From: Austin, Julian
Sent: Thu May 06 23:49:49 2010
To: Tooms, Paul J; Brookes, David; Hill, Trevor; Nichols, Mark; Openshaw, Graham (TecPM)
Cc: Wilson, Roberta; Birrell, Gordon Y
Subject: Latest update on cause of erosion
Importance: Normal
Attachments: Assessment of Observed Erosion within Kinked Riser - Update.doc

Paul,

As we discussed earlier, here are the latest FE model results for a 9 5/8" casing string trapped in the kink. The headline of this update is that the larger diameter casing pipe, in attempting to conform within the riser kink, undergoes a local buckle that significantly closes down the cross-section, which could lead to high velocity jets with short-term erosion potential at the edges of the pipe. This report may be of assistance with identification of any trapped pipes using radiography. Trevor and I will liaise to discuss pressure drops.

Kind regards,
Julian

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Assessment of Observed Erosion within Kinked Riser

Brief: To assess a range of potential scenarios that may have caused the observed erosion damage to the kinked 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

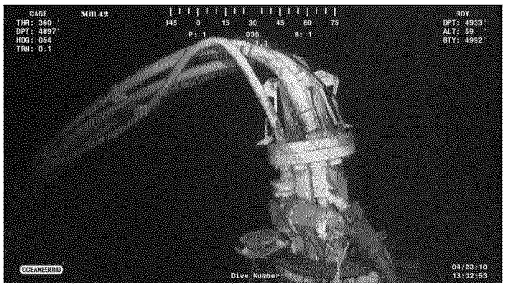

Photo 2 Close-up view of the riser base

An initial assessment of the potential for erosion at the kink was made by using a finite element model of the kinked riser, with and without a drill pipe inside, to predict the remaining flow apertures at the minimum cross-section of the kink. These were used together with standard erosion calculations and some conservative assumptions about flow rate and sand loading to conclude that none of the predicted flow apertures were small enough to present an erosion threat over a period of several months (Reference 1).

However, two leaks exhibiting the characteristics of erosion damage appeared on the kink on 4/28/10 (Photos 3, 4). The potential for escalation of these leaks was assessed in Reference 2, and once again it was concluded that for all pipe crushing scenarios considered ($6^5/_8$" and $5^1/_2$" drill pipes within the riser in various locations) the flow restriction should not have been sufficient to lead to erosion. An additional scenario of cracks in the drill pipe was considered to be a possible cause.

This technical note attempts to explain the origin of these leaks by using the finite element model to explore some further scenarios involving pipes within the riser. As a precursor to this exercise, the model results have been dimensionally validated against photos of the riser to ensure that any conclusions made are robust.

Photo 3 Erosion leaks (4/28/10)

Photo 4 Erosion leaks (5/4/10)

Validation of the finite element model

An elastic-plastic finite element model was used in References 1 and 2 to explore the likely range of flow restrictions that could be presented by the kinked riser pipe and by a range of kinked drill pipes that may or not be inside the riser pipe. Transparent views of this finite element model (with a drill pipe inside the riser) are shown below. In order to provide confidence in the ability of this model to predict flow apertures accurately, the model has been validated against the geometry of the actual kink. This validation has been carried out using photographs of the damaged riser assembly to relate the dimensions of undamaged auxiliary pipes captured at the same optical distance to the dimensions of the damaged portions of the riser.

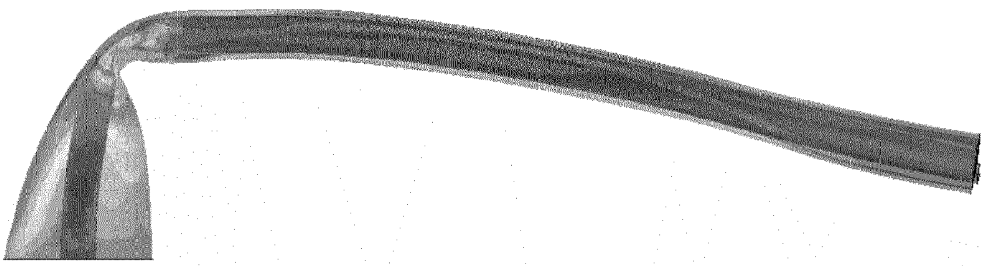

Figure 1 FE model of drill pipe inside kinked riser pipe showing strain contours

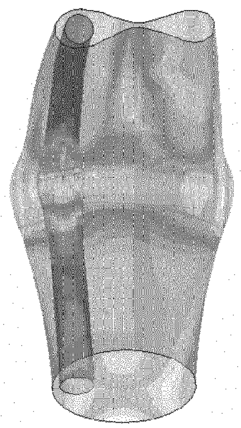

Figure 2 FE model of drill pipe inside kinked riser pipe showing strain contours

The key dimensions that have been validated are:

- The minimum thickness of the kink;
- The maximum width of the kink;
- The thickness of the “dogbone” shape of the buckled riser pipe.

The outlines of these key features have been carefully constructed in the photos, taking account of shadowing effects *etc*. Measurements have then been extracted from the finite element model for these features when viewed from the same perspective.

<u>Thickness of kink in riser and dogbone on the non-erosion side</u>

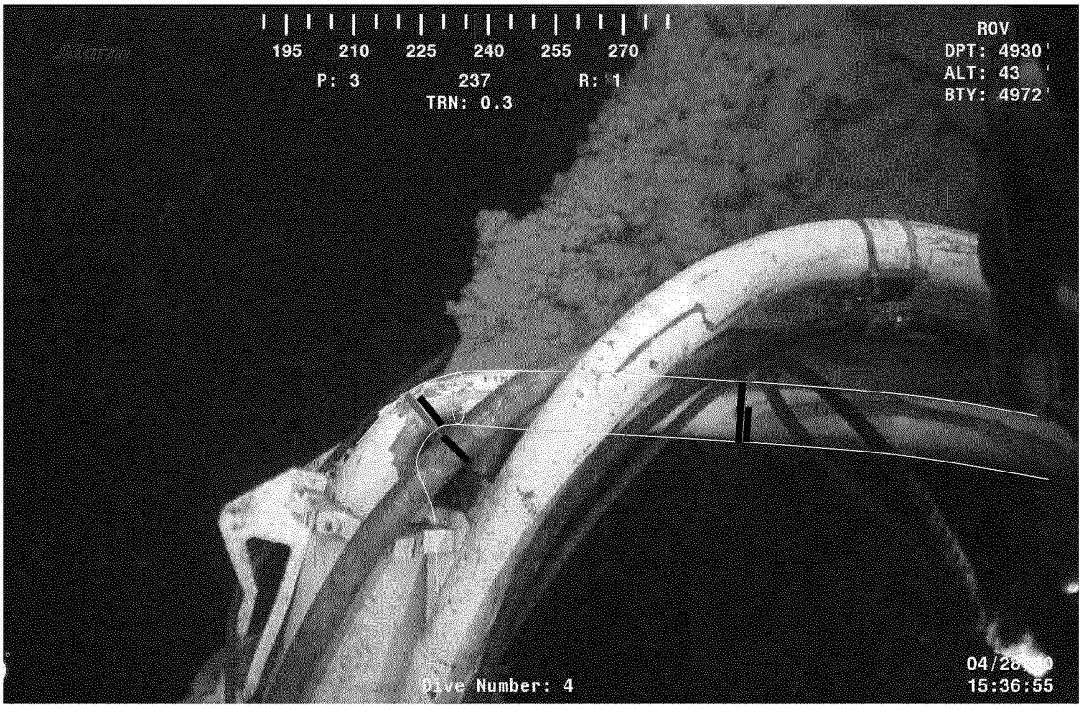

Figure 3 Definition of the thickness in the kink in the riser and the dogbone

Feature	Photo		Reference
Kink thickness on non-erosion side	Snap 04_28_10 15:36:55		3.5" Hydraulic line
FEA Model	Reference (photo)	Kink (photo)	Kink (actual)
4.79"	0.36/0.37 (green)	0.47/0.48 (blue)	4.6"

Feature	Photo		Reference
Kink thickness on erosion side	Snap 04_28_10 15:36:55		3.5" Hydraulic line
FEA Model	Reference (photo)	Kink (photo)	Kink (actual)
5.28"	No photo	No photo	No photo

Feature	Photo		Reference
Height of dogbone on non-erosion side	Snap 04_28_10 15:36:55		3.5" Hydraulic line
FEA Model	Reference (photo)	Dogbone (photo)	Dogbone(actual)
6"	0.36/0.37 (green)	0.6/0.61 (red)	5.8"

Feature	Photo	Reference
Height of dogbone on erosion side	Snap 04_28_10 15:36:55	3.5" Hydraulic line

FEA Model	Reference (photo)	Dogbone (photo)	Dogbone (actual)
7.6"	No photo	No photo	No photo

Width of kink in riser

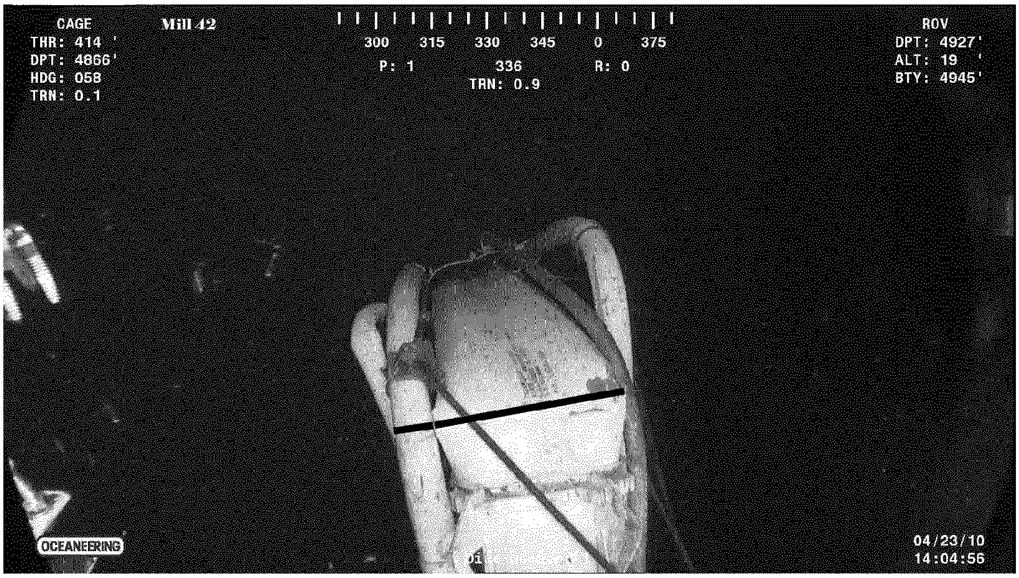

Figure 4 Definition of the width of the kink

Feature	**Photo**		**Reference**
Width of kink	Snap 04_23_10 14:04:56		6.625" Choke and Kill line
FEA Model	Reference (photo)	Kink (photo)	Kink (actual)
33"	0.58 (green)	2.8 (red)	32"

Conclusions from validation exercise

The finite element model produces results that are within about 5% of the estimates from the photographs. This is considered to be an acceptable accuracy to make robust predictions of flow apertures for a range of scenarios involving different combinations of drill pipes within the riser pipe.

Comparison of FE model results with observations

The transparent views of one of the FE model runs have been superimposed on the photos in Figures 5 and 6. The excellent fit between model and measurement can be seen, in particular the overall shape of the kink and the thickness of the dogbone. One feature that suggests additional conservatism in the finite element results is the fact that the neck of the kink is actually fatter than the model prediction. This implies that there is more space within the kink for flow and for other pipes than the model results indicate, or that the model does not yet contain a fat enough pipe.

The run selected was for a $6^5/_8$" diameter 0.5"WT drill pipe located in one of the "lobes" of the dogbone, *i.e.* towards one side of the riser pipe. The colouring in these plots provides an indication of mechanical strain levels with red being high (~25-40%) and dark blue indicating zero strain.

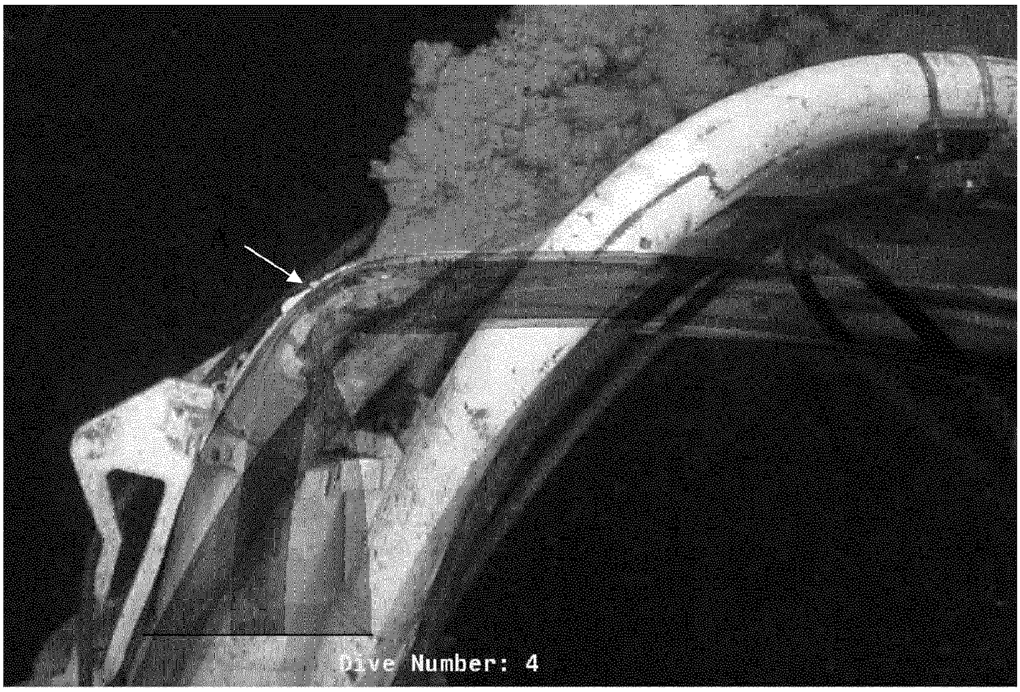

Figure 5 Finite element model superimposed on kinked riser pipe (side view)

Figure 6 Finite element model superimposed on kinked riser pipe (end view) (Erosion orifices are indicated as red dots)

Referring to Figure 5, the radial location of the minimum section of the drill pipe is consistent with the pattern of oil emerging from the riser pipe, suggesting that a reduced aperture in the drill pipe is indeed the cause of the erosion (not cracks in the pipe as suggested to be possible in Reference 2, since the flow from cracks would most likely have emerged radially from the point marked A). However, note that the smallest aperture reported in Reference 2 was 4.5 square inches, more than 2 times the size estimated to be required to cause the observed erosion within the observed timescale at a conservative estimate of the leak rate of 10mbpd.

Figure 6 shows the view from above the kink, where the $6^5/_8$" pipe can be clearly seen sitting between the two dots that represent the erosion leaks. It is pretty obvious that the $6^5/_8$" pipe in its as-modelled crushed state could not be responsible for causing those erosion holes. In fact, if a $6^5/_8$" 0.5"WT pipe is completely flattened the farthest apart two such erosion jets could be would be $5^5/_8$" x $\pi/2$ = 8.84". The distance between the two erosion jets has been estimated from Photo 4 to be approximately 13".

One possibility is that there could also be a piece of casing pipe around the drill pipe within the kink, since a completely flattened $9^5/_8$" casing pipe would be capable of providing two erosion jets at a maximum aperture of 13.6". Having both pipes within the geometry of the kink would also make it more likely that there is enough material crushed within the riser to result in erosion apertures small enough to have eroded through the riser pipe in 5 days.

An additional consequence of there being small enough apertures to cause active erosion jets is that such apertures could also present a significant pressure drop to flow through them. This implies that the pressure in the drill/casing pipes upstream of these flow orifices could be higher than might otherwise be assumed.

Finite element results for a $9^5/_8$" casing pipe trapped inside one lobe of the riser pipe are shown in Figures 7 and 8. This scenario provides some particularly intriguing results. In Figure 9 the minimum flow aperture can be seen to be unduly small for the space available in the kink; this is a consequence of a local buckle that forms in the pipe as it tries to conform to the confines of the distorted riser pipe. The smaller diameter pipes experience this type of buckle to a much lesser degree.

The small aperture is shown more clearly in Figure 10; it has a total area of $4in^2$ made up of $2.8in^2$ in the right hand aperture and $1.2in^2$ in the left hand aperture. A total aperture of $4in^2$ is still not in the erosion risk region; however, the shape of the crushed pipe makes it clear that reducing this to the $2in^2$ aperture required to cause erosion for the assumed leakage rate and sand conditions would not be difficult. There are several reasons in addition to the buckle why the casing pipe appears to close down more readily than the small diameter drill pipes considered previously:

- Large pipes are easier to close down than small diameter pipes of the same thickness and material because the moment available to deform the extreme edges of the pipe is larger for a given closing force;

- An 80ksi yield strength material was assumed for the casing - this falls a long way short of the 135ksi strength of S-135 drill pipe;
- The weight of casing pipe assumed (47 lb/ft) has a wall thickness < 0.5".

Figure 7 FE model for trapped casing superimposed on kinked riser pipe (side view)
Note the near metal to metal contact at the minimum cross section

Figure 8 FE model for trapped casing superimposed on kinked riser pipe (end view)
(Erosion orifices are indicated as red dots)

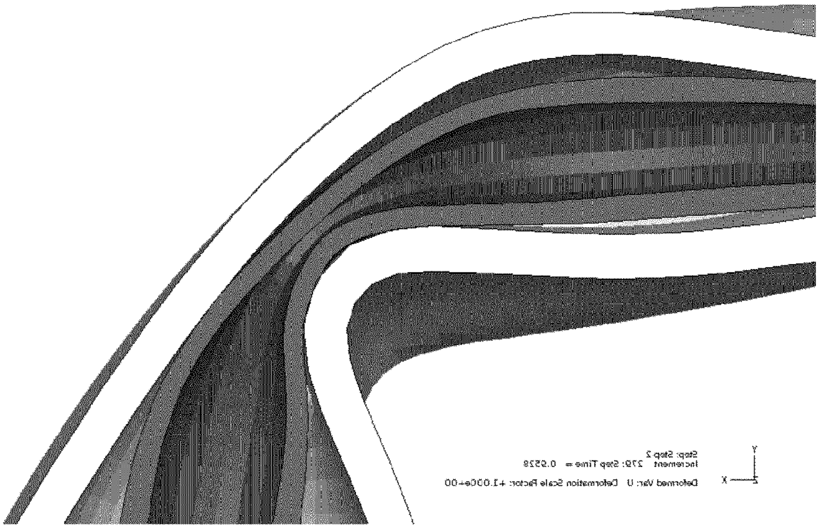

Figure 9 Close-up of FE model results for a trapped $9^5/_8$"casing pipe

Figure 10 Minimum aperture from FE model results for a trapped $9^5/_8$"casing pipe

Conclusions

The results for the trapped $9^5/_8$" pipe offer a plausible explanation for the observed erosion on the back of the kink. It is recommended to attempt to identify the location of any pipes within the kinked riser using a radiographic method. Figures 8 and 10 provide a guide to where the most likely trapped pipes are to be found based on this study and consistent with the observed erosion.

A finite element analysis of a $9^5/_8$" casing pipe containing a $6^5/_8$" drill pipe is also underway; this Technical Note will be updated when results of this analysis are available.

References

1. Document number 2200-T2-DO-RP-4001 "Assessment of Erosion Potential within Deepwater Horizon Kinked Riser : Drill Pipe Update - Draft"

2. "Escalation of Erosion within Deepwater Horizon Kinked Riser"