Kinked Riser Joint
3D Modelling Inspection
Photogrammetry and Analysis

Report

Macondo Deepwater Horizon Response

For BP Exploration & Production Inc.

Date: 22 July 2010
Project: BP_DWH_R10356

Private and Confidential

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Revision	Date	Description	Originated	Reviewed	Approved
C1	09/07/2010	Initial Draft	T.dG	M.M.	A.T.
C2	12/07/2010	Figure 17 replaced Appendix A - Photo catalogue Recommendations modified	T.dG	A.H.	A.H.
C3	22/07/2010	Added cross-section flow area analysis, etc.	M.M.	A.T.	A.T.

Executive Summary

Client	BP Exploration & Production Inc.
Project	Deepwater Horizon LMRP Inspection
Facility	Macondo MC 252 Wellhead
Vessel Contractor	Global Industries
Vessel	Olympic Challenger
Inspection dates	21 June 2010 - 24 June 2010 on vessel. All images taken on 22 June 2010
Inspection and Analysis program	The 47ft (approx) kinked riser joint was lifted from the seabed to the deck of the Olympic Challenger prior to June 21, 2010. While on the deck of the Olympic Challenger, the riser section was photographed extensively for the purposes of producing a 3D model. The interior surface of the riser was created based on a 1-inch wall thickness. The outer riser surface was offset by 1 inch and smoothed to generate an approximation of the interior surface. The full (left) and partial (right) drill strings were constructed inside the riser. Cross-sections of the drill strings were generated at each analysis location to fit within the interior riser surface, and to have perimeters equivalent to that of a 5.5 in circle. The lengths between analysis locations were interpolated to generate the remaining sections of the drill strings. At each analysis location, the flow area was calculated through the interior of the riser: (1) without obstructions, (2) with entire area within drill strings obstructing flow, and (3) with flow through riser and drill strings. Wall thicknesses of 1 inch, 0.4 inches and 1.55inches in were used for the riser, drill strings, and tooling joints, respectively.
Results	Measurements taken of the scale markers in the model were measured to have values within 0.5% of actual values. The analysis location found to have to smallest cross-sectional flow area was Cross-section G, located on the upstream end, in the kinked section of the riser.

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1 Project Summary

Welaptega performed a photogrammetric survey on a 40 foot section of the Deepwater Horizon marine riser to collect images for use in generating a 3D model.

The riser section was sheared off above the Macondo well just above the LMRP (before it collapsed horizontally) and then separated from the rest of the riser another 47ft (approx) downstream. Figure 1 is a photo of the riser joint taken from Olympic Challenger on 22 June 2010.

Figure 1: Riser joint recovered to Olympic Challenger

Welaptega Marine took approximately 1200 photos of the riser for the purposes of photogrammetric 3D modelling. A total of 534 photos were used to create the 3D model. Figure 2 shows a screen shot of the completed 3D model point cloud as viewed from a similar orientation to Figure 1.

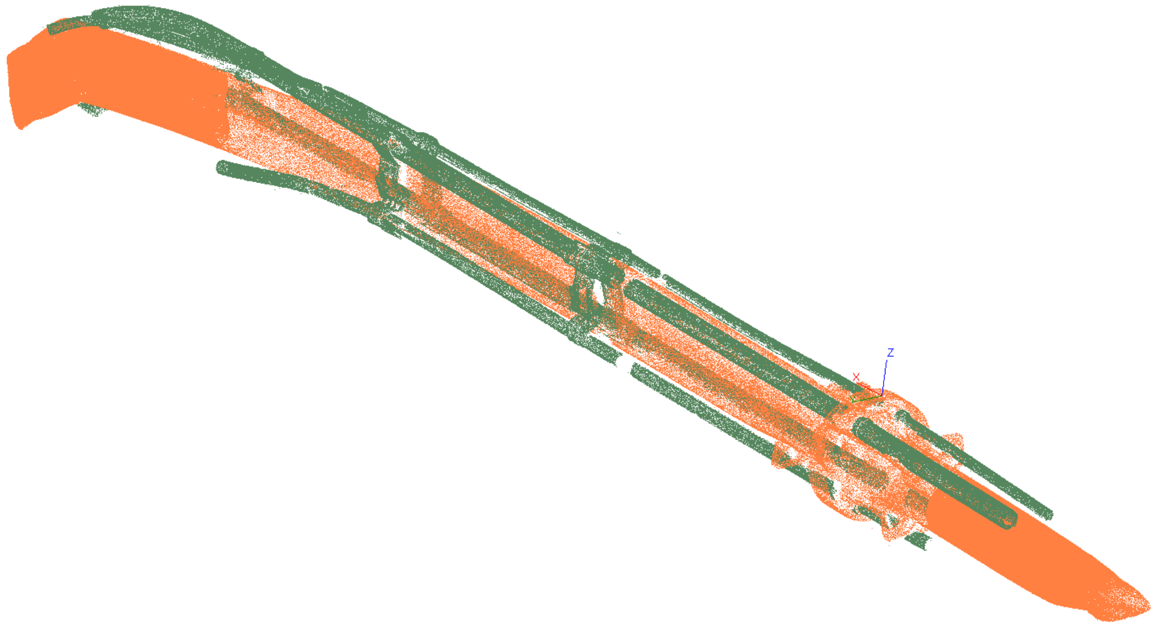

Figure 2: 3D model of full riser assembly

2 Method Statement

Welaptega 3DModelling® uses advanced photogrammetric techniques to generate geometrically accurate 3D models from 2D digital still images.

Pixels are matched between overlapping photos, and model geometry is calculated through a series of iterations based on the pixels' relative positions.

Contrast, texture, and clarity must be present in the project images to allow the software to accurately locate each point coordinate. Model accuracy is directly impacted by image quality and the amount of overlap between photos.

Camera Calibration

Cameras and lenses used to capture project photos are calibrated to produce a file containing camera and lens parameters. The calibration file is included in the processing to account for spherical distortion in the project images. The calibration process documentation is available upon request.

Model Generation

Welaptega 3D photogrammetry software processes images, in pairs, to identify groups of matching pixels using colour and contrast as matching criteria. Typically set to search for groups of 20 pixels, the software creates a point for each matching group it finds, and assigns the point a set of 3D coordinates. Each project image is processed with all other project images to produce the largest data sample available in the collected project photos.

A 'least squares' calculation is performed on each sample of point coordinates to determine the mean 3D coordinates for all points in the model. The relative errors, or residuals, between the mean point coordinate and the coordinates associated with each image pair are calculated and evaluated. Points showing high residuals (coordinates having relative error equal to or greater than three standard deviations) are removed, and then the sample is re-processed to determine the standard deviation for each image, and the variance factor for the model. The variance is the expectation, or mean, of the squared deviations of the points from their expected means. The software iterates these calculations until all points having high residuals have been removed.

Scaling

Scaling can be performed using either the known offset between cameras, or based on the known dimensions of an object in the model.

Welaptega uses a magnet with a target pattern, designed with an offset of 88mm horizontally (3.46in), and 15mm (0.59in) vertically. A Welaptega target scaling magnet is shown in the following figure.

Figure 3: Welaptega target magnet

More than one target magnet is typically placed on the object during photography to provide several opportunities for scaling input and verification.

Points are created (digitized) on the white targets seen on the magnet face. The photogrammetry software detects the center point of each target to allow scaling points to be precisely and consistently located in all images.

Multiple images of each target magnet are collected for inclusion in project processing to create a large sample of scaling points. Scaling point coordinates are processed using the same method used to generate the model, so that only points within close proximity to the mean location are used for scaling.

Accuracy Verification Method

Model accuracy is verified using two methods. The first occurs prior to export of the geometry. The software calculates the distance between two selected points of known offset on the model, and uses the mean coordinate location to calculate the point-to-point distance. This value is compared to the known physical dimension to obtain an accuracy value.

The second method is performed by opening the model with photo-overlay, and measuring the point-to-point distances between targets on the scaling magnets. The model is generated by exporting the coordinates of the image pair, rather than the mean point coordinate locations of the sample. This means that the result of the point-to-point measurement could fall anywhere within the tolerance of the relative error for the image pair that was used to produce that piece of the model. This measurement is subject to the user’s ability to choose the centers of the targets.

A figure illustrating the second type of accuracy measurement is provided in the following figure.

Figure 4: Example of measurement of scale bar accuracy verification (distance measured shown in blue). Distance Measured = 3.47in; Actual Distance = 3.465in

Both the first and second accuracy verification methods are limited to small sections of the model. To guarantee the accuracy of the entire model, objects of known dimensions and spacing would have to be placed in many locations all over the component.

3 Data Acquisition

The riser was recovered to the deck of the Olympic Challenger vessel prior to the photography survey. The main riser casing had peripheral control lines attached to it that were present for the photography. Additional straps and chains were used to secure the riser assembly, and are subsequently included in the photographs and 3D model. These parts were trimmed away from the point cloud to analysis the riser geometry.

Five magnetic scale bars were placed on the riser assembly.

The riser was photographed using a Canon EOS 7D digital SLR camera with 18 megapixels of resolution. A 24mm wide angle prime lens was used.

The entire riser assembly was photographed from close range and with at least 50 percent overlap between adjacent photos. Linear strips of photos were taken along the length of the riser at hourly clock positions around the riser circumference - some photos were also taken at half hour clock positions. The 5-o'clock, 6-o'clock, and 7-o'clock positions were photographed after the riser lifted and reoriented on the deck.

Photos were taken in daylight conditions. The photos were taken during periods of overcast weather or with the deck crane positioned such that photos were not taken directly into the sun.

Approximately 1200 photos were taken of the riser assembly.

Following the offshore photography, the camera and lens were calibrated at the BP offices in Houston.

4 3D Model

The finished 3D model was built using a total of 534 images. The model was scaled using a series of 22 dimensions on each of the five scale bars in the model.

4.1 3D Model Point Cloud Screen Shots

The following figure shows the 3D model of the full riser assembly, with all supporting equipment, including securing straps, supporting blocks, magnets, and peripheral pipes. The main riser is shown in orange.

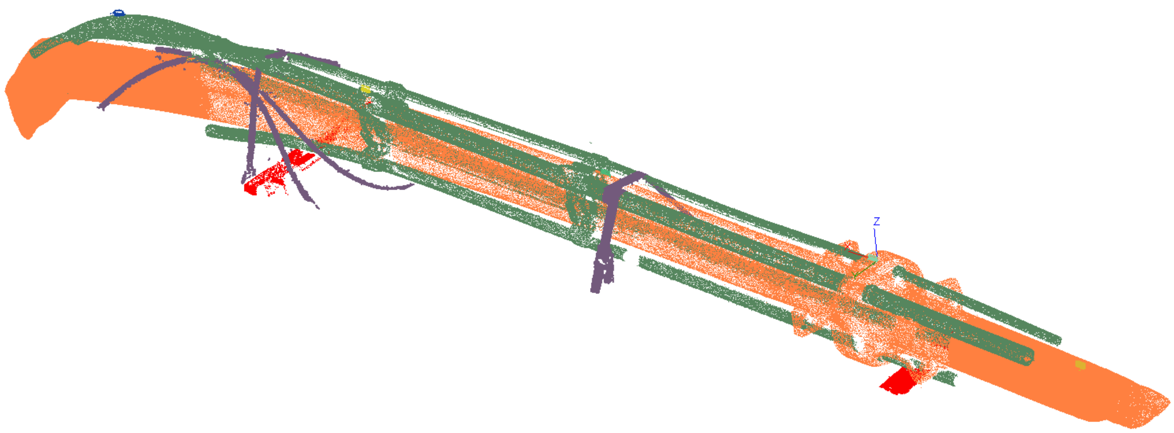

Figure 5: 3D model of riser with all attached pipes

The following figure shows the main riser and peripheral pipes only.

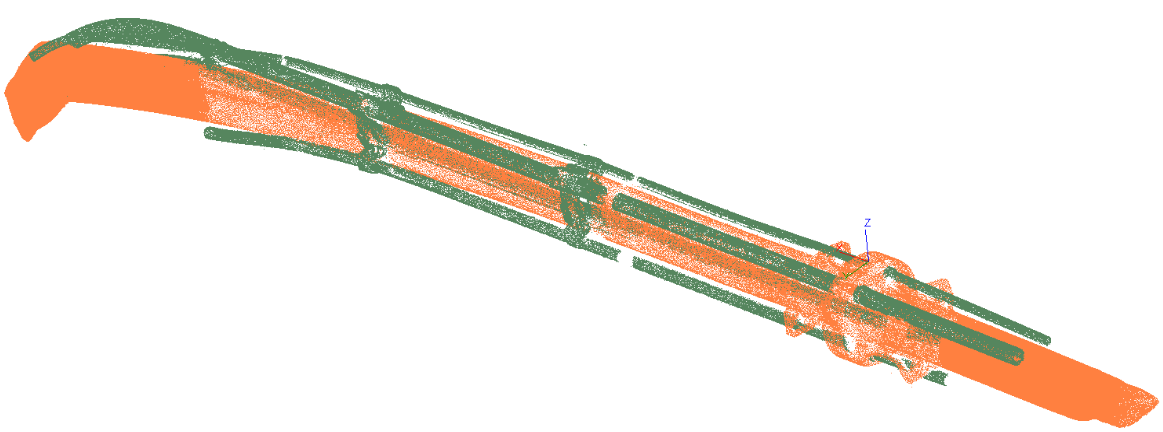

Figure 6: 3D model of the riser casing and peripheral lines

The following figure shows the main riser only.

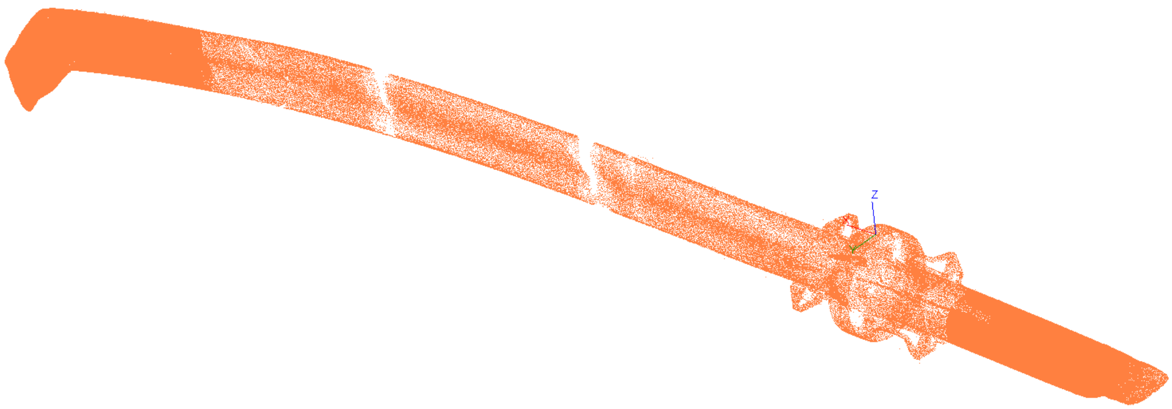

Figure 7: 3D model of the riser casings with peripheral lines removed

The point cloud in the middle section of the riser has been reduced due to the large size of the file slowing the analysis. The point clouds representing the ends of the riser have not been reduced. The middle section can be restored to its full density if required.

The following figures show additional views of the riser with the support blocks included to reference orientation of the riser.

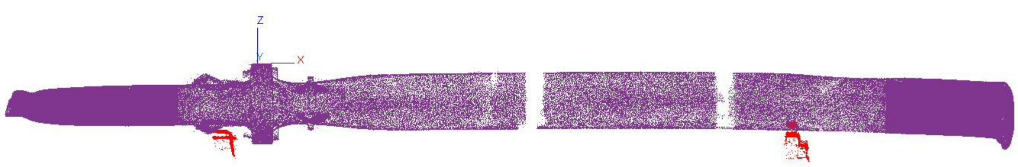

Figure 8: Plan view - kinked section facing into the page

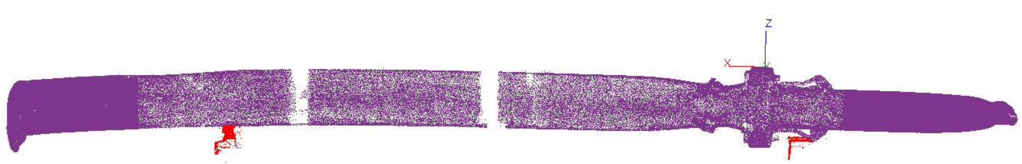

Figure 9: Plan view - kinked section facing out of the page

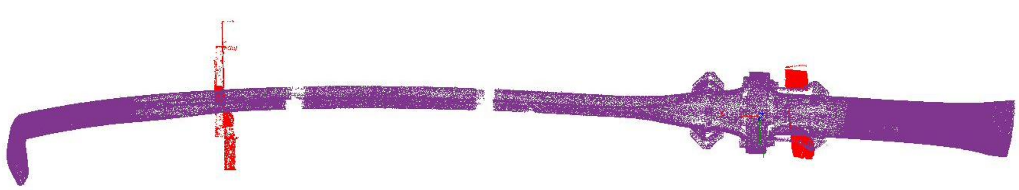

Figure 10: Top view

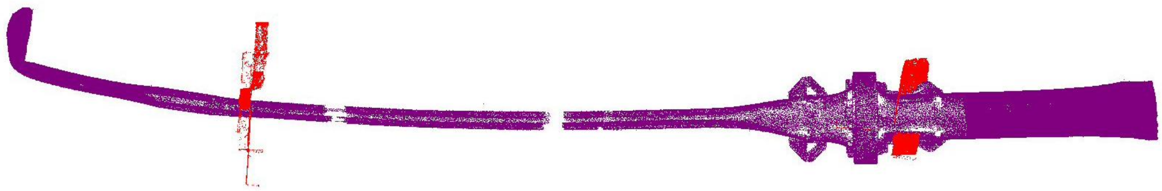

Figure 11: Bottom view

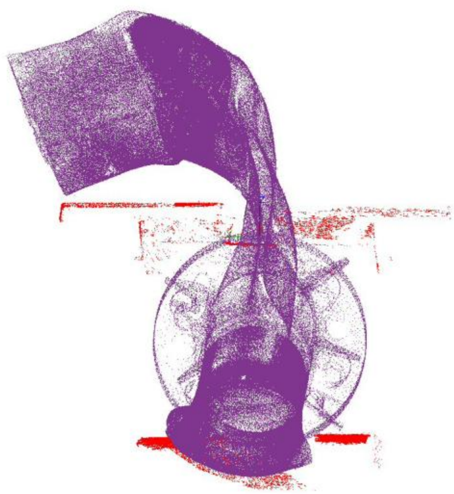

Figure 12: From downstream end looking upstream

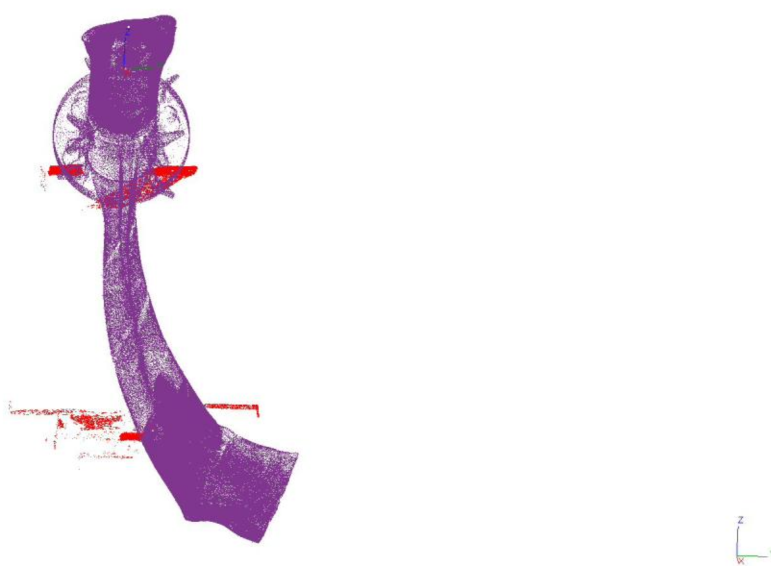

Figure 13: From upstream end looking downstream

The following figures show the upstream end and downstream ends of the riser as point clouds (left) and in a photo (right).

Figure 14: Upstream end of riser with two drill pipes highlighted

Figure 15: Downstream end of riser with drill pipe highlighted

The following figures show the point cloud of the kinked section of the riser where holes are present. The first figure is a point cloud of the riser surface, and the second a photo of the same section of riser with the holes annotated.

Figure 16: Surface of upstream kinked section where holes are present

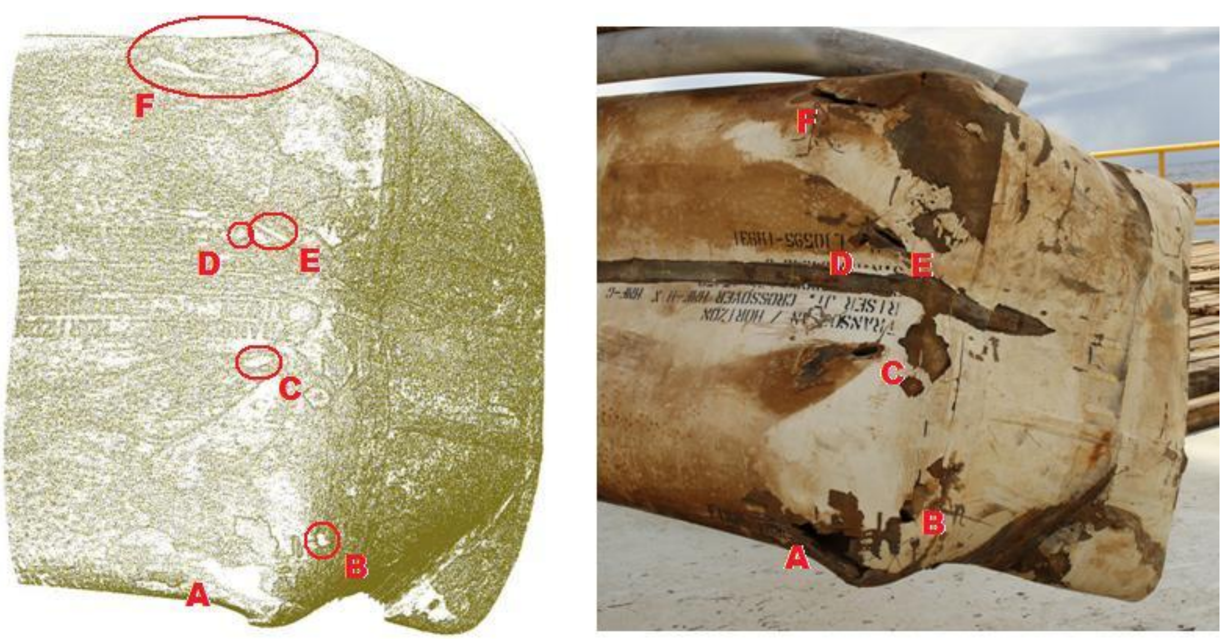

Figure 17: Annotated Point Cloud and photo of kinked section

4.2 3D Model Meshed Surface Screen Shots

The model point cloud was divided into three sections: upstream (kinked), mid-stream, and downstream. A surface mesh was constructed over each section, as shown in the figure below. Downstream is represented in blue, mid-stream in yellow, and upstream in purple.

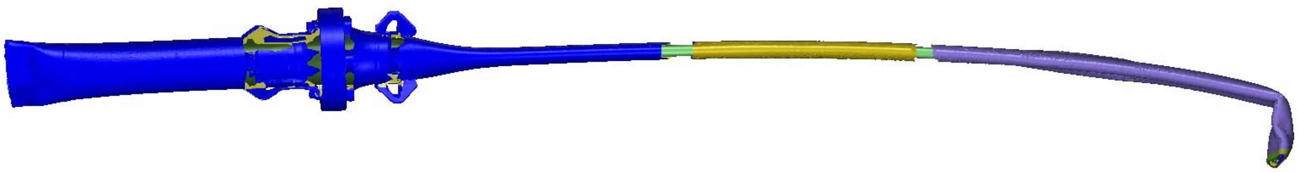

Figure 18: Meshed Riser 3D model

The following figure shows the downstream end of the riser as (1) a point cloud, (2) with a mesh applied, and (3) with photo overlay applied.

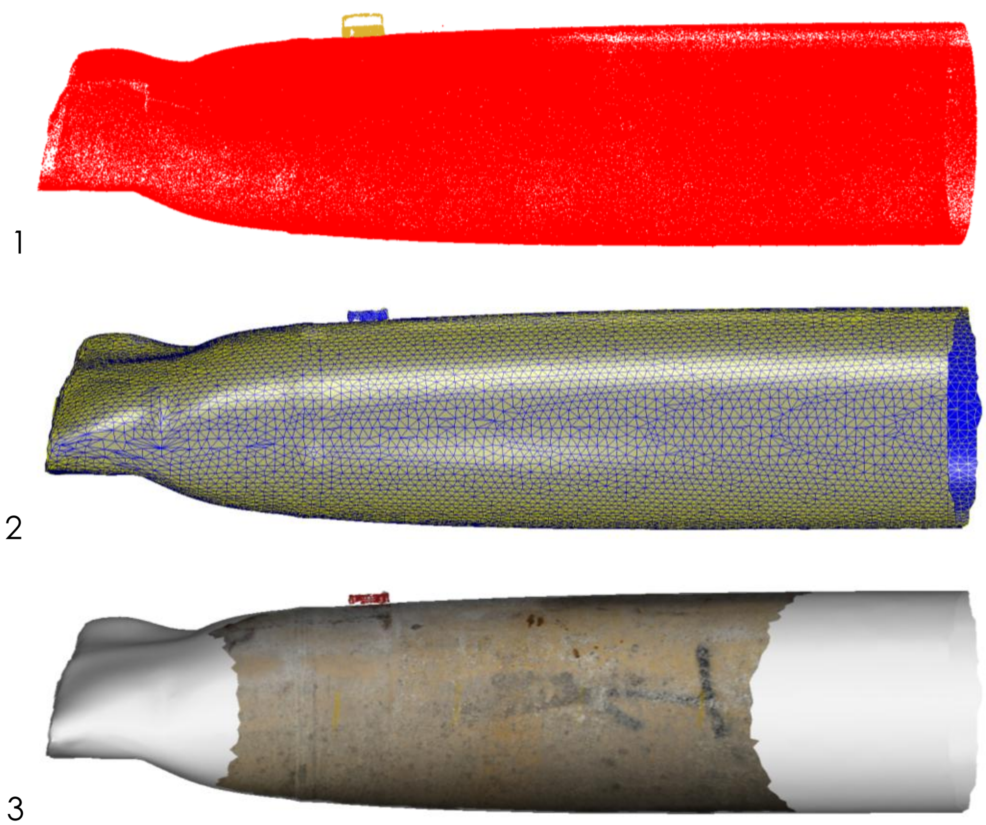

Figure 19: Downstream end of riser: point cloud; meshed surface; meshed surface with photo overlay

4.3 Accuracy Verification

A series of measurements of individual data terrain models (DTMs) with scale bar photo overlays were taken to determine the accuracy of the model (as per Section 2). Table 1 provides parameters of the model and accuracy measurement values.

Table 1: Model parameters and accuracy.

Parameter	Value
Number of Images Used	534
Number of Scale Bar Inputs	110
Variance Factor	1.80
Worst Accuracy Measurement Error (method 2)	0.29%
Reported Accuracy*	<0.5%

*Model measurements only carry 2 decimal places. The model would have to be processed in mm instead of inches for measurements to provide a more precise accuracy.

5 Construction of Geometry Inside the Riser

A surface mesh was constructed over the main riser point cloud, then the geometries of the interior riser surface, and of the left (full) and right (partial) drill stings were constructed as separate meshes. Steps performed during construction are summarized in this section of the report.

5.1 Interior Riser Surface

To generate the interior surface of the riser, the exterior surface mesh was offset by 1 inch toward the riser center. For simplicity and the purposes of analysis, the riser was assumed to have a constant wall thickness of 1inch, as decided by BP E&P.

A limited part of the interior surface was included in the original model at the extreme upstream and downstream ends of the riser. The offset interior surface was joined to the original model at both upstream and downstream ends. The upstream end of the model, showing the original interior and exterior surfaces, is shown below.

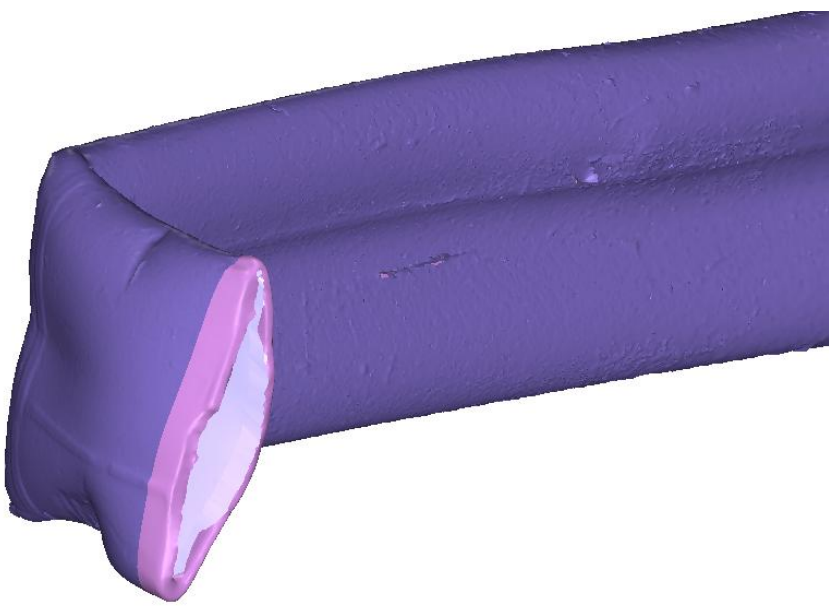

Figure 20: Upstream End of Model showing Original Interior Geometry

The interior surface of the downstream section of the model surrounding the flange was estimated based on the parts of the exterior surface having smooth geometry. The section of interior surface inside the flange was interpolated using adjacent smooth surfaces.

5.2 Drill String Construction

The two lengths of drill string (left and right) were constructed based on information provided by BP. The following dimensions were used for both strings:

Table 2: Dimensions Used For Construction of Interior Geometry

Component	Parameter	Dimension (Inches)
Drill String (both)	Diameter	5.5
	Perimeter	17.375
	Wall thickness	0.4
Tooling Joint (both)	Outer Diameter	7.1
	Inner Diameter	4.0
	Length (upper chamfer to upper chamfer)	25.0
Riser	As-built diameter	21
	Wall thickness	1.0

*Note: The right tooling joint was not constructed to have the length specified above.

5.2.1 Tooling Joint Construction

The locations of the tooling joints were estimated based on photographs taken after sections of the riser wall had been cut-out, and by using the bulges present on the right side of the upstream section. The left tooling joint was assumed to be in its as-built condition.

The left tooling joint was constructed next to the flange, toward the upstream end of the model. The closest edge of the left tooling joint was located approximately 370 inches (just under 30 feet, measured along riser surface) from the upstream end. The tooling joint location is depicted within the cross-section of the riser in the following figure.

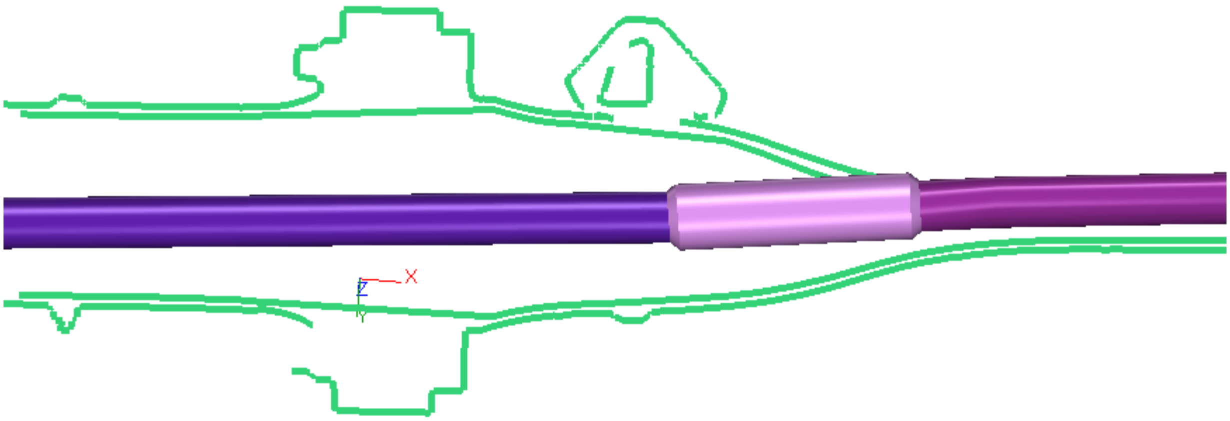

Figure 21: Left Tooling Joint Shown Inside Riser Cross-section (near flange)

The figure below shows the constructed left tooling joint with some dimensions indicated.

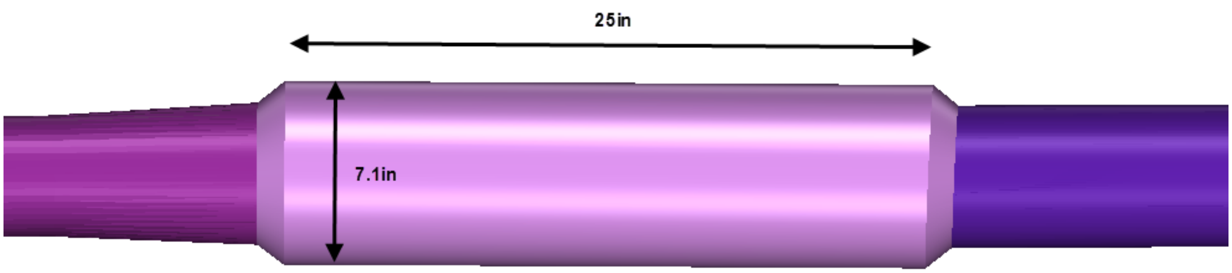

Figure 22: Left Tooling Joint

The right tooling joint was constructed to start at a distance of 95in (just over 8 feet, measured along riser surface) from upstream end. The right drill string ends 43 inches further downstream, at a distance (measured along riser surface) of 138 inches (11.5 feet) from the upstream end.

Because the right tooling joint was distorted out of its as-built shape, the first 22 inches were constructed with a diameter of 7.1inches, and the remaining length (up to 27 inches) was generated to be as close to circular as possible while fitting within the interior riser surfaces. The detail of the right tooling joint distortion was not captured in the model, and was instead represented by a round section of smaller diameter that tapers to become the right drill string.

The right tooling joint, having a total length of 27 inches, is shown in the following figure. The transition of the tooling joint into the drill string is indicated by the green line, where the diameter is 6.8 inches. The green lines above and below the tooling joint represent the cross-section of the riser through the central axis of the right string.

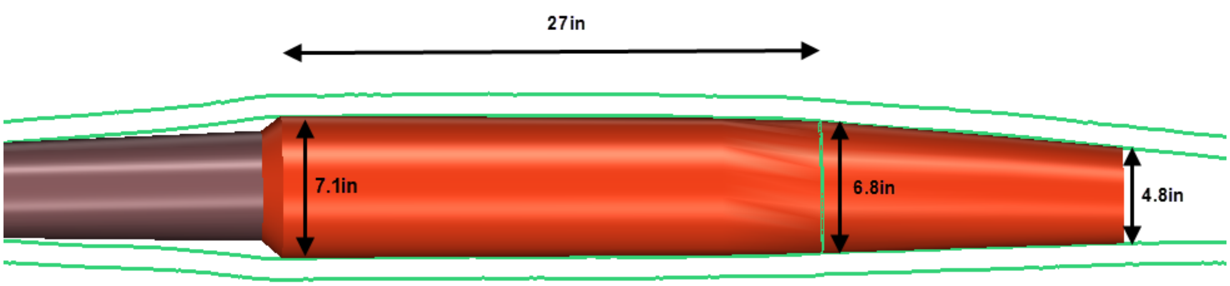

Figure 23 Right Tooling Joint

5.2.2 Drill String Construction

Seven locations along the length of the riser, plus 14 locations through the kink, were selected for cross-section analysis. The contours of the drill strings were constructed within the interior riser surface at each of the selected locations. Drill string contours were constructed to have perimeters within +/- 0.05 inches of 17.375 inches, and to fit within the upper and lower riser surfaces. Lengths of the drill string between the selected contours were interpolated to fit within the interior riser surface.

Constructed contours for the left and right drill strings are shown inside cross-section H(i) in the figure below. The left and right drill string exterior contours are shown in purple. The interior surfaces of the drill strings were generated by offsetting each exterior contour by 0.4 inches. The perimeters for both the left and right string exterior H(i) drill string contours was 17.41inches.

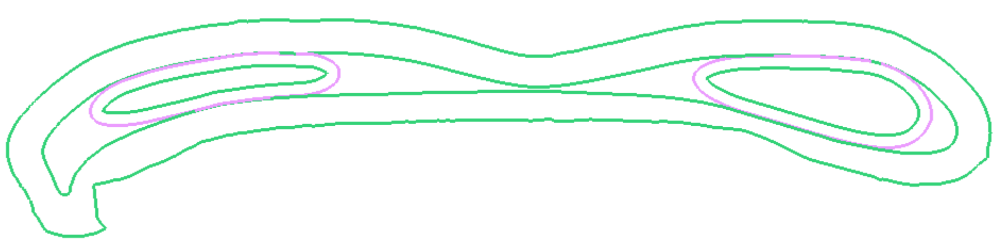

Figure 24: Drill String Contours Constructed within Cross-section H(i) through Kink

Left drill string contours A through M are shown in the following figure.

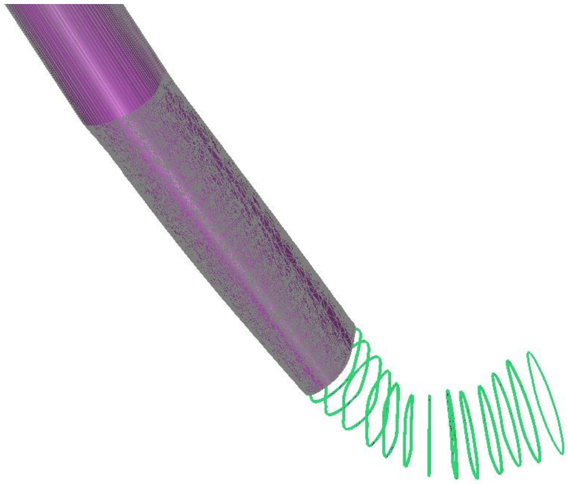

Figure 25: Constructed Contours of kinked section of left drill string

A mesh was created between the cross-sections to produce the left drill string, and the same procedure was performed for the right. The resulting left and right drill string kink meshes are shown in the following figure.

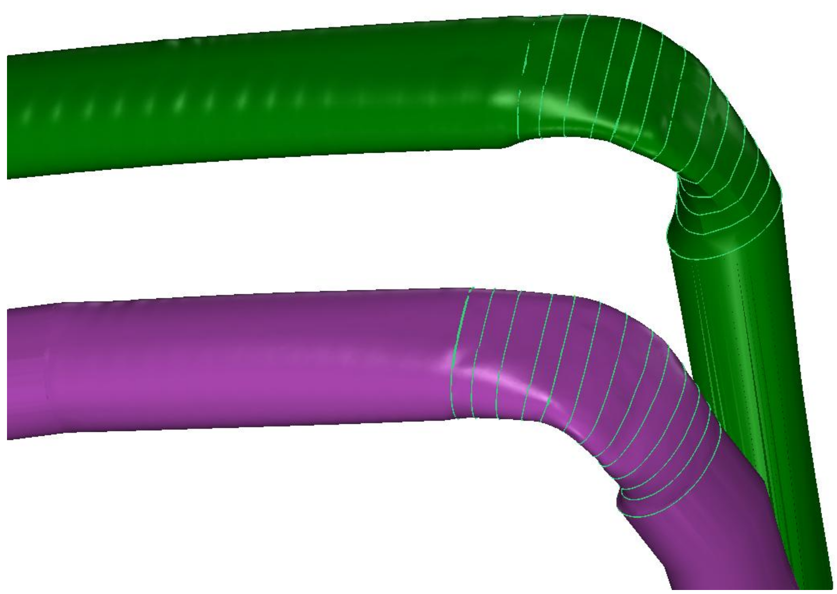

Figure 26: Left and Right Drill Strings Kinked Section Constructed Meshes

The fully constructed left and right drill strings are shown in the figure below.

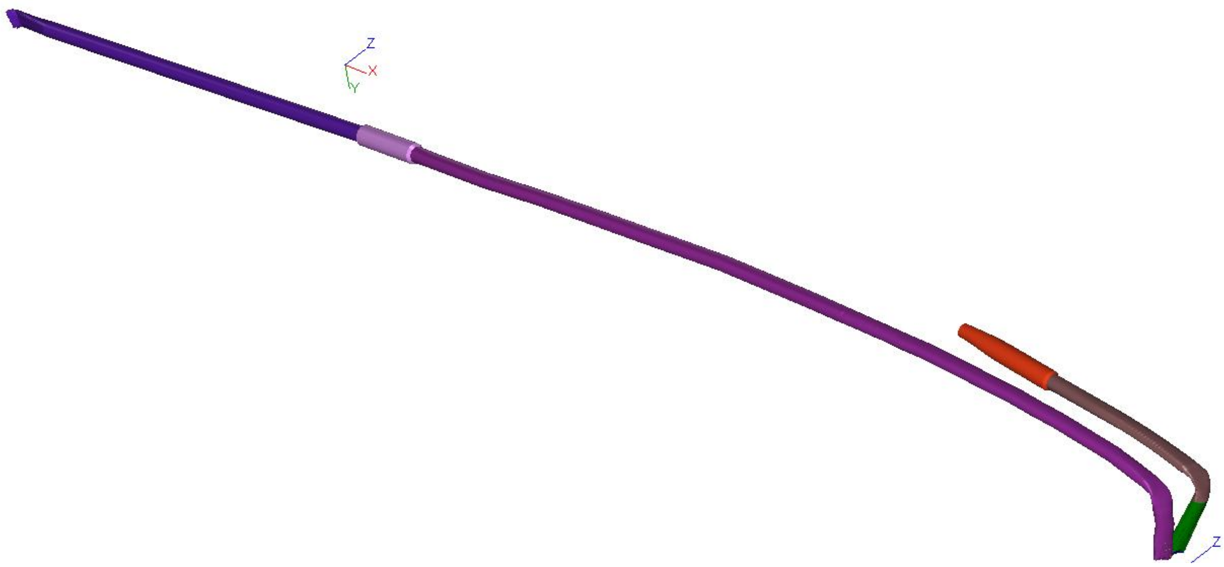

Figure 27: Fully Constructed Drill Strings

6 Cross-section Analysis

Analysis was performed only on the main riser. Point clouds representing other components of the model were trimmed away prior to analysis.

All cross-section figures are shown as viewed from upstream.

6.1 Lengthwise Cross-sections

Lengthwise cross-sections were taken through the upstream section of the riser to find the location where the offset between the upper and lower interior riser surfaces was a minimum. Measurements were done first at 3-inch intervals, and then at smaller intervals until the cross-section having the smallest distance between surfaces was determined.

Cross-section 13.75 was found to have the smallest minimum offset between interior surfaces of 0.13 inches and is indicated by the green line in the following figure.

Figure 28: Lengthwise Upstream Contour with Minimum Distance Between Riser Surfaces

The locations of all lengthwise cross-sections and a table of the minimum distance measurements can be found in Appendix B.

6.2 Cross-sections A to M through Kinked Section

Fourteen cross-sections were taken in the kinked section of the model to find the location having the smallest flow area. Cross-section contours are shown in green. Every effort was made to take cross-sections through a plane perpendicular to the riser; however, selection of the perpendicular direction was subject to the user's judgment.

The radial cross-section having the smallest distance between upper and lower riser surfaces was also determined for comparison with the result of the measurements taken of the lengthwise cross-sections.

The locations of cross-sections A to M are depicted in the following figure.

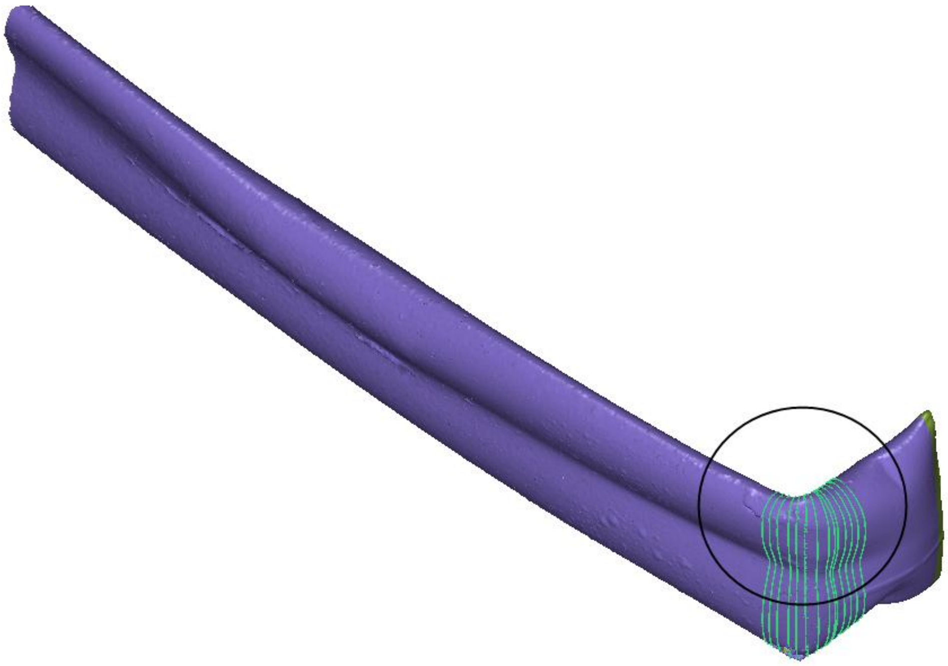

Figure 29: Cross-sections A-M Through Kinked Section

Labels of the cross-sections are provided in the close-up view of the kink below.

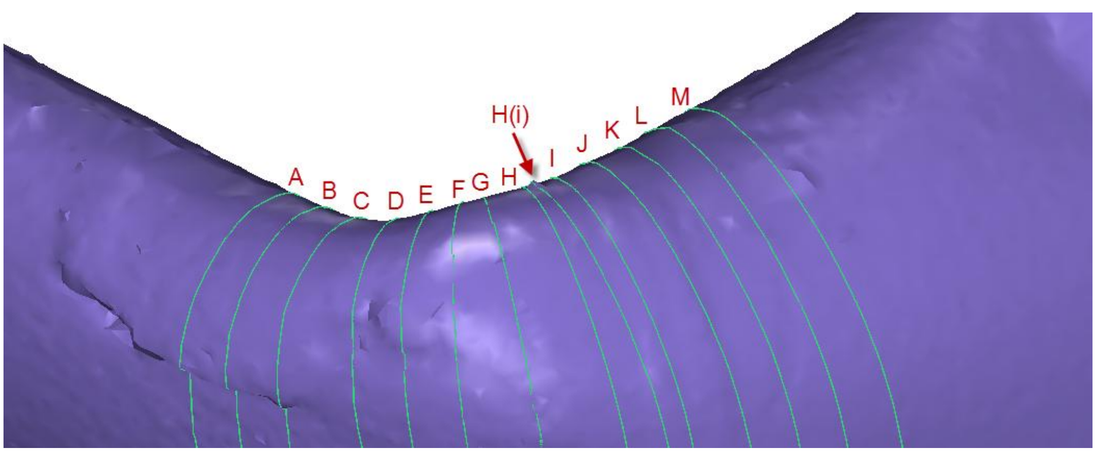

Figure 30: Locations of Cross-sections A to M

One photo (image 4 o'clock-03) was overlaid on the upstream section of the model to show the hole locations with respect to the cross-sections. Cross-sections A to M are shown on the photo-overlay model, and holes are labeled in yellow in the following figure.

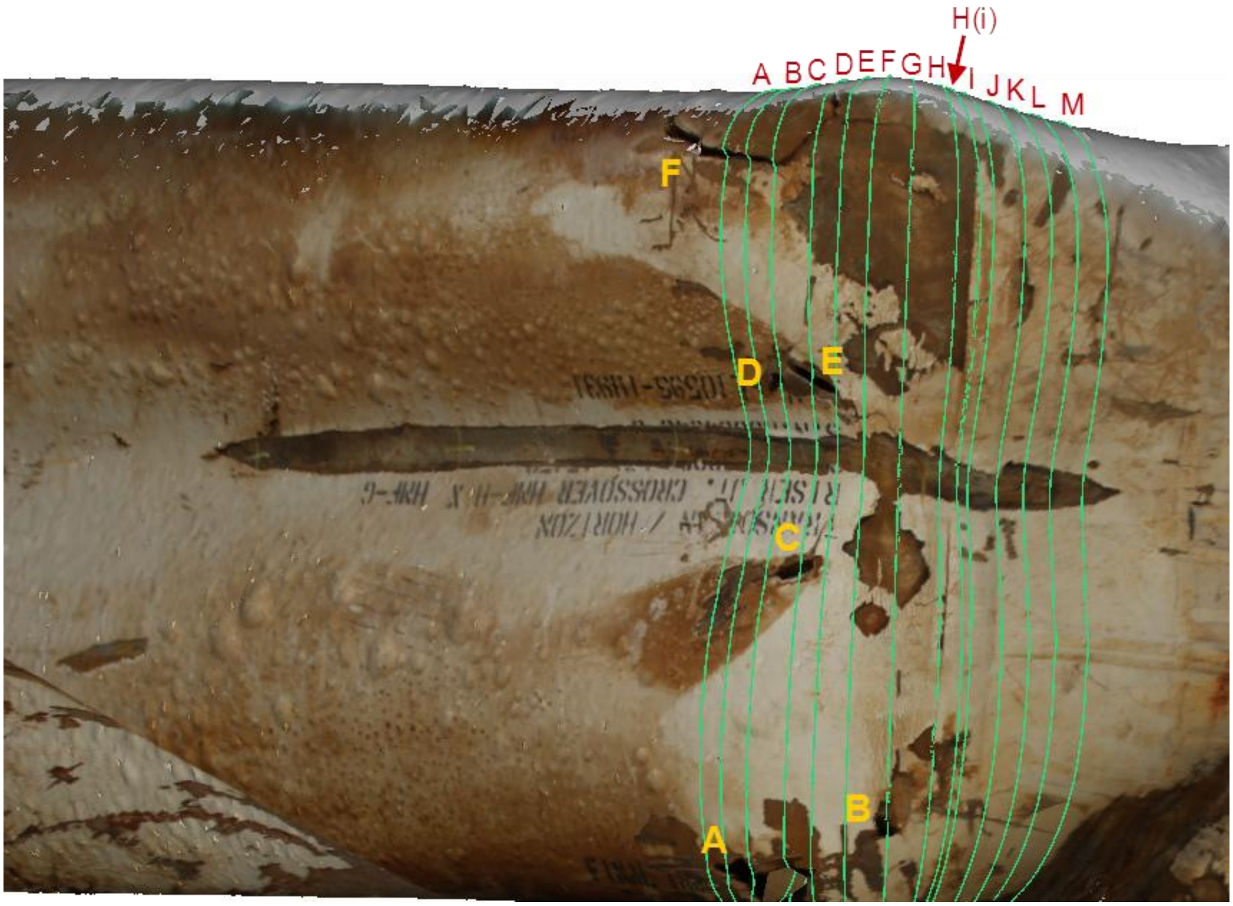

Figure 31: Cross-sections A to M (red labels) and Holes Locations (yellow labels) shown on Photo-overlay model

The table below summarizes the holes through which each cross-section passes.

Table 3: Identification of Cross-sections Passing Through Holes

Cross-section	Holes Cross-section Passes Through
A	F
B	F, A
C	F, D, A
D	F, E, A, C
E	E, A
F	-
G	B
H	-
H(i)	-
I	-
J	-
K	-
L	-
M	-

Cross-section H(i) was found to have the smallest distance between interior riser surfaces of 0.13 inches. The figure below shows lengthwise cross-section 13.75, and radial cross-section H(i) on the upstream section of the model. The intersection of these two cross-sections is marked by a red circle, and indicates the point on the model where the distance between interior riser surfaces is the shortest.

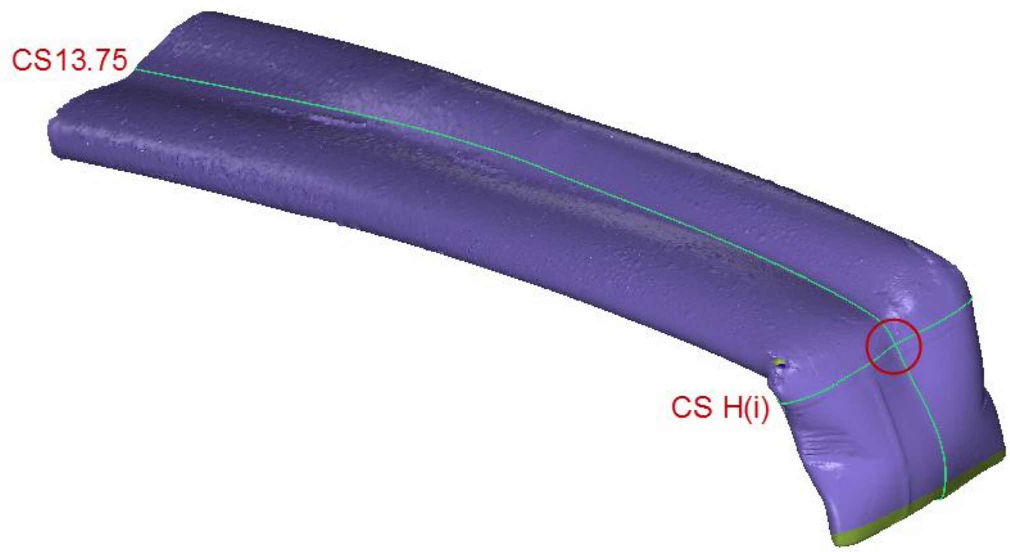

Figure 32: Intersection of Lengthwise and Radial cross sections having minimum distance between surfaces - H(i) and 13.75

Flow area was calculated for each cross-section using three configurations:

1. Unobstructed flow through riser (no drill strings)
2. Flow through riser, obstructed by drill strings
3. Flow through both riser and drill strings

Each configuration is illustrated using Cross-section B (CSB) below.

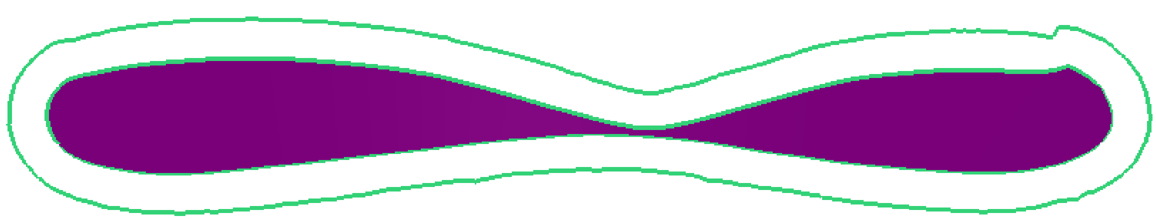

Figure 33: Configuration 1 – Unobstructed Flow Area through CSB

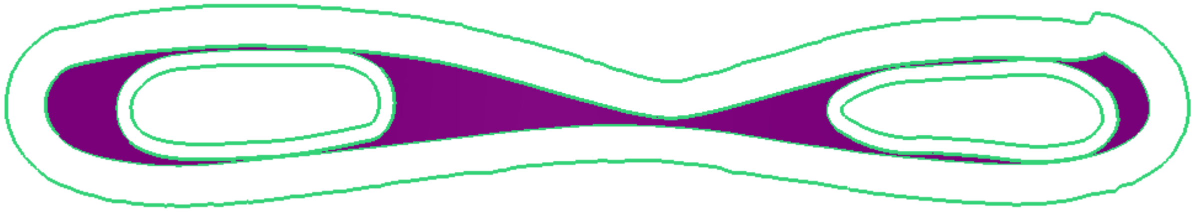

Figure 34: Configuration 2 – Flow Area Obstructed by Drill Strings through CSB

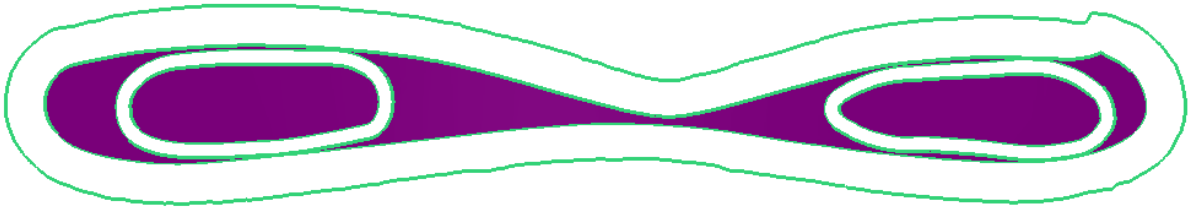

Figure 35: Configuration 3 – Flow Area through Riser and Drill Strings through CSB

Cross-section G was determined to have the smallest flow area. Results of minimum separation distance and area measurements for all kink cross-sections and are provided in the table below. The locations of the cross-sections as measured along the riser surface from the upstream end of the riser are also provided in the table.

Table 4: Flow Areas Through Kink Cross-sections A to M

Cross-section	Cross-section location measured along outer riser surface from upstream end (inches)	Minimum Separation Distance Between Interior Riser Surfaces (in)	Configuration 1 Unobstructed Flow Area (in^2)	Configuration 1 Percent of Area of 19 inch diameter Circle %	Configuration 2 Obstructed by Drill Strings Flow Area (in^2)	Configuration 3 Flow Area through Riser and Strings (in^2)
A	31.9	0.21	60.5	21	22.8	47.6
B	31.1	0.21	55.9	20	22.0	43.0
C	29.6	0.19	49.4	17	18.8	36.5
D	28.9	0.19	42.0	15	16.3	29.2
E	27.8	0.22	37.0	13	14.6	24.2
F	26.5	0.33	33.3	12	14.3	20.4
G	25.2	0.31	**31.7**	**11**	**12.9**	**18.8**
H	24.0	0.16	36.9	13	13.4	24.2
H(i)	23.0	**0.13**	41.9	15	15.3	29.0
I	22.5	0.18	47.1	17	18.2	34.4
J	21.6	0.49	60.5	21	26.3	47.7
K	20.6	0.91	71.9	25	32.4	59.1
L	19.3	1.54	84.4	30	42.0	71.5
M	18.2	2.62	103.8	37	58.0	90.8
Circle 19 inch Diameter	-	-	270.6	100	-	-

Figures of kink cross-sections A to M, and flow area calculation results for the drill strings in each cross-section can be found in Appendix D.

6.3 Lengthwise Cross-sections through Right Tooling Joint

A lengthwise cross-section through the highest point of the right side of the riser was taken and measured to determine how the height of the bulge changed over the length of the riser.

The location of the lengthwise cross-section is illustrated in the following figure.

Figure 36: Location of Lengthwise Cross-section shown through Outer Riser Surface (aligned with axis of constructed right tooling joint)

The right tooling joint is shown within the lengthwise cross-section in the following figure.

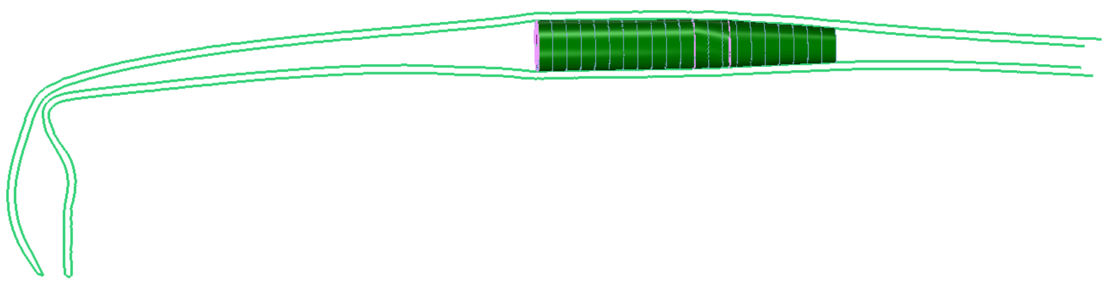

Figure 37: Constructed Drill Pipe Shown within Lengthwise Cross-section

Note: the constructed drill pipe shown in Figure 2 was generated based on the space available within the riser. The downstream end of the right drill string has been represented by a circular pipe rather than the actual irregular shape.

Cross-sections of the tooling joint were taken at 2-inch increments and measured for height.

The pink lines indicate the 0in (start of tooling joint), 22in, and 27in (end of tooling joint) locations in the following figure.

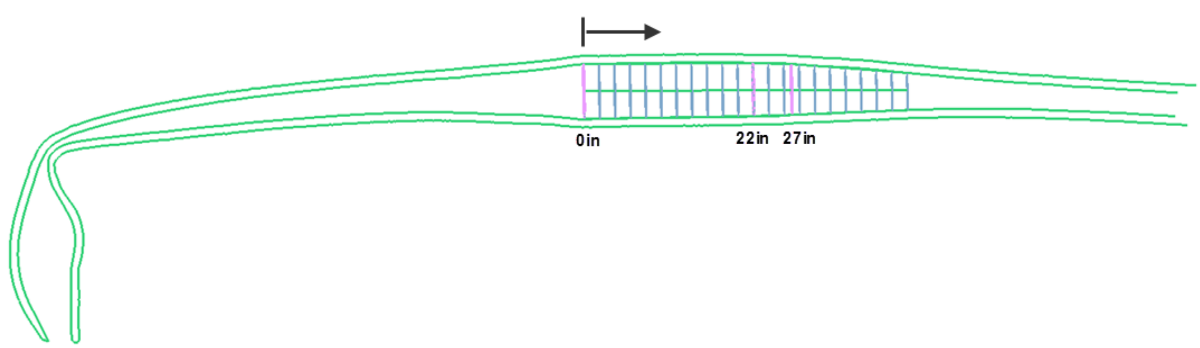

Figure 38: Locations of Cross Sections through Right Tooling Joint

The heights of the tooling joint cross-sections are provided in the table below.

Table 5: Heights of Cross-sections through Right Tooling Joint

Cross-section (distance from upstream end of right tooling joint, inches)	Height of Cross-section (inches)
0	**7.09**
2	7.07
4	7.06
6	7.03
8	7.02
10	6.99
12	6.97
14	6.94
16	6.92
18	6.9
20	6.88
22	**6.86**
24	6.74
26	6.62
27	**6.57**
28	6.45
30	6.22
32	5.99
34	5.75
36	5.51
38	5.28
40	5.04
42	4.8

Results are illustrated in the following graph, showing that cross-section height begins to decline at 22 inches, then begins to decline more rapidly at 27 inches, where the tooling joint ends.

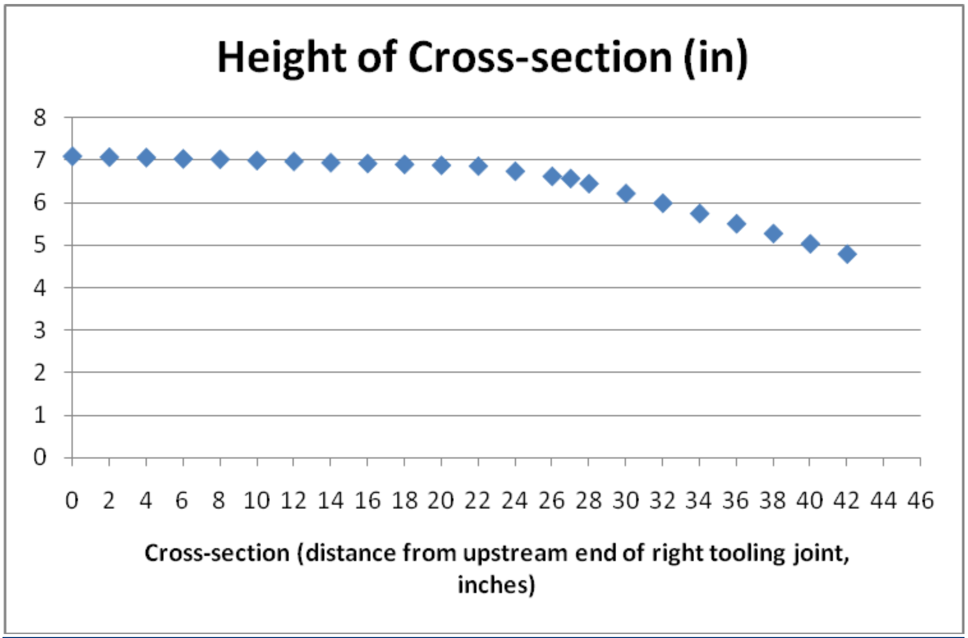

Figure 39: Graph of Right Tooling Joint Cross-section Height

6.4 Cross-sections 1 to 7

Seven cross-sections were taken through the riser and drill strings at the locations indicated in the following figures. Flow areas were measured for each cross-section based on the same three configurations used for the kink cross-sections.

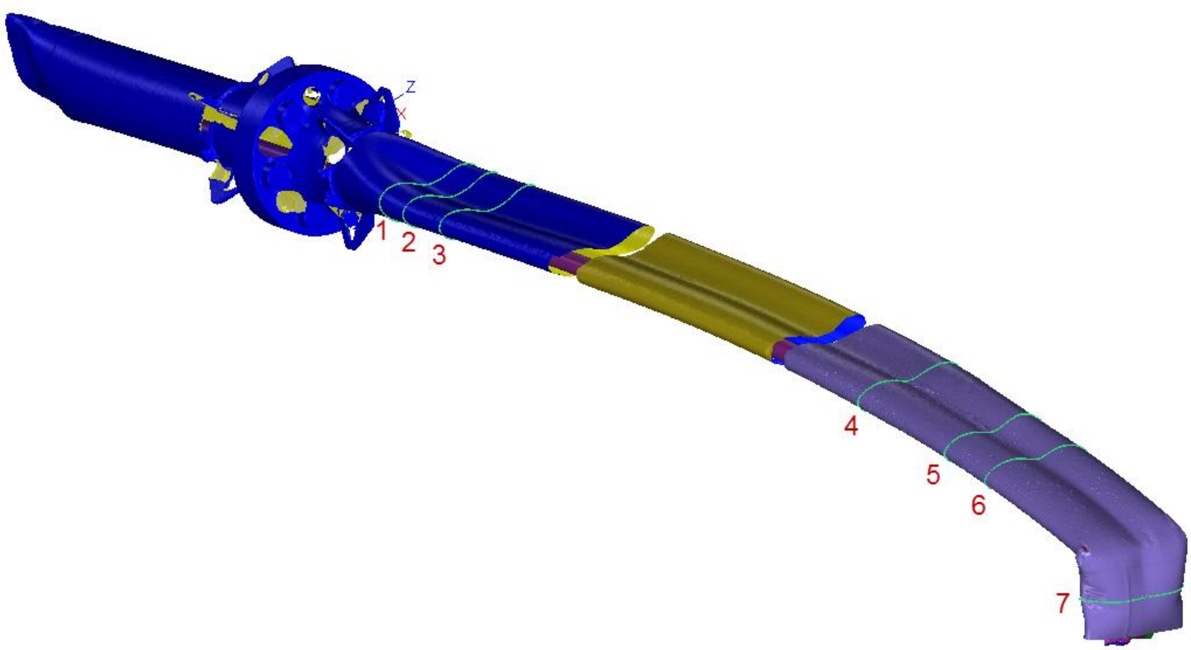

Figure 40: Locations of Cross-sections 1 to 7 Shown on Outer Riser Surface

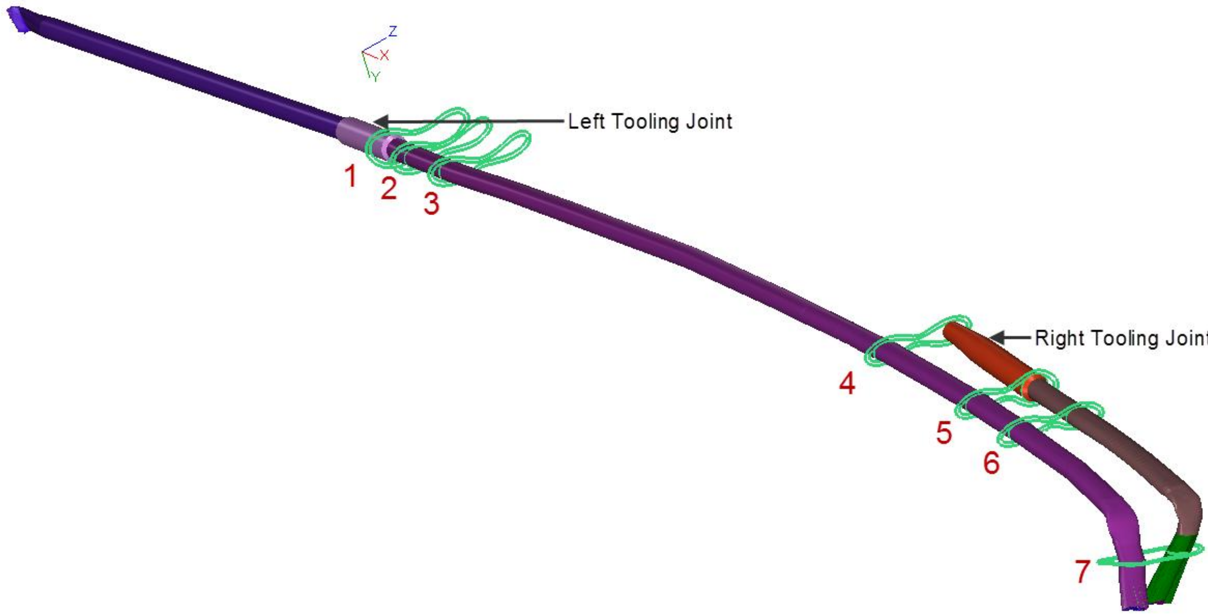

Figure 41: Locations of Cross-sections 1 to 7 shown on Left and Right Drill Strings

The flow area calculations for cross-sections 1 to 7 are provided in the following table. Figures showing all cross-sections can be found in Appendix C, as well as a table that includes the flow areas of each drill string.

Table 6: Flow Areas of Cross-sections 1 to 7

Cross-section	Configuration 1 Unobstructed Flow Area (in^2)	Configuration 2 Obstructed by Drill Strings Flow Area (in^2)	Configuration 3 Flow Area through Riser and Strings (in^2)
1	141.4	101.8	114.4
2	72.6	49.3	66.2
3	88.9	65.5	82.4
4	87.5	64.9	81.0
5	104.7	42.8	71.3
6	85.7	40.2	72.8
7	157.9	112.2	145.0

7 Conclusions and Recommendations

Accuracy measurements taken on the model resulted in errors below 0.5 percent.

Cross-section G was determined to have the smallest flow area, measured to be 31.7in^{2}, when unobstructed by the drill strings.

Welaptega can perform additional analysis upon request.

Appendix A - Photo Catalogue

Photos were taken along the full length of the riser maintaining a circumferential clock position to ensure overlap of the photos. The folder structure for the photo catalogue is described below. The full catalogue of photos has been provided to BP separate from this report.

Appendix 1: Photo Catalogue

Folder	First Photo in Folder	Last Photo in Folder	Description
Riser Orientation 1			
1 o'clock photos	DWH Riser 3DM 1 o'clock (1)	DWH Riser 3DM 1 o'clock (57)	Downstream end moving upstream
2 o'clock photos	DWH Riser 3DM 2 o'clock (1)	DWH Riser 3DM 2 o'clock (88)	Downstream end moving upstream
3 o'clock photos	DWH Riser 3DM 3 o'clock (1)	DWH Riser 3DM 3 o'clock (43)	Downstream end moving upstream
4 o'clock photos	DWH Riser 3DM 4 o'clock (1)	DWH Riser 3DM 4 o'clock (43)	Upstream end moving downstream
8 o'clock photos	DWH Riser 3DM 8 o'clock (1)	DWH Riser 3DM 8 o'clock (57)	Downstream end moving upstream
9 o'clock photos	DWH Riser 3DM 9 o'clock (1)	DWH Riser 3DM 9 o'clock (31)	Upstream end moving downstream
10 o'clock photos	DWH Riser 3DM 10 o'clock (1)	DWH Riser 3DM 10 o'clock (44)	Downstream end moving upstream
1030 photos	DWH Riser 3DM 10.5 o'clock (1)	DWH Riser 3DM 10.5 o'clock (54)	Downstream end moving upstream
1130 photos	DWH Riser 3DM 11.5 o'clock (1)	DWH Riser 3DM 11.5 o'clock (108)	Downstream end moving upstream
12 o'clock photos	DWH Riser 3DM 12 o'clock (1)	DWH Riser 3DM 12 o'clock (51)	Upstream end moving downstream
Riser Orientation 2			
5 o'clock photos ORI 2	DWH Riser 3DM 5 o'clock ORI2 (1)	DWH Riser 3DM 5 o'clock ORI2 (37)	Downstream end moving upstream
6 o'clock photos ORI 2	DWH Riser 3DM 6 o'clock ORI2 (1)	DWH Riser 3DM 6 o'clock ORI2 (39)	Downstream end moving upstream
7 o'clock photos ORI 2	DWH Riser 3DM 7 o'clock ORI2 (1)	DWH Riser 3DM 7 o'clock ORI2 (32)	Downstream end moving upstream
10 o'clock photos ORI 2	DWH Riser 3DM 10 o'clock ORI2 (1)	DWH Riser 3DM 10 o'clock ORI2 (34)	Upstream end moving downstream
11 o'clock photos ORI 2	DWH Riser 3DM 11 o'clock ORI2 (1)	DWH Riser 3DM 11 o'clock ORI2 (35)	Upstream end moving downstream
12 o'clock photos ORI 2	DWH Riser 3DM 12 o'clock ORI2 (1)	DWH Riser 3DM 12 o'clock ORI2 (38)	Upstream end moving downstream

Miscellaneous Folder	
Photo	Description
DWH Riser Inspection Misc 1	Entire Riser 3 o'clock
DWH Riser Inspection Misc 2	Entire Riser 3 o'clock
DWH Riser Inspection Misc 3	Enterprise from Olympic Challenger deck
DWH Riser Inspection Misc 4	Enterprise from Olympic Challenger deck
DWH Riser Inspection Misc 5	Enterprise from Olympic Challenger deck
DWH Riser Inspection Misc 6	Enterprise from Olympic Challenger deck
DWH Riser Inspection Misc 7	Enterprise from Olympic Challenger deck
DWH Riser Inspection Misc 8	Rotating Riser to ORI2

DWH Riser Inspection Misc 9	Deck Crane
DWH Riser Inspection Misc 10	Rotating Riser to ORI2
DWH Riser Inspection Misc 11	Rotating Riser to ORI2
DWH Riser Inspection Misc 12	Downstream cut end
DWH Riser Inspection Misc 13	Downstream cut end
DWH Riser Inspection Misc 14	Downstream cut end
DWH Riser Inspection Misc 15	Downstream cut end
DWH Riser Inspection Misc 16	Downstream cut end
DWH Riser Inspection Misc 17	Downstream cut end
DWH Riser Inspection Misc 18	Downstream cut end
DWH Riser Inspection Misc 19	Downstream cut end
DWH Riser Inspection Misc 20	Downstream cut end
DWH Riser Inspection Misc 21	Downstream cut end
DWH Riser Inspection Misc 22	Downstream cut end 9 o'clock Crack
DWH Riser Inspection Misc 23	Downstream cut end 9 o'clock Crack
DWH Riser Inspection Misc 24	Downstream cut end 9 o'clock Crack
DWH Riser Inspection Misc 25	Downstream cut end 9 o'clock Crack
DWH Riser Inspection Misc 26	Entire Riser 9 o'clock
DWH Riser Inspection Misc 27	Kink inside 9 o'clock
DWH Riser Inspection Misc 28	Kink outside 3 o'clock
DWH Riser Inspection Misc 29	Downstream cut end 4 o'clock
DWH Riser Inspection Misc 30	Downstream cut end 4 o'clock
DWH Riser Inspection Misc 31	Downstream cut end 4 o'clock
DWH Riser Inspection Misc 32	Downstream cut end 4 o'clock
DWH Riser Inspection Misc 33	Downstream cut end 4 o'clock
DWH Riser Inspection Misc 34	Downstream cut end 7 o'clock
DWH Riser Inspection Misc 35	Downstream cut end 8 o'clock
DWH Riser Inspection Misc 36	Downstream cut end 8 o'clock
DWH Riser Inspection Misc 37	Downstream cut end 8 o'clock
DWH Riser Inspection Misc 38	Downstream cut end 8 o'clock
DWH Riser Inspection Misc 39	Kink inside 9 o'clock
DWH Riser Inspection Misc 40	Kink inside 9 o'clock
DWH Riser Inspection Misc 41	Kink inside 9 o'clock
DWH Riser Inspection Misc 42	Kink inside 9 o'clock
DWH Riser Inspection Misc 43	Kink inside 9 o'clock
DWH Riser Inspection Misc 44	Kink inside 9 o'clock
DWH Riser Inspection Misc 45	Kink inside 9 o'clock
DWH Riser Inspection Misc 46	Kink outside 3 o'clock
DWH Riser Inspection Misc 47	Kink outside 3 o'clock
DWH Riser Inspection Misc 48	Kink outside 3 o'clock
DWH Riser Inspection Misc 48	Kink outside 3 o'clock
DWH Riser Inspection Misc 49	Kink outside 3 o'clock
DWH Riser Inspection Misc 50	Kink inside 9 o'clock
DWH Riser Inspection Misc 51	Kink inside 9 o'clock
DWH Riser Inspection Misc 52	Kink inside 9 o'clock
DWH Riser Inspection Misc 53	Kink inside 9 o'clock
DWH Riser Inspection Misc 54	Kink inside 9 o'clock
DWH Riser Inspection Misc 55	Rotating Riser to ORI2
DWH Riser Inspection Misc 56	Crack at downstream cut end
DWH Riser Inspection Misc 57	Crack at downstream cut end
DWH Riser Inspection Misc 58	Drill pipe at downstream cut end
DWH Riser Inspection Misc 59	Drill pipe at downstream cut end
DWH Riser Inspection Misc 60	Downstream cut end
DWH Riser Inspection Misc 61	Drill pipe at downstream cut end
DWH Riser Inspection Misc 62	Downstream cut end 9 o'clock Crack
DWH Riser Inspection Misc 63	Downstream cut end 9 o'clock Crack

DWH Riser Inspection Misc 64	Downstream cut end 9 o'clock Crack
DWH Riser Inspection Misc 65	Downstream cut end 9 o'clock Crack
DWH Riser Inspection Misc 66	Saw cut at 39ft
DWH Riser Inspection Misc 67	Crack along inner side of Kink
DWH Riser Inspection Misc 68	Crack along inner side of Kink
DWH Riser Inspection Misc 69	Crack along inner side of Kink
DWH Riser Inspection Misc 70	Crack along inner side of Kink
DWH Riser Inspection Misc 71	Crack along inner side of Kink
DWH Riser Inspection Misc 72	Crack along inner side of Kink
DWH Riser Inspection Misc 73	Crack along innerside of Kink
DWH Riser Inspection Misc 74	Upstream cut & 2 Drill pipes
DWH Riser Inspection Misc 75	Upstream cut & 2 Drill pipes
DWH Riser Inspection Misc 76	Upstream cut & 2 Drill pipes
DWH Riser Inspection Misc 77	Upstream cut & 2 Drill pipes
DWH Riser Inspection Misc 78	Upstream cut & 2 Drill pipes
DWH Riser Inspection Misc 79	Upstream cut & 2 Drill pipes
DWH Riser Inspection Misc 80	Upstream cut & 2 Drill pipes
DWH Riser Inspection Misc 81	Upstream cut & 2 Drill pipes
DWH Riser Inspection Misc 82	Upstream cut & 2 Drill pipes
DWH Riser Inspection Misc 83	Kink Hole A
DWH Riser Inspection Misc 84	Kink Hole B
DWH Riser Inspection Misc 85	Kink Hole B
DWH Riser Inspection Misc 86	Kink Hole C
DWH Riser Inspection Misc 87	Kink Hole D & E
DWH Riser Inspection Misc 88	Kink Hole F
DWH Riser Inspection Misc 89	Kink Hole F
DWH Riser Inspection Misc 90	Kink Hole F
DWH Riser Inspection Misc 91	Kink End 5 o'clock
DWH Riser Inspection Misc 92	Upstream cut
DWH Riser Inspection Misc 93	Upstream cut & 2 Drill pipes
DWH Riser Inspection Misc 94	Upstream cut & 2 Drill pipes
DWH Riser Inspection Misc 95	Upstream cut & 2 Drill pipes
DWH Riser Inspection Misc 96	Upstream cut & 2 Drill pipes
DWH Riser Inspection Misc 97	Length view (Upstream to Downstream) of Riser
DWH Riser Inspection Misc 98	Cut Control Line
DWH Riser Inspection Misc 99	Cut Control Line
DWH Riser Inspection Misc 100	Flange Looking upstream
DWH Riser Inspection Misc 101	Flange Looking upstream
DWH Riser Inspection Misc 102	Flange Looking upstream
DWH Riser Inspection Misc 103	Flange Looking Downstream
DWH Riser Inspection Misc 104	Flange Looking Downstream
DWH Riser Inspection Misc 105	Flange Looking Downstream
DWH Riser Inspection Misc 106	Flange Looking Downstream
DWH Riser Inspection Misc 107	Control lines
DWH Riser Inspection Misc 108	Control lines
DWH Riser Inspection Misc 109	Control lines
DWH Riser Inspection Misc 110	Outside of Kink
DWH Riser Inspection Misc 111	Outside of Kink
DWH Riser Inspection Misc 112	Outside of Kink
DWH Riser Inspection Misc 113	Outside of Kink

Appendix B – Upstream Lengthwise Cross-sections

The locations of the lengthwise upstream cross-sections are shown in the figure below. Cross-sections were named based on their distances from the right side of the model (i.e. Cross-section 1 is located to the right, Cross-section 27 to the left).

Cross-section 13.75 had the smallest distance between interior riser surfaces and is indicated by the thickest green line in the figure.

Figure 42: Upstream Lengthwise Cross-sections

The minimum distances between interior riser surfaces for all lengthwise cross-sections taken are provided in the following table.

Table 7: Minimum Distances Between Interior Riser Surface in Lengthwise Upstream Cross-sections

Cross-section (inches from right)	Minimum Distance Between Interior Riser Surfaces in Lengthwise Cross-section(inches)
1	Not measured
2	Not measured
3	1.64
4	Not measured
5	Not measured
6	1.19
7	Not measured
8	Not measured
9	0.9
10	Not measured
11	Not measured
12	0.33
13	0.19
13.5	0.13
13.75	0.13
14	0.13
14.5	0.19
15	0.3
15.5	0.41
16	0.53
16.5	Not measured
17	Not measured
18	0.9
19	Not measured
20	Not measured
21	0.93
22	Not measured
24	1.03
27	1.11

Appendix C - Cross-sections 1 to 7

The drill string flow areas at cross-sections 1 to 7 are summarized in the following table.

Table 8: Drill String Flow Areas through Cross-sections 1 to 7

Cross-section	Left Drill String (or tooling joint) Flow Area (in^2)	Right Drill String (or tooling joint) Flow Area (in^2)
1	12.6	0 (n/a)
2	16.9	0 (n/a)
3	16.9	0 (n/a)
4	16.1	0 (n/a)
5	15.9	12.6
6	16.1	16.5
7	15.4	17.4

Cross-sections 1 to 7 are shown in configuration 3 to illustrate the shape of the contours inside each cross-section.

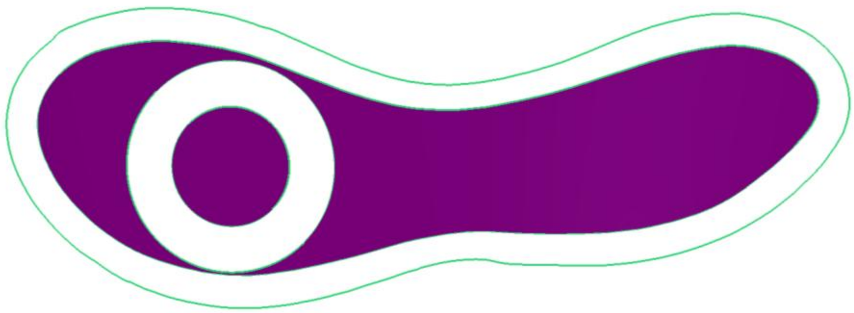

Figure 43: CS 1 with left drill string thickness of 1.55in (interior flow diameter of 4in)

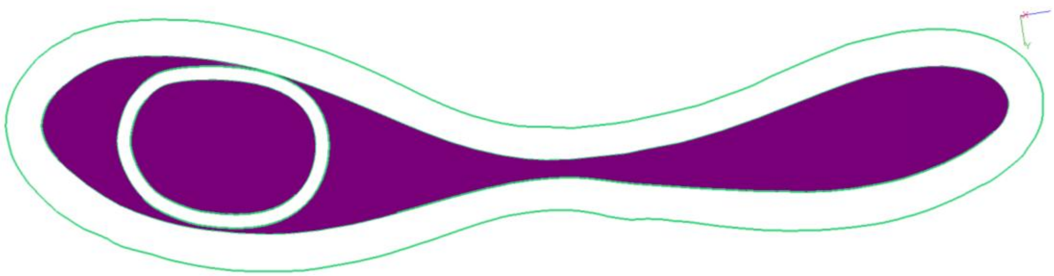

Figure 44: CS2 Flow Area through Riser and Left Drill String

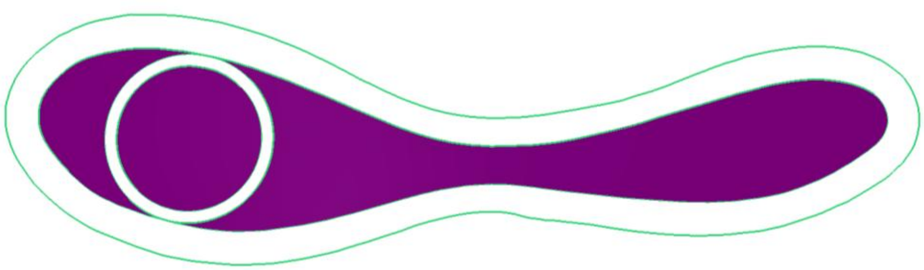

Figure 45: CS3 Flow Area through Riser and Drill String

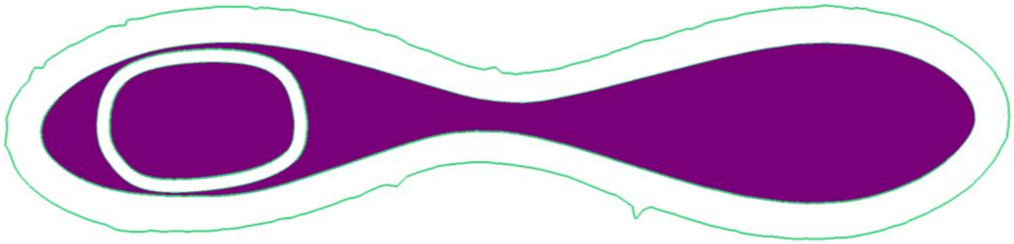

Figure 46: CS4 Flow area

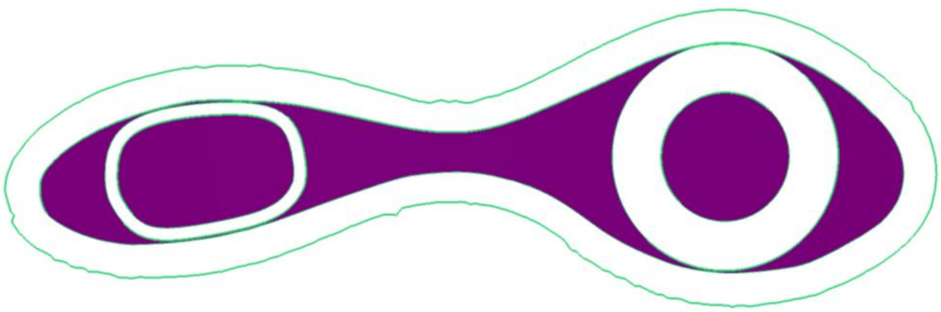

Figure 47: CS5 Wall thickness of 1.55in used for tooling joint

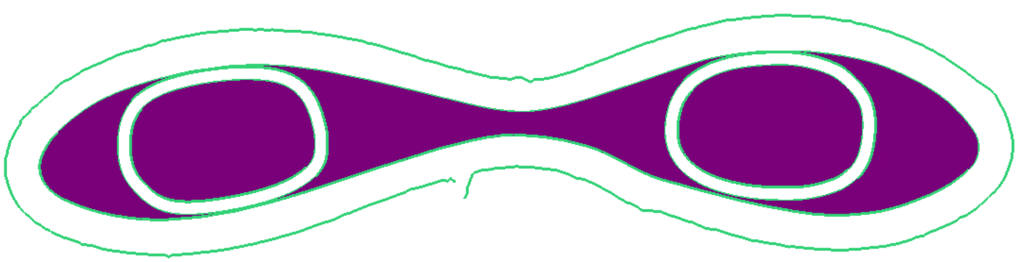

Figure 48: CS6 Flow Area

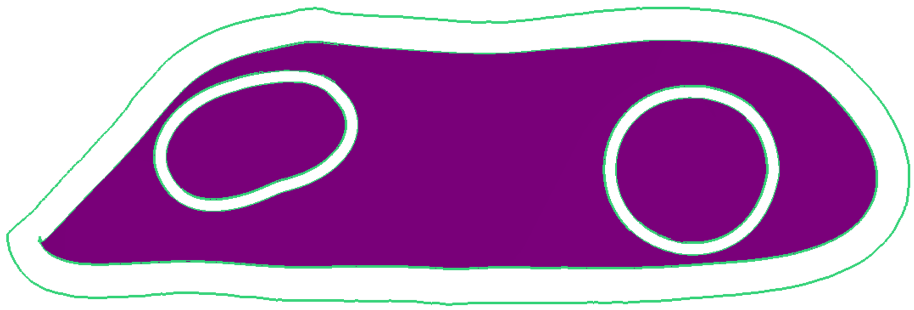

Figure 49: CS7 Flow Area

Appendix D - Cross-sections A to M

The drill string flow area calculation results for the kink cross-sections are provided in the table below.

Table 9: Drill String Flow Areas through Cross-sections A to M

Cross-section	Left Drill String (or tooling joint) Flow Area (in^2)	Right Drill String (or tooling joint) Flow Area (in^2)
A	12.8	47.6
B	11.3	43
C	9.7	36.5
D	7.3	29.2
E	5.3	24.2
F	2.5	20.4
G	1.5	18.82
H	2.8	24.2
H(i)	4.4	9.3
I	5.2	11
J	7.7	13.7
K	11.2	15.5
L	12.7	16.8
M	15.4	17.4

Figures of all kink cross-sections are shown below.

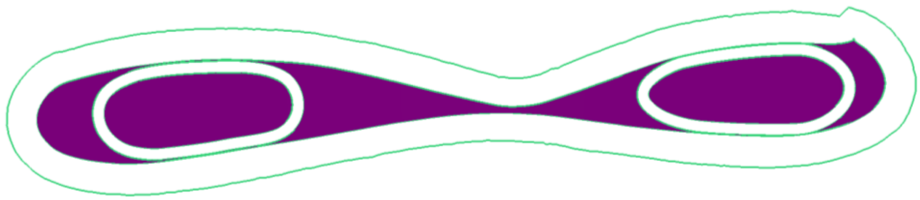

Figure 50: CS A Flow Area

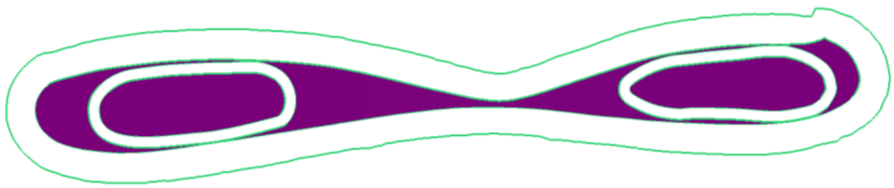

Figure 51: CS B Flow Area

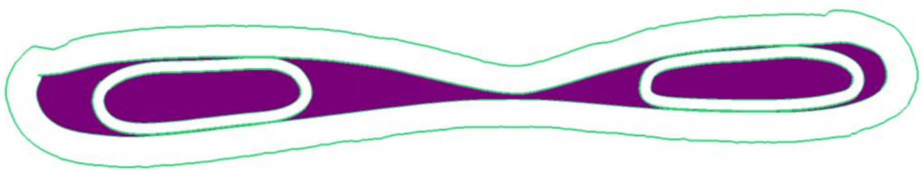

Figure 52: CS C Flow Area

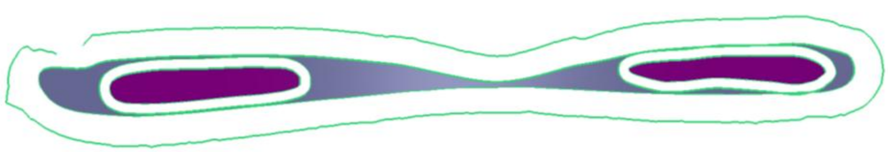

Figure 53: CS D Flow Area

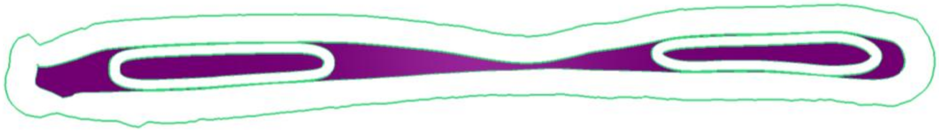

Figure 54: CS E Flow Area

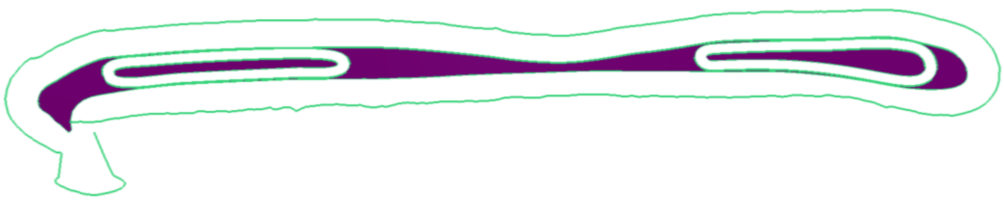

Figure 55: CS F Flow Area

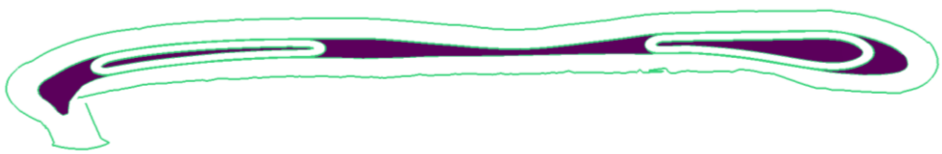

Figure 56: CS G Flow Area

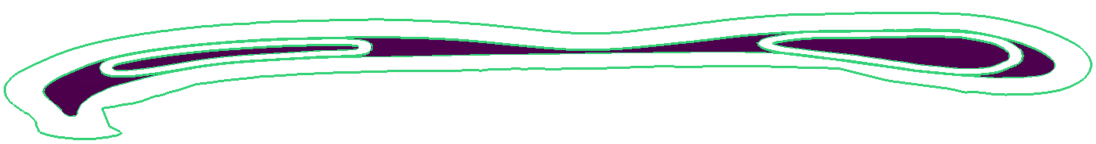

Figure 57: CS H Flow Area

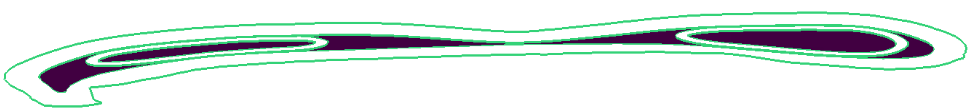

Figure 58: CS H(i) Flow Area

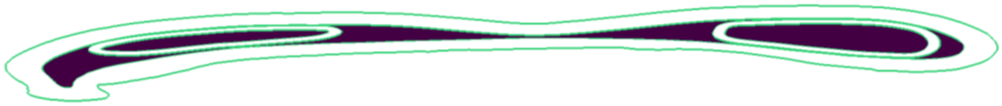

Figure 59: CS I Flow Area

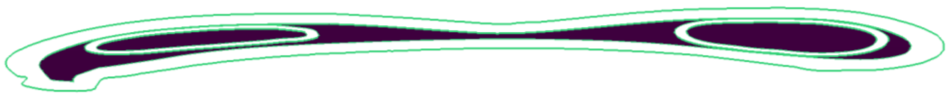

Figure 60: CS J Flow Area

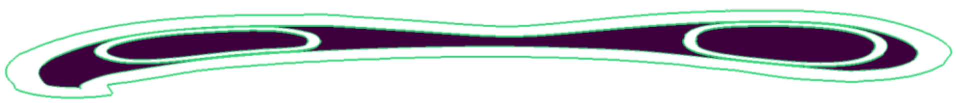

Figure 61: CS K Flow Area

Figure 62: CS L Flow Area

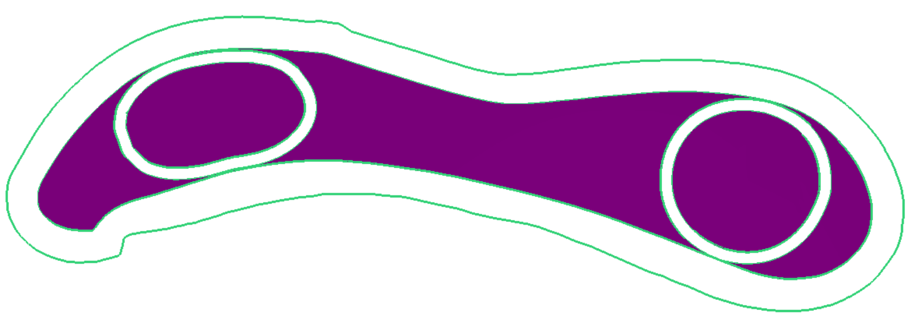

Figure 63: CS M Flow Area