Minutes
of
FPSOs Present and Future Workshop

Session V
Vessel Motion/Stability

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MR. D'SOUZA: Thank you, Skip. Good afternoon, ladies and gentlemen, and welcome to Session V on Vessel Motion and Stability. My name is Richard D'Souza. I'm with Brown & Root Energy Services. I'm a veteran of 26 years in this industry and I'm proud to say that I've survived about five boom and bust cycles.

In the Gulf of Mexico, a ship-shaped FPSO will either be permanently or disconnectedly turret moored in order to align itself to the prevailing environment for the simple reason that ship-shaped configurations are not designed to be operable in deep seas. If permanently moored, it must survive hurricane events. If it is disconnectedly moored, it must remain connected and operable in extreme winter events.

FPSOs ability to weathervane into the prevailing seas to constrain unstable lateral or fishtailing motions and to sustain extreme metocean conditions are critical to their survival and operability. Additionally, the responses of the FPSO directly impact the design of two key system elements. Those are the risers and the moorings.

This weathervaning capability and generally larger responses in waves are what differentiate the ship-shaped FPSO configuration from other floating OCS facilities that have been approved by the coastal authorities to date, and those are the TLP, the spar and the semi. The reliability and safety of the FPSO system is directly linked to the degree of confidence that we have in predicting its weathervaning capability and its motions.

In this session we will address the current state of the practice of predicting weathervaning and motion response, the level of confidence in these predictive tools, the validation based on model test and field experience, and areas for improvement in these predictive capabilities and, therefore, the system reliability.

I will predicate this by reminding the audience that ship-shaped (inaudible) FPSOs and FSOs have been operating successfully for over 30 years worldwide and many in regions with significantly more hostile environments than the Gulf of Mexico. Industry has and continues to expend significant effort in improving our predictive capabilities and validation of these tools. So being a naval architect by background, I thought that this excerpt that you see on the screen of "A Seafarer's Poem" eloquently captured the issues we're about to address in this session.

The two major issues that we're going to be discussing are, one, the weathervaning and directional stability, and you have an entire spectrum of weathervaning capabilities available to the industry. One is the passive weathervaning where it's simply turret moored and there are no external effects, such as thrusters, to assist in the weathervaning. The second is to include heading controls of some form to enable better alignment with the seas. Progressively, you have thruster-assisted mooring, and at the other extreme of the spectrum we have dynamic positioning. In going from passive to dynamic positioning, we have increasing capability to align with the seas but also have increasing operational and mechanical complexities.

So some of the issues that I thought about which I thought were of some significance for this session were -- and I think very fundamentally it's the computation of environmental loads. Without the ability to accurately predict the forces and moments introduced by the wind, waves and currents, you're not really going to be able to design or be able to predict the weathervaning capabilities. In addition, if they're thruster-assisted then the thruster mooring and thruster interaction issues become of extreme importance.

Furthermore, when you're turret moored in very deep waters where the stiffness of the mooring system is relatively soft, one can undergo fairly large dynamic instabilities in the horizontal plane, so the computation of small and large amplitude coupled with the sway, roll and yaw response in steady and time-varying noncolinear environments is paramount. And finally, as always, to increase our level of confidence in the weathervaning capabilities we have to be able to validate by modeling testing.

On the global performance front, we start off with being able to prescribe certain design constraints for the global performance parameters of interest. That is a function of the operators. They have to decide what is important and what those limits are. To some extent they could be prescribed by the coastal authorities or by the class societies.

The prediction of and the design for short- and long-term extreme global performance response is really the crux of getting the confidence that we need for operability and survivability.

Perhaps the most vexing and also one of the more important parameters is the prediction of roll amplitude, and this is vexing because it is so highly nonlinear (inaudible) even in a weathervaning FPSO or one that is largely aligned with the predominant environment, you will get some obliquity with the waves and as a result you will experience very large amplitude roll motions which can degrade operability and in the extreme affect survivability.

Another important extreme response in extreme seas is slamming. As we know, these can be induced in heavy seas and can result in, as a result of concentrated dynamic pressures, damage to the hull either at the bow or at the stern. Such incidents have been recorded, resulting in stoppage of production, so it has become a fairly significant issue of late, particularly in hostile environments.

Green water is critical because an avoidance of green water is important. Green water overtopping at the bow, sometimes over the side, can result in stoving in of deck structures, and avoidance of green water, and the prediction of it, of course, becomes of significance.

Predicting maximum offsets is important for the design of the mooring system and the risers. Prediction of maximum mooring line tension is something that the industry has devoted a lot of time and attention to and is critical to the design of a key structural component, which is the (inaudible) system.

Predicting maximum heave also affects risers and moorings, those two key elements that I referred to earlier, and the emergence of the thrusters in extreme seas, which is the converse, perhaps, of green water when it comes to thrusters used to dynamically position vessels, it's important that those thrusters now emerge.

In addition, we will be discussing in these sessions, the panel sessions, sloshing, global bending and fatigue, which are also weight induced, and motion and loading on the hull.

And finally, in addition to being able to predict these extreme responses, we have to be able to find ways to mitigate these responses when they exceed design constraints, so all of these are open issues that will be discussed in these sessions.

I took some time to try to capture in a broad sense what some of these global performance issues are in the form of questions. They're more questions to the industry. And I asked the following questions -- this is to ourselves as a group: Have we adequately captured lessons learned to apply to future designs? We do a good job in forums such as these. We discuss them, in some cases we do a good job of recording them, but do we do a good enough job of disseminating this information and making sure that subsequent designs benefit from the lessons learned from previous experience.

And another question is: Do we have enough previous experience? I think we could point to the many FPSOs and FSOs that have been out there, but the fact is that FPSO experience in the North Sea, in hurricanes and typhoons, while you could argue is extensive, could also be argued as not being statistically large enough, perhaps, to develop the level of competence we need to say that we fully understand what's going on in these environments.

This is one for the oceanographers: Without understanding the drivers or being able to characterize the drivers -- which is the environmental conditions, wind, wave and currents, the amount of linearity, the intensities, it's very difficult to be able to accurately even begin to predict the responses, so it's important that we get a firm grip and a firm understanding of metocean conditions at a particular site.

And, of course, the eternal question: Are we satisfied with the current state of predictive analytical and scale model capabilities, and these will be addressed by the panel members as we go through.

Another one, to me, which is quite important because of the extreme unfamiliarity with the response of FPSOs and the warning systems and the risers, the question always is are we satisfied with the current state of practice in predicting extreme response, both short- and long-term?

This one is new to me. Hull form definition is one that I believe has not been given enough attention. Again, as a naval architect, I feel that naval architects are trained to design hull forms for seakeeping for performance in waves. I don't believe this industry uses that knowledge sufficiently. Now you probably can argue with me otherwise, but I do believe to a large extent we can improve the global performance, optimize the efficiency in waves by paying proper attention to the design of the hull form. It's a science that naval architects are intimately familiar with.

So having said that, I'd like to invite the panelists to offer their views. And we have Adrian MacMillan with DNV as our first panelist, followed by Tim Finnigan from Chevron and Marty Krafft of FMC Energy Systems, and I have to say that Adrian and Tim are present at very short notice and we're very grateful that they volunteered to be panelists. So without further ado, I'd like to have Adrian come and discuss his issues.

MR. McMILLAN: Good afternoon, everyone. I hope you're wide awake after your heavy lunch. You've probably got good strong coffee in your belly to keep you awake during this sometimes dry presentation.

This afternoon we're going to talk about some of the technology opportunities which are available for FPSO analysis, and this afternoon I was intending to cover personally the fatigue, sloshing and loading operational aspects which should be considered in an FPSO design.

Schematically there I've just got some representations of the wave load analysis and pressure distributions and resulting stresses on the hull, and as we get into complex hull forms you can quite obviously see, as Richard was saying, that you need to treat these vessels as a shape-shaped structure in terms of the naval architecture requirements.

Obviously the bow region needs to be shaped like a ship. This is in a harsh environment. In a benign environment it's not so critical, but in an area where you are going to be subjected to a lot of seas, you need to consider all of these from the strength perspective, from an operational perspective and from the fatigue perspective.

So in terms of fatigue, where are the areas of concern? The problem we have here in our diagram is a web frame and adjacent to that it has a bulkhead. So with an FPSO, as you do with a tanker, you have a large number of longitudinal connection details (inaudible) and these include brackets and lugs, so there's a lot of connections which need to be checked for fatigue, checked for strength, and also inspected throughout the life of the vessel, and it's not generally possible to inspect all of these connection details throughout the life of the vessel and we're looking at possibly keeping the vessel on station and not putting it into a dry-dock, as you do with a traditional tanker, for up to 20 years and possibly even longer, so it's important that we look at these fatigue issues in a great amount of detail.

In addition, since we've seen from the Coast Guard the last couple of days that they are requiring double skin in terms of double bottom and double sides, that again increases the number of connection details that need to be analyzed and inspected. And, in addition, you will have hopper knuckles. The kinds of frame gussets may not necessarily be such a huge detail except as an indication of the web frame for the inner side. And these are probably mainly typical tanker type details.

However, for an FPSO you also have riser porches, you'll have topside stool connections, you may have multiple deck penetrations, you have possibly bilge keels, which fall under the category of a tanker connection detail. However, there may be some other issues you need to consider specific for the FPSO.

You have erection butts, again a typical tanker detail, but again these items can be difficult to inspect and should be analyzed in terms of fatigue. You may have numerous couplers on the main support structures. On your deck you have probably moonpools and turrets, you have flare towers, crane pedestals and helidecks, so it's vital. There are a lot of potential fatigue sites on your FPSO, so it's critical for you to be able to understand the fatigue performance of your design in order to be able to ensure that you can operate that throughout its life effectively and efficiently because the cost for repairing some of these details can be quite prohibitive because it includes -- if you have a damage in the bottom of a tubal you may need to get through the adjacent tanks, you need to get repair people onsite, you need to stop operations in those regions. It can be very expensive, but not impossible.

So in order to be able to investigate the fatigue factors, you need to consider the loading, and one important issue to consider with fatigue is that -- and Richard brought up this -- it's imperative that the oceanographers get decent and workable data for the strength analysis and fatigue analysis of these FPSO structures because a 10 percent uncertainty in your loading could mean a 30 percent uncertainty in your fatigue life, and it has a very nonlinear effect, a cubic function effect, depending on the SN curve that you're looking at, and that particle of uncertainty can make or break a detail. So we really need to make sure that we understand all the necessary loading configurations and loading issues.

So here I've listed some of the loading issues that are important. Naturally, the hull girder loads, longitudinal bending, transverse bending, et cetera, axial ports, are critical and used in the design of the FPSO from a strength perspective.

You have external pressures -- the wave elevation on the side. You have internal pressures because hopefully you have cargo in your tanks, otherwise you're not making any money. You have differential pressures from the cargo to the ballast tanks, so that will induce -- some local deformations of the structure will induce further stresses.

Those kind of loads, if you look at, say, a typical longitudinal stiffener on a side shell, that stiffener will bend due to that level of pressure. It will get an axial stress due to the global moments and forces and if we take that picture and bear in mind what I said before with the frame and the bulkhead adjacent to each other, you will also get stresses induced in that stiffening connection detail where the frame is less stiff than the transverse bulkhead so that the external pressures will force that frame to deflect more from the bulkhead. And that induces another stress which needs to be considered in terms of fatigue, and that's typically the largest contribution to fatigue damage for a broken connection at a bulkhead, and I think through experience people have found that fatigue cracks around the bulkhead region have been worse.

In addition, most of the hydrodynamic analysis that's completed these days is in linear frequency domain, (inaudible) a certain watermark and it will give you a dynamic pressure distribution corresponding to that; however, you do need to take into consideration that the wave elevation will fluctuate above and below that mean waterline. So say the wave will go from here down to here, so that induces -- that modifies your dynamic pressure that you may get from your (inaudible), and that needs to be considered when you're doing a fatigue calculation and it's quite important since in these areas the fatigue damage for the sides and internal gusset plate are more prone to fatigue damage at that waterline region.

In addition, you also need to take into consideration the double bottom/double side stresses that are induced due to the alternative load configuration. You also have the topside loads, and although they're dominated probably by a static component, however the topsides will need to be supported by the structure, such as deck web frames and frames longitudinal and transverse.

Again we can reduce these relative deflection stresses for a topside module in that the fame will deflect further than the passive bulkhead or the longitudinal bulkhead adjacent to it with an (inaudible) and those stresses need to be taken into consideration and not just the inertial dynamic stress components.

Mooring forces and riser loads, that's a complex issue in itself. You need to include the masses of the mooring and the risers in the hydrodynamic analysis of the FPSO itself. The influence on the motions of the FPSO hull is not greatly influenced by the moorings and risers; however, as Richard pointed out, the influence of the FPSO hull on the moorings and risers is another matter itself, and decoupling these can be a problem, and that will be covered in Marty's presentation later.

In addition, you also have the vessel motion due to the inertial loads that can be the heavy equipment, such as cranes, flare towers.

And another issue is that a lot of our experience with fatigue has been from the tanker background and a tanker operates either in a ballast condition or in a fully-loaded condition, so essentially it will have a fully-loaded draft and a ballast draft. However, an FPSO is constantly loading and unloading, so it's important to make sure that you have a sufficient number of intermediate drafts considered in your fatigue analysis, particularly for the side longitudinal positions where the dynamic pressures due to the relative wave elevation are critical. I'll have this in a bit more detail.

The sloshing effects, if they are a problem for the vessel design they should be considered in fatigue for certain types of environments only, but that needs to be evaluated on a case-by-case basis, and also the proportion of time in each loading condition, whether it's 33 percent fully loaded, 33 percent intermediate and 33 per ballast or if you have different proportions there. Those all need to be taken into account.

In addition, you have to look at your stress concentration factors. They have a high influence. You have geometric stress concentration factors due to weld geometry, gross geometry, eccentricity, and that comes into your fabrication tolerances.

Other fatigue issues are, of course, the SN curves, fabrication tolerances for corrosion protection is a big issue, mean stress effects. There is a lot of discussion in the industry on how to solve this and a lot of these are actually being reviewed, in character at least. The aim of these JIPs are to achieve uniform industry requirements, and that's with regard to designers' limits and the operators and class societies. Two of them are loading capacity and the fatigue for the FPSOs. As an example of that same thing, we recently did work for a major oil operator covering these issues to try and make it one concise document for fatigue analysis.

Sloshing: We have various filling heights in an FPSO which you don't have in a tanker. Class rules allow some sort of estimation of their sloshing loads but generally those rule requirements are based on empirical formulas and need to be investigated further for certain types of configurations. We've done a number of tests to ensure that the class rules are the same group, but there are always limitations in empirical formulas. It can be studied more accurately with hydrodynamic analysis, or alternatively, mitigated by the introduction of more efficient and effective slosh problems.

The last issue I wanted to discuss here is the loading operation issue. Because of the loading issues, an FPSO, because it goes under a number of different loading configurations off-loading and on-loading, can have large still water bending moments and shear forces which are important for a traditional tanker because that normal tanker may not be designed for that configuration. So if you're going to look at a conversion you need to consider these effects. And when you're onsite, you need to look at the dynamic plus the static loads, whereas the tanker is just looked at in terms of the maximum still water bending moments that may be induced alongside, so you have different allowable stresses.

And I'm sure that none of us really want to try and have a deck look like this at any point in time. It's hard for the crew to operate on a sloping deck like this. These can be large stresses or buckling, and we also have -- you know, this is induced by multiple loading configurations which implies heavy reliance on the loading computer and the master's competence. So we can either design this issue out so that the master doesn't need to worry about that as much or make sure that he's extremely competent since we don't want to end up with these situations.

And that should summarize what I had in mind, anyway.

MR. FINNIGAN: Give me a moment to get my slides up here. Can you all hear me okay?

AUDIENCE: Yes. Fine.

MR. FINNIGAN: As Richard pointed out, I'm Tim Finnigan. I work with Chevron Petroleum Technology Company Floating Systems and Anchor Riser Warning Systems. I've been working for Chevron for 20 years, which makes me kind of a novelty, I guess, in the industry, to stay with one company for that duration nowadays.

I was asked just Monday to serve on this panel and raise the issue of technology gaps for vessel motion and stability of FPSOs. So in preparation, I spoke with some FPSO contractors, I reviewed our internal R&D budget in this particular area, and then after hearing yesterday that MMS is depending in part upon this workshop to decide whether FPSOs will be permitted in the Gulf, I've come to the conclusion that there are no gaps.

(Laughter.)

MR. FINNIGAN: Obviously, as they tell us in the technology companies, there are only opportunities, so I use the term opportunities in addressing the technical challenges and issues for various systems and subsystems in our offshore facilities.

You've heard in the last day and a half that the industry has designed and built over 70 FPSOs worldwide, which I believe is testimony to the fact the industry does have the tools and experience necessary to build and design FPSOs in a variety of environments and water depths.

Nevertheless, we also acknowledge that there are some technical issues that you heard from Adrian that warrant further attention, especially as we continue our venture into deeper waters and more harsh environments, and in particular, in response to the demand that we're all hearing from our various owners and operators for faster cycle time from discovery to first oil. So we find ourselves needing to strike a delicate balance between optimization of design and safety in design.

I was asked, and Adrian, in the course of our presentations to raise some issues and encourage debate and discussion. So with that in mind, I encourage you at the end of our presentation to step forth and ask questions, and further recognizing the experience in the audience, I'd ask if the audience has the background expertise, to respond to those questions themselves. So don't be shy when the time comes.

Adrian has focused on primarily the structural aspects and I will try to focus on some of the hydrodynamics aspects of FPSO analysis in the design of my talk, beginning with metocean criteria, which we have heard throughout the workshop to be a major theme for the design of FPSOs as well as other floaters.

I will then continue on with some hydrodynamic loading issues, since we all know that all offshore design problems start with the proper establishment of the hydrodynamic loads and we just simply pass those on to our structural people for the design. So I plan in touching upon the problem of hydrodynamic issues to address some of the validation issues on hydrodynamic models since we all know that in order to keep hydrodynamicists employed we have to do model tests supported by field data to help identify new hydrodynamic problems which require new numerical models which then require more model tests and more field data and we keep our longevity going that way. So we'll do our best to keep coming up with the problems so they can look at them, all in the interest of understanding the loading that goes into a system so we can better optimize our design and reduce our safety factors eventually.

Then I'll throw in a few thoughts on what I think is required to help us meet these technical challenges, or opportunities as we're calling it.

Getting on into Metocean criteria, FPSOs are probably more sensitive to a proper combination of environmental loads than any other structure. Under light ship conditions, winds are going to dominate the behavior of the FPSO and in hurricanes we have a lot of turbulent intensity to deal with. Under loaded conditions, the currents could control, which is the opposite, at least, of an FPSO, and in many cases the wave-induced responses are going to govern the subsystem design. It will affect your exploratory motions, ship roll and heave, which all in turn will affect your subsystem design -- your risers, process equipment and moorings -- so proper accounting for the joint statistics is important.

Also, as was pointed out earlier, the oceanographers not only need to help us with our wave criteria but help us to understand the current environments that we're going to be exposed to. We're all aware of the loop and eddy currents in the Gulf of Mexico. There are some other cold core currents hanging around there that may come back and bite you in the design. In West Africa we've experienced very high velocity surface jets. It doesn't affect our risers that much or our deep draft issues, but their velocities are quite high in the upper five meters or so, so we have to consider that in our FPSOs.

There are other interesting behaviors in the presence of high currents that could affect the steepness of your waves, and steepness, as you know, that affects green water issues and wave slamming and wave impact issues. And, finally, we have directionality and directional spreading that not only need to be considered but we sometimes can take advantage of them in our design.

While I'm on the topic of metocean criteria, I should point out that there is growing database of environmental data that's available for all offshore design, FPSOs as well. You will hear Casper, I think, later talk to you about the GUMSHO database, we have the CASE Eddy Model that's been developed by industry, the Satellite data, and infrared data that is available on-line so you can get real-time evaluations as well as collect those and get historical data for weather conditions, and numerical hindcast models are continuing to be developed, as well as forecast models. In fact, there's a project that is ongoing right now, touched upon briefly by Peter Mills yesterday, where we're looking at forecasting the behavior and response of FPSOs in the North Sea.

Twenty years ago we were satisfied with a specification of a hundred-year return period wave for the design of fixed offshore structures and a tremendous amount of research was done to characterize what that wave was and what it looked like. The hundred-year wave does have some meaning for floating systems but I don't think it's as significant as understanding how each subsystem may be governed by criteria that is not found in that particular hundred-year wave, and I don't know if either Marty or Casper touch upon that.

For example, mooring systems may be governed by the hundred-year loop current, the risers by the hundred-year maximum pitch and heave of the vessel and hull loads by a hundred-year steep or hundred-crest of a wave. Anyway, several methods have been examined in the past, including response-based criteria, spectral response surface methods, to help us to establish new design criteria.

Use of response-based criteria and other instruments will lead to optimized design criteria and help minimize the design loads while at the same time identifying responses which may be adversely affected by environmental combinations that may not have otherwise been identified.

And speaking on directionality and spreading, the picture on the left is actually taken from some fixed jacket model testing done some time ago. Directionality included in the design has been shown to lead to reduced fatigue loading for jacket structures and jacket members, but also for risers and floating systems you can take advantage of directionality of the waves, looking at how the environments can come from various directions in your total fatigue estimates, and spreading itself can be used to help reduce the extreme and fatigue load calculation.

However, it's not always clear that spreading is going to cause reduced loads so we need to have models in our hand to be able to address these highly nonlinear and irregular events in the design of our systems and these sometimes have to be supplemented by model tests and field experience. This is a point I'll touch upon briefly in a little bit.

We heard Adrian speak a little bit ago about the impact and importance of understanding the varying weather surface on the hull of an FPSO for estimating your hull strength. Our tools to date have been focused on linear hydrodynamic models. There have been significant advances in the past in hydrodynamic modeling that should help assist in the design of FPSOs and other floaters. WAMIT is a first-order program that does have some second-order features that go with it, but there's a tool that should be out very shortly out of MIT called Fast WAMIT where they've accelerated the power output so you can solve problems on the orders of many thousands of elements on your laptop P.C. in a matter of a couple of hours instead of days on a Cray. With that same acceleration now they're doing precorrected FFT, you can see forward into certain of the other nonlinear kind of naming codes that are available or being developed. They're not available as a tool yet today that you can go out and buy them necessarily, but certain contractors who specialize in hydrodynamic analysis have those tools. SWAN, AEGIR, LAMP in particular are tools that look at solutions for diffractions, provide frac analysis, and I think some of us are aware of the numerical wave tanks that universities such as MIT and OTRC have been developing to help look at the nonlinear problems.

And CFD tools, because of the increased power of computers and P.C.s, are popping up everywhere to address the nonlinear loads. However, you must be knowledgeable and cautious in looking at CFD tools. There are lots of tools out there, also referred to as colorized fluid dynamics, so they are powerful but we have to recognize the limitations under which they were designed and developed.

We heard green water impact discussed as a theme throughout this workshop so I don't think I'll go over the definition of green water again. I will point out that green water has become a topic of considerable interest because of recent accidents and incidents in the North Sea, and the HSE and NPD in particular have stressed and encouraged the development of yet another JIP that's referred to as Safe Flow which will focus on, in effect, the design issues for FPSOs and the loads that are incurred through green water.

About a year ago the Green Lab tool was completed, an empirical model to look at green water effects on FPSOs and in auxiliary structures on the FPSOs that, as we heard yesterday from

Peter Mills again, is being used now to assess all the floaters in the North Sea. And in an environment such as the Gulf of Mexico where you often have waves, maybe not as large as the North Sea, but still waves that could impose green water effects, you will need to consider the use of these green water tools in your design.

This shows a couple of case examples. It doesn't show very well in the picture, but this is actually a trading tanker that had suffered buckling. The bow buckled from a combination of green water, excessive load of the green water on the bow, as well as the slamming effect, so it's attesting only to the fact that green water and slamming are serious considerations to look into for the whole structure design.

There's a set of pictures that I stole from our operators in the North Sea, looking at what green water can do to an FSU. This is the Alba FSU, the pipe support damage, in this particular case the damaged control box and steps that are dislodged, none of these posing a safety hazard to the crew on board the ship, but it disrupted the production enough so that you have lost time, down time, to affect your bottom line economics for your field. So more cases, examples, that show you need to consider and assess the effect of green water.

I think I heard that someone will be coming with, I believe, a couple more in more detail. I'm just touching upon some of the issues.

There are a number of coupled analysis issues. DeepStar in particular has been involved in a beam structure study addressing the behavior of FPSOs, spars, TLPs, to use a couple of analysis tools. That result is just now wrapping up and there should be some follow-up studies in a wave basin to address the effect of coupling.

There are second and higher order diffraction effects that you can include in coupled analysis tools. Line and riser dynamics and damping have shown to be important for some systems. There are subissues that some folks in the industry are looking at. Some people argue whether risers can be used as moorings. The couple analysis is going to be required to adequately address that problem. Loads into the turrets are going to be affected by proper consideration of coupled decks and on down the line.

There are a number of tools, again, in the industry that have become available recently to do couple analysis. The DeepStar project by -- I think there are somewhere between 11 and 13 contractors that stepped forward to provide analysis, so it's another testament to the fact that the tools are out there and they're available to us in our projects and we need to take advantage of them when building our systems in the Gulf of Mexico in particular.

An issue on model testing comes up. Even though we have better tools today, we still want to go to model basins to validate those tools, and preferably we have field data, but there's always limitations in tools, limitations in model data and limitations in field data. In model testing we've experienced these relating to turbulence in the basin, especially for structures that are sensitive to motion. Model testing, however, can help us get some indication of the effects of directional seas and on the behavior of, possibly, wind shifts, if not in our basin still something we have to consider in our designing for the Gulf of Mexico.

We do have problems in mock basins today with the water depth limitations. I believe the deepest, let's say a 180 or so scale, can go to a 3,000-foot prototype model depth and a lot of our systems we're looking at are 6 to 8,000 feet. So if we are concerned about the effect of risers and mooring on a system, then we are going to need to come up with some creative solutions and also some modeling systems to address deep water systems, and I understand that is being pursued by some of our major basin contractors at this time.

And, finally, I'd like to close my talk with some statements on meeting these technical challenges or opportunities. I hope I've given you a flavor of the technical issues that we are facing in deep water FPSO and given you food for thought, and I've identified that the industry is working on the analysis side to meet those challenges. Continued research and development in the area of FPSO development is going to require cooperative projects between producers and contractors, and it's going to require appropriate funding, continued funding at the university level, to assure that we have a continuous flow of qualified engineers coming into the industry.

The issue was raised yesterday on the competency of the crew. I think we need to be concerned about the competency of engineers that are going to be coming out to support us and perhaps bringing them on board to work for the oil industry instead of Internet companies. Internet companies and Wall Street are taking a lot of the really qualified people in the industry. It's a serious concern. I don't know how many people have faced this in their companies, but we've seen a lot of negative responses to job offers in recent months. So the burden is upon us in this room to impress upon our senior management the value of continued research in these areas, and more important, to make sure that we have appropriate allocation of resources, both in technology funding and personnel funding.

I'll get off my soapbox and pass it on to the next speaker.

MR. KRAFFT: Thank you, Richard. One of the disadvantages of being in the last session on the last day of the workshop is that a lot of my best stuff has already been talked about in earlier sessions. I think the good news is that's an indication we're obviously on the same page in terms of where FPSOs are going. I'll also be able to go through some of my material a little bit quicker.

I'm Marty Krafft. I'm a senior research engineer with FMC SOFEC and I want to talk to you today a bit about how the motions of an FPSO compare with existing platforms in the Gulf of Mexico, such as TLP, spar and semi.

First I did want to point out what has been -- there we go. There have been presentations earlier and yesterday that showed that there are FPSOs in environments that are at least as harsh as we have in the Gulf of Mexico. Our hundred-year criteria approach in the Gulf is 12-plus meters. As you can see, around the rest of the world we have FPSOs in environments that are as severe, if not more. I have supplemented (inaudible) specifically Brazil is only 8 meters, because that's where you find some of our very deepest FPSO moorings, so although the wave heights aren't as great, combined with extremely deep water it makes them some of the most impressive systems out there to date.

There is an FSO in the Gulf of Mexico, as we talked about yesterday, the PEMEX Canterell field in Campeche Bay, southern Gulf of Mexico. The water depth is only 80 meters. The wave height is about 9 meters, but it still was quite a significant design challenge for the mooring with such a large tanker, 352,000 dead weight tons with 2.3 million barrel storage. I believe you've seen -- I understood yesterday that the off-loading method is both simultaneous tandum and side-by-side mooring. The Campeche system has been tested in a five-year hurricane last year.

Another system that Tom talked about earlier is the Amoco Liuhua FPSO in the South China Sea. It's a one-million barrel storage tanker that was hit by typhoon Sally just months after it was installed in '96. It turns out that the wave heights for Sally were equivalent to what we have in the Gulf of Mexico in terms of a one-thousand year criteria. At the bottom we're comparing the hindcast weather with our hundred-year Gulf of Mexico criteria.

Green water for Liehua is a very important issue. This is a much smaller destroyer but we don't have too many pictures of FPSOs with green water so I though I'd throw this in. The Liehua system was extensively tested for both seakeeping and green water (inaudible) and green basins are on the lower. And our purpose here was to design the proper breakwater systems in the event that we would get on-deck green water.

Thanks, Tim, for introducing my colorized fluid dynamics. I will be the first to admit that although these tools look impressive there are -- they do model qualitatively very well with some of the things that we see in the model basin, but there's still quite a bit of validation left to be done, so I'll just flip through a sequence of these CFDs, stepping in time.

This particular model has only about 600,000 cells. This was done about four or five years ago. In today's models for the same program we're using about 3 or 4 million elements and it takes about a day or two on, say, a 6-700 megahertz P.C.

Okay. The existing platforms we have in deep waters, as I said, are the TLPs, spar and semi, and the typical riser configurations of these out there are either top tension vertical risers, steel catenary risers, or some combination of both. In (inaudible) we did have a semi-submersible free-standing bridge and tower with flexible jumpers up to the semi.

Here I'm comparing the total horizontal offset of an FPSO with the TLP, spar and semi, and I've expressed the offset in terms of percentage of water depth. Here you're looking at about 6,000-foot depth. A one-million barrel tanker FPSO has about 10 percent offset with an inverter catenary mooring. If we convert that to a top mooring, taut polyester system, we can cut the offset in half.

The semi-submersible also has a 10 percent offset. It is with the catenary system. If we had been able to use a top mooring on a semi, we'd also have been able to reduce the offset. And you can see the TLP and spar are both similar, about 5 percent offset. So we can look at what we can do with an FPSO compared to existing platforms. The total horizontal offsets are fairly close but we're not going to be able to use, we're not likely going to be able to use, the same kind of top tension or simple catenary risers that we use on the existing platforms.

I've plotted here three key motions that are important for riser design -- heave, pitch and vertical acceleration. In a one-million barrel FPSO we have about 15-16 meters of heave. If we double the storage size to 2 million barrels, we have a significant reduction and then so forth and so on -- a semi, TLP and spar, successfully decreasing heave motions. These heave, pitch and accelerations for the FPSO are all wave frequency. In the TLP, semi and spar some of this motion here is due to wave frequency, but some of it is due (inaudible) and low frequency as well.

Basically these types of systems -- the TLP, semi and spar -- are de-turned from the waves, that is, they're smaller hull concepts. Whereas the storm wave periods are in the range of 4 to 20 seconds, the semi-submersible has heave and pitch periods f 20 to 50 seconds, and the spar and TLP 30 to 150 seconds, so the dynamics of TLP, spar and semi would be somewhat less severe than for an FPSO. The FPSO natural periods are right in tune with the wave periods.

So in the Gulf of Mexico we're likely going to be needing to use some kind (inaudible) of decoupled riser configuration.

What are some the ways we can minimize these motions or what are some of the motion (inaudible) riser systems that are available? First of all, (inaudible) we can minimize wave frequency motions. We're going to probably be building new-built vessels for the most part. There's a lot we can do in the hull form design to reduce motions. We can utilize an oversized hull. You saw in the previous slide the difference in heave in going from a one-million barrel to a two-million barrel vessel is quite significant. We had to add thruster assist to the mooring systems so that reduces the relative wave heading -- relative wave/vessel heading. This will reduce the motions as well as the (inaudible) offsets. In addition, if you have a thruster you can build your turret closer to midships and further reduce your heave motions and (inaudible).

We've already discussed the taut polyester. It can significantly reduce offsets. I've got an example of one compliant riser configuration, a steel lazy wave, and a decoupled type riser configuration would be a hybrid (inaudible) with steel and flexible jumpers.

In terms of hull form optimization, the shipyard's goal is clear, maximize volume, minimum steel, and what you're going to end up with is a barge type vessel with a small L/B. That's going to result in (inaudible) compared to typical trading tankers.

There's a mooring riser design and we want to minimize wave frequency motions to make it easier to design our (inaudible) riser. For the Terra Nova project, Brown & Root spent quite a bit of time and effort optimizing their hull to minimize heave and pitch motions. In addition, this vessel has quite a large (inaudible) green water and a tremendously extended fo'c'sle deck to protect the bow region from green water.

In terms of directional stability, this plot is very simple. The X axis is the turret location for amidships. The right vertical axis is the vessel heading, so if my turrets are located close to the bow of the ship and I subject my vessel to colinear wind, waves and current, then the red line shows the result (inaudible) vessel heading. Of course you'd expect that to be zero in a colinear case, but as the turret moves aft towards amidships, suddenly you find a point where the vessel is no longer stable. This is still in a colinear environment. This is an area where you may consider thruster assistance. The trade-off is that when you go from the bow aft, the vertical motion of the FPSO decreases and, for example, you might have an upper limit threshold on what heave motion your risers can handle and use that criteria as a way of deciding how much thruster assist versus how far out the turret can be located.

A simple sketch showing what the taut polyester system looks like compared to an inverted chain-wire-chain with buoy system. I've shown here a flexible mazy wave configuration. In deeper waters (inaudible) we're not going to be able to use flexible type, we're going to need an alternative, either synthetics, which are not available yet, or steel pipe, but steel pipe needs to have a much more open configuration than what you could get away with with flexible pipe. We have to respect the minimal bend radius and stress concentrations around that shaft.

I think the basic case FPSO in the Gulf is going to have a chain-wire-chain converted catenary system. Taut polyester is still somewhat new. It is extensively being used in Brazil but in all the studies that I've been doing in recent years the basic case has always been the chain-wire-chain, and I believe we'll (inaudible) being successful.

There's a nice decoupled type solution originally developed by Mobil, Dave Garrett. We have what's called a TLR riser system. We have simple steel catenary risers coming up from the seabed to a tethered buoy and then flexible jumpers up to the FPSO.

If you look a little bit closer here you can see the buoy and flexible jumpers. The flexible lines can handle a lot more (inaudible) motion and offset them to the steel lines. The added benefit is that the (inaudible) are drastically reduced because you've only got short jumpers going up to the turret, so that helps simplify the turret design, particularly in deep water.

That concludes my presentation. And, Richard, do we have any additional comment?

MR. HEYL: My name is Caspar Heyl. I'm a research engineer with FMC SOFEC and I will give a short presentation on long-term response analysis and focus in particular on extreme (inaudible) for a turret moored tanker in the Gulf of Mexico.

As mentioned earlier, in the design of these systems we're trying to find a way to define extreme response, which might be the hundred-year roll response, and at the present most design practice is to use a hundred-year wave condition combined with maybe a hundred-year wind, a hundred-year current, and expose the system to that dynamic as your design load.

An alternative to this to get a more accurate extreme design response is to (inaudible) response analysis and calculate the actual hundred-year responses, responses with a hundred-year return period. In order to do this, you will need an accurate description of the environment in the form of a joint distribution of all the (inaudible) parameters that are important to the problem. In this case that would be your wind, wave and current, both intensities and direction.

A way to solve the problem is to make use of a hindcast database that contains a lot of storms that can be used to calculate long-term responses. You couple this with an accurate response model. Special interests in this case would be responses such as the roll of the tanker, green water, and these are responses that are typically not going to be governed by the hundred-year wave condition or the hundred-year combined with your wave and wind condition. (Inaudible) with green water is that maybe your maximum green water will occur at a smaller sea state than the hundred-year sea state, but with a shorter period, which creates a steeper sea. Those are the kind of problems that could be identified by performing the proper long-term response analysis.

Some of the results that I'll be showing this afternoon come from a joint study that was performed two years ago by Shell, SOFEC and Amoco where the goal was to calculate the long-term responses of a (inaudible) tanker in the Gulf of Mexico. In addition to that, they also derived some response-based design criteria, which are those particular environmental conditions that will give you your hundred-year response. And you will get different design criteria for each response parameter that you would be interested in.

Some other parameters that were studied in this case, we looked at the effect of wave spreading on the responses and we looked at the effect of the turret position on responses.

The vessel that we studied was a 120,000 dead weight ton tanker with a constant draft of about 60 percent. The mooring system was a catenary mooring system and inverted chain-wire-chain system. In order to perform the long-term analysis what we needed is a proper short-term distribution function and in this case we used the previous model as data on the same tanker to help us with that.

Very quickly I will go over the methodology that was used which you see outlined here, starting off with hurricane data and a hurricane hindcast database for the Gulf of Mexico which contains about 11,000 records. Each record represents an hourly average of the significant wave height, peak period, wave direction, steepness (inaudible) and wind speed and direction, current speed and direction and a value for the short-cresting of the seas.

Then with a frequency domain analysis we need -- so that we use a very accurate frequent domain analysis and (inaudible) which run very quickly and we were able to perform a couple of analyses with mooring and risers for all of the 11,000 records in the database. We actually did this multiple times for different turret locations and both for short-crest and long-crest seas.

When you work your way through the database, you can calculate short-term probability for a particular storm that passes over a particular rig point and you can calculate that by simply taking apart all the individual distribution functions for each hour that the storm lasted at that rig point. That was called the medium term probability in this case.

Then to get the distribution function for just a single storm, (inaudible) taking the average of all the grade points of that particular storm (inaudible) to get a nice smooth, long-term distribution function for a random storm. It would also average all the storms that were in the database. In this case there were 35 storms in the database which covered about 85 years. Since it's known that the arrival of hurricanes in the Gulf of Mexico is a (inaudible) process you can then calculate the long-term probabilities for any desired term period.

We talked about the medium responses. What you see here are two graphs that show that sequence of records for this database that gave us the maximum roll and the maximum tension event. It was the sixth storm in the database, a hurricane from 1915. They didn't have named hurricanes (inaudible). This is at grid point 310 and you see how (inaudible) in the left plot where the hours are plotted that the hurricane actually exceeded the threshold there for about 16 hours, and you can see the wave heights quickly increasing to a maximum of about 12 1/2 meters and then decreasing again afterwards.

What you also see is that while the wave height is decreasing again, the relative wave heading of the vessel is actually increasing. This is probably caused by the fact that the (inaudible) moment caused by the waves is reduced and the vessel is more under the influence of the wind and current.

To illustrate that I have an animation that shows the direction of wind, current and waves over time and the resulting heading of the vessel. The green arrow represents the wind direction and strength, the yellow arrow represents the waves, and the red arrow represents the current. This is not exactly the same sequence. This is a little bit of a longer sequence. This particular storm resulted in the worst (inaudible).

Now you can see the wind, wave and current just past their maximum and they are decreasing now, but they're getting less and less aligned. With that current strength it has affected the heading of the vessel. And at this point you saw that the vessel almost mounted the waves where you get very large wave shear force on the vessel which can result in (inaudible) offsets.

And now the result of the vessel (inaudible) relative wave angle is that you will have large roll motions. In this case you also see the current making rather large directional changes. These are at one-hour time steps. Each step represents one hour of the database, averaged out as a wave height and wind speed (inaudible).

Now you see some results from the long-term response analysis. What you see here is a comparison of the long-term responses that were calculated with short-term responses. The response of each was gathered to analyze the system with the typical hundred-year wind, wave and current for the Gulf of Mexico. We actually compared it to three different short-term cases. The yellow bar is just a wind, wave and current (inaudible) in the same direction, colinear case. The blue bar represents the environmental case that is recommended in the DNV (inaudible) where the wind and current are both at 30 and 45 degrees from the waves. The green bar shows a case where the wind and current are at an angle with the waves (inaudible) joint distribution of wind, wave and current in the Gulf of Mexico as they would, on average, be in a hurricane.

As you can see, the heave and pitch responses are very close to the short-term responses. However, the short-term responses are predicting the hundred-year heave and pitch by a little bit. More importantly, if you look at the roll, of course in the colinear case you're not going to see any roll, but the other two of our cases, the DNV case and the Gulf of Mexico case, (inaudible) predicted the maximum roll by almost 50 percent. One of the reasons is the alignment in the wind, wave and current is still such that the vessel will never take a very large angle to the wave.

What you see here is a collection of all the short-term responses from the database, so each dot actually represents a simulation to one of the database records, so there's about 11,000 dots in this picture. What you can see is that the most probable roll response plotted versus significant wave height, and what became clear is that the larger responses actually occur at smaller wave heights. (Inaudible) with significant height increases the wind and currents have more effect on determining the heading of the vessel and the vessel can end up with a very unfavorable heading with respect to the waves which will result in the large rolling.

The next slide shows you the effect of short-crested seas. This was also one of the parameters that we studied. Typically most of the (inaudible) is now full-crested seas without wave spreading, both in the analysis and model testing, and in this case the program only took the wave spreading into account in the (inaudible) of the responses. This means that the low-frequency (inaudible) are unaffected in this case, which in reality they are not. In reality, when you have spread seas you actually will probably see some increase in your (inaudible).

These are long-term distribution functions for roll both with wave spreading and without wave spreading, and you can see that in this case with wave spreading there's a much steeper distribution function.

Now we see some numbers on the roll response. What I've put in the table here are responses to the derived design criteria, so these are not actually the calculated (inaudible) responses but these are responses to -- that the storm that will be really your hundred-year roll and put them together for both long-crested waves and short-crested waves, both the hundred-year response and the thousand-year response, and as you can see the roll response is considerable. So is the (inaudible).

Finally, to draw some conclusions from all of this, as mentioned before by Richard, roll is a complex response and I think that it has maybe not received all the attention it deserves. It's very nonlinear. (Inaudible) interaction with large sway-yaw motion you'll have to be accurate in predicting your response to the yaw motions to get an accurate roll response prediction. You have to be accurate in your prediction of the database nonlinear damping and stiffness.

The third point, the large roll amplitudes, in this study it appears that the smaller sea states -- and the database that was used was actually put together using a threshold for significant wave height to include only sea states with a significant wave height of more than 7 1/2 meters, and as you could see in one of the earlier slides a lot of the large rolls response was around 8 or 9 meter significant seas. So it might be worth it to repeat this sort of exercise and include more of the data that was in the original database.

Some of the mitigations that were already mentioned before, you could think of thruster assist that could be programmed to react to the (inaudible) wave and try to get the vessel more headed into the waves if necessary. Another option is to fit the vessel with bilge keels or double side bilge keels, and the main conclusion is that when designing turret moored FPSOs in areas with hurricanes where you have these tremendous misalignments in wind, wave and current, it's necessary for roll response to perform a long-term response analysis.

Thank you.

QUESTIONS & ANSWERS

MR. HARRISON: Actually, these are more points of clarification than questions. This is Garth Harrison, Texaco, and I'll start with the last and work back to the front, okay?

The roll amplitudes were very distinguishable with the double (inaudible).

MR. HEYL: Single amplitude.

MR. HARRISON: Thank you. Marty, two points. One, what are you doing on the heave and pitch periods? They looked more like roll periods to me, didn't seem long enough. Is that a fair observation?

MR. KRAFFT: I was giving a range. The shorter periods would be corresponding to the heave, the longer ones to pitch and roll, which for TLPs are fairly symmetric, so pitch and roll are essentially the same whereas pitch and roll periods would differ somewhat.

MR. HARRISON: I thought I was looking at heave and pitch periods on a ship-shaped (inaudible).

MR. KRAFFT: From 8 to 16 seconds. 16 is probably a little bit on the high side, but 12-13 seconds is not unusual for larger tankers. It depends on -- if you have swell, the tanker will respond also in that area, but the natural periods, I probably should have backed off a couple of seconds, say up to 14 seconds.

MR. HARRISON: But it sounds more like roll periods to me than pitch. I thought the pitch was always generally longer than roll in the FPSO ship-shaped department.

MR. KRAFFT: Roll periods would be, say, 13-16 seconds, and pitch and heave should probably be cut off somewhere around 13 or 14 seconds. That's an extreme.

MR. HARRISON: Going through your presentation, you pointed out that the polyester taut leg system reduced excursion and offset blah, blah, and had a lot of good points, but in your conclusion you said the base cable probably would be chain-wire-chain (inaudible) so you've gotten such good results from (inaudible) so why do you conclude that the other would be base cable?

MR. KRAFFT: I should clarify. Going by what the operators were saying, they were headed for their first FPSOs, so, "yes, on your taut mooring tell me how much cheaper it is." The polyester is 20 percent cheaper than the wire, but when you get rid of the ground chain you end up with a polyester system that's 40 percent of the cost of a chain-wire-chain with buoys, but long-term institute data on polyester moorings is not there so the U.S. operators are taking a more cautious approach.

I will say that there are some U.S. operators working in Africa that for the off-loading buoys will be using polyester because that's a lower risk carrier than connecting to an FPSO (inaudible). I should have said what we're likely to see for a first system is a conventional chain-wire-chain with some kind of a (inaudible) decoupling system.

And as I mentioned before, we've got taut polyester systems on semis and FPSO-based systems in Brazil as well as semi.

MR. HARRISON: There was a reference to limitations on model tank testing on water depth and I understand from (inaudible) this month they're opening their new deep water model tanks, just for general information, which is good for up to 900 meters.

MR. FINNIGAN: That's the 3,000 or so foot limitation that I was mentioning. That would be on a scale of 1 to 76 or 80, somewhere there, 87, I think for an average, and they are the deepest basin at this point that can address the combined wind, wave and currents, so that number is very (inaudible).

MR. HARRISON: That's all I have, thank you.

I've got one more. Can I go back for one more?

MR. D'SOUZA: Certainly.

MR. HARRISON: Thank you. Hull forms, which Richard brought up, Shehallion was badly damaged in the hull (inaudible). Was that as a result of a hull form design, do you think?

MR. D'SOUZA: Is (inaudible) here? He was with BP when they did Shehallion. But the answer to that, and I'm saying this without really knowing for sure, is that I believe the hull form design did contribute to that slamming damage, yes.

MR. KRAFFT: And as Caspar pointed out, the hundred-year response may not come from a hundred-year wave. I think it was the idea that a lower, steeper wave caused that damage to be (inaudible).

MR. LEE: Craig Lee from ABS. Couple of questions, may not be particularly for individual speaker on the panel, can answer together. One question regarding the vessel heading, the (inaudible) where you were interpreting the diagram there, my question, what you consider in determination of where they're heading because where they're heading permits for FPSOs design which relate to (inaudible) motion and green water.

(Inaudible) to Caspar, you are doing a very good job but my question to you, what do you consider about (inaudible) through and our (inaudible) frequency bridge because the turret has (inaudible). If you try to apply (inaudible) diffraction theory there, it could be some (inaudible).

The third question's about we talk about how hundred-year response, not hundred-year environmental load. So Caspar already mentioned there may be some short wave cause worst case on green water, but as we see that can also cause worst case for dynamic load, so what you consider in your design for analysis? Thank you.

MR. KRAFFT: I think on the first question, if I understand you right, it's that the yaw angle or the heading of the vessel must depend on dynamic effects of the wind, waves and current. Is that correct?

MR. LEE: Yeah. More than that. Also the difference the (inaudible) part away from the prior location.

MR. KRAFFT: Yes, that's correct for a given turret location if the environmental condition will give you a different heading.

MR. LEE: Plus, the (inaudible) in the mooring rockers (inaudible) motion.

MR. KRAFFT: On mean vessel heading for a turret moored vessel, I would say that the mooring and risers are not going to have a large effect on your vessel heading.

MR. LEE: For green water for OTRC (inaudible)?

MR. HEYL: The mean heading is just determined by your location of your turret.

MR. LEE: No, design (inaudible) dynamic heading, not only a static heading.

MR. HEYL: Oh, yes, absolutely. In the analysis that we do, it is a fully-coupled analysis.

MR. KRAFFT: My point was just one example showing mean environmental forces for one sea state, how it affects vessel heading versus the turret location.

Yes, you were correct, the mooring risers must be considered as well.

MR. EGGERS: Did we complete the answer to that question? I guess so.

David Eggers, Mentor Subsea. We also partook in a couple of analyses with DeepStar and we evaluated the spar and we noticed that there wasn't a whole lot of difference in decoupling the risers and moorings, especially in the deep water case. I'm just curious if you guys have found the same type of results, if you will, with the FPSO. I think Richard -- I don't know if you guys did the FPSO or not but I think SOFEC did; is that correct? Could y'all comment on that.

MR. KRAFFT: Your question was the effect of risers on spar motions?

MR. EGGERS: What I was saying is when you did the couple analysis, okay, when we did it with the spar (inaudible) we noticed that there wasn't a large difference in the results, the motions, if you will, of the spar, if you coupled the analysis or if you decoupled the analysis. In other words, if you looked at the riser and moorings together and if you looked at them separately, we didn't see a big difference in deep water. In other words, is there really a need for a coupling analysis in deep water? With the spar we don't think so.

MR. KRAFFT: All right. I still agree with Richard, the moorings and risers may not affect some platforms, may not affect the motions greatly, but the motions of the platform need to be considered with the risers in place so that you get the exact combination, or a complex combination of motions that are going on will be imparted to your risers, not just taking an extreme offset, adding to it and excluding wave motion and not having the actual wave (inaudible) acting on the risers as well.

MR. D'SOUZA: And certainly for the second order affects the impact of risers and moorings on the surge and sway damping is very, very critical, and by including it in the model you get a fairly accurate representation of what that damping term is going to be, and in terms of the total offset which in turn affects the risers and mooring line tensions it is critical that those components be coupled.

MR. FINNIGAN: I'd like to address the issue on coupling on the effect of the spar response. And even though I didn't see (inaudible) talk at the OTC I've heard it personally from him where they found for spar design the inclusion of the viscous effects of the riser on the keels -- of the spar keel joints had a significant affect on mitigating the effect of the heave of the spar. There is significant mine damping seen in the catenary moored spars that he showed in his numerical analysis reduced the heave behavior as well as the effect of friction between the riser and the hull, and used that analysis as well, that type of analysis, coupled analysis, to explain why the Oryx spar in particular was not seeing the kind of heave that they would predict.

So for the spar platform there is both field experience evidence, model evidence and numerical evidence that shows the coupling effects are very important and need to be considered.

MR. McMILLAN: Not that I've directly been involved in this work but I understand that (inaudible) these results have demonstrated the same as Richard saying that the motion response of the FPSO hull is quite significant on moorings and risers and the coupling effects are important to include. However, for a spar and a TLP, the same set of conclusions -- the coupling and decoupling doesn't seem to be as critical as it is for an FPSO. That's more in the moorings and riser issues.

UNIDENTIFIED SPEAKER: (Inaudible) I'm (inaudible) ABS. I wasn't planning on coming up, but generally let's address some of the (inaudible) system. I was directly involved in some of the work. (Inaudible) the answer also compare only the mooring system. We have to consider in terms of the field (inaudible) cost the riser. I think the past week we're using less cost riser system with reducing offset of the vessel will be an important consideration.

And especially the couple panelists presenting the response-based criteria, I would like to ask anyone and everybody, is the industry ready to use the response-based criteria, especially for FPSO analysis in view of the uncertainty involved as presented and also the severity of (inaudible) floating system. And another thing to consider may be the combination -- I mean the richness of the hindcast database. It's pretty good in the Gulf of Mexico but other parts of the world I don't think it's that.

So I just want to throw that in for everybody's consideration. Thank you.

MR. HEYL: I can say one thing about the response-based criteria. I think the prime function of the response-based criteria is to be a tool in the initial analysis on new projects, because when you do a long-term analysis you actually get your hundred-year responses and you don't need response-based criteria to -- then you don't need them anymore. You can derive your response-based criteria to help you in your next design to speed up your initial design. But they wouldn't be used for the final detailed design.

UNIDENTIFIED SPEAKER: Because that's (inaudible) that's fine. Because what I mean is compare with some traditional hundred-year storm base, whether it's wind driven or current driven type, as it is regulated by the CMR (inaudible).

UNIDENTIFIED SPEAKER: I have a fun comment and maybe y'all will want to close on this one, but you saw that picture that Marty showed, the photo of the destroyer. I don't know how many in the back of the room could see that closely, but that destroyer was doing underwater replenishment. There were hydrocarbons being transferred from the aircraft carrier over to the destroyer, so things can always get worse.

MR. HUANG: Ken Huang from ABS. I have personally observed model testing (inaudible) for FPSO being hit by a design wave (inaudible) coincide with this natural (inaudible) pitch and the whole ship is rocking just like -- you know, up and down (inaudible) so my question is simply that, as we know, the major concern for FPSO design in terms of motion, mooring (inaudible) even including the green water effect are all due to the wave-induced motion right at this natural period of pitch. So as we know that the design wave period will very well coincide with this natural period of pitch, how or in any way we can alleviate this problem. Any thoughts?

MR. D'SOUZA: Well, Ken, I think, yes, you will get (inaudible) the heave and pitch natural periods are in the same period as the period of significant wave energy. However, fortunately for us, in the ship-shaped configurations those motions are also heavily damped, so you don't get the dynamic amplification in those modes of motion as you would, say, for roll motion, and I don't think that is as critical in terms of trying to move the pitch and heave period away from that particular period of wave energy. It's not that critical. That's my opinion.

MR. LEE: Craig Lee from ABS. Seems (inaudible) people here so I just heard our friends, they introduce their software and technology about fatigue. I would like to use this opportunity to introduce ABS just release FPI guide which provide you a quite similar (inaudible) to design the FPSO using the site-specific environmental condition, also providing a tool to use in your data, analyze your design condition for your structure which we use to improve and (inaudible) hull technology.

This item has been released in OTC time, May 1st, and will be available -- it is under printing, will be available at the end of June. If you are interested, you can give your name to me. I can provide you this guidance. This is a complete guidance, including the loading structure criteria and facility and the export-import system, all in one package.

In addition to that I have a couple of questions. Just when we study the motion from the conversion (inaudible) I'm now showing the panelist, you have conceded that backflow are a factor because when you convert (inaudible) normally the deck of the tanker does not have (inaudible) FPSO, sometimes even higher than 55,000 times. Do you consider the KG effect due to this loading?

Second, when mooring (inaudible) to the motion is that a significant effect of the motion in going to deep water? Do you address this in the future?

And the coupling motion, does this mooring system affect the stress design? And maybe this from -- I thought the rolling motion -- I think rolling motion is very important for stability and the topside structure design, and I'm not sure this -- from your experience what the limit to the (inaudible) normal design you try to use in there special design to limit the roll motion to 20 degree or also (inaudible) is it includes the criteria you normally design. I also would like to know.

So the other one, off-loading condition, when you off-load, you have onsite -- you have side by side or you have using the tandem? How do you consider motion? What -- you don't usually consider hundred-year storm. What condition you design for this off-loading condition?

And one comment to the gentleman, he talking about the long-term -- long-crest and short-crest sea. I think it depends on your wave height. You showed me a short wave crest that has lower roll motion, but I'm not sure of this because depending on how you put your wave direction (inaudible).

Another question is, when we talk about a weathervaning system, weathervaning normally is plus or minus 30 degrees. How did you determine your roll motion, the maximum roll motion?

Do you consider (inaudible) case or how do you design with the -- under the weathervaning system, how do you come up with maximum roll motion for the design?

I think that's too many questions.

MR. KRAFFT: I recommend that we each pick one. On the PEMEX off-loading, (inaudible) had specified a criteria whereby the maximum sea mitigating wave height varied heading in respect to the vessel, so if it was head-on waves we should be able to handle up to 2 1/2 or 3 meter seas, quartering waves, the criteria was reduced to about 1 1/2 to 2 meters, and then beam-on would be 1 1/2 meters.

In addition to that there's another matrix depending on the size of the tanker that was off-loading. So larger tankers we would lower the sea state and smaller tankers we would increase the sea state, so it was quite a comprehensive program for determining side by side and tandem mooring loads on the hawsers.

MR. McMILLAN: I think one of your questions was related to whether you include the mass of the topsides in the (inaudible) analysis. And, yes, you should include those sequences, their center of gravities and the mass in the hydrodynamic analysis. It's imperative.

MR. FINNIGAN: Probably still on the question (inaudible) about how the max roll motion was determined. When we're doing our response-based analysis with the hindcast set of data, you're using, as Caspar showed, thousands of combinations of hourly wave heights, winds and currents, and the max roll that would come out of that, provided you set your criteria low enough (inaudible) you may not have gone low enough with your wave height threshold, the roll is going to come out and then you'll have a statistical distribution of your maximum response versus all these storms. The roll response isn't being selected, and I don't think Caspar has suggested that it's selected, but it's coming out of the analysis as being the max hundred-year roll that occurred. So it's not a case of picking a heading, but it's what came out of the weathervaning combined analysis with their combined events.

I hope that answers your question.