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EXPERIMENTAL TESTS ON STEEL TELESCOPIC PROPS
DISCUSSION OF IMPORTANT ASPECTS

João André, António M. Baptista
Structures Department, National Laboratory for Civil Engineering (LNEC),
Av. Brasil 101, 1700-066 Lisboa, Portugal
jandre@lnec.pt, ambaptista@lnec.pt

Dinar Camotim
Dept. of Civil Engineering, IST, Technical University of Lisbon
Av. Rovisco Pais, 1049-001 Lisboa, Portugal
dcamotim@civil.ist.utl.pt

Abstract

Telescopic props represent a common solution to support the formwork during the construction of buildings. The design of these props is often associated to high safety factors, due to insufficient information about their real behavior at the construction site, under the influence of load eccentricities and geometric imperfections. A research project is now being developed at the Portuguese National Laboratory for Civil Engineering (LNEC), involving experimental and numerical studies of the props behavior and, in particular, of the effects of the geometric imperfections and corresponding tolerances on their stability. The experimental studies will be carried out in accordance with the provisions stipulated by the European Standard EN 1065:1998 “Adjustable telescopic steel props”. A series of tests involving the testing of 70 telescopic props subjected to axial compression is scheduled. This paper describes the test procedure and presents a bibliographic review focusing in the most important factors influencing experimental test results.

Introduction

This paper concerns temporary structures, in particular telescopic props for temporary support of slabs. The main goal of this paper is to present a review of the test procedure and discuss some special issues that one has to account, and their influence on the props’ behavior.

Telescopic props are structural elements formed by two tubes of hollow circular shaped section. The force transmission between the two tubes is made by a pin and a collar nut, which are a part of the length adjustment device. The props considered in this study are made of steel, in accordance with the European structural steel standards.

Very often, the agents involved in the construction works consider that the use of temporary structures does not require a careful planning. In general practice, the design of temporary structures is based in very simplified calculations, without taking in account several risks associated with their specific use, and without stating the conditions required to assure their quality. The design project itself may be incorrect, by negligence or misunderstanding of their structural behavior, or incomplete, not specifying the required tolerances and thus letting the erection in the construction site to the initiative of the workers, many without experience. In the case of props, those that are damaged in such a way that reduce significantly their strength capacity should be removed. Nevertheless they are very often used in these conditions, disregarding all safety policies.

Other frequent anomalies are:

- Unaccounted horizontal actions or accidental actions in the design process;
- The insufficient load bearing capacity of the foundation, either by lack of soil resistance or base instability or unpredicted foundation settlements;
- Existence of initial curvatures on the props' tubes;
- Existence of load eccentricities especially in fork shaped base plates and in square base plates due to base plate defects;
- Poor load distribution, namely in the case of high concentrated loads;

As a consequence, news of accidents involving this type of structures are relatively common, many of them with fatal casualties, due to the total or partial collapse of the temporary structure, or even of the supported permanent structure. For this reason, some initiatives have been developed at the European Union level with the objective of reducing their occurrence, producing standards or recommendations for the design, quality control, and use of these structures.

This study is part of a larger research project currently under development at the *Laboratório Nacional de Engenharia Civil* (LNEC), under the title "Safety of temporary structures for construction support", regarding for a better understanding of the behavior of these structures and, consequently, for improved methods to evaluate their safety.

Importance of experimental tests

Structural mechanics is the engineering discipline that deals with the determination of the strength and stiffness of structures, for example. There are two approaches towards this goal: theoretical mechanics, focusing increasingly on numerical methods in the most recent years, and experimental mechanics. The two approaches are intrinsically complementary. As Drucker stated in 1967 (Drucker, 1967): "Theory awaits experiment and experiment awaits theory in a wide variety of fields. Often the two must go hand in hand if any significant progress is to be made".

One should remember that though carefully chosen mathematical models may predict the expected physical behavior, it is up to experiments to verify this predicted behavior and validate the calculations. Even if very advanced analysis of the effects of the most important parameters could be made, uncertainties may remain as a result of some aspects of behavior of real structures which may have been neglected or poorly represented in the calculations. These uncertainties could be revealed by experiments.

One should demand precision and discipline not only to the use of advanced numerical methods but also to experimental mechanics. The confidence that can be placed in experimental results obviously depends on the care taken by the experimenters. It will also be greater when the number of available results are larger.

The following sequence of developments added an array of capabilities that describe the experimental potential as it is today (Birkemoe, 1996).

- Hydraulics replaced the mechanically driven screws as an alternative loading method. Development of the electrical resistance strain gauges brought electronic load sensing which was quicker in response and provided a signal which could be used for control.
- Electronic displacement devices replaced mechanical ones for further improvement in measurement and control.
- Hydraulic capabilities were enhanced with the advent of the oil-hydraulic servo-valve used to control the flow of oil under pressure. When combined with two-way hydraulic 'actuators' the heart of 'servo-controlled closed-loop' testing emerged.
- The use of computers in the lab for the acquisition and real-time processing of data combined with direct feedback control enables experimentation which can simulate changing boundary conditions as they might be influenced by the measured response of the element under test.

Singer et al (1998) discusses the purpose of experiments in the computer area.

Nevertheless one must not forget, as in theory so in experiment, it is the basic thought process that precedes the actual study, which guides and harnesses these capabilities. The first question one has to address when planning an experiment is “what is the aim of the experiment?”. If the data obtained in the experiment is to be employed for design guidelines, the specimens should estimate the real structure, as well as boundary conditions and environment.

In the case of telescopic props, the experimental tests are justified for several reasons:

- To study the influence of the length adjustment device and its influence on the overall behavior of the prop;
- To study the influence of the holes on the interior tube, namely the effect of stress concentration around them. For thin-walled elements the existence of holes or cutouts may lead to local buckling and a sharp reduction of the buckling load;
- To study the behavior of the base plates, and therefore the evolution of the prop end conditions along the loading;
- To study the influence of various geometric imperfections;
- To provide the data required to help in (i) the development and validation of a shell finite element model intended to analyze telescopic props and also in (ii) the elaboration, calibration and validation of a design curve, which will be employed to estimate the load-carrying capacity of axially compressed telescopic props commonly used in the construction industry (mostly with scaffolding purposes).

Important aspects to be considered

One vital element to obtain a good correlation between experimental and numerical results is to know as best as possible the material and geometry properties, and the fabrication processes.

Deviations from the ideal geometrical form, termed as "geometrical imperfections", influence the ultimate strength of structures. Their magnitude and configuration are important parameters, see Koiter (1945).

These geometrical imperfections can roughly be divided in:

a) Variations of cross-sectional data, ovalization of circular tube shapes, for example;
b) Deviations in longitudinal direction from ideal straight axis, causing load eccentricities and initial out-of-straightness.

The actual dimensions of structural assemblies and members can be established through direct physical length measurement which will show deviations from specifications and permit calculation of measured geometric properties. Eccentric load transfer may be caused by variations of the cross sectional dimensions of the member itself. Still, considering the strength of the cross-section, the influence of variations in cross-sectional properties is usually small when compared with the effect of variations in yield stress (ECCS, 1976).

The bow imperfection can be approximated by the first term of a Fourier series. For example, for a curvature with maximum amplitude of L/650 near the quarter points, the substitute half sine-curve has a central bow of L/1000 (ECCS, 1976). Other imperfections such as the presence of residual stresses and load eccentricities can also be modeled by using an equivalent initial curvature. However, one should avoid considering the unrealistic simultaneous combination of the most unfavorable values.

S. Toma and Wai F. Chen (1983) concluded from numerical studies using the so called "assumed deflection method" that the initial imperfection (with maximum offset, a, at mid span) reduces the ultimate strength of the column significantly; with a=L/1000 the reduction is about 20%.

J.L. Peng et al (1997), observed that the main parameters affecting the load-deflection behavior of falsework columns are the effective length factor K (which includes the rigidity of the supports) and the initial imperfections, which accounts for the load eccentricity (e) and initial crookedness of the member. They concluded, by doing compression tests on pinned-pinned tubes with small height, that the peak capacity of a tubular column may decrease as much as 70% if e/L increases from 1/1000 to 1/100, although e/L=1/1000 was considered a reasonable estimate of the initial imperfection for design purposes.

ECCS (1984) recommends that for each structural member to be tested, the actual cross-section dimensions and longitudinal deviations should be measured over the length of the specimen (minimum of 3 locations, and 7 locations, respectively). Different ways of determining the initial imperfection of a member are listed elsewhere [].

Furthermore, it is well understood that the mechanical properties are a fundamental aspect in determining a column behavior. In perfect columns stressed above the proportional limit, imperfections of the column material may lead to bending because of the unsymmetrical pattern of the yielded zones with respect to the principal axes of the cross section. The global yield stress of a material can be determined by stub-column compression tests (slenderness chosen between 10 and 15) or axial tensile coupon tests, these last being preferred because of the difficulty of allowing a uniaxial stress system to develop in the middle of the specimen length in stub tests or the possibility of member buckling. Concerning tensile tests, particular attention should be set when removing a coupon from a larger metal section, because it may be compromised by the presence of residual stresses which cause cutting and machining difficulties. Special care must be taken to prevent the common occurrence of permanent straining in the material.

Although the yield stress may vary over the member and within the cross-section, its effect is relatively small when compared to the effect of the residual stresses. Elongation is also an important parameter, since it gives an indication about the material ductility, which is important for elastoplastic postbuckling behavior.

The presence of unavoidable residual stresses should be accounted for, because of their effect on the loss of stiffness due to plastic deformations. In special cases, like tubular columns, the interaction of longitudinal and circumferential residual stresses has to be considered. It was concluded that the influence of the initial curvature decreases with increasing residual stresses (ECCS, 1976). Welded elements usually have higher residual stresses than rolled elements, and their magnitude depends on the geometry of the cross-section (tubes' sections tend to have less residual stresses). They also tend to have a greater out-of-straightness. Hence welded columns have lower strengths than corresponding rolled elements. The effect of residual stresses is smaller in elements made of steels with higher yield strength. Techniques for measuring residual strains through mechanical release or removal of the stresses using electric resistance gauges or mechanical measurements are well documented in the Guide to Stability Design Criteria for Metal Structures (SSRC, 1998).

S. Toma, et al (1989), conducted several numerical tests on tubular columns. They studied the effect of initial deflections and residual stress on the column strength. They concluded that for large initial deflections, 0,1% of the column length (which is in most design codes the prescribed allowed initial deflection), the column strength is reduced significantly. The residual stress also reduces the column strength considerably in the transitional range from elastic to plastic when the initial deflection is small.

In column testing, it is important to know the type of boundary conditions, because they influence the effective slenderness ratio of the column, for example, as pointed out by Singer (1998).

J.L. Peng et al (2001) compared numerical results and experimental tests of modular falsework systems. They concluded that the sleeve connection joining the modular falsework units behave like a rigid joint and accurate results are obtained by modeling a continuous member at the sleeve connection. On the other end, M. El-Sheikh and Wai F. Chen (1988) pointed that the effect of joint flexibility between two telescopic tubes must be included in the analysis of telescopic steel shores, using a bilinear model to represent the behavior of such a joint, with assumed values for joint stiffness. They concluded that the joint flexibility decreases the axial stiffness, as well as the load-carrying capacity of a telescopic steel shore.

Standard requisites for telescopic props

Since the Bragg report (1975), following an accident with a major falsework construction over the River Loddon that collapsed in 1972, several standards and recommendations within the field of temporary structures have been adopted by different European countries.

The CEN (European Committee for Standardization) has also published recently a series of specific standards within this field, such as the EN 1065:1998.

European standard EN 1065:1998

This standard requires the determination of a large number (20) of dimensional properties of the props' components, which may require a few hundreds of measurements. Material characterization of each tube is needed. For each type of prop, twelve tensile tests on samples from the props should be carried out in accordance with Annex E of EN 10002-1:2006.

The props should be tested at three extension lengths: maximum, minimum and intermediate. The intermediate position is determined by doing up to 7 auxiliary tests and determining the most critical extension length, i.e., the one at which the props have less resistance. Furthermore, the prop should be tested in two configurations: normal and inverted. In each position 4 tests should be carried out, in a total of up to 31 compression tests for each prop type. The props will be tested assuming three types of imperfections, with values that, in general, are conservative:

- Load eccentricity, e, of 10 mm;
- Initial curvature caused by the clearance between the inner and the outer tubes in the overlap zone;
- Initial curvature due to deviations in tube configuration, which is represented by means of a preflexure with a sinusoidal shape, with a maximum offset of $a = L/500$ at the middle of the prop.

The initial curvatures are imposed by rotating the bottom base plate and using a ball joint at the top base plate, which is deviated from the prop axis to materialize the load eccentricity.

Concerning the instrumentation, it is usually desirable to measure the most important deflections and twists to compare the behavior of the column specimen under load with theoretical predictions of behavior. Lateral deflections perpendicular to the minor cross sectional inertia axis direction should be recorded by means of displacement transducers at the quarter points and other critical locations, as required. Strains are measured to evaluate the bending moments, and to determine the effects of some singularities in the model (holes and overlapping length regions). End rotations, and relative prop member rotations, are measured by electrical rotation gages or equivalent, and the load is registered from the testing machine.

At the start of the test, a preload should be applied (1/20 to 1/15 of the estimated ultimate load capacity of the column), to preserve the initial test position, and to check if the devices are working properly. Next, the test load shall be applied using displacement control, either in steps, not exceeding 20% of the anticipated failure load, or increasing uniformly, at a rate not exceeding 20% per minute the anticipated failure load.

The results shall be divided by a reduction factor accounting for the differences between the actual yield stress and nominal yield stress, and then treated statistically to determine the characteristic value of the props' resistance.

Conclusions

This paper focuses the importance of experimental tests, in particular of telescopic props, and discusses some major factors that influence their behavior. Finally, the test procedure specified in the European Standard EN 1065 is summarized.

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