A method of improving earthquake resistance of existing spillway piers provided in a dam. The method includes a following step. End portions of a main beam and top portions of existing spillway piers are connected to each other with a high damping device having a history damping property with high primary rigidity. The high damping device has a yield displacement amount in seismic velocity smaller than a tolerance of a displacement amount of the existing spillway piers. The high damping device has a yield load value in seismic velocity greater than a maximum seismic force generated therein in a bridge-axis direction due to a large-scale earthquake.
**FIG. 10**

Viscous Stress

- Bingham Fluid (seismic velocity)
- Bingham Fluid (velocity of expansion and contraction)
- Newtonian Fluid
- Dilatancy Material

Velocity Gradient
FIG. 12

Damper Reaction Force $R$ (kN)

![Graph showing damper reaction force versus displacement amount.](image-url)
FIG. 13

Damper Reaction Force $R$ (kN)

Yield Load

-1500 -1000 -500 0 500 1000 1500

-17.5 -15 -12.5 -10 -7.5 -5 -2.5 0 2.5 5 7.5 10 12.5 15

Extension Displacement Amount $\delta$ (mm) Compression

Using Area $E$
FIG. 14

Damper Reaction Force $R$ (kN)

Yield Load

Extension Displacement Amount $\delta$ (mm) Compression
FIG. 20

Horizontal Force of Top Portion of Spillway Pier When Moment Causing Crack In Concrete is Generated (kN)
METHOD OF UPGRADING SEISMIC PERFORMANCE OF EXISTING SPILLWAY PIERS ON DAMS AND COUPLED EARTHQUAKE-RESISTANT STRUCTURE

TECHNICAL FIELD

[0001] The present invention relates to a method of improving earthquake resistance of existing spillway piers on dams and also relates to an earthquake-resistant bridge in a dam.

BACKGROUND ART

[0002] A spillway gate G is provided in a dam for controlling a water volume in case of flood. As illustrated in FIG. 19a, spillway piers 15, 16 are provided on two ends of the spillway gate G, respectively. The spillway piers 15, 16 support an operation bridge 17 that is provided above the spillway gate G. A gate lifting device M1 for lifting the spillway gate G is provided on the operation bridge 17. The gate lifting device M1 is operated to open and close the spillway gate G. When the spillway gate G is opened and closed, a weight of the spillway gate G is supported by the two spillway piers 15, 16 via bearing members of the operation bridge 17.

[0003] A bearing structure for supporting a main beam 18 that forms a beam of the operation bridge 17 normally includes a fixed bearing structure on one end of the main beam 18 and a movable bearing structure on another end of the main beam 18 to allow expansion and contraction of the main beam 18 due to a variation in temperature. However, if the main beam 18 has the movable bearing structure on its other end, the spillway pier having the fixed bearing structure and the spillway pier having the movable bearing structure shake freely and independently from each other in case of an earthquake. This makes stress to be concentrated on a basal portion of each spillway pier.

[0004] Patent Documents 1 and 2 disclose technology for solving the problem that seismic force is concentrated on the spillway pier having the fixed bearing structure.

[0005] Patent Document 1 discloses that a movable bearing member interposed between the top of a bridge footing and the continuous beam serves as a slidable bearing during normal movement, but serves as a fixed bearing or resilient fixed bearing during earthquake.


DISCLOSURE OF THE INVENTION

[0012] The present invention has been completed in view of the circumstances described above. It is an object of the present invention to improve earthquake resistance of existing spillway piers.

Means for Solving the Problem

[0013] The present invention provides a method of improving earthquake resistance of existing spillway piers on dams. The existing spillway piers are arranged on two sides of a gate provided in the dam and support an existing bridge including a main beam made of steel, a gate lifting device provided on the existing bridge, and the gate. The main beam includes a fixed bearing structure on one side and a movable bearing structure on another side. The method comprises steps of connecting an end portion of the main beam close to the movable bearing and a top portion of one of the existing spillway piers with a high damping device including Bingham fluid as working fluid and having a history damping property with high primary rigidity, setting a yield displacement amount of the high damping device in seismic velocity to be smaller than a tolerance of a displacement amount of the existing spillway pier, and setting a yield load value of the high damping device in seismic velocity to be greater than a maximum seismic force generated in the high damping device in a bridge-axis direction due to a large-scale earthquake. The high damping device receives the maximum seismic force generated therein in the bridge-axis direction due to the large-scale earthquake within an area of the high primary rigidity before the history damping property is exerted.

EFFECTS OF THE INVENTION

First Effect

[0014] According to the present invention, a high damping device provided on a main beam is stretched with respect to a
spillway pier with a relative displacement and receives a maximum seismic force. Therefore, the displacement of the top portion of the spillway pier is kept to be small and reaction forces are less likely to be concentrated on a basal portion of the spillway pier.

Second Effect

[0015] Working fluid used for the high damping device is Bingham fluid that has less velocity dependency of seismic velocity in the relation between an amount of displacement and a reaction force (a spring force). Therefore, in case of any earthquakes including short-periodic earthquake having great seismic velocity and long-periodic earthquake having low seismic velocity, high rigidity of the damper is obtained. Accordingly, in case of any earthquakes, constant earthquake-resistant performance of the spillway pier is obtained. In other words, in case of any earthquakes, an amount of displacement of the top portion of the existing spillway pier having a small amount of reinforcing steel can be kept to be a tolerance or smaller.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG. 1 is a perspective view illustrating a dam and an existing bridge according to a first embodiment of the present invention;
[0017] FIG. 2 is a front view illustrating the existing bridge;
[0018] FIG. 3 is a horizontal cross-sectional view illustrating a support structure of a spillway gate;
[0019] FIG. 4 is a cross-sectional view along a C-C line in FIG. 2;
[0020] FIG. 5 is a cross-sectional view along a D-D line in FIG. 4;
[0021] FIG. 6 is a front view illustrating an earthquake-resistant bridge with a method of improving earthquake resistance;
[0022] FIG. 7 is an enlarged view of FIG. 6;
[0023] FIG. 8 is a plan view illustrating screwing points with bolts;
[0024] FIG. 9a is a partially cross-sectional view illustrating an inner structure of a high damping device (a piston is located in a middle portion);
[0025] FIG. 9b is a partially cross-sectional view illustrating the inner structure of the high damping device (the piston is located at an end of a stroke);
[0026] FIG. 9c is a partially cross-sectional view illustrating the inner structure of the high damping device (the piston is located at an end of a stroke);
[0027] FIG. 10 is a diagram illustrating rheograms of Bingham fluid;
[0028] FIG. 11 is a diagram illustrating a pattern of a load applied to the high damping device according to displacement control;
[0029] FIG. 12 is a diagram illustrating a history pattern of the high damping device;
[0030] FIG. 13 is a diagram illustrating a correlation property of an amount of displacement of the high damping device and a reaction force of the high damping device (in seismic velocity);
[0031] FIG. 14 is a diagram illustrating a correlation property of an amount of displacement of the high damping device and a reaction force of the high damping device (in expansion and contraction velocity due to a variation in temperature);
[0032] FIG. 15 is a front view illustrating an existing bridge according to a second embodiment;
[0033] FIG. 16 is a front view illustrating an earthquake-resistant bridge with a method of improving earthquake resistance;
[0034] FIG. 17 is a front view illustrating a part of FIG. 16 with enlarged;
[0035] FIG. 18 is a front view illustrating an existing bridge according to a modification;
[0036] FIG. 19a is a front view illustrating a structure of a bridge supporting a spillway gate;
[0037] FIG. 19b is a front view illustrating spillway piers that have fallen; and
[0038] FIG. 20 is a diagram illustrating a yield curve of the spillway piers.

DESCRIPTION OF THE REFERENCE NUMERALS

[0039] 10: Dam body
[0040] 20: Existing bridge
[0041] 20': Earthquake-resistant bridge
[0042] 31, 33, 35: Existing spillway piers (Spillway piers)
[0043] 40: Existing operation bridge (Existing bridge body and Bridge body)
[0044] 41: Beam member
[0045] 45: Plate deck
[0046] 50A, 50B: Main beam
[0047] 70: High damping device
[0048] 71: Cylinder
[0049] 73: Piston
[0050] 80: Bingham fluid
[0051] 120: Existing bridge
[0052] 120': Earthquake-resistant bridge
[0053] 131, 133, 135: Existing spillway piers (Spillway piers)
[0054] 140: Existing operation bridge (Existing bridge body and Bridge body)
[0055] 150A, 150B: Beam member
[0056] G1, G2: Spillway gate (Gate)
[0057] δy: Yield displacement amount in seismic velocity
[0058] δc: Tolerance of displacement amount of existing spillway pier (displacement amount of top portion)
[0059] Rα: Yield load in seismic velocity
[0060] Fm: Maximum seismic force
[0061] F: Fixed bearing structure
[0062] M: Movable bearing structure

BEST MODES FOR CARRYING OUT THE INVENTION

FIRST EMBODIMENT

[0063] A first embodiment of the present invention will be explained with reference to FIGS. 1 to 14.

1. Explanation of Structure of Existing Bridge 20

[0064] A reference number 10 in FIG. 1 indicates a dam body made of concrete. A reference numbers G1, G2 indicate spillway gates (an example of a gate). Each of the spillway gates G1, G2 is configured to partially close a discharge opening 11 formed in the dam body 10. The spillway gate G1 closes a left half of the discharge opening 11 and the spillway gate G2 closes a right half of the discharge opening 11. The
spillway gates G1, G2 are made of iron and supported by an existing bridge 20 that will be explained next.

[0065] The existing bridge 20 mainly includes existing spillway piers 31, 33, 35 and an existing operation bridge (an example of an existing bridge body) 40. The existing spillway piers 31, 33, 35 support the spillway gates G1, G2, the existing operation bridge 40 and gate lifting devices M1, M2. The existing spillway piers 31, 33, 35 are made of reinforced concrete and arranged in a width direction of the discharge opening 11. Specifically, as illustrated in FIG. 2, the existing spillway pier 31 is provided at a left side of the left-side spillway gate G1 and the existing spillway pier 35 is provided at a right side of the right-side spillway gate G2. The existing spillway pier 33 is provided between the spillway gates G1, G2.

[0066] As illustrated in FIG. 3, the existing spillway piers 31, 33, 35 extend in a water discharging direction (water flowing direction). Fitting grooves 31A, 33A, 35A are formed on side surface walls of each existing spillway pier 31, 33, 35 so as to correspond to the spillway gates G1, G2.

[0067] Each of the fitting grooves 31A, 33A, 35A extends straight in an up-down direction (in a vertical direction to a paper plane in FIG. 3). Two side ends of each spillway gate G1, G2 are fitted to the corresponding fitting grooves 31A, 33A, 35A with a constant gaps therebetween.

[0068] Accordingly, the left-side spillway gate G1 illustrated in FIG. 2 is guided in a vertical position by the existing spillway piers 31, 33 and moves in the up-down direction along the fitting grooves 31A, 33A. The spillway gate G2 is guided in a vertical position by the existing spillway piers 33, 35 and moves in the up-down direction along the fitting grooves 33A, 35A.

[0069] Each of the existing spillway piers 31, 33, 35 is designed according to a seismic coefficient method. As illustrated in FIG. 20, a yield load Py of reinforcing steel is smaller compared to a tolerance Pc of a horizontal force (a load) that can be applied to the top portion of the existing spillway pier 31, 33, 35. If the displacement amount of the top portion is approximately 10 mm, an amount of the horizontal force reaches the tolerance Pc. The tolerance be of the displacement amount of the top portion of the existing spillway pier 31, 33, 35 is approximately 10 mm. In the following explanation, the three existing spillway piers 31, 33, 35 are collectively referred to as an existing spillway pier 30.

[0070] As illustrated in FIG. 2, the existing operation bridge 40 includes a beam member 41 and a plate deck 45 that are made of steel. The beam member 41 includes main beams 50A, 50B each of which extends in a bridge-axis direction of the existing operation bridge 40 (right-left direction in FIG. 2) and a crossbeam (not illustrated) extending in a width direction of the existing operation bridge 40. In the following explanation, the two main beams 50A, 50B are collectively referred to as a main beam 50.

[0071] The main beam 50 is made of steel and has a web 53 extending in the up-down direction and flanges 54, 55 on upper and lower sides of the web 53, respectively. The main beam 50 is provided between the two adjacent existing spillway piers 30. Namely, the main beam 50A is provided between the existing spillway pier 31 and the existing spillway pier 33 and the main beam 50B is provided between the existing spillway pier 33 and the existing spillway pier 35. The main beam 50 is a beam of the existing operation bridge 40.

[0072] A bearing structure of each main beam 50A, 50B includes a fixed bearing structure on one side and a movable bearing structure on another side. The stationary bearing structure supports a load of the main beam 50 and restricts displacement of the main beam 50 in the bridge-axis direction (displacement of expansion and contraction due to a variation in temperature). The movable bearing structure supports a load of the main beam 50 and allows displacement of the main beam 50 in the bridge-axis direction (displacement of expansion and contraction due to a variation in temperature).

[0073] In FIG. 2, the symbol indicated by a triangle with a character “F” represents that the bearing structure between the main beam 50 and the existing spillway pier 30 is a fixed bearing structure, and the symbol indicated by a circle with a character “M” represents that the bearing structure between the main beam 50 and the existing spillway pier 30 is a movable bearing structure. In the following explanation, on the main beam 50, the fixed bearing structure side is referred to as one end side and the movable bearing structure side is referred to as another end side.

[0074] Hereinafter, the bearing structure of the main beam 50A will be explained. As illustrated in FIG. 4, an upper end portion 41A, 44A of each of the existing spillway piers 41, 44 is a flat support surface and it supports either end portion of a lower flange 55 of the main beam 50A.

[0075] As illustrated in FIG. 5, bolt insertion holes 57A, 57B are formed in the left end portion 57 and the right end portion 58 of the lower flange 55 of the main beam 50A, respectively. Bolt holes (not illustrated) are formed in an upper wall 31A, 33A of the existing spillway pier 31, 33 corresponding to the bolt insertion holes 57A, 58A formed in the main beam.

[0076] Bolts B are inserted through the bolt insertion holes 57A, 58A of the main beam 50A and screwed up in the corresponding bolt holes of the existing spillway pier 31, 33. Accordingly, the end portions 57, 58 of the main beam 50A is mounted to the upper walls 31A, 33A of the existing spillway piers 31, 33 with bolts.

[0077] As illustrated in FIG. 5, each bolt insertion hole 57A formed at the end portion 57 side of the main beam 50A has a circular shape and the bolt B is inserted through the bolt insertion hole 57A without any gap therebetween. Therefore, after fastening with the bolts B, the displacement of the end portion 57 of the main beam 50A is restricted in the width direction and in the bridge-axis direction with respect to the upper wall 31A of the existing spillway pier 31 (a fixed bearing structure F).

[0078] As illustrated in FIG. 5, each bolt insertion hole 58A formed at the end portion 58 side of the main beam 50A has an elongated shape extending in the bridge-axis direction. Accordingly, even after fastening with the bolts B, the bolts B can move relatively in the insertion holes 58A. Therefore, the displacement of the end portion 58 of the main beam 50A is restricted in the width direction with respect to the upper wall 31A of the existing spillway pier 31 and the displacement of the end portion 58 is allowed in the bridge-axis direction (a movable bearing structure M). The movable bearing structure is provided on the end portion 58 at the another end of the main beam 50 to allow expansion and contraction of the main beam 50 due to a variation in temperature.

[0079] As illustrated in FIG. 4, a number of the elongated main beams 50A, 50B (for example, three) are arranged parallel to each other in the width direction of the existing operation bridge 40. A plate deck 48 is placed on the main beams.
50A, 50B that are arranged parallel to each other. The plate deck 48 is formed by steel assembled in a grid pattern and has a whole length extending over the three existing spillway piers 31, 33, 35. The plate deck 48 has a width substantially same as the top portion of the existing spillway pier 31, 33, 35. The main beams 50 that are arranged parallel to each other support the plate deck 45 evenly.

[0080] As illustrated in FIG. 2, gate lifting devices M1, M2 are provided on the plate deck 45 corresponding to the spillway gates G1, G2, respectively. The gate lifting device M1, M2 winds up and unwinds a wire W for lifting and lowering the spillway gates G1, G2. Each of the gate lifting devices M1, M2 is activated to lift and lower (open and close) each spillway gate G1, G2 independently. The spillway piers 31, 33, 35 support the weight of the spillway gates G1, G2 generated in opening and closing the gates via the existing operation bridge 40.

2. Explanation of Method of Improving Earthquake Resistance of Existing Spillway piers 30

[0081] In the first embodiment, following four processes are performed for the existing bridge 20 to improve earthquake resistance of the existing spillway piers 30.

[0082] (1) In each span of the existing operation bridge 40, the end portion 58 of the main beam 50 close to the movable bearing structure and the top portion of the existing spillway pier 30 close to the movable bearing structure are connected to each other via a high damping device 70 having a history damping property with high primary rigidity.

[0083] (2) A yield displacement amount by of the high damping device 70 in the seismic velocity is set to be smaller than a tolerance 8c of the displacement amount of the existing spillway pier 30 (the displacement amount of the top portion).

[0084] (3) A yield load value Ra of the high damping device 70 in the seismic velocity is set to be greater than a maximum seismic force Fm that is generated in the high damping device 70 in the bridge-axis direction due to a large-scale earthquake.

[0085] (4) In each span of the existing operation bridge 40, the end portion 57 of the main beam 50 close to the fixed bearing structure and the top portion of the existing spillway pier 30 close to the fixed bearing structure are connected to each other via a connecting member 60 of a pin structure.

[0086] The processes of (1) to (4) are performed for both of the main beam 50A and the main beam 50B and the operation is same. In the following, the main beam 50A will be explained.

[0087] Explanation of the Processes (1) to (3)

[0088] As illustrated in FIG. 9a, the high damping device 70 includes a cylinder 71, a piston 73, a piston rod 75 and an orifice 77. Working fluid 80 is sealed in the cylinder 71. The piston rod 75 includes the piston 73 that divides inner space of the cylinder 71 into two spaces. The orifice 77 is formed between an outer peripheral surface of the piston 73 and an inner peripheral surface of the cylinder 71.

[0089] A guide pin 73A is provided at a distal end of the piston 73. The guide pin 73A is fitted to a guide groove 71A formed on the cylinder 71. The piston 73 reciprocately moves along an axial line L with the guide pin 73A being guided by the guide groove 71A.

[0090] As illustrated in FIG. 7, in the process (1), the high damping device 70 is arranged in a horizontal position such that the axial line L is parallel to a horizontal direction and the high damping device 70 is positioned below the end portion 58 of the main beam 50A. Thereafter, a bracket 91 provided at an axial end of the high damping device 70 is fixed to a side surface of the top portion 34 of the existing spillway pier 33. A bracket 92 provided at the other axial end of the high damping device 70 is fixed to a fixing member 93 that is provided on a lower surface of the end portion 58 of the main beam 50A.

[0091] Accordingly, the brackets 91, 92 of the high damping device 70 are fixed to the existing spillway pier 33 and the main beam 50A, respectively. The end portion 58 of the main beam 50A is connected to the top portion 34 of the existing spillway pier 33 via the high damping device 70 the axial line L of which is parallel to the horizontal direction (the bridge-axis direction). The high damping device 70 is thus provided to each of the three main beams 50A that are arranged parallel to each other in the width direction of the existing operation bridge 40.

[0092] The high damping device 70 used in the method of improving earthquake resistance includes Bingham fluid as the working fluid 80 and has a history damping property with high primary rigidity. Bingham fluid (plastic fluid, an example of which is highly viscous silicone) 80 has a property that the rheogram is discontinuous from the original 0 (Bingham fluid has certain viscous stress even if velocity gradient is zero) as illustrated in FIG. 10. The property of Bingham fluid changes from elasticity to plasticity just before or just after Bingham fluid reaches compressed limit.

[0093] Therefore, the high damping device 70 functions as an elastic member until the Bingham fluid 80 reaches compressed limit. Change of damper reaction force R according to the displacement amount δ is represented by a primary straight line. For example, the primary straight lines from point 0 to point 1 and from point 6 to point 8 (in compression) in FIG. 12 and from point 2 to point 4 (in extension) in FIG. 12 indicate the change of damper reaction force R in response to the displacement amount δ. An area in which the Bingham fluid 80 has an elastic property is referred to as a primary rigidity area. The primary rigidity k1 represents inclination of the straight line and indicated by the following formula.

\[ k1 = \frac{Ra \cdot by}{formula 1} \]

[0094] Ra: yield load

[0095] by: yield displacement amount

[0096] After the Bingham fluid 80 reaches compressed limit, it has a plastic property and moves through the orifice 77 into a space on an opposite side from the space in which the Bingham fluid 80 was (see FIGS. 9b and 9c). The high damping device 70 reaches a yield point and, keeps a yield load Ra and only the displacement amount δ increases (for example, from point 1 to point 2, from point 4 to point 6, and from point 8 to point 9 in FIG. 12). Hereinafter, an area in which the Bingham fluid 80 has a plastic property is referred to as a secondary rigidity area.

[0097] As illustrated in FIG. 11, an axial force of extension and compression is repeatedly applied to the high damping device 70 to control displacement to produce a sine curve. Then, the high damping device 70 has a history damping property (a hysteresis property). Specifically, relation between the displacement amount δ and the damper reaction force R represents a correlation indicating a history loop of a parallelogram having an original point 0 as a center (see FIG. 12).

[0098] The high damping device 70 has almost no velocity dependency in the seismic velocity. The high damping device
70 has high primary rigidity in both cases of short-periodic earthquake and long-periodic earthquake. "High primary rigidity" means that the primary rigidity k1 is high, namely, that the inclination of the line is great as illustrated in FIG. 12. Specifically, high primary rigidity of the high damping device 70 means that the primary rigidity k1 is 400 kN/mm or more. [0099] The primary rigidity of the high damping device 70 has almost no velocity dependency in the seismic velocity because the Bingham fluid having appropriate hardens and the orifice of an appropriate gap are used for the high damping device 70. The high damping device 70 has high primary rigidity because the Bingham fluid having appropriate hardness and the orifice of an appropriate gap are used for the high damping device 70. [0100] The yield load (that is a maximum reaction force) Ra of the high damping device 70 is proportional to a volume of the high damping device 70 (the filling amount of the Bingham fluid 80) if the cross sectional area of the orifice 77 is same. Therefore, the high damping device having a great volume is selected to increase the yield load Rc. The primary rigidity k1 of the high damping device 70 has a tendency to be proportional to, viscosity of the Bingham fluid 80. Therefore, the high damping device 70 having high-viscosity Bingham fluid 80 is selected to reduce the yield displacement amount 6. [0101] Generally, the high damping device 70 is designed so that the yield load Ra in the seismic velocity is smaller than the maximum seismic force Fm. Accordingly, in case of a large-scale earthquake, the high damping device 70 reaches a yield point and follows the history damping loop illustrated in FIG. 12 and absorbs vibration energy corresponding to an area surrounded by the history damping loop. [0102] The high damping device 70 is used in the method of improving earthquake resistance of the present embodiment, however, unlike a conventional general technology of applying the high damping device 70 for dealing with a large-scale earthquake, it is not expected to use history damping property that is ability of absorbing earthquake energy. [0103] As will be explained later in the processes (2) and (3), a special using method of the high damping device 70 is applied in the method of improving earthquake resistance of the present embodiment. Specifically, the method of the present embodiment uses the property of the high damping device 70 obtained only in the primary rigidity area of an elastic behavior before exertion of the history damping property. In the method of improving earthquake resistance of the present embodiment, such a special using method of the high damping device 70 is referred to as a high damping device special application method. [0104] In this specification, a large-scale earthquake motion is defined as follows. In a building having an own natural period ranging from 0.1 seconds to 0.7 seconds, a large-scale earthquake motion is defined as an earthquake motion that causes the response acceleration spectrum of the building of 700 (cm/s²) or more in response to the earthquake motion. According to dam earthquake resistance performance reference examination standard (proposa) and exposition thereof that were published in March 2005 from River Bureau of Ministry of Land, Infrastructure and Transport, a large-scale earthquake motion (an earthquake motion of level 2) is likely to have greatest influence on an object of the earthquake resistance performance reference examination (for example, an object spillway pier). [0105] In the processes (2) and (3), the yield displacement amount 6y is set to be smaller than the tolerance 6c of the displacement amount of the existing spillway pier 30 (the displacement amount of the top portion). The yield load value Ra of the high damping device 70 in the seismic velocity is set to be greater than the maximum seismic force Fm that is generated in the high damping device 70 in the bridge-axis direction by a large-scale earthquake. The processes (2) and (3) are executed in earthquake-resistant designing, that is, before the execution of the process (1). Earthquake resistance is evaluated in the earthquake-resistant designing. [0106] According to the method of improving earthquake resistance of the present embodiment, the yield displacement amount 6y of the high damping device 70 in the seismic velocity and the yield load Ra in the seismic velocity are set as mentioned before. Accordingly, the high damping device 70 receives the maximum seismic force Fm that is generated therein in the bridge-axis direction by a large-scale earthquake within the high primary rigidity area (an area E in FIG. 13) before the history damping property of the high damping device 70 is exerted. Namely, a reaction force of the high damping device 70 against the maximum seismic force Fm is generated in the high primary rigidity area. [0107] Accordingly, the high damping device 70 provided on the main beam 50 restricts the displacement of the top portion of each existing spillway pier 31, 33, 35, and the displacement amount of the top portion of each existing spillway pier 31, 33, 35 is restricted to be the tolerance 6e or smaller. [0108] Specific setting values in the processes (2) and (3) will be described. The tolerance 6c of the displacement value of the top portion of the existing spillway pier 30 is approximately 10 mm and the yield displacement amount 6y of the high damping device 70 in the seismic velocity is approximately 2.5 mm that is 7.5 mm smaller than the tolerance 6c. The maximum seismic force Fm that is applied to the high damping device 70 in the bridge-axis direction by a large scale earthquake is supposed to be from 600 kN to 800 kN. The yield load value Ra of the high damping device 70 in the seismic velocity is set to be approximately 1000 kN as illustrated in FIG. 13. The yield load value Ra is approximately 200 kN greater than the maximum seismic force Fm. The seismic velocity is supposed to be approximately from 0.01 m/s to 2 m/s. [0109] The maximum seismic force Fm is a maximum value of an axial force (an external force acting on the axial line) acting on the high damping device 70 in the bridge-axis direction when large-scale earthquake happens. In other words, in case that the high damping device 70 is replaced with a rigid component without expansion or contraction, simulation of applying seismic force is practiced and a reaction force that the replaced rigid component receives from the existing spillway pier 33 is the maximum seismic force Fm. The maximum seismic force Fm is computed based on data of ground in the periphery of a dam, data of weight of each construction (specifically, each existing spillway pier, each existing operation bridge) and data of an own natural period of each construction, and seismic data relating to supposed large-scale earthquake (data of a depth of hypocenter, data of magnitude of earthquake and data of distance from hypocenter to the dam). [0110] A buckling load of the main beam 50A is approximately 2000 kN. The yield load value Ra of the high damping device 70 in the seismic velocity is approximately 1000 kN that is approximately 1000 kN lower than the buckling load of the main beam 50A. Therefore, in case of an earthquake, a
load that causes buckling of the main beam 50A is not applied to the main beam 50A via the high damping device 70.

[0111] The yield load Ra of the high damping device 70 in the seismic velocity is approximately 1000 kN and the maximum reaction force Rb of the high damping device 70 in the velocity of expansion and contraction due to a variation in temperature (the velocity of expansion and contraction of the main beam 50A due to a variation in temperature) is set to be approximately 200 kN. Namely, the maximum reaction force Rb in the velocity of expansion and contraction (the velocity of the expansion and contraction of the main beam) is 20% or less of the yield load Ra in the seismic velocity (see FIG. 14). Therefore, in a normal state, the high damping device 70 does not damage the spillway piers 31, 33 and the main beam 50A that are formed in connection with the high damping device 70. The velocity of expansion and contraction of the main beam due to a variation in temperature is supposed to be 1.0×10^{-5} m/s to 8×10^{-5} m/s. The maximum reaction force Rb in the velocity of expansion and contraction is not described as the yield load Rb in the velocity of expansion and contraction. This is because the high damping device 70 has certain following characteristics in a slow displacement caused by the velocity of expansion and contraction due to a variation in temperature, and therefore, an exact yield point is less likely to be obtained actually.

[0112] Explanation of Process (4)

[0113] The connecting member 60 is a pin structure and includes a shaft pin 65 and two brackets 61, 63 that are rotatably connected to each other by the shaft pin 65. The pin structure is referred to as a structure that does not restrict rotation (the two brackets connected by the pin can be freely rotated).

[0114] In the process (4), the connecting member 60 is positioned at the lower end portion of the main beam 50A. Then, the bracket 61 is fixed to a side surface of the top portion 32 of the existing spillway pier 31 with bolts B'. The bracket 63 is fixed to a lower surface of the end portion 57 of the main beam 50A with bolts B'.

[0115] Accordingly, the brackets 61, 63 of the connecting member 60 are fixed to the top portion 32 of the existing spillway pier 31 and the end portion 57 of the main beam 50A, respectively. This connects the main beam 50A and the existing spillway pier 31 via the connecting member 60.

[0116] The end portion 57 of the main beam 50A is fixed to the top portion 32 of the existing spillway pier 31 with the existing fixed bearing structure (fixing with the bolts B) and the connecting member 60.

[0117] As illustrated in FIG. 8, in the present embodiment, the number of the bolts B' used for attaching the connecting member 60 is greater than the number of the existing bolts B. The bolts B' sufficiently increase attachment strength of the connecting member 60 and the main beam. Therefore, the connecting member 60 can independently receive seismic force applied to the end portion 57 of the main beam 50A. The connecting member 60 is attached to all of the three main beams 50A that are arranged in the width direction of the existing operating bridge 40.

[0118] By executing the processes (1) to (4), the existing bridge 20 is altered to an earthquake-resistant bridge 20' including following five configurations (see FIGS. 6 and 7). A first configuration includes the existing operating bridge (a bridge body) 40. A second configuration includes the three existing spillway piers (a number of spillway columns) 30 that support the existing operating bridge 40. A third configuration includes the main beam 50 that is provided between the adjacent existing spillway piers 30 in each span of the existing operation bridge 40. A fourth configuration includes the high damping device 70 that connects the end portion 58 of the main beam close to the movable bearing structure and the top portion of the existing spillway pier 30. A fifth configuration includes the connecting member 60 that connects the side portion 57 of the main beam 50 close to the fixed bearing structure and the top portion of the existing spillway pier 30.

[0119] In the earthquake-resistant bridge 20', the yield displacement amount by of the high damping device 70 in the seismic velocity is set to be smaller than the tolerance ε of the displacement of the existing spillway pier 30. The yield load Ra of the high damping device 70 in the seismic velocity is set to be greater than the maximum seismic force that is generated in the high damping device 70 in the bridge-axis direction by a large-scale earthquake. Therefore, the high damping device 70 receives the maximum seismic force Fm that is generated therein in the bridge-axis direction by a large-scale earthquake within the high primary rigidity area (the area E in FIG. 13) before the history damping property of the high damping device 70 is exerted.

3. Explanation of Effects

3-1. Effects of High Damping Device Special Application Method

[0120] The high damping devices 70 attached to the main beams 50A, 50B resist the maximum seismic force Fm with a small relative displacement with respect to the existing spillway piers 31, 33, 35 and receive the maximum seismic force Fm. Therefore, the displacement amount of the top portion of each of the existing spillway piers 31, 33, 35 is restricted to be the tolerance ε or smaller. Therefore, in case of an earthquake, a great moment is less likely to be applied to the basal portions of each of the existing spillway piers 31, 33, 35. The load (the seismic force) applied to the top portion of each of the spillway piers 31, 33, 35 does not reach the tolerance Pe. Therefore, in case of an earthquake, the spillway piers 31, 33, 35 are not damaged and kept same as before the earthquake. The spillway gates G1, G2 are opened and closed without any troubles and dam impoundment control can be executed normally.

[0121] To improve earthquake resistance of the existing spillway piers 31, 33, 35, for example, the existing spillway piers 31, 33, 35 may be renovated to increase the amount of reinforcing steel. However, such antisismic reinforcement requires a big construction work and a huge cost. According to the method of the present embodiment, to improve earthquake resistance of the spillway pier 30, the existing spillway piers 31, 33, 35 do not require any renovation but require attaching of the connecting members 60 and the high damping devices 70 that is a simple structure alternation construction. Therefore, compared to the case in that the existing spillway piers 31, 33, 35 are renovated to be reinforced, a cost is remarkably reduced and it is quite effective.

[0122] The main beam 50 is made of steel and expanded and contracted due to a variation in temperature. The high damping device 70 is yielded in response to the slow displacement of the main beam 50 caused by expansion and contraction due to a variation in temperature before the main beam 50 buckles to release (allow) the expansion and contraction of the main beam 50. Especially in the present embodiment, as illustrated in FIG. 12, the maximum reaction force Rb in the
velocity of expansion and contraction due to a variation in temperature is set to be 20% or less of the yield load $R_a$ in the seismic velocity. Therefore, in a normal state, the high damping device 70 does not damage the spillway pier 30 and the main beam 50 that are formed in connection with the high damping device 70.

[0123] The high damping device 70 using Bingham fluid 80 as the working liquid has substantially the same high primary rigidity in both cases of a short-periodic earthquake having great seismic velocity and a long-periodic earthquake having low seismic velocity (the high damping device 70 has almost no velocity dependency in the seismic velocity). Therefore, in case of any earthquakes, the high damping device 70 has substantially the same earthquake resistance performance and the displacement of the top portion of each of the existing spillway piers 31, 33, 35 having a small amount of reinforcing steel is restricted to be the tolerance $\delta c$ or smaller.

[0124] A damper using a dilatancy material as the working fluid may have imitable great reaction force if an unexpected earthquake happens. If such a case happens, the reaction force acting on the main beam 50 excessively increases and the main beam 50 may be buckled or the bearing point of the main beam 50 may be damaged. In the high damping device 70 of the present embodiment, if an unexpected earthquake happens and the axial force greater than the yield load $R_a$ acts on the high damping device 70, the property of the high damping device 70 shifts from the primary rigidity to the secondary rigidity to release the axial force. Therefore, even if an unexpected earthquake happens, the main beam 50 is not buckled and the bearing point of the main beam 50 is not damaged.

3-2. Effect of Attaching of Connecting Member 60

[0125] By the attaching of the connecting member 60, the main beam 50 is fixed to the top portion of the existing spillway pier 30 with the existing fixed bearing structure (the fixing by the bolts B) and the connecting member 60.

[0126] Especially in the present embodiment, as illustrated in FIG. 8, the number of the bolts B used for the attachment of the connecting member 60 is greater than the number of the existing bolts B. The bolts B′ effectively increase shear strength. Therefore, the connecting member 60 independently receives seismic force applied to the end portion 57 of the main beam 50.

SECOND EMBODIMENT

[0127] Next, a second embodiment of the present invention will be explained with reference to FIGS. 15 to 17.

[0128] In the first embodiment, the method of improving earthquake resistance with the existing operation bridge 40 made of steel is explained. In the second embodiment, a method of improving earthquake resistance with an existing operation bridge 140 made of concrete will be explained. The same symbols are applied to components same as those in the first embodiment and explanation thereof will be omitted or simplified.

1. Explanation of Structure of Existing Bridge 120 that Supports Spillway gate G

[0129] The reference number 10 in FIG. 15 indicates a dam body made of concrete. The reference numbers G1, G2 indicate the spillway gates. Each of the spillway gates G1, G2 is configured to partially close the discharge opening 11 formed in the dam body 10. The spillway gate G1 closes a left half of the discharge opening 11 and the spillway gate G2 closes a right half of the discharge opening 11. The spillway gates G1, G2 are made of iron and supported by an existing bridge 120 that will be explained next.

[0130] The existing bridge 120 mainly includes existing spillway piers 131, 133, 135 and an existing operation bridge 140. The existing spillway piers 131, 133, 135 are made of reinforced concrete and arranged in a width direction of the discharge opening 11. Specifically, as illustrated in FIG. 25, the existing spillway pier 131 is provided at a left side of the left-side spillway gate G1 and the existing spillway pier 135 is provided at a right side of the right-side spillway gate G2. The existing spillway pier 133 is provided between the spillway gates G1, G2. The three existing spillway piers 131, 133, 135 are collectively referred to as an existing spillway pier 130.

[0131] Base members 132, 134, 136 are provided on side surfaces of the existing spillway piers 131, 133, 135, respectively. Each of the base members 132, 134, 136 is provided on the top portion of each existing spillway pier 131, 133, 135, respectively. Upper surfaces 132A, 134A, 136A are flat support surfaces. Each of the upper surfaces 132A, 134A, 136A is provided at a same height.

[0132] Each of the existing spillway piers 131, 133, 135 is designed according to a seismic coefficient method. As illustrated in FIG. 20, the yield load $P_y$ of reinforcing steel is smaller compared to the tolerance $P_c$ of a horizontal force (a load) that can be applied to the top portion of the existing spillway pier 131, 133, 135. If the displacement amount of the top portion is approximately 10 mm, an amount of the horizontal force reaches the tolerance $P_c$. The tolerance $\delta c$ of the displacement amount of the top portion of the existing spillway pier 131, 133, 135 is approximately 10 mm. In the following explanation, the three existing spillway piers 131, 133, 135 are collectively referred to as an existing spillway pier 130.

[0133] The existing operation bridge 140 is made of reinforced concrete and provided over the three existing spillway piers 131, 133, 135. As illustrated in FIG. 15, steel reinforcing bars J are put in the middle portion of the existing operation bridge 140 and the existing spillway pier 133, and the existing operation bridge 140 is fixed to the existing spillway pier 133 located in the middle. The steel reinforcing bars J are also put in a left end portion 141 of the existing operation bridge 140 and the left-side existing spillway pier 131 and also put in a right end portion 145 and the right-side existing spillway pier 135. Accordingly, the left and right end portions 141, 145 of the existing operation bridge 140 are fixed to the left-side existing spillway pier 131 and the right-side existing spillway pier 135, respectively.

[0134] The gate lifting devices M1, M2 are provided on the existing operation bridge 140 corresponding to the spillway gates G1, G2, respectively. The gate lifting device M1, M2 wends up and unwinds a wire $W$ for lifting and lowering the spillway gates G1, G2. Each of the gate lifting devices M1, M2 is activated to lift and lower (open and close) each spillway gate G1, G2 independently. The spillway piers 131, 133, 135 support the weight of the spillway gates G1, G2 generated in opening and closing the gates via the existing operation bridge 140.

2. Explanation of Method of Improving Earthquake Resistance of Existing Spillway Pier 130

[0135] In the second embodiment, following five processes are performed to the existing bridge 120 to improve earthquake resistance of the existing spillway piers 131, 133, 135.
In each span of the existing operation bridge 140, a beam member 150 made of steel is provided between the adjacent existing spillway piers in the bridge-axis direction. In each span of the existing operation bridge 140, one end portion of the beam member 150 is connected to the corresponding existing spillway pier 130 via the connecting member 60 of a pin structure. In each span of the existing operation bridge 140, another end portion of the beam member 150 is connected to the corresponding existing spillway pier 130 via the high damping device 70 having a history damping property with high primary rigidity. A yield displacement amount Δ of the high damping device 70 in the seismic velocity is set to be smaller than a tolerance δ of the displacement amount of the existing spillway pier 130 (the displacement amount of the top portion). A yield load value Ra of the high damping device 70 in the seismic velocity is set to be greater than the maximum seismic force Fm that is generated in the high damping device 70 in the bridge-axis direction due to a large-scale earthquake. The process (1) will be explained. The beam member 150 is made of steel. The beam member 150 includes a web 153 extending up-down direction and flanges 154, 155 at an upper portion and a lower portion of the web. The beam member 150 has a cross section of an L-shape. A length of the beam member 150 is substantially same as a distance between the two adjacent ones of the existing spillway piers 131, 133, 135. In the process (1), the beam member 150A is additionally provided between the existing spillway pier 131 and the existing spillway pier 133 in the bridge-axis direction. The beam member 150B is additionally provided between the existing spillway pier 131 and the existing spillway pier 133 in the bridge-axis direction. “Additionally” is referred to as a condition that the beam members are additionally provided by executing the method of improving earthquake resistance. Specifically, as illustrated in FIG. 16, the beam member 150A is provided at the lower left side of the existing operation bridge 140 and arranged horizontally between the existing spillway piers 131 and 133. End portions 157, 158 are attached to the upper surface 132A, 134A of each base member 132, 134. The beam member 150B is provided at the lower right side of the existing operation bridge 140 and arranged horizontally between the existing spillway piers 133 and 135. End portions 157, 158 are attached to the upper surface 134A, 136A of each base member 134, 136. The beam members 150A, 150B have fixed bearing structures (the fixed bearing structure similar to the first embodiment) on sides close to the existing spillway pier 133 and movable bearing structures (the movable bearing structure similar to the first embodiment) on sides close to the existing spillway piers 131, 135. Similar to the main beams 50A, 50B as explained in the first embodiment, three beam members 150A and three beam members 150B are arranged parallel to each other in the width direction of the existing operation bridge 140. The process (2) will be explained. The connecting member 60 is a pin structure similar to the connecting member of the first embodiment. The connecting member 60 includes the shaft pin 65 and two brackets 61, 63 that are rotatably connected to each other by the shaft pin 65.

In the process (2), one end portion 157 of the beam member 150A is connected to the existing spillway pier 133 via the connecting member 60. One end portion 157 of the beam member 150B is connected to the existing spillway pier 133 via the connecting member 60. The beam member 150A will be explained. As illustrated in FIG. 17, the connecting member 60 is positioned at the lower right end portion of the beam member 150A. Then, the bracket 61 is fixed to the base member 134 of the existing spillway pier 133 with bolts. The bracket 63 is fixed to a lower surface of the one end portion 157 of the beam member 150A with bolts. Accordingly, the brackets 61, 63 of the connecting member 60 are fixed to the base member 134 of the existing spillway pier 133 and the one end portion 57 of the beam member 150A, respectively. This connects the beam member 150A and the existing spillway pier 133 via the connecting member 60. The connecting member 60 is attached to each of the three beam members 150A that are arranged parallel to each other in the width direction of the existing operation bridge 140. Next, the process (3) will be explained. Similar to the first embodiment, the high damping device 70 includes the cylinder 71, the piston 73, the piston rod 75 and the orifice 77. Bingham fluid 80 is sealed in the cylinder 71 as working fluid. The piston rod 75 includes the piston 73 that divides inner space of the cylinder 71 into two spaces. The orifice 77 is formed between an outer peripheral surface of the piston 73 and an inner peripheral surface of the cylinder 71. The high damping device 70 has a history damping property with high primary rigidity similar to the first embodiment. In the process (3), another end portion 158 of the beam member 150A is connected to the existing spillway pier 131 via the high damping device 70. Another end portion 158 of the beam member 150B is connected to the existing spillway pier 135 via the high damping device 70. The beam member 150A will be explained. The high damping device 70 is arranged in a horizontal position such that the axial line L is parallel to a horizontal direction and the high damping device 70 is positioned at a lower left side of the beam member 150A. Thereafter, as illustrated in FIG. 17, a bracket 91 provided at an axial end of the high damping device 70 is fixed to a side surface of the base member 132 of the existing spillway pier 131. A bracket 92 provided at the another axial end of the high damping device 70 is fixed to a fixing member 93 that is provided on a lower surface of the beam member 150A. Accordingly, the brackets 91, 92 of the high damping device 70 are fixed to the existing spillway pier 131 and the another end portion 158 of the beam member 150A, respectively. The beam member 150A is connected to the existing spillway pier 131 via the high damping device 70 the axial line L of which is parallel to the horizontal direction. The high damping device 70 is thus provided to each of the three beam members 150A that are arranged parallel to each other in the width direction of the existing operation bridge 140. In the processes (4) and (5), the yield displacement amount Δ of the high damping device 70 in the seismic velocity is set to be smaller than the tolerance δ of the displacement amount of the existing spillway pier 130. The yield load value Ra of the high damping device 70 in the seismic velocity is set to be greater than the maximum seismic
force F_m that is generated in the high damping device 70 in the bridge-axis direction by a large-scale earthquake. The processes (4) and (5) are executed in earthquake-resistant designing. Earthquake resistance is evaluated in the earthquake-resistant designing. The specific setting values are same as those in the first embodiment.

According to the method of improving earthquake resistance of the present embodiment, the yield displacement amount by of the high damping device 70 and the yield load Rs are set as mentioned before. Accordingly, the high damping device 70 receives the maximum seismic force F_m that is generated therein in the bridge-axis direction by a large-scale earthquake within the high primary rigidity area (the area E in FIG. 13) before the history damping property of the high damping device 70 is exerted. Namely, a reaction force of the high damping device 70 against the maximum seismic force F_m is generated in the high primary rigidity area.

By executing the processes (1) to (5), the existing bridge 120 is altered to an earthquake-resistant bridge 120 including following five configurations. A first configuration includes the existing operating bridge (a bridge body) 140. A second configuration includes the three existing spillway piers (a number of spillway columns) 130 that support the existing operating bridge 140. A third configuration includes the beam members 150A, 150B that are made of steel and provided between the adjacent existing spillway piers 131, 133, 135 in each span of the existing operation bridge 140. A fourth configuration includes the connecting member 60 of a pin structure that connects the one end portion 157 of the beam member 150A, 150B and the existing spillway pier 130. A fifth configuration includes the high damping device 70 that connects the other end portion 158 of the beam member 150A, 150B and the existing spillway pier 130.

2. Explanation of Effects

The high damping devices 70 attached to the beam members 150A, 150B resist the maximum seismic force F_m with a small relative displacement with respect to the existing spillway piers 131, 133, 135 and receive the maximum seismic force F_m. Therefore, the displacement amount of the top portion of each of the existing spillway piers 131, 133, 135 is restricted to be the tolerance 8c or smaller. Therefore, in case of an earthquake, a great moment is less likely to be applied to the basal portions of each of the existing spillway piers 131, 133, 135. Therefore, in case of an earthquake, the spillway piers 131, 133, 135 are not damaged and kept same as before the earthquake. The flood water gates G1, G2 are opened and closed without any troubles and dam impoundment control can be executed normally.

By the attachment of the connecting member 60, the end portion 157 of the beam member 150 is fixed to the base member 134 of the existing spillway pier 133 with the bolts B and the connecting member 60.

Similar to the first embodiment, the number of the bolts used for attaching the connecting member 60 is greater than the number of the existing bolts B. The bolts sufficiently increase shear strength of the connecting member 60. Therefore, the connecting member 60 can independently receive seismic force applied to the end portion 157 of the beam member 150.

The attachment positions of the connecting member 60 and the high damping device 70 are determined with considering a moving area of the spillway gates G1, G2 so that the connecting member 60 and the high damping device 70 do not come in contact with the spillway gates G1, G2 when they are lifted (water is discharged).

3. Other Embodiments

The present invention is not limited to the aspects explained in the above description made with reference to the drawings. The following aspects may be included in the technical scope of the present invention, for example.

(1) In the first and second embodiments, two spillway gates for controlling a water volume are provided. However, the number of the spillway gates is not necessarily to be two but may be more than two or one.

(2) In the first embodiment, the left end portions of the main beams 50A, 50B have a fixed bearing structure and the right end portions of the main beams 50A, 50B have a movable bearing structure. The bearing structure is not limited thereto, and for example, as illustrated in FIG. 18, the bearing structure of the main beam 50A in the first embodiment may be altered so that the main beams 50A, 50B are supported by the middle spillway pier 33 with a fixed bearing structure.

(3) In the first embodiment, as a configuration example of the high damping device 70, the orifice 77 is formed between the outer peripheral surface of the piston 73 and the inner peripheral surface of the cylinder 71. However, the orifice 77 is not necessarily formed in the above configuration, but may be formed in the piston.

(4) In the first and second embodiments, the construction method for improving earthquake resistance is applied to the existing bridge 20, 120 that supports the spillway gates G1, G2. However, the method may be applied to the existing bridge that supports sand elimination gates.

(5) In the second embodiment, in each span of the existing operation bridge 140, the steel beam member 150 is additionally provided in the bridge-axis direction between the adjacent existing spillway piers below the existing operation bridge 140. The beam member 150 may be additionally provided between the adjacent existing spillway piers at a side of the existing operation bridge 140. The method of improving earthquake resistance of the second embodiment may be applied to a steel bridge provided in a dam.

A method of improving earthquake resistance of existing spillway piers on a dam, the existing spillway piers being arranged on two sides of a gate provided in the dam, the existing spillway piers supporting an existing bridge including a main beam made of steel, a gate lifting device provided on the existing bridge, and the gate, and the main beam including a fixed bearing structure on one side and a movable bearing structure on another side, the method comprising a step of:

connecting an end portion of the main beam close to the movable bearing and a top portion of one of the existing spillway piers with a high damping device including Bingham fluid as working fluid and having a history damping property with high primary rigidity, the high damping device having a yield displacement amount in seismic velocity smaller than a tolerance of a displacement amount of the existing spillway pier, and the high damping device having a yield load value in seismic velocity greater than a maximum seismic force generated in the high damping device in a bridge-axis direction due to a large-scale earthquake.
2. The method of improving earthquake resistance of existing spillway piers on a dam according to claim 1, further comprising connecting an end portion of the main beam close to the fixed bearing structure and a top portion of the existing spillway pier with a connecting member of a pin structure in each span of the existing bridge.

3. A method of improving earthquake resistance of existing spillway piers on a dam, the existing spillway piers being arranged on two sides of a gate provided in the dam, the existing spillway piers supporting an existing bridge and a gate lifting device provided on the existing bridge, the method comprising:

- providing a beam member made of steel between the existing spillway piers that are adjacent to each other in each span of the existing bridge so as to be parallel to a bridge-axis direction;
- connecting one end portion of the beam member and one of the spillway piers with a connecting member of a pin structure in each span of the existing bridge; and
- connecting another end portion of the beam member and one of the existing spillway piers in each span of the existing bridge with a high damping device including Bingham fluid as working fluid and having a history damping property with high primary rigidity, wherein:

the high damping device has a yield displacement amount in seismic velocity smaller than a tolerance of a displacement amount of the spillway pier, and the high damping device has a yield load value in seismic velocity greater than a maximum seismic force generated in the high damping device in a bridge-axis direction due to a large-scale earthquake; and

the high damping device receives the maximum seismic force generated therein in the bridge-axis direction due to the large-scale earthquake within an area of the high primary rigidity before the history damping property is exerted.

4. An earthquake-resistant bridge in a dam comprising:

- a bridge;
- a number of spillway piers provided on two ends of a gate in the dam, the spillway piers supporting the bridge, a gate lifting device provided on the bridge, and the gate;
- a main beam made of steel and forming a beam of the bridge, the main beam provided between the spillway piers that are adjacent to each other in each span of the bridge and having a fixed bearing structure between one end thereof and one of the spillway piers and having a movable bearing structure between another end thereof and one of the spillway piers; and
- a high damping device configured to connect an end portion of the main beam close to the movable bearing structure and a top portion of the spillway pier in each span of the bridge, the high damping device including Bingham fluid as working fluid and having a history damping property with high primary rigidity, wherein:

the high damping device has a yield displacement amount in seismic velocity smaller than a tolerance of a displacement amount of the spillway pier, and the high damping device has a yield load value in seismic velocity greater than a maximum seismic force generated in the high damping device in a bridge-axis direction due to a large-scale earthquake; and

the high damping device receives the maximum seismic force generated therein in the bridge-axis direction due to the large-scale earthquake within an area of the high primary rigidity before the history damping property is exerted.

5. The earthquake-resistant bridge in a dam according to claim 4, further comprising a connecting member of a pin structure configured to connect an end portion of the main beam close to the fixed bearing structure and a top portion of the spillway pier.

6. An earthquake-resistant bridge in a dam comprising:

- a bridge;
- a number of spillway piers provided on two ends of a gate in the dam, the spillway piers supporting the bridge, a gate lifting device provided on the bridge, and the gate;
- a beam member made of steel and provided between the spillway piers that are adjacent to each other in each span of the bridge so as to be parallel to a bridge-axis direction;
- a connecting member of a pin structure configured to connect one end portion of the beam member and one of the spillway piers in each span of the bridge; and
- a high damping device configured to connect another end portion of the beam member and one of the spillway piers in each span of the bridge, the high damping device including Bingham fluid as working fluid and having a history damping property with high primary rigidity, wherein:

the high damping device having a yield displacement in seismic velocity smaller than a tolerance of a displacement amount of the spillway pier, and the high damping device having a yield load value in seismic velocity greater than a maximum seismic force generated in the high damping device in a bridge-axis direction due to a large-scale earthquake, and

the high damping device receives the maximum seismic force generated therein in the bridge-axis direction due to the large-scale earthquake within an area of the high primary rigidity before the history damping property is exerted.

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