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Full-scale experimental study on the influence of damages on the static behavior of the single-layer cable net structure

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ABSTRACT

As a novel type of supporting structure of glass buildings, the single-layer cable net will inevitably be subjected to different kinds of damage during service. In order to study the influence of potential damage on its static behavior, a full-scale static test of the single-layer cable net is performed on a 4 × 4 grid model with the dimensions 4.85 m × 4.85 m. Three types of damage are investigated: failure of the connectors between horizontal and vertical cables, loss of prestress in the cable, and damage and failure of the cable anchorage end. The experimental results show that failure of connectors has little influence on the static behavior of the single-layer cable net. The change of nodal displacements induced by the cable prestress-loss does not exceed 15%. The cable anchorage failure affects significantly the local part of the structure, and the induced change of nodal displacements can be up to 36%. It is found that, the influence of damage is stronger on nodal displacements than on cable tension forces, and the intensity of this influence depends on the extent and location of damage. The influence decreases when the load increases. The research results in this paper provide some qualitative conclusions for safety evaluation of single-layer cable net structures and establish a foundation of the further study.

1. Introduction

As a supporting structure, the single-layer cable net has been widely used in glass buildings in recent decades because of its attractive appearance and simplicity [1,2]. Examples include the Basel railway station in Switzerland (Fig. 1), Kempinski Hotel in Munich, Tower Place in the UK, and the New Poly Plaza in Beijing (Fig. 2). As a novel type of prestressed structure, the single-layer cable net has many advantages such as large flexibility, light weight, small damping, and low natural frequencies. A single-layer cable net structure comprises prestressed cables, cable connectors (i.e., the connectors between horizontal and vertical cables), and anchors between cables and the main structure (Fig. 3). Extensive research has been done on the static and dynamic behavior, geometric nonlinearity, and construction technology of single-layer cable net structures. Carré and Daudeville [3] proposed a model to predict the strength of prestressed structural glass, which was validated by experimental results from four-point bending test. Simple models have been developed by Kwan to analyze geometrically nonlinear cable structures to obtain the nonlinear static response to load [4] and to estimate the natural frequencies [5]. Chisalita [6] studied the geometry nonlinearity and material nonlinearity of cable networks. Vyzantiadou and Avdelas [7] examined the morphological and structural details of point-fixed glazing systems and proposed a new design approach for this kind of structure. Parameter studies are performed by Geschwindner and West [8] on natural frequencies of cable structures. The finite element method was employed to study the static [9,10] and dynamic properties [11,12] of single layer cable net structures. The numerical results were verified experimentally. Feng et al. [13] studied the working mechanism of single-layer cable net supported glass curtain walls experimentally and numerically. All the research mentioned above has been focused on the intact single-layer cable net structures and this is true for most work in the literature.

In practice, as the supporting structure of glass buildings, the single-layer cable net would inevitably be subjected to different kinds of damage during service. For example, damage of the cable anchorage end would lead to prestress-loss of the cable. The prestress in the cable would decrease over time due to the intrinsic mechanical properties of the materials. Temperature change would also induce prestress-loss. Furthermore it is difficult to ensure the cable prestress is identical to the designed value. In particular, the cable connectors may be relaxed or even fail completely. These factors would affect not only the mechanical behavior of the single-layer cable net structure (e.g., loading capacity and stiffness), but also the safety and durability of the structure. However, until now, to the best of the authors' knowledge, the effect

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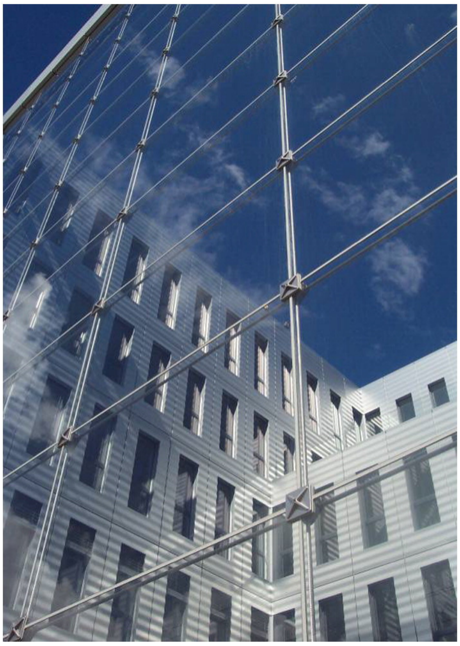

Fig. 1. Basel railway station.

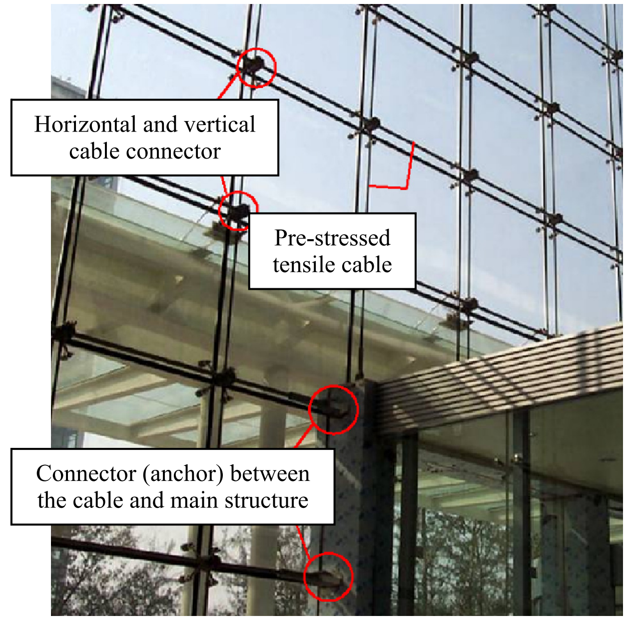

Fig. 3. The components of a single-layer plane cable net.

of potential damage on the mechanical properties of the single-layer cable net structure has not yet been carefully studied in the literature.

In this paper, in order to investigate the influence of damage on the static behavior of the single-layer cable net structure, a full-scale static test is performed on a 4 × 4 grid model with the dimensions 4.85 m × 4.85 m. Three types of damage are considered: horizontal and vertical cable connector failure, prestress loss of the cable, and damage and failure of the cable anchorage end. In the experiments, nodal displacements and tensile forces in the cables are measured and the effects of damage are discussed in detail.

2. Damage factors and their genetic analysis

In this section, the following three important types of damage and their genesis are discussed: failure of the horizontal and vertical cable connector, prestress-loss of the cable, and damage and failure of the cable anchorage end.

Fig. 2. Beijing New Poly Plaza.

2.1. Horizontal and vertical cable connector failure

The horizontal and vertical cable connector comprises the pressure part, screw and nut (Fig. 10a). The horizontal and vertical cables are connected tightly by the prestress generated by screwing the nut and it can also lock the position of cables to avoid sliding during loading. The prestress from the nut-screwing may decrease due to the cyclic loading passing through the horizontal and vertical cables. Besides, improper construction and material defects may also lead to prestress-loss, which will cause sliding of the connector between the horizontal and vertical cables under certain conditions.

2.2. Prestress-loss in the cable

The single-layer cable structure is a flexible supporting system and normally in an undetermined state (actually it is a mechanism before the prestress is applied). Therefore the application of the cable prestress is required to maintain the stability of the structure shape and necessary stiffness which affects significantly the mechanical behavior of the structure. However, prestress-loss in the cable is unavoidable because of the following reasons:

(1) Stress relaxation of the steel cable: Stress relaxation occurs in all kinds of steels because part of the elastic deformation transforms to plastic deformation due to the accumulation of metal lattice dislocations. Under long term loading, the amount of relaxation in the steel cable is related to the load and its ambient temperature. This relaxation will usually increase when the load or the temperature increases.
(2) Temperature changes: Ambient temperature changes during the service of the single-layer cable net structure. When ambient temperature increases, the prestressed cable expands and the prestress is reduced. The amount of cable prestress-loss is the product of the temperature difference, the elastic modulus and the linear expansion coefficient of the cable.

The loss of the cable prestress caused by cable stress relaxation and temperature changes is uniform along the cable length and it is independent of other cables.