



Paper 5

DEVELOPING GUIDELINES FOR EVALUATING DAMAGE TO SUBSEA PIPELINES

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Abstract

Subsea pipelines and flowlines are periodically subjected to damaging events such as anchor snags that result in massive pipeline movements, dropped object damage, internal/external corrosion damage, and connection leaks. Knowing how to respond to these damage events is often challenging, especially considering the potential for product release. The cost of production shut-ins can be very high and avoiding un-necessary shut-ins is desirable.

Over the past several decades a significant body of work has been accumulated as an industry on best practice response to incidents and how to repair pipelines when necessary. The knowledge base associated with pipeline damage assessment resides with operators, research organizations and collaborative groups. This paper provides information about the ongoing SPDA-1-2 study for PRCI, *Developing Guidelines for Evaluating Damage to Subsea Pipelines*. Presently, this multi-year study is focused on shallow water pipelines, and future efforts will address deepwater pipelines. The paper provides a brief overview of the current state of the art, results from an industry survey where operators were asked about how they respond to pipeline damage, and insights associated with the ongoing efforts to develop the guidelines as part of the PRCI study.

1. INTRODUCTION

Subsea pipelines and flowlines are periodically subjected to damaging events such as anchor snags that result in massive pipeline movements, dropped object damage, internal/external corrosion damage, etc. Knowing how to assess these damage events is often challenging, especially considering the potential for product release. The cost of production shut-ins can be significant and avoiding un-necessary shut-ins is desirable. While most pipeline operators have company-level procedures and programs in place for responding to pipeline emergencies, at the current time there is no single resource for providing guidance for the pipeline industry. For this reason, the Pipeline Research Council International, Inc. (PRCI) commissioned the SPDA-1-2 project, *Developing Guidelines for Evaluating Damage to Subsea Pipelines*. The primary focus of this study is to develop guidelines for operators to respond in an effective and timely manner to damage once it occurs.

The program was originally envisioned as a four-year study, with the program currently being in its second year. Initial efforts focused on assessing industry's current state of the art with primary emphasis on how to best evaluate pipeline damage from a mechanics standpoint. Also included in the first year's efforts was a survey used to capture the offshore pipeline industry's perspectives on the following subjects.

- Types of damages that occur.
- Methods for evaluating the damage including inspection techniques.
- Finding guidelines that are currently in existence and used by operators in addressing damage.
- Survey of repair techniques.

After extensive communications among PRCI members of the SPDA-1-2 Technical Committee, it was decided to focus efforts during the second year of the study on shallow water pipelines (i.e. depths up to 1,000 fsw), while work in the third year will focus on deepwater pipelines. Efforts during the fourth year will generate a comprehensive guideline document accompanied with a workshop.

This paper has been prepared to provide the pipeline industry with an update on the current program, as well as provide insights on the critical elements required for effectively responding to pipeline emergencies. The sections of this paper that follow include a *Background* section based on work from the first year's efforts providing an overview on subsea pipeline damage. The *Industry Survey* section provides data acquired during the survey of operators and includes several graphs showing the collected results. The focus of this paper is to provide for the offshore pipeline industry a preliminary overview of the Response Plan being developed a part of the SPDA-1-2 program, including a decision tree flowchart (hereafter referred to as the *Response Plan Decision Tree*). Information associated with this effort is presented in the *Response Plan Guideline Development* section. A *Case Study* section has also been prepared to provide the reader with a hypothetical scenario demonstrating how the proposed guideline process can be used. A *Closing Remarks* section provides a brief discussion on the upcoming work scope and associated deliverables.

2. BACKGROUND

Over the past 20 years a significant body of work has been accumulated in association with efforts to evaluate damage to subsea pipelines. Listed below are some of these efforts.

- Full-scale burst and fatigue tests on pipes having dents, gouges, dents with gouges, and wrinkles.
- Finite element modeling of dents to calculate alternating stresses for estimating remaining life.
- Modeling damage associated with anchor impact including pipe-soil interaction to evaluate the global displaced response of the pipeline.
- Studies using numerical modelling and full-scale testing to evaluate the integrity of specific subsea dents using in-line inspection (ILI) data and dent profiles measured using remotely-operated vehicles (ROVs).
- Studies and efforts addressing the repair of subsea pipelines including management of the Response to Underwater Pipeline Emergencies program (RUPE) started in 1978. RUPE is composed of a consortium of 31 oil and gas transmission companies.
- Design of pipeline replacement spool pieces associated with remediation activities. These efforts have included engineering design, developing drawings packages, calculating remediation costs, interfacing with insurance companies and adjusters, and assisting in deployment of pipeline systems.

One of the most critical elements required to assess pipeline damage is classification of defects. There is a significant amount of information available in the open literature on this subject; however, one of the challenges is putting everything together in a manner that can be used to actually assess damage severity. Integrating previous lessons-learned in association with defect classification is an important element in this study. This information will be used to provide a systematic methodology for operators and pipeline service companies who are tasked with making decisions about what to do when pipeline damage occurs.

Because of the extensive research that has been conducted world-wide relating to damaged pipelines, it is possible to draw information required on a range of defect types. The driving motivation for many of these research programs was to develop a better understanding of damaged pipelines to characterize their behavior in relation to certain damage mechanisms. As with many areas of engineering, the ability to accurately predict the response of structures is important to ensure adequate safety and predictable performance. The complexities associated with damaged pipelines make this a challenging task. Material issues, corrosion, cyclic pressure conditions, pipe-soil interactions, and complicated stress fields are just a few of the possible examples.

Provided below are the major defect classifications that typically arise when assessing pipeline damage.

- Coating damage
- Internal or External Corrosion Damage
- Plain dents
- Constrained dents
- Gouges
- Mechanical damage e.g. "U" shaped grooves from cables, scores, etc.
- Wrinkles and kinks
- Rupture

One of the most comprehensive efforts conducted by an oil company that parallels the objectives of this study was executed by Shell Pipeline Company in evaluating damage inflicted to the 20-inch gas pipeline during Hurricane Katrina. The fitness for service effort involved numerical modelling. Also involved were nine pressure cycle fatigue tests carried to failure and one burst test. The results of this program were documented in a 2008 OTC paper entitled *Methodology to Establish the Fitness for Continued Service of a Hurricane Damaged Export Pipeline in 1000 m of Water*.¹ Included in this paper is a six step assessment process that includes the following tasks.

- Step one consists of preliminary inspection to assess the extent and type of damage. This is generally done by flying the affected section of the line with an ROV. At this stage, extensive photographic (and video) evidence is collected. The operator is now able to assess the basic extent of damage.
- Step two is when a decision is made if the pipeline or flowline needs a replacement, repair or if the line can be put back in service. At this stage, the user determines if fitness for service can be reliably carried out.
- Step three consists of establishing clearer inspection and evaluation protocols for every type of damage that can be expected in this pipeline.
- Step four consists of carrying out API Level 1, Level 2 or Level 3 types of assessments (as detailed in the OTC paper).
- Step five is carried out if analytical techniques in Levels 1, 2 and 3 failed to demonstrate adequate line integrity. At this stage, Level 4 (full-scale testing) is resorted to, in order to demonstrate continued integrity.
- Step six consists of coming up with a conservative residual life, followed by the determination of the inspection interval.

It is envisioned that these six steps will serve as a foundation for the proposed efforts associated with this study. Because they are based in part on the API 579 Fitness for Service document, their very approach is based upon industry-accepted methods that have been used widely in the downstream industry. Some pipeline operators are currently using API 579 as part of their integrity management

¹ D. Raghu, R. Swanson, and C. Alexander, (May 2008), "Methodology to Establish the Fitness for Continued Service of a Hurricane Damaged Export Pipeline in 1000 m of Water," Paper No. OTC-19653-PP, 2008 Offshore Technology Conference, May 5–8, 2008, Houston, Texas.

program because of its sequence-based approach that encourages and rewards detailed investigations.

3. INDUSTRY SURVEY

To collect information from pipeline operators regarding their experiences and practices regarding wrinkle bends, a survey was conducted. Stress Engineering constructed a web-based tool for collecting survey information that was posted at www.ses-surveys.com. Results from the collected data can be seen on this website. A screen shot of the website is shown in Figure 1.

A total of ten operators responded to the survey that included the following companies:

- Chevron
- Shell
- Marathon
- TransCanada
- BP
- El Paso
- Williams

Survey results were based on a total of 26 questions. Provided in Figure 2 through 5 are pie graphs showing responses to four of these questions. The survey was used to gather information on the problems and solutions associated with operating damaged subsea pipelines.

The pipelines considered in the survey are used in varying depths of water. Four of seven responses indicated that the water depth for their pipelines was at least 1,000 feet.

The majority of the pipe diameters that were used were either between 6 and 12 inches or greater than 12 inches. The survey results indicated that there are several types of damages that can occur to subsea pipelines; where anchors, storms, and corrosion are the leading causes of damage. Additionally, mudslides and interactions with platforms, jack-up rigs or spud barges have been observed as causes for subsea damage.

The methods of locating and assessing the damage also vary; however, they include ROVs, side scan sonar, divers, and in-line inspection (ILI) tools.

Based on three of the eight responses, thermal expansion has contributed to either buckling or pipeline creeping from original position. However, these displacements were not deemed unacceptable.

Exposed pipelines have other possible complications. Five of eight responses experienced problems with unsupported lengths of pipe. The remediation techniques that were listed are employed almost equally.

Damage to pipelines does occur annually, though usually less than five times a year.

The companies had varying policies when dealing with subsea pipeline damage. Only half of the responders appear to consider future conditions such as cyclic pressure fatigue, while five of eight votes indicated that they have no system in place to detect leaks. Five of seven are members of RUPE, and two of seven are members of Deep Water RUPE (DW-RUPE). In terms of pipeline repair, damage is expected to be repaired within three months.



Figure 1. Screen shot from www.ses-surveys.com

Which of the following water depths do the majority of your subsea pipeline systems operate?

- None
- Less than 200 feet [2 votes]
- 200 to 1,000 feet [1 vote]
- Greater than 1,000 feet [4 votes]

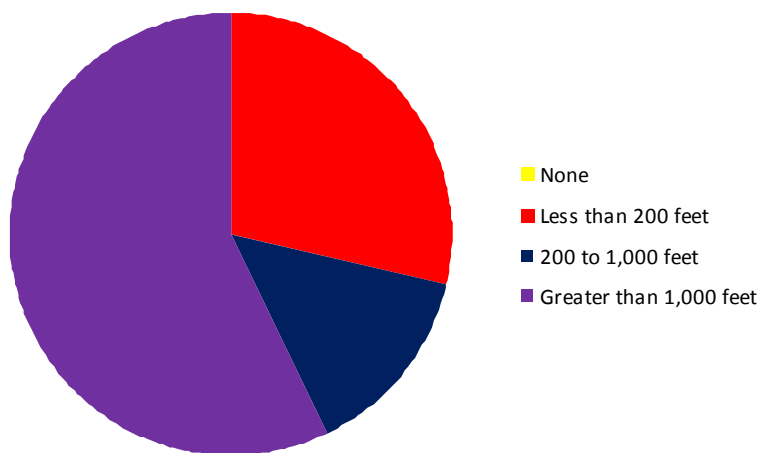


Figure 2. Survey response to question concerning pipeline water depths

What types of damages (i.e. categories) have occurred in your pipeline system?

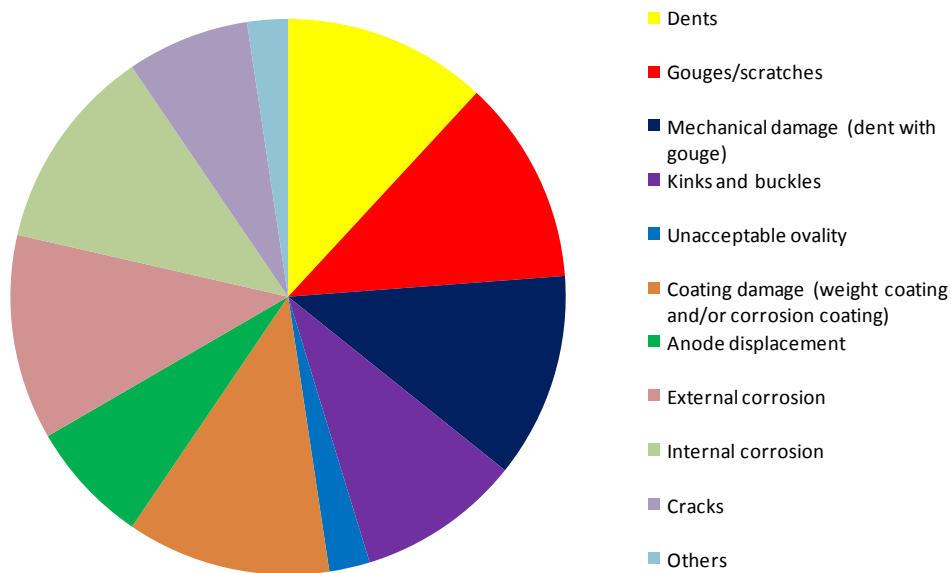


Figure 3. Survey response to question concerning damage categories

What sources of damage have been observed in your system?

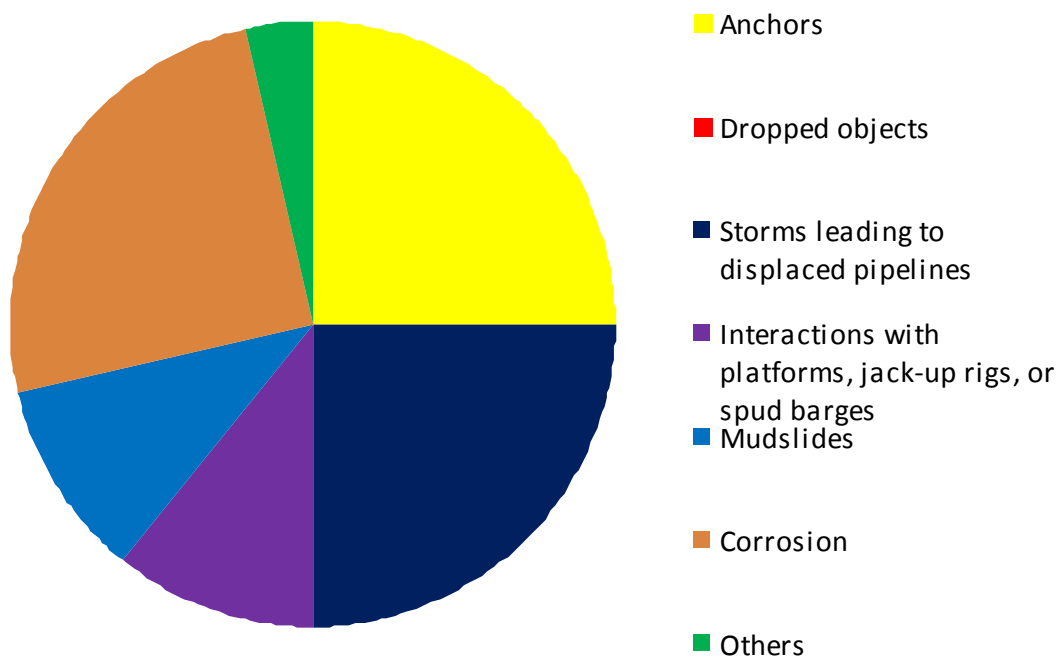


Figure 4. Survey response to question concerning sources of damage

Insurance-related question: How do you quantify the severity of damage associated with a particular damage scenario?

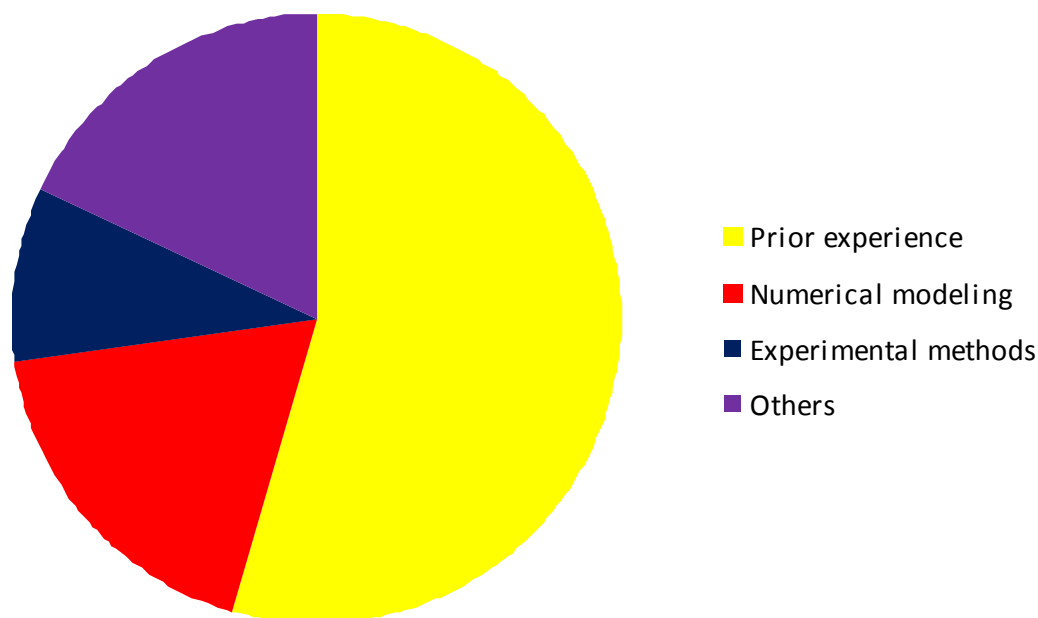


Figure 5. Survey response to question concerning quantifying damage severity

4. KNOWLEDGE GAPS

When conducting comprehensive research programs, it is common to perform *state of the art* assessments to determine the prevailing level of knowledge and common industry practices on a particular issue. Part of this effort involves identifying knowledge gaps that exist within the current base of understanding. Listed below are the knowledge gaps that were identified as part of the SPDA-1-2 year one effort. The identified gaps came primarily from the literature review, although some insights were gained from the on-line industry survey data.

- Better understanding of the hurricane aftermath including on-bottom reverse currents.
- Crossing design methods need to be standardized
- Methods must be found to include in guidelines techniques for modelling soil liquefaction when calculating stability.
- In situ instrumentation to monitor pipelines during service and record real-time data
- Limit state design for high pressure flowlines and pipelines
- Pipe-in-pipe applications
- Strain limits acceptability
- Collapse of subsea pipelines and in particular the effects of combined bending (i.e. addressed in API RP 1111)
- Leak detection
- Dropped object: planning, analysis, testing, and mitigation (numerical analyses offer rapid quantitative risk evaluation of dropped object scenarios, including interaction with different shaped objects)
- Risk-based assessment process
- Repair methods such as RUPE (e.g. the probability of needing a deepwater repair is low, but the consequences are high)
- Financial costs associated with subsea pipeline damage and corresponding repair costs
- Fitness for service methods based on API 579

- Protocols for inspecting damaged subsea pipelines (i.e. visual, ILLI, etc.)
- Effects of environment including soil, current, free spans, etc.
- Flow assurance and how it is impacted by subsea damage
- Pipe-soil interaction
- Strain limits, especially for pipelines displaced by anchors

5. RESPONSE PLAN GUIDELINE DEVELOPMENT

An initiative to develop a guideline document for responding to pipeline emergencies is complex. Developing the proper framework for approaching this problem is essential. The sections that follow include a list of key questions that were addressed before developing the Response Plan. Once concrete answers were developed for the posed questions, the outline for the guideline document was developed. Provided below are the specific steps associated with the response plan, accompanied by a detailed flowchart.

5.1 Key Questions

Listed below are the key questions that required answers before the Response Plan could be developed. Also include are the answers that were developed by the authors and members of the SPDA-1-2 team.

What is our program objective?

Develop guidelines for responding to a pipeline damage emergency in a timely and effective manner.

What is the scope of this program?

Offshore installed pipelines in diver-depths (up to 800 - 1000 fsw).

Why is the program being conducted?

A poor response will have undesirable environmental, public relations, political and economic consequences.

How should the program be started?

Develop the Response Organization and a Response Plan. The elements of the Response Plan shape the organizational needs.

5.2 Response Plan Steps

There are six key elements that are identified as the basis of Response Plan, as shown in the following chart (Figure 6).

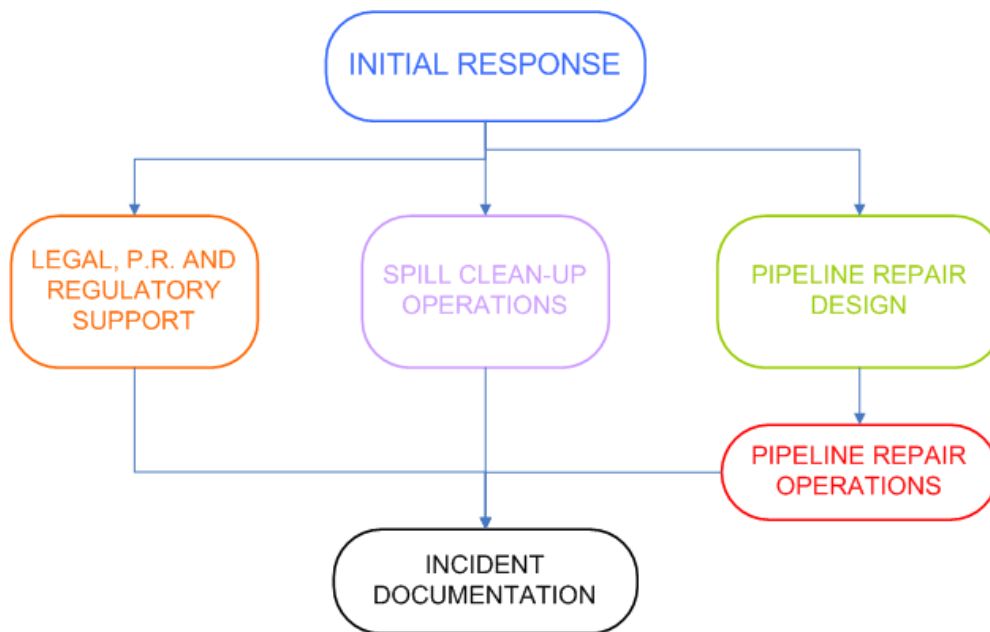


Figure 6. Six Key Elements of Response Plan

These major elements of the Guidelines were developed from a much more detailed Response Plan (decision tree) which is too detailed to be useful in this paper. The tree is a graphical representation of the thirty steps identified as critical to the response effort. The flowchart is color-coded to match the respective response steps in the detailed Guidelines.

The 30 steps are listed as follows.

5.2.1 Initial Response

1. Receive notice of events that might result in pipeline damage, or receive notice of a leaking or damaged pipeline
2. If the notice is credible, engage the first phase of the response organization to confirm that the damage or leak truly exists and that the pipeline is owned by the operator.
3. Notify regulators
4. Concurrent with 3, Take immediate steps to minimize environmental damage by shutting off the leak and initiating spill response.
5. Concurrently with 3, mobilize Incident Command Organization
6. Concurrently with 3, initiate immediate public and governmental relations responses.
7. Concurrently with 3, engage legal council, insurance.
8. (a)Take immediate (survey) steps to locate the damage, and (b) assess the nature of the damage, the level of damage, the availability of repair methods and the need for rapid repair response. Cause of damage is important, but secondary at this point.
9. (a)Initiate a plan for ongoing production operations in light of the damage and (b) investigate the cause.
10. Decide on repair or abandon line
11. Begin looking for materials
12. Design the repair

5.2.2 Pipeline Repair Operations

13. Make commitments for access to repair services, vessels, divers, etc., and pipe repair apparatus, clamps or connectors.
14. Obtain permits
15. Notify insurance on repair plans
16. Mobilize repair team
17. Perform repair job
18. Test the repair
19. Demobilize repair system
20. Re-Commission Line
21. Document the repair (provide as-built drawings)

5.2.3 Spill Clean-up Operations

22. Sustained spill response: Continue operations to minimize environmental damage:
23. When the oil spill is cleaned up, demobilize response effort.
24. Document Spill Response

5.2.4 Legal, P.R., and Regulatory Support

25. Sustained regulatory communication
26. Sustained public relations communication.
27. Sustained legal counsel and insurance communications
28. Prepare post- response statement

5.2.5 Post Incident Review

29. Perform a post-incident review of the documented results.
30. Recommend modifications to these guidelines based on lessons learned.

5.3 Response Organizational Elements

In order for the Response Plan to be executed in a timely and effective manner, it is essential that an organizational framework be in place. Provided below is the organization structure to lead and support the Response Plan as outlined above. Included in the list are the respective responsibilities and Response Plan step numbers to be completed by each group.

Command Center: Response Manager, Repair Operations Manager, Spill Operations Manager, Response Public Relations Manager. Response Communications Manager. (For small events managers can manage multiple areas).

Lead Damage Assessment Engineer. Leads team in Steps 2 and 6.

Lead Spill Response Engineer. Leads team in Steps 3 and 16.

Lead Repair Engineer. Leads team in Steps 7 through 14.

6.0 CASE STUDY

An ideal means for demonstrating the usefulness of the proposed guideline document is implementation using a hypothetical case study. Provided below are details associated with damage that occurred to a subsea pipeline. Although this particular scenario was crafted by the authors, particular aspects of this incident are based on prior occurrences. Also included in this presentation are the corresponding steps associated with the Guidelines.

Setting: A 24-inch oil pipeline was snagged by an anchor in 250 of water in the Gulf of Mexico 5 miles off the coast of Louisiana. At the time of the incident the pipeline was operating at 50% SMYS. In the vicinity of this particular pipeline, four operators had operating liquid pipelines. Operators were notified of a leak in the area after a commercial fishing boat notified the U.S. Coast that a sheen had been observed on the water (Step 1).

Initial Response: The initial response involved a visual inspection via helicopter surveillance, along with sending a survey vessel to the reported site. Divers and ROVs were deployed subsea to find the source of the leak and verify that the pipeline in question was indeed the operator's pipeline (Step 2 and Step 8a). The operator notified regulators, and initiated work to minimize environmental damage by shutting down the pipeline (Steps 3 and 4) and preparing for mobilization oil spill cleanup equipment and vessels to cleanup the oil that had leaked (placed on stand-by). A pre-planned Incident Command Organization was mobilized to manage the response (Step 5).

Pipeline Repair Design: Next, the survey crew begins taking steps to quantify the properties of the cracked dent and the gouge on the dent surface (Step 8b.) Because of commercial commitments, the operator notified their clients of the situation, along with their insurance company (Steps 25-27) Based on an assessment of alternate production alternatives, and ready access to available repair connectors for a spoolpiece repair (Steps 9a and 11), the operator made a commitment to regulators and their clients that production would be diverted to a parallel pipeline system while the pipeline was being repaired. An estimate was offered that the repair work would be completed within 60 days (Step 12)

Additionally, the operator was able to determine which vessels were in the vicinity of the pipeline during the time of the incident (Step 9b). A lay barge contractor was identified as the instigator. Their insurance company agreed to cover costs for repairing the pipeline, along with compensation for a portion of the lost production.

In the Detailed Offshore Pipeline Damage Incident Response Guidelines (decision tree), the **Initial Response** steps appear as shown in the flowchart provided below (Figure 7).

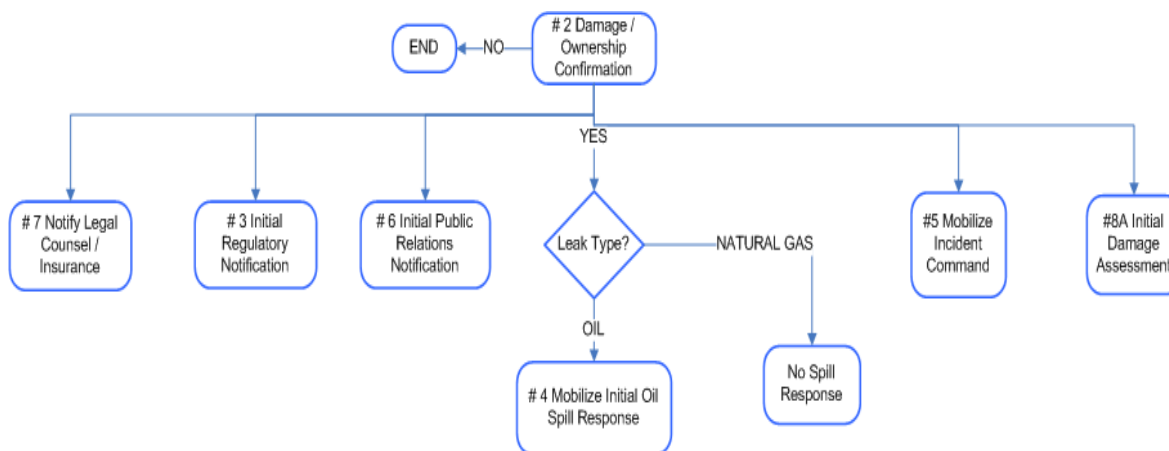


Figure 7. Initial Response Steps

Pipeline Repair Operations: Using the *Response Plan Guideline Document*, the operator initiated and completed the following phases of work (based on Steps 13 through 20).

- Commit to services/vessels/repair Equipment
- Obtain permits
- Notify insurance on repair plans
- Mobilize repair team
- Perform repair job
- Test the repair
- Demobilize repair system
- Re-Commission Line

The repair was completed in 35 days and, after re-commissioning, service was restored to the pipeline.

Spill Clean-up Operations: Because the leak in the pipeline was relatively minor (less than 500 gallons actually leaked), and that the oil on the surface had dispersed, no efforts were made to clean up the damage (Steps 22 and 23).

Legal, P.R. and Regulatory Support: Support was sustained (Steps 25-27) until there was no further need for this support. **Results:** After all repair efforts were completed, the operators advised the regulators that all issues had been addressed. The operator opted to not issue a press release or notify the public (Step 28). Outside legal counsel was retained to interface with the insurance company, who eventually covered all costs as requested by the operator.

Incident Documentation & Review: The operator prepared a Spill Response Document (Step 24) and a Repair Document (including as-built drawings) (Step 21). Finally the operator held a Post Incident Review of all activities (Step 29) and provided recommendations to revise the Guidelines based on lessons learned from the incident (Step 30).

6. CLOSING REMARKS

This paper has provided a basic overview of the PRCI SPDA-1-2 study, *Developing Guidelines for Evaluating Damage to Subsea Pipelines*. This program is a four year study, although it is currently within the second year of work. The primary focus of this study is to develop guidelines for operators to respond in an effective and timely manner to damage once it occurs.

The current focus is on shallow water pipelines, although the 30-step process will be expanded so that the guidelines can be used for responding to deepwater pipeline emergencies. This research program has been developed by operators for operators. It is intended to be practical and seeks to provide industry with a systematic means for responding to pipeline damage emergencies. In addition to benefitting individual operators, there are other far-reaching benefits as this guideline document provides a vehicle for interfacing with regulators and all affected parties. Once all phases of the current program have been completed, PRCI and Stress Engineering Services, Inc. will host a workshop for offshore pipeline operators to disseminate the lessons learned and encourage the adoption of the proposed guidelines.

7. ACKNOWLEDGEMENTS

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