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From: Rainey, David I
Sent: Tue Apr 27 15:46:38 2010
To: Wallace, Jane C. (HOU)
Subject: FW: Engineering Update for BST
Importance: Normal
Attachments: Erosion Potential within Kinked Riser - Final Draft.doc

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From: Rainey, David I
Sent: Tuesday, April 27, 2010 10:29 AM
To: Price, Bruce
Subject: FW: Engineering Update for BST

pls print

From: Birrell, Gordon Y
Sent: Tuesday, April 27, 2010 6:24 AM
To: Rainey, David I
Subject: FW: Engineering Update for BST

As discussed.

GYB

From: Austin, Julian
Sent: Tuesday, April 27, 2010 6:10 AM
To: Birrell, Gordon Y; Cook, Howard H
Cc: Owen, Les L; Petruska, David J; Tognarelli, Michael A; Tooms, Paul J; Evans, Geoff; Nichols, Mark; Beynet, Pierre A; Pattillo, Phillip D; Neilson, Ian; Driscoll, John; Hill, Trevor; Brookes, David; McConnell, Ginna L
Subject: RE: Engineering Update for BST

All,

Please find attached a draft Technical Note on the potential for erosion of the kink in the riser. This note has been subject to peer review by Trevor Hill on Flow Assurance and John Martin on Erosion.

Geoff and I are currently working with Frazer-Nash to understand the more complex scenario of the drill pipe still being within the pipe which may change the landscape somewhat, and I expect to update this note to reflect that output within a day or so.

Kind regards,

Julian

Assessment of Erosion Potential within Deepwater Horizon Kinked Riser

Brief: To establish the potential for erosion within the kink at the base of the Deepwater Horizon riser.

The base of the Deepwater Horizon riser developed a kink of approximately 90 degrees extent when the drilling rig sunk on 4/22/10 (Photos 1, 2). This kink may restrict the bulk flow from the wellhead and there is potential for the flow velocity through this restriction to be sufficient to cause erosion local to the kink.

Photo 1 View of the riser and BOP

Photo 2 Close-up view of the riser base

This Technical Note presents some analysis aimed at quantifying the likely risk of erosion in the vicinity of the kink and elsewhere, based on what is currently known about the condition of the riser system and the rates of leakage. The assessment is based on current estimates for:

- the size of the flow restriction;
- the leakage rate;
- the pressure upstream of the kink;
- the fluid properties, including solids content;
- the flow losses in the riser.

The size of the flow restriction is first estimated, then the pressure and leakage rate are used to develop flow velocities, which are then assessed for erosion potential.

Size of the flow restriction

The size of the flow restriction has been estimated in three independent ways:

- Visually from subsea photographs of the external appearance of the kink;
- Using the results of Finite Element Analysis of the bend event at the kink;
- Indirectly using assumptions about the leakage rate, maximum upstream pressure and fluid properties and a standard orifice calculation.

Bending of circular pipes results in buckling of the initially circular cross-section into a figure of eight or "dogbone" shape. When the bend is sufficiently sharp to form a kink, the tightest part of the bend is expected to reduce to a flow path that has two teardrop-shaped lobes. Another factor that may influence the size of the flow restriction here is the possibility for there to have been a 6 5/8" drill pipe inside the riser at the kinked location. This possibility is reviewed based on available evidence.

Method 1. Visual interpretation

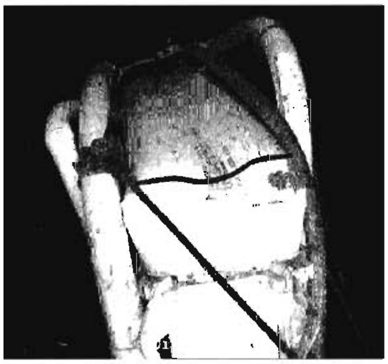
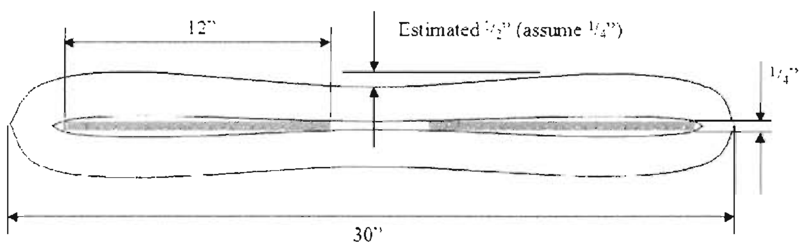


Photo 3 View of the top surface **Photo 4 View of the inside corner**

The size of the flow restriction was initially estimated from the external appearance of the kink (Photos 3, 4). Note that in these views there is no visible evidence of a $6^5/_8$" drill pipe being inside the riser. The dogbone shape is highlighted by the red lines. The minimum dimensions of the internal aperture were estimated by conservatively assuming that the depth of the dip in the top and bottom surfaces was just $^1/_4$" and that metal to metal contact was achieved at the middle of the dogbone. Figure 1 shows the minimum cavity that could feasibly be created at the tightest part of the kink using this simple concept. The cavity has two lobes that can be represented by thin rectangles of dimension 12" x $^1/_4$", or a total aperture of 6 square inches. This estimate could be refined using detailed measurements of the kink, and is considered to be very conservative.



Method 2. Finite Element Analysis

An elastic plastic Finite Element Model of the riser pipe was constructed and then bent using a combination of moment and cantilever bending loads to introduce a kink of similar appearance and location to that in the riser. The global appearance of the FE model is compared to the riser photos in the sequence of figures overleaf. It can be seen that the FE model reproduces the features of the kinked riser closely, including the sharp internal corner, the overall width of the kink, and the dogbone shape of the horizontal section of pipe.

The final shape of the kink has been arrived at using both lower bound and mean values for the yield and ultimate strength of the X80 riser, both with and without the $6^5/_8$" drill pipe inside the riser. The lower bound runs are aimed at identifying the minimum aperture that can be generated, in order to maximise the potential for flow velocities in the erosion risk range to develop. The mean strength runs are an attempt to generate the maximum aperture, to understand whether the drill pipe could actually be within the kink without any visible external evidence. The results are discussed below.

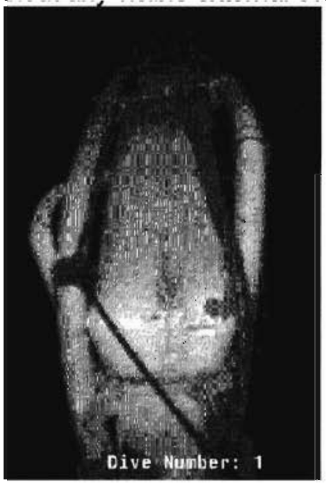


Photo 5 View of the outside of kink

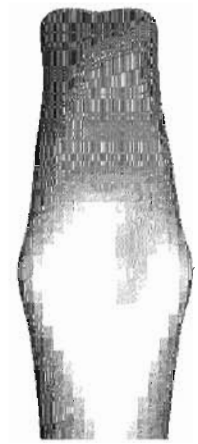


Figure 2 Model view of the outside of kink

Photo 6 View of the inside of kink

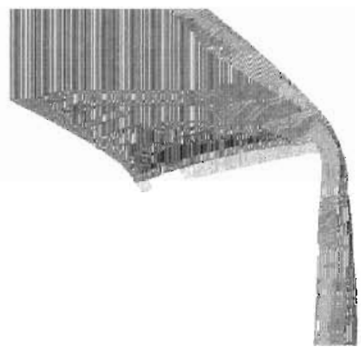


Figure 3 Model view of the inside of kink

A view of the minimum possible flow restriction is shown in Figure 4 below, using minimum material properties and without the drill pipe inside. The flow area is estimated to be 23 square inches. The lobes do not close up anywhere near so much as was assumed in the conservative interpretation of the visual data. Note that the plots show the pipe wall centreline, so a gap between the upper and lower surfaces is not a physical gap, but rather the separation of centrelines. The plot in Figure 5 shows non-zero contact stresses on the pipe wall indicating that metal to metal contact was achieved in this run.

Figure 4 Minimum flow aperture

Figure 5 Contact stresses in the kink

Analysis to predict the maximum aperture developed using mean properties and with the drill pipe inside is currently underway, but has not yet been completed. This Technical Note will be updated when these results become available. The erosion calculations later in this report for the minimum flow aperture also consider the case where the drill pipe has become lodged in one of the lobes.

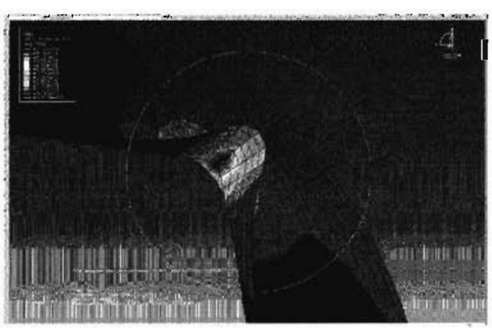
Method 3. Using leakage rate, fluid properties and maximum upstream pressure
The third method uses standard orifice calculations to estimate the flow restriction that would be required to be present at the kink assuming a given leakage rate, seabed pressure, flow loss in the riser, pressure upstream of the kink, and the fluid properties.

- The leakage rate has been estimated from oil sheen measurements on the surface to be between 1mbpd and 10mbpd;
- The seabed hydrostatic pressure is a confident estimate of 2250psi;
- Flow losses in the riser are estimated to be less than 10psi;
- The wellhead pressure is estimated to be about 7500psi;
- Fluid properties include a measured GOR of 3000scf/stb, and a bubble point of 6550psi at 273F.

Assuming an upstream pressure of 7500psi and the maximum leakage of 10mbpd yields a pair of circular orifices of 0.5inch diameter, or a total flow aperture of 0.4 square inches, more than an order of magnitude less than the minimum apertures estimated by either the visual or finite element methods.

Discussion
The most accurate estimate of the flow restriction presented by the kink is considered to be range of values produced in the finite element analysis. Field measurements of the riser would provide a useful comparison. The lack of agreement with the standard orifice calculations suggests that either the leakage rate is considerably greater or the pressure upstream of the kink is not equal to full wellhead pressure. It is not credible that the leakage rate could be so dramatically underestimated, since the flow restriction presented by the most likely range of flow apertures in the kink would barely choke the well flow at all.

A more plausible reason is that there is a more acute flow restriction upstream of the kink, possibly within the BOP structure or downhole. The finite element model provides evidence that this is most likely to be the case. Following the loading step used to produce the kink, a further pressure load step was applied to the kink whilst holding the bending load on the riser. This step indicates that under an internal pressure of 7500psi the kink would open up considerably and become an entirely different shape. Figures 8 and 9 compare the shape of the kink at internal pressures of 2500psi and 7500psi respectively. The fact that this distortion has not occurred makes it likely that the pressure upstream of the kink is only modestly in excess of the seabed pressure at the riser exit.



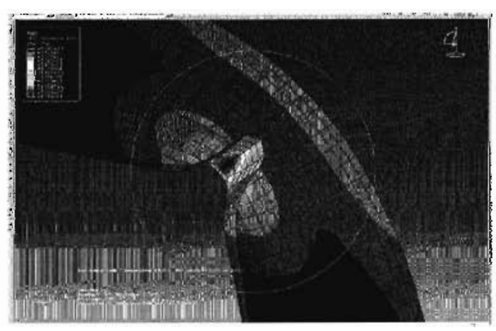


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Figure 8 Shape of kink at 2500psi **Figure 9 Shape of kink at 7500psi**

A further possible scenario is that the drill pipe is still present within the kink and that the oil observed to be emanating from the drill pipe is being choked by a flow restriction in the drill pipe at the kink. This could be the point where the pressure drop from wellhead pressure occurs, and explain why the riser does not appear to be subject to wellhead pressure. The oil observed to be leaking from the riser may be emanating from a downstream breach in the drill pipe. Further finite element runs are being carried out to address this possibility.

2. Calculation of erosion rates

BP uses the SPPS (Sand Production Pipe Saver) erosion model developed as part of a Joint Industry Project by the University of Tulsa. This is the model normally used by BP in the design of production systems subject to erosion.

The kink has been modelled as a 1.5D bend, the geometry of each lobe of the aperture is a larger radius bend than 1.5D, so this geometric model is considered to be conservative. The fluid properties downstream of the kink have been taken as 100°C and 2500psi. These are considered as worst case values for the purposes of calculating erosion. Flow is considered as highly turbulent with a viscosity of 0.6cp for the oil and 0.01cp for the gas. These values are considered to be conservative.

It is understood that there is no sand control feature in the well, so the maximum anticipated value of 100 lbs/1000 bbl and 150μm was used to characterise the sand loading. These values are considered high for sand production. The assumed sand rate is an order of magnitude higher than that normally considered as a default design value.

The results obtained for the kink are shown in Tables 1 and 2 below, for assumed total leakage rates of 1mbpd and 10mbpd respectively. The lobes that constitute the aperture through the kink are treated as two separate orifices, each with half of the leakage rate flowing through them (i.e. 0.5mbpd and 5mbpd). Table 2 also contains an additional result for the case where one lobe is blocked by the drill pipe.

1mbd total leakage rate	Single lobe area	Erosion rate
Visual method	3 in^2	0.2mm/yr
FEA lower bound method	11.5 in^2	<0.01mm/year
5000psi pressure drop	0.2 in^2	2,500mm/yr

Table 1. Erosion rates at a total leakage rate of 1mbpd

10mbd total leakage rate	Single lobe area	Erosion rate
Visual method	3 in^2	100mm/yr
FEA lower bound method	11.5 in^2	2mm/yr
FEA method (1 lobe blocked)	11.5 in^2	15mm/yr
5000psi pressure drop	0.2 in^2	>10,000mm/yr

Table 2. Erosion rates at a total leakage rate of 10mbpd

Discussion

Based on the insight provided by the Finite Element Analysis, the initial visual estimate of the maximum flow restriction of the kink is considered to be too conservative and should be ignored. This estimate was necessarily conservative due to the inability of the available ROV photos to clearly show a side view of the hinge location due to the presence of the choke and kill lines.

The results for the 5000psi pressure drop are also not considered credible, given the very small orifice that would be required to be developed in a 21" riser pipe, and these results should also be ignored. However, these numbers do provide valuable evidence that a pressure drop from the assumed 7500psi wellhead pressure may be occurring upstream of the kink, and that the erosion rate estimated for this orifice size may be appropriate at that location. However, this situation would only result in erosion if the high velocity jet were impinging on a surface.

The lower bound results from the Finite Element Analysis show clearly that the kink does not provide a significant flow restriction over the range of observed leakage flow rates, and that the predicted erosion rates are low. Detailed measurements of the kinked area would provide further confidence that the large apertures exist at the kink.

A sensitivity case based on blocking one lobe of the flow path with drill pipe predicts a rather higher erosion rate but still one that can be tolerated for a period of several months to a year. Confirming the presence/location of any drill pipe in the kinked area will provide some useful input to the relevance of this sensitivity study.

In summary, within the bounds of the assumptions made herein and taking account of the levels of conservatism in the erosion assessment, it is concluded that erosion is not an issue for the medium-term integrity of the kink in the riser.

Conclusions

1. The most credible estimate of the minimum flow aperture resulting from the kink in the riser predicts a total flow area of 23 square inches. This represents a negligible flow restriction and will result in an insignificant pressure drop.

2. The flow velocity through the most credible aperture at the maximum estimated leak rate does not present an erosion problem over a timescale of six months.

3. Orifice calculations for a pressure drop from the assumed wellhead to seabed pressure suggest that the kink is not the main source of flow restriction and therefore another restriction must exist elsewhere in the system. The most probable location is upstream of the kink since it appears that the shape of the kink is not consistent with it being currently subject to full wellhead pressure.

4. Erosion may be occurring at the location where the pressure drop from wellhead pressure is occurring; however this would only be the case if the high velocity jet were impinging upon another surface.