FATIGUE CRACK IN GUSSET PLATES

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Abstract:

Gusset plates are used commonly in truss joints. The simplest form of joints in a truss system consists of bolted or riveted connections. There may be instances when the bolt or rivet holes develop side cracks while drilling the rivet-holes or bolt-holes.Cracks may even develop due to static or fatigue loads during service life of the structure. It becomes imperative to determine the remaining fatigue life of the truss members and gusset plates in order to determine the safe life of the structure. This becomes more critical when the loads are heavy and fluctuating as in industrial structures or bridges. Fluctuating loads lead to fatigue and the structure may fail after a number of load cycles even if the stress values are well below the yield stress. This paper adopts a fracture mechanics based approach to determine the crack propagation characteristics and the crack length versus number of cycles using Paris' law. FRANC2D has been adopted here for the computational simulation of crack growth. The fatigue life of a crack around bolt holes has been estimated. The approach gives significant information regarding the fatigue life and crack propagation characteristics and may be incorporated in design of truss systems.

Keywords: Fatigue, Crack propagation, Gusset plates, Paris law, Fracture mechanics

INTRODUCTION

Trusses are usually employed when large spans are required to be covered. Truss members are predominantly under the effect of direct tension and compression. As trusses can span over large spaces and can carry large loads, trusses are the structural system of choice for bridges, industrial sheds, etc. The construction of a truss requires a joinery which is realized with the help of gusset plates. Gusset plates are thick sheets of steel that are used to connect truss members with each other or for connecting beams with columns, etc. The forces in members of a truss system are transferred through gusset plates. Thus, the design of gusset plates take up a lot of effort as the shape and size of the plate depends upon the joint under consideration. Classically, trusses are made of mild steel and so are gusset plates. The joinery may be achieved by either bolting or riveting the angle sections with the gusset plates, or by welding them together. While welding is a good choice, it offers a potential threat of transfer of crack from one part of the component to the other. Besides, bolting and riveting are the common choice because the simplicity involved in fabrication of the joints. However, bolting and riveting operations require drilling of bolt or rivet holes in the gusset plates in alignment with the holes in the tension or compression members. There is a very high possibility of micro or macro-cracks developing in the bolt holes, which would seriously hamper the performance of the joints. Further, the trusses used in industrial structures are often subjected to fatigue loads, which may introduce number of cracks at the vicinity of the bolt holes after some number of cycles. It becomes imperative then to determine the remaining life of the joints or members based on fatigue crack propagation. Also, if the fatigue life of the joint is taken into consideration during the design phase, the life of the joint and consequently that of the structure may be considerably enhanced (Broek, 1984).

Fracture mechanics is a branch of solid mechanics that deals with the study of stress and strain fields around existing cracks in a structure and tries to describe the behavior of the structure under effect of existing and propagating cracks. A structure may be subjected to static or repetitive or cyclic loads. A structural component may fail under the effect of repeated cyclic loads which may be of much smaller magnitude than the static failure loads. Such a failure of a component is termed as a fatigue failure. Most industrial structures are usually subjected to fatigue loads. Hence, it is extremely common to observe fatigue cracks emanating from bolt or rivet holes in the joints. Fracture mechanics however has a drawback in that it requires an existence of a crack in the structure. Thus, if a new structure is required to be designed, a probable location and size of the crack must be anticipated in order to employ the principles of fracture mechanics; and thereby understand the crack propagation behavior. The probable locations from where the cracks may emanate are called hot-spots. The determination of hot-spots is vital to accurate description of fatigue failure in structural components. Since the analysis is carried out using finite element method, the crack propagation problem becomes mesh sensitive. Fatigue is the degradation of material and subsequent crack propagation under the influence of repeated cyclic loads on a structure. Commonly, the fatigue life of a component can be described by the well-known Paris' law (Dahlberg and Ekberg, 2006). Paris law requires two material constants for characterization of the crack propagation behavior; viz., m and C. Experiments are required for determination of m and C (Anderson, 2005). A limitation with the Paris' law is that it describes the crack propagation phase, but the description of crack initiation phase must be done either by experimental observations or by other appropriate fracture models (Prashant Kumar, 1999).

Pugno *et al*. (2006) extended the Paris' law to take into consideration some of the deviations from the power-law regime using Wohler SN curves for the materials. This approach is suggested to be a more generalized form of Paris' law and may be more suitable for fatigue characterization. However,

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fresh experiments may be required to obtain the material constants for employing this law. Aygul (2012) performed finite element analysis of steel and composite bridges under various stress ranges. The failure propagation of welded connections has been performed based on the notch stress approach proposed by Radaj *et al*. (2006). Myers studied gusset plates under live loads in Warren truss gusset plates using finite element simulations. Fleck and Smith (1984) studied fatigue crack growth rate and closure response of BS4360 50B steel on a gas storage vessel under service load history. They employed Paris' law for simulation of crack growth. Choudhary *et al*. (2004) performed experiments at 823 K in air and studied the fatigue failure characteristics of specimen welded base metal, weld metal and heat affected zone under constant amplitude loading. They ascertained that the Paris' law was sufficient to predict the fatigue failure in base and weld metal.

ANALYSIS OF GUSSET PLATE

A typical gusset plate for an N-truss has been considered for analysis here.A schematic of the gusset plate considered here is shown in Figure 1.

For determination of the locations from where the cracks may emanate, a preliminary analysis of the joint has been carried out. The finite element mesh of 6-noded linear strain triangular elements along withthe von Mises equivalent stresses computed using FRANC2D have been shown in Figure 2. FRANC2D is a two dimensional, finite element based program for simulating crack propagation in planar structures. The von Mises equivalent stress values reported in the plot are in MPa. The

Figure 1: Schematic of Gusset Plate

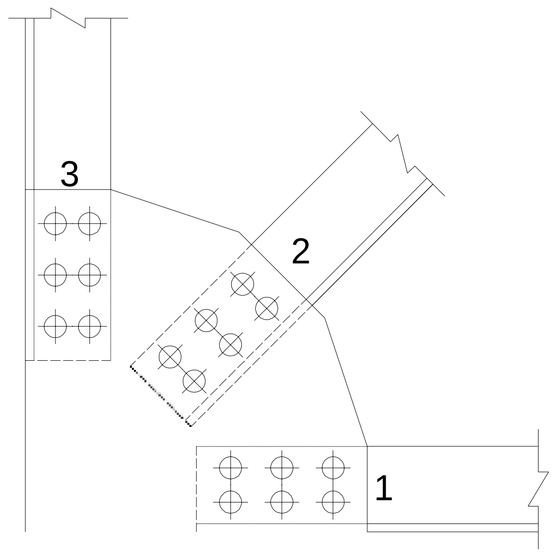
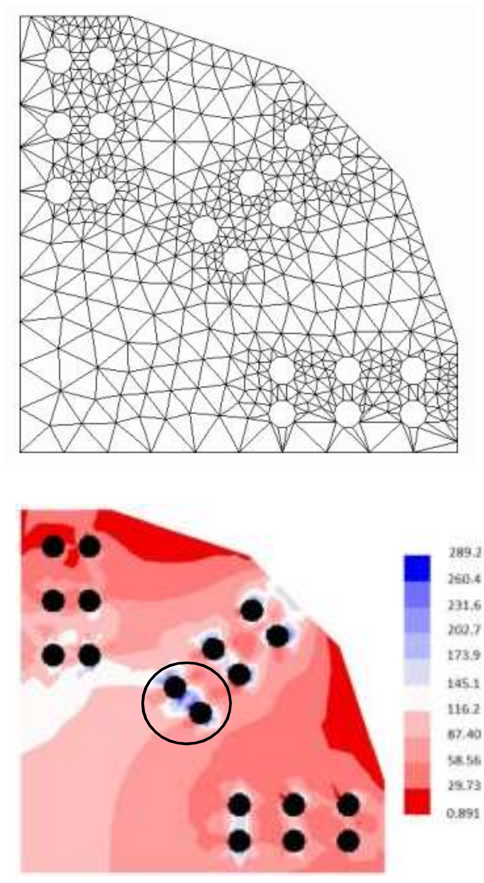


Figure 2: Finite Element Mesh and Von Mises Equivvalent Stresses



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critical location for crack propagation was recognized from the equivalent stresses as between the two inner bolt holes in the inclined member connection, shown encircled in Figure 2. After finalizing the location, initial cracks of length 1mm were introduced at the edge of the bolt holes as shown in figure. Material properties of steel were adopted for the stress analysis.For fatigue analysis using Paris' law, the parameters were adopted as $m = 3$ and $C = 10^{-11}$ (Prashant Kumar, 1999). The crack was allowed to propagate in FRANC2D simulation. The initial and final configurations of the cracks are shown in Figure 3. For both the cracks, the crack length v/s number of cycles has been obtained as an output of FRANC2D and has been reproduced in Figure 4. It is observed that Crack 1 is the critical crack and propagates more rapidly than the Crack 2. The crack propagation has been simulated till a crack length of approximately 11.5 mm for Crack 1. Of course the gusset plate should not be allowed to be in service till such a large crack length gets developed. A reasonable crack length at which the gusset plate may be changed in would be approximately 6mm, which corresponds to 40,000 load cycles. The decision whether this

Figure 3: Initial and Final Configurations of Cracks

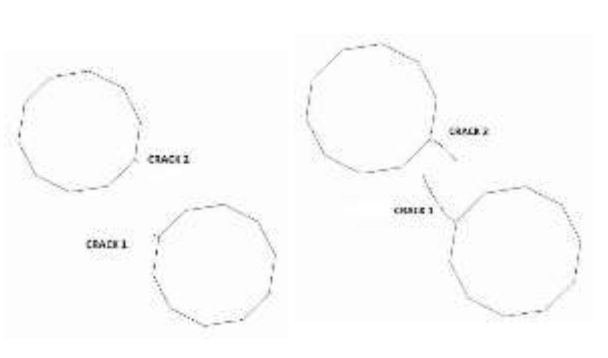
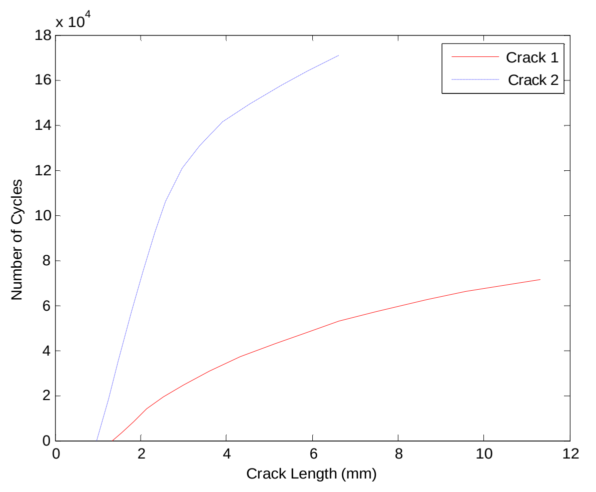


Figure 4: Crack Length v/s Number of Cycles for Cracks



life span is sufficient depends on the number of load cycles imposed in a day and would depend on the structure under consideration.

CONCLUSION

Fracture mechanics based fatigue analysis of a gusset plate has been described here. The life of the gusset plate as estimated by the Fracture Mechanics based fatigue analysis approach has been studied. FRANC2D has been used successfully for the fracture analysis of cracks in bolt holes in gusset plates. The approach adopted gives a very good description of the fatigue life of the gusset plate. Fracture based analysis should be adopted in the design procedure for clearer description of crack propagation and estimation of life of the gusset plates.

REFERENCES

1. Anderson T L (2005), "Fracture Mechanics-Fundamentals and Applications", 3e, Taylor and Francis.

ISSN: 2278-4632
Vol-10 Issue-12 No.03 December 2020

2. Aygul M (2012), "Fatigue Analysis of

Welded Structures Using the Finite Element Method", Licentiate of Engineering Thesis, Dept. of Civil and Environmental Engineering, Chalmers University of Technology, Sweden.

3. Broek D (1984), *Elementary Engineering Fracture Mechanics*, Martinus Nijhoff Publishers, The Netherlands.

4. Choudhary B K, Roedig M and Mannan S L (2004), "Fatigue Crack Growth Behavior of Base Metal, Weld Metal And Heat Affected Zone of alloy 800 at 823 K", *Transactions of the Indian Institute of Metals*, Vol. 57, No. 6, pp 639-649.

5. Dahlberg T and Ekberg A (2006), *Failure Fracture Fatigue: An Introduction*, Overseas Press (India) Pvt Ltd.

6. Fleck N A and Smith R A (1984), "Fatigue Life Prediction of a Structural Steel Under Service Loading", *International Journal of Fatigue*, Vol. 6, No. 4, pp. 203-210.

7. Myers M M (2011), "Modeling and Analysis of Steel Gusset Plates in Truss Bridges Under Live Load", Master of Science Thesis, Graduate School, New Brunswick, The State University of New Jersey.

8. Prashant Kumar (1999), *Elements of Fracture Mechanics*, Wheeler Publishing.

9. Pugno N, Ciavarella M, Cornetti P and Carpinteri A (2006), "A Generalized Paris' Law for Fatigue Crack Growth", *Journal of the Mechanics and Physics of Solids*, Vol. 54, pp. 1333-1349.

10. Radaj D, Sonsino C M and Fricke W (2006), "Fatigue Assessment of Welded Components", IIW doc., IIS/IIW-1221- 93, The International Institute of Welding.