Proceedings of the 26th International Conference on Offshore Mechanics and Arctic Engineering
OMAE2007
June 10-15, 2007, San Diego, California, USA

OMAE2007-29051

TN X SN FATIGUE CURVES FOR KS HOOK AND CHAIN USING FINITE ELEMENTS MODELLING AND MODEL TEST

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ABSTRACT

The new scenario of oil exploration in ultra deep water moves forward to 3000 m, has been putting for the companies that accept this technological challenger significant, border of the techno-scientific knowledge. Therefore, nowadays in this case of ultra deep waters, where the forces above the mooring lines are increase and the use of the new material in Petrobras Floating Production Units, it is necessary the good numerical analyses and experimental test by the mooring line. It appears the need to look for a solution for the problems according to the changes of the polyester rope in the production platform without the bottom extension change and its foundation (fixed point). According to this challenge it was necessary to develop a remote connection and disconnection device. This device is the KS hook and its optimization has been created using the fracture mechanical conception optics and computers tools (FEM and mooring software).

There are two conditions to develop this device: one condition is functional and the other is structural. For the functional condition, it's necessary to create the facilities for handling and installations. For the structural conditions, it is necessary to use the special wrought steel material, treatment for steel characteristic and right geometry.

Finite Elements Modeling analyze used the Ansys software, considered the hardness profile material for Minimum Break Load (MBL). The lifetime design is about 25 years for this case and the fatigue analysis considered the residual stress and plasticity for structural device. Previous simulation is especially important in predicting behavior and in the development of new design products before testing. The model was meshed with 3D first order tetrahedral elements solid45. The mesh was sufficiently fine to ensure minimal loss of accuracy in curved geometry.

There isn't a TN fatigue curve (reference API Fatigue curves) for this KS Hook device geometry, in this case become necessary to use the model test to obtain this curve with the extrapolation of the results. The Finite Elements Modeling analyze used with the Material SN Fatigue curve will be used for this validation.

Previous simulation is especially important in predicting behavior and in the development of new design products before testing.

INTRODUCTION

The new scenario of oil exploration in ultra deep water moves forward to 3000 m, has been putting for the companies that accept this technological challenger significant, border of the techno-scientific knowledge. Therefore, nowadays in this case of ultra deep waters, where the forces above the mooring lines are increase and the use of the new material in Petrobras Floating Production Units, it is necessary the good numerical analyses and experimental test by the mooring line. It appears the need to look for a solution for the problems according to the changes of the polyester rope in the production platform without the bottom extension change and its foundation (fixed point). According to this challenge it was necessary to develop a remote connection and disconnection device. This device is the KS hook and its optimization has been created using the fracture mechanical conception optics and computers tools (FEM and mooring software).

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There isn't a TN fatigue curve (reference API Fatigue curves) for this KS Hook device geometry, in this case become necessary to use the model test to obtain this curve with the extrapolation of the results. The Finite Element Modeling analysis used with the Material SN Fatigue curve will be used for this validation.

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MOTIVATION

The KS hook geometry doesn't have specific Fatigue TN curve. The KS40 and KS50 Hook has high load capacity equal of the 95mm chain and 120 mm chain, grade 4. The 120 mm chain G4 has 1400 t MBL and a long fatigue life. To test the fatigue life it is very expensive and there is the possibility to damage the traction test machine. Because of this it was necessary to look for an alternative solution for fatigue test. First solution was the analysis using the finite elements with the feature material SAE 4340 steel fatigue SN Curve and to compare with the 120 mm Chain grade 4 fatigue SN Curve.

Second solution, there isn't a TN fatigue curve (reference API Fatigue curves) for this KS Hook device geometry, in this case it is necessary to use the model test to obtain this curve with the extrapolation of the results. The Finite Elements Modeling analyze (Stress concentration Factor) used with the Material SN Fatigue curve will be used for this validation.

FINITE ELEMENT MODELLIG

Finite Elements Modeling analyze used the Ansys software, considered the hardness profile material for Minimum Break Load (MBL). The lifetime design is about 25 years for this case and the fatigue analysis considered the residual stress and plasticity for structural device.

Previous simulation is especially important in predicting behavior and in the development of new design products before testing.

The model was meshed with 3D first order tetrahedral elements solid45. The mesh was sufficiently fine to ensure minimal loss of accuracy in curved geometry.

The Figure 1 shows the geometry of the KS12 hook for the model test. This KS12 Hook represent the same geometry of the KS40 and a 1/3 reduction of KS40 size.

Figure 1 – KS12 Hook Solid 3D Modelling.

The Figure 2 shows the regions of applied load and radial restrictions. The total applied load was 2450 KN.

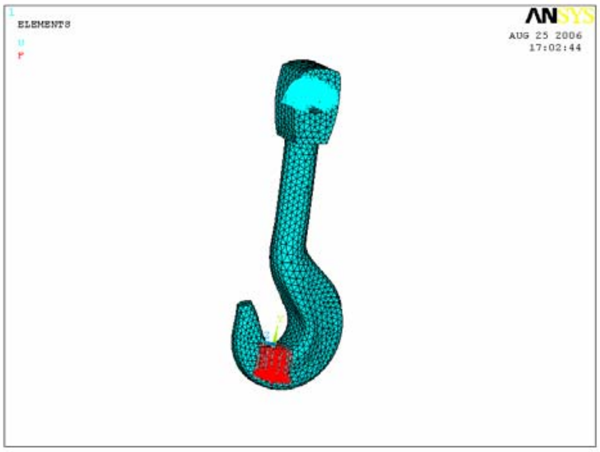
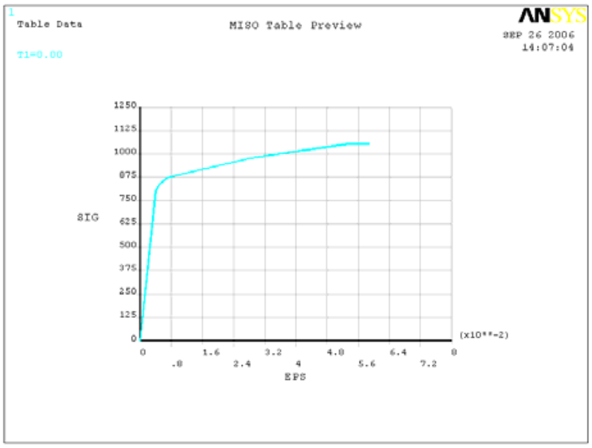


Figure 2 – KS12 hook with the regions of applied load and radial restrictions.

The Graph 1 shows steel forged SAE4340 Strain versus Stress Curve.



Graph 1 – Steel Forged SAE4340 Strain x Stress Material Curve.

The Figure 3,4,5 and 6 show the result of the proof load test used in the FEM.

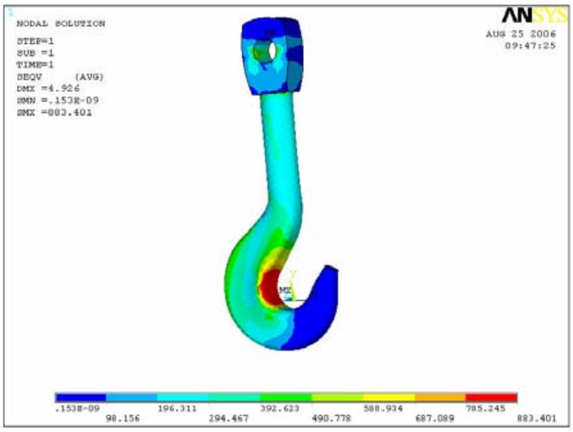


Figure 3 – Proofload Equivalent stress Diagram

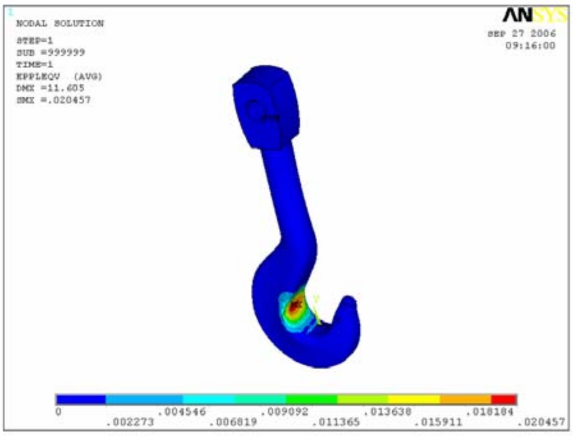


Figure 4 - *Proofload* Equivalent Strain Diagram

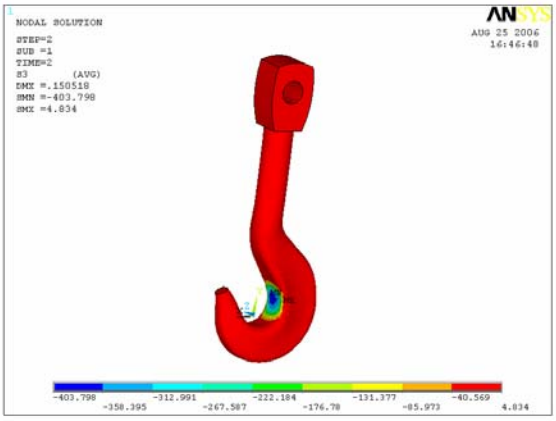


Figure 5 – Residual Compress Stress (s3) after KS12 Hook proofload.

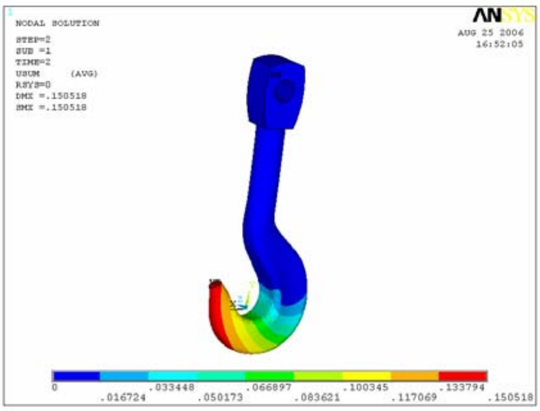


Figure 6 – Strain Total in the proofload

The Figure 7 shows the Equivalent Stress with 25% dynamic load applied to the fatigue test.

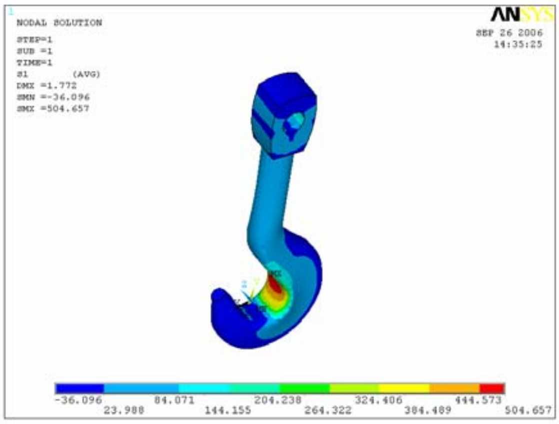


Figure 7 – Equivalent Stress with 25% Dynamic Load

FATIGUE TESTING CONDITIONS

According to table 1, the procedure KS12 Hook Fatigue Test has been using the traction Machine in the load application of 20% MBL average load of the 12 Hook (312 tf), with an associated dynamic load of the 15%, 25%, 30% and 35% MBL (+ 7,5 %, +12,5 %, +15 % and +17,5% of the MBL);.

For this test it's necessary high load application and a lot of cycles.

Table 1 – Load Condition

Dynamic Load	Minimum Load	Maximum Load	Average Load	Load Amplitude
46,8 tf	39 tf	85,8 tf	62,4 tf	15% of the MBL(312 tf) hook
78 tf	23.4 t	101,4 t	62,4 t	25% of the MBL(312 tf) hook
93.6 tf	15,6 t	109,2 t	62,4 t	30% of the MBL(312 tf) hook
93.6 tf	15,6 t	109,2 t	62,4 t	35% of the MBL(312 tf) hook

Notes:

1. It's necessary at least more two hooks with 30 % of MBL average load. To check the average load influence.

2. There will not be fatigue test in the point of 30% hook break load (312 tf) dynamic amplitude.

Figure 8 – Mechanical, Equipments, corrosion and Technological Material Petrobras CENPES Laboratory,

Figure 9 – Hook Fatigue test Arrangement 3D draw

Figures 10 and 11 – KS12 Hook with and shackles and chain links connection Details

Figures 12 and 13 – General Hook arrangement

Table 2 – KS12 hook hardness (Brinell)

Hook no	Hardness Brinell
01	302
02	300
03	300
04	311
05	302
06	302
07	311
08	302
09	311
10	311
11	300

FATIGUE TESTS RESULTS

The first KS12 Hook, ruptured in 252.000 cycles, this result is satisfactory and conform to table 1, it is a good Fatigue Life performance.
The pictures below show the details about the KS12 hook fracture.

Figure 14 and 15 – The Details about the KS12 hook fracture.

Figure 16 and 17 – The Details about the KS12 hook fracture.

Figure 18 – The General Details about the KS12 hook fracture.

Figure 19 – The Position of KS12 hook fracture

The second Hook fractured in 342,000 cycles.

Figure 20 – The Details about the second KS12 hook fracture.

THE KS50 HOOK FATIGUE ANALYSIS USING THE FEM RESULTS AND THE SN FATIGUE CURVE OF THE SAE 4340 HOOK MATERIAL.

Finite Elements Model Results

According to the Figure 21, the maximum equivalent value obtained is 760 MPa in the spot stress point where the stress are tractions according to the display of the tensions 3 in the main diagram of in the Figure 22.

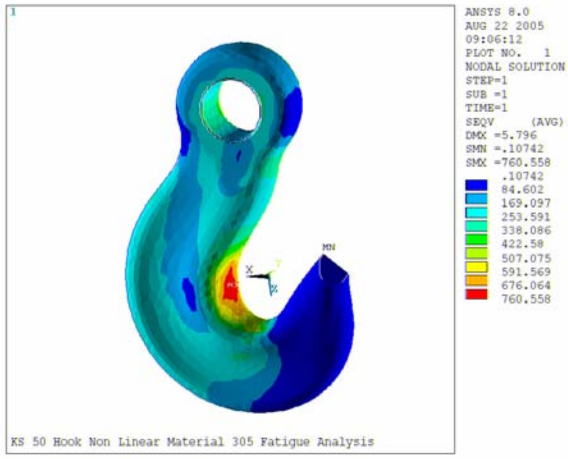


Figure 21 – Equivalent Stress Diagram

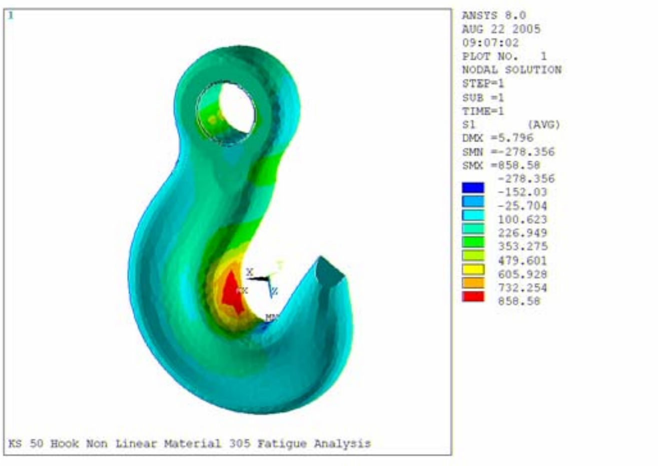


Figure 22 – Main Traction Tension Diagram

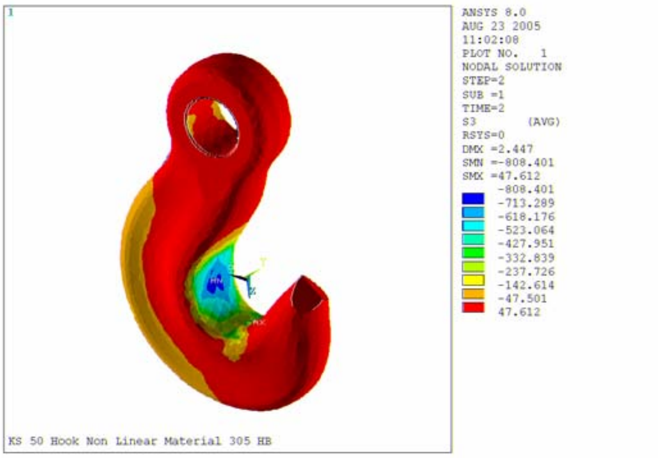
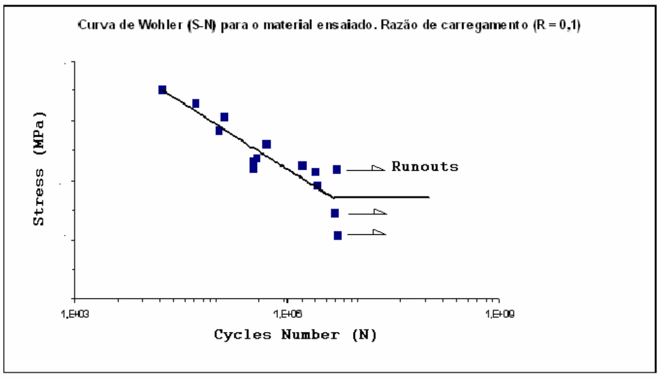


Figure 23 – Compress Residual Stress (s3) after the *proof load* of the 120 mm chain G4

The Fatigue Analysis Using the FEM Results and the Graph 2 of the SN Fatigue Curve of the SAE 4340 Hook Material

Using the Graph 2 of the Fatigue results for the hook material below, it is obtained the estimate of the approximate life (200,000 cycles). The 200,000 cycles value is higher than the 39,000 cycles value (obtained in API formula) for the 120 mm G4 chain with the same dynamic load. This first analyze did not consider the residual stress in the spot stress point but the result is satisfactory for the hook KS fatigue life.



Graph 2 – SN Fatigue Curve of the SAE 4340 Hook Material (Reference: UFRGS University)

THE KS50 HOOK FATIGUE ANALYSIS USING THE SN CHAIN FATIGUE CURVE

Evaluation of a Fatigue Curve

The fatigue curve has the following expression:

$$N.S^m = a_D$$

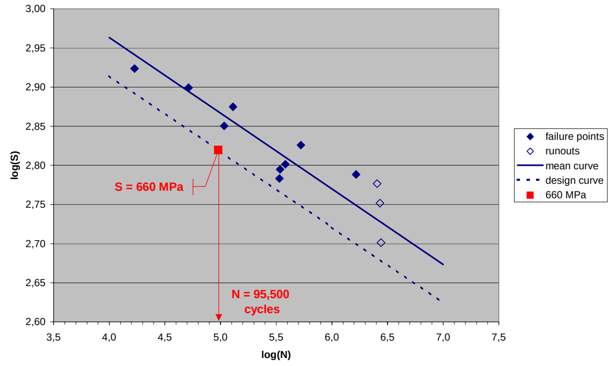
where:

- N is the number of stress ranges (cycles);
- S is the stress range in MPa;
- a_D is the intercept of the S-N curve;
- m is the slope of the S-N curve.

Using the data obtained for the material of KS50 hook and taking in account the mean tension of the tests (Goodman expression) the parameters of the mean and design curves are shown on table below. The runouts were not taken in account to obtain the mean curve. The design curve is the mean curve minus twice the standard deviation.

	a_D	m
Mean curve	4.56×10^{34}	10.346
Design curve	1.42×10^{34}	10.346

Using the design curve and considering a stress range (S) of 660 MPa the number of cycles N will be approximately 95,500 cycles. See Graph 3 below showing the fatigue data and the curves in a log(S) x log(N) graph and the point considered.



Graph 3 – The Fatigue Data and the Curves in a log(S) x log(N)

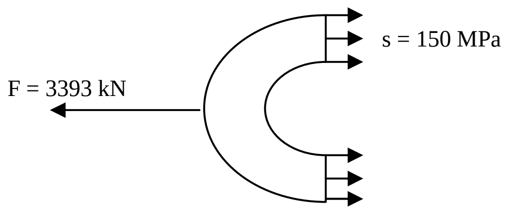
The fatigue life of KS hook is greater than chain even considering the factor 2 stated by DNV OS-E301 (Chapter 2, Section 2, item F 204, page 36).

The Use of SN Fatigue Curve Chain

The problem to use this curve is the KS Hook accessories doesn't have specific fatigue SN curve, in this case it is necessary to use the extrapolation to the SN fatigue curve Chain.

The use of SN fatigue curve Chain [3] for free corrosion (m = 3.0 and a_D = 12.436) and the stress concentration of 660 MPa don't correspond to the fatigue life of the KS hook as explained below. These fatigue curves use the stress concentration factor only during the chain curve creation. To use this curve is necessary to take the tension and divide by cross section area to obtain the input stress value.

For the use of the Chain SN Fatigue Curve, taking the example of a 120 mm chain it's necessary 3393 kN tension range and the division of the chain cross section area (2.262 x 10^{-2} m²). So the stress will be 150 MPa.



The paper OTC 8148 [1] shows that the stress concentration factor is 3.87 for a stud chain which the length of the link is 6 times the nominal diameter. So the stress range will be 580 MPa (3.87 x 150). If the b1 curve is used for this chain, the fatigue life will be 13951 cycles. This number is lower than the 35546 cycles, if the fatigue curve for chain in seawater [4] is used.

CONCLUSIONS

If the fatigue curve for chain is used to extrapolate the fatigue life for KS Hook, the stress range cannot be 660 MPa. The fatigue strength must not be evaluated according to the stress concentration factor.

If the stress is 71.3 MPa (tension range over cross section area) the fatigue life of KS Hook will be 7.7x 106 cycles. The KS cross-section area is 47.6 10-3 m².

In this case using the fatigue curve for chain the fatigue life for the hook KS50 will be 7.7x 106 cycles. This result assists our expectation.

Using the Graph 1 of the fatigue results for the hook material, it is obtained the approximated estimate life (200,000 cycles). The 200,000 cycles value is higher than the 39,000 cycles value (obtained in API formula) for the 120 mm G4 chain with the same dynamic load. This first analysis did not consider the residual stress in the spot stress point but the result is satisfactory for the hook KS fatigue life.

For the second analysis, according to the Figure 4, the compress residuals stress considered the main values 1 difference of the stress with compress stress module. The difference obtained a result smaller than 100 MPa. When applying this result directly in the fatigue SN curve for the steel SAE4340 (Graph 1), finally for this case the fatigue life for the hook KS50 will be infinite.

The solution: there isn't a TN fatigue curve (reference API Fatigue curves) for this KS Hook device geometry; in this case it is necessary to use the model test to obtain this curve with the extrapolation of the results. The Finite Elements Modeling analyzes (Stress concentration Factor) used with the Material SN Fatigue curve, will be used to predict the result.

According to table 1, the procedure KS12 Hook Fatigue Test has been using the traction Machine in the load application of 20% MBL(312 tf) average load, with an associated dynamic load of the 35% MBL (+17,5% of the MBL).

The first KS12 Hook ruptured with 252,000 cycles, this result is satisfactory, and it is a good Fatigue Life performance. The second KS12 Hook fractured in 342,000 cycles. The Third KS12 Hook didn't fracture in 500,000 cycles, the fatigue test stopped (run out).

According to graph 4, the SN KS Hook Fatigue curve predicted the result with an associated dynamic load of the 35% MBL using the Finite Elements analysis (the stress is around 600 MPa). The result was 251,000 cycles (SN Design Fatigue curve). This result will be 750,000 cycles, if the Mean Fatigue Curve is used.

The model test result will validate the fatigue life analyses.

ACKNOWLEDGMENTS

The authors would like to thank the University of Rio Grande do Sul for the technological cooperation.

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