MINIMISING THE EFFECT OF DEEPWATER CURRENTS ON DRILLING RISER OPERATIONS

by

Dr Tim Farrant & Dr Khalid Javed

2H Offshore Engineering Limited

Woking, Surrey, UK

Deepwater Drilling Technologies, Aberdeen Marriot, Aberdeen, January 2001

The operation of deepwater drilling risers is highly dependent on the current loading experienced by the riser through the entire water depth. Riser analysis allows the effects of ocean currents on installation and operability to be assessed and provides guidance for detailed planning of well execution.

A brief review of current profiles with respect to location and oceanographic processes is given. The effect of current profile and strength is discussed with respect to drilling downtime, need to disconnect, drift-off events, installation and hang-off.

INTRODUCTION

Deepwater drilling operations are sensitive to ocean currents due to the length of the riser and the large top tensions required to support the riser string [3]. If severe currents are present, key aspects of riser operation can be severely limited, for example:

- Riser installation may be disrupted;
- Drilling downtime may be incurred;
- Survival envelopes for drift-off events may be reduced;
- Fatigue due to Vortex Induced Vibration (VIV) may become excessive [4];

Deepwater drilling riser analysis provides a means for identifying the critical stages of the drilling program and enables strategies to be developed to combat loss of riser operability. Such strategies may include careful control of riser base tension, precise control of vessel position, modifications to the stack-up order or the use of VIV suppression devices such as strakes.

Deepwater currents have through-depth profiles that are the result of many different oceanographic processes. The importance of particular oceanographic processes varies greatly with location. Understanding the effect of these varied current profiles on riser response provides guidance for the detailed stages of operational planning.

REVIEW OF CURRENT PROFILES

Typical through-depth profiles are discussed with respect to oceanographic processes for some of the main regions of deepwater exploration. Note that the discussion for each location is not exhaustive and does not include all the ocean current phenomena that will occur.

West of Africa - Angola

Currents in the West of Africa are generally small in magnitude, less than 0.3m/s for the vast majority of the time, and are driven by the much larger scale circulations of the South Atlantic Basin such as the South Equatorial Current (travelling East-West as a surface layer) and the Equatorial Undercurrent (travelling West to East underneath). As a consequence, the current offshore Angola has a consistent direction and may be assumed to be co-linear throughout the water depth for the purposes of riser analysis. Even so, more extreme currents can be encountered, for example, close to the discharge of the Congo River if the flow is also accelerated by winds. In such extreme cases current speeds in the surface layer may reach 1m/s. Forecasting such events is often not practical.

Gulf of Mexico

Hurricane events generate inertial currents as they travel across an oceanic body of water. These inertial currents are short lived and decay once the storm has passed. The high current region starts on the surface and propagates down in a spiral through the water depth. The duration of these events is typically 10 days. These currents are never co-linear through the water depth and have typically a maximum velocity of 1m/s.

Loop currents occur in the Gulf of Mexico when eddies are separated from the Gulf Stream (see Figure 1). The profile can be unidirectional and is usually sheared, i.e. high velocities occur at the surface and reduce progressively with depth. Loop currents can last from a few days or up to six weeks. Maximum current velocities can reach up to 2m/s on the surface diminishing in strength with depth.

Offshore Brazil – Campos Basin

Current arises due to large scale ocean circulation. In the first 1000m of water depth the current profile is dominated by the Antarctic Intermediate Water Jet flowing to the North. At water depths beyond 1500m the current is dominated by the North Atlantic Deep Water Jet flowing southward. Both of these jets are relatively low speed and rarely exceed 0.4m/s. Sketches of the current directionality are shown in Figure 2 for flow in the two opposing current layers. In between the two opposing current regimes there is a region where current speeds are reduced. In the 100m closest to the surface much higher current speeds are experienced due to the action of wind. In the extreme, surface currents of 1.5m/s may be observed.

DRILLING DOWNTIME, DISCONNECTION AND DRIFT-OFF SURVIVAL

Drilling Downtime

According to API 16Q [1] and AMJIG [2], drilling downtime is incurred if the mean angles of the upper and lower flex-joints exceed +/-2 degrees. This limit is intended to reduce wear on flex-joint and riser joint bores although, in practice, drilling contractors often strive to work well below these limits. Current loading is the major cause of mean rotation across the flex-joint, assuming the vessel is able to hold station to within a few metres of the well location. Wave loading will cause vessel pitch and heave but this will have little effect on the mean angle of the upper flex-joint because these motions cause an oscillation around the mean deflection. At the riser base in water depths greater than 500m, the lower flex-joint is located so far from the surface that it experiences negligible motions due to wave loading.

As the overall strength of the current profile increases, the riser deflects and the mean flex-joint rotations increase, as illustrated in Figure 3. The range of vessel offsets within which drilling may continue (when the mean angle is less than 2 degrees) is referred to here as the drilling envelope. Often one flex-joint will rotate more than the other, due to non-uniform current profile and riser weight distribution, and it will be necessary to move up or downstream to fully exploit the drilling envelope.

The importance of current directionality on the drilling envelope is illustrated in Figure 4 by the comparison of the flex-joint rotations with vessel offset for a drilling riser operating in a water depth of over 2500m in the Campos Basin. In the first case (upper graph), the riser is subjected to a statistically derived co-linear current profile that does not take into account the two layers of opposing currents predominating at this location. The current profile is sheared and the surface current speed is 0.9m/s. Both the upper and lower flex-joints have considerable mean rotation when the vessel has zero offset, implying that the entire length of the riser experiences significant current loading. The drilling envelope is very restricted in spite of a large 600kips overpull at the lower flex-joint, suggesting that significant downtime may be incurred due to current loading. This restricted drilling envelope might be improved either by selection of very high top tension (if sufficient capacity exists) or installation of more tensioner capacity. The former option is undesirable, because of the risk of equipment failure, and the later latter involves considerable expenditure.

If the drilling envelope is assessed with a more realistic two layer opposing current profile (see lower graph Figure 3), the lower flex-joint is found to have negligible rotation when the vessel is at zero offset. This implies that, even though the surface current velocity is 1.2m/s, the net current loading on the majority of the riser length is negligible. The upper flex-joint, on the other hand, has a large rotation when the vessel has no offset, which arises from the high surface current. Therefore, although the surface currents are high the drilling envelope is considerably larger than that found for the assumption of a co-linear current profile. Such a drilling envelope is likely to be acceptable without any changes to operational practice or riser equipment, emphasising the importance of current directionality for drilling downtime.

Disconnection and Drift-Off Survival

In the event of the DP system capability being exceeded by bad weather or a sudden loss of station keeping ability occurring (e.g. due to vessel black-out), disconnection of the riser must be achieved without exceeding the limits of the tensioning and wellhead systems. In the case of bad weather, disconnection is most likely to be planned and the criteria of the connected non-drilling envelope will apply. In practice this usually means that conductor stresses must remain below 80% of the material yield strength and tensioner and slip-joint stroke ranges must not be exceeded. Alternatively, when drift-off occurs, due to loss of station keeping ability, the emergency disconnection sequence is initiated and survival envelope criteria apply. The survival envelope is determined by the requirements that conductor stresses must remain below the material yield strength and that the tensioner stroke range is not exceeded. See [2] for the definition of these operational envelopes.

The effect of current on the non-drilling and survival envelopes is illustrated graphically in Figure 5 for a drilling riser in 1000m water depth. The current profile in this example is co-linear and sheared. As current strength increases the downstream offset at which the conductor stress exceeds allowable limits reduces, for both the non-drilling and survival envelopes. This is due to the increased bending moment induced in the wellhead system by current loading over the entire length of the riser. In spite of this reduction in allowable downstream vessel offset, the overall size of the non-drilling and survival envelopes does not reduce substantially with current strength. Instead, the vessel is required to be positioned further upstream to retain the same margins from the edges of the non-drilling and survival envelopes.

In an emergency disconnection scenario, sufficient margin of vessel offset must be maintained from the downstream survival envelope to allow activation of the disconnection sequence. As current speed increases, the drift-off velocity of the vessel is also likely to increase and this, combined with the reducing downstream survival limit, results in a possible need to position the vessel further and further upstream. An example of the margin required for disconnection as current speed increases is shown on Figure 5 for two disconnection response times. Also shown is the maximum operating current for the dynamic positioning (DP) system. It is assumed that planned disconnection of the riser will take place when the DP system capability is exceeded.

In greater water depth, the loading induced in the conductor and wellhead increases due to the additional weight and current loading of the longer riser string. This results in a reduction in the size of the non-drilling and survival envelopes when expressed as a percentage of water depth. Figure 6 shows the survival envelope for the riser analysed in Figure 5 extended to a water depth of 2000m. The size of the reduction will depend to some extent on the severity of current profile at lower depths. If there is little current at greater depths, the majority of the reduction in envelope size will be a due of the additional weight of the string, which might be compensated for with additional buoyant joints in the stack-up.

Although the survival envelope may be reduced in size the disconnection envelope may not be affected so significantly because the vessel will have to drift further downstream to achieve the same percentage offset. This is illustrated by the disconnection envelopes indicated in Figure 6, which are based on the assumption that the vessel drifts at the speed of the surface current and disconnection response times are the same as those for the 1000m case. The disconnection envelopes for the 2000m case are only slightly smaller than those for the 1000m water depth when there is high surface current.

The above discussion illustrates the typical effects of extending riser operations to deeper water on survival and non-drilling envelopes. If comprehensive current data is available over the entire water depth it is possible to assess whether there is sufficient margin for emergency disconnection of the riser. In many cases, for example when currents are small at depth, drift-off assessments may demonstrate that drilling in greater water depths need not necessarily require higher capacity equipment, such as the use of heavier duty wellhead and conductor systems.

HANG-OFF AND INSTALLATION

The effect of current on the hang-off response is mainly the drag force acting on the riser along the current direction. This drag is high if the drag diameter of the riser is large. Using buoyancy joints increase the drag diameter. It is therefore necessary to optimise the location and number of buoyancy joints to be used in such a way that the required top tension and an acceptable hang-off response both are achieved simultaneously. The current tends to bring the hanging riser close to the vessel moonpool. One of the aims of the riser analysis and design is to avoid any such riser-vessel interference.

The current profile and the speed will determine the deflection of the hanging riser during a hang-off or installation. The stresses in the hanging riser are dependent on both the current and on the waves. Vessel pitch and surge motions also contribute to the riser's swing in a hanging position.

Envelopes

To assess the riser response during hang-off or installation, the analyses are carried out for a range of waves and currents. The following criteria may be used to define the limiting environmental conditions during hang-off:

- Extreme flex-joint rotations < +/-9° maximum
- Riser stresses < 0.67 yield stress API [1], 0.8 yield stress AMJIG [2]
- Interference with the vessel – none allowed
- Stroke – must not exceed that allowed by the slip joint

Figure 7 shows a few examples of hang-off envelopes in different environmental conditions. These envelopes are, as stated above, not only dependent on the current but also the waves, the riser stack-up configuration, moonpool dimension and the hang-off arrangements.

Similar envelopes or windows can be obtained for the installation scenario. Generally the installation is modelled for the following 3 stages:

- When the BOP-stack is in the wave zone
- When the BOP is at the middle of the water depth
- When the BOP is near the seabed.

The base of the hanging riser when it reaches the wellhead is not vertically below the vessel depending on the current profile and speed. Analysis should be carried out to determine the vessel offset distance so that connection to the wellhead may be done properly. Figure 8 shows a typical relationship between the surface current speed and displacement at the base of the riser.

CONCLUSIONS

Comprehensive current profile data describing all significant oceanographic processes with respect to probability of occurrence and directionality are essential for the reduction of conservatism in drilling riser analysis.

When the riser is connected, drilling downtime is found to be sensitive to directionality of long term deepwater current flows, which are driven by large scale ocean circulation. Improperly evaluated current data may lead to an unduly pessimistic assessment of drilling operations prompting consideration of riser operation with large top tension, tensioning equipment upgrades or even selection of another vessel.

When assessment of the emergency disconnection envelope is carried out careful definition of current profiles ensures that the effects of deepwater do not result in the over-design of wellhead and conductor systems.

In the hang-off or installation mode, the current profile shape determines the shape of the hanging riser. This has the maximum curvature near the vessel end. The current affects;

- the maximum riser deflection in the moonpool and the limiting riser stresses. Severity of the current near the surface can be related to the moonpool deflection and the maximum riser stress.
- the displacement of the base of the riser away from wellhead. The whole current profile including the near bottom current will affect this deflection.

Therefore the riser analysis predicts the environmental conditions (waves and currents) in which the riser installation/hang-off can safely take place. Depending on the current speeds and the other riser design factors, the hang-off or installation can be improved, for example, by making the hanging riser less buoyant. The possibility of allowing the slip joint to stroke may also be considered in order to improve the riser hang-off response.

Deepwater currents can have significant effect on all aspects of riser operation. Analysis of the effect of current on the riser provides guidance for the detailed planning stages of a drilling operation. However, comprehensive current data, properly accounting for the dominant oceanographic phenomena, are an essential component of such an assessment.

REFERENCES

1. American Petroleum Institute (API) – "Recommended Practice for Design, Selection, Operation and Maintenance of MARINE drilling Riser Systems". API-RP-16Q, First Ed., API, Washington, 1993.
2. 2H Offshore Engineering Limited – "Deep Water Drilling Riser Integrity Management Guidelines", Revision 2, project report for AMJIG group, March 2000.
3. Howells, H., Bowman, J. - "Use of New Technologies for Optimum Drilling Riser Configuration in Deep Water". Improved Drilling Efficiency Through Better Management and Application of Technology, ICM Marketing, Marriott Hotel, Aberdeen, June 1997.
4. Howells, H. - "Deep Water Drilling Riser Technology, VIV & Fatigue Management". Drilling Engineering Association (Europe), 4th Quarter Meeting, Paris 1998.

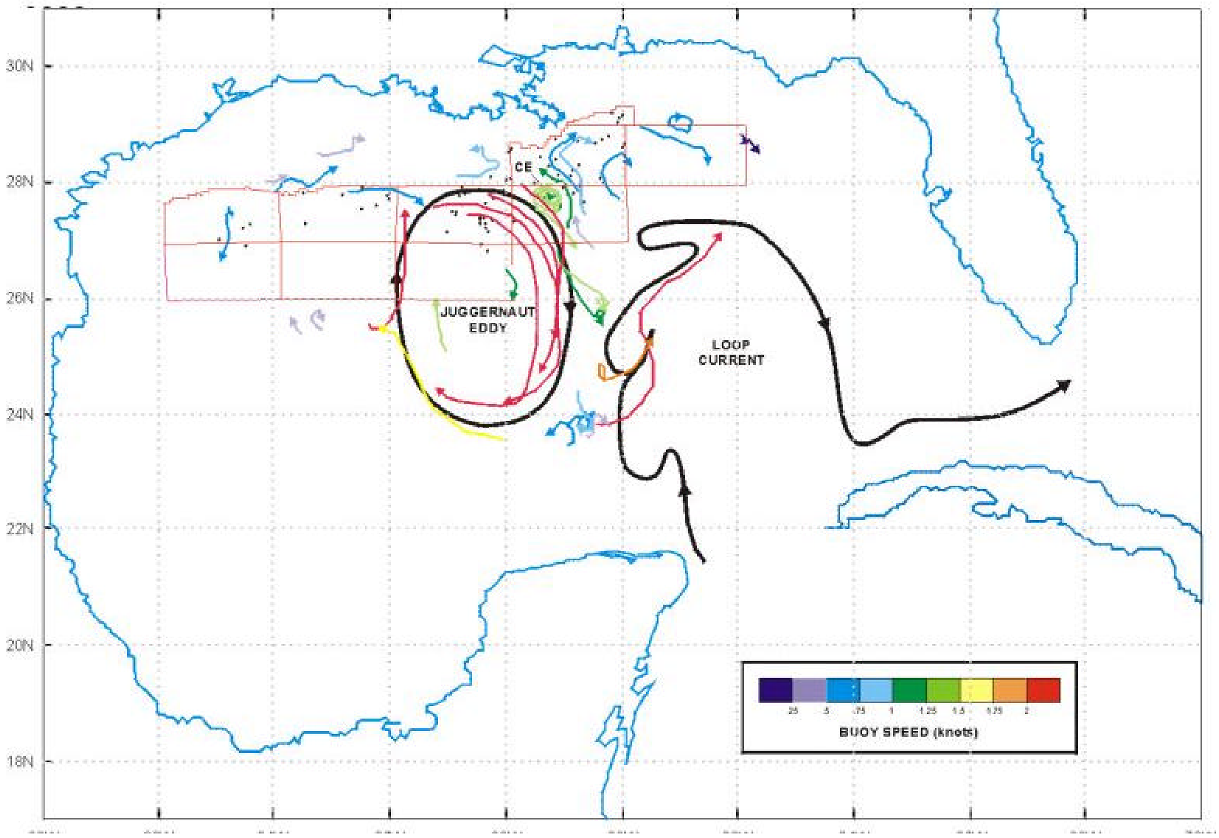


Figure 1 – Loop Current Eddy in the Gulf of Mexico

Source: EDDY WATCH

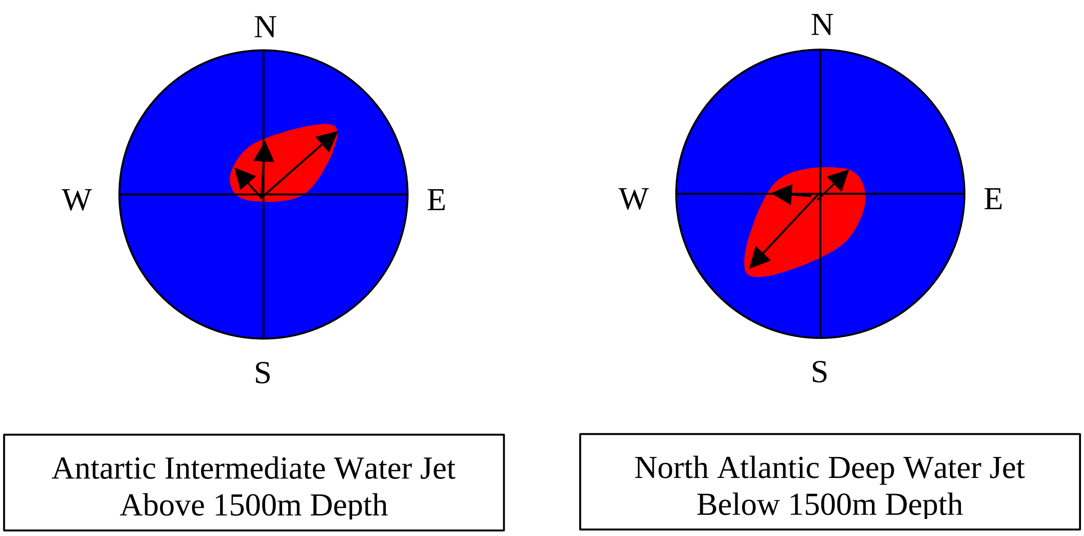


Figure 2 – Directionality of Different Current Layers in the Campos Basin

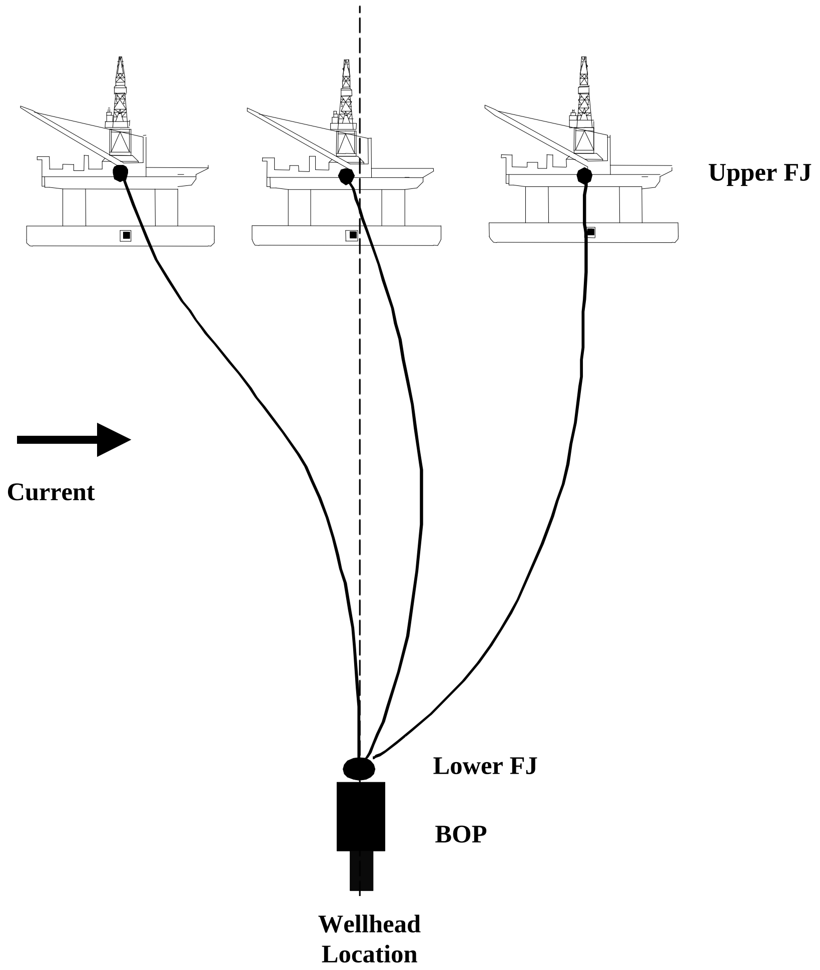
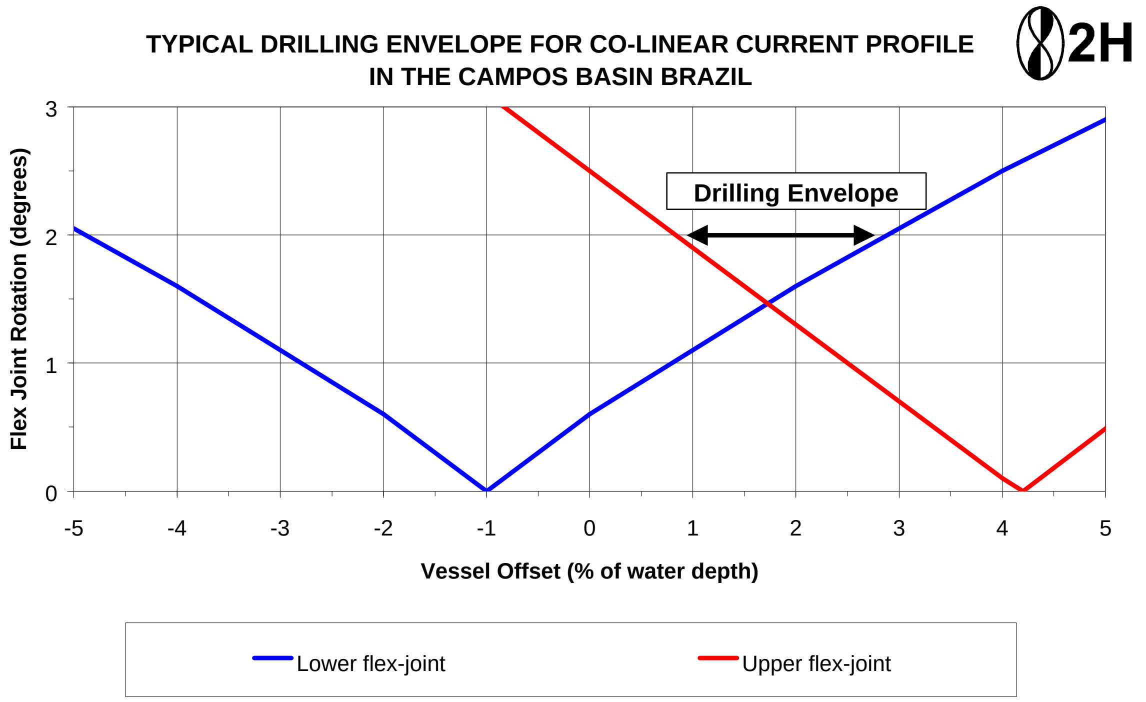


Figure 3 – The Effect of Current on Flex-joint Rotation



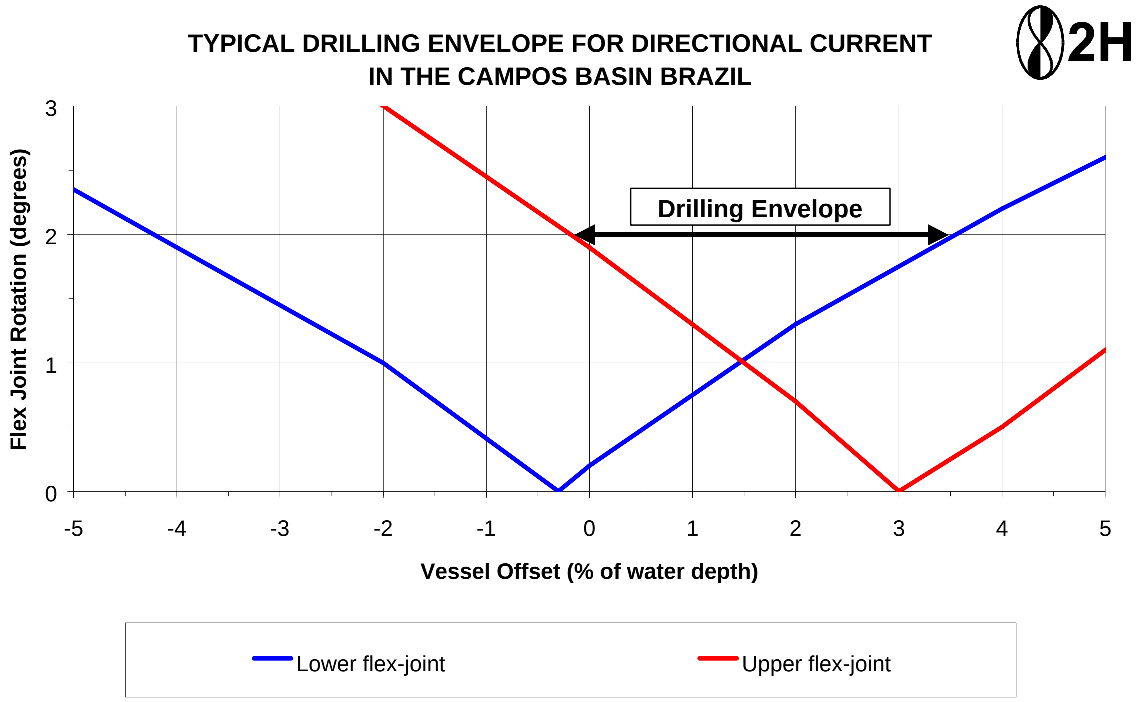


Figure 4 – Comparison of Drilling Envelopes for Co-Linear and Directional Currents in the Campos Basin, Brazil

(+ve vessel offset is downstream)

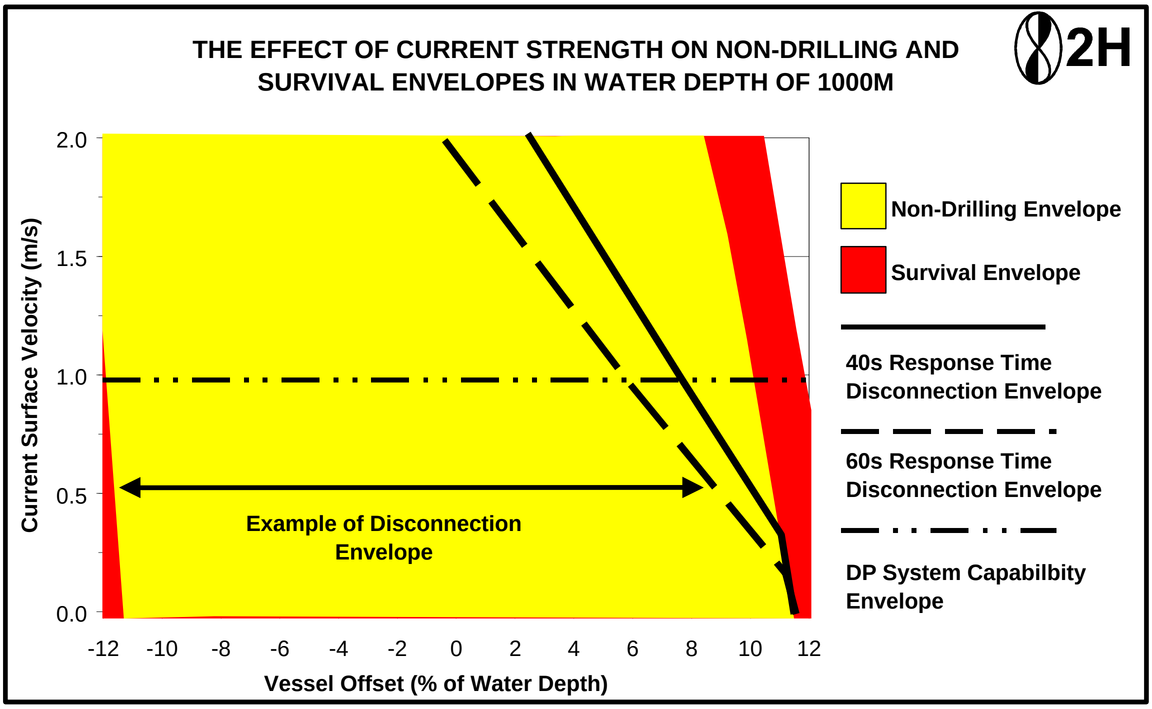


Figure 5 – The Effect of a Sheared Co-linear Current Profile on Riser Disconnection Envelopes in a Water Depth of 1000m

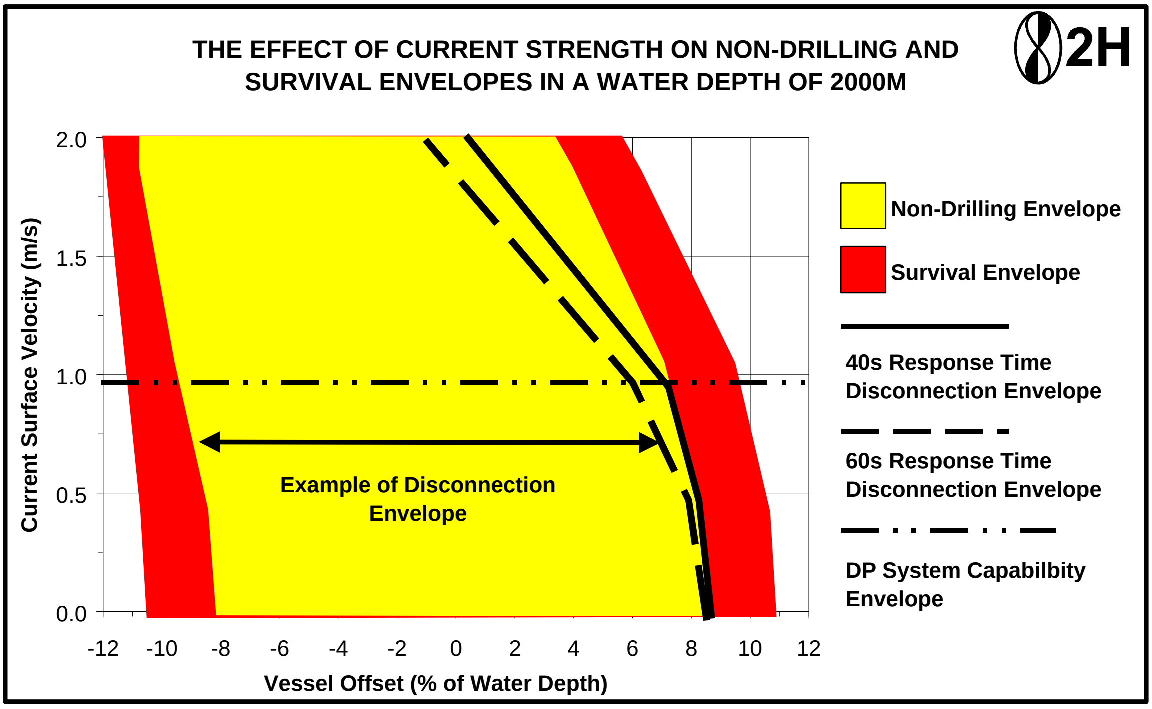


Figure 6 – The Effect of a Sheared Co-Linear Current Profile on Riser Disconnection Envelopes in a Water Depth of 2000m

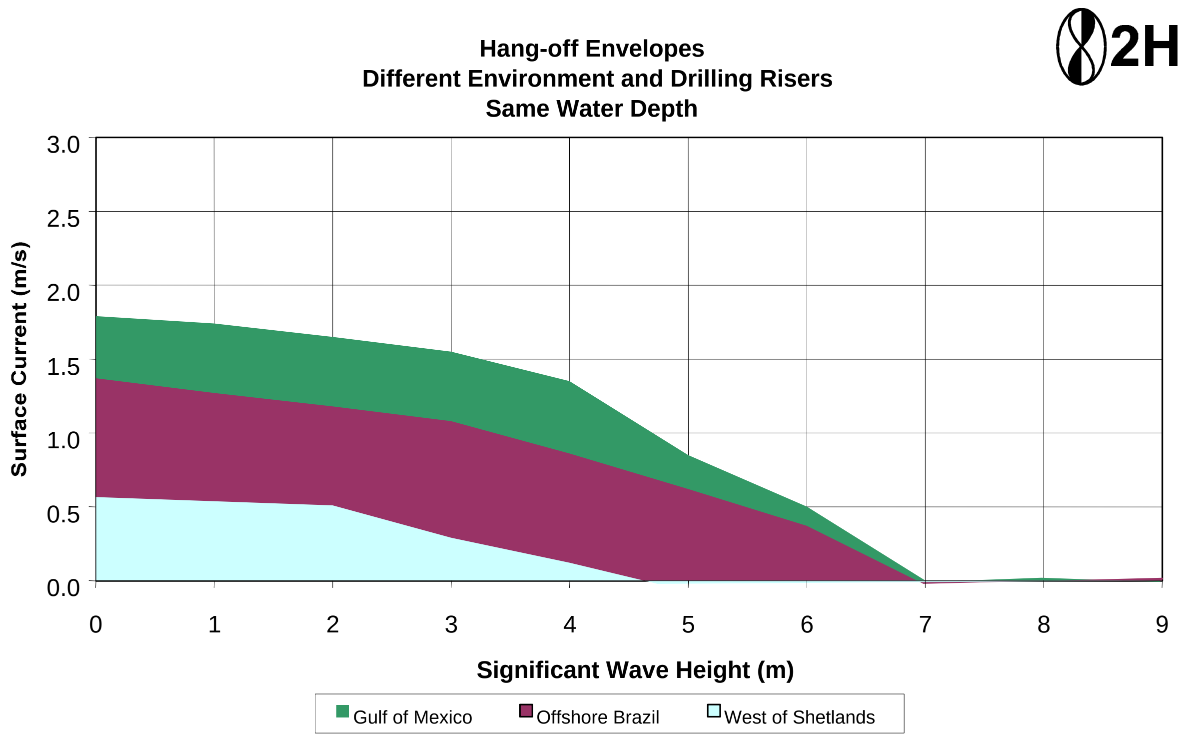


Figure 7 - Hang-off Envelopes

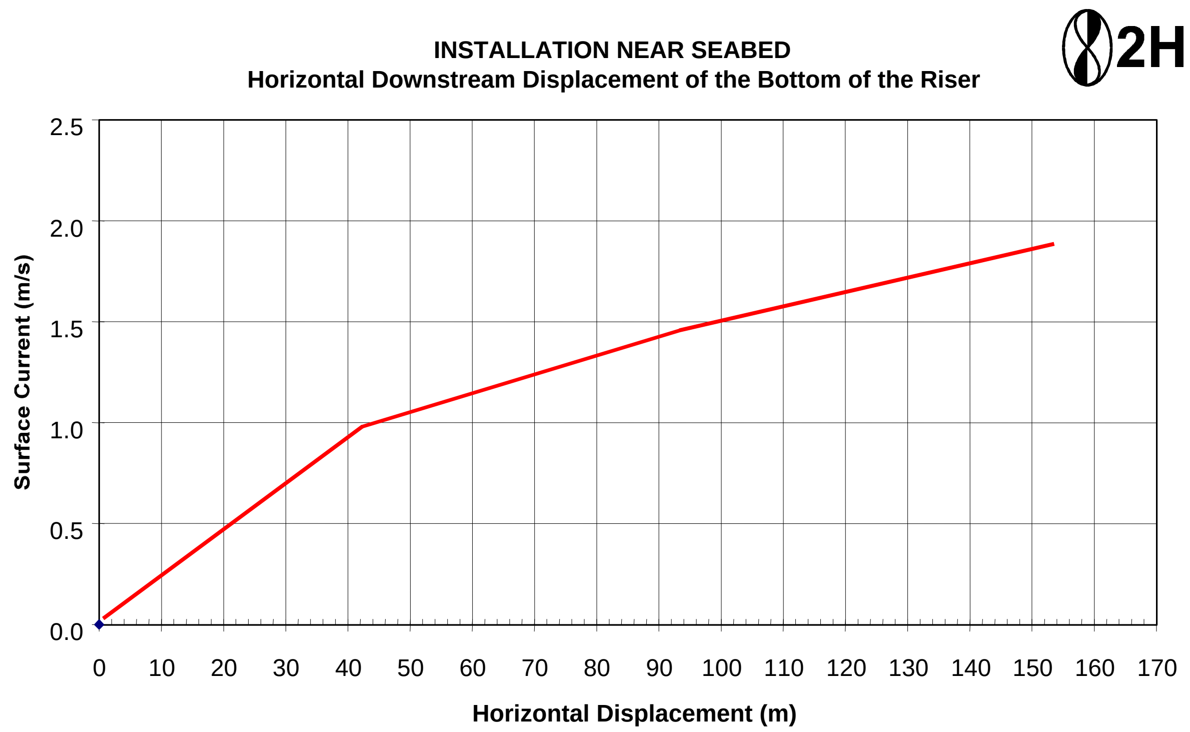


Figure 8 - Displacement Due to Current During Installation