

TUNNEL CONSTRUCTION METHOD AND MACHINE

DESCRIPTION

The present invention falls generally within the technical field of construction of natural tunnels. In particular, the invention relates to a method and a machine for constructing natural tunnels by means of excavation with “traditional” technique.

In very general terms, the construction of natural tunnels by means of excavation essentially comprises three operations: underground excavation, removal of the excavated material and application of one or more lining layers to stabilize and consolidate the excavation walls. These operations form the basis of the techniques most widely used today to construct natural tunnels by excavation, namely the “traditional” technique and the “mechanized” technique.

According to the “traditional” technique, the above-mentioned basic operations are carried out discontinuously, largely in succession, and repeated cyclically until the tunnel is completed. Each of them requires a direct and substantial workforce intervention and the use of a plurality of operating machines, vehicles, and equipment, which have to pass or be moved repeatedly along the tunnel during the construction thereof to reach a respective working front or region.

In further detail, in an embodiment typical of known methods for constructing natural tunnels by means of excavation with “traditional” technique, each advance cycle comprises firstly advancing an excavation front of the tunnel by a predetermined advance length. The excavation front is point-excavated by means of conventional excavating machines. Simultaneously with and/or subsequently to the excavation, the excavated material is removed by means of dump trucks that transport the excavated material outside the tunnel under construction, passing through it repeatedly.

Once the tunnel length just excavated has been freed of the excavated material, a primary lining, also known as first phase lining or temporary lining, having the purpose of stabilizing the cavity in the short term, so as to allow the workers to operate therein safely, is applied onto walls exposed by the excavation, in particular onto the radial walls. The primary lining is usually made of shotcrete. Often, before applying shotcrete, large metal reinforcement profiles, called ribs, are laid. Such reinforcement profiles are shaped according to the excavation cross-sectional profile and are arranged longitudinally at regular intervals along the excavation. In this case, the shotcrete is subsequently applied onto the intrados of the ribs and between the ribs themselves, thus incorporating them in one single structure. For these operations, suitable operating machines, such as pumping machines for applying the shotcrete and machines for lifting and laying the ribs, and related service vehicles, such as concrete mixers and load trucks

for transporting the ribs and other materials, are used, which shall be able to pass through the tunnel under construction as far as the newly excavated tunnel length.

Other work fronts upstream – with reference to the direction in which the excavation is advanced – of the excavation front are then advanced, at which works are made aimed at creating a final lining of the tunnel, also known as second phase lining, which is required for ensuring the long-term stability thereof.

In particular, at a first work front upstream of the excavation front, two lateral shoulders, also known in the art as kerbs, made of reinforced concrete and parallel to each other, are further built on opposite sides of the tunnel base. At a second work front, upstream of the advance front of the kerbs, an inverted arch, also made of reinforced concrete, is built at the bottom of the tunnel, between the two kerbs previously built. Lastly, at a third work front upstream of the advance front of the inverted arch, the final lining of the tunnel is built at the vault and the sidewalls. Typically, this operation comprises laying waterproofing sheets on the corresponding surfaces, building a steel reinforcement framework and concrete casting with radial thickness varying from 30 cm to 120 cm with the aid of a large monolithic formwork, transversally shaped according to the final tunnel cross-sectional profile and having length of, e.g., 10 m, which can be moved along the tunnel on rails temporarily laid on the previously built kerbs.

The operations linked with casting of the final lining at the vault and sidewalls, and of the inverted arch on the bottom, significantly obstruct or totally block the passage of operating machines, vehicles, or equipment through the tunnel sections involved and therefore the passage thereof from/to the excavation front. During said operations, which in the case of the final lining can take up to 10-12 hours, it is not possible to advance the excavation. The latter is resumed in a subsequent advance cycle, when the tunnel sections involved in the advance of the final lining or the inverted arch are free again.

From the above it is apparent that the excavation advance speed – which is the most impacting factor on tunnel construction times and, therefore, costs – with the “traditional” technique is intrinsically limited by the nature and sequence of the operations carried out. Moreover, it is generally found in practice that the excavation advance speed with “traditional” technique is considerably influenced by the experience and skill of the workforce involved and by the site management.

External conditions being the same, higher excavation advance speeds can be obtained by means of the “mechanized” technique. In this case the basic operations mentioned at the beginning are carried out continuously and simultaneously, by means of large specially designed automated machines, called TBM (Tunnel Boring Machines). These machines

perform the excavation in an integral and continuous manner while simultaneously removing the excavated material from the excavation front and laying the tunnel lining upstream of the excavation front. In this case, the creation of a primary lining is not required and the final lining is immediately built by sequentially placing lining rings onto the whole perimeter of the excavation section, each lining ring being formed of a plurality of appropriately shaped prefabricated concrete elements, called segments. All these operations are carried out in a completely mechanized manner, with minimum workforce; in this case the job of the workers is essentially limited to monitoring the progress of the excavation and operation of the TBM.

Although the “mechanized” technique normally allows higher excavation advance speeds, the extremely high cost of the TBM makes it economically viable only for the construction of sufficiently long tunnels, in particular tunnels at least 2 km long, and in ground having a sufficiently uniform composition, to avoid as far as possible costly machine standstills due to unforeseen events during the excavation.

For the construction of shorter tunnels, in particular tunnel shorter than 2 km, and/or in ground having very heterogeneous composition, the “traditional” technique remains the most advantageous solution in terms of cost-benefit ratio, if not also the most appropriate for technical reasons. The “traditional” technique for the excavation of natural tunnels is therefore still extremely widespread today and subject to developments and improvements.

In view of the above, the main object of the present invention is to reduce the construction times of a natural tunnel by excavation with “traditional” technique.

A further object of the present invention is to reduce the impact of the experience or skill of the site workforce on the construction times of a natural tunnel by excavation with “traditional” technique.

The Applicant has perceived the possibility of achieving said objects in a particularly effective manner by using a different way of building the tunnel final lining as compared to that used in the construction of natural tunnels by excavation with “traditional” technique according to the prior art, as described above.

In particular, in a first aspect thereof, the invention relates to a method for constructing natural tunnels, wherein a tunnel under construction comprises an excavation front, a final lining front upstream of the excavation front in an excavation advance direction, and a work region between the excavation front and the final lining front, comprising the steps:

- a) advancing the excavation front by a predetermined advance length by means of point excavation with one or more self-propelled excavating machines;
- b) removing excavated material from the work region by means of one or more dump trucks;

- c) applying a primary lining onto walls exposed by the excavation at the advance length of the excavation front;
- d) advancing the final lining front by a predetermined advance length by creating a final lining onto the primary lining applied at the same advance length in a previous advance cycle;
- e) repeating steps a) to d) until the tunnel is completed,

wherein step d) of advancing the final lining front comprises assembling at least one full ring of prefabricated segments and is carried out simultaneously with step a) of advancing the excavation front,

wherein step d) of advancing the final lining front is carried out by means of a segment placing machine having a tubular frame, and

wherein the passage or displacement of operating machines, vehicles, or equipment from/to said work region during step b) of removal of the excavated material and step c) of applying the primary lining takes place through the tubular frame of the segment placing machine.

Within the framework of methods for constructing natural tunnels by means of excavation with “traditional” technique, the invention proposes to create the final lining of a tunnel by placing prefabricated segments, assembled to form rings extending along the whole perimeter of the excavation cross section, instead of building said lining completely on site, by building a steel reinforcement framework and subsequent concrete casting with the aid of appropriate formworks, as in the prior art. The segments are placed in a mechanized manner, by means of a specially designed segment placing machine, simultaneously with advance of the excavation front.

These measures significantly speed up each advance cycle of the method for constructing natural tunnels according to the invention, with advantage to the overall times and costs for constructing the tunnel.

First of all, in fact, choosing a final lining made of segments advantageously allows leaving out the steps of building the kerbs and the inverted arch at the bottom of the tunnel, which are instead essential for subsequent creation of the final lining at the vault and sidewalls in the prior art methods for constructing tunnels by excavation with “traditional” technique.

Secondly, keeping the lining length the same, building a final lining by placing segments is in itself significantly faster than building a final lining with the same features by means of casting in place. For example, for a tunnel length of 1 m, building a final lining by placing segments can typically take approximately 1 hour or even less, whereas casting in place requires several hours.

The shorter duration of the final lining front advance step in the method of the invention allows

complete time overlap thereof with the excavation front advance step, which, referring again to a front advance of 1 m, typically requires 3 to 12 hours, depending on the rock conditions. This time overlap brings two advantageous effects. On the one hand, the final lining front advance step is masked, in terms of time, by the excavation front advance step and therefore no longer affects the overall tunnel construction times. On the other hand, said step no longer causes downtime for carrying out other steps of the method, since the temporary blocking of the tunnel section affected by the operations for advancing the final lining front now takes place during the excavation step, which can normally proceed and be completed autonomously, without the need for a simultaneous and repeated passage of operating machines, vehicles, or equipment from/to the work region of the tunnel, as required instead for the excavated material removal step and for the primary lining application step.

In addition to the above, the prefabricated segments are placed by means of a self-propelled segment placing machine specially designed for use in the method described above, having a tubular frame through which, at least when the machine is inactive, namely it is not placing segments, operating machines, vehicles, or equipment needed for carrying out other steps of the method, particularly the excavated material removal step and the primary lining application step, can freely pass or be displaced from/to the work region at the excavation front. Downtimes resulting from repeated displacements of the segment placing machine away from its work position in order to free the passage from/to the work region and repositioning of the same to resume placing of the segments in a new final lining front advance step can thus be avoided. This aspect too contributes to speeding up each advance cycle of the method for constructing natural tunnels according to the invention.

Furthermore, since the final lining front advance step is now performed in a mechanized manner, the execution times and quality thereof are only marginally affected by the experience and skill of the site workforce. Said step can therefore be standardized in terms of duration and quality and, if required, also completely or partially automated.

A further advantage connected with the method for constructing natural tunnels according to the invention lies in the reduced distance between the excavation front and the final lining front, due to elimination of the advance fronts of the kerbs and the inverted arch and the possibility of rapidly advancing the final lining front. A shorter tunnel length between the two above-mentioned fronts, where only the primary lining is present, improves the site safety conditions and, above all in difficult geological conditions, reduces the probability of subsidence of the primary lining without the need for additional reinforcement works, which would negatively affect the tunnel construction times and costs.

Preferred embodiments of the method for constructing natural tunnels described above are the subject of respective dependent claims, whose content is fully incorporated herein by reference. In a second aspect thereof, the invention relates to a self-propelled segment placing machine for placing prefabricated segments of a final lining of a natural tunnel, comprising:

- a longitudinally extended tubular frame, having transverse dimensions that allow operating machines, vehicles, or equipment used in construction of the tunnel to pass or be displaced therethrough, and
- segment handling means associated with the tubular frame and displaceable relative to the tubular frame between a segment taking position and a plurality of segment placing positions for assembling full rings of segments at walls of the tunnel,

wherein in a rest configuration of the segment placing machine the tubular frame is freely practicable by said operating machines, vehicles, or equipment, and

wherein the tubular frame comprises a plurality of anchoring devices which can be radially extended therefrom for temporarily anchoring the segment placing machine to walls of the tunnel.

Within the framework of a method for constructing tunnels by means of excavation with “traditional” technique, the segment placing machine of the invention allows a final lining of the tunnel under construction to be built in a completely mechanized manner, significantly limiting the workforce required. Furthermore, at least in a rest configuration thereof, namely when it is not placing segments, the segment placing machine of the invention does not hinder the passage or movement of operating machines, vehicles, or equipment from/to the work region at the excavation front of the tunnel under construction, since in this case said passage or movement can take place through the segment placing machine itself. Therefore, it is not necessary to repeatedly move the machine away from and back to the respective work front to allow other steps of the tunnel construction to be performed. The segment placing machine of the invention therefore contributes to achieving all of the advantages described above with reference to the method of the invention, in particular as far as reduction of the construction times and impact of the site workforce on such aspect are concerned.

Preferred aspects of the segment placing machine described above are the subject of respective dependent claims, whose content is fully incorporated herein by reference.

Further features and advantages of the invention will become clearer from the following detailed description of preferred embodiments thereof, made hereafter, for indicating and non-limiting purposes, with reference to the attached drawings, in which:

- Fig. 1 is a schematic perspective longitudinal section view showing steps in the

construction of a tunnel according to the method of the present invention;

- Fig. 1a is a schematic longitudinal section view corresponding to Fig. 1;
- Fig. 1b is a schematic cross section view at the plane B-B of Fig. 1a;
- Fig. 2 is a schematic perspective longitudinal section view showing a further tunnel construction step according to the method of the present invention;
- Fig. 2a is a schematic longitudinal section view corresponding to Fig. 2;
- Figs 3 and 4 are schematic perspective longitudinal section views showing a further tunnel construction step according to the method of the present invention;
- Figs 3a and 4a are schematic longitudinal section views respectively corresponding to Fig. 3 and 4;
- Fig. 5 is a schematic perspective longitudinal section view showing a further tunnel construction step according to the method of the present invention;
- Fig. 6 is a schematic perspective longitudinal section view showing a further tunnel construction step according to the method of the present invention;
- Fig. 7 is a schematic perspective view of a segment placing machine according to the present invention, in a rest configuration;
- Fig. 7a is a schematic front view of the segment placing machine of Fig. 7;
- Fig. 8 is a schematic perspective view of the segment placing machine of Fig. 7, in a work configuration, and
- Fig. 8a is a schematic front view of the segment placing machine of Fig. 8.

Figs 1 - 6 show steps in the construction of a natural tunnel, generally indicated by reference numeral 1, by means of excavation, according to the method of the present invention.

As can be better seen in Fig. 1a, an excavation front EF, a primary lining front PLF upstream of the excavation front EF, and a final lining front FLF upstream of the primary lining front PLF can be identified in the tunnel 1 under construction. Still upstream of the final lining front FLF is a carriageway plane front CF, upstream of which a carriageway plane 5 has already been built in the tunnel 1 (see Figs 2, 3, 4, 5 and 7).

Unless indicated otherwise, in the context of the present description and subsequent claims, the terms “upstream”, “downstream” shall be understood with reference to an excavation advance direction, indicated by an arrow A in Fig. 1a.

Furthermore, in the context of the present description and subsequent claims, the region of the tunnel 1 between the excavation front EF and the final lining front FLF is also indicated as “work region”.

Each of the above-mentioned fronts is progressively advanced during construction of the tunnel

1, until completion thereof. If excavation conditions permit, during construction of the tunnel 1 the mutual distances between said fronts can be maintained substantially constant.

In the region between the excavation front EF and the primary lining front PLF, the tunnel 1 can have radial walls either still without any lining, i.e., bare, (see Fig. 1a - 3a) during the excavation steps and excavated material removal steps, or provided with a primary lining 2 which is being built (see Fig. 4a, Fig. 5).

In the region between the primary lining front PLF and the final lining front FLF, the tunnel 1 has radial walls provided with a finished primary lining 2, intended to achieve short-term stability conditions of the excavated cavity and allow the workforce to operate safely.

Preferably, the primary lining 2 comprises in a known manner metal reinforcement ribs 21, arranged longitudinally at regular intervals along the tunnel 1, for example at a mutual distance of about 1 m, and a layer of shotcrete 22, possibly reinforced with wire meshes or metal fibers, applied on the intrados of the ribs 21 and therebetween.

The ribs 21 can be made, for example, of structural steel and have open cross-sectional shapes, such as H shapes (HEA – HEB beams) or double-T shapes (IPE beams), or closed cross-section shapes. In the latter case, the inner volume of the ribs 21 can be conveniently filled with concrete by means of pumping after installation of the ribs 21.

In any case, the ribs 21 preferably have a circumferentially closed shape, for example substantially circular, and extend continuously along the whole perimeter of the cross section of the tunnel 1. For the sake of clarity, in the longitudinal section views, the ribs 21 are explicitly shown only at the work region, however it is understood that they are present in the same way in any portion of the tunnel 1 upstream of the primary lining front PLF.

In the work region, and particularly in the region between the primary lining front PLF and the final lining front FLF, on the bottom of the tunnel 1 there is a temporary tamped earth work floor 3, made with part of the excavated material resulting from advance of the excavation front EF.

Upstream of the final lining front FLF, the radial walls of the tunnel 1 also have a final lining 4, applied onto the primary lining 2.

The final lining 4 is made here by means of prefabricated segments 41 assembled to one another so as to form a plurality of circular closed rings 42, mutually adjacent in the direction of longitudinal development of the tunnel 1.

The segments 41 are prefabricated elements made of reinforced concrete, possibly reinforced with metal fibers. Preferably, when installed, each segment 41 is mechanically interconnected to the adjacent segments 41 both in a circumferential direction, namely within a same ring 42

of segments 41, and in longitudinal direction, namely with the rings 42 of segments 41 immediately adjacent to the ring 42 comprising the segment 41 in hand. The segments 41 of each ring 42 can be conveniently arranged so as to be circumferentially offset relative to the segments 41 of the adjacent rings 42 (not shown in the figures).

Preferably, the segments 41 of the final lining 4 are not placed in direct contact with the underlying primary lining 2, but rather an annular gap is left which is subsequently pressure-filled with hydraulic mortar 43.

With reference to Figs 1 - 6 and to the tunnel 1 described above, a preferred embodiment of the method according to the present invention for constructing natural tunnels by means of excavation shall now be explained in detail. In particular, the steps of a generic advance cycle forming the core of said method and which is repeated until the tunnel 1 is completed will be explained.

In particular, as apparent from Figs 1, 1a, 1b, each advance cycle comprises a step of advancing the excavation front EF by a predetermined advance length by means of point excavation with one or more excavating machines. Said excavating machines operate in the work region, between the excavation front EF and the final lining front FLF. By way of example, Figs 1, 1a, 1b show an excavating machine 100 provided with a breaker; alternatively or additionally, according to the type of rock or ground found, in order to carry out point excavation at the excavation front EF, excavating machines provided, for example, with backhoe buckets, rippers or roadheaders could be used.

Advance of the excavation front EF is preferably carried out by full-section excavation. As apparent in particular from Fig. 1b, by using a point excavation technique, the cross section of the excavation is not restricted to a circular shape, as in the case of excavation with "mechanized" technique by means of TBM.

As still apparent from Figs 1, 1a, 1b, simultaneously with the excavation for advancing the excavation front EF, also the final lining front FLF is advanced by a predetermined advance length, by assembly of at least one further full ring 42' of segments 41 on the previously applied primary lining 2. In Figs 1 and 1a the further ring 42' is shown still in the construction phase. Preferably, the advance length of the excavation front EF and the advance length of the final lining front FLF are substantially equal and, preferably, correspond substantially to the width of a ring 42 of segments 41. Consequently, the longitudinal extension of the work region between the excavation front EF and the final lining advance front is maintained substantially constant in the subsequent advance cycles for constructing the tunnel 1. However, the possibility of advancing the excavation front EF and the final lining front FLF by respective

different advance lengths is not excluded. For example, if regions with less cohesive ground are encountered during construction of the tunnel 1, at least in one advance cycle it may be advantageous to advance the final lining front FLF by a longer length than the corresponding advance length of the excavation front EF, so as to reduce the longitudinal extension of the work region, where the walls of the tunnel 1 are provided only with the primary lining 2. In this case, for example, it is possible to maintain unchanged the advance length of the excavation front EF and double the length of the advance length of the final lining front FLF by placing two full rings 42 of segments 41.

The segments 41 are placed in a mechanized manner by means of a self-propelled segment placing machine 200, specially designed for use in the method of the invention and shown in more detail in Figs 7, 7a, 8 and 8a.

As apparent in particular from Figs 7 and 8, the segment placing machine has a longitudinally extended tubular frame 201. The tubular shape of the frame 201 is adapted to the shape of the internal cross section of the tunnel 1, as resulting from placing of the final lining 4. In particular, in the case shown here, the frame 201 has a generally circular cross section.

The frame 201 preferably has a reticular structure, formed of a plurality of circumferential ribs and a plurality of longitudinal cross members. A first longitudinal end, in the followings also indicated as “leading end”, of the frame 201 extends preferably in a plane substantially perpendicular to the direction of longitudinal development of the frame 201, while a second longitudinal end, in the followings also indicated as “trailing end”, extends preferably in a plane inclined towards the first longitudinal end relative to the direction of longitudinal development. These features result overall in a “rib cage”-like shape of the frame 201, which is particularly advantageous for lending the segment placing machine 200 stability in static and dynamic conditions and structural resistance and, at the same time, for reducing the weight thereof and limiting the amount of material required for building the frame 201.

In any case, regardless of the specific shape and configuration, the tubular frame 201 has internally transverse dimensions that allow the passage or displacement therethrough of operating machines, vehicles, or equipment used for constructing the tunnel 1 and, in a rest configuration of the segment placing machine 200, the tubular frame 201 is freely practicable by said operating machines, vehicles, or equipment, as described in further detail below with reference to the method of the invention.

To allow the above-mentioned passage or movement to take place easily, the segment placing machine 200 preferably comprises a motorable plane 202 extending longitudinally inside the tubular plane 201 at the base thereof, preferably throughout the length thereof. Alternatively to

the motorable plane 202, a pair of parallel rails could be provided, for example.

The segment placing machine 200 comprises segment handling means associated with the tubular frame 201 and displaceable relative thereto between a segment taking position and a plurality of segment placing positions to form the rings 42 of segments 41 of the above-described final lining 4 of the tunnel 1, as shown in Figs 1, 1a, 1b and further described in detail below.

In a preferred embodiment of the segment placing machine 200, the segment moving means comprise a robot arm 203 displaceable along a circular guide rail 205, integral with the tubular frame 201 and arranged perpendicular to the direction of longitudinal extension of the tubular frame 201. This design has proven to be particularly effective for combining simple construction and operating flexibility with the need to avoid, at least in a rest configuration of the segment placing machine 200, the presence of fixed obstacles that prevent the passage of operating machines, vehicles, or equipment through the tubular frame 201.

The circular guide rail 205 has a closed shape and is preferably arranged at the leading end of the tubular frame 201, preferably on an inner side thereof.

The robot arm 203 is configured and dimensioned for handling the segments 41 in order to place them to create the final lining 4 of the tunnel 1. In particular, the robot arm 203 can be conveniently configured as a robot arm with three axes of articulation, preferably parallel to one another, and comprise four sections mutually articulated at said axes of articulation, wherein the two end sections comprise or consist of a segment taking head and a base for coupling with the guide rail 205, respectively.

Preferably, the segment placing machine 200 further comprises at least a movable bridge 204, for the temporary motorable connection between the segment placing machine 200 and the work region of the tunnel 1. The bridge 204 can comprise a single motorable plane or, as in the embodiment shown in the figures, a pair of parallel rails. Preferably, the bridge 204 is mounted to the same circular guide rail 205 as the robot arm 203 and is displaceable along said guide rail in a coordinated manner with the robot arm 203.

In view of the high loads which the segment placing machine 200 has to withstand while placing of the segments 41, due to the weight of the robot arm 203 (for example, 1.8 - 2 t) and additionally to the weight of the segment supported and handled thereby (typically, 2 - 2.5 t), the tubular frame 201 comprises a plurality of anchoring devices 206 for temporary anchoring of the segment placing machine 200 to the walls, in particular to the final lining 4, of the tunnel 1. In this way it is possible to effectively ensure the stability of the segment placing machine 200 during the placing operations, which is an essential requirement in order for the latter to be

carried out accurately and without problems.

The anchoring devices 206 are configured as anchoring devices radially extensible towards the outside of the tubular frame 201, and can consist, for example, of hydraulic thrust jacks. Preferably, the anchoring devices are distributed on the tubular frame 201 so as to form at least one ring, preferably at least at the guide rail 205.

The segment placing machine 200 preferably comprises a plurality of motorized wheels 207, associated with the tubular frame 201, by means of which it can be displaced inside the tunnel 1, on the previously laid final lining 4. The wheels 207 preferably have independent and swiveling rotation axes. The wheels 207 are arranged at least at the base of the segment placing machine 200, in particular according to at least two rows extending longitudinally along the tubular frame 201. Further wheels 207 can be located, individually or in rows, also in other positions of the tubular frame 201, for example in a vault region thereof.

Figs 7 and 7a show in particular the segment placing machine 200 in a rest configuration, in which it is not placing segments 41. In this configuration the robot arm 203 is preferably arranged extended substantially parallel to the tubular frame 201 along the inner side thereof, preferably in a vault region thereof, so that it does not constitute an obstacle to the passage of operating machines, vehicles, or equipment through the tubular frame 201. The bridge 204, on the other hand, is in a use position, at the base of the tubular frame 201, to create a motorable connection between the motorable plane 202 of the tubular frame 201 and a motorable surface, in particular the temporary work floor 3 (not shown here), of the tunnel 1, located downstream of the segment placing machine 200.

Fig. 8 and 8a, on the other hand, show the segment placing machine 200 in a generic work configuration for placing the segments 41. In this configuration the robot arm 203 projects at least partly longitudinally and/or transversally from the tubular frame 201, in a position along the circular guide rail 205 variable according to the placing positions of the segments 41. The bridge 204 is instead located along the circular guide rail 205 in a not-in-use position, variable according to the position of the robot arm 203.

Referring again to Figs 1, 1a, 1b, the assembly of the at least one further full ring 42' of segments 41 to advance the final lining front FLF carried out by means of the segment placing machine 200 described above preferably comprises repeatedly moving the robot arm 203 along a circular path, defined by the guide rail 205, between a segment taking position and a plurality of segment placing positions distributed along said circular path.

The segments 41 necessary for building the further full ring 42' of segments 41 can be conveniently provided to the segment placing machine 200 in batches, for example on a suitable

self-propelled segment carrier wagon 300, preferably equipped to carry simultaneously all the segments 41 necessary for creating a full ring 42.

To move the segment carrier wagon 300 from the area of the tunnel 1 already provided with the carriageway plane 5, upstream of the segment placing machine 200, to the segment placing machine 200, a self-propelled service platform 400 is preferably used, which can be moved back and forth between the carriageway plane front CF and the trailing end of the segment placing machine 200. The self-propelled service platform 400 moves on the final lining 4 of the tunnel 1 similarly to the segment placing machine 200 and, for said purpose, is preferably provided with a plurality of motorized wheels, with swiveling and independent rotation axis. In general, the self-propelled service platform 400 can be advantageously used for transferring all the operating machines, vehicles, or equipment used for constructing the tunnel 1 according to the method of the invention within the section of tunnel 1 between the trailing end of the segment placing machine 200 and the carriageway plane front CF, even though this will not be explicitly mentioned below.

While the segment placing machine 200 is placing the segments 41, other operating machines, vehicles, or equipment cannot pass through it and therefore reach the work region and the excavation front EF or move away therefrom. In the method according to the invention, however, the temporary blocking of the section of tunnel 1 where the segments 41 are being placed during the final lining front FLF advance step no longer represents an obstacle to carry out other steps of the method, since said blocking occurs during the excavation step to advance the excavation front EF, which step, on the one hand, can proceed and be completed without the need for a simultaneous and repeated passage of operating machines, vehicles, or equipment from/to the work region and the excavation front EF, and, on the other hand, assuming a same advance length, has a longer duration, typically 1 to 10 times longer, compared to the duration of the step of advancing the final lining front FLF by placing segments 41, so that it masks the latter completely in terms of time.

Once the step of advancing the final lining front FLF has been completed, the segment placing machine 200 can remain in the same position in the tunnel 1, but is set to its rest configuration, already described above with reference to Fig. 8 and 8a. In this way, the passage of operating machines, vehicles, or equipment from/to the work region of the tunnel 1 is again possible.

Once the step of advancing the excavation front EF has also been completed, after moving away from the work region, if necessary, operating machines, such as the excavating machine 100, used for the excavation, the resulting excavated material is removed, as shown in Fig. 2 and 2a. For said operation one or more dump trucks 500 are used, which can be loaded by means of

one or more loading shovels 600. The dump trucks 500 and the loading shovels 600 move from/to the work region of the tunnel 1 through the segment placing machine 200, which remained in its position in the tunnel 1.

After the work region of the tunnel 1 has been freed of the excavated material, the primary lining front PLF is advanced, by applying the primary lining 2 onto the walls, in particular the radial walls, exposed by the excavation carried out in the previous step of advancing the excavation front EF.

As shown in Figs 3, 3a, 4, 4a, application of the primary lining 2 comprises the laying of at least one further rib 21'. The ribs 21 used in the method according to the invention can conveniently be of the type comprising articulated sections, as described for example in patent application WO 2015/186029 A2, the content of which is fully incorporated herein by reference. In this case, the ribs 21 are preassembled outside the tunnel 1, transported inside the tunnel 1 in a folded configuration (Fig. 3 and 3a) to the respective laying point, in particular the previously excavated advance length of the excavation front EF, and finally unfolded for laying at the laying point. The transport and/or placement of the ribs 21 can in this case be carried out with the aid of a general-purpose excavating machine 700, or also by means of a dedicated machine, in particular provided with two or more movable arms (not shown). However, the use of conventional ribs 21, formed of separate sections which are transported inside the tunnel 1 in a disassembled condition and then assembled on site at the time of installation, is not excluded.

The creation of the primary lining 2 preferably also comprises the application of a layer of shotcrete on the walls, in particular the radial walls, exposed by the excavation and on the intrados of the at least one further rib 21' previously laid (see Fig. 5). Said operation is carried out in a known manner with the aid of at least one pumping machine 800 for application of shotcrete, supplied by a concrete mixer 900. Also in this case, the pumping machine 800 and concrete mixers 900 move from/to the work region of the tunnel 1 through the segment placing machine 200, which remained in its position in the tunnel 1.

Once creation of the new length of primary lining 2 has been completed, the final lining 4 can be completed at the advance length of the final lining front FLF. In particular, hydraulic mortar can be pumped into the gap between the further ring 42' of segments 41 placed and the underlying primary lining 2, by means of a suitable pumping machine (not shown), of known type.

Once creation of the new portion of final lining 4 has been completed, the segment placing machine 200 can move forward, on the final lining 4 previously applied, by a length

substantially equal to the advance length of the final lining front FLF, so that its leading end is again at the (new) final lining front FLF.

At this point a new advance cycle comprising the steps previously described can begin.

In addition to the steps described above, the method of the invention for constructing natural tunnels can optionally comprise, in all or only some of the advance cycles necessary for constructing the tunnel 1, further steps ancillary to the implementation of the steps described above, in a manner known to those skilled in the art.

Fig. 6 shows, for example, an optional step of consolidating the excavation front EF, which may be required before advancing the excavation front EF in grounds without or with low cohesion. In particular, again by way of example, Fig. 6 refers to a case of consolidation of the excavation front EF by means of fiberglass reinforcements, which are created by making in the excavation front EF a series of perforations by means of a drilling machine 1000, inserting fiberglass tie rods into said perforations and then pressure-injecting concrete.

From Fig. 6 it also appears that, once an operating machine has reached the work region passing through the segment placing machine 200, the latter can be temporarily moved away from the final lining front FLF, namely moved in the opposite direction to the advance direction A of the excavation, to ensure, if necessary, further operating space for the operating machine in the work region.

The present invention, further to an “industrialization” of the step of building the final lining, i.e., of advancing the corresponding front, thus speeds up the times for constructing natural tunnels by means of excavation with “traditional” technique and reduces the influence of the experience and skill of the site workforce on construction times of the structure and on the end quality thereof.

CLAIMS

1. Method for constructing natural tunnels, wherein a tunnel (1) under construction comprises an excavation front (EF), a final lining front (FLF) upstream of the excavation front (EF) in an excavation advance direction (A), and a work region located between the excavation front (EF) and the final lining front (FLF), comprising the steps:
 - a) advancing the excavation front (EF) by a predetermined advance length by means of point excavation with one or more self-propelled excavating machines (100);
 - b) removing excavated material from the work region by means of one or more dump trucks (500);
 - c) applying a primary lining (2) onto walls exposed by the excavation at the advance length of the excavation front (EF);
 - d) advancing the final lining front (FLF) by a predetermined advance length by creating a final lining (4) onto the primary lining (2) applied at the same advance length in a previous advance cycle;
 - e) repeating steps a) to d) until the tunnel (1) is completed,wherein step d) of advancing the final lining front (FLF) comprises assembling at least one full ring (42') of prefabricated segments (41) and is carried out simultaneously with step a) of advancing the excavation front (EF),
wherein step d) of advancing the final lining front (FLF) is carried out by means of a segment placing machine (200) having a tubular frame (201), and
wherein the passage or displacement of operating machines (100, 600, 700, 800), vehicles (500, 900), or equipment from/to said work region during step b) of removing excavated material and step c) of applying the primary lining (2) takes place through the tubular frame (201) of the segment placing machine (200).
2. Method according to claim 1, wherein assembling the at least one full ring (42') of segments (41) by means of the segment placing machine (200) comprises repeatedly moving a robot arm (203) along a circular path between a segment taking position and a plurality of segment placing positions distributed along said circular path.
3. Method according to any one of the previous claims, wherein the excavation front (EF) and the final lining front (FLF) are respectively advanced substantially by a same advance length.
4. Method according to any one of the previous claims, further comprising, after step d) of advancing the final lining front (FLF), advancing the segment placing machine (200) on the previously created final lining (4), preferably by a length equal to the advance length

of the final lining front (FLF).

5. Method according to any one of the previous claims, further comprising moving a self-propelled service platform (400) for transferring operating machines (100, 600, 700, 800, 1000), vehicles (300, 500, 900) or equipment in a tunnel portion between a rear end of the segment placing machine (200) and a carriageway plane front (CF) of the tunnel (1) located upstream of the segment placing machine (200).
6. Self-propelled segment placing machine (200) for placing prefabricated segments (41) of a final lining (4) of a natural tunnel (1), comprising:
 - a longitudinally extended tubular frame (201) having transverse dimensions which allow operating machines (100, 600, 700, 800, 1000), vehicles (500, 900), or equipment used during the construction of the tunnel (1) to pass or be displaced through the tubular frame (201), and
 - segment handling means (203) associated with the tubular frame (201) and displaceable relative to the tubular frame (201) between a segment taking position and a plurality of segment placing positions for assembling full rings (42, 42') of segments (41) at walls of the tunnel (1),wherein in a rest configuration of the segment placing machine (200) the tubular frame (201) is freely practicable by said operating machines (100, 600, 700, 800, 1000), vehicles (500, 900), or equipment, and
wherein the tubular frame (201) comprises a plurality of anchoring devices (206) which can be radially extended therefrom for temporarily anchoring the segment placing machine (200) to walls of the tunnel (1).
7. Segment placing machine (200) according to claim 6, wherein the segment handling means (203) comprise a robot arm (203) displaceable along a circular guide rail (205) integral with the tubular frame (201) and arranged perpendicularly to a direction of longitudinal extension of the tubular frame (201).
8. Segment placing machine (200) according to claim 7, wherein in a rest configuration of the segment placing machine (200) the robot arm (203) is extended substantially parallel to the tubular frame (201) along an inner side thereof, preferably in a vault region thereof.
9. Segment placing machine (200) according to claim 7 or 8, wherein in a work configuration of the segment placing machine (200) the robot arm (203) projects at least partially longitudinally and/or transversally from the tubular frame (201).
10. Segment placing machine (200) according to any one of claims 6 to 9, further comprising at least one movable bridge (204) for establishing a motorable connection between the

segment placing machine (200) and a work region of the tunnel (1).

11. Segment placing machine (200) according to claim 10 when dependent on claim 7, wherein the movable bridge (204) is displaceable along the circular guide rail (205) of the robot arm (203), in coordination with the robot arm (203).
12. Segment placing machine (200) according to any one of claims 6 to 11, wherein the anchoring devices (206) are located so as to form at least one ring around the tubular frame (201).