Safety and Health at Work 12 (2021) 544–545

Contents lists available at ScienceDirect

Safety and Health at Work

journal homepage: www.e-shaw.net

Letter to the Editor

Comments on a Case Study on Engineering Failure Analysis of Link Chain

Keywords:
Chain fracture
Failure analysis
FEM simulation
Fractographicanalysis
Industrial accident

A B S T R A C T

The article by Tae-Gu Kim et al. conducted elastic FE modeling, which was inappropriate for fracture of elastic-plastic chain material (11.3% of elongation). FE analysis results and the findings in the fractographic analysis did not tally but contradicted each other. The article identified “incorrect installation”/bending forces as the root cause while FE results of the chain under bending forces showed very low stresses at fracture locations but the highest stress in the middle of shank of the chain. The article’s “step-like topographies indicating the fracture due to bending moment rather than uniaxial tension” lacked scientific support. The load value carried by each chain section under bending/incorrect installation was only half of that under tension, thus the article using same load value in FE simulation comparison for bending and tension was incorrect. The real cause of the chain fracture was likely improper checking the lifted load or/and using the wrong chain with much lower safety working load.

To the Editor(s),

Introduction of the article by Tae-Gu Kim et al.[1] did not focus on failure analysis of chain fracture but attempted to investigate “incorrect installation”. FE simulation results did not support but contradicted their conclusion “fractographic analysis reveals that the crane fracture catastrophically by bending forces”.

In failure analysis on crane-related incidents (including chain used in crane operation), it’s important to collect background information including working conditions, lifting load, specifications, safety working load (SWL)/working load limit (WLL), service history etc. [2,3]. However, these could not be found in the article.

1. Comments on fractographic analysis

The chain fractured at the locations where the crown and shank intersected, as shown in Fig. 1, based on Fig.2 of the article [1]. Radical patterns arrowing to the chain inner surface (intrados) was observed on L/H fracture surface (Fig.3 of the article) [1], suggesting that crack likely initiated around the chain inner surface, where presence of high tensile stress under tension load [5,6] but very low stresses under bending load (Fig.11 of the article) while a so called “crushed damage” area was found there, indicating “crushed damage” could not be formed by the compressive load which the article claimed. The article did not conduct necessary detail examination on “crushed damage” area to determine its nature, it looked like an impact damage after the chain fracture.

The article stated that “Figs. 4B and 5C show the step-like topographies indicating the fracture due to bending moment rather than uniaxial tension.” No scientific base supports such claim. ASM Metals Handbook clearly stated that the microscale appearances of fractures in parts failed in bending are not different from those in tensile loading conditions [4]. Therefore, “step-like topographies” (only ~30 microns per step) as microscopic features under high magnifications cannot be taken as characteristic for bending moment fracture. Furthermore, bending moment and tension in chain were not contrary, both sides of the chain were subject to bending moment and tensile force when it was loaded by tension, as shown in Fig. 2 [5], i.e. no real uniaxial tension in link chain loading.

2. Comments on FE modeling

The authors assumed only bending load acted on the chain, based on “incorrect installation” in Fig. 7B of the article. However, the actual loading condition was a mixture of tension and bending,

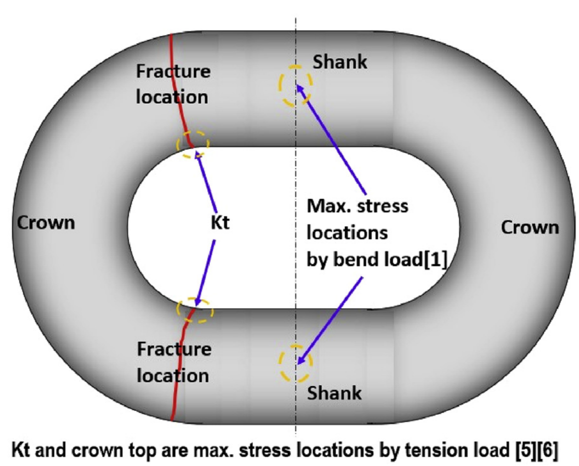

Fig. 1. Schematic of link chain stresses and fracture locations.

2093-7911/$ – see front matter
https://doi.org/10.1016/j.shaw.2021.05.001

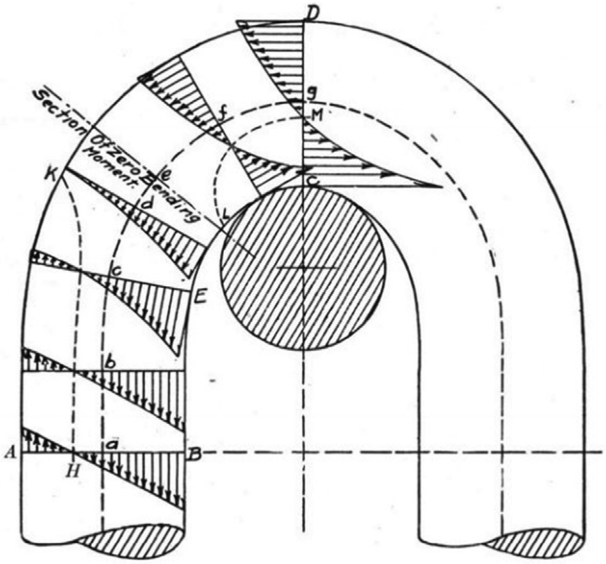

Fig. 2. Stress distribution of link chain under tension load [5].

the loading direction was about 30-40° away from the tension direction. Furthermore, the lifted load/weight in incorrect installation was shared by two sections of the chain over hook. Each section only carried half load but FE analysis applied full load for bending/incorrect installation. Thus, FE analysis on the chain under bending load did not simulate the reality of chain "incorrect installation" and dramatically exaggerated the stresses.

In boundary and load conditions for FE model, the authors simply applied uniform loadings to nodes on cross section of the chain, while actual loadings were transferred between chains by chain contact surfaces in complex nonuniform distribution, resulting in significant errors in calculated stresses.

FE results showed that maximum stress under bending at 5 tons was 1,236 MPa, exceeding material yield strength of 805 MPa and tensile strength 1,204 MPa, suggesting that elastic FE modeling used in the article was inappropriate for fracture of elastic-plastic chain material with elongation of 11.3%. After chain material yielded, the actual stress only increased much less than 100 MPa per 1% strain while the stress in elastic model would increase more than 2000 MPa for every 1% strain, i.e. elastic modeling would result in huge deviation from the reality in this case.

3. Discussion

As observed in fractographic analysis, there was significant plastic deformation (chain narrowing), suggesting that the chain was fractured by overload. Chain narrowing was in-plane deformation, mainly caused by in-plane loads such as tension while the bending load was out-of-plane load but no out-of-plane deformation was observed on the chain. The chain fractured at the locations where the crown and shank intersected. Coincidently, the maximum stress of the chain under tension located there (Kt-intrados where crown and shank intersected) [5,6], while the stresses at fracture locations under bending load were very low but the maximum stresses under bdending were located on upper surfaces in the middle of shanks (Fig.11 of the article [1] and Fig. 1).

FE results in the article showed that the stress at the fracture locations under 5 tons of tension load was about 306 MPa while that under 5 tons of bending load was only 25 to 160 MPa (Figs. 10 and 11 of the article) [1], indicating that the stress at fracture locations produced by tension load were several times higher than that by the same amount of bending load. Therefore, the chain in this case fractured by tension overload not bending one. The article mistook bending moment same as bending force but they were totally different (moment = force x distance) [7].

Failures in lifting equipment could result in fatality and severe economic loss. They are generally regulated and rated with SWL/WLL. The design factor/safety factor, the ratio of the minimum breaking load to SWL/WLL, shall be minimum of four for chain sling required by relevant standards/regulations [8].

If the background information was properly collected (including site survey), the lifted load, SWL/WLL, and installation conditions of the chain could be got, the investigation would be easier to draw right conclusion, resulting in significant cost and time saving.

Because the chain fractured was due to tension overload, the root cause of the chain fracture was likely that the rigger(s)/worker(s) did not properly check the lifted load or/and used the wrong chain with much lower SWL/WLL.

The authors did not validate their hypothesis "chain was fractured by bending forces/incorrect installation" through lifting experiment and examining chain fracture locations and fracture surfaces.

4. Conclusion

1. The failure mechanism of chain fracture was tension overload instead of bending one.
2. FE results contradicted the findings of fractographic analysis of the article. Elastic modeling in the article was not appropriate for fracture of elastic-plastic chain material. The bending load in FE simulation comparison was incorrectly used twice the actual load.
3. The root cause of the chain fracture was not "incorrect installation" but likely improper checking the lifted load or/and using the wrong chain with much lower SWL/WLL.
4. Proper collection of relevant background information is necessary in failure analysis.

Conflicts of interest

The author has no conflicts of interest to declare.

References

[1] Kim Tae-Gu, Lee Seong-Beom, Lee Hong-Chul. A case study on engineering failure analysis of link chain. Safety Health Work 2010;1:43–50.
[2] Klinger C. Failures of cranes due to wind induced vibrations. Eng Failure Analysis 2014;43:198–220.
[3] Yu George YH. Forensic investigation on crane accidents. Int J Forensic Eng 2017;3:319–41.
[4] Becker Metals WT, Dennis Mcgarry. Mechanisms and appearances of ductile and brittle fractureIn Failure analysis and prevention, vol. 11. ASM Metals Handbook; 2002. p. 587–626.
[5] Goodenough GA, Moore LE. The strength of chain links, Engineering Experiment Station. Bulletin No.18. University of Illinois; 1907. 29 p.
[6] Bastid Philippe, Smith Simon D. Numerical analysis of contact stresses between mooring chain links and potential consequences for fatigue damage. In: 32nd international conference on ocean, offshore and arctic engineering. ASME; 2013.
[7] Elements of a moment; 2021.. http://web.mit.edu/4.441/1_lectures/1_lecture5/1_lecture5.html.
[8] ASME B30.9-2014Slings, SECTION 9-1.4; 2015. 5 p.

George Y.H. Yu
Department of Forensic Engineering, Universal Technology Centre, Singapore
E-mail address: george.yu@ut.sg

1 December 2020
Available online 12 May 2021