Journal of Constructional Steel Research 92 (2014) 195–210

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Analysis of the stress-erection process of Strarch frames considering the joint connection properties

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ARTICLE INFO

Article history:
Received 13 August 2012
Accepted 15 September 2013
Available online 8 November 2013

Keywords:
Strarch system
Stress-erection
Beam-column
Semi-rigid
Post-tension
Dynamic relaxation method

ABSTRACT

In this paper, the unique stress-erection process for constructing stressed-arch (Strarch) frames is studied for various joint connection conditions. To analyze the stress-erection process of a Strarch frame, an analysis method is developed using a large deformational elasto-plastic beam-column element, considering Eulerian finite rotation and various joint connection properties. The explicit quasi-static dynamic relaxation method is used for the numerical method. The numerical results are compared with simple equations that are proposed to predict the jacking and member forces, and good agreement is obtained. Using the proposed numerical method, the required tendon jacking and member forces are successfully predicted. As a result, the effect of a semi-rigid connection in the flexible top chord is relatively small for Strarch systems. The difference in the axial force when a hinge connection is used is small compared with the allowable axial force and can be ignored. Therefore, it is reasonable to model the flexible top chord as a plane truss system with an initial imperfection rather than as a beam-column system.

1. Introduction

During the stress-erection process, stressed-arch (Strarch) frames are assembled close to ground level in a flat configuration with a simple supported boundary condition and then, using a series of high-strength steel-stressing tendons, are "stress-erected" into the final arch-shaped configuration typical of a Strarch system. One end of a roller support is then fixed into a hinge-support condition. One of the advantages of the Strarch system is its convenient construction process.

However, the initial curvature induced by the stress-erection process may exceed the yielding strain or curvature. Consequently, when erection is complete, the flexible top chord member may be in a plastic yielding state, and plastic hinges may occur at the flexible top chord joint, according to the beam-column approach. The fixed section of the truss, usually composed of haunch sections, does not change in shape during the stress-erection process and remains elastic.

The unique stress-erection process, its effects on the overall statics of the Strarch frame and the change in the shape of the flexible section all contribute to design feature considerations that, in some instances, fall outside the range of "conventional" design. Pioneering researchers and Strarch International have undertaken extensive experimental and theoretical investigations to substantiate the Strarch design methodology. They have developed a new design method for the Strarch top chord member based on parametric studies of Strarch frames using a rigorous finite element code [1–3] and have verified the design method for numerous projects [4,5].

However, research is lacking on numerical methods for analyzing the unique feature of the Strarch system and the stress-erection process, due to the difficulties inherent in the analysis. Therefore, it is not currently possible to accurately predict the exact frame shape and change of member force during the stress-erection process. Only the prediction of the required tendon force is possible using the linear analysis method to model the erection process. However, it has been demonstrated that the essentially linear elastic response assumed by Key et al. [4] is valid over the normal range of working loads while approaching the ultimate strength limit state of the frames.

Despite the reasonably linear response of a Strarch frame, the process of stress-erection of a Strarch frame is an interesting subject for the researcher and engineer. During the process, the rigid or semi-rigid bolt-jointed flexible top chord member may change in strength due to yielding by some features of the system, such as a simply supported boundary condition or a sleeve and gap in a bottom member as illustrated in Fig. 1, which permit one roller support to freely slide to the other hinge support by the jacking force through the tendon in the bottom chord. Without this, the erection process would not be possible for the Strarch system. As a result, plastic hinges may occur at the joint of the flexible top chord member, and the rigidly and semi-rigidly jointed frame element exhibits nearly free rigid body rotation, as does a hinge-jointed truss structure.

In addition, to analyze the process correctly, the numerical method adopted should consider the change of the state of the system, such as the critical point of singularity when the plastic hinges occur. The rigidly

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http://dx.doi.org/10.1016/j.jcsr.2013.09.011

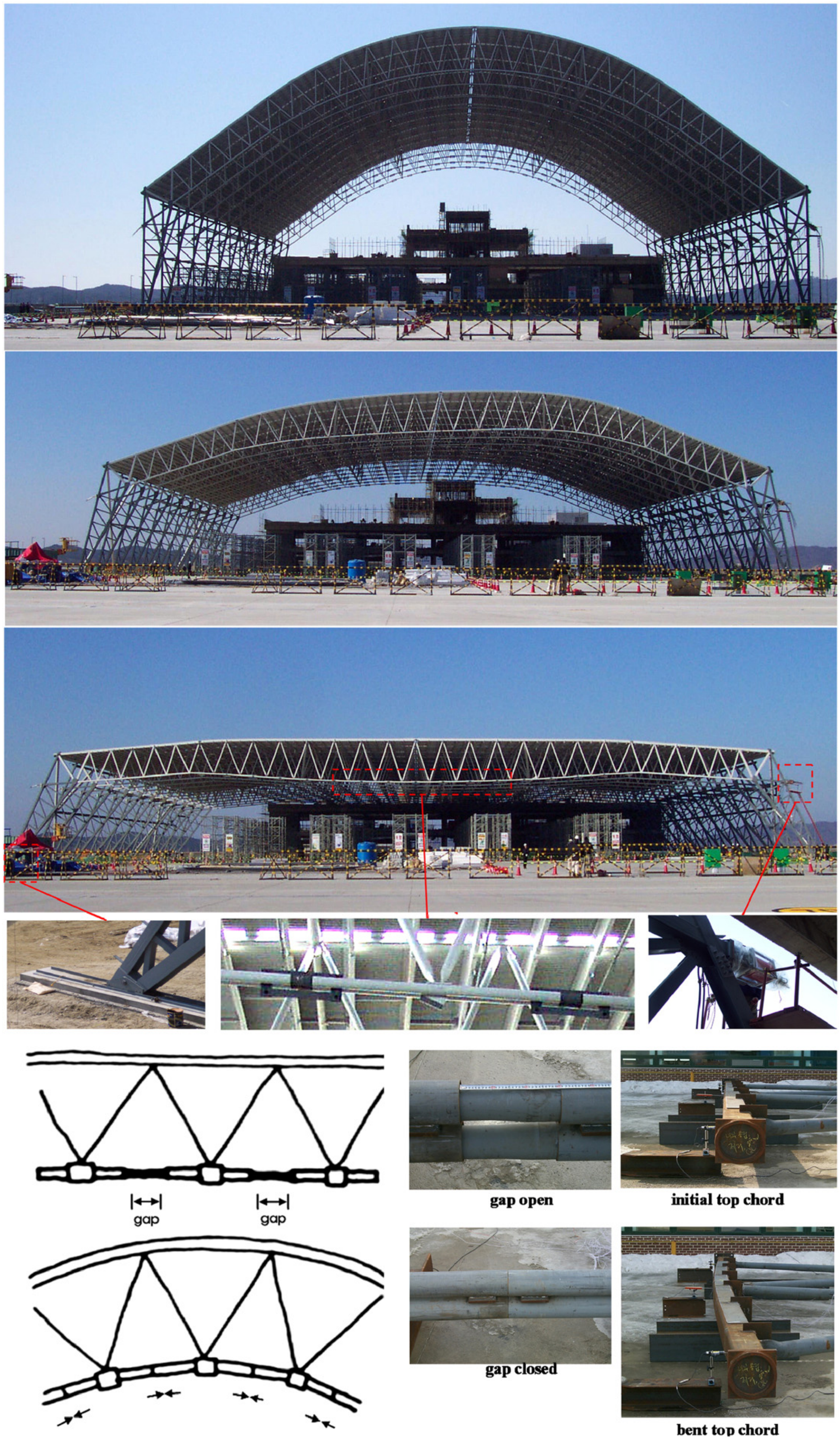

Fig. 1. Strarch system and stress-erection process.