Materials and Design 52 (2013) 308–314

Contents lists available at SciVerse ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Technical Report

# Effect of stress distribution on the tool joint failure of internal and external upset drill pipes

Shuai Luo, Sujun Wu *

*School of Materials Science and Engineering, Beihang University, Beijing 100191, PR China*

ARTICLE INFO

*Article history:*
Received 3 December 2012
Accepted 24 May 2013
Available online 7 June 2013

ABSTRACT

Detailed investigation was carried out on the tool joint failure of the internal & external upset (IEU) GSS105 drill pipes. Stresses were analyzed using 2D finite element method (FEM) for the threaded tool joint of the drill pipe under the combined loading conditions containing preload, tensile and bending loads. The stress concentration factors in the pin and box were calculated. Results showed that the maximum stress concentration occurred at the roots of the first tooth from the pin tool joint shoulder of the drill pipe. Fractographic observation revealed that the tool joint failure of the drill pipe was caused by fatigue crack nucleated at the tooth root and propagated through the wall of the tool joint. The deterioration of the fatigue resistance of the tool joint is related to dogleg region where severe cyclic bending load exists due to the local deviation of the drill pipe from the vertical line.



## 1. Introduction

Tool joints, including pin and box, are important parts joining drill pipes serially to make a drill string, which is the key tool in oil wells to transfer the applied torque to the bit at the bottom of the well. The failure of the drill pipes occurred mostly in the tool joint due to continuous changeable load of tension, bending, impact, internal pressure and a certain amount of torque [1–5]. Therefore, it is necessary and urgent to study the mechanism of fatigue failure in tool joint of the drill pipes.

Threads at both ends of the tool joints play the vital role in connection. When the drill string is in service, considerable stresses are expected in the teeth of tool joint. Tafreshi and Dover [6] employed finite element method (FEM) to analyze the stress distribution around the threaded connections of tool joints, and presented the load distribution of the teeth of tool joint and stress concentration factors (SCF) at the teeth root. In their work, it was concluded that the location of maximum stress concentration at the tool joint was present. Tafreshi [7] and Bahai [8] analyzed the stresses at the drill pipe connections by using an axisymmetric 2D FEM model, which pointed out that the maximum SCF always located at the first engaged tooth of the pin. Stress concentration at the tooth root is inevitable, and should be within the design safety factor [9]. Therefore, the static stresses at the tooth root alone cannot cause fracture.

Previous researches [10–12] on the failure of the drill pipes showed that the fatigue damage of drill pipes always occurs in the pipe section at the dogleg region. However, clear explanation is required for the reasons why the dogleg accelerates fatigue failure. In the present study, in order to understand the failure mechanism of the tool joints of the drill pipes, FEM analysis was carried out by employing Plane42 elements and linear contact elements at each tooth. Local stress distribution at each tooth of the threads and variations of SCF at the teeth roots of the pin and box were investigated under same work conditions. The effect of the alternating bending stress caused by dogleg area or bending section of the oil well on the fatigue failure was discussed.

## 2. Drill string configuration and axial force calculation

Eight drill pipes fractured due to cracks at the tooth root of the tool joint during normal drilling in one oil well with a service life much shorter (5–15 h) than the design life (720 h). Therefore, it is of great significance to analyze the failure causes of the drill pipes. The detailed parameters of drill pipe failures are listed in Table 1. All the failed drill pipes are 5–1/2″ IEU drill pipes with similar failure mode. In the present study, the failed drill pipe with the shortest service life of 302 min before failure, Case No. 3, was taken as the failure analysis specimen for consideration.

The drilling direction of drill pipe always changes and deviates from the vertical direction due to the geologic characteristics and manufacture related factors. The projection drawing of the oil well, including the drilling depth, overall variation of the drill string inclination angle and the dogleg severity, is shown in Fig. 1. It was found that the depth of failure position on the drill pipe concerned is 910 m underground, where the actual maximum overall 3D angle change rate (dogleg severity) is 0.53°/25 m within the first 1000 m depth from the ground.

* Corresponding author. Tel.: +86 1082316326; fax: +86 1082317108.
*E-mail address:* wusj@buaa.edu.cn (S. Wu).

0261-3069/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.matdes.2013.05.073

**Table 1**
Parameters of the drill pipe failures.

| Failure case (No.) | Well total depth (m) | Depth of failure position (m) | Service life (Min) | Angle of inclination ($\beta$/deg) | Dogleg severity (deg/25 m) |
|---|---|---|---|---|---|
| 1 | 5596.11 | 930 | 788 | 0.29 | 0.05 |
| 2 | 5598.81 | 930 | 790 | 0.29 | 0.05 |
| 3 | 6362.69 | 910 | 302 | 0.29 | 0.53 |
| 4 | 6576.20 | 1400 | 394 | 0.27 | 0.17 |
| 5 | 6588.63 | 1350 | 409 | 0.29 | 0.45 |
| 6 | 6604.00 | 2000 | 412 | 0.26 | 0.33 |
| 7 | 6631.48 | 2350 | 426 | 0.24 | 0.34 |
| 8 | 6631.63 | 2300 | 427 | 0.36 | 0.63 |

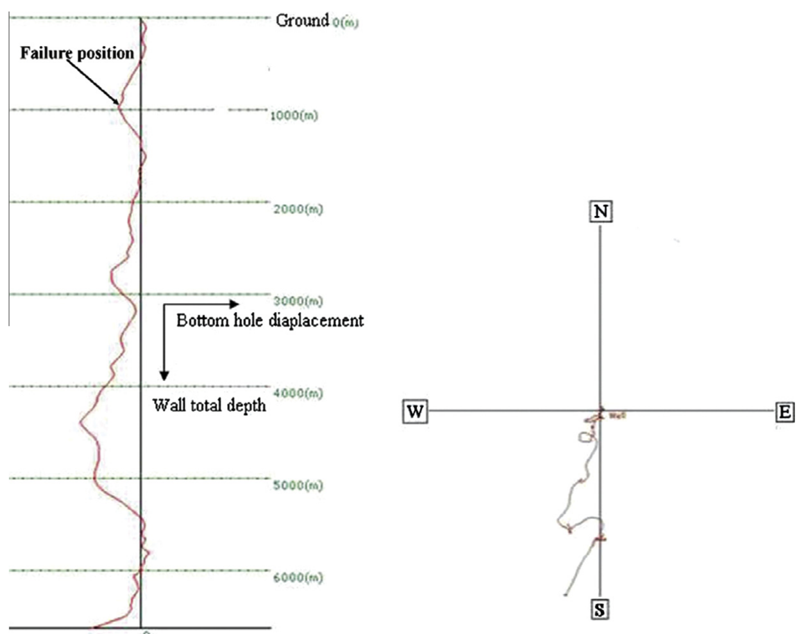


**Fig. 1.** The projection drawing of the oil well (a) vertical drawing and (b) horizontal view.

The depth of the oil well is 6362.69 m for Case No. 3. The drilling string of the well is divided into four segments as illustrated in Fig. 2 and the detailed parameters of each segment are listed in Table 2. The failure position of the drill pipe is in the first segment which is the IEU GSS105 drill pipe with a diameter of 139 mm.

The axial force of the drill pipe at failure position which is required for the FEM stress analysis can be divided into two parts. One is from the gravity of the drilling string and another is from the torque. The force from the gravity can be calculated based on the following formula [13]:

$$F_a = \sum_{K=1}^{n} \Delta H_k q_{km} - H_a(A_{a0}\gamma_0 - A_{a1}\gamma_1) \quad (1)$$

where $q_{km} = q_K - (A_{K0}\gamma_0 - A_{K1}\gamma_1)$, $F_a$ is the axial force at failure position under wellhead, $n$ is the segment of drilling string under failure position, $\Delta H$ is the length of segment, $H_a$ is the distance from ground to failure position, $A_{a0}$ is the outer circle area of the failed segment, $A_{a1}$ is the inner circle area of the failed segment, $A_{K0}$ is the outer circle area of the $k$th segment, $A_{K1}$ is the inner circle area of the $k$th segment, $\gamma_0$ is pipe mud weight rate, $\gamma_1$ is tube mud weight rate, $q_k$ is gravity unit length pipe in air, $q_{km}$ is gravity unit length pipe in mud. Based on the above theoretical calculation, an axial force from gravity was obtained as $1.38 \times 10^6$ N.The axial force resulting from the applied torque can be calculated based on the following formula:

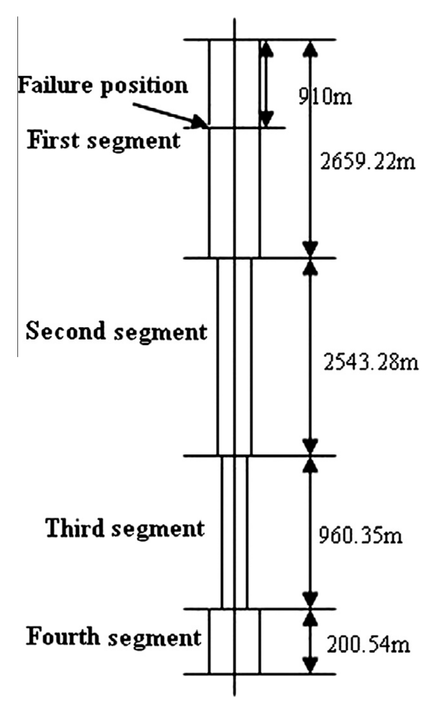


**Fig. 2.** The sketch of the drilling string.