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Failure analysis of torsional buckling of all-terrain crane telescopic boom section

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ABSTRACT

A telescopic boom section (TBS) is a type of slender thin-walled structure equipped in all-terrain cranes. It has an irregular cross-section and bears complex multi-directional loads; thus, local buckling failure is apt to occur under large hoisting loads, sudden rotation brakes or gusts. In this study, the torsional buckling of a TBS under multi-directional loads is investigated. To accurately and quickly predict the buckling load of the TBS, geometric, material and status nonlinear finite element (FE) analyses with implicit and explicit methods were used to study the telescopic boom of an all-terrain crane QAYX. The critical buckling load obtained using the displacement, strain and stress were discussed, in which the load obtained using the stress state transition was closest to the experimental critical buckling load. The implicit method required less computational time and demonstrated a qualitatively good agreement with the strain measurements before reaching buckling failure. The explicit method calculated an accurate deformation when compared with the experimental result and implicit method; however, a large local deformation resulted in the calculation of the implicit method being unable to converge after buckling.

1. Introduction

A telescopic boom is an important part of the all-terrain crane, and it consists of several separated TBSs, which hoist the load and expand the operational scope. The TBS consists of dissimilar thicknesses and high strength steel, and the cross-section is an irregular oval, as shown in Fig. 1. Buckling stability is a significant factor affecting the telescopic boom's carrying capacity and safety performance. When the crane is hoisting a certain load, and if a small perturbation load is further applied, then the stress, strain and local deformation will suddenly and rapidly change. The TBS cannot maintain the original balance state, and an extremely large local deformation leads to a “broken arm” accident; thus, it is necessary to predict the critical buckling load accurately.

The TBS bears various loads in multiple directions, such as the structure self-weight of a fixed lattice jib or luffing fly jib and the telescopic boom, hoisting load and wind load. Particularly, when the fixed lattice jib or luffing fly jib is too long, a sudden rotation brake generated by the inertia loads or a non-working gust may cause the TBS to experience buckling failure. The calculation of the telescopic boom critical buckling load is based on the steel-structure design criteria [1,2], crane design criteria [3,4], analytical method [5,6] or FE method. The design criteria and analytical method are typically applied to a regular structure bearing a one-directional load, such as a flat structure bearing uniform axial compression, I-shaped beam structure, and elliptical and

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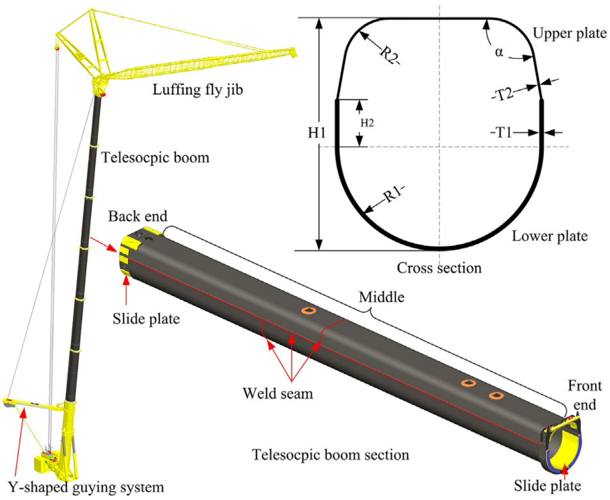

Fig. 1. A TBS of the all-terrain crane.

circular cross-section; however, research on multi-direction irregular structures is lacking. Eigenvalue and nonlinear analyses are the FE methods used to analyze the buckling stability of complicated structures. The eigenvalue method is used to study the linear elastic structural stability. The low-order buckling mode deformation results obtained using the eigenvalue method were set as the initial structure deformation to analyze the effects of structural geometric defects, welding residual stresses or cracks on the buckling stability [7–13]. A nonlinear analysis is used to study the buckling problem influenced by nonlinear factors. Nonlinear factors include large geometry deformations and material and state nonlinearities, which can be considered separately or simultaneously, and the analysis method is typically separated into implicit and explicit methods. The implicit method is used to analyze the structural load and stress before and close to buckling [14–17] whereas the explicit method is used to analyze the stress and deformation post-buckling [18–21]. Rust et al. studied the ultimate bearing capacity of a shell structure using the implicit and explicit methods [22]. Li et al. researched the overall buckling of a crawler crane lattice boom using the implicit incremental displacement method [23].

In previous studies [24], the accident analysis of an all-terrain crane QAYX was performed. Local bending buckling caused the boom to break. This paper aims to further study the torsional buckling feature of a TBS under multi-directional loads and develop a finite element analysis framework to effectively predict the telescopic boom critical buckling load.

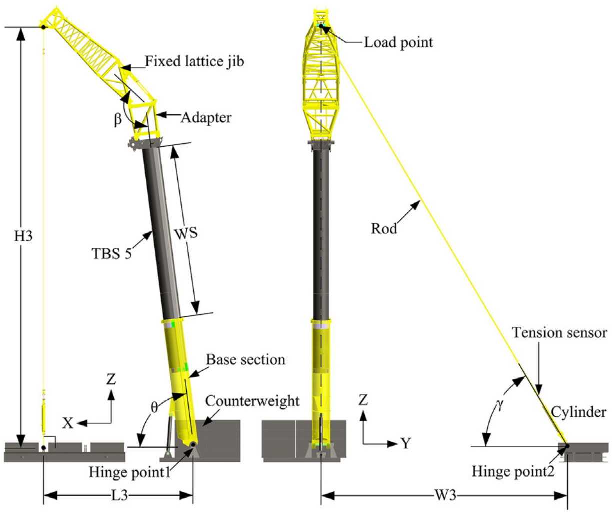

Fig. 2. Sketch of experimental structure.