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The Mobile Crane-Related Industrial Accident Caused by the Failures of Bolts

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Abstract

In this study, the cause of the failure of the fastening bolts which led to the mobile crane-related industrial accident was investigated. At the time of the accident, the fastening bolts of the bucket-type work platform attached to the end of the boom head of the mobile crane were failed and the bucket-type work platform fell down to 6 m resulting in two deaths while two workers were carrying out the work of attaching some steel parts to the ceiling in the tunnel on the bucket. The process of the accident and the situation of the accident site were identified through the investigation of the industrial accident site and the possibilities of failure of the fastening bolts were checked by using the finite element analysis of the bucket-type work platform and the bolts. In the accident, it was judged that the two upper bolts loosely fastened to the nuts were failed first, then, the two lower bolts were failed and the bucket-type work platform fell to the ground through the investigation of the industrial accident and the finite element analysis which confirmed that the bolts would not have failed if the bolts had properly installed between the end of the boom head and the bucket-type work platform but only the two lower bolts could not withstand the loads applied at the time of the accident also.

Through this study, the necessities for preventing improper fastening of bolts and damaging to the bolts at the time of detaching and attaching a bucket-type work platform to a mobile crane by prohibiting the use of a mobile crane illegally installed a bucket-type work platform as an aerial work platform and forcing to use a legally certified aerial work platform instead, and the necessities for checking the proper fastening of bolts and the preventing measures against loosening of bolts and nuts were identified.

Keywords: Industrial accident; Mobile crane; Failure of bolt; Finite element analysis;

INTRODUCTION

A mobile crane mounted on the cargo or the special type vehicle refers to machinery that move unspecified places by itself and hangs up heavy objects and carries them up and down and side by side using power [1, 2]. In the industrial sites, when bolts used for the purpose of fastening mechanical parts of mobile crane are broken by overload, fatigue, poor connection, etc., these cases frequently tend to be associated with serious industrial accidents to cause severe injuries and deaths.

However, the studies on the causes of bolts failures with respect to the investigation of the industrial accidents have not been studied much. In this study, the mobile crane-related industrial accident which led to the death of two workers in the bucket attached to the end of the boom head of the mobile crane was investigated mainly in terms of bolts failures. At the time of the accident, the fastening bolts of the bucket-type work platform were failed and the bucket-type work platform fell down to 6 m while two workers were carrying out the work of attaching some steel parts to the ceiling in the tunnel on the bucket.

Figure 1: The mobile crane (cargo crane truck) used

Figure 2: The work of attaching some steel parts in the tunnel

Figures 1 and 2 show the mobile crane used at the time of the accident and the work of attaching some steel parts in the tunnel. Then, Figures 3, 4 and 5 show the bucket-type work platform fell down, the deformed shape of the lower part of the connecting end of the boom head and the bolts broken at the time of accident.

Figure 3: The bucket-type work platform fell down

Figure 4: The deformed connecting end of the boom head

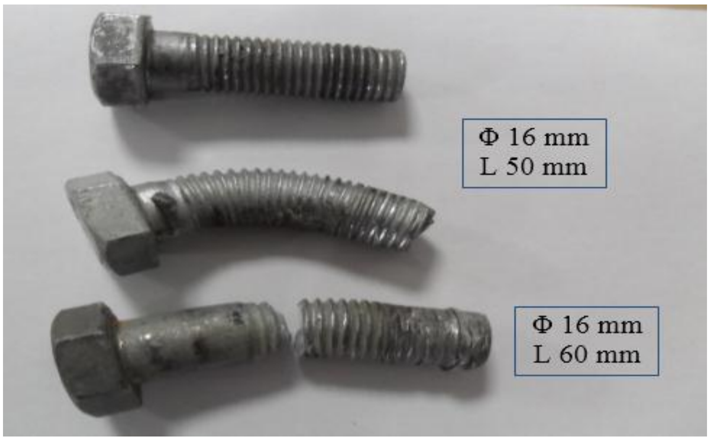


Figure 5: The fastening bolts broken by the accident

METHODS

The process of the accident and the situation of the accident site were identified through the investigation of the industrial accident site, then, the bucket-type work platform was modeled to be analyzed by the finite element analysis and the information from the accident site was applied to the finite element analysis conditions. In order to review the possibility of the failure of the fastening bolts, EN 1993-1-8:, Eurocode 3: Design of steel structures. Part 1-8: Design of joints was referred [3].

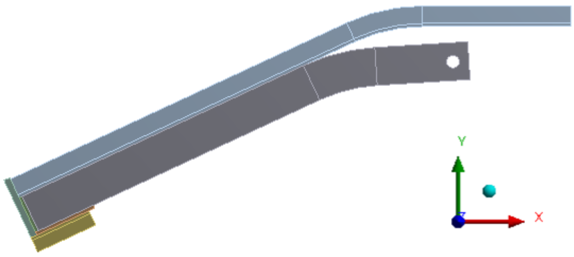
RESULTS

The bucket-type work platform modeling

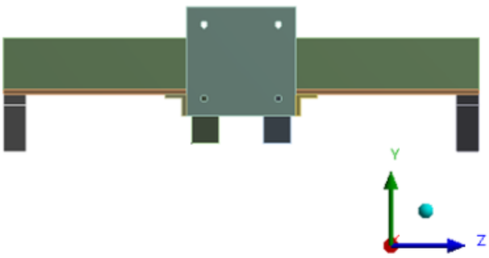
Through the accident site investigation, it was identified: 1) the bucket-type work platform was connected to the end of the boom head by fastening four bolts (upper two bolts: M16x50, lower two bolts: M16x60, strength classification: 9.8); 2) the bolts were improperly fastened without using a torque wrench; 3) the sum of the weight of the bucket only and the steel parts for attaching to the ceiling in the bucket was 150 kg; and 4) two workers in the bucket at 6 m height carried out the work attaching some steel parts to the ceiling with ascending the boom of the mobile crane raised at an inclination of 25° when the accident occurred. Also, when the broken bolt part around the region fastened to the nut was checked, 10 mm clearance was identified considering the thickness of the end of boom head and the nut.

Based on the above-mentioned investigations of the accident site, the bucket-type work platform excluding the bucket was modeled and the total weight of the sum of the weights (150 kg) of the bucket only and the steel parts in the bucket and the weight (140 kg) of two worker in the bucket was applied to the connection position where the bucket was connected as the external load. The modulus of elasticity of 200 GPa, Poisson's ratio of 0.3, bulk modulus 166.67 GPa and shear modulus 76.92 GPa provided by the manufacturer were applied on the bucket-type work platform.

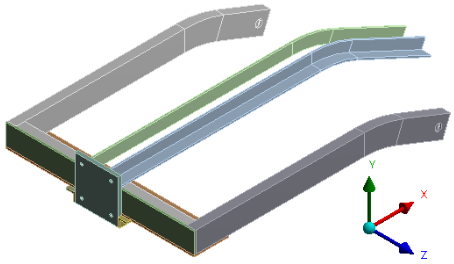
(a) Bucket-type work platform



(b) XY view



(c) YZ view



(d) XYZ view

Figure 6: The modeling of the bucket-type work platform

The fastening characteristics of bolts

In order to confirm the safety and fastening characteristics of the bolts on condition that they were correctly connected between the end of the boom head and the bucket-type work platform, finite element analysis was performed applying the boundary condition that the four bolts were completely fixed.

As a result, it was confirmed that a large von Mises stress occurred at the four bolted portions (see Figure 7) [4], a tensile force was applied to the upper bolt and a compressive force was applied to the lower bolt.

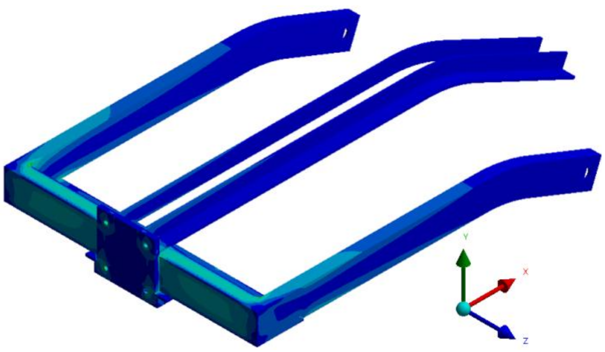


Figure 7: Von Mises stress distribution

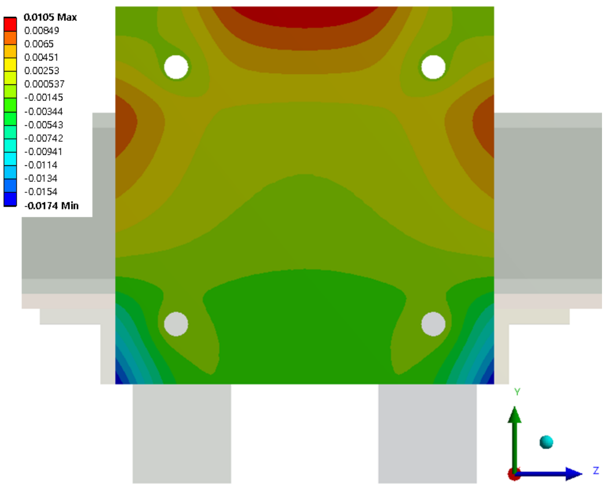


Figure 8: X-deformation (U_x) distribution

By referring to the above and the curved figure of the lower part of the connecting end of the boom head (refer to Figure 4), after the two upper bolts had been broken by the tensile force, the two lower bolts were supposed to be broken while sustaining the whole load applied at the time of the accident [5]. In addition, the X-deformation (U_x) along the Y-direction distance of the end plate of the bucket-type work platform to which the bolts are fastened tends to change from the tensile direction to the compressive direction around the lower support on condition that the four bolts are fully fixed (see Figure 8).

Review of the fastening bolt safety

In order to check the safety of the fastening bolt in a case that the four bolts were properly connected between the end of the boom head and the bucket-type work platform, finite element analysis was performed applying the boundary condition that the end plate of the bucket-type work platform to which the four bolts are fastened was fixed, the analysis result values from FEA and EN 1993-1-8: Eurocode 3: Design of steel structures. Part 1-8: Design of joints [3] was used to check the safety of the bolts. Then, the safety when connected with only the two lower bolts after two upper bolts were broken was checked also.

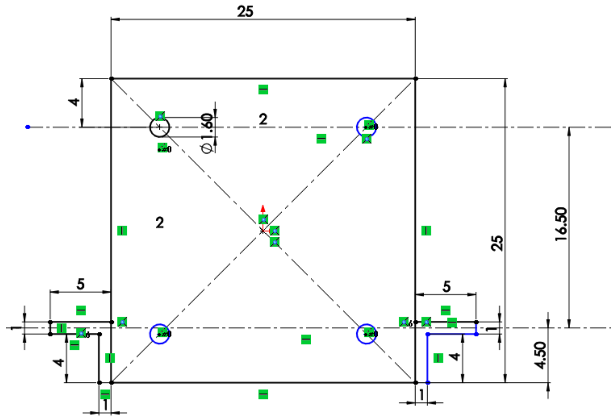


Figure 9: The end plate of the bucket-type work platform

- Review of the safety on a condition that four bolts firmly fastened

$$F_{t,Ed} = F_{t1Ed,M,1Bolt} + F_{t1,Ed,N,1Bolt} \quad (1)$$

$$F_{t1,Ed,M,1Bolt} = \frac{M_{Ed} \times h_1}{n_v \times \sum h_r^2} \quad (2)$$

$$F_{t1,Ed,N,1Bolt} = \frac{N_{Ed}}{n_t} \quad (3)$$

$$F_{t,Rd} = \frac{k_2 \times f_{ub} \times A_S}{\gamma_{Mb}} \quad (4)$$

Where

$F_{t1,Ed,M,1Bolt}$ = The tension force from bending moment for one bolt from bolt-row1

$F_{t1,Ed,N,1Bolt}$ = The axial force for one bolt from bolt-row1

$F_{t,Rd}$ = The design tensile force per bolt for the ultimate limit state

h_1 = The vertical distance from bolt-row1 to the center of rotation axis (h_1=16.5 cm)

n_v = The number of vertical bolt-rows (n_v=2)

Σh_r^2=The sum of the squares of the vertical distances between bolt-row 'r' and the center of compression axis

M_{Ed} = The bending moment

N_{Ed} = The axial force

n_t = The number of bolts (n_t=4)

k_2 = 0.9 (refer to Table 3.4 in [3])

f_{ub} = The minimum tensile strength of the bolt (f_{ub}=90,000 N/cm^2)

As = The tensile stress area of the bolt (As=2.0106 cm^2)

γ_{Mb} = Partial safety factor for bolts resistance (γ_{Mb}=1)

Table 1: Review of the fastening bolt safety

M_{Ed}	N_{Ed}	$F_{t1,Ed,M,1Bolt}$	$F_{t1,Ed,N,1Bolt}$	$F_{t,Ed}$	$F_{t,Rd}$	$F_{t,Rd}/F_{t,Ed}$
466564 (N·cm)	-1,896 (N)	14,138 (N)	-474 (N)	13,664 (N)	180,954 (N)	11.92

※ For MEd and NEd, the FEA results were applied under the boundary condition that the end plate of the bucket-type work platform was fixed.

Since the comparison value ($F_{t,Rd}/F_{t,Ed}$) between the force ($F_{t,Rd}$) that one bolt can endure when considering the minimum tensile strength of the bolt (M16, strength classification 9.8) and the tensile force ($F_{t,Ed}$) applied to the one upper bolt by bending moment and axial force is 11.92, it was expected that the fastening bolt would not fail if there was no serious damage on bolt due to wear and fatigue, loosening of bolts and nuts or very strong external impact.

- Review of the safety on a condition that only two lower bolts supported the total loads

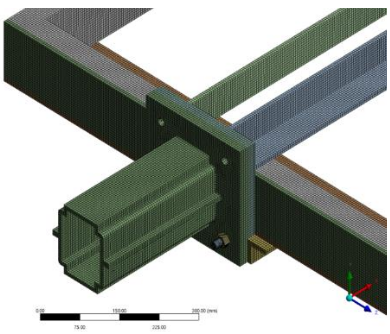


Figure 10: Modeling to check the safety of the lower bolts

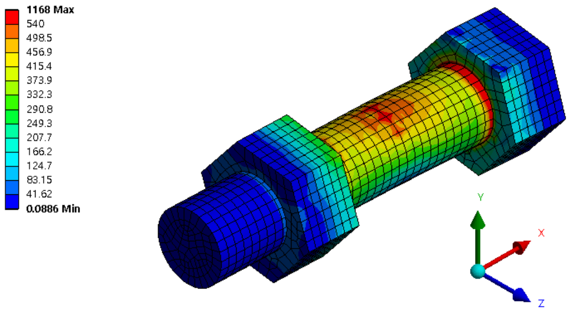


Figure 11: Von Mises stress distribution of the lower blot

Considering the maximum von Mises stress of the lower bolts obtained from FEA was 5,477 N/mm^2 and the minimum tensile strength of 900 N/mm^2 of the M16 bolt (strength classification 9.8), it was confirmed that when the upper fastening bolts were failed, the lower fastening bolts only could not withstand the loads applied at the time of the accident. Also, it was identified that the deformed shape of the connecting end of the boom head shown in FEA was very similar to the actual one (see Figs. 4 and 12).

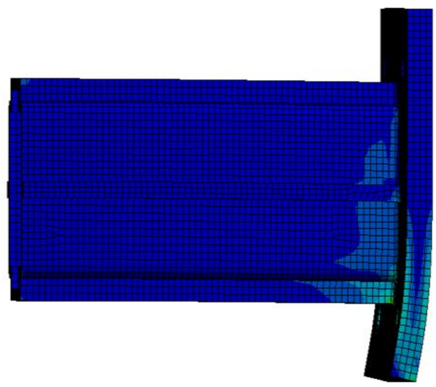


Figure 12: The deformed connecting end of the boom head shown in FEA

CONCLUSION

It was considered that the upper bolts, which received the tensile force, loosely being fastened to the nuts at the time of the accident were first broken by the loosening of nuts and other external factors and the lower bolts were broken while sustaining the whole load applied at the time of the accident after upper bolts failed and then the bucket-type work platform fell to the ground 6 m below taking into account the facts that the finite element analysis showed that the bolts would not failed if the bolts had been correctly fastened, the bolts were improperly fastened without using a torque wrench when the accident occurred and the 10 mm clearance in the broken bolt part was identified considering the thickness of the end of boom head and the nut.

In order to prevent the similar accident, the importance of the necessities for preventing improper fastening of bolts and damaging to the bolts at the time of detaching and attaching a bucket-type work platform to a mobile crane by prohibiting the use of a mobile crane as an aerial work platform and forcing to use a legally certified aerial work platform instead, which is forced by local rule on occupational safety and health standard in the Republic of Korea [6], checking the proper fastening of bolts and preventing loosening of bolts and nuts were confirmed.

Conflicts of Interest

No potential conflicts of interest relevant to this article were reported

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