

Description

METHOD FOR CONSTRUCTING AN UNDERGROUND STRUCTURE

Technical field

5 The present invention relates to the construction of underground structures such as road, pedestrian or railway tunnels, in particular those passing beneath existing subterranean structures and/or urban constructions.

Prior art

10 Tunnels are most often constructed using diaphragm walls, enabling digging from the surface.

 However, the construction of tunnel segments beneath existing structures is complex because a traditional open trench cannot be used therefor.

 The usual method for digging a tunnel segment beneath an underground structure consists in shoring the tunnel as it progresses (i.e. as it is being dug) or in mechanically
15 digging by means of a tunnel boring machine.

 The main disadvantage of the first method is the time spent constructing the shoring and, for the second, the installation time and the bulk of the tunnel boring machine. Constructing an entire tunnel using a tunnel boring machine is generally the most expensive solution.

20 It is also known practice to provide pre-reinforcement of the pipe-umbrella type. This method is based on the installation of a network of horizontal reinforcement tubes on the periphery of the tunnel section to be dug and the driving (sliding) of a precast structure, in the form of a box, inside the network of tubes while progressively excavating the ground.

 Reinforcement tubes are usually steel tubes that are installed by drilling, for example
25 using a microtunnel boring machine, before being filled with concrete.

 This technique requires management of the horizontal forces for driving the box into the ground reinforced in this way. The pushing force enabling the box to slide may be provided by pusher jacks bearing against a reaction web or by cables moved by traction jacks.

30 Application SG10201901625P describes a method in which precast concrete boxes with steel cutting edges are pulled below the surface using high-strength steel traction jacks and cables.

Application SG10201704749S describes a method using a pre-reinforcement structure consisting of steel tubes in order to protect the structure during installation by driving, the latter being pushed between a vertical starting shaft and a vertical destination shaft.

5 Application JP2023174120 discloses a method in which the box is equipped with rods that can move vertically through its upper wall and are actuated by jacks installed inside the structure. A steel wall is interposed between the movable rods and the ceiling of the cavity overhanging the structure, beneath the pre-reinforcement tubes. The pressure exerted on the steel wall by the rods compensates for the sagging of the tubes under the load. The
10 pushing force required for driving is exerted by cable traction jacks acting between the box to be pushed and another box arranged on the opposite side of the site to be crossed.

 The methods disclosed in these applications are relatively difficult to implement in order to install underground structures beyond a certain size, on account of the frictional forces encountered, and make it difficult to control the levelling of the structure. In addition,
15 the installation of movable rods in JP2023174120 requires holes in the upper wall of the box, and the installation of the jacks requires the presence of a lower support wall. This method is therefore applicable only to boxes that are closed at the bottom, occupying the entire section of the tunnel to be constructed, thus limiting the size of the structure that can be driven into the ground.

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Disclosure of the invention

 There is thus a need for a method for constructing an underground structure, in particular a tunnel segment, in particular beneath an existing structure, that overcomes all or some of the drawbacks of the known methods.

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Summary of the invention

 The invention meets this need by proposing a method for constructing an underground structure, in particular a tunnel segment, using at least one precast box, comprising the steps of:

- 30 - constructing a pre-reinforcement at least with upper reinforcing tubes arranged above a digging area,

- progressively excavating the ground in the digging area in front of the precast box,
- progressively driving the precast box as the excavation progresses, with the interposition of height-adjustable lower sliding supports between the precast box and the ground of the excavated cavity.

The lower sliding supports make it possible to compensate, by acting across their height, for any settling of the ground that occurs during driving.

The invention saves time in the construction of an underground structure such as a tunnel segment beneath an existing structure. It also guarantees the stability and geometry of the structure, whether subterranean or on the surface, overhanging the underground structure to be built, while significantly reducing the pushing forces required to drive the precast box.

The invention makes it possible to precisely control the levelling of the box and to keep it at the desired inclination, which is preferably zero, in spite of any settling of the ground beneath the load.

The invention makes it easier to slide the box, and makes it possible to control the forces during driving, because it is easier to determine the properties of the sliding between the box and the lower sliding supports than if the box were to slide directly on the ground.

On account of the reduction in the driving forces, the invention makes it possible to reduce the bulk of the reaction frame required for driving, and in particular to use another box, which is immobilized, located at the other end of the site to be crossed, as a reaction frame.

Preferably, reinforcing tubes are installed in the lower part of the site to be crossed, to serve as a support for the lower sliding supports. These tubes can be driven across the site to be crossed in the same way as the upper reinforcing tubes, and filled at least partially with a cementitious material. Preferably, the lower reinforcing tubes are cut over part of their height from their upper generatrix, preferably halfway up, as the excavation progresses, in order to allow the fixing of support plates intended to support the lower sliding supports. The lower reinforcing tubes are preferably filled halfway up with a cementitious material.

Preferably, the lower sliding supports are fixed relative to the ground, and it is the box that slides in contact with them. In a variant, the lower sliding supports are secured to

the box, and slide on one or more fixed plates, resting for example on the lower reinforcing tubes.

The lower sliding supports may comprise, on the upper face, a sliding pad made of a material with a low coefficient of friction, preferably a dynamic coefficient of friction
5 (during sliding) of between 2 and 5%, in particular made of reinforced PTFE.

The surface of the box arranged facing the lower sliding supports may be covered with one or more sliding plates, in particular one or more metal plates, in particular made of stainless steel.

Preferably, the lower sliding supports each comprise a jack controlled on the basis of
10 any settling of the ground by a computer-assisted lifting (CAL) system, this controlling making it possible to keep the box level as desired. In a variant, the control is performed manually. A CAL system is an assembly incorporating data-processing, automation and hydraulics, capable of continuously controlling and ensuring coordinated operation of jacks on several different paths. A CAL system can in particular enable:

- 15 - uniform controlled lifting,
- uniform controlled lowering,
- controlled tilting,
- controlled deformation, and/or
- lifting or lowering with pressure regulation only, altitude control only, or
20 both, in particular in real time.

The lower sliding supports may each comprise a jack, which may be a hydraulic jack, acting between two telescopic parts of the support, these telescopic parts absorbing the shear forces as the box slides.

Each lower sliding support may comprise a position-locking system, which makes it
25 possible to prevent the jack from collapsing in the event of accidental loss of pressure.

Once the box has advanced beyond the supports and/or is in place, the lower sliding supports may be removed in order to be reused, after final supports have been installed.

Preferably, the method comprises the installation of height-adjustable upper sliding supports interposed between the box and the upper reinforcing tubes.

30 These upper sliding supports are preferably fixed relative to the upper reinforcing tubes, advantageously being fixed thereto.

Preferably, the upper sliding supports each comprise a jack, preferably a flat jack, into which a setting material, preferably a cementitious material, is injected.

These jacks may be controlled so as to act on the bending of the upper reinforcing tubes, in order to compensate for their deflection under load.

5 The upper sliding supports are preferably fixed to the pre-reinforcement tubes, in particular by welding, and comprise, on the lower face, a sliding pad, preferably with a dynamic coefficient of friction (during sliding) of between 2 and 5%, in particular made of reinforced PTFE.

10 The surface of the box facing the upper sliding supports may be covered with one or more sliding plates, in particular one or more metal plates, in particular made of stainless steel.

15 The theoretical load pressing down on an upper support may be evaluated with a computational model taking into account the ground and the structures involved. A margin of error of 20% can be taken into account in this evaluation. It is preferable for the preload on the upper support not to exceed the theoretical load so that it is not overloaded. The residual deformation of the upper reinforcing tube supported by this upper support is generally less than the geometrical tolerance considered, which is within a centimetre, being for example from 5 to 10 mm, this range of values being compatible with the permissible settling. The jacks of the upper sliding supports may be fed at a pressure selected on the basis of the theoretical position of the corresponding upper reinforcing tube, for example at 80% of the theoretical load level.

20 Geometrical (vertical) levelling control of the upper supports may be implemented (for example by means of an optical level or laser level) in order to check and possibly correct the load values applied.

25 The jacks of the upper supports may, if necessary, be controlled by an automated lifting (CAL) system that controls the position of the upper reinforcing tube and adjusts the pressure in the jack so as to yield the desired position for the tube. In a variant, the control is performed manually or semi-automatically.

30 The method may be implemented with alternating excavation phases and driving phases, the length of the segment excavated during an excavation phase preferably being between 1 and 3 m.

The method may comprise the installation of the lower sliding supports after an excavation phase, before the start of the driving phase. This installation is carried out, for example, by fixing one or more rows of lower sliding supports on the portion of the lower reinforcing tubes that has just been uncovered, cut and provided with one or more support plates.

The method may comprise the installation of the upper sliding supports after an excavation phase, before the start of the driving phase. This installation is carried out, for example, by fixing one or more rows of upper sliding supports on the portion of the upper reinforcing tubes that has just been uncovered.

Preferably, the driving is carried out using cable jacks. These jacks preferably act on two precast boxes arranged on either side of the area to be excavated, as mentioned above. This makes it possible to limit or avoid the bulk of a rear reaction frame.

The term "box" should be understood to mean any precast element intended to form all or part of the underground structure. The box may correspond to an entire section of the underground structure or to just part thereof, advantageously its upper part. In this case, after the box has been installed, the remainder of the section can be excavated and constructed in situ, in particular its lateral walls and its foundation slab.

The box can thus have a cross section with the general shape of an inverted U, optionally with one or more vertical support webs, which may or may not be temporary.

The box is preferably made of reinforced concrete, in a shaft for accessing the site to be crossed. The method according to the invention may thus include digging at least one shaft, for example two access shafts, one upstream and one downstream, arranged on either side of the area in which the underground structure is to be constructed.

The method may include drilling boreholes using a microtunnel boring machine, and then installing pre-reinforcement tubes in these boreholes, these tubes then being injected with a hardening material, preferably a cementitious material.

The method may involve drilling boreholes using a microtunnel boring machine, and then installing tubes intended for the passage of traction cables.

Brief description of the drawings

The invention may be understood better from reading the following description of nonlimiting implementation examples thereof, and from examining the appended drawing, in which:

5 [Fig. 1] Figure 1 illustrates the driving of the precast boxes beneath the pre-reinforcement structure,

 [Fig. 2] Figure 2 is a schematic and partial top view of the precast boxes connected by the cable jacks,

 [Fig. 3] Figure 3 is a schematic view in longitudinal section illustrating the role
10 of the sliding supports and of the support jacks, the angles and unevenness (or displacements) of the horizontal reinforcing tubes being shown in exaggerated manner,

 [Fig. 4] Figure 4 is an exploded view of an upper support,

 [Fig. 5] Figure 5 is a schematic perspective view of a lower support, and

 [Fig. 6] Figure 6 illustrates the controlling of the jacks of the lower sliding
15 supports using a CAL system.

Detailed description

The method according to the invention includes, after digging access shafts 50 and 60 of the tunnel segment to be constructed, constructing a pre-reinforcement structure 30
20 through the ground T of the site to be crossed, as illustrated in Figures 1 and 2.

This structure 30 comprises a series of upper reinforcing tubes 31 arranged side by side, preferably horizontally and parallel to one another, and a set of lateral reinforcing tubes 32, which are preferably horizontal and arranged one beneath the other. The tubes 31 and 32 are preferably made of steel.

25 In order to install the reinforcing tubes 31 and 32, boreholes are drilled, for example, with a microtunnel boring machine (typical diameters of between 0.5 and 2.0 m).

The tubes 31 and 32 are then driven into the boreholes thus formed, and the tubes are then injected with concrete once installed.

Boreholes are also drilled for the installation of lower reinforcing tubes 33 through
30 the ground T (only one of these tubes is partially visible in Figure 1). These tubes 33 are filled with concrete only in their lower half, and are intended to be progressively cut halfway up as the ground T is excavated, as explained below.

The shafts 50 and 60 comprise respective vertical walls 51 and 61, which may have any shape.

Additional tubes (not visible) may be installed through the ground T of the site to be crossed to serve as passage conduits for cables 41 intended for driving the precast boxes 10 and 20 used for producing the tunnel segment, as explained below.

The precast boxes 10 and 20, sometimes also referred to as "box culverts", correspond in the example in question to the upper part of the tunnel section to be constructed.

The box 10 may be made of reinforced concrete, inside the shaft 50, and comprises, as can be seen in Figure 1, an upper wall 11 extended downwards on the sides by two vertical lateral uprights 12 and 13. Temporary vertical reinforcement webs 14 may be provided, as illustrated. The box 20 produced in the shaft 60 may have a similar shape in cross section.

The boxes 10 and 20 comprise sheaths that pass through them along their length and in which the traction cables 41 extend.

One or more sliding plates 17 are positioned on the upper face of the box 10, in line with each upper reinforcing tube 31, as illustrated in Figure 3. Each plate 17 is, for example, made of stainless steel. The same applies to the box 20.

The lower faces of the lateral uprights 12 and 13 and of the webs 14 are also lined with one or more sliding plates 18, for example made of stainless steel.

Upper sliding supports 80 (also referred to as "support dies") are intended to be fixed to each reinforcing tube 31 as the ground T is excavated, as explained below.

Each upper sliding support 80 comprises, as illustrated in Figure 4, a cradle 81 having a concave upper face designed to closely follow the cylindrical shape of the tube 31 and a lower face in contact with a flat jack 82 (known per se and shown schematically). The latter bears, on its lower face, a sliding pad 83, made of a material with a low dynamic coefficient of friction, as mentioned above, for example reinforced PTFE, in particular that sold under the name Isoglide, intended to come into contact with the underlying sliding plate 17. The flat jack 82 and the cradle 81 are housed in a housing 84. The cradle 81 is preferably arranged so as to be able to be fixed by welding to the tube 31, beneath which it is arranged.

The method is also implemented using lower sliding supports 90, one of which is shown in isolation in Figure 5.

These supports 90 comprise two telescopic parts 92 and 93 engaged one inside the other, and a hydraulic jack 94 interacting between the telescopic parts in order to adjust their spacing. The telescopic parts can absorb the horizontal forces, the jack 94 withstanding only the vertical forces.

- 5 A locking system 95, for example using a nut, is advantageously provided in order to lock the jack in position, for safety purposes.

The free face of the upper part 92 is lined with a sliding pad 96 made of a material with a low coefficient of friction, for example reinforced PTFE, in particular that of the Isoglide brand.

- 10 The jacks 94 can be controlled by a CAL system 120 on the basis of information delivered by a measuring system 130, 131 as detailed below. The CAL system can be designed to automatically coordinate all the jacks 94 simultaneously by analysing the lifting parameters (pressure and stroke of the jack, movements of the box), while ensuring in real time precision to within a tenth of a millimetre.

- 15 The jacks 82 of the upper sliding supports 80 can also be controlled by a suitable system 140 feeding them with a pressurized setting material, for example a cement slurry. This control system may be a CAL system. Such a system can also make it possible to correct excessive settling/displacement at the upper supports. In a variant, the jacks 82 are controlled manually.

- 20 Once constructed, the boxes 10 and 20 are installed in the site to be crossed in the following manner.

First of all, the cables 41 are installed while being retained on the side of one of the boxes, in this case the box 20 in the example in question, by stops 42, as illustrated in Figure 2, and are engaged in traction jacks 40 on the side of the other box 10.

- 25 The cables 41 pass through the ground by means of the tubes previously installed therein.

The ground T is excavated in front of the box 10 over a distance of around 2 to 3 m for example, the reinforcing tubes 31 being able to withstand vertical loads over such a span of 2 to 3 m without intermediate support.

The cradles 81 of the upper sliding supports 80 are progressively welded to the underside of the upper reinforcing tubes 31 thus uncovered, as the ground T inside the surface described by the reinforcing tubes 31 and 32 is excavated.

5 The level of the lower face of a sliding pad 83 not yet engaged on the box is very slightly higher than that of the sliding plate 17, as can be seen in Figure 3.

The lower tubes 33 are cut halfway up on the portion uncovered by the excavation, then one or more horizontal plates 100 are welded to the half-cylinder thus cut, in order to install the lower sliding supports 90.

10 Once the supports 90 have been installed in the lower part and the cradles 81 have been welded in the upper part, the box 10 can be shifted towards the inside of the site via the use of cable traction jacks 40 fixed to the rear of the box 10. The immobilized box 20 is then used as a reactive resistance frame.

The spacing of the supports 80 and 90 in the direction of progression of the box 10 is, for example, around 1.5 m.

15 As soon as the box 10 has engaged with an upper support 80 and a lower support 90 by around 75 to 100 cm, the flat jack 82 of the support 80 is loaded at a value close to the estimated theoretical vertical load, for example around 80% thereof.

The pressure thus exerted on the corresponding tube 31 makes it possible to compensate for the deflection it may have undergone during removal of the ground T.

20 Figure 5 illustrates the possibility of the jacks 94 of the lower supports 90 being controlled by the automated lifting system 120 so as to keep the box 10 at a pre-defined level H, even in the event of the ground settling.

25 The vertical stroke of the jacks 94 can in particular be controlled automatically in order to accommodate the unevenness (deformations) that may affect the reinforcing tubes 33 on which the strut 10 rests during shifting. This unevenness corresponds to bending deformations of the reinforcing tubes 33 induced by settling that may occur in the underlying ground K.

30 The unevenness of the supports 90 can be measured with respect to a horizontal reference by any means, for example mechanical ruler, spirit level, optical level, by one or more lasers 130 coupled to detectors 131, in order to generate vertical stroke adjustment

setpoints for the jacks 94. Vertical reactions/forces can be measured simultaneously for verifying/controlling the safety of the operation.

The unevenness compensation phase can be controlled by the CAL system 120, the latter carrying out the measurements, generating and applying the jacking setpoints automatically, in real time.

By way of example, Figure 6 illustrates the reaction of the system 120 to subsidence of the ground at the support 90 in the centre of the figure. It can be seen that the jack 94 is controlled so as to lengthen in order to compensate for this subsidence.

Given that the jacks 82 receive a setting material, the upper supports 80 retain the elongation that they assumed during pressurization.

In the general sequence of tasks, the phases of horizontally shifting the box 10 and of jacking in order to compensate for vertical unevenness alternate, each of the shifting phases being followed by a compensation phase.

The operation may be repeated as many times as is necessary for the box 10 to reach its final position, namely excavating the ground, installing the upper 80 and lower 90 supports, sliding the box 10, pressurizing the upper supports 80 and adjusting the level of the lower face of the box 10 using the lower supports 90.

The same procedure is carried out for the box 20 on the opposite side, until the boxes 10 and 20 meet with a predefined free space between them, for example of around 2 to 3 m.

The join between the boxes may be made of cast-in-place concrete.

Of course, the invention is not limited to the example that has just been described.

For example, the anchoring for the traction cables may be provided on a wall of a fixed frame.

It is also possible for the traction cables to be passed through some of the reinforcing tubes present on the periphery of the box. The box can thus be anchored via a remote rear structure.

The CAL system may be replaced by a manual jacking system.

Claims

1. Method for constructing an underground structure, in particular a tunnel segment, using at least one precast box (10; 20), comprising the steps of:
 - constructing a pre-reinforcement at least with upper reinforcing tubes (31) arranged above a digging area,
 - progressively excavating the ground in the digging area in front of the precast box,
 - progressively driving the precast box as the excavation progresses, with the interposition of height-adjustable lower sliding supports (90) between the precast box and the ground of the excavated cavity.
2. Method according to Claim 1, being used to construct an underground structure such as a tunnel segment, beneath an existing structure.
3. Method according to either one of the preceding claims, wherein reinforcing tubes (33) are installed in the lower part of the site to be crossed, to serve as a support for the lower sliding supports (90).
4. Method according to the preceding claim, said tubes (33) being driven through the site to be crossed in the same way as the upper reinforcing tubes (31), and filled at least partially with a cementitious material, the tubes being cut over part of their height from their upper generatrix, preferably halfway up, as the excavation progresses, support plates (100) intended to support the lower sliding supports (90) preferably being fixed to said tubes, the lower reinforcing tubes preferably being filled halfway up with a cementitious material.
5. Method according to any one of the preceding claims, the lower sliding supports being fixed relative to the ground, the box sliding in contact with them, the lower sliding supports preferably comprising, on the upper face, a sliding pad (96) made of a material with a low coefficient of friction.

6. Method according to the preceding claim, the surface of the box arranged facing the lower sliding supports being covered with one or more sliding plates (18), in particular one or more metal plates, in particular made of stainless steel.
- 5 7. Method according to any one of the preceding claims, the lower sliding supports (90) each comprising a jack (94) controlled on the basis of any settling of the ground by a computer-assisted lifting (CAL) system (120, 130, 131), this controlling making it possible to keep the box level as desired.
- 10 8. Method according to any one of the preceding claims, the lower sliding supports (90) each comprising a jack (94) acting between two telescopic parts (92, 93) of the support, these telescopic parts absorbing the shear forces as the box slides, each lower sliding support (90) preferably comprising a position-locking system, which makes it possible to prevent the jack from collapsing in the event of accidental loss of pressure.
- 15 9. Method according to any one of the preceding claims, wherein once the box has advanced beyond the supports and/or is in place, the lower sliding supports (90) are removed in order to be reused, after final supports have been installed.
- 20 10. Method according to any one of the preceding claims, comprising the installation of height-adjustable upper sliding supports (80) interposed between the box and the upper reinforcing tubes (31).
- 25 11. Method according to Claim 10, the upper sliding supports (80) being fixed relative to the upper reinforcing tubes (31), preferably being fixed thereto.
- 30 12. Method according to the preceding claim, the upper sliding supports (80) each comprising a jack (82).
13. Method according to the preceding claim, said jack being a flat jack (82), into which a setting material, preferably a cementitious material, is injected.

14. Method according to either of Claims 12 and 13, said jacks being controlled so as to act on the bending of the upper reinforcing tubes (31), in order to compensate for their deflection under load.
- 5 15. Method according to any one of Claims 10 to 14, the upper sliding supports (80) being fixed to the pre-reinforcement tubes (31), in particular by welding, and comprising, on the lower face, a sliding pad (83).
- 10 16. Method according to any one of Claims 12 to 15, said jacks (82) being controlled by an automated lifting (CAL) system (140) that controls the position of the upper reinforcing tube (31), the pressure in the jack being adjusted so as to yield the desired position for the tube (31).
- 15 17. Method according to one of Claims 10 to 16, the surface of the box facing the upper sliding supports (80) being covered with one or more sliding plates (17), in particular one or more metal plates, in particular made of stainless steel.
- 20 18. Method according to any one of the preceding claims, being implemented with alternating excavation phases and driving phases, the length of the segment excavated during an excavation phase preferably being between 1 and 3 m.
- 25 19. Method according to any one of the preceding claims, comprising the installation of the lower sliding supports (90) after an excavation phase, before the start of the driving phase.
- 30 20. Method according to Claim 18 and one of Claims 10 to 17, comprising the installation of the upper sliding supports (80) after an excavation phase, before the start of the driving phase.
- 30 21. Method according to any one of the preceding claims, the driving being carried out using cable jacks (40), the latter preferably acting on two precast boxes (10, 20) arranged on either side of the area (T) to be excavated.

22. Method according to any one of the preceding claims, the box corresponding to just the upper part of the section of the underground structure, and wherein, after the box has been installed, the remainder of the section is excavated and constructed in situ, the box preferably having a cross section with the general shape of an inverted U, preferably with one or more temporary vertical reinforcement webs (14).