Structural Design and Analysis of FPSO Topside Module Supports

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This paper addresses the unique structural challenges associated with the design and analysis of topside module support structures for installation on FPSO decks. Specifically, this paper addresses the loading on the interface stool structures while subjected to loads originating from hull girder deformation, FPSO tank pressure loads, and topside inertial loads due to vessel motions. The results of an advanced finite element based analysis approach is presented and compared to the results of a simple design method. The effects of hull girder deformation due to vertical bending moment loading are compared to the effects of local deck deformation due to loading induced by the FPSO tank structures and topside modules.

KEY WORDS: FPSO or FSO Vessels; Floating Production Storage and Offloading; Structural Design and Assessment; Spectral Fatigue Assessment; Advanced Finite Element Analysis; Classification Calculations, Topside Installations.

NOMENCLATURE

ABS	American Bureau of Shipping
B	Moulded Breadth
DLP	Dominant Load Parameter
FEA	Finite Element Analysis
FPSO	Floating Production Storage and Offloading
FSO	Floating Storage and Offloading
PHASE B	ABS SafeHull Program, Version 10.0
SAGA	Viking Systems' Structural Assessment Software

INTRODUCTION

This paper discusses the use of advanced methods to determine the interaction between the topside installations and the hull structure of FPSO units. The purpose of the paper is to present results of a method developed to accurately assess the response of the hull and the stool interface structure when subjected to loads originating from the hull structure loading and the topside structure loading. The paper first discusses the strength and loading parameters involved in the structural design of hull supports and stools considering the following: hull girder loads, hull girder strength, local deck stiffness due to frame and stiffener spacing, proximity to bulkheads, acceleration loads, inclination loads, internal tank fluid loads, and topside installation method of connections such as welded and sliding connections.

Additional considerations affecting the topside design include clearance requirements under the modules for piping and inspection, frame spacing and longitudinal spacing of the FPSO hull structure, and explosion scenarios.

STOOL DESIGN TYPES

A module is installed on the FPSO deck via deck stools of varying type and size, and is typically employed in a system as shown in Table 1.

Table 1. Stool Design Types

	Description	Number of Stools	Stool Design Size and Stiffness	Deck Reinforcement Expected
A	Stools at each frame	3-6 long. 2-4 transv.	Slides, small, stiff	No
B	Stools span two frames	2 long. 2 transv.	Welded, large, stiff	Yes
C	Gussets at each frame	3-6 long. 2-4 transv.	Welded, small, flexible	No
D	Stools span two frames	3-4 long. 2 transv.	Slides, large, stiff	Possibly

See Figs. 1-4 for a schematic drawing of each stool-to-module connection type or, in the case of the gusset, the connection to the deck. The connection between the deck and the stool or gusset is assumed to be welded. The actual connection design to the deck is typically comprised of welding along transverse frames and longitudinal stiffeners.

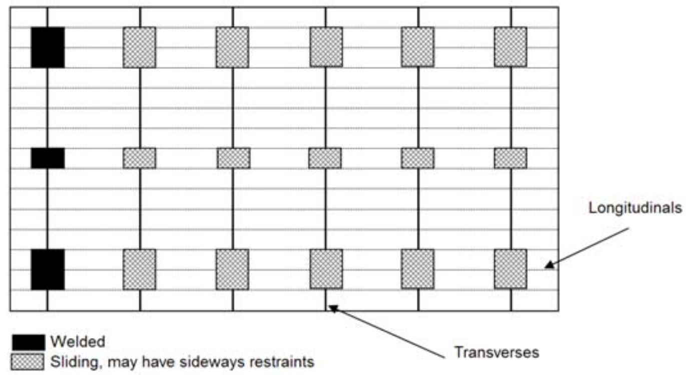

Fig 1. Schematic of Connection Type A

Types A and C typically do not require under deck structure modification or reinforcement, whereas Type B typically requires deck plating inserts and under deck reinforcement.

Typically, deck stools or gussets are arranged to allow welding to the ship structure at structurally sound locations such as web frames and transverse bulkheads in the longitudinal direction, and at longitudinal stiffener and longitudinal bulkhead locations in the transverse direction.

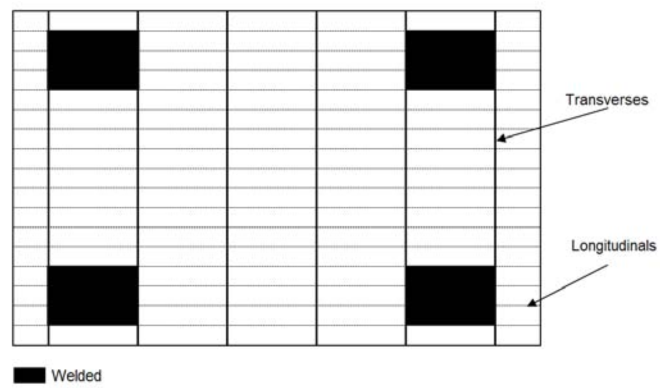

Fig 2. Schematic of Connection Type B

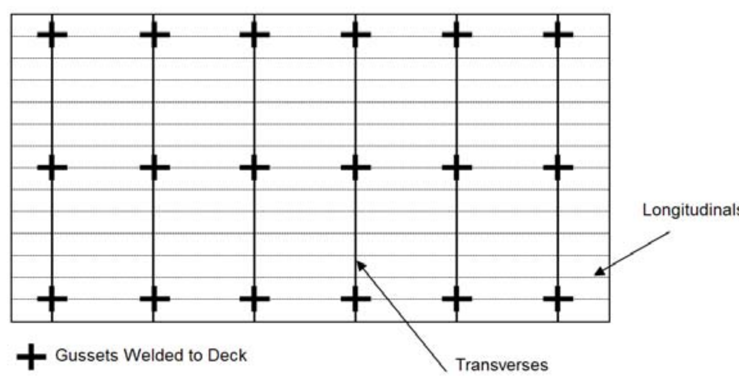

Fig 3. Schematic of Connection Type C

Fig 4. Schematic of Connection Type D

INTERACTION LOADS

Topside structures are subject to the hull girder deflections of the FPSO as a result of still water bending and wave-induced bending. In addition, hull girder shear force changes across transverse bulkheads can introduce local deflections between deck stools. The differential pressure loads on transverse and longitudinal bulkheads also produce deck deflections which in turn load the topside structure via the deck stools.

The hull girder structure loading is affected by the mass of the topside modules and its static and dynamic load effect on the resulting hull girder shear force and bending moment. In addition, the local mass distribution of the modules affects the deck structure locally from static and dynamic loads. Finally, due to the strength of the topside supporting structure, the hull girder loads introduce forces into the topside structure which in turn produce forces back to the ship deck locally via the deck stools. The sliding connection design reduces the effect of the topside module supporting structure on the hull girder by allowing movement when the connection friction is overcome by the horizontal force. A summary of the loads is listed in Tables 2 and 3.

Dominant Hull Girder Loads

The loads in Table 2 provide interacting loads from hull deflection-induced loading on the deck structure, and from the tank pressure loading acting on the deck via bulkhead structures.

Table 2. Dominant Hull Girder Loads

Load	Components
Hull Girder Bending	Still Water and Wave Induced
Hull Girder Shear	Still Water and Wave Induced
Differential Pressure on Transverse Bulkheads	Static and Inertia Pressure
Differential Pressure on Longitudinal Bulkheads	Static and Inertia Pressure

Dominant Topside Module Loads

The loads from the topside modules as shown in Table 3 result in force-induced loading.

Table 3. Dominant Topside Loads

Load	Components
Module Reaction Loads from Hull Deflection and Tank Loads	Static and Dynamic Loads
Loads due to FPSO Inclination	Static and Dynamic Accelerations
Loads due to FPSO Acceleration	Dynamic Accelerations
Module Mass Distribution and Center of Gravity	Static and Dynamic Accelerations
Module Location on FPSO, i.e each module gets unique combination of 6 degree of freedom accelerations and hull girder loads	Static and Dynamic Accelerations

ANALYSIS PROCEDURE

The analysis procedure consists of finite element model creation, load development, solving, and assessment of results.

Finite Element Modeling

The finite element model creation typically consists of a full length FPSO model, a cargo block model, or a 3-hold model type as in ABS SafeHull Phase B. The partial models are loaded at their cut sections with still water and wave-induced hull girder shear force, bending moment and torsional moment to represent the loading from the structure that is not modeled. The model loads are then balanced to reduce error from load imbalance. The models are restrained entirely at one of the cut ends, or by a few restraints that are free to undergo hull deformation. In the case of the cut models, the absolute deflection level will not match that of the actual unit or the full model, however the relative deflections will be practically the same, justifying the use of partial models.

Finite Element Loading

It is preferred that the loads be established using a direct analysis procedure for calculating wave-induced hull pressures, motions-induced inertia loads of the hull and topside structure, and tank loads and fluids in the topside modules. The preferred choice is a hydrodynamic analysis method such as presented in Ref. 1 (Henriksen, 2007) using the magnitude and phase lag definition of each response of motions, accelerations and pressure to define the maximum response Dominant Load Parameter (DLP) for a number of maximum load events using either short-term or long-term responses. The DLP's must be combined with actual FPSO loading conditions to develop maxima of still water and wave-induced loads for each structure to be validated. Alternatively, rule based programs such as ABS Phase B can be used.

The loads correspond to operating conditions or transit conditions.

Interaction Load Assessment

The topside modules and hull structures will be subjected to the loads shown in Tables 2 and 3. In addition, the stiffness of the topside modules and the hull structures will also affect the local response in vicinity of bulkheads and the variation in the topside stools as used throughout the deck of the FPSO. The interaction loads between the hull and the topside modules are shown in Tables 4 and 5, where the severity of the interaction loading is also assessed qualitatively.

Table 4. Foundation Effect on Topside Modules from Hull Girder Deflection

Relative Deflection Mode	Severity	Load Origin	Primary Factors
Longitudinal	Low for Slide Types A,D High for Welded Types B, C	Still Water and Wave Hull Girder Vertical and Horizontal Bending	Hull Length Hull Breadth Block Coefficient Longitudinal Strength Topside Installation Height
Vertical	Medium	Hull Vertical Bending	Hull Length Hull Breadth Block Coefficient Longitudinal Strength
Transverse	Minor	Transverse Bending	Transverse Strength Topside Installation Height Topside Module Width

The loads imparted to the deck from the topside structure are also a function of the module supporting system (Types A, B, C, and D) which may include sliding pads designed to isolate the longitudinal or transverse deflections resulting from hull girder bending.

Table 5. Topside Module Effect on Hull

Force Direction	Severity	Load Origin	Primary Factors
Longitudinal	Low	Surge, Pitch, Yaw Inclination and Acceleration	Topside Module Mass Topside Module CG
Vertical	High	Heave, Pitch, Roll Inclination and Acceleration	Topside Module Mass Topside Module CG Topside Module Width Topside Module Length
Transverse	Medium	Sway, Roll, Yaw Inclination and Acceleration	Topside Module Mass Topside Module CG

Interface Structure Modeling

For the connection modeling of the interface structure, a number of finite element properties can be used as described in Fig. 5 as “block”, “sheet”, and “wire”.

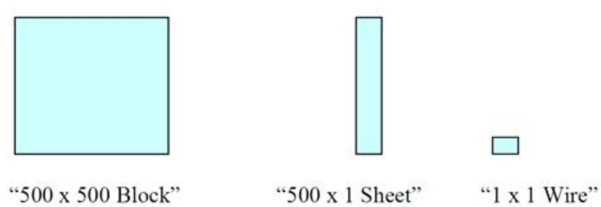

Fig 5. Connection Beam Element Property Types

In cases where welded connections are used, a “block” type must be used. The use of the “block” element allows for assessing the reaction loads between the hull and the topside modules. In addition, deflections can be assessed for use by the topside module steel design effort.

In the special case of sliding connections being installed on top of the modules to separate the hull girder longitudinal deflections from the topside modules, an iterative approach can be used as follows:

1. Create chart of stool connector types, i.e. welded, partial restraint, or sliding
2. Start by assigning “Block” type beam element properties to all Module Connectors
3. Solve the model, inspect results from each case
4. For elements showing uplift at sliding connectors, change Module Connector to “Wire” type
5. Re-solve model, inspect results.
6. Check if any new uplift at sliding connectors occurs; if so, repeat steps 4-5, otherwise go to step 7
7. Calculate the ratio of shear force divided by axial force for longitudinal direction
8. Calculate the ratio of shear force divided by axial force for transverse direction
9. If ratios in the steps above are greater than the friction coefficient, change to “Sheet” type
10. In case both directions slip, then change to “Block” type, but use rod element (or use “Block” element with small inertias)
11. Maintain welded or restrained connections defined in step 1
12. Re-solve model, inspect results
13. Repeat Steps 7-11 until there is convergence
14. Finally inspect if steps 6 and 9 are met; if so, the solution is complete, otherwise go back to step 2

The choice of beam elements with different properties for simulation of sliding connection conditions is made to allow for keeping the same finite element, and changing only the properties, to allow an easy elemental assessment of the connection conditions during each step.

Finite Element Results Assessment

The global response can be used to determine the maximum stresses in the hull structure and the stool or gusset supporting structures. The global model assessment of the responses incorporating usage factors are applied to the yield stress of the material for assessment of yield and buckling of the structures.

CASE STUDY

The following serves as a case study of a recent project where the topside modules are installed using a combination of welded connections and sliding connections. The module selected in this case study is a heavy module with 21 stools. Note that similar results have been obtained for lighter modules and for other locations on the deck of the FPSO.

Deflection Based Loads on the Topside Stools

As described in the loading section above, the dominant load on the topside modules, the topside stools, and the interface between the structures results from the hull deflections in way of the module supports. The following section describes an approach developed to determine the impact of the many load components on the resulting deflections in way of the topside supports.

The deflections at the top of the stools, in way of the interface between the stool and topside module structure, depend on the relative stiffness of the hull, main deck, stool, and topside module structure. Therefore, an integrated global FEA model is used to evaluate the response of the combined structure to the combination of static loading and design environmental conditions.

The integrated global FEA model used in this case study includes the hull structure for the entire length of the cargo block, the stools, the pipe rack, and the first level framing structure up to and including the process deck for the topside modules. The module supports in the case study include six (6) welded anchor stools (three stools in way of each of the two transverse frames near the center longitudinal center of the module). The stools in way of the other frames, near the forward and aft ends of the modules include steel-on-steel sliding connections that allow for fore and aft movement at the stool / module interface. In the initial global model analysis, it is assumed that the longitudinal sliding force present in the sliding connections is not sufficient to overcome the friction force, and the connections are modeled with “block” elements as if they were welded connections.

In this case study, the global FEA model analysis considers 10 static operating conditions, which are combined with 100 year extreme environmental loads to create a series of 46 combined design load cases for the operating site. A similar series of environmental loads are combined with the transit loading condition with dry topside modules to evaluate the effect of the voyage to the operating site on the structure; however, for clarity, the remainder of this case study will focus on the results of the site design load cases.

Longitudinal Deflections

The resulting nodal deflections from the analysis of the 46 design load cases on the integrated global FEA model are used to evaluate the magnitude of the longitudinal deflection present in the main deck structure and at the stool / topside module interface.

The resulting longitudinal deflections in the main deck, at the base of the topside stools, are plotted in Figure 6 for the 46 design load cases along the length of the cargo block. The deflections are presented in mm and are plotted as the relative deflection between each frame and the transverse bulkhead at the aft end of the cargo block.

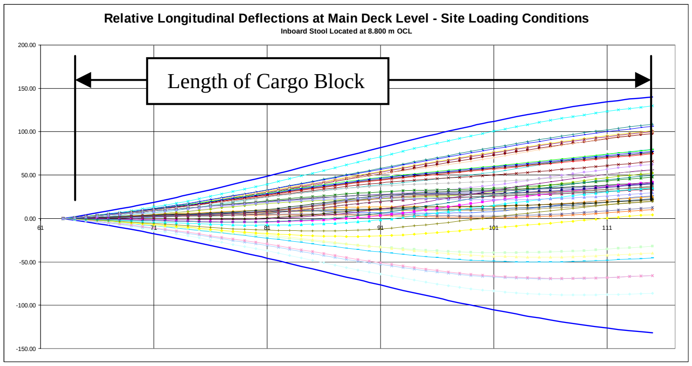

Fig 6. Relative Longitudinal Deflection at Main Deck Level

The deflection results shown in Figure 6 indicate that the longitudinal deflection in the main deck resulting from the maximum hogging condition at the operating site are approximately 0.715 mm / m, while the maximum sagging condition will induce approximately 0.606 mm / m of longitudinal deflection.

The resulting longitudinal deflections at the interface level at the top of the stools are plotted in Figure 7 below for the 46 design load cases along the length of the cargo block. The deflections in Figure 7 illustrate the effect of the topside module stiffness vs. the stiffness of the main deck and stool supports.

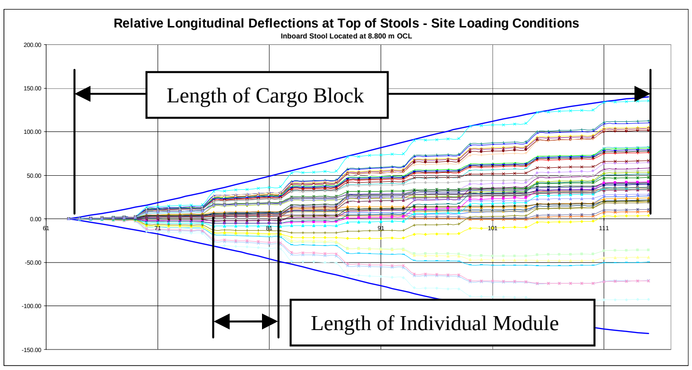

Fig 7. Relative Longitudinal Deflection at Top of Stools

The deflection results shown in Figure 7 indicate that the longitudinal deflection at the top of the stools, in way of a topside module, resulting from the maximum hogging condition at the operating site are approximately 0.210 mm / m, while the maximum sagging condition will induce approximately 0.175 mm / m of longitudinal deflection.

The differences between the longitudinal deflections in the main deck and at the top of the stools illustrate the amount of longitudinal deflection that will be experienced by the topside stools if the sliding connections do not slide. The topside module presented in this case study is approximately 31 m long, and is therefore subjected to the following deflections shown in Table 6:

Table 6. Summary of Longitudinal Deflection in Stools

Load Case	Longitudinal Deflection over the Length of the Module		Deflection in Stools *
	Main Deck	Top of Stool	
Max Hog	22.2 mm	6.5 mm	15.7 mm
Max Sag	18.8 mm	5.4 mm	13.4 mm

* The total deflection in the stools will be shared between the forward and aft stools with each experiencing approximately half of the total deflection.

The fore and aft force generated at the interface between the top of the stool and the topside module structure is the sliding force, which will initiate the slide between the module and stool if the friction force between the structures is overcome. Additional information on the development of the friction force is provided in the next section.

Vertical Deflections

As described in the loading section above, the vertical deflection in way of the topside support stools is the result of the overall hull girder deflections, the local deflection of the main deck structure resulting from the loads imposed by the topside module, and the local deflection of the main deck structure resulting from the pressure loading in the tank boundaries below the deck.

The layout of the module support stools for the module used in this case study and their relationship to the main supporting members under the main deck are shown in Figures 8 and 9 below.

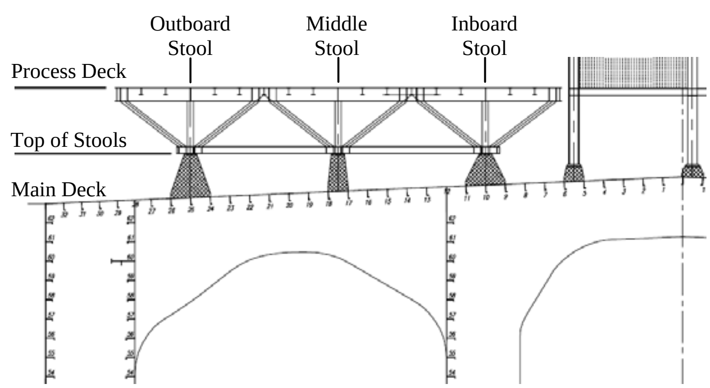

Fig 8. Typical Transverse Section in way of Topside Module

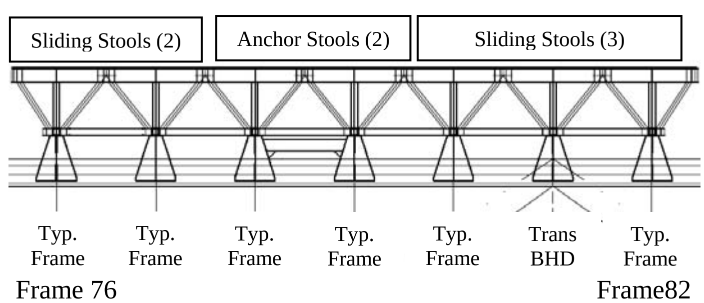

Fig 9. Typical Longitudinal Section in way of Topside Module

The resulting nodal deflections from the analysis of the 46 design load cases on the integrated global FEA model are used to evaluate the magnitude of the vertical deflection present in way of the topside support stools.

The resulting vertical deflections for the 46 design load cases are plotted in Figure 10 for the inboard stool location. The vertical deflections are also plotted for the middle stool location in Figure 11 to illustrate the effect of the under deck structure on the resulting vertical deflections in way of the support stools.

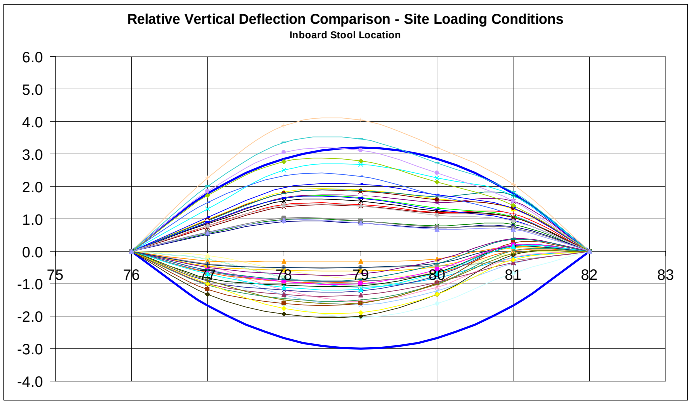

Fig 10. Relative Vertical Deflection (mm) at Inboard Stool Location from Frames 76 to 82

As seen in Figure 10, the presence of the transverse bulkhead at Frame 81 introduces a stiff support point in the deck structure and creates a local hogging deflection around the transverse bulkhead. While the local effect of the transverse bulkhead is evident in Figure 10 in way of the inboard stool, the effect is more pronounced in Figure 11 in way of the middle stool.

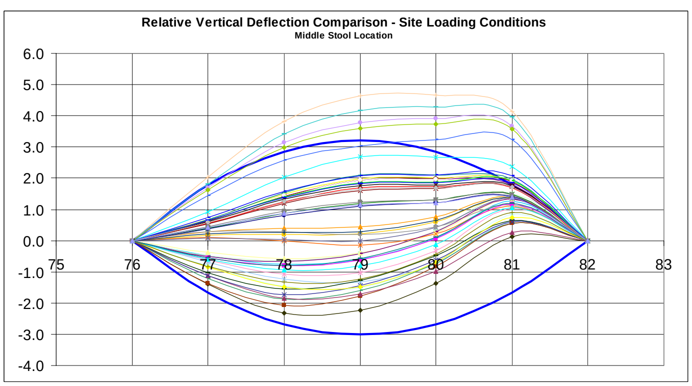

Fig 11. Relative Vertical Deflection (mm) at Middle Stool Location from Frames 76 to 82

As shown in Figure 8, the transverse location of the inboard stool is relatively close to the longitudinal bulkhead, which provides a stiff under deck support and mitigates the local effect of the transverse bulkhead. The middle stool is located near the mid span of the side tank deck transverse, away from the longitudinal bulkheads, and is subjected to greater variations in vertical deflection resulting from the impact of the topside module on the flexible main deck support structure.

The vertical force generated at the interface between the top of the stool and the topside module structure is a function of the loads applied to the model, the distribution of mass in the module, and the relative deflections in the main deck support stools. The vertical force in the support stools dictates the magnitude of the friction force between the structures that must be overcome before the sliding connections will slip.

Iterative Analysis Procedure Results

An iterative analysis procedure, as described in the beginning of this paper, has been performed using Viking Systems' SAGA Software on the topside module presented in this case study. The results of the study indicate that when subjected to 100-year extreme environmental loads, the longitudinal force present at the interface between the topside modules and the support stools will be sufficient to overcome the friction force in the sliding module connections, and the connections will slide and relieve the longitudinal forces applied to the modules and stools.

A comparison of the FEA deflection results from the case study module before and after the iterative analysis procedure is shown in Figures 12 and 13. The model in Figure 12 shows the results for the maximum sagging condition with all fixed connections in way of the anchor stools and in way of the sliding connections. The model in Figure 13 shows the result for the same loading condition after the final stage of the iterative analysis procedure to adjust the physical properties of the connection elements in way of the stool and topside module interface to account for the presence of uplift and / or sliding.

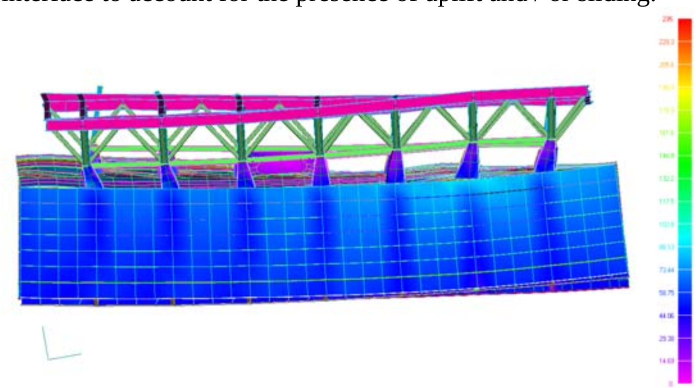

Fig 12. FEA Model Results for All Fixed (Welded) Connections.

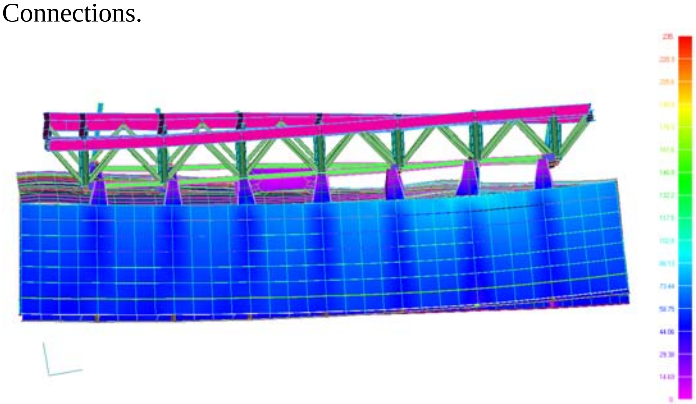

Fig 13. FEA Model Results for Final Iteration representing a sliding system.

Note in Figure 12, that the stools bend since they are more flexible than the deck and the topside beams. Note in Figure 13, that the stools do not bend since the topside beams were able to slide, thus minimizing the effects of the hull girder deformation on the module stools

The final connection details at the completion of the iterative analysis procedure for the elements representing the interface between the topside modules and support stools for the maximum sagging condition shown in Figure 13 are provided in Table 7 below.

Table 7. Final Connection Details from Iterative Analysis

	Frame 76	Frame 77	Frame 78	Frame 79	Frame 80	BHD 81	Frame 82
Inboard	SupportSlip	SupportSlip	SupportStuck	SupportStuck	SupportSlip	SupportSlip	SupportSlip
Middle	SupportSlip	SupportSlip	SupportStuck	SupportStuck	SupportSlip	SupportSlip	SupportSlip
Outboard	SupportSlip	SupportSlip	SupportStuck	SupportStuck	SupportSlip	SupportSlip	SupportSlip

As shown in Table 7, the longitudinal force has overcome the friction force at all sliding connections.

Impact of Iterative Analysis Procedure on Resulting Stress

The FEA results for the analysis model with the all fixed connections and the final connections resulting from the final step of the iterative analysis procedure have been evaluated for all 46 site loading conditions to determine the effectiveness of the analysis procedure on the design and verification of the structure.

The stress results for the four following structural groups have been evaluated to determine the impact of having sliders installed:

- Main Deck Transverse Webs / Bulkheads
- Main Deck Plating
- Main Deck Longitudinal Stiffeners
- Topside Support Stools

The maximum yielding evaluation ratios for each of the four structural groups, before and after the iterative analysis procedure, are presented in Table 8 below.

Table 8. Results of All Fixed vs. Iterative Analysis

	Stress Ratio	Stress Ratio
Location	Max. Fixed	Max. Iterative
Transverse Web Frames	0.58	0.58
Main Deck Plating	0.55	0.51
Main Deck Longitudinals	1.16	0.60
Support Stools	0.77	0.84

As seen in Table 8, the all fixed connection assumption provides an accurate assessment of the maximum stress results for the transverse web frames and main deck plating. The all fixed connection assumption under-estimates the maximum resulting stresses in the stool structure by approximately 10%, and over-estimates the resulting stress in the main deck longitudinal stiffeners by nearly 50%. The distributions of the maximum yield evaluation ratios for the seven support frames for the case study module are shown in Figures 14 through 17 for the main structural groups.

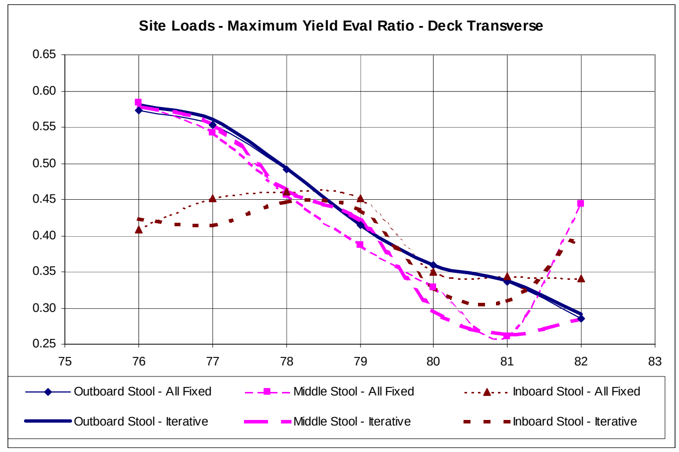

Fig 14. Effect of Sliders on Stress in Deck Transverse

As seen in Figure 14, the stress in the deck transverses is relatively low and the maximum stress is not significantly affected by assuming whether the design is all welded or fitted with sliding connections.

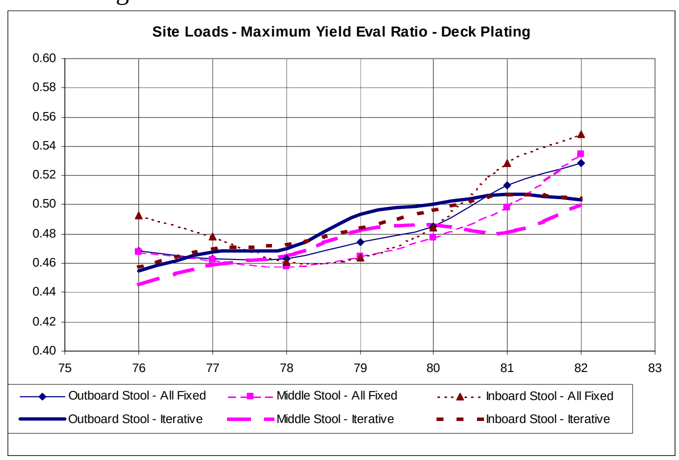

Fig 15. Effect of Sliders on Stress in Deck Plating

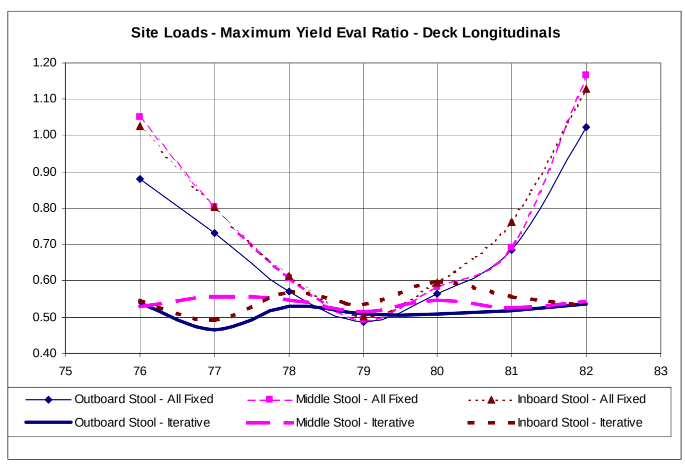

Fig 16. Effect of Sliders on Stress in Deck Longitudinal Stiffeners

As seen in Figure 15, the stress in the deck plating is relatively low and the maximum stress is not significantly affected by assuming whether the design is all welded or fitted with sliding connections.

As shown in Figure 16, the assumption of all fixed connections between the topside module and the supporting stools leads to a significant increase in the deck longitudinal stiffener stresses. At either end of the topside module, the stress in the deck longitudinal stiffeners increases by approximately 100% over the mean stress level at the center of the module. The increase in stress is a result of the bending loads imposed by the stools at the deck connection due to hull girder deformation.

The results of the iterative analysis show the benefit of a sliding connection between the topside module and support stools, as the stress in the deck longitudinals is fairly constant over the length of the module, and is not significantly affected by the presence of the topside module. This result proves that the use of sliding connections like Type A or D (or a flexible system like Type C) allow the use of standard stiffener sizes to resist the topside module loading. This is of importance in tanker conversions to FPSO service where the reinforcement of longitudinals would be costly. For newbuilding the use of Type B connections are often preferred to reduce the amount of connections, but this connection typically requires additional under deck reinforcements.

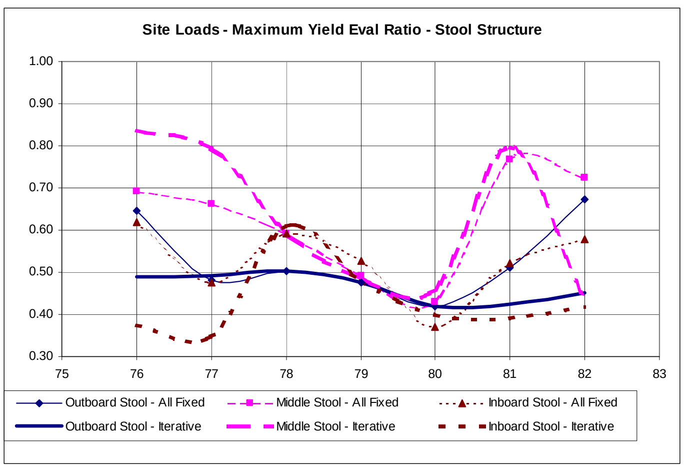

Fig 17. Effect of Sliders on Stress in Stools

The stress in the stool structure is dependent on the number, and location, of stools that slide and those that do not. In the analysis with the all fixed assumption, the longitudinal reaction forces created by the hull girder bending are distributed among all of the fixed connections. With the iterative analysis, the stools that slide are no longer effective in restraining the longitudinal reaction forces from the module. This can increase the total reaction force on the individual stools that do not slide, and results in the increased stress levels shown in Figure 17.

CONCLUSIONS

The design of topside module supporting structures using stools and gussets requires an early assessment of the preferred stool design type. This early decision is likely based on an existing design which is believed to work well from experience and feed back from installations in service, rather than actual engineering calculations on a number of different possible solutions. All methods shown in this paper can potentially be made to work on any FPSO deck foundation, but in each case, advanced methods must be employed to validate the design. As described in this paper, the factors at play affecting the design are many-fold as they come from both FPSO tank loading conditions, assignment of still water shear force and bending allowables, site and transit loads, motions, constructability, and survivability from explosion scenarios.

From the strength and loading interaction combinations between the hull and topside modules, it is therefore concluded that the design of stools and hull reinforcements must be evaluated by advanced analysis methods using a procedure like the one presented in this paper.

The conclusion from the case study presented in this paper and similar case studies performed by the authors on a range of hull types, environment loading, and topside module weights indicate that the effect on the hull structure of sliding connections in the interface between the topside modules and support stools can be evaluated with an all fixed analysis model to allow for a simpler analysis method. As shown in Table 8, the maximum yielding evaluation ratios for the transverse webs and main deck structure are accurately predicted with the all fixed connection analysis.

The stress in the main deck longitudinal stiffeners in way of the support stools is over-estimated with the all fixed connection analysis, and is considered to be very conservative. If the simpler all-fixed connection analysis provides acceptable results in the main deck longitudinals, the structure can be considered adequate for the design loading conditions. However, if the results of the all fixed connection analysis produce unacceptable stress results in the main deck longitudinals, an advanced iterative analysis procedure can be employed to evaluate the effect of the sliding connections. As shown in this paper, the advanced analysis can lead to substantial reductions in the resulting stress in the deck longitudinals.

As shown in Table 8, the stress in the support stool structure is under-estimated with the all fixed connection analysis. In the all fixed analysis, the longitudinal hull deflections are applied to the module through the fixed connections at all stools. In the iterative analysis procedure, as the sliding connections at some stools begin to slide, the other stools that do not slide pick up a greater share of the force resulting from the longitudinal hull deflections. As a result, the stools that are subjected to the greatest vertical load (as the result of stiff under deck structure, applied load, or module mass distribution) provide the greatest resistance to sliding, and can receive a greater level of stress than is predicted with the all fixed analysis. Based upon the experience gained from this case study and others, it is recommended that a 15% factor of safety be applied to the stress results from the all fixed analysis when evaluating the support stool structure for a system fitted with sliders.

The use of an all fixed connection approximation in the analysis of the stool design is only valid if the same stool design is used at all longitudinal locations. If the structure of the support stools is optimized to have unique geometry or scantlings at each frame, a full iterative analysis procedure is recommended to evaluate the impact of the sliding connection on the stools at each frame, as the location of the maximum stress response will move between stools as the connections begin to slide.

If the same structure is used for all support stools, the all-fixed connection analysis can be used in conjunction with the applicable safety factor on the support stool stress to validate the design.

It is recommended that the fatigue analysis uses an all-fixed connection type whether the design employs sliding connections or welded connections. The fixing of sliding connections for fatigue analysis is considered most appropriate since the majority of the fatigue damage will come from less severe loads that are less likely to introduce sliding of the connection.

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