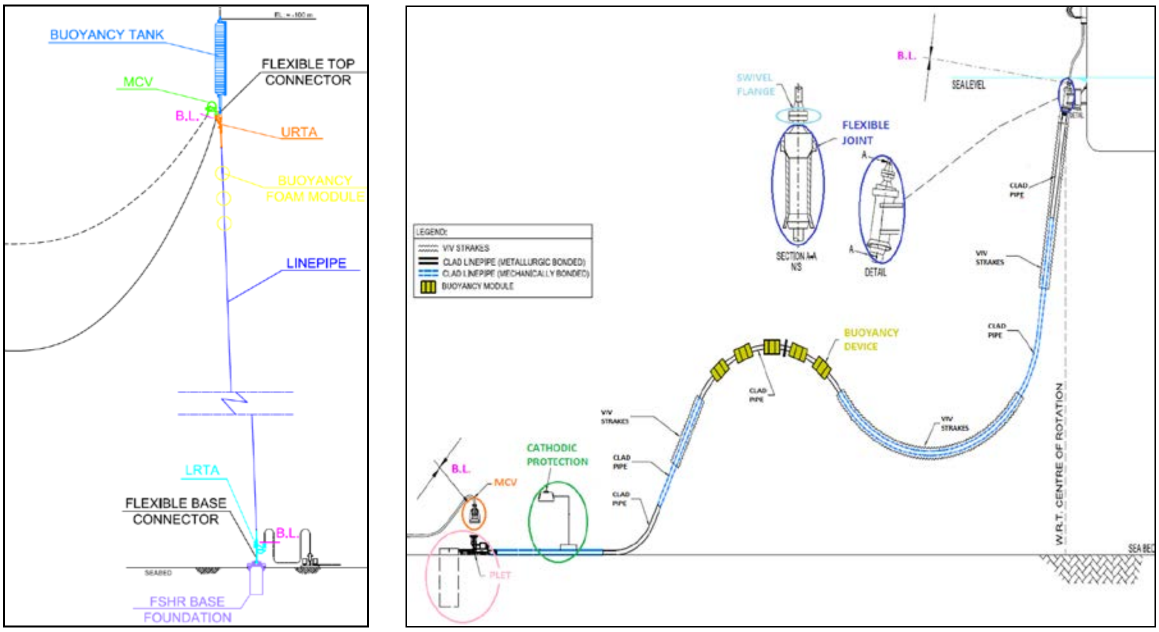
3.1. Description

Case-study 2 concerns two riser systems, a steel lazy wave riser (SLWR) and a Free Standing Hybrid Riser (FSHR). Figure 3 shows the schemes of the two riser systems.

Due to the system complexity the risers have been designed as "Maintenance Free". In particular the preventive maintenance will not be performed on the riser systems. The only type of maintenance possible on the systems is the corrective maintenance, as a result of anomalies highlighted during an inspection.

The application of a reliability analysis on these system aims at validating the design, in particular the "Maintenance Free" concept, and at defining a criticality list of the items composing the system, to establish an order of priority for the Inspection activities to be performed during the operational life of the riser systems.
It is to be noted that the definition of an inspection interval aims also at detecting the failure mechanism before item failure.

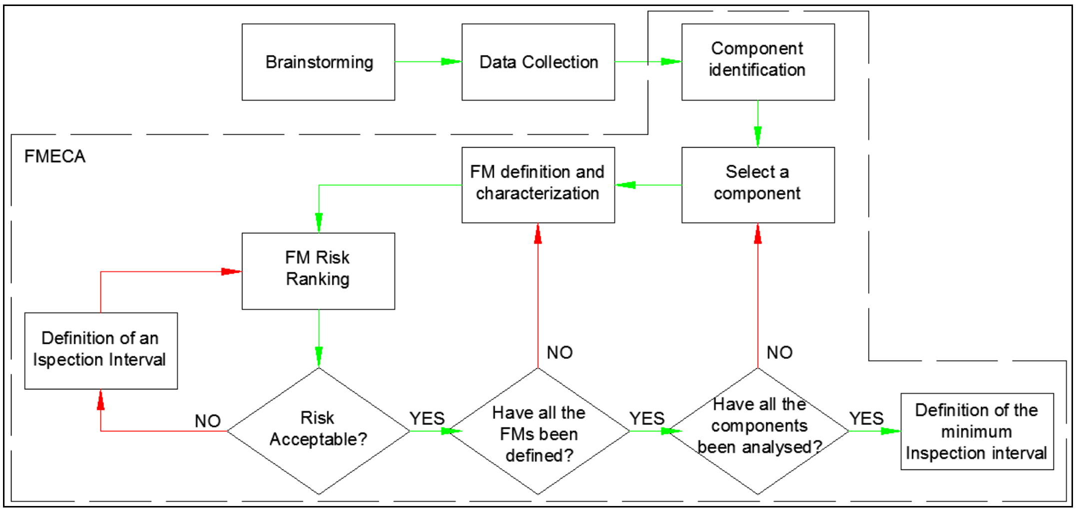
Figure 3: FSHR and SLWR scheme
(B.L. = Battery Limit, MCV = Vertical Connection Module, URTA = Upper Riser Termination Assembly, LRTA = Lower Riser Termination Assembly).



3.2. Methodology

The methodology followed to perform this study consists of the main steps listed in the following Figure 4.

Figure 4: Scheme of the methodology adopted for the Case-study 2.



Brainstorming and Data Collection
The same approach used in the case-study 1 has been applied.

FMECA execution
The FMECA (Failure Mode, Effect and Criticality Analysis) execution consists of the assessment of the effects of each failure mode in terms of loss of system functionality, the identification of the relevant detection method and of possible compensating provisions, the assessment of the risk for each failure mode and finally the evaluation of the Minimum Inspection Interval.

The FMECA has been developed following the template shown in the Figure 5.

Figure 5: FMECA Template.

ID	Component	Function	Failure Mode	Failure Rate (h^{-1})	P_i	Failure Mechanism or cause	Failure Local Expected Consequence	Failure Detection/ Mitigation	Failure System Expected Consequence	Risk Ranking			Recommended Inspection interval (y)	P_i*	Residual Risk Ranking considering Inspection		
										C	P	R			C	P	R

Identification of the components of the riser system
The analysis has been developed at Main Equipment level: this means that the system has been subdivided in sub-items. Each sub-item has been then associated to Main Equipment set in the Data Collection Table.
In this step the column ID, Component and Function have been filled.

Identification and characterization of the FMs for each component
The failure modes for each component have been identified on the basis of the Data Collection Table. For each FM, the Failure mechanism or cause, the Failure Expected Consequence (Local and on the system) and the already foreseen Failure Detection/Mitigation have been identified.

Risk Ranking

The risk ranking have been performed by means of a risk matrix obtained from IEC standard 60812 [1] and is shown in Figure 6.

Figure 6: Risk Matrix.

Likelihood Class		Severity Class			
		1: Insignificant	2: Marginal	3: Critical	4: Catastrophic
		System performance degradation, NO damage to the system and NO threat to life or injury	System performance degradation, limited damage to system, NO threat to life or injury	Loss of system's primary functions, damage to environment, NO threat to life or injury	Loss of system's primary functions, damage to environment and/or personal injury.
5: Frequent	Pi ≥ 0.2	Undesirable	Intolerable	Intolerable	Intolerable
4: Probable	0.1 ≤ Pi < 0.2	Tolerable	Undesirable	Intolerable	Intolerable
3: Occasional	0.01 ≤ Pi < 0.1	Tolerable	Undesirable	Undesirable	Intolerable
2: Remote	0.001 ≤ Pi < 0.01	Negligible	Tolerable	Undesirable	Undesirable
1: Improbable	0 ≤ Pi < 0.001	Negligible	Negligible	Tolerable	Tolerable

For the scope of this analysis the following rules have been considered:

- If the risk level is Negligible or Tolerable, the level of risk is broadly acceptable;
- If the risk level is Undesirable, the level of risk is tolerated only if risk reduction is impracticable or is kept as low as reasonably practicable by adopting reduction measures unless their cost is grossly disproportionate to the improvement gained. An Inspection interval shall be defined;
- If the risk level is Intolerable, the level of risk is not acceptable and risk reduction measures are required. An Inspection interval shall be defined.

P_i has been calculated by means of the following equation [1].

$$P_i = 1 - e^{-\lambda_i \cdot t_j} \qquad (1)$$

where

λ_i = failure mode failure rate.

t_j = time of active component operation.

The likelihood classes of each FM for the Risk Ranking have been determined first of all considering t_j equal to the design life (30 years).

The likelihood class, obtained in function of P_i, has been decreased by one unit if Detection measures are put in place and are able to detect/mitigate at least one of the identified Failure mechanisms or causes. This approach has been followed in order to take into account the presence of Detection/Mitigation measures, as suggested by IEC 60812 [1].

Evaluation of the Inspection interval and of the Residual Risk

For the Failure Modes, whose risk level is Undesirable or Intolerable, the Risk has been reduced considering the positive impact of Inspection activities: in particular the hypothesis of restoring the items to "as good as new" has been applied. This assumption can be considered in this case reasonable and realistic as during an accurate and systematic Inspection the status of the item is verified and, in case of any anomalies, the item can be maintained and/or substituted. Moreover the Inspection allows to detect the cause of all the failure modes identified in the FMECA, before the failure of an item.

The calculation of the Inspection interval has been performed in the following way:

- P_i* has been calculated considering the Equation 1 and t_j equal to the Inspection interval;

- as per the first Risk Ranking, the likelihood class, obtained in function of P_i*, has been decreased by one unit if Detection/Mitigation measures are put in place and are able to detect/mitigate at least one of the identified Failure mechanisms or causes;
- the Inspection interval has been obtained iteratively, with the purpose to reduce the risk to an acceptable level. The minimum Inspection interval has been considered corresponding to 1 year, to be in line with the interval suggested by international standards (e.g. DNV-RP-F206, [7])
- the residual risk have been evaluated considering the risk matrix reported in Figure 6, suggesting additional safety measure in case of not acceptable results, on the basis of a criticality ranking of the items in the battery limits of the study.

3.3. Results

Brainstorming

Table 5 shows the main components and sub-components of the two riser systems.

Table 5: FSHR and SLWR components and subcomponents.

FSHR		
Main Component	**Subcomponent**	**Spare part**
Buoyancy Tank	Tank composed by 21 compartments	YES, one compartment
	Pipework - ballasting system	YES
	Valves - ballasting system	YES
	Central core	NO
	Flexible Top Connector (Male connection)	NO
URTA (Upper Riser Termination Assembly)	Flexible Top Connector (Female connection)	NO
	Piping	NO
	Structural parts	NO
	Isolation valve	NO
	Diverless connector (Male connection)	NO
MCV (Vertical Connection Module)	Diverless connector (Female connection)	NO
	Gooseneck	NO
	Structural reinforcements	NO
	Swivel Flange	NO
	Isolation valve	NO
Linepipe	Linepipe	NO
Buoyancy Foam Module	Buoyancy Module	YES
	Clamp	YES
LRTA (Lower Riser Termination Assembly)	Piping	NO
	Structural parts	NO
	Diverless connector Hub	NO
	Isolation valve	NO
	Flexible Bottom Connector (Male connection)	NO

SLWR		
Main Component	**Subcomponent**	**Spare part**
Flexible Joint	Flexible Joint Support	NO
	Flexible Joint System	NO
Swivel Flange	Swivel Flange	NO
Line pipe	CLAD Pipe (Metallurgic Bonded)	NO
	CLAD Pipe (Mechanically Bonded)	NO
	VIV Strakes	YES
Buoyancy Device	Buoyancy Module	YES
	Clamp	YES
PLET (Pipeline End Terminator)	Pipe Structural parts and anchoring system	NO
	Pipe	NO
	PLET/MCV connector (Female Connection)	NO
		NO
MCV (Vertical Connection Module)	PLET/MCV connector (Male Connection)	NO
		NO
	Pipe	NO
	Structural part	NO
	Swivel Flange	NO
Cathodic Protection	Anode Sled	NO
	Continuity Cable	YES

<table>
<tr><th colspan="3">FSHR</th><th colspan="3">SLWR</th></tr>
<tr><th>Main Component</th><th>Subcomponent</th><th>Spare part</th><th>Main Component</th><th>Subcomponent</th><th>Spare part</th></tr>
<tr><td rowspan="2">Foundation</td><td>Flexible Bottom Connector (Male connection)</td><td>NO</td><td rowspan="3"></td><td>Mechanical Connection</td><td>YES</td></tr>
<tr><td>Structural parts</td><td>NO</td><td rowspan="2">Anode</td><td rowspan="2">NO</td></tr>
<tr><td>Cathodic Protection</td><td>Anode</td><td>YES</td></tr>
</table>

The following detection measures have been identified for the FSHR:

- The tension on the Flexible Top connector can be monitored by the Top Tension Monitoring system.
- The tension on the following components can be extrapolated by the measurement of the Top Tension Monitoring system: Structural components of URTA, Riser line pipe, Flexible Bottom connector.
- A Local Camera can monitor the following items: Flexible Top connector, the components of the MCV, the components of the URTA.

The following detection measure has been identified for the SLWR:

- The tension on the following components can be extrapolated by the measurement of the Top Tension Monitoring system: Flexible joint, Swivel flange, Riser line pipe, PLET.

<u>Data Collection</u>

The following Table 6 reports a portion of the data collection used for the case-study 2. Due to the particular features of the items in the battery limits of the system few data have been extracted from commercial databases. The most part of the failure rates have been statistically calculated starting from all input data from operational experience and from vendors. They can be considered suitable and conservative for all items belonging to systems object of analysis.

Table 6: Extract of Data Collection

Equipment	Failure Modes	Failure Rate $[h^{-1}]$	MTTF [y]	ART [h]
Riser Base	Structural Deficiency	1.10E-06	104	5.1
Valve - manifold	External Leakage - process medium	2.20E-07	519	15.2
	Leakage in closed position	1.10E-07	1038	26.6
	Other Failure Mode(s)	6.00E-08	1903	5
VIV	General damage	8.54E-07	1170732	240
…	…	…	…	…

<u>FMECA</u>

The systematic performance of the FMECA allowed the identification of a detailed list of critical items for FSHR and SLWR, (see examples in the following Table 7 and Table 8). Results are shown in terms of risk associated to the failure of each piece of equipment without inspection and related residual risk following the recommendation of a defined inspection interval.

Table 7: FSHR criticality list and recommended Inspection Interval.

Item	Risk without Inspection	Recommended Inspection interval (y)	Residual Risk
Structural Part of foundation (Riser base)	Intolerable	1	Undesirable
Structural parts LRTA	Undesirable	1	Undesirable
Flexible Bottom Connector (rotolatch)	Intolerable	1	Tolerable
Line pipe, Gooseneck, URTA piping	Intolerable	2	Tolerable

Item	Risk without Inspection	Recommended Inspection interval (y)	Residual Risk
LRTA piping	Undesirable	2	Tolerable
Structural parts URTA	Undesirable	2	Tolerable
Structural part MCV	Intolerable	2	Tolerable
Buoyancy tank central core	Undesirable	3	Tolerable
Isolation valves (MCV, URTA, LRTA)	Undesirable	5	Tolerable
Flexible Top Connector and Swivel Flange	Undesirable	16	Tolerable
Diverless connectors (MCV, URTA, LRTA)	Undesirable	28	Tolerable
Buoyancy Module, Buoyancy Clamp, Anode and Buoyancy Tank	Tolerable	(a)	(a)
Pipework and valves of the ballasting system	Negligible	(a)	(a)
NOTE: (a): The Risk without Inspection is acceptable, therefore a minimum Inspection interval is not suggested.			

Table 8: FSHR criticality list and recommended Inspection Interval.

Item	Risk without Inspection	Recommended Inspection interval (y)	Residual Risk
PLET Structural parts and anchoring system	Intolerable	1	Undesirable
Anodes	Intolerable	1(b)	Undesirable
Flexible Joint Support and Flexible Joint System	Intolerable	1	Tolerable
CLAD Pipe (Metallurgic and Mechanically Bonded)	Intolerable	2	Tolerable
Pipe PLET and Pipe MCV	Undesirable	2	Tolerable
MCV structural reinforcements	Undesirable	2	Tolerable
Anode Sled	Undesirable	5	Tolerable
Swivel Flange and MCV Swivel Flange	Undesirable	16	Tolerable
PLET/MCV connector, VIV strakes, Mechanical connection for Anode Sled, Buoyancy Module and clamp. Continuity Cable	Tolerable	(a)	(a)
NOTE: (a): The Risk without Inspection is acceptable, therefore a minimum Inspection interval is not suggested. (b): If it is necessary to improve the inspection interval, a spare anode should be installed. In this case the risk results tolerable also without inspection.			

The results reported in Table 7 and Table 8 show that the most stringent requirements in term of Inspection Intervals are connected with the components subjected to high stress (e.g. riser base, Flexible Bottom Connector, PLET etc.) and for which detection measures and/or spare parts are not foreseen. For these item the Inspections are essential and permit to reduce the risk to acceptable level.

4. CONCLUSION

In the common practice the application of the RAM techniques to subsea systems is not widely diffused, differently from the standard Oil & Gas industry (such as onshore plant or offshore platform). In this frame the reliability methods do not require the development of new approaches, but the adaptation of the existing RAM techniques to these new subsea systems.

The two case-studies reported in this paper demonstrate the effectiveness and the benefits of the application of the existing RAM tools to subsea systems. The main design improvements have been reached by means of the identification of the critical items, moreover it also possible to give recommendations and define a guideline for the maintenance and inspection activities.
Finally the RAM methods are essential to validate the design, verifying the availability target.

The main criticality connected with this tools and highlighted in the two case-studies is the lack of reliability data. The development of “ad hoc” database, based on the Oil & Gas Company experience on subsea systems, should be an important future development to allow a more and more consolidate application of the RAM techniques to increasingly wide field of application.

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