Engineering Failure Analysis 33 (2013) 251–264

Contents lists available at SciVerse ScienceDirect

Engineering Failure Analysis

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

Failure analysis and solution studies on drill pipe thread gluing at the exit side of horizontal directional drilling

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ARTICLE INFO

Article history:
Received 31 August 2012
Received in revised form 16 May 2013
Accepted 27 May 2013
Available online 11 June 2013

Keywords:
Drill pipe thread
Failure analysis
Bending load
Horizontal directional drilling
Finite element analysis

ABSTRACT

With its advantages of a shorter construction period, fewer external constraints, and higher construction quality, horizontal directional drilling (HDD) technology has become widespread throughout the world's trenchless industries. However, thread gluing accidents have often occurred at the exit side during construction. Not only has this caused an excessive number of drill pipe failures, but it has also significantly extended the construction time, thus greatly limiting the development of HDD technology. In order to reveal the failure causes, the authors of this study researched the construction conditions of the Lanzhou-Zhengzhou-Changsha third crossing of the Yangtze River. Then, material tensile property tests and make-up and break-out tests of the same batch of drill pipe were performed to observe the material properties and structural parameters. A 3D drill pipe thread finite element model (FEM) was established based on principles of virtual work, nonlinear contact theory, and the elastic–plastic yield criterion, which may be loaded by various combining loads, such as make-up torque and bending moment, which cannot be loaded on a 2D model. Analysis of the construction situations with this FEM showed that insufficient make-up torque was the main predisposition factor and bending moment generated by the drill pipes hanging were the immediate causes of the failure accidents. Some improvement measures have been proposed according to the failure causes, and successfully applied in engineering. A beveled shoulder thread (BST) was proposed, which is superior to the API thread by having a higher bending strength, larger flexural rigidity and a stronger seal performance withstand bending load, and is thus suitable for HDD. The work presented in this paper is a reliable guideline for reducing thread gluing accidents and thus reducing construction time in HDD projects.

1. Introduction

Horizontal directional drilling (HDD) technology has been widely adopted for oil and gas pipeline in crossing rivers, channels, highways, railways and other complex or unsuitable shallow buried areas. Moreover, it may also be applied in municipal engineering (e.g. electric cables, optical cables, tap water pipes), crossing buildings, and so on. With the advantages of a shorter construction period, fewer external constraints, better construction effects, lower construction costs, as well as its advantages of not damaging the ground environment and increasing the stability control, HDD technology has gained attention throughout the trenchless industries of the world [1]. However, during the HDD construction process, exit side drill pipe thread gluing accidents have led to an excessive amount of drilling pipe waste, in turn significantly extending the construction time. Therefore, it is necessary to reduce thread gluing accidents, thereby reducing the construction time in HDD

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http://dx.doi.org/10.1016/j.engfailanal.2013.05.017

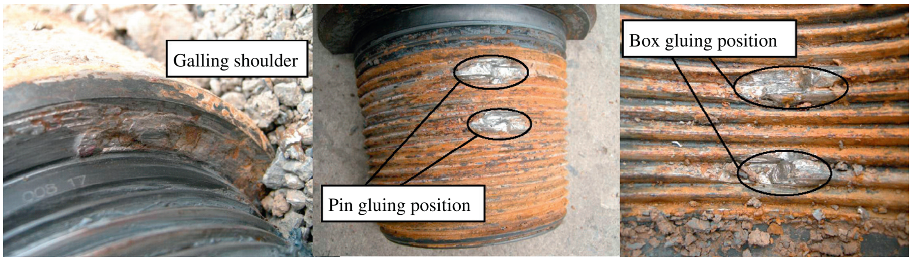

Fig. 1. Galling shoulder and gluing thread.

projects, by researching the failure reasons of HDD drill pipe thread gluing accidents. At present, most studies concerning HDD technology have focused on increasing the pipe's service life and pipe repairing technology [2,3], with only a small number of studies concerning the failure causes of drill pipes.

The methods used to analysis connection thread may be divided into three categories: experimental, analytical and finite element simulation. Based on fatigue life experiments, Seys et al. [4], through fatigue life experiments, showed that the standard thick-walled connection has a higher fatigue life than thin-walled ones. Wittenberghe et al. [5] presented an optical dynamic 3D displacement analysis technique for evaluating the crack propagation in a threaded pipe assembly. Wei and Suraj [6] applied tensile tests, and recommended that the minimum number of turns of the threaded engagement should be at least eight in any practical engineering application of steel tie rods. Baragetti et al. [7] studied the friction behavior in many conditions of the API NC50 rotary shouldered connection, using both analytical and experimental methods. Chen et al. [8,9] established an analytical model based on the geometric parameters of thread tooth and the calculation method of tightening torque on P-110S threaded connections. Due to the limitations of experimental and analytical methods which cannot precisely determine the stress level and the state of the contact stress, as of yet most scholars have used the finite element method to study the mechanics characteristics of thread connections.

At present, the main method used to research conical threaded connections with the finite element method has been the 2D axisymmetric model. Macdonald and Deans [10] analyzed the drilling string thread stress with 2D FEM. Knight and Brennan [11] indicated the maximum stress of drill collar at the position of the first engagement thread turn and computed the fatigue life of drill collar with a 2D model. Yuan et al. [12,13] applied the 2D FEM and presented the stress and temperature field distribution of the API round threaded connection. Lin et al. [14] established a 2D axisymmetric finite element analysis model and analyzed the mechanical properties of double shoulder tool joints. In the HDD process, the drill pipe mainly bears make-up torque and bending moment, but bending moment cannot be applied to the 2D models, and in addition these models cannot be used to simulate make-up torque, because they do not include the helical thread geometry. As a result, 2D models cannot be used to study the thread connection security under torque and bending moment load, therefore we must establish the 3D FEM to study the failure reasons of HDD drill pipe thread gluing accidents. Due to the complexity of drill pipe thread geometry (i.e. conical thread helix, too many tiny faces, irregular geometry), there have been very few reports on the 3D FEM of conical thread, except for those made by the author of the present paper [15,16].

During the construction process of the Lanzhou-Zhengzhou-Changsha third crossing of the Yangtze River, a large number of drill pipe threads underwent gluing failure accidents at the HDD exit side. Fig. 1 shows the failure characteristics, in which the drill pipe thread shoulder galled severely, and the pin and box glued at the first and fifth engaged turns. In order to determine the reasons for failure, drill pipe thread material tension property determination and thread make-up and break-out tests were carried out, and 3D drill pipe thread FEM was established. With the aim of solving these failure problems, some proper improvements were proposed, as was a new drill pipe thread geometry, which has a stronger bending performance.

2. Analysis of construction conditions

The drill pipe thread gluing occurred at the exit side of the HDD crossing. The crossing length is 1970 m, depth is 73 m, and the exit angle of the exit side drill pipe is 16°. During the construction process, the axial load and torque load applied on the exit side drill pipes are both small. The drill pipes hang in the air behind the exit point.

Only the friction between the drill pipes and drilling hole generates the axial load and torque load at the exit side. Its effect is insignificant in comparison with the other loads. The hanging drill pipes behind the exit point bend downwards until contact with the ground caused by gravity. The drill pipe bending FEM is then established, and the schematic diagram is shown in Fig. 2. According to the distance between the highest bending point and exit point a, the distance between the highest bending point and the ground b, the trigonometric relations are determined (a = 6.2 m, b = 1.35 m). Supposing that the deformation of the drill pipes between the exit point and bending highest point is homogeneous, the computed drill pipe bending radius of the curvature is 14.2 m.

Due to the limitations of local construction conditions, the make-up method for the drill pipe is shown in Fig. 3. The digger forces the drill pipe to contact the ground, and the drill pipe thread is made up manually.