

DESCRIPTION

Title of Invention

ARTIFICIAL GROUND STRUCTURE

5 Technical Field

[0001]

The present disclosure relates to an artificial ground structure that can ensure inclination and width required for a road, for example, without being affected by geography in building the road in a mountain area or the like.

10 Background Art

[0002]

In the case of building an artificial ground, such as a road, for example, in a mountain area, a portion of an existing slope higher than the planned height of a road surface is cut and a portion of the existing slope lower than the planned height of the road surface is embanked to make a structure with a flat-shaped road surface. In this case, due to the resultant modification of the existing slope, the living environment of plants and creatures is significantly affected, which is not preferable in terms of environmental conservation in many cases. Further, in the case of installing bridge beams across a valley, it is necessary to build large scale bridge piers on a slope and hence, large scale excavation work and foundation work are required. In this case, the environment is significantly affected, and a long construction period is required, thus increasing costs. In view of the above, an artificial ground structure in the form of a pier bridge is devised where piles are installed on a slope, and girders and road floor slabs are installed on the piles. In the artificial ground structure, a plurality of steel pipe piles are installed in the ground along the road direction and the direction perpendicular to the road, and steel pipe struts are joined to the upper portions of the steel pipe piles. Further, panel point parts are installed on the upper ends of the steel pipe piles or the steel pipe struts, and main girders and cross girders are provided in such a way as to couple the panel point parts. Floor slabs are installed on the main girders and the cross girders. The steel pipe piles or the steel

pipe struts have long portions protruding from the ground and hence, intermediate panel point parts are provided at the intermediate portions, and intermediate girders are provided in such a way as to couple the intermediate panel point parts (see Patent Literature 1, for example). With such a configuration, the steel pipe piles and the steel pipe struts of the artificial ground structure are subjected to eccentricity adjustment and joined to each other, and the steel pipe piles and the steel pipe struts are coupled with adjacent steel pipe piles or adjacent steel pipe struts and hence, even when the bearing piles have a long protruding length from the ground, it is possible to suppress bending moment and displacement.

Citation List

Patent Literature

[0003]

Patent Literature 1: International Publication No. WO 2021/090439

Summary of Invention

Technical Problem

[0004]

Due to the experience of earthquakes, such as the Great Hanshin earthquake, the Great East Japan earthquake, and the Kumamoto earthquake, there is an increasing importance in ensuring earthquake resistance of artificial ground structures including road structures more than ever. Steel pipe piles and steel pipe struts (collectively referred to as "bearing piles") forming an artificial ground structure have portions protruding from the ground, and these portions are conventionally designed with the goal of ensuring strength within the elastic range of the material against inputs caused by earthquakes. However, when the portions of the bearing piles that protrude from the ground are designed to have strength against inputs caused by earthquakes to prevent the portions from exceeding the yield point, the problem is that the bearing piles forming the artificial ground structure are required to have a large outer diameter, leading to a large weight.

In contrast, in the case where steel pipe piles specified in JIS A 5525, for example, are used as bearing piles, performance of the bearing piles when the

bearing piles exceed the yield point is not specified at all and hence, the problem is that it is impossible to expect energy absorption due to plastic deformation against inputs caused by large earthquakes.

[0005]

5 An object of the present disclosure, which has been made to overcome the above-mentioned problem, is to provide an artificial ground structure in which earthquake resistance is improved by energy absorption due to plastic deformation of the bearing piles corresponding to vibration caused by a large earthquake, the artificial ground structure including the bearing piles having a large protruding amount
10 from the ground.

Solution to Problem

[0006]

 An artificial ground structure according to one embodiment of the present disclosure includes: bearing piles driven into ground in lines in a first direction, in
15 which an artificial ground extends, and in a second direction intersecting with the first direction; upper end panel point parts installed on upper ends of the bearing piles; a first girder part configured to connect two adjacent upper end panel point parts of the upper end panel point parts; and a floor slab installed on the upper end panel point parts and the first girder part, wherein the bearing piles are set such that a hysteresis
20 curve for horizontal displacement and horizontal load when the bearing piles receive a level 2 earthquake motion has a spindle shape.

[0007]

 An artificial ground structure according to another embodiment of the present disclosure includes: bearing piles driven into ground in lines in a first direction, in
25 which an artificial ground extends, and in a second direction intersecting with the first direction; upper end panel point parts installed on upper ends of the bearing piles; a first girder part configured to connect two adjacent upper end panel point parts of the upper end panel point parts; and a floor slab installed on the upper end panel point parts and the first girder part, wherein a bearing pile of the bearing piles is formed
30 from an electric resistance welded steel pipe subjected to heat treatment, has a yield

ratio for respective parts, including a welded part, of 85% or less, and has Charpy absorbed energy of 27 J or more.

Advantageous Effects of Invention

[0008]

5 According to the embodiment of the present disclosure, a bearing pile having a long protruding length from the ground can also ensure positional accuracy of an upper end panel point part, and can have a reduced outer diameter dimension and a reduced weight of the bearing pile. Further, the bearing pile is configured such that the hysteresis curve has a spindle shape when the relationship between horizontal
10 displacement and horizontal load is measured for a level 2 earthquake motion, which is an input corresponding to a large earthquake, and hence, the bearing pile can stably absorb vibration energy due to plastic deformation. The artificial ground structure uses such bearing piles, thus achieving improved earthquake resistance.

Brief Description of Drawings

15 [0009]

 [Fig. 1] Fig. 1 is a schematic view of a road structure 100 according to Embodiment 1.

 [Fig. 2] Fig. 2 is a diagram illustrating the cross sectional structure of the road structure 100 shown in Fig. 1 taken along A-A.

20 [Fig. 3] Fig. 3 is a diagram illustrating the cross sectional structure of the road structure 100 shown in Fig. 1 taken along B-B.

 [Fig. 4] Fig. 4 is a diagram illustrating the cross sectional structure of the road structure 100 shown in Fig. 1 taken along C-C.

25 [Fig. 5] Fig. 5 is a diagram illustrating the layout of first girder parts 41 of the road structure 100 shown in Fig. 1.

 [Fig. 6] Fig. 6 is a perspective view showing an example of the structure of the upper portion of the road structure 100.

 [Fig. 7] Fig. 7 is a diagram illustrating an example of the cross sectional structure of an upper end panel point part 50a of the road structure 100 according to
30 Embodiment 1, and an area around the upper end panel point part 50a.

[Fig. 8] Fig. 8 is a top plan view of the upper end panel point part 50a shown in Fig. 7.

[Fig. 9] Fig. 9 is a diagram illustrating the cross sectional structure of an intermediate panel point part 50b of the road structure 100 according to Embodiment 1, and an area around the intermediate panel point part 50b.

[Fig. 10] Fig. 10 is a top plan view of the intermediate panel point part 50b of the road structure 100 according to Embodiment 1.

[Fig. 11] Fig. 11 is a diagram illustrating the cross sectional structure of an intermediate panel point part 150b of the road structure 100 according to Embodiment 1, and an area around the intermediate panel point part 150b.

[Fig. 12] Fig. 12 is a diagram illustrating a state where a steel pipe pile 20 is placed in a hole 95.

[Fig. 13] Fig. 13 is a diagram illustrating the structure of a formwork jig 70 used in a temporary joining step in Embodiment 1.

[Fig. 14] Fig. 14 is a side view showing an example of a cover plate 399.

[Fig. 15] Fig. 15 is a diagram illustrating the cross sectional structure of a road structure 1000 according to a comparison example.

[Fig. 16] Fig. 16 shows hysteresis curves obtained by performing a cyclic loading test on steel pipes used for the bearing piles 10 according to Embodiment 1.

[Fig. 17] Fig. 17 is a schematic view of a test specimen for the cyclic loading test.

[Fig. 18] Fig. 18 is a diagram illustrating a step of welding an electric resistance welded steel pipe used for the bearing pile 10 according to Embodiment 1.

[Fig. 19] Fig. 19 is a cross-sectional view of a welded part of the electric resistance welded steel pipe used for the bearing pile 10 according to Embodiment 1.

[Fig. 20] Fig. 20 is a table showing outer diameter, plate thickness, and components of electric resistance welded steel pipes from which test pieces for a strength test are sampled.

[Fig. 21] Fig. 21 is a diagram showing the relationship between nominal stress and nominal strain obtained by performing a tensile test using test pieces.

[Fig. 22] Fig. 22 shows the results obtained by performing the tensile test using the test pieces.

[Fig. 23] Fig. 23 is a diagram showing the results of a Charpy test obtained by performing the tensile test using test pieces.

5 [Fig. 24] Fig. 24 is a diagram illustrating the cross sectional structure of an upper end panel point part 550a of the road structure 100 according to Embodiment 1, and an area around the upper end panel point part 550a.

[Fig. 25] Fig. 25 shows a top plan view and a side view of the upper end panel point part 550a of the road structure 100 according to Embodiment 1.

10 [Fig. 26] Fig. 26 is a cross-sectional view taken along F-F in Fig. 25(b).

[Fig. 27] Fig. 27 is a diagram illustrating the cross sectional structure of an intermediate panel point part 550b of the road structure 100 according to Embodiment 1, and an area around the intermediate panel point part 550b.

15 [Fig. 28] Fig. 28 is a diagram illustrating the cross sectional structure of an upper end panel point part 250a, which is a modification of the upper end panel point part 50a of the road structure 100 according to Embodiment 1, and an area around the upper end panel point part 250a.

[Fig. 29] Fig. 29 is a top plan view of the upper end panel point part 250a shown in Fig. 28.

20 [Fig. 30] Fig. 30 shows a side view and a top plan view of the structure of an intermediate panel point part 250b, which is a modification of an intermediate panel point part 150b of the road structure 100 according to Embodiment 1, and an area around the intermediate panel point part 250b.

25 [Fig. 31] Fig. 31 is a diagram illustrating the cross sectional structure of a modification of the road structure 100 according to Embodiment 1.

[Fig. 32] Fig. 32 is a schematic view showing an example of a road structure 100 according to Embodiment 2.

[Fig. 33] Fig. 33 is an enlarged view of a section K shown in Fig. 32.

30 [Fig. 34] Fig. 34 is an enlarged view of a bearing pile 10a including an intermediate panel point part 50b or 150b, of bearing piles 10a shown in Fig. 32.

[Fig. 35] Fig. 35 is an enlarged view of a section L shown in Fig. 32.

[Fig. 36] Fig. 36 is an enlarged view of a section M shown in Fig. 32.

[Fig. 37] Fig. 37 is a diagram schematically showing the relationship between horizontal displacement δ and stress σ of respective inter-node parts 10A, 10B, 10C, 10D, 10Ca, 10Da, 10Cb, and 10Db shown in Fig. 33, Fig. 34, Fig. 35, and Fig. 36.

[Fig. 38] Fig. 38 is a graph showing the relationship between the ratio of a length h_3 of the inter-node part 10C on the ground side to a protruding amount h of a long bearing pile 10a and the value of G in a formula (16) and a formula (17) for two bearing piles 10 shown in Fig. 35.

[Fig. 39] Fig. 39 is a diagram showing the relationship between horizontal displacement δ and stress σ of the inter-node part 10A and the inter-node part 10C of the two bearing piles 10.

[Fig. 40] Fig. 40 is an enlarged view of the section L shown in Fig. 32, and is also a diagram obtained by shortening the bearing pile 10a compared with that in Fig. 35.

[Fig. 41] Fig. 41 is a diagram schematically showing the relationship between horizontal displacement δ and stress σ of the long bearing pile 10 and the short bearing pile 10a shown in Fig. 40.

[Fig. 42] Fig. 42 is a diagram schematically showing the relationship between horizontal displacement δ and stress σ when the material of a reference pile and the material of a comparison pile have the same yield stress and when the material of the reference pile and the material of the comparison pile have different yield stresses.

[Fig. 43] Fig. 43 is a diagram schematically showing the relationship between horizontal displacement δ and stress σ when the reference pile and the comparison pile have different outer diameters.

[Fig. 44] Fig. 44 is a diagram illustrating the road structure 100 according to Embodiment 2.

[Fig. 45] Fig. 45 is an enlarged view of the bearing pile 10 of the road structure 100 according to Embodiment 2.

[Fig. 46] Fig. 46 is a diagram illustrating the road structure 100 according to

Embodiment 2 in cross section perpendicular to the y direction.

[Fig. 47] Fig. 47 is a flow of a method for constructing the road structure 100 according to Embodiment 1.

Description of Embodiments

[0010]

Hereinafter, Embodiments of the present disclosure will be described with reference to drawings. The present disclosure is not limited by Embodiments described below. Respective drawings are schematically shown, and relative sizes, plate thicknesses and the like of respective parts are not limited to the dimensions illustrated. Further, the relationship of sizes of the respective components in the following drawings may differ from that of the actual ones.

[0011]

Embodiment 1.

Fig. 1 is a schematic view of a road structure 100 according to Embodiment 1.

Fig. 2 is a diagram illustrating the cross sectional structure of the road structure 100 shown in Fig. 1 taken along A-A. Fig. 3 is a diagram illustrating the cross sectional structure of the road structure 100 shown in Fig. 1 taken along B-B. Fig. 4 is a diagram illustrating the cross sectional structure of the road structure 100 shown in Fig. 1 taken along C-C. Fig. 5 is a diagram illustrating the layout of first girder parts 41 of the road structure 100 shown in Fig. 1. Fig. 6 is a perspective view showing an example of the structure of the upper portion of the road structure 100. The road structure 100 is installed on the ground having large undulations, such as a mountain area. The road structure 100 is a structure used in a case where a road is provided along the slope of a mountain area, a case where an existing road provided along a slope is widened, or a case where a road is provided to straddle a stream portion of a mountain area, or other cases, for example. In Embodiment 1, as an example of an artificial ground structure, the road structure 100 installed along the slope of a mountain area will be described. The y direction shown in Fig. 1 is a direction in which the road structure 100 extends, and the z direction is a direction in which bearing piles 10 extend. However, the road structure 100 is not limited to a road

structure that extends linearly. As shown in Fig. 5, for example, the road structure 100 may be a road structure that extends in a curved manner when viewed in a top plan view. The artificial ground structure is provided to build an artificial flat ground on a ground 90 having large undulations, such as a mountain area, and is also applicable to a heliport, a passing turnout connected to a road, or a drone port, for example, in addition to the road structure 100. The artificial ground structure allows a facility, such as a building, to be built on the upper surface thereof.

[0012]

As shown in Fig. 2 to Fig. 4, the road structure 100 includes a plurality of steel pipe piles 20 driven into the ground 90. Each steel pipe pile 20 is erected in a hole formed in the ground 90 such that a pile head 21 protrudes from a surface 94 of the ground 90. Holes are drilled in the ground 90 by a down-the-hole hammer or the like such that the holes penetrate through a sediment layer 92 and reach a support layer 93. The steel pipe pile 20 is placed in each hole formed in the ground 90, and the hole is filled with a filler, such as concrete or mortar, so that the steel pipe pile 20 is erected in the ground 90. The x direction shown in Fig. 2 or the like is a direction perpendicular to the y direction in which the road structure 100 extends and perpendicular to the z direction in which the bearing piles 10 extend.

[0013]

The plurality of steel pipe piles 20 are driven into the ground 90 in a line in a first direction, which is the direction in which an artificial ground formed as a road extends. As shown in Fig. 5, the first girder parts 41 are arranged in a curved manner along a slope or the like, for example, and the road is formed by installing road floor slabs 99 on the first girder parts 41. In Embodiment, the first direction is a direction extending along this road. The road floor slab 99 may be simply referred to as "floor slab". In the case where the artificial ground structure is used as a heliport, for example, a helicopter lands on the upper surface of the floor slabs. There may also be cases where a facility, such as a building, is built on the floor slabs.

[0014]

The plurality of steel pipe piles 20 of the road structure 100 include first steel

pipe piles 20a and second steel pipe piles 20b. A steel pipe strut 30 is joined to the upper side of each first steel pipe pile 20a. The steel pipe strut 30 is joined to the upper end of the first steel pipe pile 20a corresponding to the height from the surface 94 of the ground 90 at which the road floor slab 99 and the first girder part 41 are installed. Triangle symbols shown in Fig. 1 to Fig. 4 show joint portions 11 between the first steel pipe piles 20a and the steel pipe struts 30. At each joint portion 11, the first steel pipe pile 20a and the steel pipe strut 30 are joined by welding, for example. However, each joint portion 11 may have a structure where a first steel pipe pile 20a located on the side close to the ground 90 and a steel pipe strut 30 joined to the upper side of the first steel pipe pile 20a are joined to each other by an eccentric joint part 60b (see Fig. 11). A columnar structure erected in the ground 90 may be referred to as the bearing pile 10. Particularly, the above-mentioned structure where the first steel pipe pile 20a and the steel pipe strut 30 are joined may be referred to as a bearing pile 10a.

[0015]

Each steel pipe strut 30 is joined to a pile head 21a of the first steel pipe pile 20a, and extends upward. An upper end panel point part 50a is joined to the pile head 12 of the steel pipe strut 30. The upper end panel point part 50a is joined to the pile head 12 of the steel pipe strut 30 by using an eccentric joint part 60.

[0016]

The upper end panel point part 50a is coupled with another upper end panel point part 50a with the first girder part 41, the upper end panel point part 50a and another upper end panel point part 50a being disposed adjacent to each other in the first direction. The first girder parts 41 installed along the first direction are particularly referred to as stringers 41a.

[0017]

As shown in Fig. 2 to Fig. 4, the upper end panel point part 50a is coupled with another upper end panel point part 50a with the first girder part 41, the upper end panel point part 50a and another upper end panel point part 50a being disposed adjacent to each other in line in the second direction intersecting with the first

direction. The first girder parts 41 installed along the second direction are particularly referred to as cross girders 41b.

[0018]

In Embodiment 1, as shown in Fig. 2 to Fig. 4, two steel pipe piles 20 are arranged in a line along the second direction intersecting with the first direction. Each cross girder 41b couples the upper end panel point parts 50a joined to the pile heads 12 arranged in a line in the second direction. That is, the first girder parts 41 are installed along the first direction and the second direction, and each first girder part 41 couples the pile heads 12 of the bearing piles 10 via the upper end panel point parts 50a. Floor slab fixing parts 42 are installed on the upper surfaces of the first girder parts 41 and the upper end panel point parts 50a. The road floor slabs 99 are fixed to the first girder parts 41 and the upper end panel point parts 50a via the floor slab fixing parts 42. Two or more steel pipe piles 20 may be arranged in a line in the second direction intersecting with the first direction.

[0019]

Each stringer 41a couples the upper end panel point parts 50a joined to the pile heads 12 of the bearing piles 10 arranged in a line in the first direction. Each upper end panel point part 50a includes two stringer connections 52a to which the stringer 41a is connected (see Fig. 7). In the case where the road structure 100 is disposed in a curved manner along a slope or the like as shown in Fig. 5, two stringers 41a connected to one upper end panel point part 50a extend such that the longitudinal directions of the two stringers 41a intersect with each other. Accordingly, the two stringer connections 52a provided to the upper end panel point part 50a also extend in such a way as to intersect with each other.

[0020]

The stringers 41a include a first stringer 41aa and a second stringer 41ab arranged in parallel in the second direction. In Fig. 5, the first stringer 41aa connects a first upper end panel point part 50aa and a second upper end panel point part 50ab with each other, the first upper end panel point part 50aa and the second upper end panel point part 50ab being installed on the pile heads 12 of the bearing piles 10

arranged in a line in the first direction. The second stringer 41ab connects a third upper end panel point part 50ac and a fourth upper end panel point part 50ad with each other, the third upper end panel point part 50ac and the fourth upper end panel point part 50ad being installed on the pile heads 12 of the bearing piles 10 arranged in a line in the first direction. As shown in Fig. 5, for example, in the case where the road structure 100 is installed in a curved manner along the slope of a mountain area when viewed in plan view, the first stringer 41aa is located on the inner side of the road structure 100 disposed in a curved manner, and the second stringer 41ab is located on the outer side of the road structure 100 disposed in a curved manner. In this case, an interval between the first upper end panel point part 50aa and the second upper end panel point part 50ab is shorter than an interval between the third upper end panel point part 50ac and the fourth upper end panel point part 50ad. Further, the first stringer 41aa is shorter than the second stringer 41ab. The first stringer 41aa and the second stringer 41ab may be disposed in parallel.

[0021]

As shown in Fig. 5, each cross girder 41b includes a coupling part 43 at a center portion thereof. The stringers 41a are connected to the coupling part 43. The stringer 41a connected to the coupling part 43 connects the coupling parts 43 of the cross girders 41b disposed adjacent to each other in the first direction. The cross girder 41b connects the first upper end panel point part 50aa and the third upper end panel point part 50ac with each other. Another cross girder 41b connects the second upper end panel point part 50ab and the fourth upper end panel point part 50ad with each other. In Embodiment 1, the cross girder 41b is configured to integrally connect two upper end panel point parts 50a. Further, the cross girder 41b includes the coupling part 43 at the center portion thereof. The coupling parts 43 being the center portions of the cross girders 41b disposed adjacent to each other in the first direction are connected with each other by a third stringer 41ac. As shown in Fig. 5, the length of the third stringer 41ac in the first direction is longer than that of the first stringer 41aa, and is shorter than that of the second stringer 41ab. In Embodiment 1, the description has been made for the case where three girder parts

41 are arranged in a line in the second direction as shown in Fig. 5. However, two girder parts 41 or a larger number of girder parts 41 may be arranged in a line in the second direction. The road structure 100 is not limited to a road structure installed in a curved manner when viewed in plan view, and may be disposed in a straight manner or may be installed in a shape obtained by combining a straight line and a curved line.

[0022]

Returning to Fig. 1, the upper end panel point part 50a is connected to the upper side of each second steel pipe pile 20b. The upper end panel point part 50a is joined to the pile head 12 of the second steel pipe pile 20b by using the eccentric joint part 60. In the same manner as the upper end panel point part 50a joined to the bearing pile 10a, the upper end panel point part 50a joined to the second steel pipe pile 20b is coupled with another upper end panel point part 50a disposed adjacent to the upper end panel point part 50a in the first direction and with another upper end panel point part 50a disposed adjacent to the upper end panel point part 50a in the second direction. The second steel pipe pile 20b where the steel pipe strut 30 is not joined to the upper side of the second steel pipe pile 20b may be referred to as "bearing pile 10b".

[0023]

As shown in Fig. 1, intermediate panel point parts 50b are provided to the bearing piles 10a. In Embodiment 1, each intermediate panel point part 50b is installed at the center portion of the steel pipe strut 30 of the bearing pile 10a. That is, each intermediate panel point part 50b is provided to the bearing pile 10a of the road structure 100 having a long protruding length from the ground 90. The intermediate panel point part 50b is coupled with another intermediate panel point part 50b provided to the adjacent steel pipe strut 30 by a second girder part 40. The second girder parts 40 installed along the first direction are particularly referred to as "stringers 40a".

[0024]

As shown in Fig. 4, the intermediate panel point part 50b is coupled with

another intermediate panel point part 50b by the second girder part 40, another intermediate panel point part 50b being installed on the bearing pile 10 disposed adjacent to the intermediate panel point part 50b in the second direction intersecting with the first direction. The second girder parts 40 installed along the second direction are particularly referred to as cross girders 40b.

[0025]

The second girder parts 40 may be installed in an inclined manner as shown in Fig. 1 and Fig. 3, or may be installed in a horizontal manner as shown in Fig. 4. The second girder part 40 shown in Fig. 3 is inclined along the slope of the ground 90 into which the bearing piles 10 are driven. That is, the intermediate panel point parts 50b provided to the bearing piles 10 driven into the mountain side of the slope are disposed at positions higher than the intermediate panel point parts 50b provided to the bearing piles 10 driven into the valley side of the slope. With such a configuration, there is no possibility that the positions at which the intermediate panel point parts 50b are installed are excessively away from the surface 94 of the ground 90. Accordingly, it is possible to suppress a situation in which a portion of the bearing pile 10 that protrudes from the ground 90 partially has an excessively large horizontal displacement δ and hence, it is possible to suppress breakage of the bearing pile 10 caused by vibration. The intermediate panel point part 50b is not limited to an intermediate panel point part installed on the steel pipe strut 30 as shown in Fig. 1 and Fig. 4, and may be installed on the second steel pipe pile 20b as shown in Fig. 3.

[0026]

(Upper end panel point part 50a)

Fig. 7 is a diagram illustrating an example of the cross sectional structure of the upper end panel point part 50a of the road structure 100 according to Embodiment 1, and an area around the upper end panel point part 50a. Fig. 8 is a top plan view of the upper end panel point part 50a shown in Fig. 7. The upper end panel point part 50a and the bearing pile 10 are joined by an eccentric joint part 60a. The eccentric joint part 60a is portion of the upper end panel point part 50a, and is combined with

the pile head 12 of the bearing pile 10 to allow the adjustment of the position of the upper end panel point part 50a relative to the pile head 12. That is, the upper end panel point part 50a can be joined to the bearing pile 10 by the eccentric joint part 60a even when the center axis of the upper end panel point part 50a does not align with the center axis of the bearing pile 10.

[0027]

In Embodiment 1, the eccentric joint part 60a includes at least a steel pipe part 51a and a support part 55a. The steel pipe part 51a is a cylindrical body forming the upper end panel point part 50a. In Embodiment 1, the steel pipe part 51a has a cylindrical shape. The support part 55a is installed at the inner upper portion of the steel pipe part 51a. The support part 55a is formed by combining plate-like parts into a cross shape, each plate-like part passing through a center axis C of the steel pipe part 51a having a cylindrical shape. The shape of the steel pipe part 51a is not limited to a cylindrical shape, and the steel pipe part 51a may be a cylindrical body having a rectangular shape, a polygonal shape, or other shapes in cross section.

[0028]

The upper end panel point part 50a includes the stringer connections 52a and a cross girder connection 53a to which the first girder parts 41 are connected. Each stringer connection 52a is connected with the first girder part 41, and the cross girder connection 53a is connected with the first girder part 41 such that the end portion of the stringer connection 52a or the cross girder connection 53a and the end portion of the first girder part 41 are clamped by splice plates 44, and the splice plate 44 and the end portion of each part are fixed by using bolts and nuts.

[0029]

A plate-like part is attached to the upper portion of the upper end panel point part 50a, so that an upper surface 57a is flat. The upper surface 57a may be inclined in conformity with the inclination of a road. The upper surface 57a has a filling hole 56a that penetrates through the plate-like part. The filling hole 56a is a hole provided for injecting a filler 80 into a space between the pile head 12 and the steel pipe part 51a, and communicates the outside and the space in the steel pipe

part 51a.

[0030]

An end surface 14 of the pile head 12 of the bearing pile 10a or 10b abuts against the lower surface of the support part 55a. The lower surface of the support part 55a and the end surface 14 of the pile head 12 abut against each other, thus determining the position of the upper end panel point part 50a in the direction of the center axis of the bearing pile 10, that is, the position of the upper end panel point part 50a in the height direction. The steel pipe part 51a surrounds the outer peripheral surface of the upper end portion of the bearing pile 10. Before the filler 80 is filled, a gap is formed between the inner side surface of the steel pipe part 51a and the outer side surface of the bearing pile 10, so the upper end panel point part 50a can be moved in the horizontal direction relative to the bearing pile 10 by an amount corresponding to the gap. As shown in Fig. 6 and Fig. 7, the support part 55a is formed by combining the plate-like parts into a cross shape. However, the support part 55a may have another mode. The support part 55a may have another structure provided that the support part 55a can hold the upper end panel point part 50a on the end surface 14 of the pile head 12, and does not obstruct the injection of the filler 80.

[0031]

There may be cases where the position of the pile head 12 of the bearing pile 10 deviates from the expected position. When the bearing pile 10 has a large protruding amount from the surface 94 of the ground 90, the pile head 12 may have large positional error due to accuracy of the steel pipe pile 20 or the steel pipe strut 30 as a single body, or due to joint accuracy between the steel pipe pile 20 and the steel pipe strut 30. For example, when the steel pipe part 51a of the upper end panel point part 50a has a cylindrical shape, and the pile head 12 has a circular columnar shape, the inner diameter of the steel pipe part 51a is set to a value 200 mm larger than the outer diameter of the pile head 12. With such a configuration, even when the pile head 12 has positional error of 100 mm at maximum in the horizontal direction, for example, the upper end panel point part 50a can be installed at the correct position, and it is also possible to ensure ease of filling the filler 80.

[0032]

The filler 80 is filled into the gap between the steel pipe part 51a and the pile head 12 from the filling hole 56a formed in the upper surface 57a of the upper end panel point part 50a. The steel pipe part 51a has an open lower side. Therefore, in a step of filling the filler 80, to prevent leakage of the filler 80 from the lower side of the steel pipe part 51a, a formwork jig 70 (see Fig. 13) is caused to abut against the lower end surface of the steel pipe part 51a to close the opening port. The formwork jig 70 will be separately described. The inner side surface of the steel pipe part 51a and the outer side surface of the pile head 12 form the gap between the steel pipe part 51a and the pile head 12, the filler 80 being filled into the gap. Protrusions 54 are formed on the inner side surface of the steel pipe part 51a, and protrusions 13 are formed on the outer side surface of the pile head 12. The protrusions 54 and 13 engage with the solidified filler 80 and hence, there is no possibility that the filler 80 is displaced in a direction along the inner side surface of the steel pipe part 51a and the outer side surface of the pile head 12. Accordingly, it is possible to improve load transfer between the upper end panel point part 50a and the bearing pile 10.

[0033]

The protrusions 13 and 54 may be formed such that reinforcing bars or steel bars are bent and fixed by welding. Alternatively, each of the steel pipe part 51a and the bearing pile 10 may be made from a steel plate with protrusions. For example, each of the steel pipe part 51a and the bearing pile 10 may be made from a checkered steel plate having protrusions arranged in the longitudinal direction and in the lateral direction on the surface thereof, or a ribbed steel pipe made from a ribbed steel plate where protrusions having a height of approximately 2 mm are arranged in lines. With the use of such a checkered steel plate or a ribbed steel pipe, it is possible to reduce a construction cost and a step for joining by welding the protrusions 54 to the steel pipe part 51a, and a construction cost and a step for joining by welding the protrusions 13 to the bearing pile 10. Further, the protrusions 13 integrally formed with the bearing pile 10 in advance and the protrusions 54 integrally formed with the steel pipe part 51a in advance increase fixing strength of

displacement preventing protrusions and hence, it is possible to reduce the dimension of the steel pipe part 51a of the upper end panel point part 50a in the height direction.
[0034]

(Intermediate panel point part 50b)

5 Fig. 9 is a diagram illustrating the cross sectional structure of the intermediate panel point part 50b of the road structure 100 according to Embodiment 1, and an area around the intermediate panel point part 50b. Fig. 10 is a top plan view of the intermediate panel point part 50b of the road structure 100 according to Embodiment 1. The intermediate panel point part 50b and the bearing pile 10 are joined by the
10 eccentric joint part 60b. The eccentric joint part 60b is a portion of the intermediate panel point part 50b, and is combined with the bearing pile 10 to allow adjustment of the position of the intermediate panel point part 50b relative to the bearing pile 10. That is, the intermediate panel point part 50b can be joined to the bearing pile 10 by the eccentric joint part 60b even when the center axis of the intermediate panel point
15 part 50b does not align with the center axis of the bearing pile 10.

[0035]

 In Embodiment 1, the eccentric joint part 60b includes at least a steel pipe part 51b forming the intermediate panel point part 50b. The steel pipe part 51b is a cylindrical body, and has a cylindrical shape in Embodiment 1. However, the shape
20 of the steel pipe part 51b is not limited to a cylindrical shape, and the steel pipe part 51b may be a cylindrical body having a rectangular shape, a polygonal shape, or other shapes in cross section. The steel pipe part 51b is a cylindrical body that surrounds the bearing pile 10, and can be joined to the bearing pile 10 in a state where the center axis of the steel pipe part 51b does not align with the center axis of
25 the bearing pile 10. The steel pipe part 51b is particularly referred to as a second eccentric joint part.

[0036]

 As shown in Fig. 10, the intermediate panel point part 50b includes stringer connections 52b and a cross girder connection 53b to which the second girder parts
30 40 are connected. In the same manner as the first girder parts 41, each stringer

connection 52b is connected with the second girder part 40, and the cross girder connection 53b is connected with the second girder part 40 such that the end portion of the stringer connection 52b or the cross girder connection 53b and the end portion of the second girder part 40 are clamped by the splice plates 44 (see Fig. 5 and Fig. 6), and the splice plate 44 and the end portion of each part are fixed by using bolts and nuts.

[0037]

The steel pipe part 51b of the intermediate panel point part 50b is a cylindrical body, thus having open end portions thereof in the up-down direction. Accordingly, the upper end of a gap between the steel pipe part 51b and the bearing pile 10 forms a filling port 56b that is an opening port for injecting the filler 80 into a space between the steel pipe part 51b and the bearing pile 10. The filling port 56b communicates the outside and the space in the steel pipe part 51a with each other.

[0038]

Before the filler 80 is filled, the gap is formed between the inner side surface of the steel pipe part 51b and the outer side surface of the bearing pile 10, so the intermediate panel point part 50b can be moved in the horizontal direction relative to the bearing pile 10 by an amount corresponding to the gap. In the case of the structure shown in Fig. 9, there is no structure that supports the intermediate panel point part 50b in the up-down direction. Therefore, when the intermediate panel point part 50b is attached to the bearing pile 10, the intermediate panel point part 50b is supported from below by causing the formwork jig 70 (see Fig. 13) to abut against the lower end surface of the intermediate panel point part 50b. The formwork jig 70 also has a function of preventing leakage of the filler 80 from the lower opening port at the time of filling the filler 80.

[0039]

There may be cases where the position of the bearing pile 10 deviates from the expected position. When the bearing pile 10 has a large protruding amount from the surface 94 of the ground 90, the bearing pile 10 may have large positional error due to accuracy of the steel pipe pile 20 or the steel pipe strut 30 as a single body, or due

to joint accuracy between the steel pipe pile 20 and the steel pipe strut 30. For example, when the steel pipe part 51b of the intermediate panel point part 50b has a cylindrical shape, and the bearing pile 10 has a circular columnar shape, the inner diameter of the steel pipe part 51b is set to a value 200 mm larger than the outer diameter of the bearing pile 10. With such a configuration, even when the bearing pile 10 has positional error of 100 mm at maximum in the horizontal direction, the intermediate panel point part 50b can be installed at the correct position, and it is also possible to ensure ease of filling the filler 80.

[0040]

The inner side surface of the steel pipe part 51b and the outer side surface of the bearing pile 10 form a gap between the steel pipe part 51b and the bearing pile 10, the filler 80 being filled into the gap. The protrusions 54 may be formed on the inner side surface of the steel pipe part 51b, and the protrusions 13 may be formed on the outer side surface of the bearing pile 10. In the case where the protrusions 54 and 13 are formed, the protrusions 54 and 13 engage with the solidified filler 80 and hence, there is no possibility that the filler 80 is displaced in a direction along the inner side surface of the steel pipe part 51b and the outer side surface of the bearing pile 10. Accordingly, it is possible to improve load transfer between the intermediate panel point part 50b and the bearing pile 10.

[0041]

The protrusions 13 and 54 may be formed such that reinforcing bars or steel bars are bent and fixed by welding. Alternatively, each of the steel pipe part 51b and the bearing pile 10 may be made from a steel plate with protrusions. For example, each of the steel pipe part 51b and the bearing pile 10 may be made from a checkered steel plate having protrusions arranged in the longitudinal direction and in the lateral direction on the surface thereof, or a ribbed steel pipe made from a ribbed steel plate where protrusions having a height of approximately 2 mm are arranged in lines. With the use of such a checkered steel plate or a ribbed steel pipe, it is possible to reduce a construction cost and a step for joining by welding the protrusions 54 to the steel pipe part 51b, and a construction cost and a step for

joining by welding the protrusions 13 to the bearing pile 10. Further, the protrusions 13 integrally formed with the bearing pile 10 in advance and the protrusions 54 integrally formed with the steel pipe part 51b in advance increase fixing strength of displacement preventing protrusions and hence, it is possible to reduce the dimension of the steel pipe part 51b of the intermediate panel point part 50b in the height direction.

[0042]

(Intermediate panel point part 150b)

Fig. 11 is a diagram illustrating the cross sectional structure of an intermediate panel point part 150b of the road structure 100 according to Embodiment 1, and an area around the intermediate panel point part 150b. The intermediate panel point part 150b can join the first steel pipe pile 20a and the steel pipe strut 30 with each other, for example, by installing a support part 55b in the inside of the steel pipe part 51b. The intermediate panel point part 150b includes, in the steel pipe part 51b, the support part 55b having a structure substantially equal to that of the support part 55a of the upper end panel point part 50a. In the same manner as the intermediate panel point part 50b, at the intermediate portion of the bearing pile 10, the intermediate panel point part 150b may be connected to the adjacent intermediate panel point parts 50b or 150b by the stringer 41a and the cross girder 41b.

[0043]

An end surface 22a of the pile head 21a of the first steel pipe pile 20a abuts against the lower surface of the support part 55b. The lower surface of the support part 55a and the end surface 22a of the pile head 21a abut against each other, thus determining the position of the intermediate panel point part 150b in the direction of the center axis of the bearing pile 10, that is, the position of the intermediate panel point part 150b in the height direction. Before the filler 80 is filled, a gap is formed between the inner side surface of the steel pipe part 51b and the outer side surface of the second steel pipe pile 20b, so the intermediate panel point part 150b can be moved in the horizontal direction relative to the second steel pipe pile 20b by an amount corresponding to the gap. In the same manner as the upper end panel point

part 50a shown in Fig. 8, the support part 55a is formed by combining plate-like parts into a cross shape. However, the support part 55a may have another mode. The support part 55a may have another structure provided that the support part 55a can hold the intermediate panel point part 150b on the end surface 14 of the pile head 12, and does not obstruct the injection of the filler 80.

[0044]

An end surface 31 of the steel pipe strut 30 is placed on the upper surface of the support part 55b. The upper surface of the support part 55a and the end surface 31 of the steel pipe strut 30 abut against each other, thus determining the position of the steel pipe strut 30 in the direction of the center axis of the bearing pile 10, that is, the position of the steel pipe strut 30 in the height direction. Before the filler 80 is filled, a gap is formed between the inner side surface of the steel pipe part 51b and the outer side surface of the steel pipe strut 30, so the steel pipe strut 30 can be moved in the horizontal direction relative to the steel pipe part 51b by an amount corresponding to the gap. With the above-mentioned configuration, the intermediate panel point part 150b can join the first steel pipe pile 20a, forming the lower part, and the steel pipe strut 30, forming the upper part, with each other in a state where the center axis of the first steel pipe pile 20a and the center axis of the steel pipe strut 30 are eccentric to each other. The intermediate panel point part 150b includes the steel pipe part 51b, which is a cylindrical body, and the support part 55a, and joins the upper part and the lower part with each other.

[0045]

As shown in Fig. 11, the intermediate panel point part 150b may include bolts 57 that are screwed into the inside of the intermediate panel point part 150b from the outer side of the steel pipe part 51b. The bolts 57 adjust and temporarily fix positions of the lower part and the upper part, which form the bearing pile 10, relative to the steel pipe part 51b. After the filler 80 is filled into the intermediate panel point part 50b and is solidified, heads of the bolts 57 may be removed.

[0046]

(Method for constructing road structure 100)

Next, a method for constructing the road structure 100 according to Embodiment 1 will be described.

[0047]

Fig. 47 shows a flow of the method for constructing the road structure 100 according to Embodiment 1. For the road structure 100, first, the steel pipe piles 20 are driven into the ground 90 in lines in the first direction, in which a road extends, and in the second direction intersecting with the first direction. This step is referred to as a steel pipe pile driving step. In the steel pipe pile driving step, first, holes are drilled in the ground 90 using a down-the-hole hammer or the like to form holes 95 into which the steel pipe piles 20 are placed (see Fig. 12). As shown in Fig. 2 to Fig. 4, the holes 95 penetrate through the sediment layer 92 located at a position close to the surface 94 of the ground 90, and reach the support layer 93.

[0048]

Fig. 12 is a diagram illustrating a state where the steel pipe pile 20 is placed in the hole 95. The portion on the right side of the center line in Fig. 12 shows a structure of the steel pipe pile 20 in cross section including the center axis of the steel pipe pile 20. The steel pipe pile 20 is placed in the hole 95 such that the distal end of the steel pipe pile 20 reaches a bottom surface 96 of the hole 95. Then, the filler 80 is injected into the steel pipe pile 20 from the open upper end of the steel pipe pile 20 in a state where the steel pipe pile 20 is positioned. Mortar or concrete, for example, is used for the filler 80. The filler 80 passes through the steel pipe pile 20 having a hollow cylindrical shape, and flows into a gap 97 between the hole 95 and the outer side surface of the steel pipe pile 20 through a through hole 15 formed at the end portion of the steel pipe pile 20 close to the bottom surface 96 of the hole 95.

[0049]

The filler 80 flowing into the gap 97 rises in the gap 97 as a space in the inside of the steel pipe pile 20 is filled with the filler 80. The confirmation of the flowing out of the filler 80 from the gap 97 over the surface 94 of the ground 90 allows the confirmation of the gap 97 between the steel pipe pile 20 and the hole 95 filled with the filler 80. In the case where the filler 80 is directly filled into the gap 97 between

the steel pipe pile 20 and the hole 95 from the surface 94 of the ground 90, it is difficult to uniformly fill the space around the steel pipe pile 20 with the filler 80. Further, depending on conditions of the ground 90, there may be cases where the hole 95 has a non-smooth surface, so earth and sand mixes into the filler 80, or a space around the bottom surface 96 is not sufficiently filled with the filler 80. However, when the steel pipe pile driving step is performed by using the structure shown in Fig. 12, the steel pipe piles 20 are driven into the ground 90 with certainty. [0050]

The plurality of steel pipe piles 20 are used in the road structure 100. All of the plurality of steel pipe piles 20 are driven into the ground 90 by the above-mentioned steel pipe pile driving step. The plurality of steel pipe piles 20 of the road structure 100 need not be steel pipe piles that have the hole 95 shown in Fig. 12. [0051]

Next, the steel pipe strut 30 is temporarily joined to the first steel pipe pile 20a of each of the plurality of steel pipe piles 20 to temporarily assemble the bearing pile 10a. Further, the upper end panel point part 50a is temporarily joined to each of the pile heads 12 of the bearing piles 10a and to each of pile heads 21b of the second steel pipe piles 20b of the plurality of steel pipe piles 20. In the temporary joining, the steel pipe strut 30, the upper end panel point part 50a, and the intermediate panel point part 50b, 150b are temporarily installed on the steel pipe pile 20 by using the formwork jig 70. This step is referred to as a temporary joining step. Particularly, a step of installing the panel point part 50 on the pile head 12, 21a or 21b is referred to as a panel point part installation step, a step of installing the formwork jig 70 on the panel point part 50 is referred to as a formwork installation step, a step of fixing the panel point part 50 to the pile head by using the formwork jig 70 is referred to as a fixing step, and a step of installing the steel pipe strut 30 on the intermediate panel point part 150b of the panel point part 50 is referred to as a steel pipe strut placing step. The panel point part installation step, the formwork installation step, the fixing step, and the steel pipe strut placing step are included in the temporary joining step. Hereinafter, the temporary joining step will be described in detail.

[0052]

Fig. 13 is a diagram illustrating the structure of the formwork jig 70 used in the temporary joining step in Embodiment 1. Fig. 13 shows the case where the upper end panel point part 50a is installed on the steel pipe pile 20. However, the same method for using the formwork jig 70 is also applicable to the case where the intermediate panel point part 50b, 150b is installed on the steel pipe pile 20. For example, the formwork jig 70 is used for the pile head 21 of the steel pipe pile 20 when the intermediate panel point part 150b is installed on the pile head 21 of the steel pipe pile 20.

[0053]

The formwork jig 70 includes a bracket 71 that supports a formwork plate 74. The bracket 71 is connected to a fixing band 73. The fixing band 73 is detachably fixed to the steel pipe pile 20 in such a way as to surround the outer side surface of the steel pipe pile 20 to fix the position of the bracket 71. A step of installing the formwork jig 70 on the steel pipe pile 20 using the fixing band 73 is particularly referred to as the formwork installation step. The formwork installation step is included in the temporary joining step.

[0054]

In the case where the bearing pile 10 is formed by joining the steel pipe strut 30 to the first steel pipe pile 20a as shown in Fig. 11, first, the intermediate panel point part 150b is placed on the pile head 21a of the steel pipe pile 20. This step is referred to as the panel point part installation step or an intermediate panel point part installation step. Thereafter, the second girder part 40 is installed on a connection 52 of the intermediate panel point part 150b. This step is referred to as a girder part installation step. The intermediate panel point part 150b is installed such that the formwork plate 74 of the formwork jig 70 is caused to abut against the lower end surface of the steel pipe part 51b. This step is referred to as the formwork installation step. The formwork plate 74 is installed in such a way as to prevent the leakage of the filler 80 injected into the inside of the intermediate panel point part 150b. The panel point part installation step, the girder part installation step, and the

formwork installation step are included in the temporary joining step. The order of the panel point part installation step, the girder part installation step, and the formwork installation step may be changed.

[0055]

5 Fig. 13 shows a state where the formwork jig 70 is installed on the upper end panel point part 50a or the intermediate panel point part 50b. As shown in Fig. 13, after the intermediate panel point part 50b is installed on the pile head 12 in the panel point part installation step, the formwork jig 70 is installed on the lower side of the intermediate panel point part 50b. The formwork jig 70 can also be installed on the
10 intermediate panel point part 150b in the same manner. The bracket 71 includes adjustment bolts 75. The distal end of the adjustment bolt 75 abuts against the outer peripheral surface of the steel pipe part 51b of the intermediate panel point part 50b placed on the formwork plate 74. The adjustment bolt 75 threadedly engages with a nut part 76, so that the position of the distal end of the adjustment bolt 75 can be
15 accurately adjusted, and the adjustment bolt 75 can temporarily fix the position of the steel pipe part 51b of the intermediate panel point part 50b. A step of adjusting and fixing the horizontal position of the steel pipe part 51b of the intermediate panel point part 50b in this manner is referred to as the fixing step. The fixing step is included in the temporary joining step.

20 [0056]

After the intermediate panel point part 150b is attached to the pile head 21a of the first steel pipe pile 20a, the steel pipe strut 30 is placed in the intermediate panel point part 50b. This step is referred to as the steel pipe strut placing step. The steel pipe strut placing step is included in the temporary joining step. Consequently,
25 as shown in Fig. 11, the steel pipe strut 30 is erected on the first steel pipe pile 20a.

[0057]

Next, the upper end panel point part 50a is attached to the pile head 12 of each bearing pile 10a where the steel pipe strut 30 is connected to the first steel pipe pile 20a, and to the pile head 12 of each second steel pipe pile 20b. This step is referred to as the panel point part installation step or an upper end panel point part installation
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step. In the same manner as the installation of the intermediate panel point part 50b on the pile head 21 of the steel pipe pile 20, the installation of the upper end panel point part 50a is performed in the panel point part installation step, the formwork installation step, and the fixing step.

5 [0058]

After the intermediate panel point parts 150b are installed, the second girder parts 40 are installed. Further, after the upper end panel point parts 50a are installed, the first girder parts 41 are installed. These steps are referred to as the girder part installation step. The girder part installation step may be included in the temporary joining step.

10

[0059]

The road structure 100 according to Embodiment 1 uses the formwork jig 70 as described above and hence, each of the bearing piles 10a and 10b can be temporarily assembled in a state where the filler 80 is not injected into a panel point part 50. Therefore, by installing cover plates (not shown in the drawing) on the temporarily assembled bearing piles 10a and 10b, and by placing, on the cover plates, a heavy machine and a material for installing piles, it is possible to erect the bearing piles 10a and 10b one after another in the first direction along the road. A step of installing the cover plates on the bearing piles 10a and 10b is referred to as a cover plate installation step. The cover plate installation step may be included in the temporary joining step. The steel pipe driving step and the temporary joining step are alternately repeated until the plurality of bearing piles 10a and 10b are finished to be erected for the entire length of the road or for the predetermined length of the road. The above-mentioned steps are collectively referred to as a bearing pile erecting step.

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20

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[0060]

After the bearing piles 10a and 10b are erected, and the upper end panel point part 50a is temporarily fixed to the pile head 12 of each of the bearing piles 10a and 10a in the bearing pile erecting step, the filler 80 is injected into each panel point part 50. This step is referred to as an injection and solidification step. The upper end panel point part 50a and the intermediate panel point part 50b are generically referred

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to as "panel point part 50". It is preferable to perform the injection and solidification step on all panel point parts 50 after the bearing piles 10a and 10b are erected in a state of temporary assembly for the entire length of a road.

[0061]

5 In the case where the road structure 100 is installed without using the formwork jig 70, a first bearing pile 10 is erected along the road extending in the first direction and, after the filler 80 injected into the panel point part 50 is solidified, a cover plate is installed on the bearing pile 10. This step is referred to as the cover plate installation step. Then, a heavy machine is placed on the installed cover plate to erect a next
10 bearing pile 10. In the case of such a step, the injection and solidification step for the filler 80 is required each time the bearing pile 10 is erected and hence, a long construction period is required. In contrast, the road structure 100 can suppress the number of times of the injection and solidification step for the filler 80 with the use of the formwork jig 70, thus having an advantage that the construction period can be
15 shortened.

[0062]

In the road structure 100, the cover plate is removed after the injection and solidification step is completed. This step is referred to as a cover plate removing step. The road floor slab 99 is installed after the cover plate removing step. This
20 step is referred to as a floor slab installation step.

[0063]

Fig. 14 is a side view showing an example of a cover plate 399. The cover plate 399 is placed on the bearing piles 10 that are temporarily assembled at the time of repeating the steel pipe pile driving step and the temporary joining step. The
25 cover plate 399 shown in Fig. 14 includes a pile head block 350a that is temporarily provided. Therefore, the cover plate 399 can be installed by causing the pile head block 350a to be fitted on the pile head 12 without installing the upper end panel point part 50a of the road structure 100. With the use of such a cover plate 399, only the steel pipe pile driving step can be collectively performed and hence, it is possible to
30 shorten a time during which a pile driver is in use.

[0064]

(Bearing pile 10)

There is one case where the bearing pile 10 according to Embodiment 1 is formed from one steel pipe, and there is another case where the bearing pile 10 according to Embodiment 1 is formed by joining two or more steel pipes. Each bearing pile 10a shown in Fig. 1 is formed such that, at the joint portion 11 shown by a triangle symbol in the drawing, the steel pipe strut 30 is joined by welding to the upper side of the first steel pipe pile 20a driven into the ground 90. In this case, the joint portion 11 may include the intermediate panel point part 50b shown in Fig. 9. The joint portion 11 may have a structure of joining the first steel pipe pile 20a and the steel pipe strut 30 with each other by using the intermediate panel point part 150b shown in Fig. 11. The bearing pile 10b shown in Fig. 1 is formed from only the second steel pipe pile 20b.

[0065]

Fig. 15 is a diagram illustrating the cross sectional structure of a road structure 1000 according to a comparison example. Fig. 15 shows a cross section perpendicular to the first direction, which is a direction in which a road extends. In the road structure 1000 according to the comparison example, a plurality of steel pipe piles 1010p are driven into a ground 90, and a footing 1091 is installed on portions of the steel pipe piles 1010p that are located in the vicinity of the ground surface. Further, a strut 1010 formed from a steel pipe having a larger outer diameter than the steel pipe piles 1010p is erected on the footing 1091.

[0066]

For the steel pipe piles 1010p of the road structure 1000 according to the comparison example, steel pipe piles specified in JIS A 5525 are often used generally. The steel pipe pile 1010p is often formed from the SKK400 or the SKK490, for example. The SKK400 or the SKK490 having a diameter of 400 to 600 mm and a plate thickness of 9 to 19 mm is often used.

[0067]

The strut 1010 of the road structure 1000 according to the comparison example

is a steel pipe column produced by combining pressed steel materials, for example.
A steel pipe column having a diameter of 3000 mm or more, for example, is used.
[0068]

5 The steel pipe piles 1010p according to the comparison example are located in
the ground 90 and hence, it is difficult to repair the steel pipe piles 1010p when the
steel pipe piles 1010p receive damage. Accordingly, in general, to prevent the steel
pipe piles 1010p from receiving damage due to a large earthquake, the steel pipe
piles 1010p are designed to be deformed within an elastic deformation range for a
material even when receiving inputs caused by earthquakes.

10 [0069]

The footing 1091 formed on the pile heads of the steel pipe piles 1010p
according to the comparison example forms the foundation of the strut 1010 to be
erected, and has a large horizontal projection area and hence, even when the footing
1091 receives inputs caused by earthquakes, the footing 1091 is supported by the
15 ground 90 surrounding the footing 1091. Consequently, the steel pipe piles 1010p
do not receive damage even due to a large earthquake.

[0070]

The strut 1010 according to the comparison example is formed from a
produced pipe having a relatively large outer diameter, and is also designed as
20 follows for inputs caused by large earthquakes. The strut 1010 is designed by taking
into account that, during a large earthquake (level 2 earthquake motion), the strut
1010 is allowed to be plastically deformed after exceeding the yield point, thus
absorbing energy due to plastic deformation. A steel pipe part used for the strut
1010 is required to have the following characteristics by SPECIFICATIONS FOR
25 HIGHWAY BRIDGES ("SPECIFICATIONS FOR HIGHWAY BRIDGES, Part II STEEL
BRIDGES, Japan Road Association, December 2017, p.10-11).

(1) Charpy absorbed energy: JIS Z 2242 ≥ 27 J

(In the case where a steel grade is SM400, SM490, SM490Y, or SMA490, and a steel
material has a thickness of more than 16 mm and 50 mm or less)

30 Further, Steel Road Bridge Design Handbook ("Steel Road Bridge Design

Handbook", Japan Road Association, November 2020, p.41-48) states that studies on yield ratio are also required in the case of taking into account plasticization of the steel material for a structure, and JIS G 3475 Carbon steel pipes for building structure requires the following characteristics for yield ratio in the case of a welded steel pipe.

5 (2) Yield ratio = yield stress/tensile strength $\leq$ 85%

The strut 1010 according to the comparison example satisfies the above-mentioned characteristics (1) and (2), so that an increase in strength is expected even after yielding and hence, the strut 1010 exhibits resilience against a seismic force.

10 [0071]

The road structure 1000 according to the comparison example described above is designed to suppress damage against inputs caused by a large earthquake. However, a large scale structure, such as the footing 1091 installed in the ground 90 and the strut 1010, is required and hence, it is difficult to apply the road structure 1000 according to the comparison example to a road installed along the slope of a mountain, for example.

15 [0072]

In contrast, in the case of the road structure 100 according to Embodiment 1, each steel pipe pile 20 driven into the ground 90 is caused to protrude from the ground 90, and the upper end panel point part 50a or the steel pipe strut 30 is joined to the upper side of the steel pipe pile 20 to increase the protruding amount from the ground 90. Further, in the bearing piles 10a and 10b, positional accuracy of the upper end panel point parts 50a is ensured by causing the upper end panel point parts 50a and the steel pipe struts 30 to be eccentric to the first steel pipe piles 20a or the second steel pipe piles 20b by using the upper end panel point parts 50a and the intermediate panel point parts 50b. In general, when there is a large protruding amount from the ground 90, the pile heads 12 of the bearing piles 10a and 10b easily have positional errors relative to the designed positions. However, the bearing piles 10a and 10b according to Embodiment 1 employ the eccentric joint structure and hence, it is possible to easily ensure positional accuracy of the pile heads 12 and the

upper end panel point parts 50a.

[0073]

The bearing piles 10a and 10b are formed from the same material as the steel pipe pile 1010p installed in the ground 90 in the comparison example and as a steel pipe pile specified in JIS A 5525. That is, an SKK material for steel pipe pile or an STK material for steel pipe for general structure is used. Accordingly, strength of the bearing piles 10a and 10b according to Embodiment 1 in the ground 90 is sufficiently ensured. However, regarding the material of the steel pipe pile specified in JIS A 5525, strength at the time of plastic deformation after yielding is not specified at all, so it is assumed that strength of portions protruding from the ground 90 cannot be ensured.

[0074]

In view of the above, the bearing piles 10a and 10b according to Embodiment 1 are formed from steel pipes suitable for earthquake resistance of the road structure 100. To be more specific, the road structure 100 of Embodiment 1 uses the bearing piles 10a and 10b that are formed from "ERW-T" subjected to post weld heat treatment, which will be described below.

[0075]

Fig. 16 shows hysteresis curves obtained by performing a cyclic loading test on steel pipes used for the bearing piles 10 according to Embodiment 1. Fig. 17 is a schematic view of a test specimen for the cyclic loading test. Regarding the steel pipe used for the bearing pile 10 according to Embodiment 1, the relationship between horizontal displacement δ /horizontal displacement δ_y at the time of yielding and horizontal load P_H is expressed by stable hysteresis curves having spindle shapes as shown in Fig. 16, the horizontal displacement δ /the horizontal displacement δ_y at the time of yielding and the horizontal load P_H being obtained by performing a cyclic loading test by applying a level 2 earthquake motion.

[0076]

As shown in Fig. 17, in the test specimen for the steel pipe used for the bearing pile 10, an outer pipe shown at the lower end portion corresponds to the upper end

panel point part 50a, an inner pipe corresponds to the bearing pile 10, and a fixing part corresponds to the first girder part 41 or the second girder part 40. The inner pipe used as the test specimen in Fig. 16 and Fig. 17 is an electric resistance welded steel pipe formed from an STK400 material for steel pipe for general structure, and the yield strength of a base metal is 395 N/mm². For the inner pipe used as the test specimen, a pipe having an outer diameter of 508 mm and a plate thickness of 19 mm was used.

[0077]

In the cyclic loading test from which the hysteresis curves shown in Fig. 16 are obtained, a cyclic load was applied in the horizontal direction while a constant axial load P_v was applied to the upper end of the test specimen. The cyclic load in the horizontal direction was applied to the upper end of the inner pipe used as the test specimen such that, when the horizontal displacement of the steel pipe at the time of nominal yield strain is taken as " δ_y ", the maximum horizontal displacement is $\delta = \pm 5\delta_y$. The horizontal load P_H being a cyclic load was increased with each cycle of cyclic loading. In the test shown in Fig. 16 and Fig. 17, the horizontal load P_H applies a load corresponding to a level 2 earthquake motion. The calculated value of the maximum load caused by the level 2 earthquake motion is $P_H = 482\text{kN}$, and the horizontal displacement δ of the steel pipe at this point is $\delta/\delta_y = 2$. The steel pipe used as the test specimen yields, and displacement of the steel pipe is approximately 2 times the displacement of the steel pipe at the time of yielding.

[0078]

As shown in Fig. 16, when a load is applied beyond the maximum load of the level 2 earthquake motion, stable hysteresis curves having spindle shapes are obtained up to $\delta/\delta_y = 5$. At the point of $\delta/\delta_y = 5$, sudden breakage, such as buckling or fracture, did not occur in the steel pipe used as the test specimen. That is, even when the bearing pile 10 using this steel pipe used as the test specimen receives a level 2 earthquake motion, the steel pipe is plastically deformed, thus stably absorbing earthquake energy and hence, breakage, such as buckling or fracture, does not occur.

[0079]

(Production of steel pipe forming bearing pile 10)

Fig. 18 is a diagram illustrating a step of welding an electric resistance welded steel pipe used for the bearing pile 10 according to Embodiment 1. An electric resistance welded steel pipe is used for the bearing pile 10 according to Embodiment 1. A steel plate is moved from left to right in Fig. 18 while being bent by rolls. In P-P cross section, the steel plate is bent into a C shape. In Q-Q cross section, the end portions of the bent plate are proximate to each other. In R-R cross section, the end portions come into contact with each other. In this process, by causing high frequency electric current to flow between power feeding contactors installed at both ends of the steel plate, electric current is concentrated on a joint portion in R-R cross section. The surface layer of the joint portion is rapidly heated by resistance heat, thus being melted, and the end portions of the bent plate are pressed and joined by squeeze rolls in S-S cross section. A welded part obtained by pressing the end portions of the bent plate has a bead protruding outward from the surface of the electric resistance welded steel pipe. In T-T cross section, the bead protruding outward from the surface of the welded part is removed by cutting.

[0080]

In general, the production for a steel pipe material is completed with the material maintained in this state. However, an electric resistance welded steel pipe where post heat treatment is performed on a welded part is used for the bearing pile 10 according to Embodiment 1. For the heat treatment method for the welded part of an electric resistance welded steel pipe, there is a method described in Japanese Unexamined Patent Application Publication No. 2009-173995, for example. In this method, an induction heating apparatus is installed for the step performed after the step that uses a bead cutter configured to remove by cutting an outer surface bead. The induction heating apparatus is configured such that a plurality of induction coils are disposed, in the form of a stand, on each of the outer surface side and the inner surface side of the welded part of the electric resistance welded steel pipe to perform induction heating on the outer surface side and the inner surface side of the welded

part. Operating conditions for the induction coils on the inner surface side are set such that full power is set for upstream stands where the temperature of the inner surface is increased until exceeding the Ac3 transformation point, and the temperature of the inner surface is kept at a predetermined temperature of more than the Curie point in the subsequent stands. Operating conditions for the induction coils on the outer surface side are set such that a power of more than zero and less than full power is set for stands up to where the temperature of the outer surface exceeds the Ac3 transformation point, and the temperature of the outer surface is kept at a predetermined temperature of more than the Curie point in stands subsequent to the above-mentioned stand. Induction heating is performed under such conditions. It is described that, with the above-mentioned heat treatment method, it is possible to increase Charpy absorbed energy of a material processed and produced into an electric resistance welded steel pipe from a hot-rolled steel strip (Ac3 transformation point: 860 degrees C) containing, by mass%, 0.05% of C, 0.2% of Si, and 1.4% of Mn based material, the electric resistance welded steel pipe having an outer diameter of 600 mm and a plate thickness of 19.1 mm.

[0081]

Fig. 19 is a cross-sectional view of the welded part of the electric resistance welded steel pipe used for the bearing pile 10 according to Embodiment 1. Fig. 19 shows the welded part of the electric resistance welded steel pipe subjected to heat treatment. The lower side of the welded part in Fig. 19 corresponds to the outer surface of the steel pipe, and the upper side of the welded part in Fig. 19 corresponds to the inner surface of the steel pipe. A weld line is a portion shown by an arrow. Portions shown by ▼ and ▲ on the inner and outer surfaces show boundaries of a heat affected zone formed by welding. For boundary lines of the heat affected zone formed by welding, a trace can be observed that has a hand drum shape having a width decreasing toward the center in the plate thickness from positions, on each of the inner and outer surfaces of the steel pipe, approximately 2 mm away from the weld line in left and right directions. The range of post weld heat treatment on the outer surface of the steel pipe is approximately 20 mm in each of the leftward

direction and the rightward direction from the center position of heat treatment. The range of post weld heat treatment on the inner surface of the steel pipe is approximately 7 mm. The weld line is deviated from the vicinity of the center of heat treatment by approximately 4 mm. However, deviation between the weld line and the center of heat treatment depends on accuracy of a seam detection device in a production line, and there may be cases where deviation is zero. As shown in the drawing, the heat affected zone formed by welding is within a range of post weld heat treatment and hence, it can be understood that, with the above-mentioned heat treatment method, the heat affected zone formed by welding is subjected to heat treatment after welding.

[0082]

(Strength of bearing pile 10)

The bearing pile 10 according to Embodiment 1 is an electric resistance welded steel pipe produced by the above-mentioned production method, and is particularly an electric resistance welded steel pipe where a yield ratio for respective parts, including the welded part, of 85% or less, and Charpy absorbed energy of 27 J or more are ensured. With such a configuration, the bearing pile 10 is plastically deformed corresponding to a level 2 earthquake motion, thus stably absorbing energy.

[0083]

Fig. 20 is a table showing outer diameter, plate thickness, and components of electric resistance welded steel pipes from which test pieces for a strength test are sampled. There are two types of electric resistance welded steel pipe from which test pieces are sampled, that is, "ERW-T" and "ERW-N". The ERW-T is produced by the production method shown in Fig. 18, and is subjected to post weld heat treatment. The ERW-N has chemical components substantially equal to those of the ERW-T, and is not subjected to heat-treatment. Both of the electric resistance welded steel pipes satisfy JIS standard (JIS A 5525).

[0084]

(Results of tensile test)

Fig. 21 is a diagram showing the relationship between nominal stress and

nominal strain obtained by performing a tensile test using test pieces. Fig. 22 shows the results obtained by performing the tensile test using the test pieces. Tensile test pieces matching JIS 12C test piece were sampled in the axial direction of an electric resistance welded steel pipe at four positions, on the cross section of the steel pipe, of 0 degrees, 22.5 degrees, 90 degrees, and 180 degrees from a welded part serving as the reference. Fig. 22 shows the results of yield stress σ_y , tensile strength σ_u , and yield ratio $YR = \sigma_y/\sigma_u$ of the test pieces.

[0085]

As shown in Fig. 21(a), in the test results for the ERW-N, which is not subjected to post weld heat treatment, the test pieces sampled from the base metal, which is not the welded part, at 22.5 degrees, 90 degrees, and 180 degrees have substantially the same curves. However, the test piece sampled at the position of 0 degrees, which includes the welded part, has a yield point and tensile strength noticeably higher than those of the test pieces sampled from the base metal. In contrast, in the case of the ERW-T shown in Fig. 21(b), a test piece sampled at the position of 0 degrees, which includes the welded part, and test pieces sampled at positions of 22.5 degrees, 90 degrees, and 180 degrees, which correspond to the base metal, have a reduced difference in curves.

[0086]

As shown in Fig. 22, in the case of the ERW-N, which is not subjected to post weld heat treatment, both yield stress σ_y and tensile strength σ_u at 0 degrees, which corresponds to the welded part, are larger than those of the base metal part, and yield ratio YR at 0 degrees is 0.94. In contrast, in the ERW-T, which is subjected to post weld heat treatment, there is a small difference between values of yield stress σ_y and tensile strength σ_u at 0 degrees, which corresponds to the welded part, and values of yield stress σ_y and tensile strength σ_u of the base metal, and a yield ratio YR at 0 degrees is 0.85. That is, by performing heat treatment on the welded part of the electric resistance welded steel pipe forming the bearing pile 10, it is possible to suppress hardening of the welded part caused by welding, it is possible to allow the welded part to have a yield point and tensile strength equivalent to those of the base

metal part, and it is also possible to adjust the yield ratio YR of the welded part to 0.85 or less.

[0087]

Fig. 23 is a diagram showing the results of a Charpy test obtained by performing the tensile test using test pieces. There are two types of electric resistance welded steel pipe from which the test pieces are sampled, that is, "ERW-T" and "ERW-N". The ERW-T is used for the bearing pile 10, is produced by the production method shown in Fig. 18, and is subjected to post weld heat treatment. The ERW-N has chemical components substantially equal to those of the ERW-T, and is not subjected to heat-treatment. Test pieces for the Charpy test matching JIS Z 2242 V-notch test piece specified in SPECIFICATIONS FOR HIGHWAY BRIDGES II, described in the above-mentioned production method, were used, that is, test pieces sampled along the pipe circumferential direction and test pieces sampled along the pipe axis direction were used. For the test pieces in the pipe circumferential direction, three kinds of test pieces were used, that is, a test piece where the distance from the notch position to the weld line is 0 mm, a test piece where the distance from the notch position to the weld line is 1 mm, and a test piece where the distance from the notch position to the weld line is 3 mm. For the test piece in the pipe axis direction, one kind of test piece was used, that is, a test piece including the weld line and sampled along the pipe axis direction. A Charpy test was performed using three test pieces for each of four kinds of test pieces in total.

[0088]

Fig. 23 shows distribution of absorbed energy relative to distance by showing the distance in the circumferential direction from the position of the weld line on the horizontal axis. Regarding the ERW-N, which is not subjected to heat treatment, a test piece sampled along the pipe circumferential direction has a low absorbed energy on the weld line, and has Charpy absorbed energy of less than 27 J. In contrast, in the case of the ERW-T, which is subjected to heat treatment, both of a test piece sampled along the pipe circumferential direction and a test piece sampled along the pipe axis direction have Charpy absorbed energy of larger than 27 J.

[0089]

In SPECIFICATIONS FOR HIGHWAY BRIDGES, it is specified that Charpy absorbed energy is 27 J or more for SM490B with an applied plate thickness of $6 \text{ mm} \leq t \leq 40 \text{ mm}$, the SM490B being a material used for bridge piers. Regarding Charpy absorbed energy, according to the results shown in Fig. 23, the electric resistance welded steel pipe formed from an SKK material and forming the bearing pile 10 according to Embodiment 1 is produced by the above-described production method, and heat treatment is performed on the welded part of the electric resistance welded steel pipe and hence, it is possible to achieve Charpy absorbed energy of 27 J or more. Accordingly, although the bearing pile 10 according to Embodiment 1 is formed from an SKK material for steel pipe pile specified in JIS A 5525, the bearing pile 10 according to Embodiment 1 can exhibit, as a bridge pier, sufficient energy absorbing ability for an impact load during a large earthquake.

[0090]

(Modifications of upper end panel point part and intermediate panel point part)

A modification of the upper end panel point part 50a and the intermediate panel point part 150b of the road structure 100 according to Embodiment 1 will be described. An upper end panel point part 550a, 250a and an intermediate panel point part 550b, 250b, which will be described below, can be replaced with the upper end panel point part 50a and the intermediate panel point part 150b of the road structure 100 described above.

[0091]

Fig. 24 is a diagram illustrating the cross sectional structure of the upper end panel point part 550a of the road structure 100 according to Embodiment 1, and an area around the upper end panel point part 550a. Fig. 24(b) shows a cross section taken along E-E in Fig. 24(a). Fig. 25 shows a top plan view and a side view of the upper end panel point part 550a of the road structure 100 according to Embodiment 1. As shown in Fig. 25, the upper end panel point part 550a and the bearing pile 10 are joined by an eccentric joint part 560a. The eccentric joint part 560a is a portion of the upper end panel point part 550a, and is combined with the pile head 12 of the

bearing pile 10 to allow the adjustment of the position of the upper end panel point part 550a relative to the pile head 12. That is, the upper end panel point part 550a can be joined to the bearing pile 10 by the eccentric joint part 560a in a state where the center axis of the upper end panel point part 550a does not align with the center axis of the bearing pile 10. The eccentric joint part 560a used in the upper end panel point part 550a and an eccentric joint part 560b used in the intermediate panel point part 550b may be generically referred to as "eccentric joint part 560".

[0092]

The eccentric joint part 560a includes an insertion part 61 and rib parts 62. The insertion part 61 has a circular columnar shape. The rib parts 62 are joined to the outer peripheral surface of the insertion part 61, and radially extend. The insertion part 61 and the rib parts 62 are disposed inside the steel pipe part 51a, which is a cylindrical body forming the upper end panel point part 550a, and the lower portions of the insertion part 61 and the rib parts 62 protrude downward from the lower end of the steel pipe part 51a.

[0093]

Fig. 26 is a cross-sectional view taken along F-F in Fig. 25(b). A lower plate 59 is joined to the steel pipe part 51a of the upper end panel point part 550a, and has an opening port 59a from which the insertion part 61 protrudes from the inner portion of the steel pipe part 51a. The opening port 59a is open to an extent that allows the insertion of the insertion part 61. Each rib part 62 includes an internal rib part 62b and an external rib part 62a. The internal rib part 62b is disposed in the steel pipe part 51a. The external rib part 62a is joined to the lower side of the lower plate 59. That is, the rib part 62 is joined to the inner portion of the steel pipe part 51a and the outer portion of the steel pipe part 51a. The external rib parts 62a and the internal rib parts 62b need not be installed depending on the strength and rigidity of the insertion part 61.

[0094]

The upper ends of the insertion part 61 and the internal rib parts 62b are fixed by welding to an upper plate 58 forming the upper surface 57a of the upper end panel

point part 550a. Further, the lower ends of the internal rib parts 62b are joined by welding to the lower plate 59. The internal rib parts 62b are also joined to the outer peripheral surface of the insertion part 61. The internal rib parts 62b couple the upper plate 58, the lower plate 59, and the insertion part 61 with each other to ensure strength and rigidity.

[0095]

The external rib parts 62a are disposed below the lower plate 59, are joined to the lower surface of the lower plate 59, and are also joined to the outer peripheral surface of the insertion part 61. The external rib parts 62a couple the lower plate 59 and the insertion part 61 with each other to ensure strength and rigidity.

[0096]

As shown in Fig. 25, the upper plate 58 is joined to the upper portion of the upper end panel point part 50a, and has two filling holes 56a that penetrate through the plate-like part. The filling holes 56a are formed at positions symmetrical relative to the insertion part 61. As shown in Fig. 26, the lower plate 59 also has two filling holes 56a in the same manner as the upper plate 58. The filling holes 56a are holes for injecting the filler 80 into a space formed between the insertion part 61 and the pile head 12. That is, in a state where the upper end panel point part 50a is placed on the pile head 12, the filling holes 56a communicate the outside, the space in the steel pipe part 51a, and the space formed between the insertion part 61 and the pile head 12 with each other. For example, in injecting a filler, such as concrete or mortar, from the outside, an inject pipe (not shown in the drawing) is inserted into the inside through the filling hole 56a formed in the upper plate 58, and the filler is injected into the filling hole 56a formed in the lower plate 59. The filler 80 is filled into the inside of the pile head 12, into which the eccentric joint part 560a forming a portion of the upper end panel point part 50a is inserted, and the filler 80 is solidified, thus joining the upper end panel point part 50a and the pile head 12 with each other.

[0097]

As shown in Fig. 24, the pile head 12 has open distal ends, and a filler receiving plate 16 is installed in a space in the pile head 12. The filler receiving plate

16 is disposed at a position lower than the lower end of the insertion part 61 inserted into the pile head 12. The filler receiving plate 16 is a part that supports the filler 80, which is injected through the filling hole 56a, to hold the filler in the pile head 12.

[0098]

5 The end surface 14 of the pile head 12 abuts against the lower surface of the lower plate 59 of the upper end panel point part 50a. That is, the upper end panel point part 50a is placed on the end surface 14 of the bearing pile 10. Such a placement determines the position of the upper end panel point part 550a in the height direction. The upper end panel point part 50a may be displaced in the
10 horizontal direction by an amount corresponding to a gap between the eccentric joint part 560a and the pile head 12. With such a configuration, the upper end panel point part 50a can be disposed at the position as designed even when the position of the center axis of the bearing pile 10 deviates.

[0099]

15 As shown in Fig. 26, the insertion part 61 is a steel pipe having a cylindrical shape. However, the insertion part 61 is not limited to a steel pipe having a cylindrical shape, and may be a steel pipe having a rectangular shape, an elliptical shape, an elongated circular shape, or a polygonal shape in cross section. It is desirable that the insertion part 61 have the same strength and rigidity in both the up-
20 down direction and the left-right direction on a paper on which Fig. 26 is drawn. In the road structure 100 according to Embodiment 1, the insertion part 61 has a cylindrical shape, and has the same strength and rigidity in all directions. The shape of the insertion part 61 may be suitably changed corresponding to strength and rigidity required for the road structure 100.

25 [0100]

 The lower end of the insertion part 61 may be closed by a plate part 64. The plate part 64 prevents the intrusion of the filler 80 into the inside of the insertion part 61, which is a steel pipe having a cylindrical shape, thus reducing the amount of the filler 80 required for joining the upper end panel point part 50a and the bearing pile 10
30 with each other. Further, the plate part 64 is formed with an outer shape larger than

the cross-sectional shape of the insertion part 61, thus protruding from the outer peripheral surface of the insertion part 61. Therefore, after the filler 80 is solidified, the insertion part 61 has increased strength in the direction in which the insertion part 61 is pulled out from the pile head 12.

5 [0101]

The eccentric joint part 560a that uses the above-mentioned insertion part 61 is also applicable to the intermediate panel point part 150b.

[0102]

Fig. 27 is a diagram illustrating the cross sectional structure of the intermediate panel point part 550b of the road structure 100 according to Embodiment 1, and an area around the intermediate panel point part 550b. The intermediate panel point part 550b includes an eccentric joint part 560b in the same manner as the upper end panel point part 550a. The eccentric joint part 560b includes an insertion part 61 and rib parts 62. The insertion part 61 is provided in such a way as to protrude from both an upper plate 58 and a lower plate 59. The rib parts 62 join the insertion part 61, the upper plate 58, and the lower plate 59 with each other. The insertion part 61 is joined to the upper plate 58 and the lower plate 59 by the rib parts 62.

[0103]

The insertion part 61 is disposed in the inside of a steel pipe part 51b in such a way as to penetrate through the upper plate 58 and the lower plate 59. The insertion part 61 may be directly joined to the upper plate 58 and the lower plate 59.

[0104]

The insertion part 61 is not limited to a configuration shown in Fig. 27 where the insertion part 61 penetrates in the up-down direction. The configuration may be adopted where the insertion parts 61 are joined to the upper surface of the upper plate 58 and the lower surface of the lower plate 59, and extend in the up-down direction from the upper surface of the upper plate 58 and the lower surface of the lower plate 59.

[0105]

The insertion part 61 extending upward from the intermediate panel point part

550b is inserted into a steel pipe strut 30, forming an upper part. The insertion part 61 extending downward from the intermediate panel point part 550b is inserted into a first steel pipe pile 20a, forming a lower part. A filler 80 is filled in a state where the insertion parts 61 extending in the upward direction from the intermediate panel point part 550b is inserted into the steel pipe strut 30, and where the insertion parts 61 extending in the downward direction from the intermediate panel point part 550b is inserted into the first steel pipe pile 20a, so that the insertion parts 61 join the steel pipe strut 30, the intermediate panel point part 550b, and the first steel pipe pile 20a with each other. In the same manner as the upper end panel point part 550a, the eccentric joint part 560b of the intermediate panel point part 550b allows the first steel pipe pile 20a, forming the lower part, to be joined with the intermediate panel point part 550b in a state where the center axis of the first steel pipe pile 20a does not align with the center axis of the intermediate panel point part 550b. The eccentric joint part 560b also allows the intermediate panel point part 550b to be joined with the steel pipe strut 30 in a state where the center axis of the intermediate panel point part 550b does not align with the center axis of the steel pipe strut 30.

[0106]

Further, each of the steel pipe strut 30 and the first steel pipe pile 20a has a filling hole 17, and the filler 80 is filled through these filling holes 17. The filler 80 is solidified, thus joining the intermediate panel point part 550b with the steel pipe strut 30, and with the first steel pipe pile 20a.

[0107]

The cross sectional structure of the steel pipe part 51b of the intermediate panel point part 550b according to Embodiment 1 taken along G-G in Fig. 27 is substantially equal to the structure shown in Fig. 26. However, the filling hole 56a need not be formed in the cross section taken along G-G.

[0108]

Next, another modification of the upper end panel point part 50a and the intermediate panel point part 150b of the road structure 100 according to Embodiment 1 will be described.

[0109]

Fig. 28 is a diagram illustrating the cross sectional structure of the upper end panel point part 250a, which is a modification of the upper end panel point part 50a of the road structure 100 according to Embodiment 1, and an area around the upper end panel point part 250a. Fig. 29 is a top plan view of the upper end panel point part 250a shown in Fig. 28. The upper end panel point part 250a includes stringer connections 52a and a cross girder connection 53a, each stringer connections 52a connecting a steel pipe part 251a with a stringer 41a, the cross girder connection 53a connecting the steel pipe part 251a with a cross girder 41b. The upper end panel point part 250a has a flat upper surface 57a.

[0110]

An eccentric joint part 260 is joined to an end surface 14 of a pile head 12 of each bearing pile 10. The lower end surface of the eccentric joint part 260 is joined to the pile head 12 of the bearing pile 10, and a plate part 261 forms the upper end surface of the eccentric joint part 260. The plate part 261 has a flat upper surface 262, so that a lower end surface 254a of the steel pipe part 251a of the upper end panel point part 250a can be placed on the upper surface 262. The plate part 261 is formed such that the upper surface 262 has a larger size than the lower end surface 254a of the steel pipe part 251a. Accordingly, the steel pipe part 251a of the upper end panel point part 250a is allowed to be placed on the upper surface 262 of the eccentric joint part 260 in a state of being displaced in the horizontal direction. That is, the bearing pile 10 and the upper end panel point part 250a can be joined to each other using the eccentric joint part 260 in a state where the center axis of the bearing pile 10 and the center axis of the upper end panel point part 250a are eccentric to each other. The eccentric joint part 260, which is the modification, may be referred to as "third eccentric joint part 260". Further, the upper surface 262 may be referred to as "joint surface".

[0111]

Fig. 30 shows a side view and a top plan view of the structure of the intermediate panel point part 250b, which is a modification of the intermediate panel

point part 150b of the road structure 100 according to Embodiment 1, and an area around the intermediate panel point part 250b. An eccentric joint part 260 may be used for joining an intermediate panel point part 250b and a first steel pipe pile 20a with each other. In the road structure 100, a steel pipe part 251b of the intermediate panel point part 250b has the same cross-sectional shape as the first steel pipe pile 20a. The intermediate panel point part 250b includes the steel pipe part 251b, stringer connections 52b, and a cross girder connection 53b. In the modification, the intermediate panel point part 250b may be integrally formed with the steel pipe strut 30 in Embodiment 1. With such a configuration, a girder part 40 can be installed on bearing piles 10a each formed by joining parts using the eccentric joint part 260.

[0112]

<Modification of road structure 100>

Next, a modification of the road structure 100 according to Embodiment 1 will be described.

[0113]

Fig. 31 is a diagram illustrating the cross sectional structure of the modification of the road structure 100 according to Embodiment 1. As shown in Fig. 2 to Fig. 4, in the road structure 100 of Embodiment 1, two bearing piles 10 are arranged in a line in the second direction intersecting with the first direction in which a road extends.

However, two or more bearing piles 10 may be arranged in a line in the second direction. The road structure 100 may also include diagonal beams 48 each coupling between the upper end panel point part 50a and the intermediate panel point part 50b or between two intermediate panel point parts 50b while being inclined relative to the cross girder 41b. The diagonal beam 48 couples two panel point parts 50 positioned at diagonal corners of a rectangular structure including the bearing piles 10 and the cross girder 41b, or a rectangular structure including the bearing piles 10 and the cross girders 40b. In the road structure 100, the deformation of the frame is suppressed by a truss structure formed from the diagonal beams 48 and hence, it is possible to reduce stress in parts. The diagonal beams 48 include diagonal beams 48a and 48b installed in a line in the second direction. The diagonal beams 48a are

installed on the mountain side of the ground 90 on which the road structure 100 is installed, and the diagonal beams 48b are installed on the valley side. It is desirable that the diagonal beams 48a located on the mountain side be inclined in the direction along the slope. In Fig. 28, each diagonal beam 48b on the valley side is inclined in the direction symmetrical to the diagonal beam 48a on the mountain side. However, the diagonal beam 48b on the valley side may be inclined in the same direction as the diagonal beam 48a.

[0114]

The upper end panel point parts 50a and the cross girder 41b may be formed into an integral body in advance to form a panel point girder. Further, the intermediate panel point parts 50b and the cross girder 40b are formed into an integral body in advance to form a panel point girder. With such a configuration, it is possible to omit the labor of individually centering the panel point part 50 for the installation and hence, a reduction in labor and process can be achieved. The intermediate panel point parts 50b and the cross girder 40b are also formed into an integral body, thus having substantially the same advantageous effect. Further, the panel point parts 50 are joined with each other by diagonal parts. Accordingly, the deformation of the frame is suppressed by a truss structure formed from the diagonal beams 48 and hence, it is possible to reduce stress in parts.

[0115]

In Embodiment 1, as an example of the artificial ground structure, the description has been made for the road structure 100 where the road floor slabs 99 are provided only on the upper ends of the bearing piles 10. However, the road floor slab 99 is not limited to only one layer in the axial direction of the bearing piles 10, and may include floor slabs forming a plurality of layers. For example, the road floor slabs 99 or floor slabs used for other applications may be provided at the intermediate portions of the bearing piles 10. In this case, the road floor slabs 99 or the floor slabs used for other applications are installed on the intermediate panel point parts 50b, 150b, 250b or 550b. There may be cases where some of the plurality of floor slabs are used as the road floor slabs 99, and others are used as floor slabs for

installing auxiliary equipment.

[0116]

(Advantageous effects of road structure 100 according to Embodiment 1)

The road structure 100 according to Embodiment 1 includes the bearing piles
5 10 driven into the ground in lines in the first direction, in which a road extends, and in
the second direction intersecting with the first direction, the upper end panel point
parts 50a installed on the upper ends of the bearing piles 10, the first girder parts 41
each connecting two upper end panel point parts 50a disposed adjacent to each other,
and the road floor slabs 99 installed on the upper end panel point parts 50a and the
10 first girder parts 41. The hysteresis curves of the bearing pile 10 for horizontal
displacement and horizontal load when the bearing pile 10 receives a level 2
earthquake motion have spindle shapes. With such a configuration, in the road
structure 100, it is possible to adjust the position of the pile head 12 of each bearing
pile 10 having a long protruding length from the ground 90, and it is also possible to
15 adjust the position of each upper end panel point part 50a joined to the pile head 12
and the position of each first girder part 41. That is, it is possible to perform
positional adjustment by displacing a part by an amount corresponding to an error
between the center axis of the lower part and the center axis of the upper part, of the
steel pipe pile 20, the steel pipe strut 30, and the upper end panel point part 50a
20 forming the road structure 100, the lower part being disposed at a lower position, the
upper part being joined to the upper side of the lower part. Therefore, in erecting the
bearing piles 10 on the ground 90, it is possible to easily ensure accuracy of the
position of each upper end panel point part 50a. Although the road structure 100
includes the bearing piles 10 having a long protruding amount from the ground 90, the
25 road structure 100 is configured to stably absorb energy due to plastic deformation
even when the bearing pile 10 receives a level 2 earthquake motion. Accordingly,
the road structure 100 is excellent in earthquake resistance.

[0117]

According to the road structure 100 according to Embodiment 1, each bearing
30 pile 10 is formed from an electric resistance welded steel pipe subjected to heat

treatment, has a yield ratio for respective parts, including a welded part, of 85% or less, and has Charpy absorbed energy of 27 J or more. With such a configuration, the bearing pile 10 can be formed from an electric resistance welded steel pipe, and energy absorption performance of the bearing pile 10 is ensured.

5 [0118]

According to the road structure 100 according to Embodiment 1, in a step performed after a weld bead is cut in production of the steel pipe, each bearing pile 10 is subjected to heat treatment by using an induction heating apparatus where induction coils are installed on the inner surface or the outer surface of the steel pipe. Therefore, the bearing pile 10 is formed from an electric resistance welded steel pipe to which post weld heat treatment is applied and hence, the welded part also has performance equivalent to the performance of other portions of the base metal. Accordingly, energy absorption performance of the bearing pile 10 is ensured.

[0119]

15 According to the road structure 100 according to Embodiment 1, an SKK material for steel pipe pile, or an STK material for steel pipe for general structure is used for each bearing pile 10. With such a configuration, the strength under the ground 90 of the bearing piles 10 of the road structure 100 is ensured as in the conventional technique, and earthquake resistance of portions protruding from the ground is also ensured.

20 [0120]

Embodiment 2.

In Embodiment 2, the detailed layout of the intermediate panel point parts 50b, 150b on the bearing piles 10 of the artificial ground structure, such as the road structure 100 according to Embodiment 1, and setting of the protruding amount of the bearing pile 10 will be described. In the respective drawings, the respective components of a road structure 100 according to Embodiment 2 having the same functions as those in Embodiment 1 are given the same reference symbols as used in the drawings for describing Embodiment 1.

30 [0121]

Fig. 32 is a schematic view showing an example of the road structure 100 according to Embodiment 2. Fig. 32 is a schematic view of the road structure 100 as viewed in the x direction. As shown in a section K in Fig. 32, the road structure 100 has a structure where the upper ends of two bearing piles 10 are connected with each other by a first girder part 41, the two bearing piles 10 differing to each other in lengths h of portions protruding from a surface 94 of a ground 90. As shown in a section L in Fig. 32, the road structure 100 has a structure where the upper ends of two bearing piles 10 are connected with each other by a first girder part 41, and an intermediate panel point part 50b is provided to the intermediate portion of one bearing pile 10. As shown in a section M in Fig. 32, the road structure 100 also has a structure where the upper ends of two bearing piles 10 are connected with each other by a first girder part 41, and intermediate panel point parts 50b provided to the intermediate portions of the two bearing piles 10 are connected with each other by a second girder part 40. The intermediate panel point part 50b may be replaced with the intermediate panel point part 150b, 250b, or 550b. Further, the intermediate panel point part 50b may be a panel point part 50 that does not use an eccentric joint part 60, 260.

[0122]

The road structure 100 includes a plurality of bearing piles 10. In the case where the road structure 100 is installed on the ground 90 having a slope or undulations, such as a mountain area, for example, there may be cases where the plurality of bearing piles 10 differ from each other in length h of portions protruding from the ground 90. When the road structure 100 receives a level 2 earthquake motion, for example, the portions protruding from the surface 94 of the ground 90 are displaced in the horizontal direction (the x direction and the y direction). Focusing on the bearing piles 10 disposed adjacent to each other in the x direction or the y direction, bending moment M and stress σ generated in the bearing pile 10 changes depending on the length h of the portion protruding from the ground 90 and on whether the intermediate portions are connected with each other by the second girder part 40. The road structure 100 is configured such that the bearing piles 10 are

plastically deformed, thus absorbing energy caused by earthquake motion, so that earthquake resistance is improved. Accordingly, it is desirable to set two bearing piles 10 disposed adjacent to each other such that an excessively large stress is prevented from being generated in one bearing pile 10.

5 [0123]

Although Fig. 32 shows the plurality of bearing piles 10 arranged in a line in the y direction in which the road structure 100 extends, in practice, the bearing piles 10 are arranged in a line also in the x direction (the direction perpendicular to the paper on which Fig. 32 is drawn), and the two bearing piles 10 disposed adjacent to each other include not only two bearing piles 10 arranged in a line in the y direction but also two bearing piles 10 arranged in a line in the x direction.

10 [0124]

The road structure 100 is a structure where the bearing piles 10 are connected with each other by the first girder parts 41 and the second girder parts 40. The bearing pile 10 can be modeled as a both ends fixed beam where a fulcrum 98 where the bearing pile 10 intersects with the surface 94 of the ground 90, an upper end panel point part 50a, and the intermediate panel point part 50b, 150b form fixed ends. Horizontal displacement δ and stress σ that are generated in the respective bearing piles 10 forming the road structure 100 will be described below.

15 20 [0125]

Fig. 33 is an enlarged view of a section K shown in Fig. 32. In the section K, two bearing piles 10 are connected with each other by a first girder part 41 at the upper ends thereof. Therefore, when a road floor slab 99 is displaced in the horizontal direction by δ due to an earthquake motion, the displacement δ_1 of the upper end of one bearing pile 10 is equal to the displacement δ_2 of the upper end of the other bearing pile 10 ($\delta_1 = \delta_2$). Broken lines shown in Fig. 33 show horizontal displacements δ of the bearing piles 10 at respective heights from the ground 90.

25 [0126]

In Fig. 33, a short bearing pile 10 is referred to as "inter-node part 10A", and a long bearing pile 10 is referred to as "inter-node part 10B". When the protruding

length of one inter-node part 10A from the ground 90 is taken as "h1", and the protruding length of the other inter-node part 10B from the ground 90 is taken as "h2", $h1 < h2$ is established. When the road floor slab 99 receives predetermined horizontal displacement δ , stress σ generated in the bearing pile 10 takes a maximum value at the upper end panel point part 50a and the fulcrum 98, forming the fixed ends. Respective calculation formulae for bending moment, horizontal displacement, and generated stress that are generated in a both ends fixed beam with the axis extending in the vertical direction are expressed as follows.

$$M = P \cdot h/2 \dots (1)$$

$$\delta = P \cdot h^3/(12E \cdot I) \dots (2)$$

$$\sigma = M/Z \dots (3)$$

Where "M" denotes bending moment, "P" denotes horizontal load, "h" denotes length of inter-node part, " δ " denotes horizontal displacement, "E" denotes Young's modulus, "I" denotes second moment of area, " σ " denotes maximum stress generated in inter-node part, and "Z" denotes section modulus.

[0127]

Based on the above-mentioned formulae (1) to (3), horizontal displacement δ is expressed by the following formula.

$$\delta = 2M/h \times h^3/(12E \cdot I) = \sigma Z h^2/(6E \cdot I) \dots (4)$$

[0128]

The relationship between stress σ_1 generated in the inter-node part 10A shown in Fig. 33 (hereinafter, maximum stress may be simply referred to as "stress") and stress σ_2 generated in the inter-node part 10B shown in Fig. 33 is expressed by the following formula (5) based on the above-mentioned formula (4) provided that the inter-node parts 10A and 10B are equal to each other in material and cross-sectional shape, and are also equal to each other in Young's modulus E, second moment of area I, section modulus Z, and yield stress σ_y . Further, as shown in Fig. 33, $h2 \geq h1$ is established, and the horizontal displacement δ of the inter-node part 10A and the horizontal displacement δ of the inter-node part 10B are equal to each other, and are expressed as $\delta = \delta_1 = \delta_2$. Based on the above and the above-mentioned formula

(4), the following formula (5) is derived.

$$\sigma_2/\sigma_1 = (h_1/h_2)^2 \dots (5)$$

That is, in the structure shown in Fig. 33, the inter-node part 10A having a shorter protruding length has a larger maximum value of generated stress than the inter-node part 10B having a longer protruding length.

[0129]

Fig. 34 is an enlarged view of the bearing pile 10a including the intermediate panel point part 50b or 150b, of bearing piles 10a shown in Fig. 32. The description will be made, with reference to Fig. 34, for relationship between σ_3 and σ_4 that are generated in inter-node parts 10C and 10D when the intermediate panel point part 50b or 150b is provided to the bearing pile 10 (in the case of two layers). The bearing pile 10a can be modeled such that the fulcrum 98, the intermediate panel point part 50b, and the upper end panel point part 50a form fixed ends. A portion from the fulcrum 98 to the intermediate panel point part 50b is taken as the inter-node part 10C, a portion from the intermediate panel point part 50b to the upper end panel point part 50a is taken as the inter-node part 10D, the length of the inter-node part 10C is taken as "h3", the length of the inter-node part 10D is taken as "h4", and $h_3 < h_4$ is established. In the case where the intermediate panel point part 50b is located at the upper end or the lower end of the bearing pile 10, such a bearing pile 10 has the configuration same as that of the bearing pile 10 having no intermediate panel point part 50b in the same manner as the bearing pile 10 shown in Fig. 33.

[0130]

Stress σ generated in the inter-node parts 10C and 10D of the bearing pile 10 when the road floor slab 99 receives predetermined horizontal displacement δ has the maximum value at the upper end panel point part 50a, the intermediate panel point part 50b, and the fulcrum 98, forming the fixed ends. Assuming that the horizontal displacement of the road floor slab 99 is " δ ", the relationship between the horizontal displacement δ_3 of the inter-node part 10C and the horizontal displacement δ_4 of the inter-node part 10D is expressed by $\delta = \delta_3 + \delta_4$.

[0131]

Based on the above-mentioned formula (4), the relationship between stress σ_3 generated in the inter-node part 10C of the bearing pile 10a shown in Fig. 34 and stress σ_4 generated in the inter-node part 10D of the bearing pile 10a shown in Fig. 34 is expressed by the following formula.

$$\sigma_4/\sigma_3 = h_4/h_3 \dots (6)$$

That is, in the structure shown in Fig. 34, the inter-node part 10C having a shorter length has a lower maximum value of generated stress than the inter-node part 10D having a longer length.

[0132]

Assume a case where the intermediate panel point part 50b is located at the center of the bearing pile 10a in Fig. 34, that is, a case where $h_3 = h_4 = h/2$. In this case, the horizontal displacement of the inter-node part 10C and the horizontal displacement of the inter-node part 10D are expressed as $\delta_3 = \delta_4 = \delta/2$, and the stress σ_3 generated in the inter-node part 10C and the stress σ_4 generated in the inter-node part 10D are expressed as $\sigma_3 = \sigma_4$. Accordingly, based on the above-mentioned formula (4), the following is obtained.

$$\delta = 2\sigma_3 \cdot Z \times (h/2)^2 / (6E \cdot I) \dots (7)$$

[0133]

Assume another case where the bearing pile 10a is not provided with the intermediate panel point part 50b in Fig. 34 (in the case of one layer). In this case, the horizontal displacement δ of the bearing pile 10a is expressed as follows.

$$\delta = \sigma \cdot Z \times h^2 / (6E \cdot I) \dots (8)$$

[0134]

In both of the case where the bearing pile 10a has one layer and the case where the bearing pile 10a has two layers, the bearing pile 10a has the same horizontal displacement δ expressed by the above-mentioned formula (7) or formula (8) and hence, $\sigma_3 = 2 \cdot \sigma$ is obtained based on the above-mentioned formula (7) and formula (8). That is, this means that in the case where the intermediate panel point part 50b is provided at the center of the bearing pile 10a (in the case of two layers), the stress σ_3 generated in the inter-node part 10C and the stress σ_4 generated in the

inter-node part 10D are 2 times as large as those in the case where the intermediate panel point part 50b is not provided (in the case of one layer). This means that even in the case where the inter-node part 10A is in the plastic region (in a yielding state), and the inter-node part 10B is not in a yielding state in Fig. 33, by disposing the intermediate panel point part 50b on the inter-node part 10B to form two inter-node parts 10C and 10D, it is possible to cause the inter-node part 10C or 10D to yield by increasing stress generated in the inter-node part 10C or 10D. By installing the intermediate panel point part 50b or 150b to form a two-layer structure by utilizing this principle when the bearing pile 10 has an extremely large protruding amount h , both of the bearing pile 10 having one layer, which forms the reference, and the bearing pile 10 having two layers are configured to be in the plastic region. With such a configuration, both of the two bearing piles 10 disposed adjacent to each other can be caused to exhibit plastic energy absorbing ability and hence, it is possible to improve earthquake resistance.

[0135]

As shown in Fig. 34, also in the case of the bearing pile 10 including the intermediate panel point part 50b, when the length h_3 of the inter-node part 10C and the length h_4 of the inter-node part 10D are set to be the same, the inter-node part 10C and the inter-node part 10D are in the plastic deformation region at the same time, thus exhibiting higher energy absorbing capacity.

[0136]

It is desirable that the road structure 100 be configured to prevent concentration of stress on some of the inter-node parts 10A to 10D when the road structure 100 receives an earthquake motion. By causing a larger number of inter-node parts 10A to 10D to exhibit energy absorbing ability, excellent anti-seismic performance can be exhibited.

[0137]

Fig. 35 is an enlarged view of the section L shown in Fig. 32. In the road structure 100, the protruding length of the bearing pile 10 from the surface 94 of the ground 90 is determined by the environment in which the road structure 100 is

installed and the height of the road floor slab 99. The case may be considered in which two inter-node parts 10A and 10B shown in Fig. 33 have a large difference between lengths h_1 , h_2 , for example. However, even in such a case, by installing the intermediate panel point part 50b on the long bearing pile 10 shown in Fig. 33 to
5 cause the long bearing pile 10 to have the same structure as the bearing pile 10a shown in Fig. 34, the stress σ_1 generated in the short bearing pile 10 (the inter-node part 10A) shown in Fig. 35 and stresses σ_3 and σ_4 generated in the inter-node parts 10C and 10D of the long bearing pile 10a can be adjusted to similar values.

[0138]

10 Fig. 36 is an enlarged view of the section M shown in Fig. 32. In the case where two bearing piles 10 of the road structure 100 are focused on, and the two bearing piles 10 have a large protruding amount from the ground 90, the intermediate panel point part 50b may be installed on each of the two bearing piles 10, and the intermediate panel point parts 50b may be connected with each other. In this case,
15 by adjusting the positions of the intermediate panel point parts 50b on the respective bearing piles 10, values of stresses σ_{3a} , σ_{4a} , σ_{3b} and σ_{4b} generated in inter-node parts 10Ca, 10Da, 10Cb, and 10Db of the respective bearing piles 10 can be adjusted to similar values.

[0139]

20 Fig. 37 is a diagram schematically showing the relationship between the horizontal displacement δ and the stress σ of the respective inter-node parts 10A, 10B, 10C, 10D, 10Ca, 10Da, 10Cb, and 10Db shown in Fig. 33, Fig. 34, Fig. 35, and Fig. 36. Fig. 37(a) is a diagram for the case where there is a relatively large difference between the length h_1 of the inter-node part 10A shown in Fig. 33 and the
25 length h_2 of the inter-node part 10B shown in Fig. 33, for example. Fig. 37(b) is a diagram for the case where there is a relatively small difference between the length h_1 of the inter-node part 10A shown in Fig. 33 and the length h_2 of the inter-node part 10B shown in Fig. 33. Although Fig. 37 shows horizontal displacement δ and stress σ having a proportional relationship, this is because the relationship is simplified for
30 the sake of description. The relationship between horizontal displacement δ and

stress σ shown in Fig. 37 is true for the plurality of inter-node parts 10A, 10B, 10C, 10D, 10Ca, 10Da, 10Cb, and 10Db of the two bearing piles 10 shown in Fig. 34, Fig. 35, and Fig. 36. The road structure 100 according to Embodiment 2 is set such that the inter-node parts 10A, 10B, 10C, 10D, 10Ca, 10Da, 10Cb, and 10Db of the two adjacent bearing piles 10 have the relationship shown in Fig. 37(b).

[0140]

The relationship between horizontal displacement δ and stress σ shown in Fig. 37 will be described by taking the two bearing piles 10 shown in Fig. 33 as an example. In Fig. 37(a), a line shown by σ_1 shows a change in maximum value of generated stress σ_1 relative to the horizontal displacement δ of the inter-node part 10A, and a line shown by σ_2 shows a change in maximum value of generated stress σ_2 relative to the horizontal displacement δ of the inter-node part 10B. Fig. 37(a) shows the case where there is a relatively large difference in length between the inter-node part 10A and the inter-node part 10B. The inter-node part 10A and the inter-node part 10B are elastically deformed within a range of stress from 0 to the yield stress σ_y , and are plastically deformed within a range of stress from the yield stress σ_y to the ultimate stress σ_u . In the structure shown in Fig. 33, when the road floor slab 99 receives a horizontal load P_H due to an earthquake motion, thus being displaced by δ in the horizontal direction, the stress σ_1 in the inter-node part 10A becomes larger than the stress σ_2 in the inter-node part 10B. When horizontal displacement δ increases, the inter-node part 10A is plasticized after exceeding the yield stress σ_y , leading to a limit of strength when reaching the ultimate stress σ_u .

[0141]

At this point, the inter-node part 10B does not yet reach the yield stress σ_y . In such a case, energy absorption due to plastic deformation is limited to the inter-node part 10A, so that the road structure 100 has a small effect of suppressing horizontal displacement δ . That is, stress concentrates on the inter-node part 10A, so that earthquake resistance of the road structure 100 is suppressed at a low level due to the local strength limit of the inter-node part 10A. That is, the inter-node part 10A yields and fractures with a smaller horizontal displacement δ than that of the inter-

node part 10B, and the road structure 100 is broken before the inter-node part 10B absorbs energy.

[0142]

Fig. 37(b) shows the case where there is a relatively small difference in length between the inter-node part 10A and the inter-node part 10B. In the structure shown in Fig. 33, when the road floor slab 99 receives a horizontal load P_H due to an earthquake motion, thus being displaced by δ in the horizontal direction, the stress σ_1 in the inter-node part 10A becomes larger than the stress σ_2 in the inter-node part 10B. However, when there is a small difference between the length h_1 of the inter-node part 10A and the length h_2 of the inter-node part 10B, the stress σ_1 in the inter-node part 10A and the stress σ_2 in the inter-node part 10B increase in the same manner with an increase in horizontal displacement δ by an earthquake motion.

[0143]

Even after yielding of the inter-node part 10A, displacement increases, and the inter-node part 10A then reaches the limit strength. The inter-node part 10B yields with a slight delay from yielding of the inter-node part 10A, and is plasticized. As shown in Fig. 37(b), the plastic deformation region of the inter-node part 10A and the plastic deformation region of the inter-node part 10B overlap with each other, and both of the inter-node part 10A and the inter-node part 10B are plasticized after exceeding the yield point, thus exhibiting an effect of absorbing energy in a range W . Consequently, as shown in Fig. 37(a), when there is a large difference in length between the inter-node part 10A and the inter-node part 10B, stress is concentrated on the short inter-node part 10A. However, as shown in Fig. 37(b), when there is a small difference in length between the inter-node part 10A and the inter-node part 10B, stress concentration on the short inter-node part 10A is relaxed, so that both of the two inter-node parts 10A and 10B exhibit energy absorbing ability due to plastic deformation. Accordingly, in the structure shown in Fig. 33, even after plastic deformation progresses, the inter-node part 10A does not reach the limit strength, so that high anti-seismic performance is exhibited.

[0144]

<Setting of length of bearing pile 10 in section K of road structure 100 shown in Fig. 32>

For example, in the case of a structure formed from two bearing piles 10 as shown in Fig. 33, horizontal displacement (yield displacement) when the short bearing pile 10 (the inter-node part 10A) reaches the yield stress σ_y is taken as " δ_{1y} ". Stress in the long bearing pile 10 (the inter-node part 10B) at this point is expressed as follows based on the above-mentioned formula (5).

$$\sigma_2 = \sigma_y (h_1/h_2)^2 \dots (9)$$

At this point, the horizontal displacement of the inter-node part 10B is δ_{1y} in the same manner as the inter-node part 10A. Thus, the yield displacement δ_{2y} , which is the horizontal displacement of the inter-node part 10B when the inter-node part 10B reaches the yield stress σ_y , is expressed as follows based on the above-mentioned formula (5) and formula (9) and due to the proportional relationship of σ_2 in the elastic region shown in Fig. 37.

$$\delta_{2y} = \delta_{1y} \times \sigma_y/\sigma_2 = \delta_{1y} \times (h_2/h_1)^2 \dots (10)$$

[0145]

In the structure formed from the two bearing piles 10 and shown in Fig. 33, when the yield displacement δ_{2y} of the long bearing pile 10 (the inter-node part 10B) is equal to or more than the yield displacement δ_{1y} of the short bearing pile 10 (the inter-node part 10A) and equal to or less than the limit horizontal displacement of the short bearing pile 10 (horizontal displacement for the limit strength), the plastic deformation regions of at least the two bearing piles 10 overlap with each other (the range W shown in Fig. 37(b) can be ensured). In other words, when the yield displacement δ_{2y} of the long bearing pile 10 (the inter-node part 10B) falls within the following range, the plastic deformation regions of the two bearing piles 10 overlap with each other.

$$\delta_{1y} \leq \delta_{2y} \leq 5 \cdot \delta_{1y} \dots (11)$$

Based on this formula (11) and the above-mentioned formula (5), the relationship between the protruding amounts h_1 and h_2 of the two bearing piles 10 is $1 \leq (h_2/h_1)^2 \leq 5$, and is expressed as $1 \leq h_2/h_1 \leq 2.23$. That is, by setting the

protruding amounts h_1 and h_2 of the two bearing piles 10 shown in Fig. 33 to the above-mentioned range, the plastic deformation regions of at least the two bearing piles 10 overlap with each other.

[0146]

5 The term "limit strength" refers to the limit stress to which the stress in the inter-node part decreases when the inter-node part is further plastically deformed after yielding. For example, in the case where the inter-node part repeatedly receives a load due to vibration, such as in earthquake, when the inter-node part is repeatedly plastically deformed after exceeding the yield point, although stress increases with an increase in displacement, stress decreases after displacement exceeds a
10 predetermined displacement. This point is taken as "limit strength". Although limit strength is, for example, the tensile stress of a material, limit strength is not limited to the tensile stress. The maximum value of the above-mentioned formula (11) is $5 \cdot \delta_{1y}$, and this value is set as the limit horizontal displacement when the inter-node part
15 repeatedly receives a load during an earthquake. In the above-mentioned case, for example, based on the experimental result shown in Fig. 16, 5 times the yield displacement δ_{1y} is set as the horizontal displacement for the limit strength. However, the limit horizontal displacement may change depending on the material, the cross-sectional shape, or the length of the inter-node part.

20 [0147]

 When the yield displacement δ_{2y} of the long bearing pile 10 (the inter-node part 10B) falls within the following range, the range W in which the plastic deformation regions of the two bearing piles 10 overlap with each other can ensure the width of $2 \cdot \delta_{1y}$ or more, so that sufficient anti-seismic performance can be exhibited.

25
$$\delta_{1y} \leq \delta_{2y} \leq 3 \cdot \delta_{1y} \dots (12)$$

 Based on this formula (12) and the above-mentioned formula (5), the relationship between the protruding amounts h_1 and h_2 of the two bearing piles 10 is $1 \leq (h_2/h_1)^2 \leq 3$, that is, is expressed as $1 \leq h_2/h_1 \leq 1.73$.

[0148]

30 <Position of intermediate panel point part 50b of bearing pile 10a in section L of road

structure 100 shown in Fig. 32>

Next, regarding the structure where the intermediate panel point part 50b is provided to only the long bearing pile 10a of the two bearing piles 10 as shown in Fig. 35, the condition of the protruding amount h of the long bearing pile 10 is obtained.

5 In the case where the structure where the bearing piles 10 each having one layer are coupled with each other as shown in Fig. 33 does not satisfy the above-described condition that $1 \leq h_2/h_1 \leq 2.23$ or $1 \leq h_2/h_1 \leq 1.73$, the intermediate panel point part 50b is provided to the long bearing pile 10. The intermediate panel point part 50b is coupled with the adjacent bearing pile 10, so that the rotation of the girder part 40 in the direction perpendicular to the axis of the girder part 40 is confined. Therefore, the inter-node parts 10C and 10D disposed above and below the intermediate panel point part 50b can be modeled as both ends fixed beams. It is assumed that the bearing pile 10a shown in Fig. 35 satisfies protruding amount $h = h_3 + h_4$ and $h_3 \geq h_4$. In the formula, " h_3 " denotes the length of the inter-node part 10C on the ground side, and " h_4 " denotes the length of the inter-node part 10D on the upper end side.

[0149]

The horizontal displacement δ_3 of the inter-node part 10C and the horizontal displacement δ_4 of the inter-node part 10D are expressed as follows based on the above-mentioned formula (4).

$$\delta_3 = \sigma_3 \cdot Z \cdot h_3^2 / (6E \cdot I) \dots (13a)$$

$$\delta_4 = \sigma_4 \cdot Z \cdot h_4^2 / (6E \cdot I) \dots (13b)$$

Based on the above-mentioned formula (6), the stress σ_4 in the inter-node part 10D is expressed as follows by using the stress σ_3 in the inter-node part 10C and the lengths h_3 and h_4 of the inter-node parts 10C and 10D.

$$\sigma_4 = \sigma_3 \cdot (h_4/h_3) \dots (14)$$

[0150]

Thus, the horizontal displacement δ of the bearing pile 10a is expressed as follows based on the above-mentioned formulae (13a) to (14).

$$\begin{aligned} \delta &= \delta_3 + \delta_4 = Z / (6E \cdot I) \times \{ \sigma_3 \cdot h_3^2 + \sigma_3 (h_4/h_3) \cdot h_4^2 \} \\ &= \sigma_3 \cdot Z / (6E \cdot I) \times (h_3^2 + h_4^3/h_3) \dots (15) \end{aligned}$$

Because $h_4 = h - h_3$ is established, the horizontal displacement δ of the bearing pile 10a is expressed as follows.

$$\begin{aligned}\delta &= \sigma_3 \cdot Z / (6E \cdot I) \times h^2 \{h/h_3 - 3 + 3(h_3/h)\} \\ &= \sigma_3 \cdot Z / (6E \cdot I) \times h^2 \times G \dots (16)\end{aligned}$$

where

$$G = h/h_3 - 3 + 3(h_3/h) \dots (16a)$$

[0151]

In contrast, the horizontal displacement of the short bearing pile 10 (the inter-node part 10A) of the two bearing piles 10 is expressed as $\delta = \sigma_1 \cdot Z \cdot h_1^2 / (6E \cdot I)$ based on the formula (4) and hence, based on $\delta = \sigma_1 \cdot Z \cdot h_1^2 / (6E \cdot I)$ and the formula (16), the following is obtained.

$$\sigma_3 \cdot Z / (6E \cdot I) \times h^2 \times G = \sigma_1 \cdot Z \cdot h_1^2 / (6E \cdot I) \dots (16b)$$

The relationship between the stress σ_3 in the inter-node part 10C of the bearing pile 10a and the stress σ_1 in the short bearing pile 10 is expressed as follows, the stress σ_3 being higher than the stress σ_1 .

$$\sigma_3 / \sigma_1 = h_1^2 / (G \cdot h^2) \dots (17)$$

[0152]

According to the above-mentioned formula (17), when the short bearing pile 10 (the inter-node part 10A) shown in Fig. 35 reaches the yield stress σ_y ($\sigma_1 = \sigma_y$), a smaller G causes a larger stress σ_3 in the inter-node part 10C of the long bearing pile 10, so that the long bearing pile 10 is likely to yield. In contrast, a larger G causes the long bearing pile 10 to be less likely to yield.

[0153]

Fig. 38 is a graph showing the relationship between the ratio of the length h_3 of the inter-node part 10C on the ground side to the protruding amount h of the long bearing pile 10a and the value of G in the formula (16) and the formula (17) for the two bearing piles 10 shown in Fig. 35. As described above, a smaller value of G causes the inter-node part 10C to be plastically deformed more readily. When the length of the inter-node part 10C is set such that the value of G takes a value close to the minimum value, both of the two bearing piles 10 can readily exhibit energy

absorbing ability due to plastic deformation. According to Fig. 38, $0.464 \leq G \leq 0.583$ is established within the range of $0.5 \leq h_3/h \leq 0.75$.

[0154]

The above-mentioned relationship between the length h_3 of the inter-node part 10C on the lower end side of the bearing pile 10a and G is also established for the inter-node part 10D on the upper end side in the same manner. That is, within the range of $0.5 \leq h_4/h \leq 0.75$ (in this case, $0.25 \leq h_3/h \leq 0.5$), G is expressed as $G = h/h_4 - 3 + 3(h_4/h)$, and the range of the value of G is $0.464 \leq G \leq 0.583$. In this case, the inter-node part 10D is more readily plastically deformed than the inter-node part 10C.

[0155]

Based on the above, the length h_3 of the inter-node part 10C of the long bearing pile 10a in Fig. 35 can be set to $0.25 \leq h_3/h \leq 0.75$. Assume the case where the bearing pile 10a has a large protruding amount h , and yields after the other bearing pile 10 (the inter-node part 10A) having a short length. In such a case, by setting the material and the cross-sectional shape of the two bearing piles 10 such that, based on the above-mentioned conditions, the inter-node part 10C yields under the condition that $G = 0.583$, which is the condition under which the inter-node part 10C is least likely to yield, even if the position of the intermediate panel point part 50b fluctuates within a range of $0.25 \leq h_3/h \leq 0.75$, at least the plastic deformation region of the inter-node part 10A and the plastic deformation region of the inter-node part 10C overlap with each other, so that the two bearing piles 10 can exhibit energy absorption performance in the range W shown in Fig. 37(b).

[0156]

Contrary to the above-mentioned case, there may be cases where the long bearing pile 10a yields first, and the short bearing pile 10 yields thereafter. In this case, it is sufficient to design a condition under which the short bearing pile 10 (the inter-node part 10A) yields under a condition that $G = 0.464$, which is the condition under which the long bearing pile 10a yields most easily. With such a design, even when the position of the intermediate panel point part 50b of the long bearing pile 10a

fluctuates within a range of $0.25 \leq h_3/h \leq 0.75$, the yield condition of the short bearing pile 10 can be safely set. That is, it is preferable to conduct studies on the two bearing piles 10 assuming that $G = 0.464$ under the condition that $0.25 \leq h_3/h \leq 0.75$, and to design the two bearing piles 10 such that the plastic deformation regions of the two bearing piles 10 overlap with each other.

[0157]

<Length h_1 of bearing pile 10 in section L of road structure 100 shown in Fig. 32>

Next, regarding the structure where the intermediate panel point part 50b is provided to only the long bearing pile 10a of the two bearing piles 10 as shown in Fig. 35, a condition of the protruding amount h_1 of the short bearing pile 10 (the inter-node part 10A) is obtained. It is assumed that the bearing pile 10a shown in Fig. 35 satisfies protruding amount $h = h_3 + h_4$, $h_3 \geq h_4$. In the formula, " h_3 " denotes the length of the inter-node part 10C on the ground side, and " h_4 " denotes the length of the inter-node part 10D on the upper end side.

[0158]

When yield displacement when the short bearing pile 10 (the inter-node part 10A) reaches the yield stress σ_y is taken as " δ_{1y} ", stress in the inter-node part 10C of the long bearing pile 10a is expressed as follows based on the above-mentioned formula (17).

$$\sigma_3 = \sigma_y \{h_1^2 / (G \cdot h^2)\} = \sigma_y (h_1/h)^2 / G \dots (18)$$

Based on the above, the displacement δ_{3y} of the bearing pile 10a when the inter-node part 10C yields is expressed as follows due to the proportional relationship.

$$\begin{aligned} \delta_{3y} &= \delta_{1y} \times \sigma_y / \sigma_3 = \delta_{1y} \times \sigma_y / \{\sigma_y (h_1/h)^2 / G\} \\ &= \delta_{1y} \times (h/h_1)^2 \times G \dots (19) \end{aligned}$$

[0159]

In the structure formed from the two bearing piles 10 shown in Fig. 35, when the yield displacement δ_{3y} of the long bearing pile 10a (the inter-node part 10C) is equal to or more than the yield displacement δ_{1y} of the short bearing pile 10 (the inter-node part 10A) and equal to or less than the limit horizontal displacement (horizontal displacement for the limit strength) of the short bearing pile 10, the plastic

regions of at least the two bearing piles 10 overlap with each other (the range W shown in Fig. 37(b) can be ensured). In other words, when the yield displacement $\delta 3y$ of the long bearing pile 10a (the inter-node part 10C) falls within the following range, the plastic regions of the two bearing piles 10 overlap with each other.

$$\delta 1y \leq \delta 3y \leq 5 \cdot \delta 1y \dots (20)$$

Based on this formula (20) and the above-mentioned formula (19), the relationship between the protruding amounts h_1 and h of the two bearing piles 10 is $1 \leq (h/h_1)^2 \times G \leq 5$, that is, the following is obtained.

$$1/G \leq (h/h_1)^2 \leq 5/G \dots (21)$$

Within the range of $0.25 \leq h_3/h \leq 0.75$, which is the desirable range of the length h_3 of the inter-node part 10C obtained from Fig. 38, when $G = 0.583$, which is the value of G at which the inter-node part 10C is least likely to be plastically deformed, is substituted in the above-mentioned formula (21), the following is obtained.

$$1.31 \leq h/h_1 \leq 2.92 \dots (22)$$

[0160]

When the yield displacement $\delta 3y$ of the inter-node part 10C of the long bearing pile 10a is within the following range, the range W in which the plastic regions of the two bearing piles 10 overlap with each other is $2 \cdot \delta 1y$ or more, so that sufficient anti-seismic performance can be exhibited.

$$\delta 1y \leq \delta 3y \leq 3 \cdot \delta 1y \dots (23)$$

Based on this formula (23) and the above-mentioned formula (19), the following is obtained.

$$1/G \leq (h/h_1)^2 \leq 3/G \dots (24)$$

Based on the above, the relationship between the protruding amount h_1 of the short bearing pile 10 of the two bearing piles 10 and the protruding amount h of the long bearing pile 10a of the two bearing piles 10 is expressed as follows.

$$1.31 \leq h/h_1 \leq 2.26 \dots (24a)$$

[0161]

Fig. 39 is a diagram showing the relationship between the horizontal

displacement δ and stress σ of the inter-node part 10A and the inter-node part 10C of the two bearing piles 10. A line A in Fig. 39 shows the relationship between the horizontal displacement δ and stress σ of the short bearing pile 10 (the inter-node part 10A), and a line B shows the relationship between the horizontal displacement δ and the stress σ of the inter-node part 10C of the long bearing pile 10a. As shown by the line B, by setting the yield displacement to satisfy $\delta_{3y} \leq 3 \cdot \delta_{1y}$, that is, by setting the relationship between the lengths h and h_1 to satisfy $1.31 \leq h/h_1 \leq 2.26$, it is possible to ensure a range of $2 \cdot \delta_{1y}$ for the range W in which both of the inter-node parts 10A and 10C are plastically deformed.

[0162]

It is preferable to set the structure shown in Fig. 33 such that both of the two inter-node parts 10A and 10B are plastically deformed when the structure receives, for example, predetermined inputs, such as a level 2 earthquake motion. For example, it is preferable to set the structure shown in Fig. 35 such that at least two of the plurality of inter-node parts 10A, 10C and 10D included in the two bearing piles 10 are plastically deformed when the structure receives predetermined inputs, such as a level 2 earthquake motion. It is also preferable to set the structure shown in Fig. 36 such that at least two of the plurality of inter-node parts 10Ca, 10Da, 10Cb, and 10Db of the bearing piles 10 are plastically deformed.

[0163]

Even in the case where the structures shown in Fig. 33, Fig. 34, Fig. 35, and Fig. 36 are set such that one inter-node part is plastically deformed, it is preferable to set the structures such that other inter-node parts not yet in a yielding state yield before the one inter-node part, which is already in the plastic deformation region, reaches the limit strength.

[0164]

Among the plurality of inter-node parts 10A, 10B, 10C, 10D, 10Ca, 10Da, 10Cb, and 10Db of the two adjacent bearing piles 10, an inter-node part that is plastically deformed when receiving predetermined inputs in the horizontal direction may be referred to as "first inter-node part", and an inter-node part that is not yet in a yielding

state when the first inter-node part is plastically deformed may be referred to as "second inter-node part".

[0165]

The road structure 100 includes the plurality of bearing piles 10. When two adjacent bearing piles 10 are selected from the plurality of bearing piles 10, the two bearing piles 10 have any one of the structures shown in the section K, the section L, and the section M shown in Fig. 32. When a part between any two adjacent parts of the fulcrum 98 of the bearing pile 10, the intermediate panel point part 50b, and the upper end panel point part 50a is defined as "inter-node part", two bearing piles 10 include at least two of the inter-node parts 10A, 10B, 10C, 10D, 10Ca, 10Da, 10Cb, and 10Db. It is preferable to set the plurality of inter-node parts 10A, 10B, 10C, 10D, 10Ca, 10Da, 10Cb, and 10Db such that at least two of the plurality of inter-node parts are in the plastic deformation region when a level 2 earthquake motion, for example, is applied. It is more preferable to set the inter-node parts such that inter-node parts other than the two inter-node parts, which are in the plastic deformation region, (inter-node parts not in a yielding state) yield before the two inter-node parts, which are already in the plastic deformation region, reach the limit strength.

[0166]

It is more desirable to set the inter-node parts such that three or more of the plurality of inter-node parts 10A, 10B, 10C, 10D, 10Ca, 10Da, 10Cb, and 10Db are in the plastic deformation region. Further, it is preferable to set the inter-node parts such that inter-node parts other than the plurality of inter-node parts in the plastic deformation region (inter-node parts not in a yielding state) yield at the same time before the plurality of inter-node parts, which are already in the plastic deformation region, reach the limit strength.

[0167]

<Setting of bearing pile 10 forming reference of entire road structure 100>

It is described above that the position of the intermediate panel point part 50b of the long bearing pile 10a of the two bearing piles 10 shown in Fig. 35 is desirably set within a range of $0.25 \leq h_3/h \leq 0.75$. However, it is more desirable that the inter-

node part 10C provided to the lower portion of the bearing pile 10a be set to have a longer length than the inter-node part 10D provided to the upper portion of the bearing pile 10a. In the case of the road structure 100, it is preferable that damage due to an earthquake or the like is prevented from occurring in the vicinity of the girder parts 41 that support the road floor slabs 99, the girder parts 41 forming the upper portion of the road structure 100. This is because even if damage or deformation occurs in the lower portion of the road structure 100, when the road floor slabs 99 and the girder parts 41 forming the upper portion of the road structure 100 are sound, it is possible to allow vehicles or the like to pass through the road structure 100 in an emergency. Taking into account the above, it is desirable to form the bearing pile 10 having the two-layer structure as in the case of the bearing pile 10a shown in Fig. 35 such that an inter-node part to be plasticized be limited to the inter-node part 10C disposed at the lower portion, and damage or deformation be prevented from occurring in the inter-node part 10D disposed at the upper portion. That is, in the structure shown in Fig. 35, it is more desirable to set the ratio of the length h_3 of the inter-node part 10C to the length h of the bearing pile 10a to $0.5 \leq h_3/h \leq 0.75$. In other words, when the length of the bearing pile 10a is taken as " h ", it is more desirable to set the length from the fulcrum 98 to the intermediate panel point part 50b to $0.5h$ or more and $0.75h$ or less.

[0168]

By setting the length to $0.5 < h_3/h \leq 0.667$, the range of the value of G becomes $0.464 \leq G \leq 0.5$ in the graph shown in Fig. 38. Thus, effect of reducing stress by the intermediate panel point part 50b of the bearing pile 10a is improved and, in the case where the long bearing pile 10a yields with a delay from yielding of the short bearing pile 10, it is possible to have a larger range for the protruding amount h of the bearing pile 10a. That is, when $G = 0.5$ is substituted in the above-mentioned formula (23), $1.31 \leq h/h_1 \leq 2.45$ is obtained, so that it is possible to increase the range for the length h of the bearing pile 10a.

[0169]

In the above-mentioned description, in the case where both of the two bearing

piles 10 have one layer (see Fig. 33), when the protruding length of the long bearing pile 10 exceeds 1.73 times the length of the short bearing pile 10, after the short bearing pile 10 yields and before reaching the limit displacement, the range W in which both of the short bearing pile 10 and the long bearing pile 10 can exhibit plastic energy absorption performance due to yielding of the long bearing pile 10 is less than $2\delta_1 y$, so that sufficient plastic energy absorption performance cannot be exhibited. When the protruding length of the long bearing pile 10 exceeds 2.23 times the length of the short bearing pile 10, after the short bearing pile 10 yields and before reaching the limit displacement, the long bearing pile 10 does not yield, thus cannot exhibit plastic energy absorption performance. Further, when the protruding amount of the bearing pile 10 is less than 7 m, the bearing pile 10 has extremely low flexibility and hence, it is necessary to take the measure of using a material having an especially high yield point, or to increase the plate thickness, for example, thus the bearing pile 10 cannot be relied on to have plastic energy absorption performance. Thus, when studies are conducted on earthquake resistance of the entire road structure 100, the protruding amount h_0 of the bearing pile 10 forming the reference is set as follows. The bearing pile 10 forming the reference may be referred to as "reference pile".

(Condition 1) Assume that the protruding amount h_0 is the protruding amount of the bearing pile 10 having the smallest protruding amount, of the bearing piles 10 having one layer and having a protruding amount of 7 m or more.

[0170]

The bearing pile 10 forming the reference is set based on the above-mentioned (condition 1), and the protruding amount of the bearing pile 10 compared with the reference is taken as "h". In such a case, it is preferable to set the relationship between h of the bearing pile 10, which is the comparison target, and the protruding amount h_0 of the bearing pile 10 forming the reference as expressed by the following formula (25) based on the above-mentioned formula (11). The bearing pile 10, which is the comparison target, may be referred to as "comparison pile".

$$1 \leq h/h_0 \leq 1.73 \dots (25)$$

In the case where the bearing pile 10, which is the comparison target, has two

layers, the protruding amount of the bearing pile 10, which is the comparison target, is taken as "h", and the height of the intermediate panel point part 50b from the ground 90 is taken as "ht". In such a case, it is preferable to set the relationship between the protruding amount h of the bearing pile 10, which is the comparison target, and the protruding amount h0 of the bearing pile 10 forming the reference as follows based on the formula (24). However, it is assumed that the range of ht satisfies $0.25h \leq ht \leq 0.75h$, ht being the position of the intermediate panel point part 50b of the bearing pile 10, which is the comparison target.

$$1.31 \leq h/h_0 \leq 2.26 \dots (26)$$

By setting the bearing pile 10, which is the comparison target, (comparison pile) to be within the range of the above-mentioned formula (25) or formula (26) relative to the bearing pile 10 forming the reference (reference pile), the plastic deformation region of the reference pile and the plastic deformation region of the comparison pile overlap with each other, the comparison pile being set to be within the range of the above-mentioned formula (25) or formula (26).

[0171]

The above-mentioned condition is based on the assumption that the protruding amount h0 of the bearing pile 10 forming the reference is smaller than the protruding amount h of the bearing pile 10, which is the comparison target. Next, the description will be made for a case where the bearing pile 10 forming the reference is shorter than the bearing pile 10, which is the comparison target.

[0172]

When the bearing pile 10, which is the comparison target, has one layer, and the bearing pile 10, which is the comparison target, is longer than the bearing pile 10 forming the reference, it is preferable to set the relationship between h of the bearing pile 10, which is the comparison target, and the protruding amount h0 of the bearing pile 10 forming the reference as follows by switching h and h0 in the above-mentioned formula (25) and based on $1 \leq h_0/h \leq 1.73$.

$$0.58 \leq h/h_0 \leq 1 \dots (27)$$

The relationship between h of the bearing pile 10, which is the comparison

target, and the protruding amount h_0 of the bearing pile 10 forming the reference is expressed as follows by combining the two conditions, that is, the above-mentioned formula (25) and formula (27).

$$0.58 \leq h/h_0 \leq 1.73 \dots (28)$$

[0173]

In the case where the bearing pile 10, which is the comparison target, has two layers, and the bearing pile 10, which is the comparison target, is longer than the bearing pile 10 forming the reference, the relationship between h of the bearing pile 10, which is the comparison target, and the protruding amount h_0 of the bearing pile 10 forming the reference is expressed as follows.

$$0.86 \leq h/h_0 \leq 2.26 \dots (29)$$

The above-mentioned formula (29) is obtained as follows.

[0174]

Fig. 40 is an enlarged view of the section L shown in Fig. 32, and is also a diagram obtained by shortening the bearing pile 10a compared with that in Fig. 35. Fig. 41 is a diagram schematically showing the relationship between the horizontal displacement δ and the stress σ of the long bearing pile 10 and the short bearing pile 10a shown in Fig. 40. The derivation of the above-mentioned formula (29) will be described with reference to Fig. 40 and Fig. 41. In the case where the protruding amount h of the bearing pile 10a having two layers is smaller than the protruding amount h_1 of the bearing pile 10 having one layer as in the case of Fig. 40, the stress σ_1 in the bearing pile 10 having one layer is expressed as follows based on the above-mentioned formula (17).

$$\begin{aligned} \sigma_1 &= \sigma_y \cdot (G \cdot h^2 / h_1^2) \\ &= \sigma_y \cdot (h/h_1)^2 \cdot G \dots (30) \end{aligned}$$

[0175]

Thus, the yield displacement δ_{1y} , which is horizontal displacement when the long bearing pile 10 having one layer reaches the yield stress σ_y , is obtained as follows due to the proportional relationship.

$$\delta_{1y} = \delta_{3y} \cdot \sigma_y / \sigma_1$$

$$= \delta 3y \cdot \sigma_y / (\sigma_y \cdot (h/h_1)^2 \cdot G)$$

$$= \delta 3y \cdot (h_1/h)^2 / G \dots (31)$$

[0176]

When the yield displacement $\delta 1y$ of the long bearing pile 10 having one layer, of the two bearing piles 10 and 10a shown in Fig. 40, is within the following range, both of the bearing piles 10 and 10a are plastically deformed, thus exhibiting energy absorption performance.

$$\delta 3y \leq \delta 1y \leq 5 \cdot \delta 3y \dots (32)$$

When the formula (31) is substituted in the formula (32), the following is obtained.

$$G \leq (h_1/h)^2 \leq 5G \dots (33)$$

[0177]

Within the range of $0.25 \leq h_3/h \leq 0.75$, which is the desirable range of the length h_3 of the inter-node part 10C obtained from Fig. 38, a smaller value of G causes a smaller σ_1 in the above-mentioned formula (30). When $G = 0.464$ is selected to set a condition under which the long bearing pile 10 having one layer and shown in Fig. 40 is less likely to yield, and when $G = 0.464$ is substituted in the above-mentioned formula (33), the relationship between the length h_1 of the long bearing pile 10 having one layer (the inter-node part 10A) and the protruding amount h of the bearing pile 10a having two layers is as follows based on $0.681 \leq h_1/h \leq 1.523$.

$$0.66 \leq h/h_1 \leq 1.46 \dots (34)$$

[0178]

When the yield displacement $\delta 1y$ of the inter-node part 10A of the long bearing pile 10 having one layer is within the following range, the range W in which the plastic regions of the two bearing piles 10, 10a overlap with each other is $2 \cdot \delta 3y$ or more, so that sufficient anti-seismic performance can be exhibited.

$$\delta 3y \leq \delta 1y \leq 3 \cdot \delta 3y \dots (35)$$

Based on this formula (35) and the above-mentioned formula (31), the following is obtained.

$$G \leq (h_1/h)^2 \leq 3G \dots (36)$$

To set the condition under which the long bearing pile 10 having one layer shown in Fig. 40 is less likely to yield, $G = 0.464$ is substituted in the formula (36). Based on $0.681 \leq h_1/h \leq 1.17$, the relationship between the length h_1 of the long bearing pile 10 having one layer (the inter-node part 10A) and the protruding amount h of the bearing pile 10a having two layers is expressed as follows.

$$0.86 \leq h/h_1 \leq 1.46 \dots (37)$$

[0179]

In contrast, in the case where the bearing pile 10a is longer than the other as in the case of Fig. 35, the relationship between the protruding amount h_1 of the short bearing pile 10 of the two bearing piles 10 and the protruding amount h of the long bearing pile 10a of the two bearing piles 10 is expressed as follows in the same manner as the above-mentioned formula (24a).

$$1.31 \leq h/h_1 \leq 2.26 \dots (38)$$

Thus, in the case where the bearing pile 10, which is the comparison target, has two layers, the relationship between h of the bearing pile 10, which is the comparison target, and the protruding amount h_0 of the bearing pile 10 forming the reference is expressed by $0.86 \leq h/h_0 \leq 2.26$ as shown in the above-mentioned formula (29) by combining the condition of the formula (37) and the condition of the formula (38).

[0180]

The conditions of the above-mentioned formula (28) and formula (29) are conditions for causing both of the plastic deformation region of the bearing pile 10 forming the reference of the road structure 100 (referred to as "reference pile") and the plastic deformation region of the bearing pile 10, which is the comparison target, (comparison pile) to overlap with each other. However, the plastic deformation region of the comparison pile longer than the reference pile and the plastic deformation region of the comparison pile shorter than the reference pile do not always overlap with each other. That is, the comparison piles do not always have a range w_1 shown in Fig. 41. However, by reducing a difference in plastic deformation

region among the plurality of bearing piles 10 to cause the plurality of bearing piles 10 to have similar plasticization property, and by appropriately setting the limit displacement by taking into account the lengths of inter-node parts, it is possible to set the comparison pile longer than the reference pile and the comparison pile shorter than the reference pile such that the ranges in which the comparison piles exhibit plastic energy absorption performance overlap with each other. Accordingly, evaluation of whether the comparison pile meets the conditions of the above-mentioned formula (28) and formula (29) can be utilized as an index to evaluate earthquake resistance of the entire road structure 100.

[0181]

<Material of bearing pile 10 and setting of section modulus Z>

The strength of the bearing pile 10 of the road structure 100 has variations depending on the material or section modulus. For example, in the case where SKK400 is used as the material for the bearing pile 10, yield stress is 235 N/mm².

However, in the case where SKK490 is used as the material for the bearing pile 10, yield stress is 325 N/mm². That is, in the case where SKK490 is used as the material for the bearing pile 10, yield stress is 1.38 times larger than yield stress when SKK400 is used as the material for the bearing pile 10.

[0182]

In the case where the outer diameter of the bearing pile 10 is 500 mm, when the plate thickness is 9 mm, a section modulus is $167 \times 10^{-5} \text{ m}^3$, when the plate thickness is 12 mm, a section modulus is $219 \times 10^{-5} \text{ m}^3$, and when the plate thickness is 14 mm, a section modulus is $253 \times 10^{-5} \text{ m}^3$. The outer diameter of the bearing pile 10 may be set within a range of 400 mm to 600 mm.

[0183]

Fig. 42 is a diagram schematically showing the relationship between horizontal displacement δ and stress σ when the material of the reference pile and the material of the comparison pile have the same yield stress and when the material of the reference pile and the material of the comparison pile have different yield stresses.

In Fig. 42, a solid line shows the relationship between the horizontal displacement δ

and the stress σ of the reference pile. A chain line and a broken line show the relationship between the horizontal displacement δ and the stress σ of the comparison pile. The broken line shows the relationship in the case where the yield stress of the comparison pile is equal to the yield stress of the reference pile, that is, σ_y , and the yield displacement in this case is 3 times the yield displacement δ_0 of the reference pile. In this case, the reference pile has room relative to the limit displacement $5 \cdot \delta_0$, and the plastic deformation region of the reference pile and the plastic deformation region of the comparison pile overlap with each other with a width of $2 \cdot \delta_0$, so that both of the reference pile and the comparison pile can exhibit plastic energy absorption performance.

[0184]

In contrast, assume a case where, as shown by the chain line in Fig. 42, the comparison pile has a large yield stress, that is, σ_c . In this case, the comparison pile is less likely to yield. When the yield stress of the reference pile is taken as " σ_0y ", the condition, under which the comparison pile yields before the reference pile reaching the limit displacement $5 \cdot \delta$, so that the plastic deformation region of the comparison pile and the plastic deformation region of the reference pile overlap with each other, is expressed as $\sigma_0y \leq \sigma_c < 5/3 \cdot \sigma_0y$ due to the proportional relationship of the elastic region of the comparison pile, that is, the following is obtained.

$$\sigma_0y \leq \sigma_c < 1.66 \cdot \sigma_0y \dots (39)$$

[0185]

Thus, when the yield stress of the comparison pile is less than 1.66 times the yield stress of the reference pile, the plastic deformation region of the reference pile and the plastic deformation region of the comparison pile overlap with each other, so that both of the reference pile and the comparison pile exhibit plastic energy absorption performance. For example, SKK400 ($\sigma_y = 235 \text{ N/mm}^2$), SKK490 ($\sigma_y = 325 \text{ N/mm}^2$) or the like is used as the material for a generally-used pile. The yield stress of SKK490 is 1.38 times that of SKK400 and hence, even when SKK490 is used as the material for the comparison pile, and SKK400 is used as the material for the reference pile, the yield stress σ_y of the comparison pile sufficiently falls within the

range of the condition of the above-mentioned formula (39), thus both materials can be used for the bearing pile 10.

[0186]

Fig. 43 is a diagram schematically showing the relationship between horizontal displacement δ and stress σ when the reference pile and the comparison pile have different outer diameters. In Fig. 43, a solid line shows the relationship between the horizontal displacement δ and the stress σ of the reference pile. A chain line and a broken line show the relationship between the horizontal displacement δ and the stress σ of the comparison pile. The yield displacement of the comparison pile shown by the broken line is 3 times the yield displacement δ_{0y} of the reference pile. In this case, the reference pile has room relative to the limit displacement $5 \cdot \delta_0$, and the plastic deformation region of the reference pile and the plastic deformation region of the comparison pile overlap with each other with a width of $2 \cdot \delta_0$, so that both of the reference pile and the comparison pile can exhibit plastic energy absorption performance.

[0187]

Consider the case of a pile having an outer diameter or a plate thickness different from that of the comparison pile shown by the broken line. In the case of a cylindrical steel pipe pile having the outer diameter of d and having the inner diameter of d_1 , horizontal displacement, section modulus, and second moment of area are as follows.

Horizontal displacement: $\delta = \sigma \cdot Z \times h^2 / (6E \cdot I)$ based on the above-mentioned formula (8)

Section modulus:

$$Z = 0.0982 \times (d^4 - d_1^4) / d \dots (40)$$

Second moment of area:

$$I = 0.0491 \times (d^4 - d_1^4) \dots (41)$$

Accordingly, the following is obtained.

$$\delta = \sigma \cdot h^2 / (6E \cdot d) \times 2 \dots (42)$$

That is, the comparison pile has a proportional relationship between the outer

diameter d and the stress σ , so that stress σ decreases with a reduction in outer diameter d . When the comparison pile has a small outer diameter, the comparison pile is less likely to yield. However, when the reciprocal of the ratio of the outer diameter of the comparison pile to the outer diameter of the reference pile is 1.66 times or less, the yield displacement δ_c of the comparison pile falls within a range of 3 times to 5 times the yield displacement δ_0 of the reference pile. For example, in the case where an outer diameter D_0 of the reference pile is 600 mm, and an outer diameter D of the comparison pile is 400 mm, $D_0/D = 600/400 = 1.5 \leq 1.66$ is established, and the plastic deformation region of the reference pile and the plastic deformation region of the comparison pile overlap with each other with a width of $2 \cdot \delta_0$, so that both of the reference pile and the comparison pile can exhibit plastic energy absorption performance.

[0188]

<Summary of conditions of bearing pile 10 of road structure 100>

(1) The road structure 100 includes the plurality of bearing piles 10 that satisfies $h_{\max} \geq 2 \times h_{\min}$ when the largest protruding amount of the bearing pile 10 from the ground 90 is taken as " $h_{\max}$ ", and the smallest protruding amount of the bearing pile 10 from the ground 90 is taken as " $h_{\min}$ ".

(2) Selection of reference pile

The reference pile is the bearing pile 10 including no intermediate panel point part 50b or 150b, the bearing pile 10 having the smallest protruding amount of the bearing piles 10 having the protruding amount h_0 of 7 m or more.

(3) Condition 1 of comparison pile

The bearing pile 10, which is the comparison target, for the reference pile is referred to as "comparison pile", and in the case where the comparison pile has a single-layer structure including no intermediate panel point part 50b, the protruding amount h of the comparison pile satisfies the following.

$$1 \leq h/h_0 \leq 1.73$$

In the case where the comparison pile has a two-layer structure including the intermediate panel point part 50b, the protruding amount h of the comparison pile

satisfies the following under the condition that $0.25h \leq h_t \leq 0.75h$ when a height from the ground 90 to the intermediate panel point part 50b is taken as "ht".

$$1.31 \leq h/h_0 \leq 2.26$$

When both of the case where the comparison pile yields with a delay from yielding of the reference pile and the case where the comparison pile yields earlier than yielding of the reference pile are taken into consideration, in the case where the comparison pile has a single-layer structure, the protruding amount h of the comparison pile satisfies the following.

$$0.58 \leq h/h_0 \leq 1.73$$

In the case where the comparison pile has the two-layer structure, the protruding amount h of the comparison pile satisfies the following.

$$0.86 \leq h/h_0 \leq 2.26$$

(4) Condition 2 of comparison pile

When the yield stress of the reference pile is taken as " σ_0 ", the yield stress of the comparison pile is taken as " σ_x ", the outer diameter of the reference pile is taken as "D0", the outer diameter of the comparison pile is taken as "Dx", $K1 = \sigma_x/\sigma_0$, and $K2 = D0/Dx$, the following is satisfied.

$$1 \leq K1 \times K2 \leq 1.66$$

When both of the case where the comparison pile yields with a delay from yielding of the reference pile and the case where the comparison pile yields earlier than yielding of the reference pile are taken into consideration, the following is satisfied.

$$0.6 \leq K1 \times K2 \leq 1.66$$

(5) It is desirable that 1/3 or more, or 1/2 or more, of the total number of the plurality of bearing piles 10 forming the road structure 100 be the bearing piles 10 that satisfy the above-mentioned conditions (1) to (4). That is, all of the plurality of bearing piles 10 forming the road structure 100 need not satisfy the above-mentioned conditions (1) to (4).

[0189]

(Advantageous effects of road structure 100 of Embodiment 2)

Fig. 44 is a diagram illustrating the road structure 100 according to Embodiment 2. In the road structure 100 shown in Fig. 44, not only that the bearing piles 10 are arranged in a line in the y direction (the left-right direction on a paper) being a direction in which a road extends, but also that bearing piles 10 are arranged in a line on the mountain side, and bearing piles 10 are arranged in a line on the valley side, so that the bearing piles 10 are arranged in two lines, the depth side of the paper being the mountain side, the viewer's side being the valley side. In the road structure 100, not only that the plurality of bearing piles 10 arranged in a line in the direction in which the road extends differ from each other in protruding amount, but also that the bearing piles 10 arranged in a line in the slope direction (x direction) differ from each other in protruding amount corresponding to the inclination of the slope. Although the surface 94 of the ground 90 in Fig. 44 is shown by a plurality of lines, a dotted line shows the surface 94 of the ground 90 into which the bearing piles 10 located at positions closest to the valley side are driven, and a solid line shows the surface 94 of the ground 90 into which the bearing piles 10 located at positions close to the mountain side are driven. The bearing piles 10 shown in Fig. 44 are given numbers from No. 1 to No. 11 in order from the left.

[0190]

[Table 1]

No.	Protruding amount (m)			Comparison pile/reference pile		Application range		Determination	
	Valley-side pile	Mountain-side pile	Reference pile	Valley-side pile	Mountain-side pile	Minimum	Maximum	Valley-side pile	Mountain-side pile
1	2.1	1.6	7.3	0.29	0.22	1	1.73	×	×
2	7.3	2.9	7.3	1.00	0.40	1	1.73	○	×
3	12.0	8.7	7.3	1.64	1.19	1.31	2.26	○	×
4	15.1	10.4	7.3	2.07	1.42	1.31	2.26	○	○
5	14.6	6.4	7.3	2.00	0.88	1.31	2.26	○	×
6	12.1	8.8	7.3	1.66	1.21	1.31	2.26	○	×
7	13.8	7.8	7.3	1.89	1.07	1.31	2.26	○	×
8	13.0	8.9	7.3	1.78	1.22	1.31	2.26	○	×
9	12.3	5.7	7.3	1.68	0.78	1.31	2.26	○	×
10	9.4	6.3	7.3	1.29	0.86	1	1.73	○	×
11	10.2	4.1	7.3	1.40	0.56	1	1.73	○	×

[0191]

Table 1 is a table showing specifications of the plurality of bearing piles 10 shown in Fig. 44 and determinations on whether the specifications are met for the above-mentioned conditions. Table 1 shows the protruding amounts of the bearing piles 10 of No. 1 to No. 11, and the ratio of the protruding amount of each bearing pile 10 to the protruding amount of the reference pile, and also shows whether each protruding amount meets $1 \leq h/h_0 \leq 1.73$ or $1.31 \leq h/h_0 \leq 2.26$, which is the above-mentioned condition (3). In table 1, the determination is made under the condition for only the case where the comparison pile yields with a delay from yielding of the reference pile, and 1/2 of all bearing piles 10 meet the condition. Thus, the road structure 100 shown in Fig. 44 satisfies the above-mentioned condition (5). In the road structure 100 shown in table 1, a bearing pile on the valley side of No.2 is used as the reference pile based on the above-mentioned condition (2).

[0192]

[Table 2]

No.	Protruding amount (m)			Comparison pile/reference pile		Application range		Determination	
	Valley-side pile	Mountain-side pile	Reference pile	Valley-side pile	Mountain-side pile	Minimum	Maximum	Valley-side pile	Mountain-side pile
1	2.1	1.6	7.3	0.29	0.22	0.58	1.73	×	×
2	7.3	2.9	7.3	1.00	0.40	0.58	1.73	○	×
3	12.0	8.7	7.3	1.64	1.19	0.86	2.26	○	○
4	15.1	10.4	7.3	2.07	1.42	0.86	2.26	○	○
5	14.6	6.4	7.3	2.00	0.88	0.86	2.26	○	○
6	12.1	8.8	7.3	1.66	1.21	0.86	2.26	○	○
7	13.8	7.8	7.3	1.89	1.07	0.86	2.26	○	○
8	13.0	8.9	7.3	1.78	1.22	0.86	2.26	○	○
9	12.3	5.7	7.3	1.68	0.78	0.86	2.26	○	×
10	9.4	6.3	7.3	1.29	0.86	0.58	1.73	○	○
11	10.2	4.1	7.3	1.40	0.56	0.58	1.73	○	×

[0193]

Table 2 is a table showing specifications of the plurality of bearing piles 10 shown in Fig. 44 and determinations on whether the specifications are met for the above-mentioned conditions. In the same manner as table 1, table 2 shows the

protruding amounts of the bearing piles 10 of No. 1 to No. 11, and the ratio of the protruding amount of each bearing pile 10 to the protruding amount of the reference pile, and also shows whether each protruding amount meets $0.58 \leq h/h_0 \leq 1.73$ or $0.86 \leq h/h_0 \leq 2.26$, which is the above-mentioned condition (3). In table 2, the determination is made under the condition for both of the case where the comparison pile yields with a delay from yielding of the reference pile and the case where the comparison pile yields earlier than yielding of the reference pile, and the number of bearing piles 10 meeting the condition is 17 out of 22, that is, 1/1.3 of all bearing piles 10 meet the condition. Thus, the road structure 100 shown in Fig. 44 satisfies the above-mentioned condition (5).

[0194]

As described above, although the road structure 100 shown in Fig. 44 is installed in a mountain area, thus including the plurality of bearing piles 10 that significantly differ from each other in length, the road structure 100 shown in Fig. 44 satisfies the above-mentioned conditions (1) to (5). Consequently, when the road structure 100 receives a level 2 earthquake motion, for example, at least 1/2 or more of the bearing piles 10 are plastic deformed, thus absorbing energy caused by vibration and hence, the road structure 100 can exhibit earthquake resistance.

[0195]

<Control of length of inter-node part>

Fig. 45 is an enlarged view of the bearing pile 10 of the road structure 100 according to Embodiment 2. Although the length of an inter-node part 10P is determined by the position of the intermediate panel point part 50b of the bearing pile 10, the length of the inter-node part 10P can also be adjusted by the structure in the ground 90 into which the bearing pile 10 is driven.

[0196]

The bearing pile 10 of the road structure 100 is placed in the hole 95 drilled in the ground 90, and a filler 82, such as concrete, is filled between the hole 95 and an underground part 18a of the bearing pile 10 to fix the bearing pile 10. In Fig. 45, a filler 81, which is a soft material, such as urethane or polystyrene foam, is filled into a

space corresponding to an underground part 18 disposed at the upper portion of the hole 95. Consequently, although the length of the inter-node part 10P is a length of a portion extending upward from the fulcrum 98 in appearance, in conducting studies on strength, the length of the inter-node part 10P is a length of a portion extending upward from a virtual fulcrum 98a. By adjusting the height of the filler 82 to be filled into a space in the ground 90, the filler 82 having high strength, it is possible to adjust the length of the inter-node part 10P of the bearing pile 10, and it is also possible to cause the plastic deformation region of the bearing pile 10 to overlap with the plastic deformation region of another bearing pile 10. In general, to move the fulcrum 98 of the ground 90, it is necessary to construct an embankment or to perform excavation work. However, according to the structure shown in Fig. 45, by only changing the filler 82 to be filled into the hole 95, it is possible to adjust the length of the inter-node part 10P. The filler 82 located on the lower side may be referred to as "first filler", and the filler 81 filled into a space on the filler 82 may be referred to as "second filler". The first filler 82 has higher strength and rigidity than the second filler 81.

[0197]

Fig. 46 is a diagram illustrating the road structure 100 according to Embodiment 2 in cross section perpendicular to the y direction. When a mountain area has a large inclination, there may be cases where the road structure 100 has a large difference in protruding amount between the bearing pile 10 on the valley side and the bearing pile 10 on the mountain side. In this case, if the intermediate panel point part 50b is provided to each of the bearing pile 10 on the valley side and the bearing pile 10 on the mountain side, and the intermediate panel point parts 50b are connected with each other by the girder part 40, there may be cases where the bearing pile 10 on the mountain side has an extremely small length of the inter-node part, so that both bearing piles 10 are prevented from exhibiting energy absorption performance. In such a case, the girder part 40 is disposed in such a way as to cause the bearing pile 10 on the valley side to have two layers, and in such a way as to cause the bearing pile 10 on the mountain side to have one layer. That is, the girder part 40 is installed in such a way as to connect the intermediate panel point

part 50b and the upper end panel point part 50a with each other. The girder part 40 that connects the upper end panel point part 50a of the bearing pile 10 on the mountain side and the intermediate panel point part 50b of the bearing pile 10 on the valley side with each other inclines along the slope. This girder part 40 may be referred to as "third girder part".

[0198]

In Embodiment 2, the description has been made for the road structure 100 where at least some of the plurality of bearing piles 10 have two layers. However, at least some of the plurality of bearing piles 10 may have three or more layers.

[0199]

The present disclosure has been described heretofore based on the embodiments. However, the present disclosure is not limited to only the configurations of the above-mentioned embodiments. Particularly, the combination of constitutional elements is not limited to the combination in the embodiments, and may be suitably changed. Further, it is also noted that various modifications, applications, and utilizations made by those who are skilled in the art as needed also fall within the gist (technical scope) of the present disclosure.

[0200]

The artificial ground structure that includes the road structure 100 described above also includes combinations of respective features shown in the following Supplements 1 to 20. Such combinations will be described below.

[Supplement 1]

An artificial ground structure including:

bearing piles driven into ground in lines in a first direction, in which an artificial ground extends, and in a second direction intersecting with the first direction;

upper end panel point parts installed on upper ends of the bearing piles;

a first girder part configured to connect two adjacent upper end panel point parts of the upper end panel point parts; and

a floor slab installed on the upper end panel point parts and the first girder part, wherein

the bearing piles are set such that a hysteresis curve for horizontal displacement and horizontal load when the bearing piles receive a level 2 earthquake motion has a spindle shape.

[Supplement 2]

5 The artificial ground structure of Supplement 1, wherein
a bearing pile of the bearing piles is formed from an electric resistance welded steel pipe subjected to heat treatment, has a yield ratio for respective parts, including a welded part, of 85% or less, and has Charpy absorbed energy of 27 J or more.

[Supplement 3]

10 An artificial ground structure including:
bearing piles driven into ground in lines in a first direction, in which an artificial ground extends, and in a second direction intersecting with the first direction;
upper end panel point parts installed on upper ends of the bearing piles;
a first girder part configured to connect two adjacent upper end panel point
15 parts of the upper end panel point parts; and
a floor slab installed on the upper end panel point parts and the first girder part,
wherein
a bearing pile of the bearing piles is formed from an electric resistance welded steel pipe subjected to heat treatment, has a yield ratio for respective parts, including
20 a welded part, of 85% or less, and has Charpy absorbed energy of 27 J or more.

[Supplement 4]

The artificial ground structure of any one of Supplements 1 to 3, wherein
the bearing pile includes a plurality of bearing piles,
when a fulcrum at which the bearing pile and a surface of the ground intersect
25 with each other and the upper end panel point parts are assumed as nodes, and a portion of the bearing pile disposed between adjacent nodes of the nodes is assumed as an inter-node part,
of the plurality of bearing piles, two bearing piles driven into the ground in a state of being disposed adjacent to each other in the first direction or the second
30 direction include a plurality of inter-node parts,

the plurality of inter-node parts include a first inter-node part and a second inter-node part, the first inter-node part being plastically deformed when receiving a level 2 earthquake motion, the second inter-node part being not yet in a yielding state when receiving the level 2 earthquake motion, and

5 a length of the second inter-node part is set such that the second inter-node part yields before the first inter-node part reaches a limit strength.

[Supplement 5]

The artificial ground structure of any one of Supplements 1 to 3, further including:

10 an intermediate panel point part installed at an intermediate portion of the bearing pile; and

 a second girder part configured to connect two adjacent intermediate panel point parts with each other.

[Supplement 6]

15 The artificial ground structure of Supplement 5, wherein
 the second girder part is inclined in a direction along an inclination of the ground.

[Supplement 7]

20 The artificial ground structure of Supplement 5 or 6, wherein
 when a length of the bearing pile including the intermediate panel point part is taken as "h",

 a length from a fulcrum at which the bearing pile and a surface of the ground intersect with each other to the intermediate panel point part is set to 0.5h or more and 0.75h or less.

25 [Supplement 8]

 The artificial ground structure of any one of Supplements 5 to 7, wherein
 the intermediate panel point part includes a cylindrical body installed in such a way as to surround an outer side surface of the bearing pile, and

30 the intermediate panel point part has a structure where the intermediate panel point part is allowed to be installed in a state of being eccentric to a center axis of the

bearing pile.

[Supplement 9]

The artificial ground structure of Supplement 8, wherein
the bearing pile is formed by joining a steel pipe strut to an upper side of a first
5 steel pipe pile driven into the ground,

at a joint portion between the first steel pipe pile and the steel pipe strut,
the cylindrical body of the intermediate panel point part is disposed in a
state of extending over an upper end portion of the first steel pipe pile and a lower
end portion of the steel pipe strut, and

10 the intermediate panel point part has a structure where the intermediate
panel point part allows the first steel pipe pile and the steel pipe strut to be joined with
each other in an eccentric state.

[Supplement 10]

The artificial ground structure of Supplement 9, wherein
15 the intermediate panel point part includes a support part in the cylindrical body,
an upper end surface of the first steel pipe pile abutting against the support part from
below, and

the steel pipe strut is erected on the support part with a lower end surface of
the steel pipe strut abutting against an upper surface of the support part.

20 [Supplement 11]

The artificial ground structure of any one of Supplements 5 to 10, wherein
the bearing pile includes a plurality of bearing piles,
when the fulcrum at which the bearing pile and the surface of the ground
intersect with each other, the intermediate panel point part, and the upper end panel
25 point parts are assumed as nodes, and a portion of the bearing pile disposed
between adjacent nodes of the nodes is assumed as an inter-node part,

of the plurality of bearing piles, two bearing piles driven into the ground in a
state of being disposed adjacent to each other in the first direction or the second
direction include a plurality of inter-node parts,

30 the plurality of inter-node parts include a first inter-node part and a second

inter-node part, the first inter-node part being plastically deformed when predetermined horizontal displacement occurs in the two bearing piles, the second inter-node part being not yet in a yield state when the predetermined horizontal displacement occurs in the two bearing piles, and

5 a length of the second inter-node part is set such that the second inter-node part yields before the first inter-node part reaches a limit strength.

[Supplement 12]

The artificial ground structure of Supplement 11, wherein the plurality of inter-node parts include a plurality of first inter-node parts.

10 [Supplement 13]

The artificial ground structure of Supplement 11 or 12, wherein when yield displacement of the first inter-node part is taken as " $\delta 1y$ ", and yield displacement of the second inter-node part is taken as " $\delta 2y$ ", a length of the first inter-node part and the length of the second inter-node part are set such that the yield displacement $\delta 2y$ of the second inter-node part satisfies $\delta 1y \leq \delta 2y \leq 3 \cdot \delta 1y$.

15 [Supplement 14]

The artificial ground structure of any one of Supplements 1 to 13, wherein an upper end panel point part of the upper end panel point parts includes a cylindrical body installed in such a way as to surround the outer side surface of the bearing pile, and

20 the upper end panel point part has a structure where the upper end panel point part is allowed to be installed in a state of being eccentric to a center axis of the bearing pile.

[Supplement 15]

25 The artificial ground structure of any one of Supplements 1 to 14, wherein in a step performed after a weld bead is cut in production of a steel pipe, the bearing pile is subject to heat treatment by using an induction heating apparatus where an induction coil is installed on an inner surface or an outer surface of the steel pipe.

30 [Supplement 16]

The artificial ground structure of any one of Supplements 1 to 15, wherein an SKK material for steel pipe pile or an STK material for steel pipe for general structure is used for the bearing pile.

[Supplement 17]

5 The artificial ground structure of any one of Supplements 1 to 16, including:
a hole excavated in the ground, the bearing pile being erected in the hole; and
a first filler and a second filler filled into a gap between the bearing pile and the
hole, wherein

the first filler is filled into a space below the second filler, and has a higher
10 strength than the second filler after the first filler and the second filler are solidified.

[Supplement 18]

The artificial ground structure of any one of Supplements 1 to 17, further including:

15 the intermediate panel point part installed at the intermediate portion of the
bearing pile; and

a third girder part configured to connect the intermediate panel point part and
the upper end panel point part that are installed on two adjacent bearing piles.

[Supplement 19]

20 The artificial ground structure of Supplement 4, wherein
the plurality of bearing piles include

one reference pile having a protruding amount from the ground of h_0 , the
one reference pile forming reference, and

a comparison pile having a protruding amount from the ground of h , and
a condition that $0.58 \leq h/h_0 \leq 1.73$ is satisfied.

25 [Supplement 20]

The artificial ground structure of Supplement 11, wherein
the plurality of bearing piles include

one reference pile having a protruding amount from the ground of h_0 , the
one reference pile forming reference, and

30 a comparison pile having a protruding amount from the ground of h , the

comparison pile including the intermediate panel point part, and
a condition that $0.86 \leq h/h_0 \leq 2.26$ is satisfied.

Reference Signs List

[0201]

5 10: bearing pile, 10a: bearing pile, 10b: bearing pile, 10A to 10D: inter-node
part, 10Ca: inter-node part, 10Cb: inter-node part, 10Da: inter-node part, 10Db: inter-
node part, 10P: inter-node part, 11: joint portion, 12: pile head, 13: protrusion, 14: end
surface, 15: through hole, 16: filler receiving plate, 17: filling hole, 18: underground
part, 18a: underground part, 20: steel pipe pile, 20a: first steel pipe pile, 20b: second
10 steel pipe pile, 21: pile head, 21a: pile head, 21b: pile head, 22a: end surface, 30:
steel pipe strut, 31: end surface, 40: (second) girder part, 40a: stringer, 40b: cross
girder, 41: first girder part, 41a: stringer, 41aa: first stringer, 41b: cross girder, 42: floor
slab fixing part, 43: coupling part, 44: splice plate, 48: beam, 48a: diagonal beam,
48b: diagonal beam, 50: panel point part, 50a: upper end panel point part, 50aa: first
15 upper end panel point part, 50ab: second upper end panel point part, 50ac: third
upper end panel point part, 50ad: fourth upper end panel point part, 50b: intermediate
panel point part, 51a: steel pipe part, 51b: steel pipe part, 52a: stringer connection,
52b: stringer connection, 53a: cross girder connection, 53b: cross girder connection,
54: protrusion, 55a: support part, 55b: support part, 56a: filling hole, 56b: filling port,
20 57: bolt, 57a: upper surface, 58: upper plate, 59: lower plate, 59a: opening port, 60:
eccentric joint part, 60a: eccentric joint part, 60b: eccentric joint part, 61: insertion part,
62: rib part, 62a: external rib part, 62b: internal rib part, 65: plate part, 70: formwork jig,
71: bracket, 73: fixing band, 74: formwork plate, 75: adjustment bolt, 76: nut part, 80:
filler, 81: filler, 82: filler, 90: ground, 92: sediment layer, 93: support layer, 94: surface,
25 95: hole, 96: bottom surface, 97: gap, 98: fulcrum, 99: road floor slab, 100: road
structure, 150b: intermediate panel point part, 200: road structure, 250a: upper end
panel point part, 250b: intermediate panel point part, 251a: steel pipe part, 251b: steel
pipe part, 254a: lower end surface, 260: (third) eccentric joint part, 261: plate part,
262: upper surface, 350a: pile head block, 399: cover plate, 550a: upper end panel
30 point part, 550b: intermediate panel point part, 560a: eccentric joint part, 560b:

eccentric joint part, 1000: road structure, 1010: strut, 1010p: steel pipe pile, 1010p:
steel pipe pile, 1091: footing.

CLAIMS

[Claim 1]

An artificial ground structure comprising:

bearing piles driven into ground in lines in a first direction, in which an artificial
5 ground extends, and in a second direction intersecting with the first direction;

upper end panel point parts installed on upper ends of the bearing piles;

a first girder part configured to connect two adjacent upper end panel point
parts of the upper end panel point parts; and

a floor slab installed on the upper end panel point parts and the first girder part,
10 wherein

the bearing piles are set such that a hysteresis curve for horizontal
displacement and horizontal load when the bearing piles receive a level 2 earthquake
motion has a spindle shape.

[Claim 2]

The artificial ground structure of claim 1, wherein

a bearing pile of the bearing piles is formed from an electric resistance welded
steel pipe subjected to heat treatment, has a yield ratio for respective parts, including
a welded part, of 85% or less, and has Charpy absorbed energy of 27 J or more.

[Claim 3]

An artificial ground structure comprising:

bearing piles driven into ground in lines in a first direction, in which an artificial
ground extends, and in a second direction intersecting with the first direction;

upper end panel point parts installed on upper ends of the bearing piles;

a first girder part configured to connect two adjacent upper end panel point
25 parts of the upper end panel point parts; and

a floor slab installed on the upper end panel point parts and the first girder part,
wherein

a bearing pile of the bearing piles is formed from an electric resistance welded
steel pipe subjected to heat treatment, has a yield ratio for respective parts, including
30 a welded part, of 85% or less, and has Charpy absorbed energy of 27 J or more.

[Claim 4]

The artificial ground structure of any one of claims 1 to 3, wherein
the bearing pile includes a plurality of bearing piles,
when a fulcrum at which the bearing pile and a surface of the ground intersect
5 with each other and the upper end panel point parts are assumed as nodes, and a
portion of the bearing pile disposed between adjacent nodes of the nodes is assumed
as an inter-node part,

of the plurality of bearing piles, two bearing piles driven into the ground in a
state of being disposed adjacent to each other in the first direction or the second
10 direction include a plurality of inter-node parts,

the plurality of inter-node parts include a first inter-node part and a second
inter-node part, the first inter-node part being plastically deformed when receiving a
level 2 earthquake motion, the second inter-node part being not yet in a yielding state
when receiving the level 2 earthquake motion, and

15 a length of the second inter-node part is set such that the second inter-node
part yields before the first inter-node part reaches a limit strength.

[Claim 5]

The artificial ground structure of any one of claims 1 to 3, further comprising:
an intermediate panel point part installed at an intermediate portion of the
20 bearing pile; and

a second girder part configured to connect two adjacent intermediate panel
point parts with each other.

[Claim 6]

The artificial ground structure of claim 5, wherein
25 the second girder part is inclined in a direction along an inclination of the
ground.

[Claim 7]

The artificial ground structure of claim 5, wherein
when a length of the bearing pile including the intermediate panel point part is
30 taken as "h",

a length from a fulcrum at which the bearing pile and a surface of the ground intersect with each other to the intermediate panel point part is set to $0.5h$ or more and $0.75h$ or less.

[Claim 8]

5 The artificial ground structure of claim 5, wherein
the intermediate panel point part includes a cylindrical body installed in such a way as to surround an outer side surface of the bearing pile, and
the intermediate panel point part has a structure where the intermediate panel point part is allowed to be installed in a state of being eccentric to a center axis of the
10 bearing pile.

[Claim 9]

The artificial ground structure of claim 8, wherein
the bearing pile is formed by joining a steel pipe strut to an upper side of a first steel pipe pile driven into the ground,
15 at a joint portion between the first steel pipe pile and the steel pipe strut,
the cylindrical body of the intermediate panel point part is disposed in a state of extending over an upper end portion of the first steel pipe pile and a lower end portion of the steel pipe strut, and
the intermediate panel point part has a structure where the intermediate
20 panel point part allows the first steel pipe pile and the steel pipe strut to be joined with each other in an eccentric state.

[Claim 10]

The artificial ground structure of claim 9, wherein
the intermediate panel point part includes a support part in the cylindrical body,
25 an upper end surface of the first steel pipe pile abutting against the support part from below, and
the steel pipe strut is erected on the support part with a lower end surface of the steel pipe strut abutting against an upper surface of the support part.

[Claim 11]

30 The artificial ground structure of claim 5, wherein

the bearing pile includes a plurality of bearing piles,
when the fulcrum at which the bearing pile and the surface of the ground
intersect with each other, the intermediate panel point part, and the upper end panel
point parts are assumed as nodes, and a portion of the bearing pile disposed
5 between adjacent nodes of the nodes is assumed as an inter-node part,

among the plurality of bearing piles, two bearing piles driven into the ground in
a state of being disposed adjacent to each other in the first direction or the second
direction include a plurality of inter-node parts,

the plurality of inter-node parts include a first inter-node part and a second
10 inter-node part, the first inter-node part being plastically deformed when
predetermined horizontal displacement occurs in the two bearing piles, the second
inter-node part being not yet in a yield state when the predetermined horizontal
displacement occurs in the two bearing piles, and

a length of the second inter-node part is set such that the second inter-node
15 part yields before the first inter-node part reaches a limit strength.

[Claim 12]

The artificial ground structure of claim 11, wherein the plurality of inter-node
parts include a plurality of first inter-node parts.

[Claim 13]

20 The artificial ground structure of claim 11, wherein when yield displacement of
the first inter-node part is taken as " $\delta 1y$ ", and yield displacement of the second inter-
node part is taken as " $\delta 2y$ ", a length of the first inter-node part and the length of the
second inter-node part are set such that the yield displacement $\delta 2y$ of the second
inter-node part satisfies $\delta 1y \leq \delta 2y \leq 3 \cdot \delta 1y$.

25 [Claim 14]

The artificial ground structure of any one of claims 1 to 3, wherein
an upper end panel point part of the upper end panel point parts includes a
cylindrical body installed in such a way as to surround the outer side surface of the
bearing pile, and

30 the upper end panel point part has a structure where the upper end panel point

part is allowed to be installed in a state of being eccentric to a center axis of the bearing pile.

[Claim 15]

5 The artificial ground structure of any one of claims 1 to 3, wherein
in a step performed after a weld bead is cut in production of a steel pipe, the bearing pile is subject to heat treatment by using an induction heating apparatus where an induction coil is installed on an inner surface or an outer surface of the steel pipe.

[Claim 16]

10 The artificial ground structure of any one of claims 1 to 3, wherein
an SKK material for steel pipe pile or an STK material for steel pipe for general structure is used for the bearing pile.

[Claim 17]

15 The artificial ground structure of any one of claims 1 to 3, comprising:
a hole excavated in the ground, the bearing pile being erected in the hole; and
a first filler and a second filler filled into a gap between the bearing pile and the hole, wherein

the first filler is filled into a space below the second filler, and has a higher strength than the second filler after the first filler and the second filler are solidified.

20 [Claim 18]

The artificial ground structure of any one of claims 1 to 3, further comprising:
the intermediate panel point part installed at the intermediate portion of the bearing pile; and

25 a third girder part configured to connect the intermediate panel point part and
the upper end panel point part that are installed on two adjacent bearing piles.

[Claim 19]

30 The artificial ground structure of claim 4, wherein
the plurality of bearing piles include
one reference pile having a protruding amount from the ground of h_0 , the
one reference pile forming reference, and

a comparison pile having a protruding amount from the ground of h , and
a condition that $0.58 \leq h/h_0 \leq 1.73$ is satisfied.

[Claim 20]

The artificial ground structure of claim 11, wherein

5 the plurality of bearing piles include

one reference pile having a protruding amount from the ground of h_0 , the
one reference pile forming reference, and

a comparison pile having a protruding amount from the ground of h , the
comparison pile including the intermediate panel point part, and

10 a condition that $0.86 \leq h/h_0 \leq 2.26$ is satisfied.