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Structural Integrity and Life Extension of Offshore Installations by Ultrasonic Peening

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Abstract

Extensive life extension studies for a FPSO installation have been carried out. High stressed welds showed too short fatigue lives in as-welded condition. Ultrasonic peening has been selected to extend the fatigue lives of the concerned weld details. The aim with the ultrasonic peening treatment was to avoid any further weld repair and by that contribute to the structural integrity of the installation during its remaining service life.

Fatigue life extension has been achieved by the application of ultrasonic peening to high stressed areas on the pallet stool- and on longitudinal-weld details on the ballast tanks on a FPSO installation.

The fatigue lives for the treated welds were extended to twenty years which is the targeted service life for the installation.

Quality Assurance and Quality Control were covered by Ultrasonic Peening Procedure Specification, applied for every treated weld. It ensures that the treatment is exactly reproduced to achieve the expected life extension.

Despite the variable weld quality encountered on the pallet stool welds the treatment was carried out at perfection and it showed to be relatively easy and straight forward application even in locations of difficult access.

The economical benefits due to reduced maintenance as a result of the ultrasonic peening treatment include:

- Avoidance of long term plan for extensive hot work
- Avoidance of long an unscheduled operational disruptions
- Increased structural safety for the installation during remaining service life
- Ultrasonic peening treatment can be applied while the installation is in operation

1. Introduction

It is the desire of every operator of an offshore installation to ensure the structural integrity during the targeted service life. In many cases the targeted service life is difficult to achieve alternatively the maintenance costs increase to unacceptable levels. Therefore an earlier life extension study of the offshore structure suspected to have structural integrity deficiencies increases the chances to keep the installation working safe for the original alt. extended design life as well as to keep the maintenance costs under acceptable level. An extensive life extension project is being carried out on FPSO Triton [1]. One of the remedies used to achieve the targeted service life on this installation is the ultrasonic peening treatment of weld connections subjected to high stresses.

To ensure the structural integrity of an operating offshore structure there are a number of interacting variables which needs to be taken into account. First of all it would be necessary to achieve the general awareness of the necessity of a life extension study for the installation. This is itself a major challenge. It is of a big concern to integrate, at an early stage into the process of life extension, a number of parties which for one reason or other there are not really convinced that something must be done now to avoid any failure of the structure in a near future. For example some of the damaging mechanisms as fatigue cracking, could show minor defects or cracks at high stressed areas which at this current stage would probably not affect the Class status of the vessel.

Fig 1 Structural integrity failure [1]

However, it should be clear that small fatigue cracks which occurs simultaneously at several locations in the hull and keep developing would have a negative influence on the structural integrity sooner or later, Fig 1.

Furthermore many times the stakeholders are not in favor of unnecessary and/or less apparent cost and/or production disruptions. This is even more accentuate when many of the stakeholders are not Naval Architects or have any possible knowledge of the implications of failure mechanisms in offshore installations.

As a result and even if it would be apparent that prevention of uncontrolled fatigue cracks is necessary every life extension project needs first to address these economical and/or political issues as much as the solutions of any encountered technical problems.

1.1 Ageing effects on offshore installations

The original design life of an offshore installation contains normal scheduled inspection intervals which are correlated towards the Class status of the vessel. However, and taken into account that FPSO vessels are not working under the exact same conditions as normal trading tankers it is crucial the inspections and their results are carefully considered against the consequences of any eventual disruption of operations including personnel safety and/or effects on the environment.

In view of the unavoidable discrepancies between original design life and engineering life it is always necessary to address these discrepancies with a long-term vision. Furthermore every operator has certainly a distinctive opinion about the time until when the installation would be producing crude oil and/or gas. For many different reasons the service life expectation for an installation keeps moving forward in time so a doubling of the original design life is more or less an accepted term today.

As a result the ageing of an installation needs to be taken into account at an early stage of the service life since it has an effect on the installations structural integrity. Thus any extension of the targeted production period would necessary include a life extension program in which all the major factors which play a roll in the ageing of the structure needs to be accounted for.

1.2 Life extension of offshore installations

It is important to note that a life extension program of an offshore installation would need to start even if not any alarming crack is detected at the structure in consideration. The scheduled inspections and subsequent Life Extension Studies which are carried out by LETS Global are to be considered a preventive measure more than a reactive one. The intention is then to prevent any disruption of the normal operation of the installation due to structural integrity failures.

With this perspective in mind it is crucial to “read” from the current clues from inspections, model analysis and measurements what would be necessary to be done in terms of corrections of current and/or future deficiencies to avoid any significant period of downtime.

Our achieved experience on FPSO installations give us a certain base for the selection and subsequent study of the factors which will play an important roll in the structural integrity of the vessel. However, it is necessary to develop an up to date full set of input and not to rely blind in any previous analysis which could contain unknown shortcomings.

For example a new set of load cases need to be incorporated to the analysis and these would also include future potential load cases as new equipment on topsides, increase oil recovery volumes, new on- offload schedules, improved/updated hindcast etc. Sensitivity studies would need to be included for example to prove the robustness of these results. It would be advisable also to implement some type of measurement in situ in the vessel to ensure that the model and its results are reliable and can be trusted as to the selection of locations in the structure which would need attention.

It would be also the intention that such a model could be used in years to come and then reviewed in order to update any changes which would be of significance for the structural integrity of the vessel.

It should be mentioned that other parts in an offshore structure besides the hull are also important from the point of view of the life extension as for example the mooring system. This would also need to be included in a life extension assessment due to its influence on the general structural integrity of the structure.

We will concentrate now and onwards on the structural integrity hull details of a FPSO installation which are sensitive from the fatigue point of view. These details of structural integrity importance, their deficiencies and the suggested remedies are the outcome of the life extension project for FPSO Triton [1].

2. Hull strength analysis

The hull strength analysis represents the behavior of the primary structure. It is based on hydrodynamics results and it is studying specifically the yielding or buckling deficiencies, as for example in the Center Line bulkhead, as well as fatigue sensitive hot spots by means of spectral fatigue.

The full ship or hull strength analysis is the starting point of any Life Extension Study. Therefore special attention must be paid to its accuracy as well as the analysis of its results. Normally it would be carried out by experienced specialist. The example presented in this report has been carried out by Bureau Veritas. Fig 1 shows a typical load case for the hull, vertical bending moment, and its influence on the pallet stools and hence on the structural integrity of the vessel.

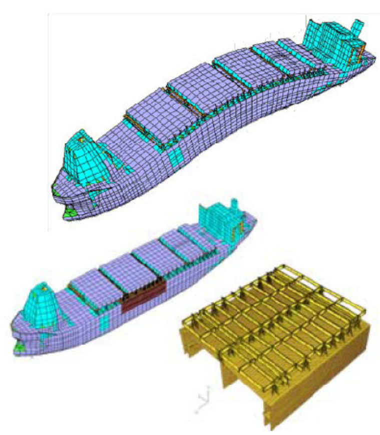


Fig 2 From full ship analysis to local stress analysis (Courtesy of Bureau VERITAS)

Based on the hull strength analysis a number of brainstorms sessions produced a range of deficiencies considered to be the most important or the ones which certainly will limit the targeted service life. The intention is to keep the vessel working on site until 2026. These brainstorm sessions paid considerable attention to the possible remedies and the consequences of every one of them on safety, production and implementing costs.

The remedies were also considered in terms of acceptable time frame since some of the details showing fatigue cracks could not wait until a specific tank will be empty for any scheduled inspection and then conduct a remedial action. Taken into account that the vessel have 12 ballast tanks and the scheduled inspection happens roughly every two years one tank would need to wait six years to receive any needed treatment. In terms of fatigue cracking that would probably mean a fatigue crack growth down to half of the plate thickness. In front of that situation the only remedy would be to carry out a weld repair but that is just what we are trying to avoid. Table 1 presents the areas which need to be considered, the remedies for every one of them as well as consequences if nothing is done, safety and production, and the “urgency” for the selected problems.

	Lower Knuckle	Side shell stiffener iwo web frame	Side shell stiffener iwo bulkhead	Lower cut-out in the hopper longitudinal	Stringers details	Stool connections to longitudinal bh	Center Line bulkhead
	Fatigue	Fatigue	Fatigue	Fatigue	Fatigue	Stress & Fatigue	Stress
2.5% fatigue crack probability occurs:	2011	2014	2008	2011	2014	2011	n/a
20% fatigue crack probability occurs	2020	2025	2011	2015	2025	2018	n/a
50% fatigue crack probability occurs	2030	2039	2017	2026	2050	2026	n/a
Most likely consequence	Leak between ballast & cargo	Leak between sea & ballast	Leak between sea & ballast	Leak between ballast & cargo	Leak between ballast & cargo	Hydrocarbon gas leak to deck	Leak between cargo tanks
Safety Impact	Medium	Low	Low	Low	Low	Medium	Low
Produc. Impact	High	Low	Low	Medium	High	Medium	medium
Repair Impact If no actions taken	High	Medium	Medium	High	High	High	Low
ACTIONS	Blast & Coat	Ultrasonic Peening	Ultrasonic Peening	Blast & Coat	Blast & Coat	Ultrasonic Peening	Vertical stiffeners
	Loading pattern	Blast & Coat	Blast & Coat	Loading pattern	Loading pattern	Blast & Coat	Loading pattern
		Loading pattern	Loading pattern			Loading pattern	
						Connect pallets	

Table 1 Life extension program for FPSO Triton

Table 1 presents the different actions which should be taken in order to remedy the encountered deficiencies. It important to note that in some cases as for example for Center Line bulkhead, the remedy for the deficiency meaning the excessive buckling was achieved by developing an improved planning of the load- and off-load tank sequence.

From the point of view life extension the fatigue sensitive locations are the parts which should need most of attention. These specific parts on the hull, which will be suffering most of ageing effects, will be where the ultrasonic peening procedure [2] would be applied and where it will be most beneficial.

Having said that it is important to note that the application of the ultrasonic peening is not indiscriminate and even if a weld shows too short fatigue life it still would need to be carefully considered the decision to apply ultrasonic peening. Preferably the welds selected for the ultrasonic peening treatment must be full penetration welds. This is to avoid unwanted root failures so any eventual fatigue crack could still be detected during regular scheduled inspections.

The ultrasonic peening has been selected for three sensitive locations on the hull as the preferred remedy. The reason for this preference is that ultrasonic peening can improve the fatigue resistance of a welded connection from a minimum of two and up to four times in life. Furthermore ultrasonic peening can be carried out in parallel to other work activities in the same area and it does not require any habitat.

The three areas selected for the application of the ultrasonic peening are: the weld connections between side shell stiffener in the way of web frames and bulkheads and stool connections to longitudinal bulkheads on cargo deck.

All these connections have been ultrasonic peening treated and/or are under treatment due the large number of ballast tanks and the time required.

In the case of the stool connections the treatment was finished for some four years ago and the fatigue cracking of these weld details have been effectively stopped.

2.1 Web frame and bulk heads

A typical web frame contains a number of weld connections exposed to high stresses and therefore prone to show short fatigue lives. These weld connections are the hopper knuckle, the side shell stiffener, hopper- and inner bottom-longitudinals. When such concerns from the hull strength analysis, are raised inspections would be necessary to confirm if these weld details are showing any signs of coating damage. That could indicate a surpass of coatings strain capacity and hence high level of stresses at that location.

Furthermore it is crucial to inspect the fabrication drawings to ensure the concerned weld connection really is done as full penetration welds and do not contain any weld defect or cracking at the root. In some cases it would be needed to confirm by measurements of plate thickness the agreement or disagreement with the thicknesses indicated in the drawings. The implications of any thickness discrepancy would be self explanatory.

Other sensitive parts located by the hull strength analysis are weld connections at transverse bulkheads. Similarly as for the weld connections from web frames the bulkheads connections to longitudinal are sensitive to loads arising from the horizontal bending moment. As a result the inner bottom longitudinal and the stringer toes and heels showed too short fatigue lives. This connection is shown in Fig 3. We include the inspection picture, the FEA local model and the result of the ultrasonic peening treatment of the location.

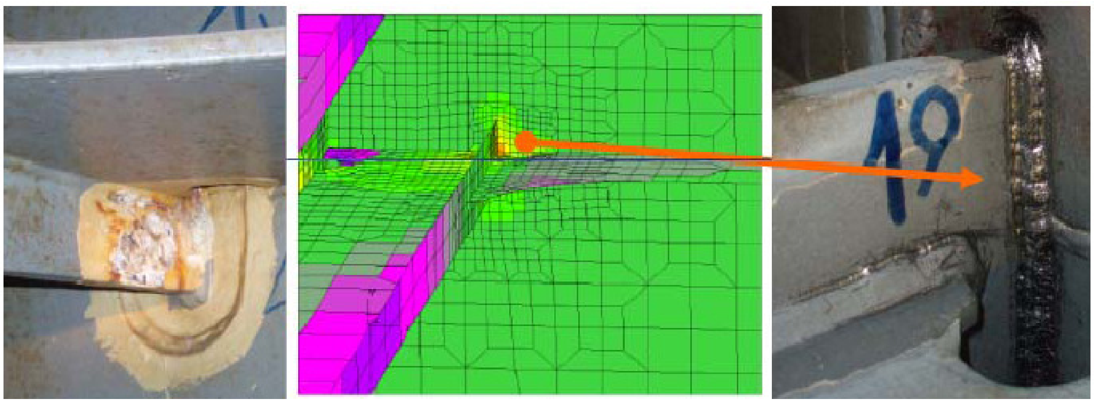
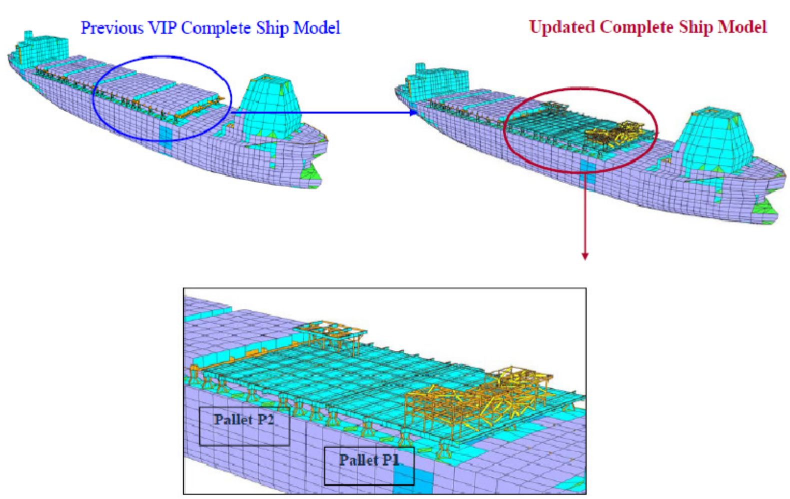


Fig 3 Area inspected, modeled and treated by ultrasonic peening [3]

2.2 Topside stool toes

The production equipment on FPSO Triton is located on the topside and the supporting steel structure is connected to the cargo deck via the pallet stools brackets and its welds, Fig 4. The equipment supporting structure and its mass are considerable more rigid than the hull itself. As a result of this difference in flexibility the weld connections joining the pallet stools to cargo deck experiments high level of stresses. Hence and due to these high stresses relatively low fatigue life was expected. Furthermore it is likely that more equipment will be needed in a near future and therefore more weight will be added to the current supporting structure.



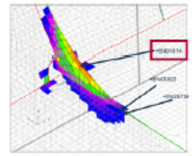
. Fig 4 Detail studies of the pallet stool structure [1]

In the new hull strength analysis the additional equipment on the topsides has not shown any impact on the fatigue results. However the fatigue strength is determined by the connection design as well as by its weld quality. As showed in Fig 5 the areas of major concern are the welds on the toes and on the side of the brackets. The brackets and welds transfer all the weight from topside structure to the longitudinal bulkhead via the pallets stools.

RAOs at bracket edge (element 91814) of Pallet P2

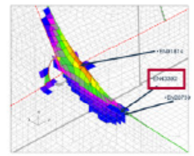
Location	Spectral Fatigue 2.5%	
	Damage for 100 years	Life years
91814 bracket edge	32/10* 26/9 in VIP project	10/3* 11/4 in VIP project

*Note: results given considering grinded/not-grinded flame cut edge



RAOs at deck-bracket weld (element 43392) of Pallet P2

Location	Spectral Fatigue 2.5%	
	Damage for 100 years	Life years
Upper deck weld	10 8 in VIP project	10 12 in VIP project



RAOs at deck-bulkhead weld (element 28739) of Pallet P2

Location	Spectral Fatigue 2.5%	
	Damage for 100 years	Life years
Lower deck weld	9 8 in VIP project	11 12 in VIP project

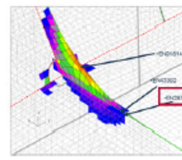


Fig 5 Fatigue results of top load effects on stool toes [1]

As presented in Fig 5 the major concerns arise from the welds on the toes and the sides of the brackets to cargo deck. Furthermore these welds have shown some varying weld quality which by itself could influence the fatigue strength negatively. Therefore these weld connections, have been considered for the application of the ultrasonic peening treatment.

The intention with the ultrasonic peening treatment is to avoid any further weld repair on these weld details during the remaining service life of the installation.

3. Ultrasonic Peening

The degree of fatigue life improvement achieved by the ultrasonic peening treatment is illustrated by the diagram in Fig 6. If we assume a stress range of 200 MPa the number of loading cycles can be increased from $80 \cdot 10^3$ up to $550 \cdot 10^3$ for same 2.5% fatigue crack probability. That is a fatigue life extension of more than four times due to the ultrasonic peening treatment.

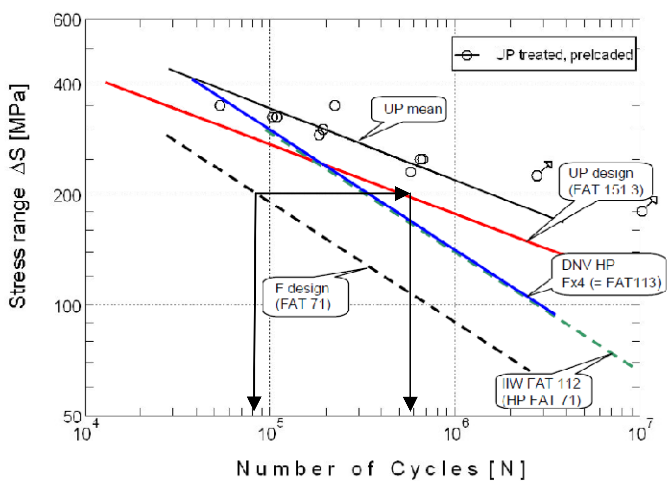


Fig 6 Fatigue life extension achieved by ultrasonic peening [4]

The poor fatigue strength encountered in weld is normally motivated by the following three factors:

- local stress concentration of stress due to the geometric discontinuity;
- the presence of sharp crack-like flaws like undercuts, slag intrusions, cold-laps, etc introduced by the welding process
- the presence of high tensile residual stresses in the weld metal and the surrounding heat affected zone

These three features are modified by ultrasonic peening treatment in one and solely working operation. The creation of a groove at the weld toe eliminates any weld toe defect and decreases the local stress concentration, Fig 7.

Hence the fatigue life extension by ultrasonic peening is achieved in part by the reduction of the geometrical stress concentration at weld toe and in part by the redistribution of weld induced residual stresses.

The redistribution of tensile residual stresses originated during and after welding procedure interacts with the compressive residual stresses induced into the HAZ during the ultrasonic peening treatment. This is illustrated in Fig 6 by the different slope for untreated respective treated welds. The redistribution of residual stresses, including the introduction of compressive stresses, contributes towards fatigue life extension by locally lowering the mean stress.

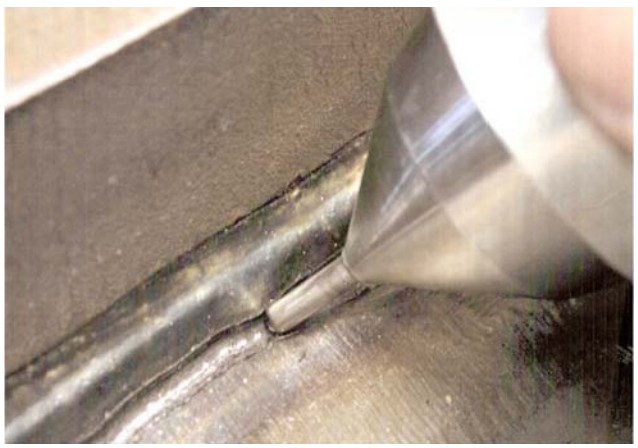


Fig 7 Creation of weld toe groove during ultrasonic peening treatment [4]

The Quality Assurance and Quality Control of the ultrasonic peening treatment is ensured by measurement of weld geometry parameters, documentation of ultrasonic parameters during the treatment as well as extensive photographic documentation of every treated weld [3].

4. Conclusions

In an extensive life extension programme for FPSO Triton the ultrasonic peening treatment was selected to extend the fatigue life of high stressed weld connections. These high stressed welds showed too short fatigue life in as-welded condition.

The aim with the ultrasonic peening treatment was to avoid any further weld repairs during the remaining service life of the installation.

Fatigue life extension has been achieved by the application of ultrasonic peening to high stressed areas on the pallet stool- and on longitudinal-weld details on the ballast tanks of FPSO Triton.

The fatigue lives for the treated welds were extended to twenty years which is the targeted service life for the installation.

Quality Assurance and Quality Control were covered by Ultrasonic Peening Procedure Specification, applied for every treated weld. It ensures that the treatment is exactly reproduced to achieve the expected life extension.

Despite the variable weld quality encountered on the pallet stool welds the treatment was carried out at perfection and it showed to be relatively easy and straight forward application even in locations of difficult access.

5. Acknowledgements

Bureau VERITAS is acknowledged for allowing the use of FEA stress plots. Mr. Ian Williams Coordinator and Manager of FPSO Triton life extension project is greatly acknowledged for allow us to the use his presentation on the FPSO Forum.

6. References

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