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Production of gas and oil from deep, high pressure, high flow-rate wells requires the use of tubing connected at regular intervals by high integrity joints. Premium connections must provide good gas tightness, joint strength, and corrosion resistance.

This paper outlines the newly developed premium threaded connection, ***FOX****, which incorporates a pitch change concept to alleviate the high tooth peak loads exhibited by conventional threaded connections. This leads to an efficient transfer of load between the components of the joint and an increase in the sealing strain energy combined with the modified metal-to-metal triple radius seal to reduce local stress concentrations.*

1 Introduction

Recent oil and gas production conditions have characterized by increasing well depths, and higher pressures, temperatures, and flow rates, resulting in a need for higher technology. Conventional API standard connections do not meet the technical requirements of such condition, and increased sealing capacity and joint strength are necessary.

Premium connections were developed, threaded, and sold by speciality companies until several years ago. Since then, mill threading, that is, threading of the pipe by the steel manufacturer, has come to be preferred by oil companies. Mill threading permits integrated quality assurance covering both pipe body manufacture and threading of the connection. In 1983, Kawasaki Steel Corporation began development of a connection to meet the aforementioned requirements. This was a joint development project with Hunting Oilfield Services Limited, and was completed in 1985. A novel threaded and coupled connection was successfully developed incorporating a "pitch change" concept that results in even thread load distribution.

The "pitch change" concept greatly increases the stored energy at the contoured metal-to-metal triple radius seal and ensures pressure tight sealing under extreme loading and rapid temperature change conditions. The connection developed is called **FOX**. This paper describes the design of the FOX premium connection and outlines test results which have confirmed the structural integrity of the connection.

2 Load Distribution on Typical Threaded Connections

Increasing well depths in the fields being developed today has led operators to demand threaded connections with metal-to-metal seals to seal against high down-hole pressures. **Figure 1** shows typical connection design. The majority of connections are based on the tried and field-proven API buttress thread form with seal features included.

Metal-to-metal seals are made effective by screwing and torquing up the male and female members of the joint until a high bearing pressure is obtained across the seal face. In theoretical analysis, finite element analysis (FEA)[1] has shown that this bearing pressure is created primarily by the thread teeth adjacent to the seal. Other thread teeth contribute little to the generation of bearing pressure. This results in deformation of the threads near

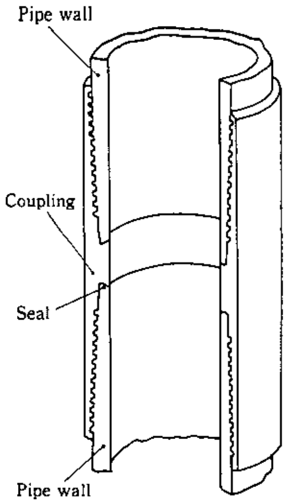


Fig. 1 Typical joint design

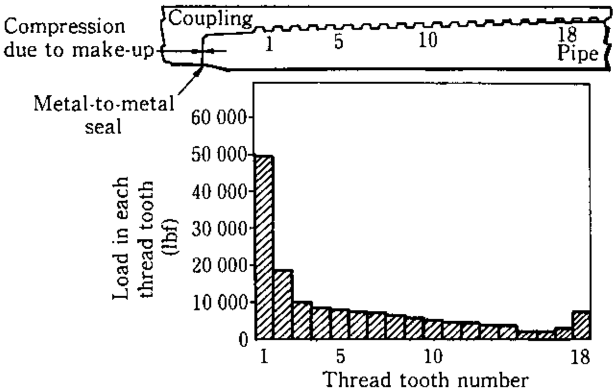


Fig. 2 Typical thread load distribution of pre-loaded connection (5 ½″ × 0.361″ API 5CT L80)

the seal which can result in galling when joints are assembled and broken-out. This is usually unacceptable, and the threads have to be re-cut. **Figure 2** illustrates the distribution of tooth loads during initial make-up.

When a number of pipes are assembled and hung vertically in a well, the uppermost pipes are subjected to high tensile loads due to the weight of the assembled pipe. Analysis and testing have shown that the teeth at the ends of the threaded region bear the majority of the tensile load during the transformation of load from the pipe to the coupling. **Figure 3** shows the theoretical load distribution determined by FEA. This distribution results in high stresses at the outer edge of the coupling, inducing outward belling of the coupling which can cause disengagement of threads and eventual parting of the pipe and coupling.

3 Modifying Thread Load Distribution

Using microcomputer modelling techniques, several

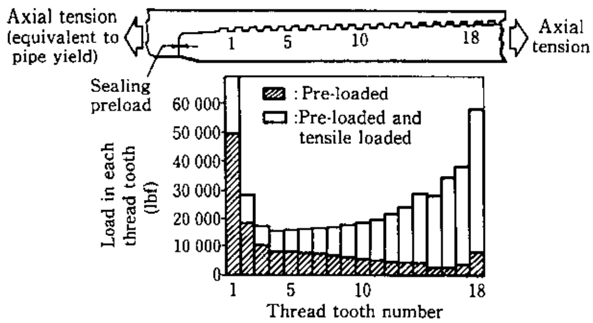


Fig. 3 Typical thread load distribution of pre-loaded and axial tensile loaded connection (5 ½″ × 0.361″ API 5CT L80)

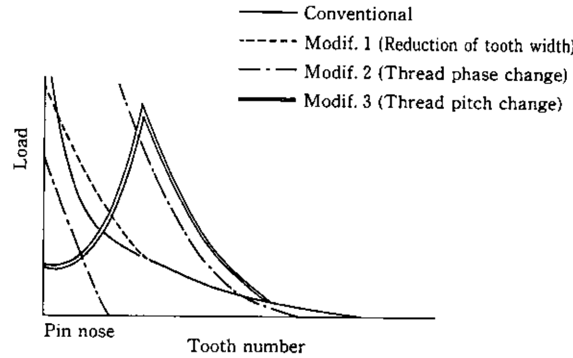


Fig. 4 Thread load distributions of pre-loaded connection

fundamental thread modifications were evaluated and the effects of the revised load transfer characteristics on the performance of the connections was predicted. The modifications studied have become possible only with the widespread availability of computer controlled lathes.

(1) Modification 1

The theory propounded previously shows that tooth and bulk compliance are the significant factors in determining tooth load distribution. It can therefore be concluded that if the compliance of highly loaded teeth could be reduced, these teeth would undergo further strain, redistributing the load to other teeth. A simple, practical method of reducing tooth compliance is to locally progressively reduce tooth width. **Figure 4** shows a comparison of the load distribution in a typical pre-loaded connection with that of a similar connection with teeth of progressively reduced thickness in the highly loaded areas. The comparison shows that thread tooth width reduction only offers a marginal improvement in load distribution.

(2) Modification 2

The published techniques for improving thread load

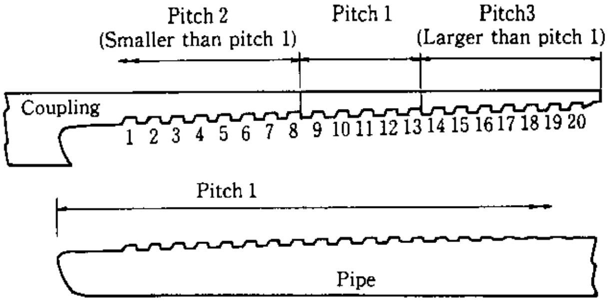


Fig. 5 FOX special thread modification design concept

distributions mostly depend on methods of generating deliberate gaps between teeth in unloaded threads. With modern machining equipment, it is possible to effectively pause during a continuous thread cutting operation. This pause causes a phase change in the thread at the pause point so that the threads on either side of the pause point are of identical pitch but of different phase. Figure 4 shows the pre-load distribution in threaded connections with and without optimized thread phase change. At the point of thread phase change, a dramatic redistribution of load occurs. Using this method, areas of the thread teeth may be effectively unloaded so that other design features such as seal grooves or ports may be included at such sections without affecting the performance of the connection.

(3) Modification 3

The preferred technique for creating gaps between the teeth has been the pitch change technique. Pitch change is incorporated by instantaneously increasing or decreasing the rate of the axial traverse insert tool during the threading operation. The embodiment of this concept is achieved by increasing the thread pitch in the region near the end of the coupling and reducing the pitch in the region near the shoulder of the coupling, with a pin of constant pitch (**Fig. 5**). There is another embodiments of the concept. For example, it may be achieved by reducing the thread pitch in the region near the shoulder of the coupling and in the pin thread run out region. In a properly assembled condition, the only box and pin thread flanks in contact lie in the central portion of the thread where the pitch is the same for the two components. To either side of the central portion, small gaps exist between the pin and box thread flanks, and these gaps progressively increase towards two ends.

When a pre-load is generated by torquing the joint, the pin is axially compressed and the flank gaps which exist between the central portion of the thread and pin nose are progressively closed until the flanks eventually make their own contribution to reacting the pre-load, in addition to those in the central portion (**Fig. 6**). On the

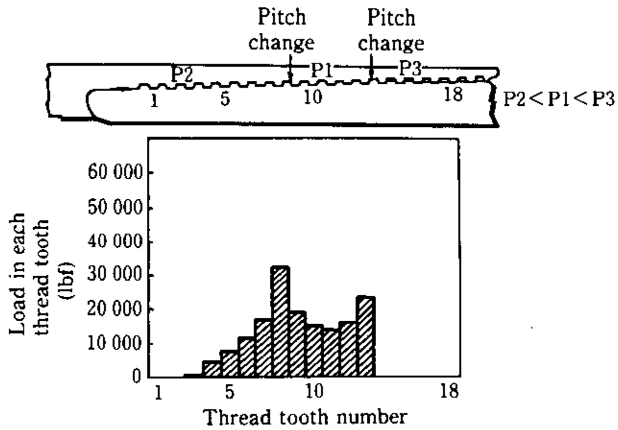


Fig. 6 Thread load distribution of pre-loaded connection with pitch change (5 ½" × 0.361" API 5CT L80)

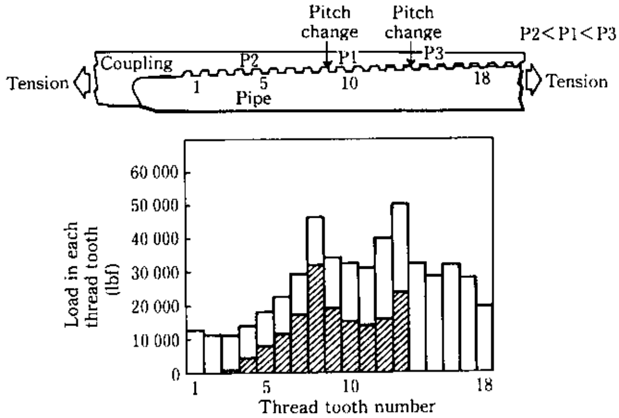


Fig. 7 Thread load distribution of pre-loaded and axial tensile loaded connection with pitch change (5 ½" × 0.361" API 5CT L80)

application of tensile load, the flank gaps which exist between the central portion of the thread and outer end of the coupling are progressively closed until these flanks make their own contribution to reacting the tensile load, in addition to those in the central portion (**Fig. 7**).

Since a greater proportion of the tensile load is transmitted by the central portion of the thread, peak loads are lower than in conventional thread, reducing the risk of coupling belling and thread disengagement. Further, with improved distribution of load along the thread, local stress concentrations are reduced, resulting in better resistance to fatigue.

4 Characteristics of FOX Connection

As described above, one of the most characteristic features of the FOX connection is even load distribution on thread teeth. From a comparison of Figs. 2 and 6, comparative characteristics may be summarized as follows:

(1) More turns of the FOX thread make a significant

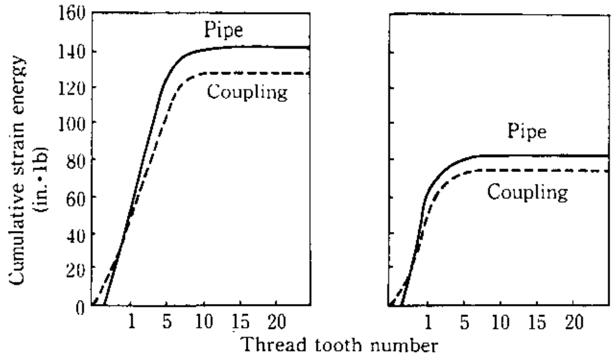


Fig. 8 Comparison of sealing feature stored energy between FOX premium joint and conventional

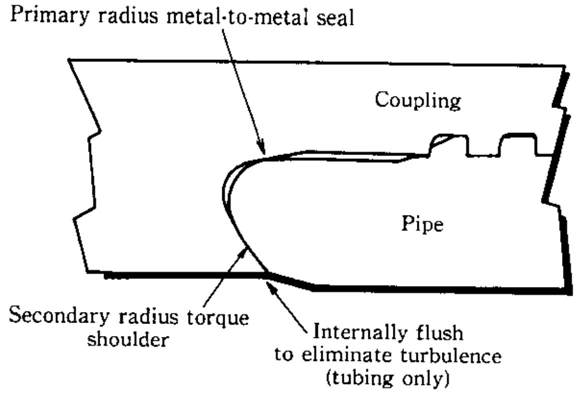


Fig. 9 Design principles of FOX contour seal

contribution to generating sealing pre-load than in conventional thread.

(2) Peak loads, and hence tooth root stresses, are 30% smaller in the FOX thread than in conventional thread.

(3) The central portion of the FOX thread carries the bulk of the pre-load, while only the first few turns carry the bulk of the load in conventional thread.

Plots of strain energy induced in the pin and coupling were obtained for conventional and FOX connections from the finite element analysis, as shown in **Fig. 8**. These plots confirm the prediction that the strain energy stored across the metal-to-metal seal in the FOX connection is significantly (about 80%) greater than in conventional connections.

Figures 3 and 7 show plots of finite element analysis results of thread load distribution under tensile loading. The load pattern was obtained with tensile loading sufficient to cause 100% pipe yield. These results are summarized as follows:

(1) The variation in thread load distribution is much greater in conventional thread than in FOX thread.

(2) The peak tooth loads, and hence tooth stresses, are greater in conventional thread.

(3) The central portion of the FOX thread carries the bulk of the load while only the extreme ends of conventional thread carry the bulk of the load.

Reduction of tooth load at the outer end of thread and the more uniform load transfer in the FOX connection has the advantage to reduce coupling belling and the tendency to jumping-out which lead to joint pull-out.

Premium joints contain metal-to-metal seals where a high local compressive stress is generated at an interface between the pin and box as a result of applying torque to the joint. The seal will be effective so long as the fluid pressure does not exceed the bearing pressure of the seal. A commonly used seal design comprises a sharp corner. A high compressive stress is induced in the short taper surface to create the seal. This seal design, however, is vulnerable to high stress concentrations at the sharp intersection. Fractures in this region are regularly reported. The contour seal used in the FOX connection comprises a pin seal with a smoothly curved profile engaging a sealing surface of corresponding profile in the coupling, as shown in **Fig. 9**. With the availability of CNC machines, the machining of such profiles is now a simple and practical proposition. Because of the generous blendig radius which this design allows, local stress concentration is reduced, giving better resistance to overtorquing. A more gradual lead-in during make-up is achieved than with the conventional sharp corner design, and the principle of triaxial compression is included. Sealing is achieved as a result of a combination of radial and axial compression of the pin nose.

To verify the reliability of FOX connection features, trials were performed on actual connections. These are described in following sections.

4.1 Make-Up and Break-Out

Figure 10 shows the torque-turn curve of a FOX connection and of a conventional connection without pitch change. From these curves, it is understood that the number of turns after the shoulder torque in the FOX

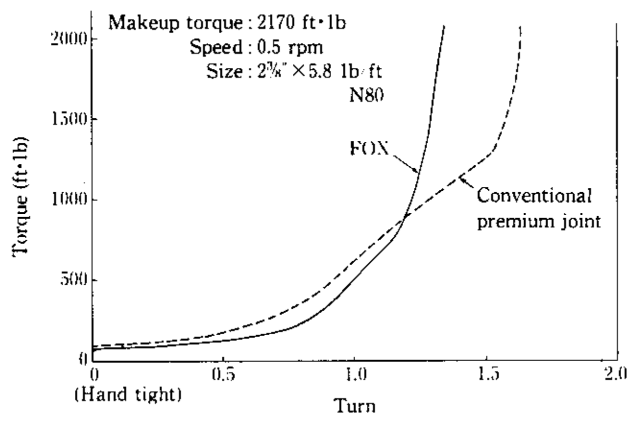


Fig. 10 Example of makeup torque-turn curve

Table 1 Results of make-and-break test and gas leak test of FOX connection

	Size / grade	5½"×20lb/ft	7"×32lb/ft		9⅝"×53.50lb/ft
		L80	L80		L80
Make-and-break test	Make up torque	6500 ft·lb	11080 ft·lb		1400 ft·lb
	No. of make-and-break repetition	10	10		10
	Result	No galling	No galling		No galling
Gas leak test	Tension	80%SMYS	80%SMYS	80%SMYS	85%SMYS
	Bending	10°/100'	10°/100'	—	10°/100'
	Internal pressure	80%SMYS	80%SMYS	80%SMYS	80%SMYS
	No. of themal cycling between 120° and 20°C	—	—	10	—
	Result	No leakage	No leakage	No leakage	No leakage

connection is larger than in the conventional joint. This fact results from the existence of a load flank gap near the torque shoulder in the FOX connection, which makes larger part compressible when the connection is pre-loaded at the seal portion. On the other hand, because the conventional connection has no load flank gap, the compressible length is extremely short when the connection is made up. If the number of turns after the shoulder tourque is larger, torque value can easily be controlled in the make-up operation for running tubing or casing. As shown in Fig. 8, sealing stored energy is 80% higher in the FOX connection than in a conventional connection because of the difference of compressible length in the sealing portion. In general use, the connection is made-up and broken-out several times. It is therefore very important to avoid damage or galling of the thread and seal surface.

In order to confirm the make-up and break-out characteristics of the FOX connection, a number of make-break tests were performed. Some results of these test are listed in **Table 1**; no damage or galling was observed.

4.2 Leak Test

Gas leak tightness is one of the most important features of premium connections, especially for use in deep and high-pressure gas wells. To verify gas leak tightness, leak tests were carried out using N_2 gas to pressurize the connection. Some results are tabulated in Table 1. Premium connections are sometimes exposed to rapid temperature changes such as accompany steam injection or acidizing. For this reason, a gas leak test was conducted with thermal cycling. No leakage was appeared (**Photo 1**).

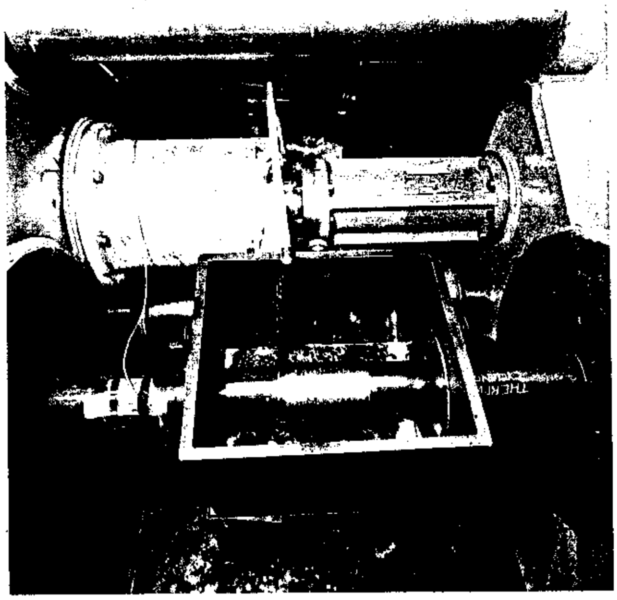


Photo 1 Thermal cycle test

To determine the stress change on the outer surface of the coupling under internal pressure, strain gages were attached to the surface of the coupling. The test piece pressurized hydraulically. The results are shown in **Fig. 11** for the FOX connection and a conventional connection without pitch change. It is clear that hoop stress on the FOX connection was lower than that on the conventional connection.

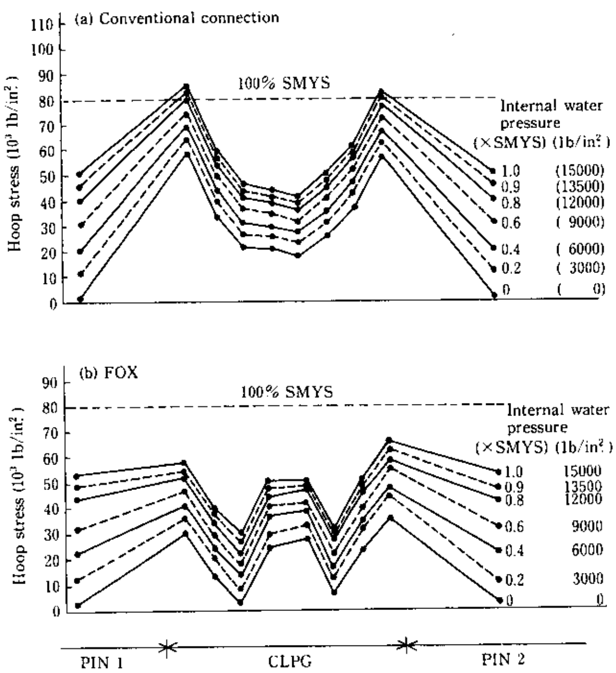
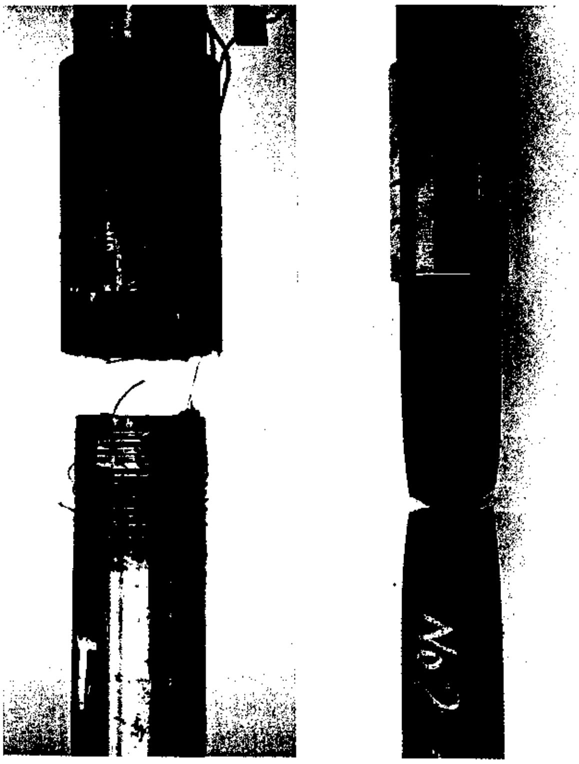


Fig. 11 Hoop stress under internal water pressure (2 ⅜" × 0.254" L80)

4.3 Tensile Test

In actual well condition, tensile load is applied to connections by the dead weight of the tubulars or by thermal change load. Therefore, connections must possess sufficient strength to maintain integrity under these tensile loads. A tensile test to fracture was performed on a 2 ⅜" O.D. size FOX connection and a conventional



Conventional joint FOX premium joint

Photo 2 Appearance of tensile failure specimens

connection. The fractures occurred on pipe body in the FOX connection, but on the thread in the conventional connection. Thread shear was observed in the conventional connection, caused by thread load peak on the end of the connection without pitch change. The appearance of the fractures in the tensile test is shown in **Photo 2**.

4.4 SSC Test

When the tensile stress on the connection is of fairly high levels, fracture is caused by H_2S in sour well.

SSC tests were performed under combined load on a FOX connection on a Kawasaki special OCTG for sour service (KO 90SS 7" O.D.). The test conditions and their results are shown in **Table 2**. The inner surface of the specimen was exposed to the solution. Failure was not observed with No. 1 or No. 2. Hoop stresses on the surface of the coupling were measured after make-up; the results are shown in **Fig. 12** for a FOX connection and a conventional connection. The FOX connection showed lower hoop stresses than the conventional connection, indicating superior performance in sour service.

4.5 FEA and Experimental Results

Although FEA has become more popular for analysis of stress level in connections, it is important to compare the FEA results with experiment by strain gauge measurement. The FEA analysis procedure is shown in **Fig. 13**. Test piece and grade were 3 ½" × 9.2 lb/ft and API

Table 2 SSC test results of FOX connection

Test specimen	Test condition				Result
	Internal pressure (SMYS*1)	Tensile stress (SMYS*1)	Solution	Exposed period (h)	
No. 1	0.1	0.8	NACE sol.*2	720	No failure
No. 2	1.0	1.0	NACE sol.	720	No failure

*1 Specified minimum yield strength

*2 0.5%CH_3COOH, 5%NaCl, H_2S saturated

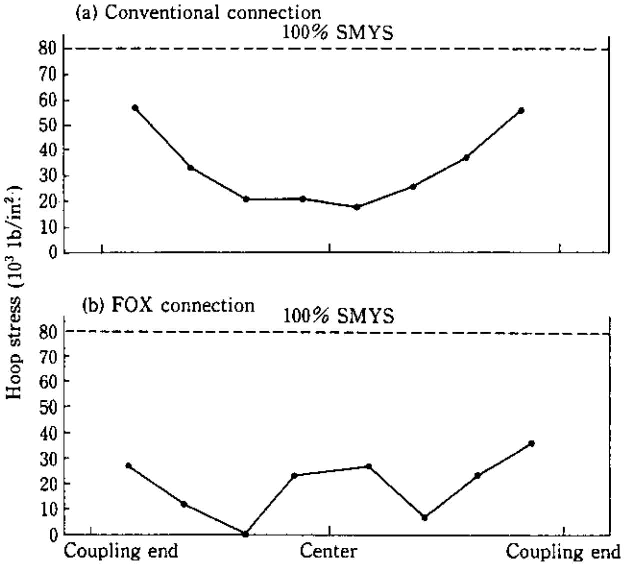


Fig. 12 Hoop stress under makeup (2 ⅞" × 0.254" L80)

Generating mesh data for a pin and a coupling

Special mesh generating program
(Capable of obtaining high accuracy coordinates)
Quadrate element with 8 nodes, and gap element
Number of elements : 1500 − 3000
Number of nodes : 2000 − 6000

Finite element analysis

MARC program (version K2)
Nonlinear analysis
Elastic-plastic problem
Contact problem

Output of calculated results

Displacement diagram
Contour map of stress and strain
Tooth load distribution diagram
Stress distribution diagram, etc.

Fig. 13 Procedure of finite element analysis of FOX joint

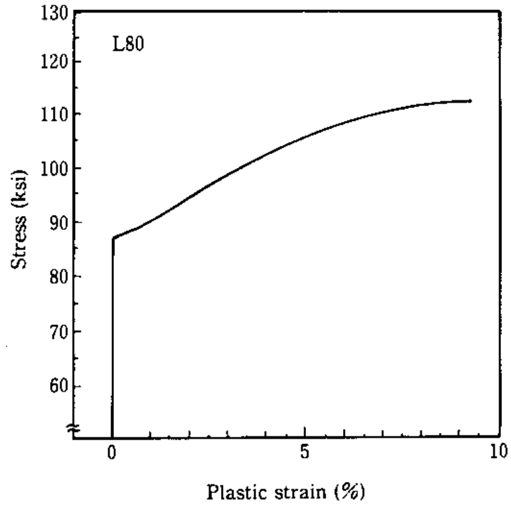


Fig. 14 Stress-strain curve of material

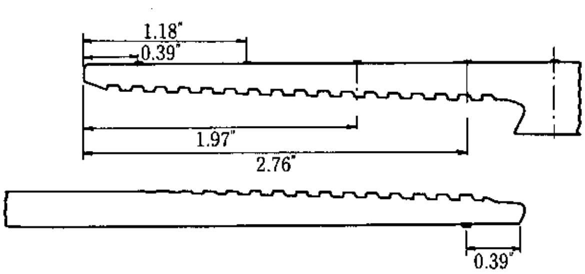


Fig. 15 Location of strain gauges (3 ½" × 9.2 lb/ft)

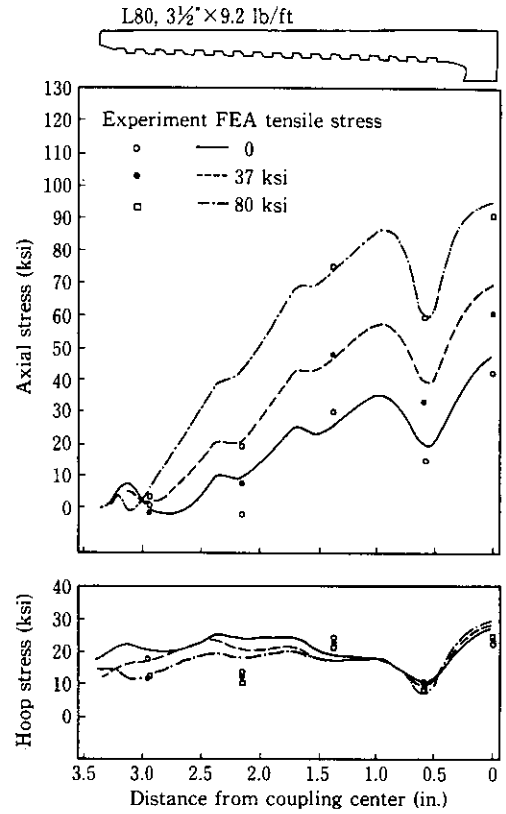


Fig. 16 Stress distribution of outside surface of a pre-loaded and tensile loaded coupling

5CT L80 respectively. The stress-strain curve of the material shown in **Fig. 14** was also used for the FEA analysis. A strain gauge was attached at the position shown in **Fig. 15** and used to compare the results of the FEA with the experimental results. Calculated results are in good accordance with experimental ones. **Figure 16** shows the stress distributions of the outside surface of the pre-loaded and tensile loaded coupling. The results of this study confirms that FEA satisfactorily simulates the actual behavior of tensile loaded connections.

5 Conclusions

In conventional threaded connections, the load distribution on individual threads is uneven. To solve the problems which result from uneven load distribution, Kawasaki Steel and Hunting Oil Field Services Ltd. successfully developed a new premium connection called "FOX" which uses the pitch change concept to ensure even load distribution. The FOX connection also has a modified metal-to-metal seal of contoured shape to reduce local stress concentration resulting from pre-load.

Characteristics of the FOX connection are summarized as follows:

(1) Lower thread tooth loads after make-up, about 30% lower than with conventional connections.
(2) Higher metal-to-metal seal energy, about 80% greater than with conventional connections.
(3) Better load distribution within the connection.
(4) Superior sealing performance and overtorque resistance resulting from new contoured seal shape.

Sale of the newly developed FOX connection began three years ago. The FOX connection is now being used in the North Sea, North America, South East Asia, and other areas without any problems and is receiving good acceptance for its easy usage.

References

1) K. Ueno, G. C. Dearden, J. K. Duxbury, and T. Maguchi: "New Concept for Load Transfer in Threaded Connections", OTC 5248, Preprint of the 18th Annual OTC, Houston (USA), May (1986), p. 221