Engineering Failure Analysis 34 (2013) 150–165

Contents lists available at ScienceDirect

Engineering Failure Analysis

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

Structural behavior of large-scale triangular and trapezoidal threaded steel tie rods in assembly using finite element analysis

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ARTICLE INFO

Article history:
Received 14 November 2012
Accepted 17 July 2013
Available online 31 July 2013

Keywords:
Steel tie rod
Threaded connection
Structural behavior
Finite element analysis, ANSYS

ABSTRACT

Pre-stressed steel tie rods are used extensively as load carrying components in structures like suspension bridges, steering systems in automotive vehicles, wings and fuselage of aircrafts, spokes of Ferris wheels, etc. The governing variables for the bearing strength of a large-scale steel tie rod (of diameter usually larger than 60 mm) include the mechanical strength of the tie rod body, geometric configuration of the thread teeth and the number of turns of thread engagement. The optimal number of turns of threaded connections of large scale steel tie rods has been predicted by full scale rupture experiments and reported previously by the authors. This paper builds up further on that work and investigates the structural behavior of the two types of threaded connections of steel tie rods, viz. (i) the triangle threaded connection, and (ii) the trapezoidal threaded connection, using finite element analysis in ANSYS. The axial displacement, equivalent stress distribution, interfacial contact pressure and sliding distance on the engaged thread teeth under different axial loads are presented and analyzed. The numerical simulations verify and expound the results of full-scale tensile rupture experiments. The concordant comparison between experimental measurements and finite element analysis provides working guidelines and support for the design and fabrication of steel tie rods in practical operations.

1. Introduction

Threaded connections of large scale steel tie rods (shown in Fig. 1) are susceptible to failure due to dynamic, fatigue, tensile and shear loading in practical engineering applications where they are used as pre-stressed structural components. The bearing strength of the tie rod assembly with its sleeve is controlled by the mechanical strength of the tie rod body, geometric configuration of the thread teeth and the number of turns of thread engagement [1]. In order to choose the most suitable type of threaded connection for any practical engineering application, knowledge of the stress distribution, interfacial contact pressure, sliding distance, length and the number of turns of thread engagement can be very crucial to ensure the overall structural safety.

Stress, deformations, fatigue and failure in threaded connections have been studied for long and the existing literature is relatively rich. Sopwith [2] performed a detailed analytical analysis of thread deformations using methods of theory of elasticity [3]. Patterson and Kenny [4] investigated a discrepancy due to incomplete thread forms between Sopwith's analytical theory and experimental results and used finite element analysis (FEA) to determine the varying stiffness of the threads. The results of this modified theory compare well with the experimental determination of thread stress using the stress freezing photo-elastic method of Hetenyi [5] before Sopwith [2]. In recent times, Brennan and Dover [6] evaluated stress intensity

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http://dx.doi.org/10.1016/j.engfailanal.2013.07.024

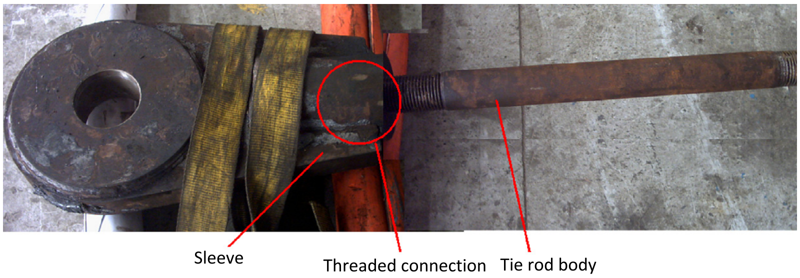

Fig. 1. Threaded connection on a large-scale steel tie rod.

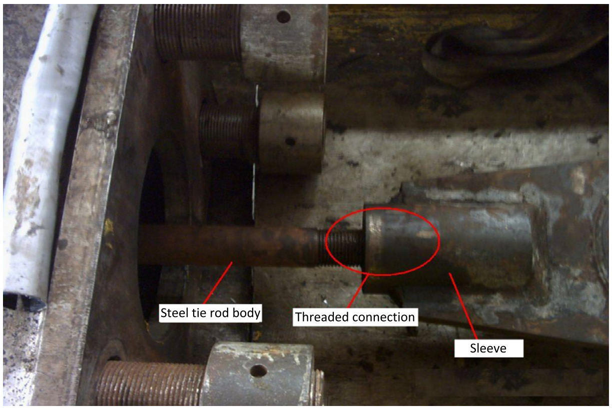

Fig. 2. Steel tie rod in tensile testing.

factors for threaded connections using multiple reference state weight function theory for any mode I crack initiating from thread roots. Wittenberghe et al. [7] reported on the fatigue life of the standard API Line Pipe coupling and two modified coupling configurations of specifications 5B [8] and 5L [9]. Korin and Ipiña [10] evaluated the fatigue life and crack growth in a bolt–nut threaded connection under tensile load. In [11], they evaluated residual stresses introduced through controlled application of an over-make-up torque in rotary shouldered connections and then returning to the nominal torque, with the aim of increasing the fatigue strength of such shouldered connections by delaying fatigue crack nucleation.

FEA of threaded connections has been performed in the past by several researchers [12–15]. A novel FEA approach was presented by Alkatan et al. [16] for calculating the axial stiffness of a threaded assembly by partitioning it into its elements including the head and the engaged length of the bolt, the nut and the fastened plates and they validated the theoretical study by new experimental model. Englund and Johnson [17] performed a detailed axisymmetric FEA taking into consideration the cylindrical nature of the loads and geometry around the shank centerline. Chen et al. [18] used the thick cylinder theory and elastic mechanics to conduct FEA of P-110S [9] conic threaded connections with interference fit and axial load to investigate the tooth load distributions on contact threaded surfaces. Rabczuk et al. [19,20] suggested newer multiple scaling and isogeometric methods to help reduce computation costs which occur invariably in numerical simulations using conventional FEA techniques, say using ANSYS or Sysweld for generic static simulation in mechanical applications as in [21–25]. Using the multiple scaling method, Andrieux and Leger [26] implemented the threaded assembly into a local problem involving only the detailed FEA of one thread, whereas the global one was modeled as a uni-dimensional elliptic problem for parametric studies.

This paper reports the structural behavior predicted by linear FEA to verify and expound the results of full-scale tensile rupture experiments (Fig. 2) carried out by the authors in Duan and Joshi [1] for determining the maximum axial working load under different numbers of turns of thread engagement for two types of steel tie rods, viz. (i) LG75-00 steel tie rods with triangle threaded connection (20Cr), and (ii) LG100-00 steel tie rods with trapezoidal threaded connection (35CrMo). Several

Table 1
Mechanical properties of tie rod steel.

Specimen	Yield strength σ_s (MPa)	Ultimate strength σ_B (MPa)	Elongation (%)	Shrinkage (%)	Young's modulus E (GPa)	Poisson's ratio υ
LG75-00	545	690	22.0	73.0	198	0.3
LG100-00	630	815	22.5	73.0	219	0.3