DESCRIPTION

CONSTRUCTION METHOD OF TUNNEL SUPPORTING STRUCTURE

TECHNICAL FIELD

[0001] The present invention relates to a construction method of a tunnel supporting structure.

BACKGROUND ART

[0002] Conventionally, when a mountain tunnel is to be excavated by an NATM method, etc., the ground exposed by the excavation of the tunnel is supported by a supporting structure to achieve stabilization of the ground. However, there is a risk in that a large pressure is applied to the supporting structure in a high overburden tunnel or a swelling ground.

[0003] JP2018-40147A discloses a tunnel supporting structure that is formed by disposing yielding members formed of cementitious hardening bodies containing porous materials in slits formed in parts of the supporting structure. The tunnel supporting structure absorbs deformation of the ground with the yielding members.

SUMMARY OF INVENTION

[0004] However, because the yielding members are heavy objects, an operation of disposing the yielding members in the slits of the supporting structure takes time and labor. Therefore, a construction method of the tunnel supporting structure disclosed in JP2018-40147A involves a problem in that an operation efficiency for the construction of the tunnel supporting structure is poor.

[0005] An object of the present invention is to improve an operation efficiency for a construction of a tunnel supporting structure.

[0006] According to one aspect of the present invention, a construction method of a tunnel supporting structure provided along an inner wall surface of a tunnel, includes: a framed-structure-unit arranging step for arranging a framed structure unit at a predetermined position; a base supporting structure forming step for forming a base supporting structure along the inner wall surface of the tunnel; and an yielding-section forming step for forming an yielding section by spraying a concrete material to the framed structure unit arranged at the predetermined position, wherein the predetermined position is a position at which the framed structure unit is arranged so as to cross the base supporting structure in a tunnel radial direction.

BRIEF DESCRIPTION OF DRAWINGS

[0007]

FIG. 1 is a longitudinal sectional view of a tunnel and shows a cross-section taken along line I-I in FIGs. 2A and 2B.

FIG. 2A is a lateral sectional view of the tunnel and shows a cross-section taken along line IIA-IIA in FIG. 1.

FIG. 2B is a lateral sectional view of the tunnel and shows a cross-section taken along line IIB-IIB in FIG. 1.

FIG. 3A is a diagram showing a framed structure unit formed of base framed structure units having a hexahedral shape (a rectangular parallelepiped shape).

FIG. 3B is a diagram showing the framed structure unit formed of the base framed structure units having a tetrahedral shape.

FIG. 4 is a diagram for explaining an example of procedures for a construction method of a tunnel supporting structure according to this embodiment.

FIG. 5 is a diagram showing a stress-strain characteristic of an yielding section according to this embodiment.

FIG. 6 is a diagram for explaining a supporting function of the tunnel supporting structure according to this embodiment.

FIG. 7 is a diagram for explaining an example of procedures of the construction method of the tunnel supporting structure according to a first modification of this embodiment.

FIG. 8 is a diagram for explaining procedures for forming a first supporting structure body according to a fourth modification of this embodiment.

DESCRIPTION OF EMBODIMENTS

[0008] A construction method of a tunnel supporting structure according to an embodiment of the present invention will be described with reference to the drawings.

[0009] A configuration of a tunnel supporting structure 100 will be described first with reference to FIGs. 1, 2A, and 2B. As shown in FIGs. 1, 2A, and 2B, the tunnel supporting structure 100 is installed along an inner wall surface of a tunnel (excavation pit) that is excavated in a ground 1. The tunnel supporting structure 100 includes steel supporting structures 110 each formed of a steel material and concrete supporting structures 120 each formed of a concrete material. The steel supporting structures 110 are first base supporting structures that are arranged in the tunnel axial direction at

predetermined intervals. In addition, the concrete supporting structures 120 are second base supporting structures formed by spraying the concrete material to the inner wall surface of the tunnel (the excavation pit) and are respectively formed between the steel supporting structures 110 disposed along the tunnel axial direction.

[0010] The tunnel supporting structure 100 further includes first yielding sections 131 each of which is formed so as to cross the steel supporting structure 110 in the tunnel radial direction and second yielding sections 132 each of which is formed so as to cross the concrete supporting structure 120 in the tunnel radial direction.

[0011] The steel supporting structure 110 is formed by using an H beam, for example. The steel supporting structure 110 has a pair of straight sections 111 extending upwards from the bottom surface of the tunnel in a straight line and a curved section 112 that has been subjected to a bending processing so as to have an arc shape. The curved section 112 may be a single member or may be formed by connecting a plurality of members.

[0012] The curved section 112 is disposed such that predetermined gaps are respectively formed between both end portions thereof and upper end portions of the pair of straight sections 111. With such a configuration, slits (predetermined spaces) 119 are respectively formed between the end portions of the curved section 112 and the upper end portions of the straight sections 111. A framed structure unit 135, which will be described later, is arranged in each of the slits 119, and the first yielding section 131 is formed by spraying the concrete material to the framed structure unit 135. By arranging the straight sections 111, the first yielding sections 131, and the curved section 112 in a continuous manner in the tunnel circumferential direction, an

arch-shaped first supporting structure body 101 mainly formed of the steel material is formed.

[0013] The concrete supporting structure 120 may have a primary sprayed concrete 121 that is formed by spraying the concrete material to the inner wall surface of the tunnel and a secondary sprayed concrete 122 that is formed by spraying the concrete material to the primary sprayed concrete 121. The sprayed concrete is formed such that the final thickness thereof falls within a range between 0.1 m to 0.25 m.

[0014] The secondary sprayed concrete 122 has a pair of straight sections 122a extending upwards from the bottom surface of the tunnel in a straight line and an arc-shaped curved section 122b.

[0015] The curved section 122b is formed such that predetermined gaps are respectively formed between both end portions thereof and upper end portions of the pair of straight sections 122a. With such a configuration, slits (predetermined spaces) 129 are respectively formed between the end portions of the curved section 122b and the upper end portions of the straight sections 122a. The framed structure units 135, which will be described later, are arranged in each of the slits 129, and the second yielding sections 132 are formed by spraying the concrete material to the framed structure units 135. By forming the straight sections 122a, the second yielding sections 132, and the curved section 122b in a continuous manner in the tunnel circumferential direction, an arch shaped second supporting structure body 102 mainly formed of the concrete material is formed.

[0016] In this embodiment, because the first yielding sections 131 and the second yielding sections 132 have the similar configuration, both sections will be described below by collectively calling them as an yielding section 130.

The yielding section 130 is formed by spraying the concrete material to the framed structure unit 135 formed of a synthetic resin material and by allowing the sprayed concrete material to be hardened. The yielding section 130 is capable of undergoing deformation in a greater degree relative to the steel supporting structure 110 and the concrete supporting structure 120 when a predetermined load is applied, and has a predetermined load-carrying capacity after the deformation is ceased. Therefore, it is preferable that the material forming the framed structure unit 135 has a lower strength against the load compared with the steel material and the concrete material and be deformed more easily.

[0017] The yielding section 130 is formed to have, for example, a rectangular parallelepiped shape having the width (the length in the tunnel axial direction) of 0.1 m to 0.3 m, the thickness (the length in the tunnel radial direction) of 0.1 m to 0.3 m, and the height of 0.2 to 0.5 m. The first yielding section 131 is formed in the slit 119 of the steel supporting structure 110. Thus, the width of the first yielding section 131 is set so as to be substantially the same as the width of the steel supporting structure 110 or so as to be slightly longer than the width of the steel supporting structure 110. A plurality of second yielding sections 132 are disposed along the tunnel axial direction between the steel supporting structures 110. Thus, the width of the second yielding section 132 is set such that a predetermined number (five in this embodiment) of second yielding sections 132 can be installed in a continuous manner in the tunnel axial direction between the steel supporting structures 110.

[0018] The framed structure unit 135 configuring the yielding section 130 will be described with reference to FIGs. 3A and 3B. As shown in FIGs. 3A

and 3B, the framed structure unit 135 (135A, 135B) is, for example, formed to have the rectangular parallelepiped shape having the width (the length in the tunnel axial direction) of 0.1 m to 0.3 m, the thickness (the length in the tunnel radial direction) of 0.1 m to 0.3 m, and the height of 0.2 to 0.5 m. The width, the thickness, and the height of the framed structure unit 135 are not limited to values falling within the above-described ranges; however, they are set such that the weight of the framed structure unit 135 enables it to be carried by one or two worker(s). Because the framed structure unit 135 is formed of a resin material and weight reduction can be achieved with ease, a degree of freedom in setting of the width, the thickness, and the height of the framed structure unit 135 is high.

[0019] The framed structure unit 135 (135A, 135B) is formed by connecting a plurality of base framed structure units 134 (134A, 134B) each contains a plurality of rod-shaped elements 133. Although the framed structure unit 135 may take several types of configurations, two types of the framed structure unit 135 (135A, 135B) will be mainly described below.

[0020] The base framed structure units 134A forming the framed structure unit 135A shown in FIG. 3A contain a plurality of straight-rod-shaped elements 133 and are formed to have a hexahedral shape (the rectangular parallelepiped shape). The base framed structure units 134B forming the framed structure unit 135B shown in FIG. 3B contain the plurality of straight-rod-shaped elements 133 and are formed to have a tetrahedral shape (a triangular pyramid shape).

[0021] As shown in FIGs. 3A and 3B, the base framed structure unit 134 (134A, 134B) has an internal space into which the concrete material can be filled. In other words, the space formed in the base framed structure unit 134

is set to have a size that allows aggregates contained in the concrete material to be sprayed to move therethrough.

[0022] The framed structure unit 135 is formed such that the respective internal spaces of the base framed structure units 134 are in communication with each other. Therefore, when the concrete material is sprayed from the outside of the framed structure unit 135, the concrete material spreads throughout the internal spaces in the framed structure unit 135. The framed structure unit 135 is formed by using, for example, a 3D printer (a three-dimensional shaping device).

[0023] The shape of the framed structure unit 135 is not limited to the examples shown in FIGs. 3A and 3B, and various shapes formed by connecting the plurality of rod-shaped elements 133 are possible. In addition, the base framed structure unit 134 forming the framed structure unit 135 is also not limited to one type of shape. For example, the framed structure unit 135 may be formed by combining the base framed structure units 134A shown in FIG. 3A and the base framed structure units 134B shown in FIG. 3B. Therefore, the deformability of the yielding section 130 formed by filling the concrete material into the framed structure unit 135 can be adjusted by adjusting the shapes, the number, the arrangement, and so forth of the base framed structure units 134 forming the framed structure unit 135.

[0024] The construction method of the tunnel supporting structure 100 will be described with reference to FIG. 4. FIG. 4 is a diagram for explaining an example of procedures of the construction method of the tunnel supporting structure 100. The construction method of the tunnel supporting structure 100 includes: an excavating step S110; a first spraying step S115; a steel supporting structure forming step S120; a first framed-structure-unit

arranging step S125; a second spraying step S140; a sprayed concrete slit forming step S145; a second framed-structure-unit arranging step S150; and a second-yielding-section forming step S155, and respective steps S110 to S155 are repeated in this order at every predetermined length. In other words, the tunnel supporting structure 100 is formed by repeating a construction cycle including the steps S110 to S155. In the following, an operation after at least one first supporting structure body 101 have already been formed will be described.

[0025] <Excavating Step>

In the excavating step S110, a blasting excavation, in which the excavation is performed by crushing the ground 1 by using an explosive, is performed and rocks and sands formed by the excavation are transported to the outside of the tunnel. In the excavating step S110, a mechanical excavation, in which the excavation of the ground 1 is performed by using a machinery, may also be performed. In the excavating step S110, the ground 1 is excavated only for the predetermined length (for example, 1 to 3 m). In the above, the predetermined length means a length from a tunnel end surface 1a in the vicinity of the first supporting structure body 101 that has already been constructed before performing the excavation operation to a position where a next first supporting structure body 101 can be formed after the excavation. In other words, the predetermined length means a length corresponding to an installation interval distance between the first supporting structure bodies 101 (center-to-center distance between two adjacent first supporting structure bodies 101). In the excavating step S110, when the excavation of the predetermined length is completed, the process proceeds to the first spraying step S115.

[0026] <First Spraying Step>

In the first spraying step S115, the concrete material is sprayed by a concrete material spraying device (not shown) to the inner wall surface of the tunnel (the excavation pit) of the predetermined length formed in the ground 1. As the sprayed concrete material is hardened, the primary sprayed concrete 121 is formed. The primary sprayed concrete 121 is formed from a ceiling surface of the tunnel to both side surfaces and is also formed on the tunnel end surface 1a. A mortar may be employed as the concrete material. In a spraying operation of the concrete material, in order to facilitate hardening and achievement of higher strength of the sprayed concrete material, an accelerator and a fiber reinforcement may also be used. When the primary sprayed concrete 121 is formed in the first spraying step S115, the process proceeds to the steel supporting structure forming step S120.

[0027] <Steel Supporting Structure Forming Step>

In the steel supporting structure forming step S120, the steel supporting structure 110 is formed so as to extend along the inner wall surface of the tunnel in the vicinity of the tunnel end surface 1a. In other words, the steel supporting structure forming step S120 is a first-base-supporting-structure forming step for forming the first base supporting structure (the steel supporting structure 110). In the steel supporting structure forming step S120, after the pair of straight sections 111 are installed, the curved section 112 is held by a supporting-structure assembling device (not shown). Then, the slits 119 are formed between the end portions of the curved section 112 and the upper end portions of the straight sections 111. In other words, the steel supporting structure forming step S120 includes a steel-supporting-structure slit forming step for forming the slits 119 crossing

the steel supporting structure 110 in the tunnel radial direction. When the slits 119 are formed between the pair of straight sections 111 and the curved section 112 in the steel supporting structure forming step S120, the process proceeds to the first framed-structure-unit arranging step S125.

[0028] <First Framed-Structure-Unit Arranging Step>

In the first framed-structure-unit arranging step S125, the framed structure units 135 are respectively arranged in the slits 119 of the steel supporting structure 110 formed by the steel supporting structure forming step S120. When the arrangement of the framed structure units 135 in the slits 119 is completed in the first framed-structure-unit arranging step S125, the process proceeds to the second spraying step S140.

[0029] <Second Spraying Step>

In the second spraying step S140, the concrete material is sprayed over the primary sprayed concrete 121 between the first supporting structure body 101 that has already been constructed in the previous construction cycle and the new steel supporting structure 110 formed by the steel supporting structure forming step S120 in the current construction cycle. In addition, the concrete material is sprayed to the framed structure units 135 respectively arranged in the slits 119 of the steel supporting structure 110.

[0030] As the sprayed concrete material is hardened, the secondary sprayed concrete 122 is formed so as to extend along the inner wall surface of the tunnel, and at the same time, the first yielding sections 131 are respectively formed in the slits 119 of the steel supporting structure 110. The secondary sprayed concrete 122 is formed so as to be substantially flush with or so as to be slightly recessed with respect to the steel supporting structure 110. By respectively forming the first yielding sections 131 in the slits 119 of

the steel supporting structure 110, a new first supporting structure body 101 is formed. As described above, the second spraying step S140 includes a first-yielding-section forming step for forming the first yielding sections 131 by spraying the concrete material to the framed structure units 135 respectively arranged in the slits 119 of the steel supporting structure 110. When the secondary sprayed concrete 122 and the first supporting structure body 101 are formed in the second spraying step S140, the process proceeds to the sprayed concrete slit forming step S145.

[0031] <Sprayed Concrete Slit Forming Step>

In the sprayed concrete slit forming step S145, the slits 129 crossing the secondary sprayed concrete 122 formed by the second spraying step S140 in the tunnel radial direction are formed. The slits 129 are formed so as to be adjacent in the tunnel axial direction to the respective slits 119 of the steel supporting structure 110. With such a configuration, the concrete supporting structure 120 having the slits 129 is formed.

[0032] The slit 129 may be formed by cutting the secondary sprayed concrete 122 by using a cutting machine (not shown) after the secondary sprayed concrete 122 is formed, or the slit 129 may be formed by forming the secondary sprayed concrete 122 after arranging a shuttering (not shown) having the rectangular parallelepiped shape at a position corresponding to the slit 129, and by removing the shuttering subsequently.

[0033] As described above, by performing the first spraying step S115, the second spraying step S140, and the sprayed concrete slit forming step S145, the concrete supporting structure 120 is formed so as to extend along the inner wall surface of the tunnel. In other words, a second-base-supporting-structure forming step for forming the second base

supporting structure (the concrete supporting structure 120) includes the first spraying step S115, the second spraying step S140, and the sprayed concrete slit forming step S145. When the slits 129 are formed in the sprayed concrete slit forming step S145, the process proceeds to a second framed-structure-unit arranging step S150.

[0034] <Second Framed-Structure-Unit Arranging Step>

In the second framed-structure-unit arranging step S150, the framed structure units 135 are respectively arranged in the slits 129 of the secondary sprayed concrete 122 formed by the sprayed concrete slit forming step S145. In this embodiment, five framed structure units 135 are arranged for a single slit 129. When the arrangement of the framed structure units 135 in the slits 129 is completed in the second framed-structure-unit arranging step S150, the process proceeds to a second-yielding-section forming step S155.

[0035] <Second-Yielding-Section Forming Step>

In the second-yielding-section forming step S155, by spraying the concrete material to the plurality of framed structure units 135 arranged in the slits 129 of the secondary sprayed concrete 122, the plurality of second yielding sections 132 are formed. By forming the plurality of second yielding sections 132 in each of the slits 129 of the secondary sprayed concrete 122, the second supporting structure body 102 is formed.

[0036] In this step S155, although a description is given of an example in which the plurality of second yielding sections 132 are formed by spraying the concrete material to the plurality of framed structure units 135 arranged in the single slit 129, the present invention is not limited thereto. The plurality of framed structure units 135 may be connected by the concrete material. In other words, in this step S155, the spraying operation of the concrete material

may be performed so as to form the single second yielding sections 132 each one of which has the plurality of framed structure units 135 in the single slit 129.

[0037] After the second supporting structure body 102 is formed, a plurality of rock bolts (not shown) are installed. The rock bolts are installed as described below, for example. Holes extending from an inner circumference wall of the secondary sprayed concrete 122 in the radial direction are first formed, and a filler is injected into these holes, and the rock bolts (not shown) are respectively inserted into the holes. A mortar is employed as the filler, for example. The rock bolts may be inserted into the holes after the filler has been injected into the holes, or the rock bolts may be inserted into the holes before the filler is injected into the holes. In addition, the installation operation of the rock bolts may be performed before the formation of the second supporting structure body 102. For example, the installation operation of the rock bolts may be performed together with the installation operation of the steel supporting structure 110. When the operations for the second-yielding-section forming step S155 are finished, the process returns to the excavating step S110, and the excavation is performed in the tunnel axial direction for the predetermined length.

[0038] As described above, by repeatedly performing the construction cycle consisting of the steps S110 to S155 for every predetermined length, the tunnel supporting structure 100 is formed along the tunnel axial direction (see FIG. 1). After a predetermined construction cycle is performed repeatedly, a lining concrete having a predetermined thickness (not shown) is formed on an inner side of the steel supporting structure 110 and the concrete supporting structure 120 forming the tunnel supporting structure 100.[0039] A case in

which the yielding sections 130 are formed in a factory, etc. in advance, the yielding sections 130 are transported to the working site, and the yielding sections 130 are installed in the slits 119, 129 will be considered. Because the yielding sections 130 having the concrete material are heavy objects, the transporting operation of the yielding sections 130 and the arranging operation of the yielding sections 130 to the slits 119, 129 take time and labor, and there is a problem in that an operation efficiency for the construction of the tunnel supporting structure 100 is poor.

[0040] In contrast, the construction method of the tunnel supporting structure 100 according to this embodiment includes the framed-structure-unit arranging step (S125, S150) for arranging the framed structure units 135, which are lighter than the yielding sections 130, which are completed objects, at the predetermined positions and a yielding-section forming step (S140, S155) for forming the yielding sections 130 in the slits 119, 129 by spraying the concrete material to the framed structure units 135 that have been arranged at the predetermined positions. In the above, the predetermined position means the position at which the framed structure unit 135 is arranged so as to cross the base supporting structure (the steel supporting structure 110 and the concrete supporting structure 120) in the tunnel radial direction. In other words, in this embodiment, the predetermined position means the position within a predetermined space (the slit 119, 129) that is formed so as to cross the base supporting structure (the steel supporting structure 110 and the concrete supporting structure 120) in the tunnel radial direction.

[0041] As described above, in this embodiment, because the light-weighted framed structure units 135 are transported from the factory, etc. to the

working site and the light-weighted framed structure units 135 are arranged in the slits 119, 129, it is possible to improve the operation efficiency for the transporting operation and the arranging operation. Because the yielding sections 130 can be formed by utilizing the concrete material to be applied to the inner wall surface of the tunnel, there is no need to transport a special-purpose concrete material for forming the yielding sections 130. Therefore, according to this embodiment, the operation efficiency for the construction of the tunnel supporting structure 100 is improved.

[0042] FIG. 5 is a diagram showing a stress-strain characteristic of the yielding section 130 according to this embodiment. The horizontal axis indicates the strain and the vertical axis indicates the stress. In FIG. 5, the stress-strain characteristic of the yielding section 130 according to this embodiment is indicated by a solid line, and the stress-strain characteristic of a sprayed concrete block without the framed structure unit 135 is indicated by a one-dot chain line.

[0043] In a high overburden tunnel and a swelling ground, a large pressure may act on the tunnel supporting structure 100 inwardly of the tunnel. As shown in FIG. 5, the sprayed concrete block without the framed structure unit 135 is deformed as a predetermined pressure acts thereon. The strain is increased as the stress acting on the sprayed concrete block is increased, and a crack is caused at the strain εu at which the stress is maximized.

[0044] Similarly, also in the yielding section 130 according to this embodiment, although the strain is increased as the stress acting on the yielding section 130 is increased, the gradient of the curve is smaller compared with that for the sprayed concrete block. In other words, the yielding section 130 has a characteristic such that the yielding section 130 can undergo the

deformation in a greater degree relative to the sprayed concrete block without the framed structure unit 135. For example, the strain ε1 of the yielding section 130 at the predetermined stress σ0 is larger than the strain ε0 of the sprayed concrete block at a predetermined stress σ0 (ε1>ε0). Thus, as a large pressure acts on the tunnel supporting structure 100, the yielding section 130 is largely compressed in the tunnel circumferential direction (the up and down direction in the figure). Therefore, the tunnel supporting structure 100 will be deformed by following the deformation of the ground 1.

[0045] As described above, in this embodiment, the yielding section 130 capable of being compressed by following the deformation of the ground 1 is installed so as to cross the base supporting structure (the steel supporting structure 110 and the concrete supporting structure 120) in the tunnel radial direction. With such a configuration, because a certain degree of deformation of the ground 1 is allowed, the pressure in the ground 1 (ground pressure) is relieved. After the certain degree of deformation has been allowed, the tunnel supporting structure 100 then supports the ground 1 rigidly.

[0046] Operational advantages achieved by installing the yielding section 130 according to this embodiment will be described, in contrast to a comparative example of this embodiment. In the comparative example of this embodiment, the above-described yielding sections 130 and the slits 119, 129 are not formed. In other words, a first supporting structure body according to the comparative example of this embodiment is formed of a steel supporting structure without the slit 119 and a second supporting structure is formed of a concrete supporting structure without the slit 129.

[0047] FIG. 6 is a diagram for explaining a supporting function of the tunnel supporting structure 100 according to this embodiment. FIG. 6 shows

a support characteristic N1 of the tunnel supporting structure 100 according to this embodiment, a support characteristic N0 of a tunnel supporting structure according to the comparative example of this embodiment, and ground characteristics GL, GH of the ground 1.

[0048] The ground 1 with the ground characteristic GH has higher overburden height relative to the ground 1 with the ground characteristic GL. As shown in the figure, the ground 1 has a characteristic in which the higher the overburden height is, the larger the ground pressure becomes, and the larger the displacement becomes, the smaller the ground pressure becomes. In addition, as shown in the figure, in the tunnel supporting structure, the larger the displacement becomes, the higher the stress acting on the tunnel supporting structure becomes.

[0049] The supported state of the ground 1 with the ground characteristic GL by the tunnel supporting structure 100 according to this embodiment is indicated by an intersection point PL1 between the curve representing the support characteristic N1 and the curve representing the ground characteristic GL. The supported state of the ground 1 with the ground characteristic GH by the tunnel supporting structure 100 according to this embodiment is indicated by an intersection point PH1 between the curve representing the support characteristic N1 and the curve representing the ground characteristic GH. the supported state of the ground 1 with the ground characteristic GL by the tunnel supporting structure according to the comparative example of this embodiment is indicated by an intersection point PL0 between the curve representing the support characteristic N0 and the curve representing the ground characteristic GL.

[0050] As can be seen from the intersection points PL0, PL1, because the

yielding section 130 is not included, for the ground 1 with the ground characteristic GL, the tunnel supporting structure according to the comparative example of this embodiment can suppress the deformation of the ground 1 and can support the ground 1 in a state in which the ground pressure is higher than that in this embodiment. However, there is no intersection point between the curve representing the support characteristic N0 and the curve representing the ground characteristic GH. This indicates that the tunnel supporting structure according to the comparative example of this embodiment is unable to withstand against the ground pressure of the ground 1 with the ground characteristic GH. In other words, it is not possible to employ the tunnel supporting structure according to the comparative example of this embodiment for the ground 1 with the ground characteristic GH.

[0051] In contrast, as can be seen from the intersection points PL0, PL1, the tunnel supporting structure 100 according to this embodiment can effectively lower the ground pressure by the compression of the yielding section 130 and can support the ground 1 that has been shifted to a state in which the ground pressure is lower than that in the comparative example. Furthermore, because the allowable deformation of the ground 1 in this embodiment is larger relative to the comparative example, it is possible to support the ground 1 with the ground characteristic GH in which the overburden height is high (see the intersection point PH1). Therefore, the tunnel supporting structure 100 according to this embodiment can cope with a wide range of the ground characteristic.

[0052] According to the above-described embodiment, following operational advantages are afforded.

[0053] In the construction method of the tunnel supporting structure 100 according to this embodiment, the yielding section 130 is formed by arranging the light-weighted framed structure unit 135 formed of the resin material to the predetermined position in the base supporting structure (the steel supporting structure 110 and the concrete supporting structure 120) and by spraying the concrete material to the framed structure unit 135. In the above, the predetermined position means the position at which the framed structure unit 135 is arranged so as to cross the base supporting structure (the steel supporting structure 110 and the concrete supporting structure 120) in the tunnel radial direction. In other words, in this embodiment, the worker is not required to lift up the yielding section 130 that is the heavy object and to arrange it to the predetermined position. By arranging the light-weighted framed structure unit 135 to the predetermined position and by spraying the concrete material, the worker can form the yielding section 130 at the position where the framed structure unit 135 is arranged. Therefore, according to this embodiment, the operation efficiency of the construction of the tunnel supporting structure 100 is improved.

[0054] The following modifications also fall within the scope of the present invention, and it is also possible to combine the configurations shown in the modifications with the configurations described in the above embodiment, or to combine the configurations described in the following different modifications.

[0055] <First Modification>

The procedures of the construction method of the tunnel supporting structure 100 are not limited to the procedures (see FIG. 4) described in the above-mentioned embodiment. For example, the tunnel supporting structure

100 may also be constructed by the procedures shown in FIG. 7. In this first modification, instead of the steps S140, S145, S150, and S155 shown in FIG. 4, steps S230 and S240 are performed. As shown in FIG. 7, in the construction method of the tunnel supporting structure 100 according to this first modification, when the arrangement of the framed structure units 135 (hereinafter, also referred to as first framed structure units 135S) in the slits 119 is completed in the first framed-structure-unit arranging step S125, the process proceeds to the second framed-structure-unit arranging step S230.

[0056] <Second Framed-Structure-Unit Arranging Step>

In the second framed-structure-unit arranging step S230, the plurality of framed structure units 135 (hereinafter, also referred to as second framed structure units 135C) are arranged along the tunnel axial direction from the first supporting structure body 101 that has already been constructed in the previous construction cycle to the new steel supporting structure 110 formed in the steel supporting structure forming step S120 in the current construction cycle.

[0057] The second framed structure units 135C are arranged at the predetermined positions in advance so as to cross, in the tunnel radial direction, the secondary sprayed concrete 122, which will be formed in the second spraying step S240 that is a subsequent step. The second framed structure units 135C may be held at the predetermined positions by a holding device (not shown) having a holding tool, or the second framed structure units 135C may be held at the predetermined positions by a holding structure (not shown) installed in the tunnel temporarily. In addition, the second framed structure units 135C may be held at the predetermined positions by connecting respective one side surface of the second framed structure units

135C to the primary sprayed concrete 121. When the arrangement of the second framed structure units 135C is completed in the second framed-structure-unit arranging step S230, the process proceeds to the second spraying step S240.

[0058] <Second Spraying Step>

In the second spraying step S240, the concrete material is sprayed over the primary sprayed concrete 121 between the first supporting structure body 101 that has already been constructed in the previous construction cycle and the new steel supporting structure 110 formed in the steel supporting structure forming step S120 in the current construction cycle. In addition, the concrete material is sprayed to the second framed structure units 135C that are held at the predetermined positions between the first supporting structure body 101 that has already been constructed and the new steel supporting structure 110. Furthermore, the concrete material is sprayed to the first framed structure units 135S arranged in the slits 119 of the steel supporting structure 110.

[0059] As the sprayed concrete material is hardened, the secondary sprayed concrete 122 is formed so as to extend along the inner wall surface of the tunnel, and at the predetermined position, the second yielding section 132 is formed. As a result, a new second supporting structure body 102 is formed. In addition, the first yielding sections 131 are respectively formed in the slits 119 of the steel supporting structure 110. As a result, a new first supporting structure body 101 is formed.

[0060] In this step S240, although a description is given of an example in which the plurality of second yielding section 132 and the single first yielding section 131 are formed by spraying the concrete material to the plurality of

framed structure units 135 held at the predetermined positions, the present invention is not limited thereto. The plurality of framed structure units 135 may be connected by the concrete material. In other words, in this step S240, the spraying operation of the concrete material may be performed so as to form the single yielding section 130 having the plurality of framed structure units 135 arranged so as to cross the concrete supporting structure 120 and having the framed structure unit 135 arranged so as to cross the steel supporting structure 110.

[0061] As described above, the second spraying step S240, which is one step in a concrete-supporting-structure forming step according to this first modification, includes a second-yielding-section forming step for forming the second yielding sections 132 together with the concrete supporting structure 120 by spraying the concrete material to the second framed structure units 135C that are arranged on the inner wall surface of the tunnel and at the predetermined positions. Furthermore, the second spraying step S240 includes the first-yielding-section forming step for forming the first yielding section 131 by spraying the concrete material to the first framed structure unit 135S that is arranged in the slit 119 of the steel supporting structure 110.

[0062] According to such a modification, it is possible to form the base supporting structure (the concrete supporting structure 120) and the second yielding sections 132 in a single step (the second spraying step S240). Furthermore, it is possible to form the base supporting structure (the concrete supporting structure 120) and the first yielding section 131 in the single step (the second spraying step S240). Thus, it is possible to achieve further improvement in the operation efficiency of the construction of the tunnel supporting structure 100.

[0063] <Second Modification>

In the above-mentioned embodiment, although a description is given of an example in which the framed structure units 135 are respectively arranged in the slits 119 of the steel supporting structure 110 after the slits 119 are formed, the present invention is not limited thereto. A framed-structure-unit arranging step for arranging the framed structure units 135 to the predetermined positions may be performed, and subsequently, a steel supporting structure forming step for forming the steel supporting structure 110 so as to be adjacent, in the tunnel circumferential direction, to the framed structure unit 135 that has been arranged at the predetermined position may be performed.

[0064] <Third Modification>

In the above-mentioned embodiment, although a description is given of an example in which the concrete material used for the secondary sprayed concrete 122 is the same as the concrete material used for the yielding section 130, the present invention is not limited thereto. The concrete material used for the secondary sprayed concrete 122 may be different from the concrete material used for the yielding section 130. For example, after the framed structure units 135 are arranged at the predetermined positions, the secondary sprayed concrete 122 may be formed by using a first concrete material so as to be adjacent, in the tunnel circumferential direction, to the framed structure units 135 that have been arranged at the predetermined positions, and thereafter, the second yielding sections 132 may be formed by spraying a second concrete material to the framed structure units 135. In other words, by forming the second yielding sections 132 using a special concrete material, the deformability of the second yielding sections 132 may be

adjusted.

[0065] <Fourth Modification>

As shown in FIG. 8, a guide section 117 for guiding the end portion of the curved section 112 when the yielding section 130 is compressed may be installed around the yielding section 130 of the first supporting structure body 101. The guide section 117 may be formed by cutting one side surface of a rectangular short pipe, for example.

[0066] FIG. 8 is a diagram for explaining procedures for forming the first supporting structure body 101. In a step S41, the pair of straight sections 111 are first installed on the bottom surface of the tunnel, and the process proceeds to a step S42. In the step S42, a plate material 116 having a rectangular flat plate shape is fixed to the upper end portion of each of the straight sections 111, and the process proceeds to a step S43. In the step S43, a lower end portion of the guide section 117 is placed so as to cover the upper end portion of the straight section 111, and the lower end portion of the guide section 117 is fixed to the straight section 111, and the process proceeds to a step S44.

[0067] In the step S44, the framed structure unit 135 is inserted inside the guide section 117 so as to be placed on the plate material 116, and the process proceeds to a step S45. In the step S45, the end portion of the curved section 112 is inserted into an upper end portion of the guide section 117. In this modification, the end portion of the curved section 112 is formed so as to extend in a straight line, and the plate material 116 having the rectangular flat plate shape is fixed thereto in advance.

[0068] The curved section 112 is held by the supporting-structure assembling device (not shown). In this state, the concrete material is sprayed

to the framed structure unit 135 through a side surface opening of the guide section 117. By allowing the concrete material to be hardened, the yielding section 130 having the rectangular parallelepiped shape is formed, and thereby, the arch-shaped first supporting structure body 101 constituted of the straight section 111, the yielding section 130, and the curved section 112, which are installed in a continuous manner, is formed.

[0069] According to such a modification, as a large ground pressure acts on the first supporting structure body 101 from the ground 1, the yielding section 130 is compressed, and at the same time, the end portion of the curved section 112 is moved by sliding downwards along the longitudinal direction of the guide section 117. Thereby, it is possible to allow the curved section 112 to be moved suitably in accordance with the deformation of the ground 1.

[0070] <Fifth Modification>

In the above-mentioned embodiment, although a description is given of an example in which the concrete supporting structure 120 is formed by the primary sprayed concrete 121 and the secondary sprayed concrete 122, the present invention is not limited thereto. Furthermore, the concrete supporting structure may be formed with a concrete laminate including three or more layers by further spraying the concrete material. In addition, the concrete supporting structure 120 may be formed of a single concrete layer rather than being formed separately in a plurality of concrete layers. For example, the spraying step S115 for the concrete material may be omitted in the above-mentioned embodiment (see FIG. 4).

[0071] <Sixth Modification>

In the above-mentioned embodiment, although a description is given of an example in which the yielding sections 130 are respectively installed to the

steel supporting structure 110 and the concrete supporting structure 120 by spraying the concrete material to the resinous framed structure units 135, the present invention is not limited thereto. While installing the above-described yielding section 130 to the concrete supporting structure 120, the above-described yielding section 130 may not be installed to the steel supporting structure 110. In this case, a conventionally known yielding supporting structure is installed instead of the yielding section 130 in the steel supporting structure 110. The yielding supporting structure is configured of, for example, a plurality of steel materials having a U-shaped cross-section and has a configuration in which end portions of the adjacent steel materials are slidably connected by being mutually overlapped for a predetermined length with U-bolts, etc.

[0072] <Seventh Modification>

In the above-mentioned embodiment, although a description is given of an example in which the yielding section 130 is formed by arranging the framed structure unit 135 in the slit 119 of the steel supporting structure 110 and by spraying the concrete material, and the yielding section 130 is formed by arranging the framed structure unit 135 in the slit 129 of the concrete supporting structure 120 and by spraying the concrete material, the present invention is not limited thereto. The yielding section 130 that has been preformed in the factory, etc. may be arranged in either one of the slit 119 of the steel supporting structure 110 and the slit 129 of the concrete supporting structure 120. In other words, the yielding section 130 may be formed by arranging the framed structure unit 135 in at least one of the slit 119 of the steel supporting structure 110 and the slit 129 of the concrete supporting structure 120 and by spraying the concrete material thereafter. Even in such

a case, compared with a case in which the yielding sections 130 that have been preformed in the factory, etc. are arranged in both of the slits 119, 129, it is possible to improve the operation efficiency of the construction of the tunnel supporting structure 100.

[0073] <Eighth Modification>

In the above-mentioned embodiment, although a description is given of an example in which the tunnel supporting structure 100 has an arch-shaped lateral cross-section, the present invention is not limited thereto. The present invention may also be applied even in a case in which the tunnel supporting structure 100 has a circular lateral cross-section. In addition, the number of the yielding sections 130 is also not limited to that in the above-mentioned embodiment. For example, in a predetermined lateral cross-section of the tunnel supporting structure 100, three or more yielding sections 130 may be installed at predetermined intervals in the tunnel circumferential direction or a single yielding section 130 may be installed.

[0074] <Ninth Modification>

In the above-mentioned embodiment, although a description is given of an example in which the framed structure unit 135 is formed of a resin material, the present invention is not limited thereto.

[0075] Embodiments of this invention were described above, but the above embodiments are merely examples of applications of this invention, and the technical scope of this invention is not limited to the specific constitutions of the above embodiments.

CLAIMS

1. A construction method of a tunnel supporting structure provided along an inner wall surface of a tunnel, comprising:

a framed-structure-unit arranging step for arranging a framed structure unit at a predetermined position;

a base supporting structure forming step for forming a base supporting structure along the inner wall surface of the tunnel; and

an yielding-section forming step for forming an yielding section by spraying a concrete material to the framed structure unit arranged at the predetermined position, wherein

the predetermined position is a position at which the framed structure unit is arranged so as to cross the base supporting structure in a tunnel radial direction, and

the framed structure unit is formed of a resin material.

2. A construction method of a tunnel supporting structure provided along an inner wall surface of a tunnel, comprising:

a framed-structure-unit arranging step for arranging a framed structure unit at a predetermined position;

a base supporting structure forming step for forming a base supporting structure along the inner wall surface of the tunnel; and

an yielding-section forming step for forming an yielding section by spraying a concrete material to the framed structure unit arranged at the predetermined position, wherein

the predetermined position is a position at which the framed structure unit is arranged so as to cross the base supporting structure in a tunnel radial direction, and

the framed structure unit is formed by connecting a plurality of base framed structure units containing a plurality of rod-shaped elements.

3. The construction method of the tunnel supporting structure according to claim 1 or 2, wherein

in the base supporting structure forming step, a slit is formed so as to cross the base supporting structure in the tunnel radial direction,

in the framed-structure-unit arranging step, the framed structure unit is arranged in the slit of the base supporting structure formed by the base supporting structure forming step, and

in the yielding-section forming step, the yielding section is formed by spraying the concrete material to the framed structure unit arranged in the slit of the base supporting structure.

4. The construction method of the tunnel supporting structure according to claim 1 or 2, wherein

in the base supporting structure forming step, the base supporting structure is formed so as to be adjacent to the framed structure unit arranged at the predetermined position.

5. The construction method of the tunnel supporting structure according to claim 1 or 2, wherein

the base supporting structure includes steel supporting structures arranged at predetermined intervals in a tunnel axial direction.

6. The construction method of the tunnel supporting structure according to claim 1 or 2, wherein

the base supporting structure includes a concrete supporting structure formed by spraying the concrete material to the inner wall surface of the tunnel.

7. The construction method of the tunnel supporting structure according to claim 6, wherein

the base supporting structure forming step includes the yielding-section forming step, and the yielding section is formed together with the base supporting structure by spraying the concrete material to the inner wall surface of the tunnel and the framed structure unit arranged at the predetermined position.