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Investigation of Joint Rotational Stiffness and Initial Geometric Imperfections of Fastener-style Tubular Steel Formwork-support

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Abstract. A fastener-style tubular steel formwork-support (FTSF) is often used for temporary support during the construction in China for its convenience and applicability. In order to modelling and performing probabilistic analysis of the stability bearing capacity of FTSF, actual data of semi-rigid joint behavior and initial geometric imperfections are needed. However, at present little information on probabilistic models of rotational stiffness and initial geometric imperfections are available in the literature. This paper presents the results of FTSF joint tests. The tests were performed on randomly chosen right-angle couplers to investigate the joint rotational stiffness. The paper also reports the findings from various site measurements of initial geometric imperfections of FTSF. The measurements consist of out of straightness and out-of-plumb of the standards. The statistical probabilistic models of the data are presented in the paper for practical application in probabilistic assessment of FTSF.

Introduction

A formwork-supporting scaffold system is temporary structural system used to support formwork whose function is to maintain plastic concrete in its desire shape until it hardens in multistory reinforced concrete building construction. Fastener-style tubular steel formwork-support(FTSF) is the most common type used in China for its convenience and applicability. In construction, the FTSF consists of couplers and steel tubes which are used repeatedly. Therefore, they usually show signs of wear and out-of-straightness of members. FTSF also show out-of -plumb of the standards due to uneven ground and erection inaccuracy.

In order to consider the semi-rigid joint behavior of FTSF, experimental studies have been conducted in the past on the rotational stiffness of right-angle couplers[1,2].It turns out that all research conducted has so far assumed the parameters of rotational stiffness model to be deterministic, and very few has considered the variation of the model..However the parameters of rotational stiffness model obtained from the research in the past differ widely, which just reflect the existence of the obvious variation. Due to lack of available test data, this paper presents tests on the right-angle couplers and discusses the semi-rigid joint behavior observed from the tests as well as the rotational stiffness derived from the test. Furthermore, considering the obviously variation in joint rotational stiffness, statistical analysis of the joint test data have been carried out in preparation for probabilistic assessment for FTSF.

Significant research has been undertaken on methods for incorporating initial geometric imperfections in structural analysis models of FTSF[1-3].Two main types of initial geometric imperfections are important in modelling, which consist of initial out-of-plumb and initial out-of-straightness. A common approach of considering initial geometric imperfections is to scale the first buckling mode and add the scaled the maximum allowable imperfection to the perfect geometry[1]. Nonetheless, this method often produces conservative predictions of the stability bearing capacity of FTSF. Another approach is to apply notional horizontal forces[2].However, some issues arise with this method. For instance, how much forces and at which location they should be applied on the FTSF. In order to resolve the issue for modelling initial geometric imperfections in FTSF, actual data of initial geometric imperfections are needed. Little information on probabilistic models of initial geometric imperfections is available in the literature at present. This paper presents the methods used and the results obtained from the measurements of initial geometric imperfections of FTSF.

Joint Rotational Stiffness of FTSF

Joint Rotational Stiffness Test Setup and Materials. The right-angle coupler rotational stiffness test was undertaken in the structure laboratory of the College of Civil Engineering and Architecture at Nanchang University. The schematic diagram of the test is shown in Fig.1,where a horizontal steel tube and a solid steel bar, which were located at the top of the triangular steel frame ,were connected by a right-angle coupler. The tubular cross-section dimension was 48 mm ×3.5 mm,and the solid steel bar had a diameter of 48 mm.The right-angle coulpers used in the test were selected randomly from various construction sites.The bolts on the couplers were tightened with the controlled torque of 40N·m by torque wrench. A concentrated weight *P* was incrementally applied to the top of the horizontal tube to create an in-plane bending moment at the coupler location. A vernier caliper was mounted to measure the vertical displacement at the free end of the steel tube, from which the in-plane rotation of the coupler could be deducted.

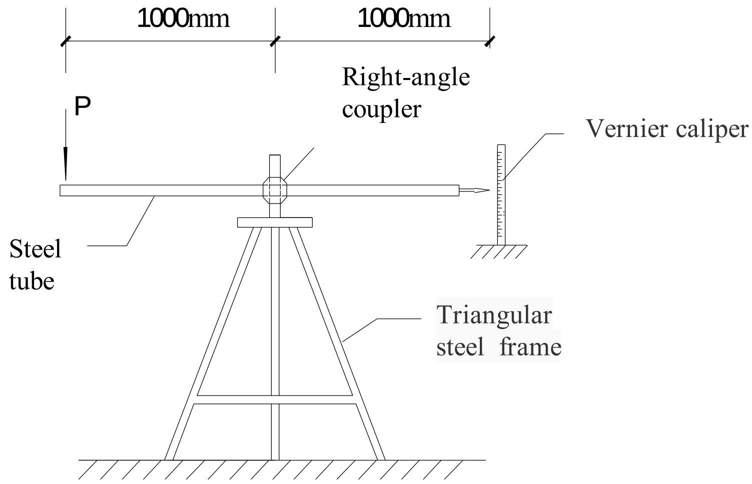

Fig.1. Schematic diagram of right-angle coupler rotational stiffness test

Joint Test Results. A total of 35 couplers were tested. After the test, the moment-rotation curves were plotted for the thirty-five couplers tested, and the results for five of them are presented in Fig.2.From the figure, it is clear that variance exists in the test results, mainly because there were differences in weight, degree of corrosion and imperfection, etc.

Joint Model and Probabilistic Studies. The relation between the moment and rotation of the coupler connections can be fitted by a logarithmic model, given as

$$M=n\ln(1+R_k\theta/n). \quad (1)$$

where M and θ are the moment and rotation of the coupler, n and R_k are shape parameter and initial rotational stiffness of the logarithmic model respectively. The coupler rotational stiffness was determined from the moment-rotation curves, as exemplified in Fig.3.From the figure, it is clear that the logarithmic model fits the test results well.

The parameters that describe the logarithmic model (n , R_k) were obtained from the joint test data presented herein. The mean values for n and R_k for different couplers are 2.07 and 19.95 kN.m/rad.

The coefficient of variation values of the joint stiffness for n and R_k are 0.618 and 0.236.These uncertainties must be studied by statistical methods to find appropriate distribution so that probabilistic assessment of the stability bearing capacity of FTSF can be performed. The data of the joint stiffness values(n , R_k) fitted to normal distributions which are shown graphically in Figs.4-5.

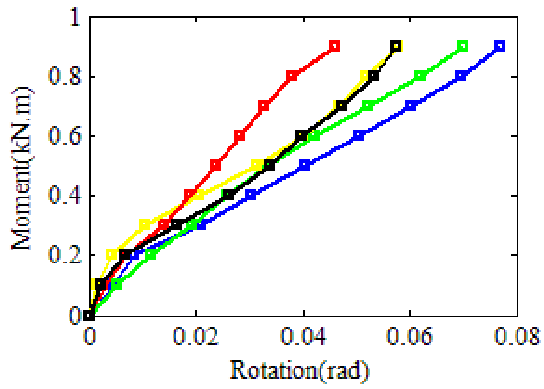

Fig.2.Five couplers test results for torsional stiffness

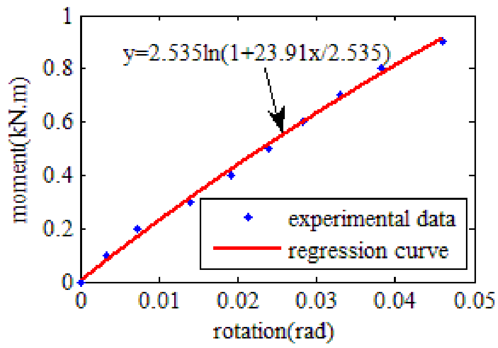

Fig.3. Typical moment-rotation curve for couplers

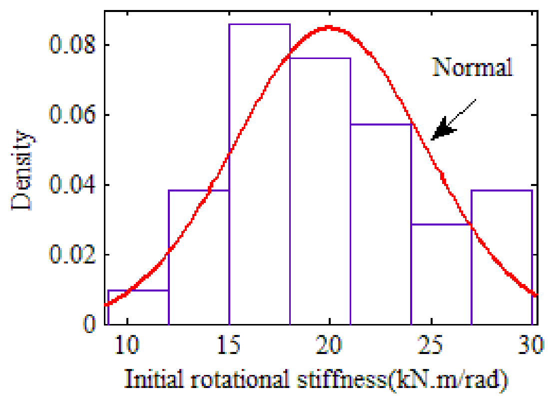

Fig.4. Fitted normal distribution of initial rotational stiffness

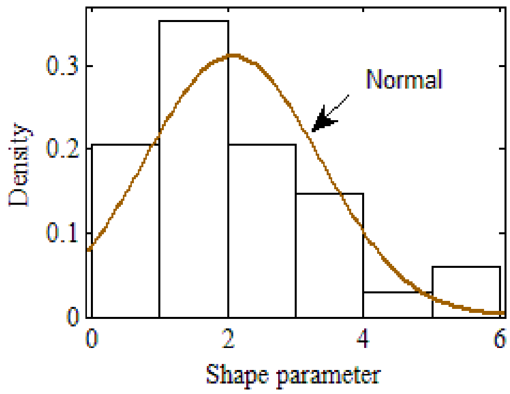

Fig.5.Fitted normal distribution of shape parameter

Initial Geometric Imperfections of FTSF

Methods of Measurement of Initial Geometric Imperfections. The data of initial geometric imperfections were collected from four different construction sites in Jiangxi province by the use of measuring equipment and a total station. In order to obtain a wide representative range of imperfection for FTSF,each site was constructed by different construction unit.

Because the standards of FTSF are usually acquired randomly from the place for steel tube pile-up in practice, some steel tubes were selected randomly as the standards of FTSF, then measured the initial out-of-straightness. Guy wire was used to measure the out-of-straightness of the steel tube. The length of steel tubes were varied between 3 m and 6 m.The detailed measuring method was listed as follows. Firstly the direction of the maximum curvature was located by visual inspection ,then along this direction pull the wire, finally use a vernier caliper to measure the out-of-straightness at the midpoint of the steel tube. Repeat the above steps three times, take the largest measurement as the initial out-of-straightness of the steel tube.

A total station was set up to measure the angle difference between the top and bottom of the standard in order to determine out-of-plumb. The horizontal distance between the standard and the total station was also measured together with the angle difference so that a simple trigonometric calculation could be carried out for the out-of-plumb, the detailed measuring method can be seen in [4].All measurements were taken before the pouring concrete on the formwork, representing actual initial geometric imperfections encountered in practice.

Survey Results of Geometric Imperfections. A total of 207 on-site measurements of the out-of-straightness were taken and 60 measurements of out-of-straightness of standards were acquired. The results of out-of-straightness of the standards were normalized with the length of the tube and the results of out-of-plumb were normalized with the height of the FTSF.The histograms of normalized out-of-straightness of the standards and normalized out-of-plumb are shown in Figs.6-7.The mean normalized out-of-straightness of the standards is 0.0020 with the standard deviation of 0.0013.The mean normalized out-of-plumb is 0.0067 with the standard deviation of 0.0025.

Discussion and Probabilistic Studies of Initial Geometric Imperfections. The mean of the normalized out-of-straightness of the standards shows smaller value than the maximum permissible out-of-straightness of $3L/1000$ where L is the member length in the China design standard for FSTF[5];however, the mean of the normalized out-of-plumb is larger than the maximum allowable out-of-plumb of $3H/1000$ where H is height of the FTSF. Therefore adopting the code recommended out-of-plumb for modelling and analysis may not produce conservative results. The fitted probability distributions are shown in Figs.6-7.

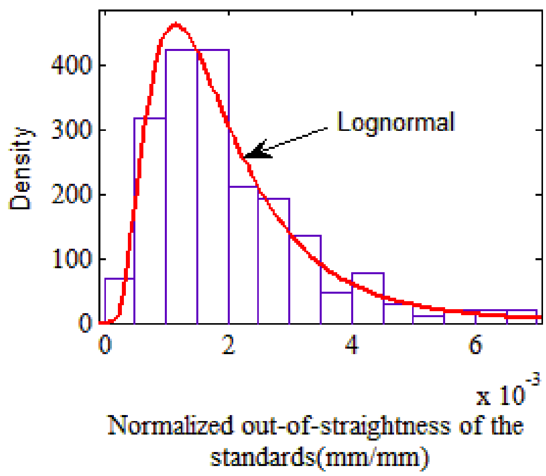

Fig.6. Histogram and fitted lognormal distribution of normalized out-of -straightness of the standards

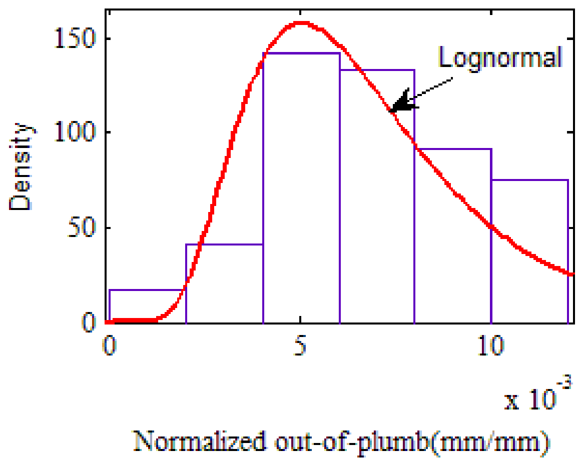

Fig.7.Histogram and fitted lognormal distribution of normalized out-of-plumb

Conclusions

In this paper, the joint rotational stiffness of FTSF is studied. Right-angle couplers were tested in a specially rig. The parameters for the joint rotational stiffness model were fitted to normal distribution for probabilistic modelling.

The paper also reports a finding of initial geometric imperfections of FTSF, which have been obtained from various constructions sites in Jiangxi province, and the results are presented as histograms and fitted statistical functions. The probability distributions are presented for the numerical modelling of FTSF.

Acknowledgments

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