Analysis of the Effects of Anchorage Failure on the Stability of a Mast Climber System

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Abstract: Mast climbing work platforms (MCWPs) have been widely used at construction sites in the United States since the 1980s. The purpose of the current study is to analyze the effects of a failure of an anchorage on the structural stability of a mast climber system using the finite element (FE) method. The FE models were constructed using commercial software (ABAQUS) and based on representative set-ups of anchored MCWPs as specified in the manufacturers' manuals. The simulated MCWP has three anchorages, and one is assumed to fail. The consequences of an anchorage failure were evaluated numerically. Our results show that the failure of an anchorage caused loading redistributions among the remaining anchorages. Although the reaction forces and moments in the supporting feet for the remaining anchorages increased slightly due to the failure of an anchorage, the structure stiffness decreased remarkably due to the anchorage failure.

***Keywords**: Mast climbing work platforms, Finite element analysis, Anchorage, Structural stability*

1. Introduction

Mast climbing work platforms (MCWPs) have been widely used at construction sites in the United States since the 1980s. Up to 16,800 workers are using mast climbers in the U.S. at any given time during a typical workday. Catastrophic failures of the equipment, although seldom happens, may potentially cause fatal consequences, compared with non-fatal occupation-related incidents involving slip, trip, and fall hazards. MCWP equipment is generally considered to be inherently safe, consequently, limited studies have been conducted on MCWPs independent of the manufacturers' design and testing. When the equipment was erected and used according to the manufacturers' recommendations during a fall-arrest condition (Harris et al., 2010) destabilizing forces were small and would not potentially cause a MCWP collapse (Wimer et al., 2017). From the standpoint of structural stability, the anchorages and their attachments are among the weakest elements for the entire MCWP setup. This is because the mast structure of an MCWP is considered a "slender" structural component, which needs anchorages to maintain its stability. The anchorages and their attachments may involve factors that are beyond the MCWP manufacturers' quality control, such as the structural conditions of the buildings to be anchored and the customers' setups and installations. In a previous study, we developed finite element (FE) models of a representative MCWP system and applied them to characterize the anchoring forces in response to different loading conditions on the platform that is operating at various heights along the mast (Wu et al., 2023). The purpose of the current study is to analyze the effects of the failure of an anchorage on the structural stability of a mast climber system using the FE method.

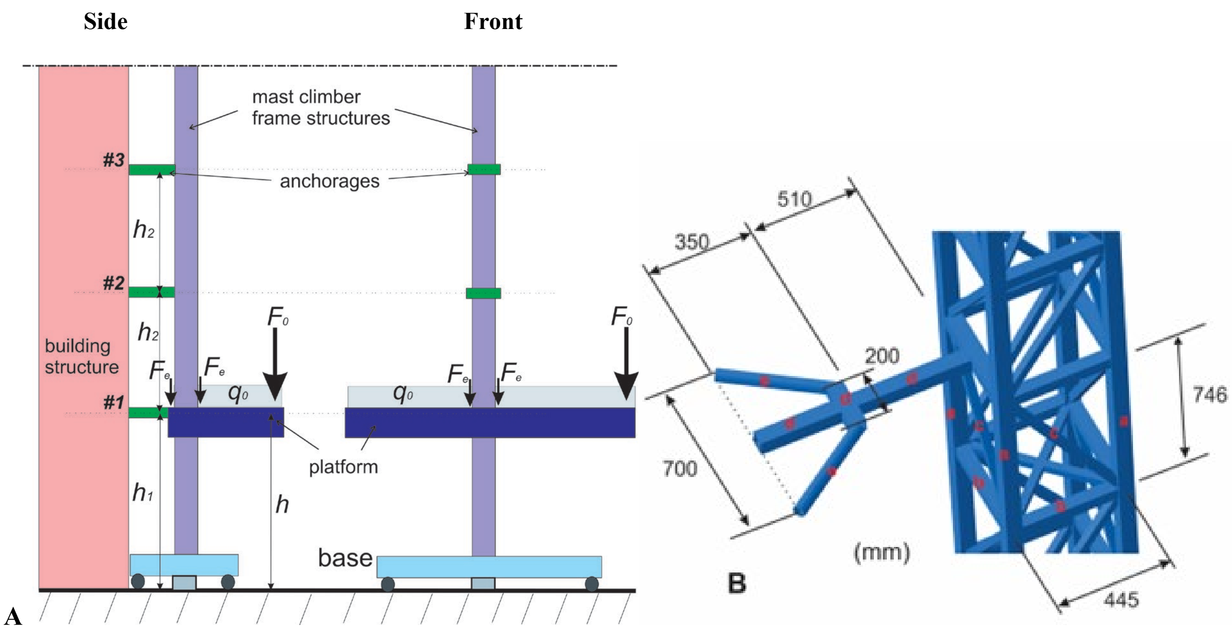


Figure 1. Conceptual design of the numerical simulations. (A) The simulation model consists of three parts: a base, a mast, and a platform. The mast has a height of 33.60 m and is connected to the construction building via three anchorages. The anchorage locations: h1 = 12.7 m and h2 = 9.05 m. (B) Detailed anchorage structure.

2. Methods

The simulation model setup is similar to our previous study (Wu et al., 2022). The simulated MCWP consists of a supporting base, a mast structure, and a platform, as illustrated in Fig. 1. The work platform had a dimension of 4.48 x 1.83 (m). The mast had a total height of 33.6 m and was connected to a construction building via three anchoring sites (#1, #2, and #3). The construction building structure was considered rigid, which has negligible deformation and will not be damaged under any loading conditions. The platform was assumed to operate at nine different positions (heights): h_i (Pi) = $h_1 + (1/4) * (i-1) * h_2$ (i = 1, 2, .., 9), where Pi (i=1,2,3,..9) represents nine platform operation locations. The FE models were developed using commercially available FE software (Abaqus, Dassault Systems, France). All construction components were assumed to be made of common structural steels (Young's modulus, E = 210 GPa; Poisson's ratio, ν = 0.3; yield stress, σ_Y = 275-355 MPa, and tensile ultimate stress, σ_T = 400-470 MPa) (BS, 2019). An evenly distributed loading (q_o = 1.0 kN/m^2), mimicking the weights of the structural components and materials, was applied on the platform working surface. In addition, a concentrated load (F_o = 10 kN) was applied to a corner of the platform. Four concentrated forces (F_e = 1.0 kN) were applied on the platform close to the mast structure (Fig. 1A), simulating the equipment weight. The total weight of the mast structure was assumed to be 12 kN and was simulated by applying small, concentrated loads (250 N) on 48 locations at 12 distributed heights along the mast. The anchorage had a typical three-foot structure, which was connected to a construction structure via right, left, and center foot (Fig. 1B). The simulations on the consequences of an anchorage failure were to assume that the three supporting feet of anchorage #2 were disconnected from the construction structure. The remaining two anchorages #1 and #3 were assumed to be well-installed and in proper working condition. The platform is assumed to work at 9 different heights (P1, P2, …P9), as shown in Fig. 2. The reference case is a structure with all three anchorages in good working condition.

From the FE analysis, we calculated the x, y, and z components, as well as the resultants of the reaction forces and reaction moments at each of the supporting feet (right, left, and center) at each of the anchorage sites. The maximal reaction anchorage forces (RF_{max}) and moments (RM_{max}) at an anchorage site were defined:

$$RF_{max} = RF_{right} + RF_{center} + RF_{left};\ RM_{max} = RM_{right} + RM_{center} + RM_{left}.$$

The maximal reaction anchorage forces (RF_{max}) and moments (RM_{max}) are the upper limits of the maximal reaction force and the maximal reaction moment, respectively, that can possibly be reached at an anchorage site.

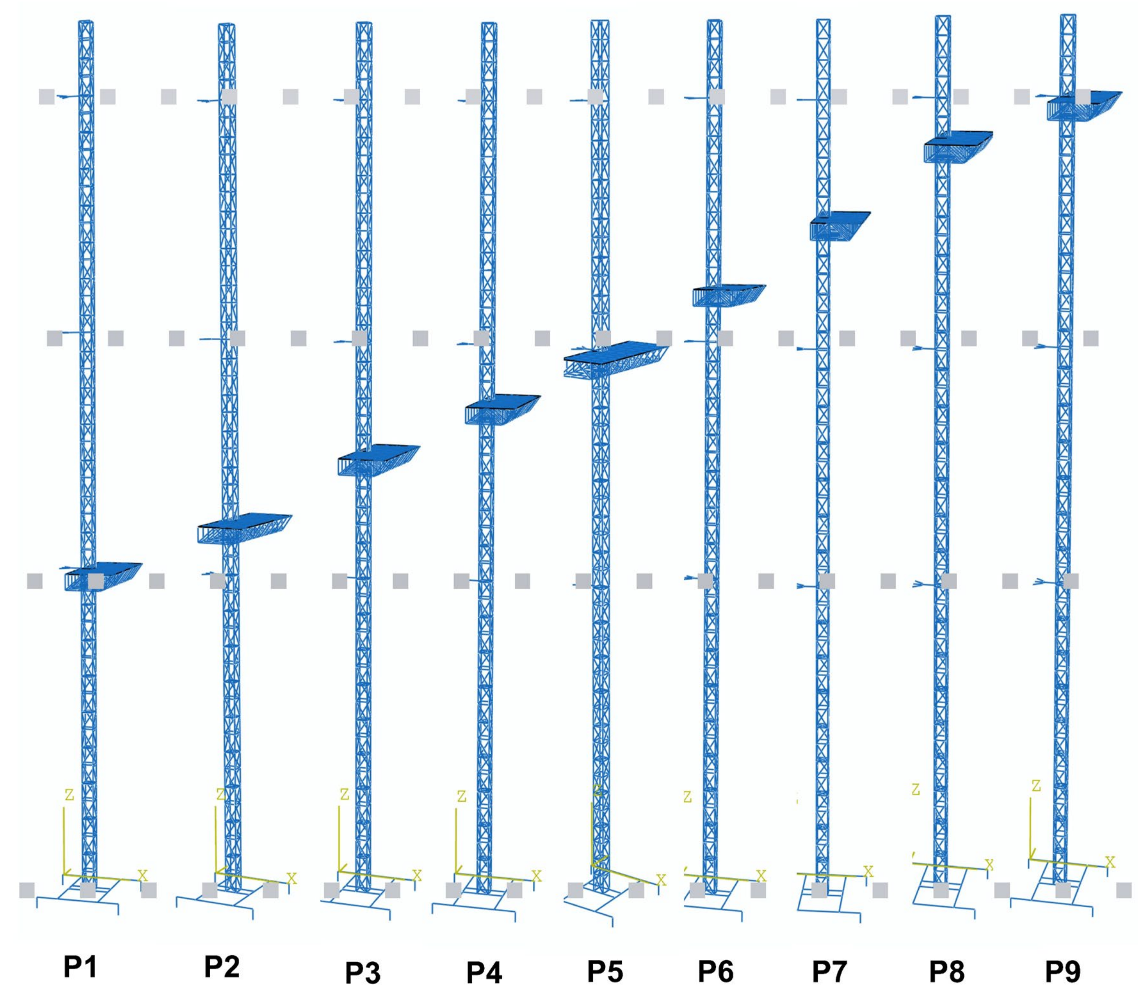
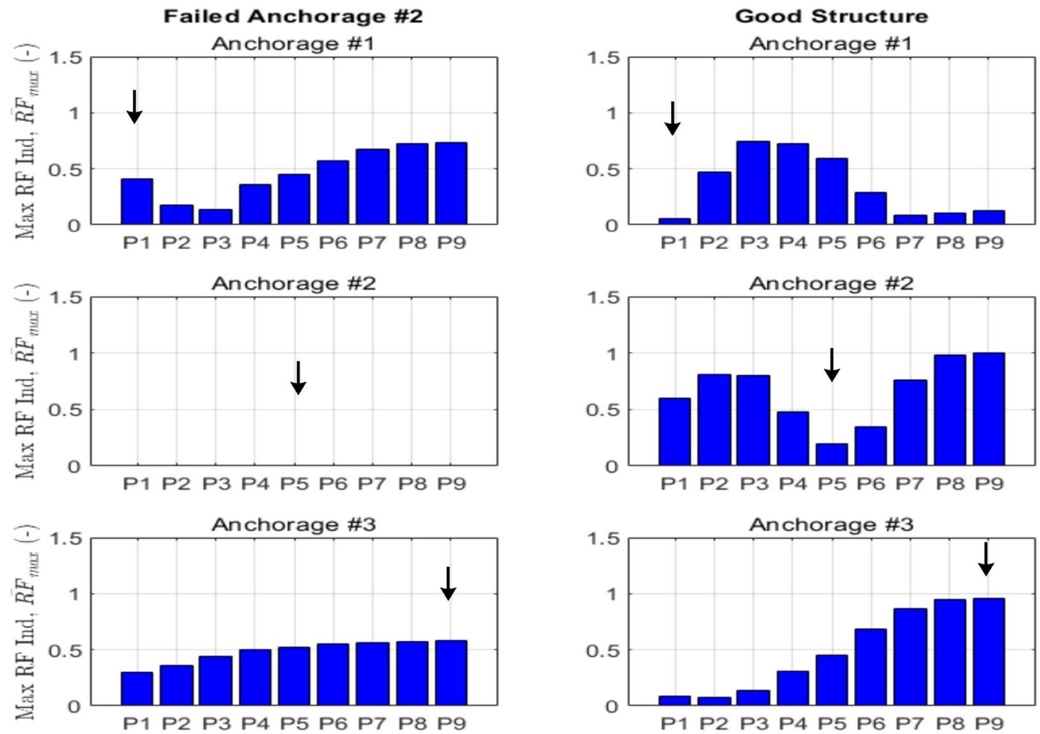


Figure 2. Finite element models of the mast climbers when the work platform operates at different heights. P1, P2, ..., P9 represent nine operation positions (heights).

3. Results

The simulation results of the maximal anchorage forces (RF_{max}) and moments (RM_{max}) for the MCWP with a failed anchorage #2 are compared to those of a good reference structure, as in Fig. 3. Since anchorage #2 failed, there were no reaction forces and moments in its three supporting feet. The anchorage supporting force was redistributed to anchorages #1 and #3. For the system with a failed anchorage #2, the maximal anchorage forces in both anchorages #1 and #3 were observed when the MCWP operated at the location of anchorage #3 or P9 position. The maximal moments in anchorage #1 were observed when the MCWP operated at the location of anchorage #3 (P9 position), whereas the maximal moments in anchorage #3 were observed when the MCWP operated around 50% of the anchorage interval from the location of anchorage #1 (P1 position). The maximal foot force was observed in anchorage #1 at platform position P9, where the reaction force reached 2.4 kN. The maximal deflection of the platform of the good reference structure was about 29.5 mm when the MCWP was at P9 position; due to the anchorage failure, it increased by 13% to 33.3 mm.



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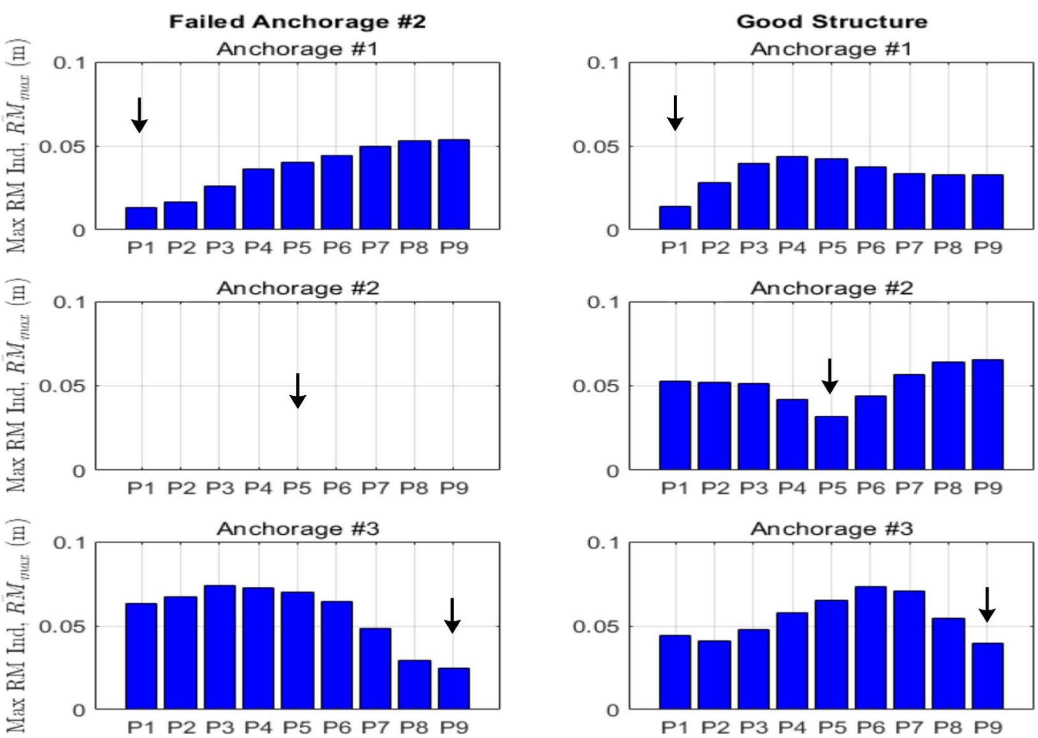

B

Figure 3. The normalized maximal anchorage force ($\overline{RF}_{max} = RF_{max}/F_0$) and moment ($\overline{RM}_{max} = RM_{max}/F_0$) as a function of the platform operation location (height). **A**: Maximal anchorage force ($\overline{RF}_{max}$). **B**: Maximal anchorage moment ($\overline{RM}_{max}$). P1, P2, ..., P9 are nine height positions, at which the platform operates. The arrows represent the positions of the anchorages. The anchorage #1, #2, and #3, respectively, is in position P1, P5, and P9.

The current simulations indicate that the failure of one anchorage site of the MCWP system caused the redistribution of the anchorage forces on the other two anchoring sites. The anchorage failure caused changes in the pattern of the force/moment distributions when the platform operates at different heights. However, little change occurred in the maximal reaction forces and moments in the three supporting feet of anchorages #1 and #3 due to the failure of anchorage #2 (Fig. 3). The anchorage failure did not change the general patterns of the force and moment distribution among the three supporting feet in anchorages #1 and #3. In both anchorages, the center foot carried less force and more moment than the other two supporting feet. Although the failure of one anchorage caused little change in the maximal anchorage forces and moments, it caused remarkable decreases in the structure stiffness. The maximal platform deflection increased by 13% due to the anchorage failure.

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Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Mention of any company or product does not constitute an endorsement by the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

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