RISER INCIDENT PREVENTION: LESSONS LEARNED FROM BRAZIL

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ABSTRACT

Even with laws, regulations, or risk management tools designed to avoid subsea accidents in offshore installations, a major accident reveals failures in companies' risk control. In addition, similarities between different riser failure events challenge the current technologies and completeness of applied risk management practices. Due to the limitation of easily accessible oil and gas reservoirs, the oil and gas industry is devoting increased interest to subsea equipment. More than 4,000 offshore pipes in Brazil include umbilical, service lines, injection lines, multiphasic lines, oil pipelines, and gas pipelines. The paper presents the analysis of all riser incidents in Brazil to verify the common causes to address gaps in riser risk management practices. The outcome of this study shows that most parts of the riser causal factor are related to equipment failures, and the most recurrent root causes are project error and integrity control. However, most investigations identified few causal factors and root causes and the absence of riser failure mode and mechanisms. Therefore, the development of incident recommendations can be prejudicated. Thus, improvements in ANP regulation and operator incident investigation procedures should be required.

1. INTRODUCTION

Oil and gas have been the most critical elements of the world's energy mix for decades and will probably persist for many years to come. Even though the global demand for these energy sources continues, the industry that provides them is changing since the world's readily accessible oil and gas reservoirs are less numerous than in the past. Thus, future oil and gas resources, especially in non-OPEC (Organization of the Petroleum Exporting Countries) countries, will tend to be deeper, harder to find, and in less accessible environments [1]; [2]. Thus, the number of subsea equipment as risers should be increased. In Brazil, the offshore industry has been rising over the years. According to ANP [3], in 2019, offshore production was around 96% of Brazilian oil and gas production, while the pre-salt share was approximately 69% of Brazilian offshore production. Therefore, shortly soon, Brazilian offshore production will increase even more due to the pre-salt field production yet to come.

The riser system of a production unit is to perform multiple functions, both in the drilling and production phases. The tasks performed by a riser system include production, injection, export/import or circulate fluids, drilling and completion & workover. A typical riser system is mainly composed of conduit (riser body), interface with floater and wellhead, components, and auxiliary (such as end fittings, bend stiffeners, riser joints, buoyancy modules, bending restrictor) [4]. Riser system failure concerning major accidents is one of the potential undesirable events in the offshore petroleum industry. One riser accident can cause considerable damages to the companies, the environment and offshore industry image due to the importance of these harmful effects to the society and offshore industries. Therefore, the prevention of incidents has special attention, safety consultants and researchers [5].

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Major hazardous are rare, and people, therefore, believe that they will never occur. Indeed, for a major accident to happen, several barriers must successively fail. In Brazil, there were 36 riser incidents reported to ANP (Brazilian National Agency of Petroleum, Gas, and Biofuels). The recurrence or similarities of incidents suggest that current lesson learning methods might not have identified, assessed, or addressed proper improvement measures. Some of these lessons can be learnt by reviewing the past accident. As a result, it is crucial to evaluate similar riser incidents to understand the interactions that support the recurrence of failures in risk control. Thus, this paper analyses 36 riser incidents that occurred in Brazil between 2013 and 2021, using information from the Detailed Incident Report received by ANP (National Agency of Petroleum, Natural Gas, and Biofuels). The objective is to identify gaps in the regulatory regime, riser design and production component.

External interference, primarily third-party activity, is one of the leading causes of natural gas and oil industry pipeline incidents. Corrosion or material construction defects are also common causes of incidents, particularly in oil industry pipelines [6]. Understanding the root cause of an accident and equipment failure is essential in making well-informed choices regarding repair strategies and mitigating future losses, increasing quality in subsequent design and produced components [7].

In this paper, first, the contextual elements of the Brazilian regulatory regime and lessons learned by accidents are reviewed. Second, 36 Brazilian riser accident causes have been analyzed. Finally, some corrective actions are proposed to prevent similar accidents from occurrence by studying the lessons learned.

2. THEORICAL REFERENCE

2.1 Brazilian subsea regulatory regime

Laws and regulations are essential to help protect people and the environment [8]. Nowadays, the offshore regulation structure in Brazil is complex and presents overlapping requirements from different authorities. There is one authority with a specific way to elaborate, approve, and enforce regulations [9]. The Offshore environment in Brazil is regulated and inspected by ANP, the Brazilian Navy, the Secretary of Labor, and IBAMA (Brazilian Institute of Environment and Renewable Natural Resources).

The ANP regulates major hazards prevention based on safety management practices. The Navy inspects marine and shipping safety enforces the International Maritime Organization (IMO) and local maritime requirements through prescriptive rules. The Secretary of Labor supervises occupational health and safety requirements through prescriptive regulations named NRs. The IBAMA is responsible for environmental requirements through licensing process and prescriptive regulation [10]. However, during the exploration and production (E&P) cycle, ANP, IBAMA, the Navy, and the Secretary of Labour are all accountable for safety issues related to installation, operation, human life, and the environment.

Today, ANP has nine active regulations of E&P operational safety. The offshore regulations based on management systems are:

1. The operational safety management system for offshore drilling rigs and production platforms (SGSO).
2. The operational safety management system for subsea systems includes flowlines, risers, and pipelines (SGSS).
3. The operational safety management system for well integrity (SGIP).

In case of an incident, operators should report to ANP within 48 hours according to severity. The ANP’s role is to enforce the implementation and continuous improvement of safety management systems through documentation analysis, performance review, incident investigation, and regular audits. It also includes informal actions to promote risk awareness among different stakeholders, such as data disclosure, thematic meetings, workshops, guidelines development, and safety alerts [10].

In 2015, Resolution ANP 41/2015 [11] established the principles for subsea installations, henceforth SGSS. This regulation specifies the essential requirements, minimal operational safety standards, and preservation of the environment to be met by the authorized agents responsible for subsea systems. The SGSS are mostly non-prescriptive. There is no direct demand for standards in the regulations. Consequently, risk evaluations must be applied by the risk owner, identifying and using good practices and appropriated standards. Then, the results of the applied standards and risk evaluations are under companies' control and checked by ANP when the system is already built, installed and in operation.

In 2018, ANP started inspections focus on SGSS requirements and subsea environment. The purpose of ANP inspections is to identify whether the concessionaire effectively complies with best management practices and establishes its safety culture according to safety regulation requirements. An inspection is a schedule considering the facility type, history, and information ANP has on the facility [12]. During inspections, ANP can lead to critical safety equipment tests, interview workers, and analyze paperwork [9]. The ANP inspection happens during the installation construction and operation [13]. After the auditing process, companies that do not follow the BSRF receive a non-conformity notification and should demonstrate that fault was eliminated and gave the root cause comprehensive and preventive treatment.

In 2003, ANP published a resolution on the incident notification and updated this regulation in 2009 [14]. Furthermore, ANP published an incident communication manual in 2013, updating it in 2014 and 2017 [15], [16] and [17]. The main objective is an orientation for incident communication, and it has brought definitions of incident types. In 2017, ANP was included riser accidents typology in the incident communication manual. This inclusion clarifies what kind of incidents must be communicated. The accident is the occurrence involving:

1. Damage to the environment or human health.
2. Material losses to own or third-party assets.
3. The fatalities or serious injury to their staff, third parties, or the public.
4. Unscheduled interruption of operations for more than 24 (twenty-four) hours.

In the case of an accident, the operator shall submit the investigation report to ANP. Besides, ANP carries out the accident investigation process to identify causes and possible solutions [14].

2.2 Lessons learned from incidents

Nowadays, accident investigation or analysis are widely recognized as an essential part of a comprehensive and efficient process of safety management. A detailed and systematic analysis of an unanticipated event allows identifying not only its immediate (primary) cause. But also the whole set of root causes whose combination led to the failure of the system and the occurrence of the corresponding harmful consequences (major accident) or an unplanned temporary hazardous condition (near-miss) [18]. It's necessary to look beyond the immediate causes to avoid the hazardous, such as inherent safer design and weaknesses in the management system. Furthermore, if the underlying causes are found, suitable recommendations should be made and carried out [19].

An essential strategy in incident prevention is to learn from previous occurrences and thus be better able to prevent them again. The accident investigation is like peeling an onion. The outer layer deals with the immediate technical causes. In contrast, the inner layers are concerned with avoiding the hazard and underlying causes, such as weaknesses in the management system. Thus, immediate causes and root causes of an accident are essential and should be considered to prevent further accidents [20].

Major accidents may be viewed as failures of risk ownership, and that improving this aspect may help resolved particular systemic issues highlighted in investigation reports. Accident models show that risk control is based on the definition and support of risk constraints among different roles in the industry, including the regulator, the companies, and the work environment. Thus, a regulator's lack of requirements or supervision may support undesirable conditions for major accident prevention, even after assigning safety responsibility to the companies, the risk owners in the functional regulatory regime (FRR). However, the FRR approach must not be limited to a set of non-prescriptive requirements and frequent audits. It also demands a good balance between dialogue, performance review, other influencing activities, building and supporting commitment, risk awareness, and safety culture [10].

3. RESEARCH METHODOLOGY

The research methodology applied in this paper is limited to the study of riser incidents occurred in Brazil, using an evaluation of the Detailed Incident Report received by ANP. There were 36 incidents between 2013 and 2021. Since 2013, ANP has incident database called SISO (Integrated operational safety system). Furthermore, ANP publishes in a site part of its information on incident communications.

We used an accident investigation approach based on the system life-cycle and management practices. The life-cycle approach has been used in earlier study as [20]. In this way, the dynamic of an accident is categorized and studied from the perspective of the system lyfe-cycle stages. The Figure 2 presents life-cycle stages for offshore structures inspired by the accident investigation from [21]. The life-cycle starts with business needs and design stages. The design is based on the limit state design methods (e.g. ultimate, fatigue, accidental, serviceability damage limit states). One of the fundamental principles of the subsea industry is that quality must be designed into equipment and processes from the beginning [22].

The next stage is fabrication, this stage can have many challenges like the necessity of an adequate monitoring of fabrication process by engineering companies, operators, rig owner and requirement for experienced engineers and fabrication experts. A lack of follow up will dramatically impact the safety, increase financial risk and open the way for re-design and modifications. The next stages within the life-cycle are represented by installations, operation and de-commissioning and marine operations are part of all of these stages. The proper planning according to standards, weather windows and environmental conditions are of high importance for marine operations. Between installation and operation stages, the commissioning which through testing, checking, verification, and documentation assure that all systems, process and components meet operational requirements. In operation stage various operations happen, e.g. production, maintenance/repair, modifications and inspections [21].

The life extension occurs when operator want to use installation after having reached to their original planned end of life. In Brazil, the operator shall communicate ANP one year before the planning lifetime expire and shall prepare document to ensure that the safety and integrity are maintained in this structure. In de-commission stage, the operator submits to ANP consent the plan to carry out the proper destination of each installation.

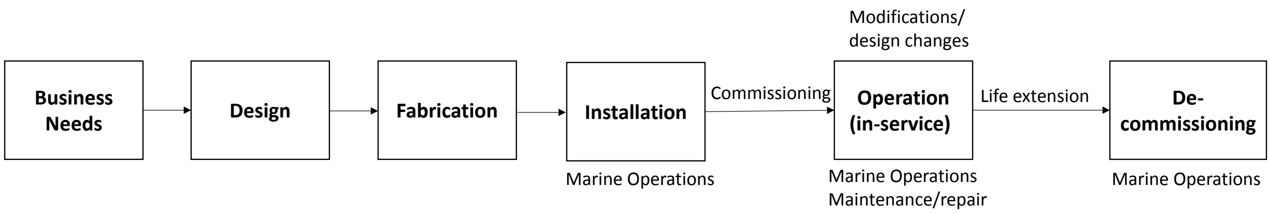

Fig.1 – Life-cycle stages for offshore structures
Based on [21]

The management practice perspective is present in previous studies as [10]. This approach identifies the main cause-related circumstances surround accidents and correlated with management practice. In Brazilian environment, the management practices for riser incidents are presented in SGSS. These regulations consist of a PSM structure based on the PSM framework of CCPS and the ANP experience in inspections and the incident investigations process [13]. The SGSS presented 21 management practices (MP) as presented in Table 1. These practices management practices are intended to be incorporated into every life cycle phase of a subsea installation to improve safety. These management practices are split into three broad categories (1) management, leadership, and personnel, (2) facilities and technology, and (3) operational practices.

Tab.1 – SGSS management practices

Group	**SGSS Management Practices**
Management, leadership, and personnel	MP6: safety culture and managerial commitment and
	MP7: workforce involvement*

Group	SGSS Management Practices
	MP8: workforce qualification, training, and performance
	MP9: work environment and human factors
	MP10: selection, control, and contracted company's
	MP11: continuous improvement and performance monitoring
	MP12: internal audits
	MP13: information and documentation management
	MP14: incident investigation
Facilities and technology	MP20: design
	MP21: manufacturing and installation
	MP26: decommissioning and deactivation
	MP15: critical operational safety elements
	MP16: risk analysis
	MP23: integrity management
	MP18: planning and management of emergencies
	MP24: reuse
	MP25: life extension
Operational practices	MP22: operation
	MP17: change management
	MP19: safe working practices and control procedures in special

The accident investigation approach includes the following steps:

1. Definition of context at the time of accident: time (e.g. year and month); age of pipe; pipe fluid; structure type (e.g. flexible or rigid); typology of incident according ANP classification; failure localization.
2. Comparison of degree of damage severity per accident.
3. Comparison of causes based on SGSS management practices.
4. Categorization in life-cycle stages.
5. Accident analysis from life-cycle stage and management practice perspective.

4. CASE STUDIES ANALYSIS AND DISCUSSION

This section explores 36 incidents used as case studies to identify the main cause-related circumstances surrounding similar incidents, over more than 7 years (from October 2013 to March 2021). The type of accidents which have been considered for this study are related to subsea installation as risers. Some of them have considerable potential or consequences, however anyone have a public investigation report from regulator's investigation.

Data about the case studies was provided by SISO which is a repository of Brazilian E&P incidents data. This system is administrated by ANP, and the data are included by operators. Today there are more than 16.000 E&P incidents communicated in SISO. All these case studies are from Brazil. In Brazil, the E&P incidents are regulated by Resolution ANP 44/2009 [14]. According to this resolution, operator should communicate to ANP in until 48 hours accidents and near-misses occurred in Brazilian onshore and offshore installations. In case of accidents, operators should send Detailed Incident Report 30 days after accident. This report should contain information about accident timeline, causes and consequences.

The incidents have been analyzed in thematic analysis, correlating causal factors, causes and circumstances to one the management practices stablished by the SGSS. The thematic analysis has been develop considering the root causes appointed by operator, each incident was grouped into management practices and a rank of topics was obtained.

4.1 ANALYSIS

In this section the data of 36 riser incidents was analyzed. It was identified that the number of accidents per year increased after 2017, the high peak was in 2017, it was registered 9 events, see Fig. 2. Possible reason and explanation about why high number in these years might be linked with the inclusion of the specific typology od accidents involving risers in the incident communication manual. Thus, clarifying the need to communicate these events to the ANP. Other reason might be linked with the publication of Resolution ANP 41/2015 that introduces specific requirements to riser. In 2017 occurred the first accident related to SCC-CO2 (CO2 Stress Corrosion Cracking) in gas injection flexible riser. This mechanism has been studies to prevent new accidents.

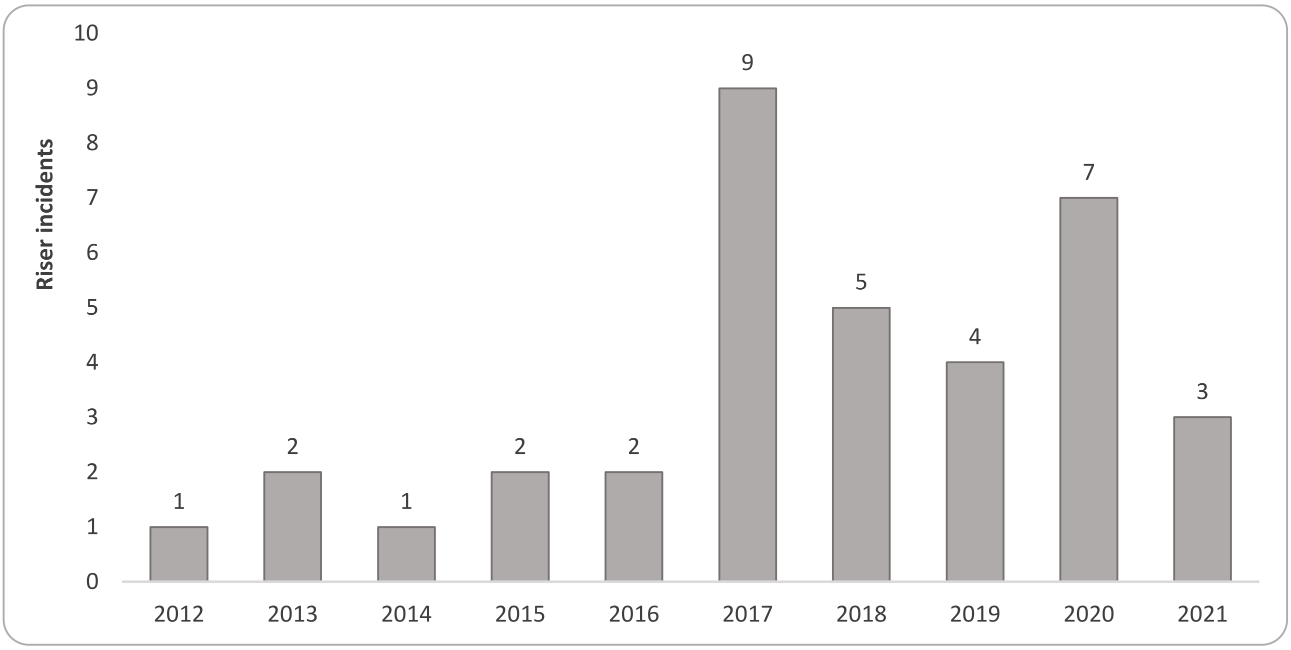

Fig.2 – Brazilian riser incidents

Furthermore, an analysis was performed to identify the number of accidents per riser structure type (rigid or flexible). It was identified that the number of accidents is higher in flexible pipelines, see Fig. 3. Possible explanation might be linked with the number of flexible risers in Brazil is most of 70% and rigid is 20%. The other equipment is riser buoyancy, mooring, joints, connection.

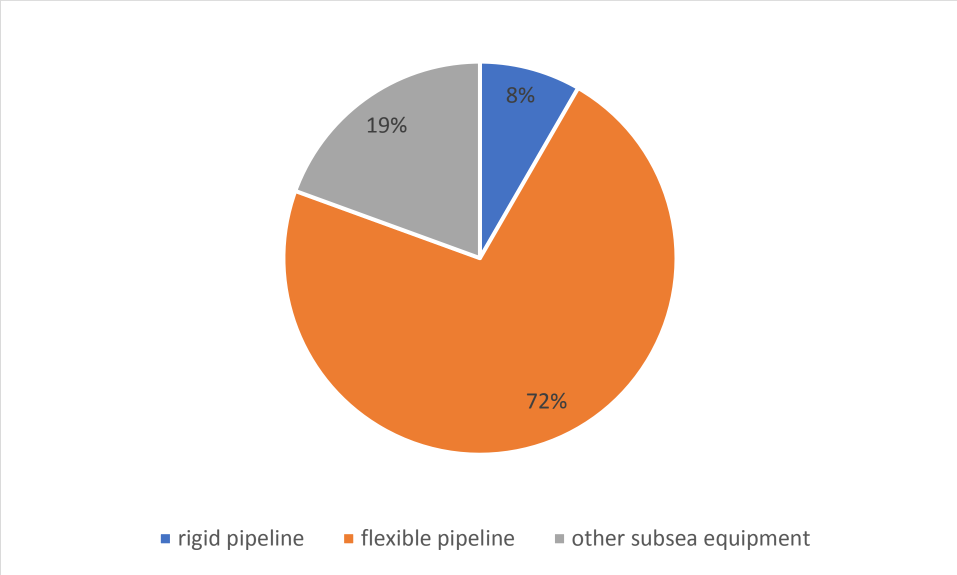

Fig.3 – Riser accidents – structure type

Around 67% of riser accident have some damage of environment since it has some hydrocarbon discharge. Fig.4 present the categories of the main events and their percentage linked with consequences severity. This classification is based ANP damage to environment classification presented in ANP [23]. The main event of accidents was identified to be minor severity since it was minor oil/gas spill or water spill.

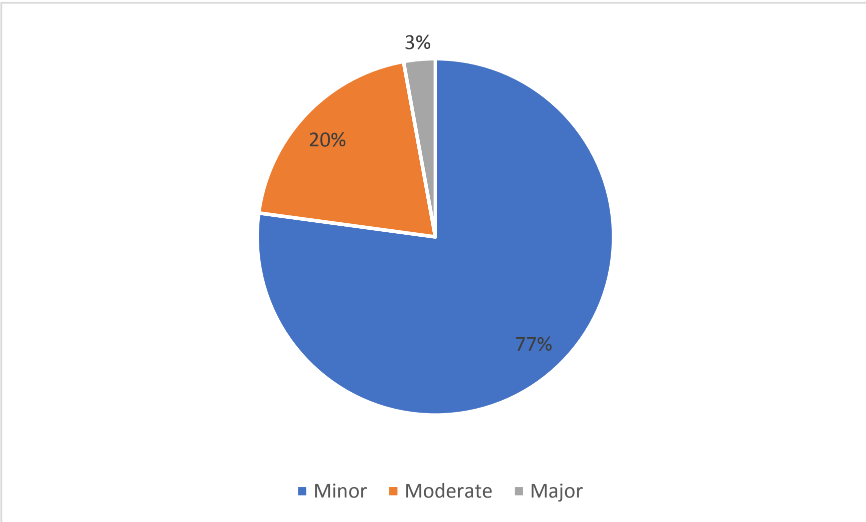

Fig.3 – Riser accidents – damage severity

According to Vicent [24] and Ibrion et al. [21], the failures in oil and gas industries can occur over all the life cycle of system and the failure is mainly connect with one more from the following causes: faults in design, material defects, manufacturing deficiencies, installation defects, maintenance deficiencies, improper operation. Moreover, a failure can be directly or indirectly caused by external stressors as: mechanical, environmental, electrochemical, thermal exposure and radiation. Corrosion failures, fatigue failures and ductile and brittle metal failures are among the most common root cause for failures in oil and gas industry. In addition to technical root causes, there are human, and organization causes for failures. For risers API RP 17B [25], API SPEC 17J [26] and DNV-OS-F101 [27] presented riser failures modes and mechanism. There most common failure mode of riser accident was structural damage, see Fig.4.

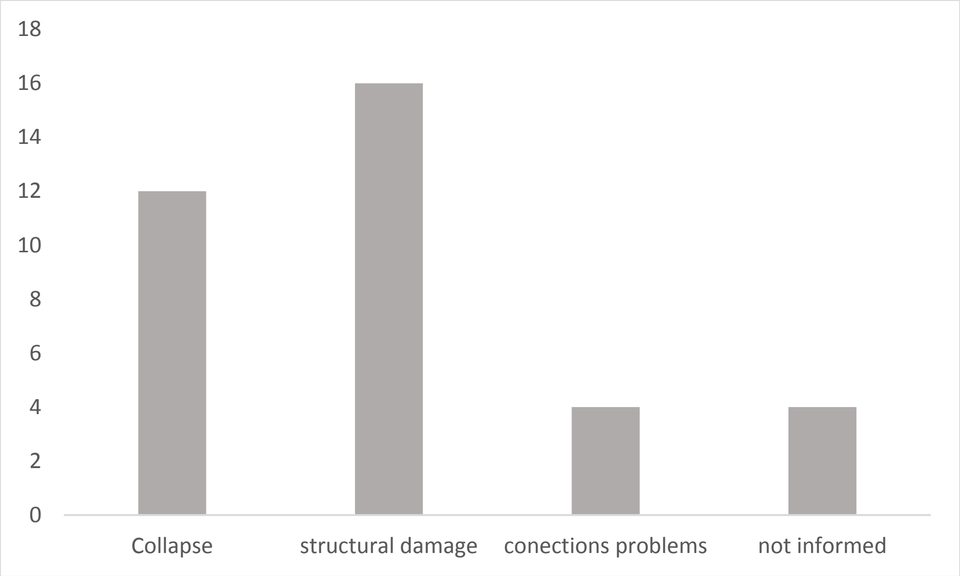

Fig.4 – Riser accidents – failure mode

After employing the life-cycle investigation approach to 36 Brazilian riser accidents, it was found out that the accident occurrence is mainly linked with the operational stage of life cycle and represents 56%, see Fig.5. Ibrion et al. [21] identified the reasons linked to operational stage be the major accident occurrence as the operation stage is the longest stage for the life-cycle of marine structure and also is very complex stage.

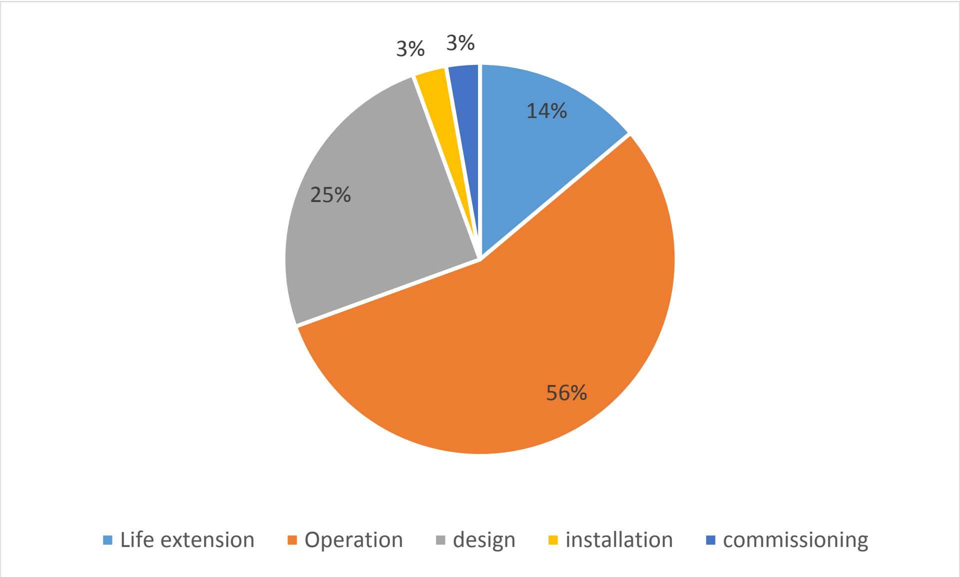

Fig.4 – Riser accidents – life-cycle investigation

Integrity management was the first aspect related to riser accidents, see Tab. 2. Possible explanation might be linked with the most riser accidents investigations just indicate immediate (primary) cause. The second most common cause was design problems. Possible explanation might be linked with the most of accidents lessons learned about was not applied to improve new riser design. The ANP regulation is non-prescriptive and there are not requirements to help operators to identify good practices and appropriate standards [11].

Tab.2 – Incident's cause-related circumstances and the correlation with SGSS

Management practice	**Number of**	**Average**
MP9: work environment and human factors	**1**	1%
MP13: information and documentation management	**2**	2%
MP14: incident investigation	**5**	5%
MP16: risk analysis	**3**	3%
MP17: change management	**2**	2%
MP20: design	**20**	21%
MP21: manufacturing and installation	**4**	4%
MP22: operation	**9**	9%
MP23: integrity management	**51**	53%

5. CONCLUSIONS

Major accident prevention is a challenge for all offshore industry, in addition to the recurrence and similarities between riser incidents may lead to doubts regarding whether all lessons from previous events have been properly learned. It can be the symptom that not all causes are identified through incident investigations, or improper lessons are assigned to prevent similar events. Using life-cycle approach, the most complex stage for riser accident is operational. By performing an analysis based on the information gathering, the major causes fall under integrity management and design categories.

Consequently, the analyzed incidents show the need to guarantee proper investigation methods, identifying all root causes. Thus, the analysis focused on the regulatory influencing factor that support risk constrains to guarantee proper human performance and safe system in oil and gas offshore production platform.

6. ABBREVIATIONS

ANP National Agency of Petroleum, Natural Gas, and Biofuels
CCPS Center for Chemical Process Safety
E&P Exploration and Production
FRR Functional Regulatory Regime

IBAMA Brazilian Institute of Environment and Renewable Natural Resources
IMO International Maritime Organization
MP Management Practices
OPEC Organization of the Petroleum Exporting Countries
PSM Process Safety Management
SCC-CO2 CO2 Stress Corrosion Cracking
SGIP Technical Regulation of the Well Integrity Management System
SGSO Technical Regulation of Operational Safety Management System for Maritime Drilling Installation and Oil and Natural Gas Production
SGSS Technical Regulation of Operational Safety Management System of Subsea System
SISO Integrated operational safety system

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