

# **PRESTRESS STRING ANNULAR SUPPORT SYSTEM, AND DEFORMATION CONTROL METHOD THEREOF**

## **TECHNICAL FIELD**

The present invention relates to the technical field of construction engineering and, in particular, to a prestress string annular support system, and a deformation control method thereof.

## **BACKGROUND**

The increasing urbanization has brought about a growing demand for underground space expansion of existing buildings. Such projects typically involve creating excavations with a depth of up to more than ten meters or even thirty meters in close vicinity of facilities like residential and commercial buildings, municipal roads, subways and municipal pressure pipelines. In order to ensure deformation of the surrounding facilities caused by excavation construction is within a controlled range, strict deformation control of foundation pit support systems is necessary. In the state of the art, for a support system within a foundation pit, this is often accomplished by:

1. stiffening a retaining wall, e.g., by expanding the cross-sectional area of soldier piles, or constructing a stiffer continuous diaphragm wall or the like;
2. using an stiffer internal support material, e.g., replacing steel pipes, H-shaped steel buttresses and the like with high-strength concrete structures;
3. increasing the cross-sectional area of the internal support system;
4. shortening the spacing between vertical supports, e.g., controlling a length of the retaining wall by constructing more vertical supports in the internal support system.

These measures suffer from the following drawbacks:

- (1) the construction cost of the retaining system soars – the measures like

retaining wall stiffening, decreasing the spacing between vertical supports and expanding the cross-sectional area of the internal support system will increase the retaining work load and raise the excavation cost;

(2) the project period will be extended – the tremendous work load will extend the project duration and impose more demanding requirements on the flexible scheduling of building materials, manpower, mechanical equipment and other resources;

(3) the stiffness of internal supports significantly decreases with the increase in their planar length;

(4) the construction of the retaining system will produce a large amount of dust and wastewater, as well as much building waste that is difficult to recycle and may cause environmental pollution.

## **SUMMARY OF THE INVENTION**

The technical problem to be solved by the present invention is to provide a prestress string annular support system and a deformation control method thereof, which can control the deformation of the prestress string annular support system when the foundation pit deforms, thus providing protection to facilities surrounding the foundation pit.

In order to solve the above technical problem, embodiments of the present invention provide an annular support system pre-stressed with tensioned strings, comprising an annular support constructed in a foundation pit and a plurality of tensioned strings extending along diameters of the annular support, any two adjacent ones of the tensioned strings being spaced apart by an equal angle, each tensioned string being at least provided with a pre-stressing means at one intersection of the specific tensioned string or an extension thereof with the annular support.

Additionally, in the annular support system pre-stressed with tensioned strings provided in the present invention, the pre-stressing means may be a jack.

Additionally, in the annular support system pre-stressed with tensioned strings provided in the present invention, the pre-stressing means may be an electric motor coupled to the tensioned string by a lead screw.

Additionally, in the annular support system pre-stressed with tensioned strings provided in the present invention, the pre-stressing means may be arranged inside or outside the annular support or so as to extend from the inside to the outside of the annular support.

Additionally, in the annular support system pre-stressed with tensioned strings provided in the present invention, the tensioned strings may be stranded steel cables, steel tubes, steel bars, or a combination thereof.

Additionally, in the annular support system pre-stressed with tensioned strings provided in the present invention, the angle between any two adjacent ones of the tensioned strings may be acute.

Additionally, in the annular support system pre-stressed with tensioned strings provided in the present invention, the tensioned strings may be arranged along radial directions of the annular support in multiple layers.

Additionally, in the annular support system pre-stressed with tensioned strings provided in the present invention, the annular support may be on-site cast with concrete, or formed by putting together preformed concrete parts, or formed by putting together steel parts.

Additionally, in the annular support system pre-stressed with tensioned strings provided in the present invention, the tensioned strings may extend through the annular support or not.

In order to solve the above technical problem, embodiments of the present invention also provide a deformation control method for the annular support system pre-stressed with tensioned strings as defined above, in which when deformation of the foundation pit in one direction or the opposite direction occurs and has caused

deformation of the annular support in the same direction, a pre-stressing force exerted on the annular support is adjusted by using a pre-stressing means associated with a tensioned string perpendicular to the direction of deformation, thus placing deformation of the annular support under control.

Compared with the prior art, in the prestress string annular support system and the deformation control method thereof according to the present invention, the system is composed of an annular support, a plurality of tensioned strings extending along diameters of the annular support and a pre-stressing means at least provided at one intersection of each tensioned string with the annular support, and is beneficial in a simple structure and low cost. The deformation control method can stiffen the annular support and stabilize the pre-stressed annular support system by adjusting a pre-stressing force exerted on the annular support through adjusting a tension force on a tensioned string using an associated pre-stressing means. When deformation of the annular support occurs, a pre-stressing force on the annular support is adjusted using a pre-stressing means associated with a tensioned string perpendicular to the direction of deformation, thus placing deformation of the annular support and hence of the foundation pit under control and providing protection to facilities surrounding the foundation pit. The prestress string annular support system and the deformation control method thereof according to the present invention dispense with the need to increase the stiffness of a retaining wall, expand a cross-sectional area of an internal support system, shorten the spacing between vertical supports or use a stiff supporting material, will not lead to environmental pollution due to the construction, and provide the benefits of a simple structure, convenient deformation control, energy efficiency, environmental friendliness, low cost and a relatively short construction period.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

Figs. 1 to 5 are schematic diagrams showing the structure of a prestress string

annular support system in top views;

Fig. 6 is a schematic diagram showing the structure of a prestress string annular support system in a side view; and

Fig. 7 schematically illustrates the principles of deformation control for a prestress string annular support system.

In these figures, 100 denotes a prestress string annular support system; 110, an annular support; 120, tensioned strings; 130, a pre-stressing means; 200, the ground; and 300, a foundation pit.

## **DETAILED DESCRIPTION**

The present invention will be described in detail with reference to the accompanying drawings.

Referring to Figs. 1 and 6, embodiments of the present invention provide a prestress string annular support system 100, comprising an annular support 110 constructed in a foundation pit 300 and a plurality of tensioned strings 120 extending along diameters of the annular support 110. Any two adjacent ones of the multiple tensioned strings 120 are spaced apart from each other by an equal angle. A pre-stressing means 130 is at least provided at one intersection of each tensioned string 120 or an extension thereof with the annular support 110.

A method of constructing the prestress string annular support system 100 according to embodiments of the present invention includes the steps of:

- (101) constructing the annular support 110 in the foundation pit 300;
- (102) after the annular support 110 reaches a desired degree of strength, arranging the tensioned strings 120 along diameters of the annular support 110 so that the tensioned strings 120 intersect at both ends with the annular support 110;
- (103) providing a pre-stressing means 130 at least at one intersection of each tensioned string 120 with the annular support 110;

(104) adjusting pre-stressing forces exerted on the annular support 110 through adjusting tension forces on the tensioned strings 120 using the pre-stressing means 130, thereby forming the prestress string annular support system 100 in the foundation pit 300.

Of course, support structures and methods well known in the art may be applied between the prestress string annular support system 100 according to embodiments of the present invention and a foundation pit retaining arrangement in the foundation pit 300. For example, support struts may be disposed between the annular support 110 and a continuous diaphragm wall for the retaining structure of the foundation pit. That is, the prestress string annular support system according to embodiments of the present invention assists in withstanding external loads. In addition, the prestress string annular support system 100 according to embodiments of the present invention is not limited to being used in a rectangular foundation pit, but is more suitable for use in a circular foundation pit.

Referring to Figs. 1 and 7, in a deformation control method for the annular support system 100 pre-stressed with tensioned strings 120 according to embodiments of the present invention, when deformation of the foundation pit 300 in one direction or the opposite direction occurs and has caused deformation of the annular support 110 in the same direction, a pre-stressing force exerted on the annular support 110 is adjusted by using a pre-stressing means 130 associated with a tensioned string 120 perpendicular to the direction of deformation, thus placing deformation of the annular support 110 under control. For example, a diametric size of the annular support 110 is adjustable up or down by changing a tension force on any tensioned string 120 using an associated pre-stressing means 130, thus placing deformation of the annular support under control.

Embodiments of the present invention provide an annular support system 100 pre-stressed with tensioned strings 120 and a deformation control method thereof. The system is composed of an annular support 110, a plurality of tensioned strings 120

extending along diameters of the annular support 110, and a pre-stressing means 130 at least provided at one intersection of each tensioned string 120 with the annular support 110, and is beneficial in a simple structure and low cost. The deformation control method can stiffen the annular support 110 and stabilize the pre-stressed annular support system 100 by adjusting an associated pre-stressing force exerted on the annular support 110 through adjusting a tension force on a tensioned string 120 using a pre-stressing means 130. When deformation of the annular support 110 occurs, a pre-stressing force on the annular support 110 is adjusted using a pre-stressing means 130 associated with a tensioned string 120 perpendicular to the direction of deformation, thus placing deformation of the annular support 110 and hence of the foundation pit 300 under control and providing protection to facilities surrounding the foundation pit 300. The annular support system 100 pre-stressed with tensioned strings 120 and the deformation control method thereof provided in embodiments of the present invention dispense with the need to increase the stiffness of a retaining wall, expand a cross-sectional area of an internal support system, shorten the spacing between vertical supports or use a stiff supporting material, will not lead to environmental pollution due to the construction, and provide the benefits of a simple structure, convenient deformation control, energy efficiency, environmental friendliness, low cost and a relatively short construction period.

Referring to Fig. 7, for example, the annular support 110 has a diameter of 100 m and an annular cross-sectional area of 1200 mm  $\times$  800 mm. Moreover, it is constructed of concrete with a strength rating of C35, and tensioned strings are provided on the annular support at 30-degree intervals. The tensioned strings are designed with a tension force  $F$  of 500 kN and a deformability indicated as  $\delta$ m. As calculated using finite element software (Abaqus), a radial stiffness coefficient  $k$  of the annular support 110 satisfies  $k=F/\delta=1673.7\text{kN/m}$ . In contrast, the stiffness of common concrete support systems with opposite buttresses in the art is 1493.3 kN/m. The annular support system

100 pre-stressed with tensioned strings 120 according to embodiments of the present invention achieves an overall improvement in stiffness of about 12%. Therefore, it provides the benefits of high stiffness, good integrality and capabilities of withstanding eccentric loads. The arrangement with an equal angle between any two adjacent tensioned strings is intended to enable higher deformation control accuracy for the annular support. The multiple tensioned strings 120 are adjustable by respective pre-stressing means 130 so that the annular support 110 is uniformly stressed and balanced, achieving accurate deformation control of the annular support 110.

At a given degree of stiffness, the annular support system 100 pre-stressed with tensioned strings 120 according to embodiments of the present invention has a smaller cross-sectional area and will produce less building waste when torn down, providing the benefits of energy efficiency and environmental friendliness.

Referring to Fig. 1, in the annular support system 100 pre-stressed with tensioned strings 120 provided in embodiments of the present invention, the pre-stressing means 130 may be a jack, which is coupled to the annular support 110 at one end and to the tensioned string 120 at the other end. Here, the two ends of the jack refer to its driven end and base. The jack is, for example, a hydraulic jack. Implementing the pre-stressing means 130 as a jack provides the advantages of convenient mounting and control and stable adjustment.

Referring to Fig. 1, in the annular support system 100 pre-stressed with tensioned strings 120 provided in embodiments of the present invention, the pre-stressing means 130 may be an electric motor, which is coupled to the tensioned string 120 by a lead screw. For example, the tensioned string 120 may be structured at one end as a lead screw including a screw shaft and a nut. In order to achieve stable control, the electric motor may be implemented as a stepping motor.

Referring to Figs. 2 to 4, in the annular support system 100 pre-stressed with tensioned strings 120 provided in embodiments of the present invention, the pre-

stressing means 130 may be arranged inside or outside the annular support 110 or so as to extend from the inside to the outside of the annular support 110. Fig. 2 shows the pre-stressing means 130 being arranged inside the annular support 110. Fig. 3 shows the pre-stressing means 130 being arranged outside the annular support 110. Fig. 4 shows the pre-stressing means 130 being arranged so as to extend from the inside to the outside of the annular support 110. That is, the pre-stressing means 130 may be arranged in any positional relationship as long as it allows a tension force on the tensioned string 120 to be adjusted and applied to the annular support 110.

Referring to Figs. 1 to 4, in the annular support system 100 pre-stressed with tensioned strings 120 provided in embodiments of the present invention, the tensioned strings 120 may extend through the annular support 110 and extend outside the annular support 110. Referring to Fig. 5, the tensioned strings 120 may be arranged inside the annular support 110 so as to extend through the annular support 110 while not extending out of the annular support 110. That is, the tensioned strings 120 may either extend through the annular support 110 or not, as long as the tension forces on the tensioned strings 120 can be adjusted and applied to the annular support 110. The tensioned strings 120 may be stranded steel cables, steel tubes, steel bars or a combination thereof. According to embodiments of the present invention, the tensioned strings 120 are preferred to be stranded steel cables, which are flexible and bendable and provide the advantages of convenient handling, adjustment and mounting.

Referring to Figs. 1 to 5, in the annular support system 100 pre-stressed with tensioned strings 120 provided in embodiments of the present invention, the angle between any two adjacent ones of the tensioned strings 120 may be acute. For example, 4 tensioned strings may be included, any two adjacent ones of which are spaced apart by an acute angle of 30 degrees. However, according to embodiments of the present invention, the number of tensioned strings is not limited to 4 but may be adjusted as required by the environment.

Referring to Fig. 6, in the annular support system 100 pre-stressed with tensioned strings 120 provided in embodiments of the present invention, the tensioned strings 120 may be arranged along radial directions of the annular support 110 in multiple layers. Different layers of tensioned strings 120 may either have the same or different arrangements. The multiple layers of tensioned strings 120 can provide deformation control at different axial locations of the annular support 110 corresponding to different depths of the foundation pit 300, thus achieving higher control accuracy.

Referring to Fig. 1, in the annular support system 100 pre-stressed with tensioned strings 120 provided in embodiments of the present invention, the annular support 110 may be on-site cast with concrete. Referring to Figs. 2 to 5, the annular support 110 may be formed by putting together preformed concrete parts or steel parts. Forming the annular support 110 by putting together preformed concrete parts or steel parts provide the benefits of a relatively short construction period and accelerated construction progress.

The present invention is not limited to the above specific embodiments, and any variations and modifications made by those skilled in the art on the basis of the above teachings fall within the scope of the invention as defined by the appended claims.

## CLAIMS

1. An annular support system pre-stressed with tensioned strings, comprising an annular support constructed in a foundation pit, and a plurality of tensioned strings extending along diameters of the annular support, any two adjacent ones of the tensioned strings being spaced apart by an equal angle, each of the tensioned strings being at least provided with a pre-stressing means at one intersection of the tensioned string or an extension thereof with the annular support.

2. The annular support system pre-stressed with tensioned strings of claim 1, wherein the pre-stressing means is a jack.

3. The annular support system pre-stressed with tensioned strings of claim 1, wherein the pre-stressing means is an electric motor connected to the tensioned string by a lead screw.

4. The annular support system pre-stressed with tensioned strings of claim 1, wherein the pre-stressing means is arranged inside or outside the annular support or so as to extend from the inside to the outside of the annular support.

5. The annular support system pre-stressed with tensioned strings of claim 1, wherein the tensioned strings are stranded steel cables, steel tubes, steel bars, or a combination thereof.

6. The annular support system pre-stressed with tensioned strings of claim 1, wherein the angle between any two adjacent ones of the tensioned strings is acute.

7. The annular support system pre-stressed with tensioned strings of claim 1, wherein the tensioned strings are arranged along radial directions of the annular support in multiple layers.

8. The annular support system pre-stressed with tensioned strings of claim 1, wherein the annular support is on-site cast with concrete, or formed by putting together

preformed concrete parts, or formed by putting together steel parts.

9. The annular support system pre-stressed with tensioned strings of claim 1, wherein the tensioned strings extend through the annular support or not.

10. A deformation control method of the annular support system pre-stressed with tensioned strings of any one of claims 1 to 9, in which when deformation of the foundation pit in one direction or an opposite direction occurs to cause a deformation of the annular support in the same direction, a pre-stressing force exerted on the annular support is adjusted by using a pre-stressing means associated with a tensioned string perpendicular to the direction of deformation, so that the deformation of the annular support is controlled.