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Effect of clamping force and friction coefficient on stress intensity factor of cracked lapped joints

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ABSTRACT

Fatigue failure of steel connections is a well-known failure mechanism, especially for structures which sustain heavy cyclic loads like steel bridges. Reliable determination of stress intensity factors (SIFs) for cracks in bolted joints is required to evaluate their safety and fatigue life. The SIF is a traditional topic in mechanics and there have been many solutions for many different cases. The effect of clamping force and friction coefficient on SIF of a crack emanated from lapped joints has not been considered in the literature. The key contribution of the present paper is to evaluate such effect on SIF of cracked single or double lapped joints using 3D finite element method (FEM). Furthermore, the variation of stress concentration factor (SCF) through the thickness of uncracked lapped joints as a function of clamping force and friction coefficient was also studied. A group of 3D finite element models for steel lapped joint was constructed. Three clamping forces of 20, 100 and 200 kN were assumed. Coefficient of friction of 0.0, 0.3 and 0.5 were studied.

It was observed that high clamping force causes a decrease in stress concentration for un-cracked connection. For cracked lapped joint, SIF decreases, i.e. increase in fatigue life, with increasing clamping force.

1. Introduction

Many bridges contain cracks like flaws, so these cracks should be considered in fatigue reliability analysis. Recently Wang et al. [1] found that a gradual drop of the reliability index with time with an upper limit was obtained for the crack growth model based on the stress intensity factor (SIF) in contrast to the linear time relation for the S–N curve model that had no upper limit. This difference is significant and reveals the importance for selecting the fatigue failure criterion. In many bridges a common method of construction is to make use of bolted joints. This joint causes a geometrical stress concentration to be combined with, under fluctuating loads, a condition of fretting between the bolt and the surface of the hole. The combination of a stress concentration with fretting may cause cracks to initiate early in the life of the structure. Generally, it is necessary to determine the SIFs in order to evaluate the crack growth, residual strength and fatigue life of the cracked joint [2–9].

Recently some researchers studied the effect of friction coefficients on fatigue life and crack growth [10,11] and the effect of friction coefficients on the torque force relationship [12] in torque tightened bolts. Moreira et al. [7] studied the fatigue crack initiation in a single lap joint. This work was focused on single geometry, a single-lap joint with three rivets rows and one rivet column. 3D stress analysis using the finite element method (FEM) was carried out in order to analyze the load

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transfer as a function of crack geometry and length, and to determine the stress intensity factors for one or two cracks emanating from the edge of the hole located at the critical cross section. Friction between the lap joint components was not taken into account. Sallam et al. [13] carried out a numerical study to investigate the behavior of a physically short fatigue crack emanating from bolted/riveted joints. Both the stress distribution in each bolt and the maximum stress concentration factor (SCF), i.e. site of crack initiation, in the bolted holes were determined. It was found that, the first bolt has the highest stress and the value depends on the number of bolts and the type of arrangement.

Chakherlou et al. [14–16] studied the effect of clamping force and friction coefficient on SCF, SIF, and fatigue life of bolt-filled hole specimens. To the best of the authors' knowledge, this research is the first to study the effect of clamping force and friction coefficient on SIF of cracked lapped joints. Therefore, the main objective of the present work is to study the influence of the clamping force and friction coefficient on the variation of SIF through the thickness of cracked single and double lapped joints using 3D FEM. The variation of SCF through the thickness of uncracked lapped joints as a function of clamping force and friction coefficient was also studied. Different parameters such as, clamping force (0, 20, 100 and 200 kN) and friction coefficient (0.0, 0.3 and 0.5) were studied.

2. Numerical work

In order to study the SCF and SIF of uncracked and cracked single or double lapped joint in 3D, a series of finite element models were developed by using solid elements and 3D surface to surface contact pairs [17], following the recommendations listed by Timothy et al. and Rahgozar et al. [18,19]. Each 3D model consists of two plates (PL1 and PL2) for single lap joint (3DS) and three plates (PL1 & 2 × PL2) for double lap joint (3DD), each plate with width (W) of 80 mm and height (H) of 232 mm, i.e. $H/W = 2.9$, the number of bolts was three. The selected bolt diameter (D) was 22 mm, i.e. $D/W = 0.275$. The thickness of the plates was chosen according to a case study evaluated by the authors [20]. Therefore, the plates were chosen to be 12 mm thickness except the thickness of middle plate in double lap joint is equal 24 mm. The steel plates and the bolts were modeled by using 3D 20 nodes elements SOLID95. Fig. 1 shows the dimensions of 3DS and 3DD. One symmetric boundary condition was used in 3DS as the connection is symmetric about *YZ* plane, while two symmetric boundary conditions were used 3DD about *YZ* and *XY* planes. The plate PL2 was restrained from its end in *X*, *Y*, and *Z* directions, while the plate PL1 was loaded by σ_o. The SCF is equal to the maximum tensile stress (σ_{11}) on the rim of the bolted holes surfaces divided by the applied stress (σ_o). In order to get accurate numerical results, a fine mesh of 4011 higher order elements (20 nodes elements SOLID95) was constructed around the rim of the bolted holes surfaces for double lap joint (quarter of the model) and 8022 elements for single lap joint (half of the model).

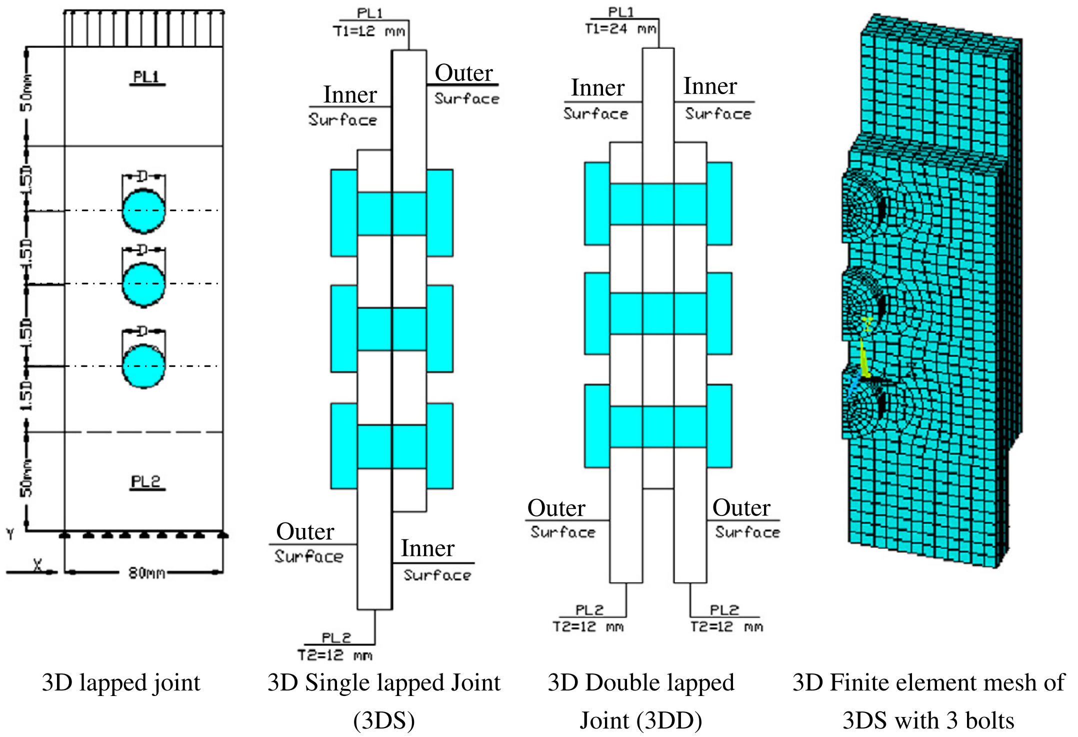

Fig. 1. The details and the components of 3DS and 3DD models.