Integrity assessment of interrupted or degraded well barriers

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ABSTRACT: Degradations or interruptions of the original well barrier elements might occur at offshore wells after some time in operation. Experience from the Norwegian Continental Shelf has shown that these problems are not always treated as thoroughly as expected by the parties involved. This paper presents an approach for an efficient visualization and description of interrupted well barriers, basically to increase the well barrier control and management. By mapping the history of operational demands and load picture of the well in combination with the status of well barriers, a consistent basis for evaluations is obtained. The main intention is thus to realize the real well problem and its underlying causes in a controlled and systematic manner. Then, the responsible parties involved can take action more accurately according to the type of failure that has been revealed.

1 INTRODUCTION

Interrupted barrier elements are related to well integrity and are critical from the point of view of safety, but also concerning production regularity and costs. Failure in the well barrier functions caused by degradations or interruptions of barrier elements needs immediate attention from the responsible bodies. During drilling and well activities there are always to be at least two independent and tested well barriers after the surface casing is in place according to the Activities Regulations of the Norwegian Petroleum Safety Authority (PSA) [1].

Experience from (PSA) [2] has shown that barrier failures occur both in newly drilled wells, and in wells that have been in operation for some time. Well integrity failures may be latent in the early constructing phase, or imposed through later maintenance tasks. Shifting between well operational phases can also initiate abnormal load situations causing well integrity failures to occur. Many of these "unexpected" loads are not necessarily taken into account in the design phase. An investigation carried out by the PSA on the Norwegian Continental Shelf showed that 14 % of 309 checked wells currently in operation had problems with, or deviations related to the well integrity [2]. Experience has also shown that integrity problems are not always treated as systematically and thoroughly as expected by the well operators.

The main objective of this paper is to present a visualization methodology for the purpose of evaluating well integrity problems that communicates facts about integrity problems to the responsible bodies. Intended users of the approach are operators, contractors, the authorities, researchers and consultants who have interest in carrying out assessments of well integrity matters. As one possible application, the options regarding future operation of wells may be clarified by the operator, with new preconditions and operational limitations.

A brief introduction to the technical problem area is given in Section 2 from a system perspective. Then a description of the three-step methodology follows in Section 3. Section 4 discusses the implications of the methodology and gives some remarks regarding applications. Finally, a brief conclusion with remarks concerning further work is outlined in Section 5.

2 PROBLEM DESCRIPTION

Well integrity problems need attention and systematic handling both from the operator's and from the safety authority's point of view. In this focused work the parties involved need appropriate tools to communicate and document the problem, both for the purposes of incident investigation, and for the planning and follow up of future well operations.

The problem under study is the apparent lack of a systematic approach to well integrity problems or barrier problems. Well barriers are defined in NORSOK D-010 [3] as envelopes of one or several dependent well barrier elements preventing fluids or gases from flowing unintentionally from the formation into another formation or to the surface.

A casing hanger problem related to a specific wellhead design has been used as a case to illustrate a well integrity problem. An investigation was carried out by the PSA in 2006 [4]. The specific casing hanger is in line with conventional wellheads, with the difference that the load bearing shoulder that supports the casing hanger has an angle (α) of only 8 degrees (see Figure 1). In more conventional designs this angle is typically 45 degrees or more. Due to the low angle and the high axial load (F) on the casing hanger, a very high normal force (Fn) is created between the casing hanger and the casing hanger seat. Figure 1 illustrates the load distribution as it exposes the casing hanger seat. It also illustrates the difference in force distribution (Fn vs. Fn') for the cases of having a load bearing shoulder angle of 8˚ and 45˚. Actually, the Fn component increases to infinity when this angle approaches zero and assuming no friction. Thus, the casing hanger failure occurs when the casing hanger is forced through the load bearing shoulder of the casing hanger seat. The mechanism is the deformation of the casing hanger seat enforced by the high normal force (Fn).

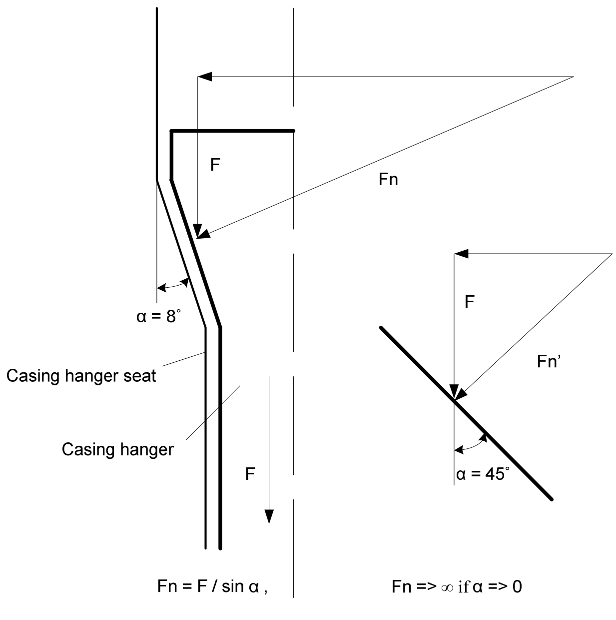

Figure 1. Comparison of the force distribution given a casing hanger seat angle of 8˚ and 45˚

3 METHODOLOGY

A three-step methodology for visualization of well integrity problems has been developed. Indirectly, the well integrity problem is shown by illustrating the historical load picture of the component that fails. More directly, it is visualized by the operational status of well barriers, both before and after the occurrence of the well integrity problem. Thus, the methodology consists of the following three steps:

1. Map the initial loads imposed through the previous operational phases of the well by use of a generic influence diagram [5].
2. Draw the well barrier schematics according to NORSOK-D010 [3] and indicate the status of barrier elements before and after the well incident.
3. Prepare the barrier diagram [6] with leak flow-paths that show the status of barrier elements after the well incident.

Each step of the methodology is explained more in detail in the following:

3.1 *Influence diagram*

The influence diagram is a method to depict relationships between various elements, or influencing factors, and how they affect on the final value or decision (adapted from [5]). An influence diagram approach is utilized here to illustrate the relation between previous operational phases and the possible loads the component under study has been, or will be exposed to. The different operational phases and loads are connected and visualized by the use of lightly and heavily shaded boxes, respectively. For the current case example, the influence diagram in Figure 2, intends to visualize the load picture as it actually affects the probability of the casing hanger failure. A quantitative application of the influence diagram is to calculate the maximum aggregated load in order to compare it with the load capacity of the casing hanger. On the second level from the top, the different well configurations are given that are of relevance to the integrity problem under study. Here, the actual well configuration is indicated by the heavily shaded box.

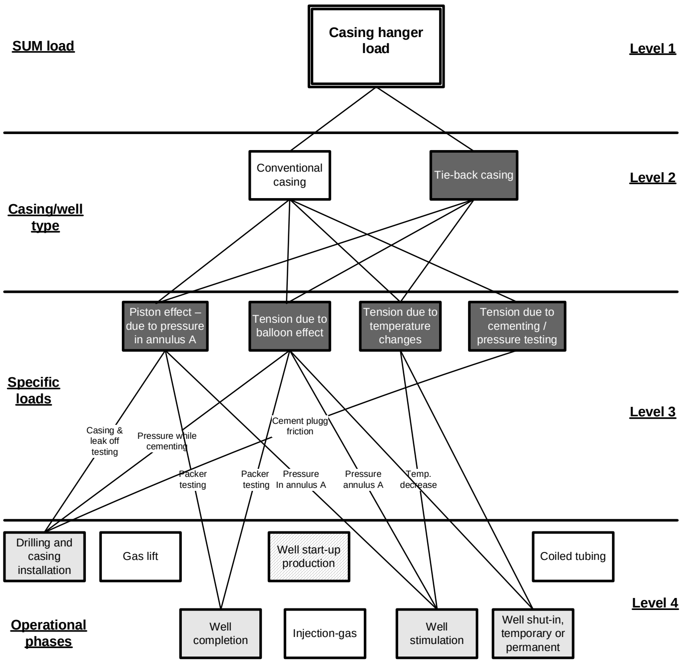

Figure 2. Influence diagram showing the actual operational phases and loads for the well type

The influence diagram has been divided into four levels. The bottom level shows the different (possible) operational phases of the well. The third level from the top identifies the different load contributions that may affect the casing hanger, given the operations. The second level from the top shows the well configurations of relevance to the current well integrity problem. Finally, the load situation for the casing hanger is described in the top level box. This may be the aggregated load, given the worst case scenario of well configuration and loads.

The specific diagram is based on a template that includes all possible operational phases and loads for the well under study. From this template the relevant operational phases are highlighted in lightly shaded boxes. Potential future operations of the well are indicated in hatched boxes. The identified loads types are shown in heavily shaded boxes at level three, similar to the box on the second level representing the well configuration under study. The other white boxes, on levels three and four, are not relevant for the well under study. The text on the connector lines, between the operational phases and loads, indicates load-causes or mechanisms that are enforced by the specific operations. In the highest level box the worst-case load may be aggregated and compared to the load capacity of the specific component. For the current case it is assumed that the calculated load factor for the casing hanger is in direct correlation with the casing hanger failure probability of the well under study.

3.2 *Well barrier schematics*

Well barrier schematics, according to NORSOK D-010 [3], are developed as a practical method to demonstrate and illustrate the presence, or non-presence of the required primary and secondary well barriers. An example of a well barrier schematics of the platform operated well is shown in Figure 3. The schematics indicate the primary and secondary well barriers with their barrier elements as broken lines. The barrier situations with the hanger in position is shown to the left in Figure 3, and the situation after the hanger has failed or dropped is shown to the right. The heavily dashed lines indicate the primary well barrier with its barrier elements. The dashed-dotted lines indicate the secondary well barrier with its barrier elements. The small-dotted lines to the right represent the secondary well barrier elements that have lost their function due to the hanger failure. Finally, the grey dashed lines to the right illustrate the elements that may compensate for the lost barrier elements, and be part of a "new" secondary well barrier. These are possible options only in case these elements can be qualified as the "new" secondary well barrier elements.

Through this kind of illustration it is possible to verify the new status of the barriers and whether it is critical or not. Future operation of the well is greatly dependent on these assessments. Control and monitoring may be planned based on these assessments to maintain the barriers.

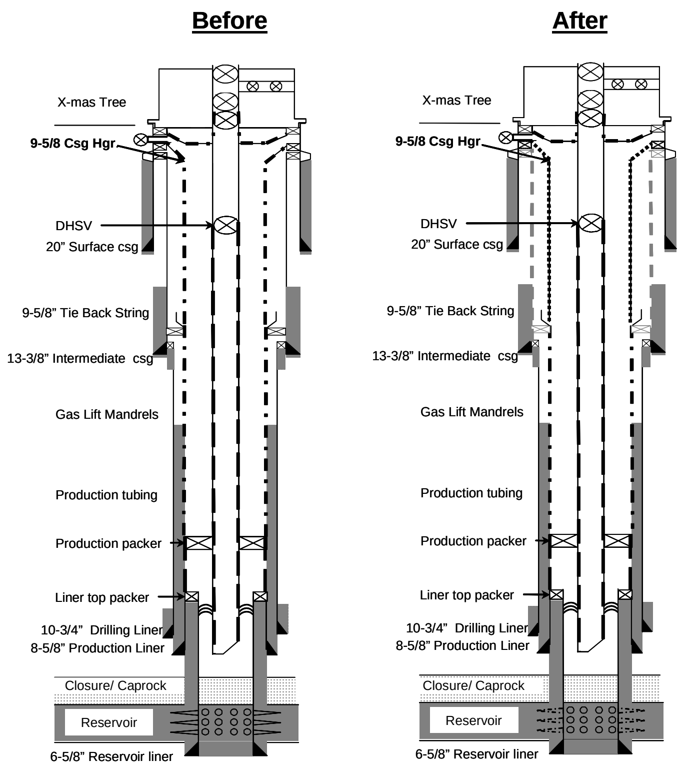

Figure 3. Well schematics, before and after the incident

3.3 *Barrier diagram*

The barrier diagram is developed as a flow-path diagram indicating the possible leak paths from the reservoir to the surroundings. In Figure 4, the barrier diagram for the current case shows the leak paths after the hanger failure has occurred, and taking into account the original well barrier elements. Each of the boxes represents the relevant well barrier element with focus on the casing hanger drop. The line types of the boxes have been given the same meaning as for the well barrier schematics in Figure 3. Thus, the elements of the primary and secondary well barrier are shown as heavily dashed boxes and dashed-dotted boxes, respectively. The arrows connecting the boxes indicate the possible leak directions.

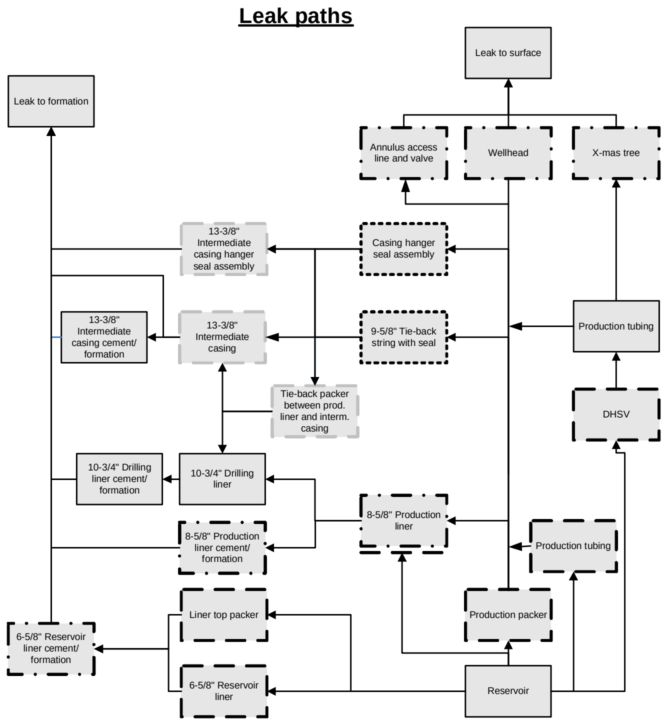

Figure 4. Barrier diagram (leak paths)

4 DISCUSSION

The following discusses implications to the parties involved, who might benefits in their work by applying all, or parts of the methodology, as it is presented in this article. Some key words with respect to different needs and applications are identified and listed below. Applications are further discussed thereafter.

Needs of the authorities

- Communicating well integrity problems, both internally and externally to the authorities
- Planning of audits
- Investigating incidents
- Following up operators after incidents
- Updating regulations

Needs of the operators

- Mapping status and the current load situation for wells under operation
- Documenting need for operational control (monitor and follow up)
- Reviewing operational demands
- Mapping additional loads when changing operational phases

Needs of contractors and suppliers

- Identifying needs of barrier pre-qualifications
- Guiding in design

Needs of researchers and consultants

- Understanding system behaviour
- Preparing basis for operational risk and reliability assessments

4.1 *Needs of the authority*

From the safety viewpoint of the authority, the methodology provides an easy overview of the well situation. It is easy to communicate facts about the actual problem to people outside, even with limited system knowledge. This is useful both internally for the authorities, and externally for to the well operators and other involved parties. At the same time it is easy to update the overview of well situations based on new information.

Both the influence diagrams and the well barrier schematics may be used in planning audits of operators based on updated well information. Another application is investigations of well incidents and following up these operators afterwards. Building knowledge about operational well aspects by the use of the current methodology will over time enforce the authority's ability to update their own regulations. The most important knowledge may be the ability to foresee effects of the ageing well facilities, rapid changes between operational well phases, effects of implementing new technology, etc. The motivation to apply it is the increasing trends of incidents or other unexpected phenomena that are observed on the NCS, and which are not yet covered by existing regulations.

4.2 *Needs of the operators*

Very often there are changes with regard to the operational phase of wells, like going from production to injection. The influence diagram method then provides a structured approach in addressing the changing loads on critical components. The assessment may reveal whether or not, critical components are affected in a negative manner with respect to safety and operation. Through the lifetime of wells this kind of load picture may be continuously updated and used actively by the operator as a means to monitor and control the well conditions. In addition to the load picture, the consequences of failures in any operational phase, such as the casing hanger failure, are easily described by well barrier schematics and well barrier flow diagrams. These are helpful tools in reviewing the operational demands of the wells.

4.3 *Needs of contractors and suppliers*

Contractors should gain access to operational experience data regarding well integrity problems that are connected to aspects of their own well designs. In their struggle to improve the design they should be more capable of identifying vulnerable components, given the updated information of incidents. The original design with its contingencies may then be reviewed with respect to the existing barrier elements, and components that may be pre-qualified to become the "new" barrier elements. Generally, the overview of well experience that the new methodology provides ensures that contractors and suppliers improve their well designs.

4.4 *Needs of researchers and consultants*

The needs from the external parties, like researchers and consultants, may be seen as more peripheral within the current context. However, the application of known methods from risk and reliability analysis into the operational phases of installations is always interesting from a researcher's point of view. Typically, these kinds of methods have been applied in the early concept design. Just as interesting, is the improved understanding of systems and system behavior that is gathered by this kind of system analysis. Knowledge is obtained with respect to the technical and operational aspects of well systems, and how these aspects influence the system integrity and its ability to maintain the safety barriers.

5 CONCLUSION

Barrier failures occur both for newly drilled wells, and for wells that have been in operation for some time. Experience has shown that these kinds of failures are not always treated thoroughly as expected by the well operators. A three-step visualization methodology for evaluating well integrity problems and communicating facts around such problems to the responsible bodies has been developed. The approach was applied to a case example involving a casing hanger problem related to a specific wellhead design. The experience from the case example shows that the methodology provides an easy approach to barrier control and management. The assessments reveal relations between operational demands/operational phases of wells and the critical exposure of components to forces. By the use of well barrier schematics and flow-path diagrams the consequences of critical component failures are defined with respect to failure conditions and well integrity. This is useful information in order to identify measures for maintaining the well barriers. The influence diagrams provide a method for calculating worst case load scenarios that is compared to the capacity of the respective component. This kind of information provides valuable input to operators who are responsible for planning the future operation of the wells. The current methodology has been developed to serve the specific needs of a SINTEF project. However, it has not been thoroughly qualified or verified to fit any general application. Thus, a possible further development of the methodology may focus on the following topics in order to fit more general purposes:

- Identify the requirements of a methodology that is designed to serve general applications
- Identify needs in a system life cycle perspective that should be served by the methodology
- Develop a plan of action for collecting and handling incident data that may be relevant for contractors and suppliers who should carry out well design
- Develop the final methodology
- Specify functional requirements of models and the connections between them in order to develop a software application
- Carry out additional case studies in cooperation with the end users to validate the appropriateness of the methodology in use.

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