A New Technique for Enhancement of Fatigue Life of Bolt-nut Connections

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Abstract. In this work, a new technique for enhancement of fatigue life of bolt-nut connections is introduced. In this technique, the threaded part of the bolt where it comes into contact with the nut is axially holed. A hole will have two opposite effects; (1) it will reduce the load carrying capacity of the bolt and (2) it will results in a more uniform load distribution. It is the subject of this investigation to find the optimum size of the hole for a specific bolt diameter. It is evident that a too small hole will have no significant effect on fatigue load and a too large hole, despite reducing the load concentration, will reduce the load capacity of the connection too. In this work, the metric bolt, M16 was selected for the experiments. Five diameters of 4, 5, 6 and 8 mm were examined in this work. The experiments were conducted under the load levels of 50 to 120 kN. The results suggest (i) the fatigue life remarkably increases for the holed specimens provided the optimum value for the hole diameter is determined and (ii) the increase in fatigue life reduces as the load increases.

Introduction

Bolt-nut connections are used in large quantity in nearly all machines and structures. Majority of connections are subjected to fluctuating loads throughout their life of services. The terminology of a bolt-nut connection is illustrated in Fig. 1.

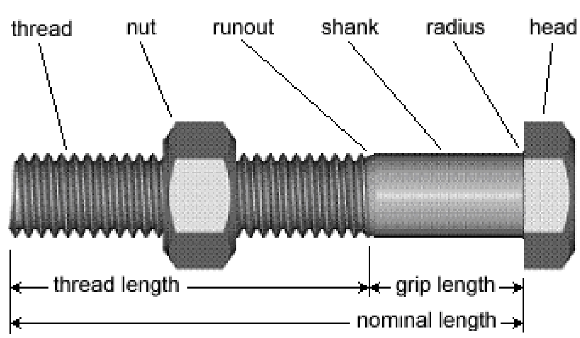

Fig. 1. Terminology of a bolt-nut connection

The enhancement of fatigue life of the connections has been the subject of many investigations over the past decades. It is well known that the load is mostly carried by the first engaging thread of the connection. This high load concentration is the main source of failure in bolt-nut connections. Den Hartog [1] has shown theoretically that the thread load is concentrated on the first threads from the clamped face of the nut and occurs due to the difference in the thread pitch induced in the nut and bolt, by compression in the nut and tension in the bolt. The distribution of the load between the engaging threads has been investigated by many researchers such as Maduschka [2] and Birger [3] and has been fully reviewed by Kenny and Patterson [4, 5]. One theory for the load distribution is provided by Sopwith [6] modified later by Stoeckly and Macke [7]. The load distribution is given by:

$$W(x) = W_m \frac{e^{u(1-x)}}{\sinh(v)}(v\cosh(vx) - u\sinh(vx)) \quad (1)$$

where w(x) is the axial load per unit length of contact at the normalized position x along the thread, x is the ratio between the distance from the free face of the nut and nut length, w_m is the mean value of w over the contact length $(\cong \pi d_p L/p)$ and u and v are constants which can be found in Ref. [6].

Despite the fact that load distribution in threads of bolt-nut connections is essentially slightly different for unified, metric or withworth standards or coarse and fine threads of each category, all investigations indicates that for all standards and thread types, load is concentrated at the first engaging thread.

Numerical simulations

Numerical simulations have been carried out using Ansys finite element code. The finite element model is depicted in Fig. 2. A three dimensional analysis has been considered in the simulations. The pattern of stress distribution in threads in y direction (axial stress) obtained from simulations is presented in Fig. 3. This stress component is the dominant stress component in bolt-nut connections.

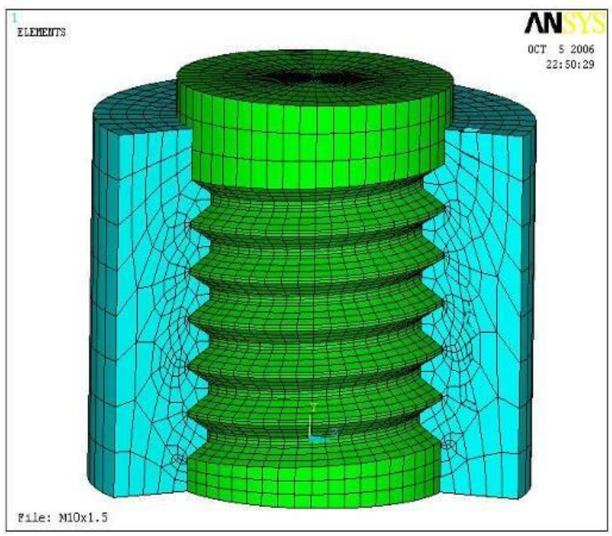

Fig.2. A finite element model for the bolt-nut connection

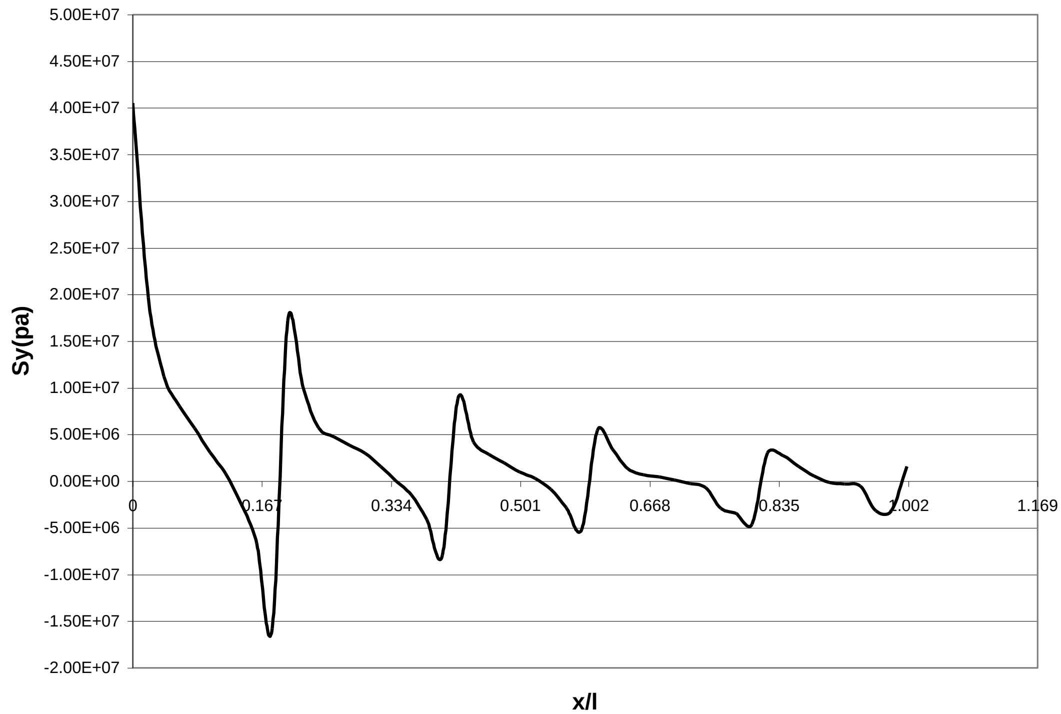

Fig. 3. The pattern of stress distribution in threads obtained from simulations

From the simulations, the load carried by each thread was also computed. The results are given in Fig. 4. The results are compared with those predicted by Stoeckley relation given by Eq. 1. As figure 4 indicates, there is a reasonable agreement between numerical simulations and Stoeckly analytical approach which has been obtained using photoelasticity method. The results also confirm the severe nonuniformity of load distributions in threads. As figure 4 suggests, most of the load is carried by the first few threads so that the portion of the load carried by 4^{th} thread on is negligible.

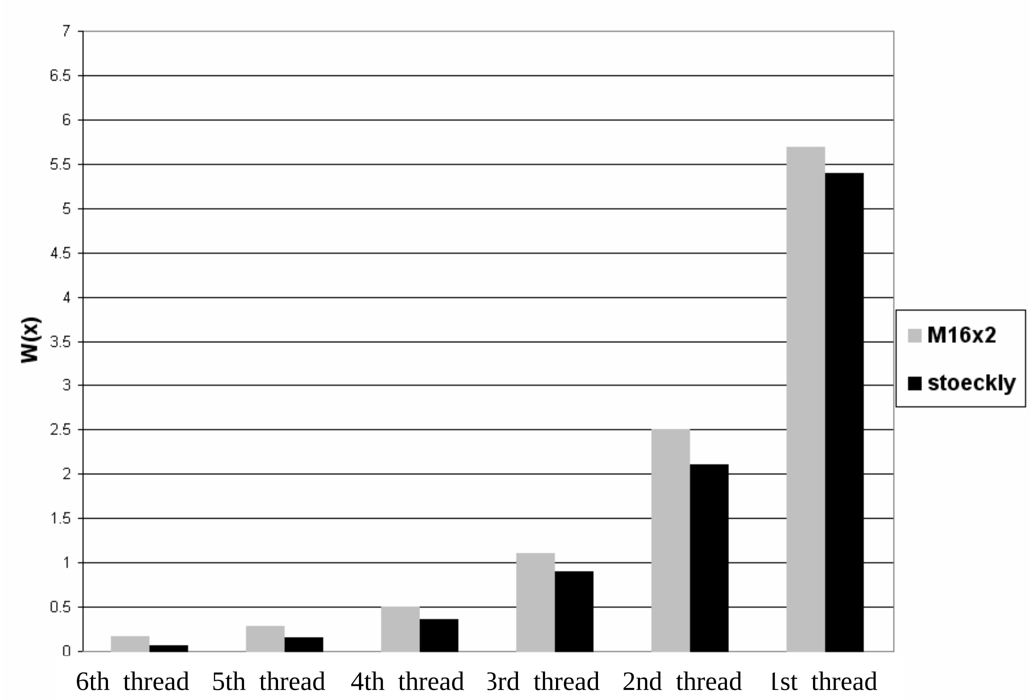

Fig. 4. Load distributions given by Stoeckly and obtained from simulation in threads of a M16 bold

The challenge is to obtain a more uniform load distribution in the engaging threads. From the literature, it can be seen that a great deal of research work has been conducted to make this load distribution more uniform. Many of the investigations have been focused on nut geometry to improve the fatigue behavior of bolt-nut connections. Majzoobi et al [8] investigated the effect of nut geometry and found that tapered nut can considerably increase the fatigue life of the bolts. Keny and Patterson [9, 10] showed that a tapered nut with an angle of a few degrees will considerably reduce the load concentration in threads of bolt-nut connection. Dragoni [11, 12] showed that the endurance load slightly increases as the pitch is decreased for small bolts of low-grade steel and conversely, the endurance load increases markedly with the pitch for large bolts of high-grade steels. Majzoobi et al [13] studied the effect of thread pitch (coarse and fine threads) on fatigue life of ISO bolts within the range of 10 < D < 24 mm (D ¼ outside diameter) and American Unified bolts within the range of 7/16″ < D < 1″. The experimental results showed that ISO standard coarse threaded bolts have a higher fatigue life than the fine threaded bolts. For unified bolts, however, when the comparison is made on the basis of core diameter, coarse threaded bolts are superior to the fine ones, whereas on a nominal based comparison, both coarse and fine threaded bolts exhibit the same loading capacity.

Experimental results

In this work, a new technique for enhancement of fatigue life of bolt-nut connections is introduced. In this technique, the threaded part of the bolt where it comes into contact with the nut is axially holed, as shown in Fig. 5.

Fig.5. An axially holed nut

A hole will have two opposite effects; (1) it will reduce the load carrying capacity of the bolt since the cross sectional area reduces and (2) it will results in a more uniform load distribution. The reason for more uniform distribution is that the hole allows the contact load components between the nut and the bolt are relieved when tightening the connection and a more uniform load distribution in threads of the connection is obtained. It is the subject of this investigation to find the optimum size of the hole for a specific bolt diameter. It is evident that a too small hole diameter will have no significant effect on fatigue load and a too large hole diameter, despite reducing the load concentration, will reduce the load capacity of the connection too. In this work, the Iso bolt, M16 was selected for the experiments. Five diameters of 4, 5, 6 and 8 mm for the hole were examined in this work. The experiments were conducted under the load levels of 50 to 120 kN using Instron fatigue testing machine. The S-N curves for M16 bolt for the fatigue loads of 50 to 120 kN for the 5 mm hole is shown in Fig. 6. As the figure suggests, the fatigue life has remarkably increased for the holed specimens. The increase of fatigue life versus hole diameter is depicted in Fig. 7. The figure indicates that the maximum life increase occurs for the hole diameter around 5 mm. This can be regarded as the optimum value for the hole diameter for M16 bolt-nut connection.

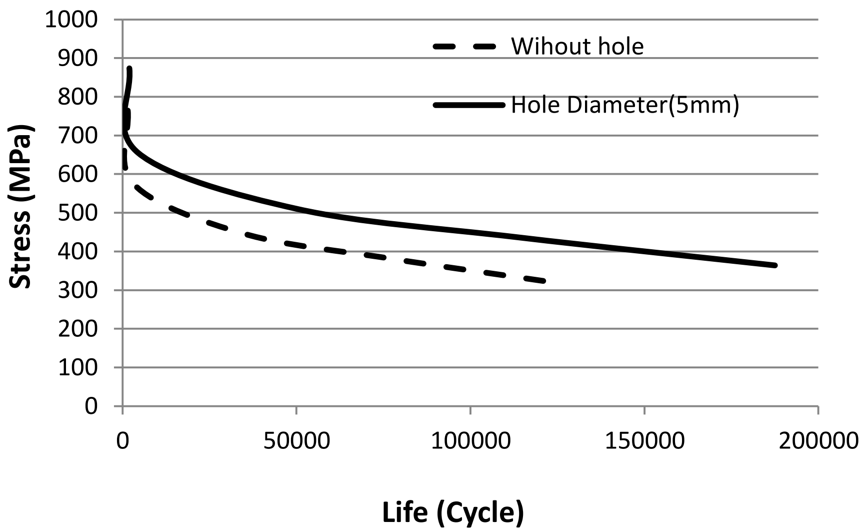

Fig. 6. S-N curves for M16 bolt for the fatigue loads of 50 to 120 kN for the 5 mm hole

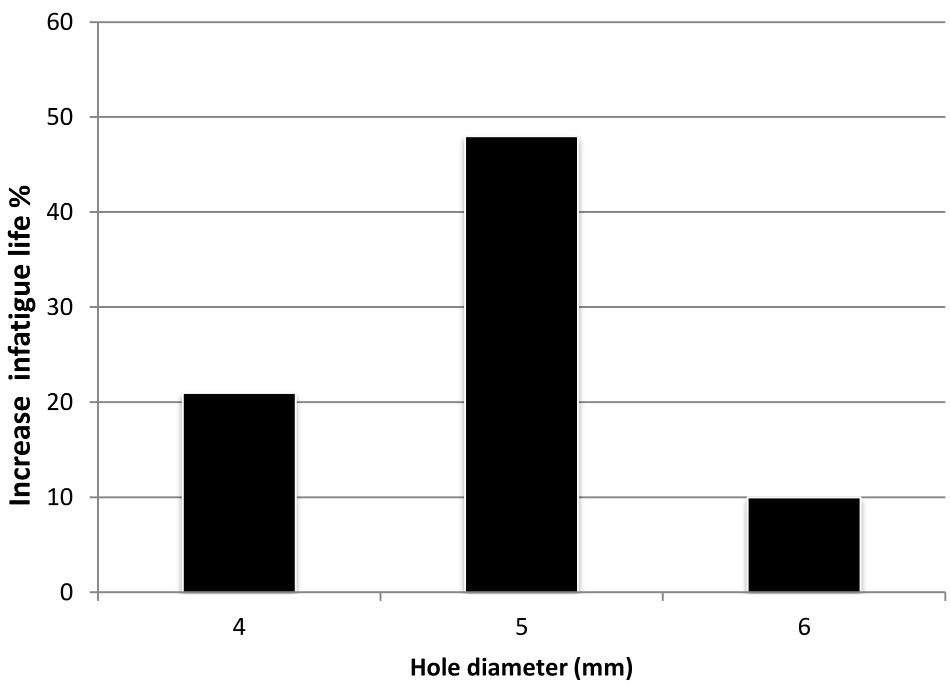

Fig. 7. The increase of fatigue life versus hole diameter

Variation of load versus the increase in fatigue life of the connection is illustrated in Fig. 8. As the figure suggests, the increase of the life depends on the applied load so that it varies from 30% for 120 kN to 50% for 50 kN.

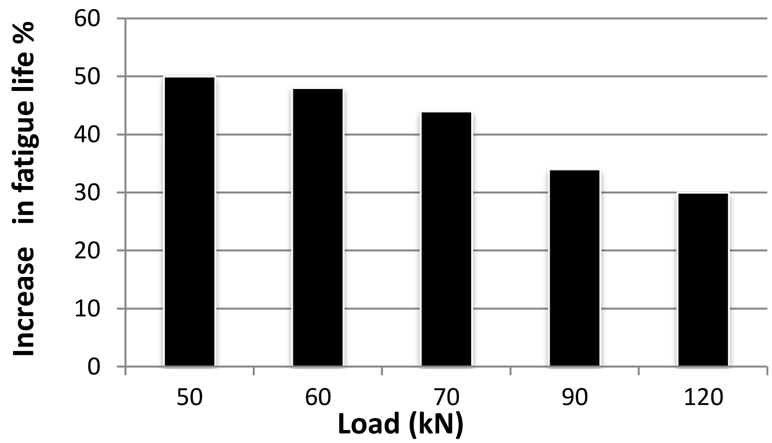

Fig. 8: Fatigue life versus the applied load for the hole of 5 mm diameter

Summary

From the numerical simulations and the experiments the following conclusions may be derived:

1. The load is carried mostly by the first few threads specially the first thread of bolt-nut connections.
2. Creation of axial hole in the engaging part of bolt and nut can significantly reduce the nonuniformity of load and increase the fatigue life of the connection.
3. For the bolt examined in this work, an increase of 30% to 50% in fatigue life of the connection was observed.
4. The maximum increase for fatigue life was obtained for the optimum value of the hole diameter.
5. The increase in fatigue life reduces as the load increases.

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