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(54) **SLIDING PENDULUM SEISMIC ISOLATOR**

ERDBEBENISOLATOR MIT SCHIEBEPENDEL

ISOLATEUR SISMIQUE À PENDULE COULISSANT

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Description

[0001] The present invention relates to a sliding pendulum seismic isolator and particularly to a sliding pendulum seismic isolator of the bi-directional type.

[0002] There is known the seismic isolation technique using sliding pendulum seismic isolators essentially comprising convex supports coupled with concave cylindrical sliding surfaces. Such isolators are usually arranged between a superstructure such as, for example, a bridge or a building, and its foundations. In case of earthquakes, the isolators allow a movement and/or a rotation of the superstructure relative to the foundations, thus protecting its integrity.

[0003] As an effect of the sliding movement of the convex supports on the cylindrical surfaces, the superstructure oscillates increasing and decreasing its potential energy according to the law of motion of a pendulum, whose natural period is defined by the radius of the cylindrical surface. The radius of the cylindrical surfaces is designed in order to optimize the natural period of the pendulum for the reduction of the seismic response of the superstructure. Moreover, a certain amount of energy is dissipated through the friction between the contact material and the cylindrical surface, thus reducing more the seismic response of the superstructure.

[0004] In order to isolate a superstructure sets of seismic isolators are generally used, comprising different types of isolator, such as, for example, multi-directional isolators and mono- and bi-directional isolators, which define a pattern of constraints between the structure and its foundations such to generate a series of programmed movements and/or rotations during an earthquake.

[0005] Patent application US 2006/0174555 in the name of Earthquake Protection Systems Inc. discloses a sliding pendulum seismic isolator provided with a lower sliding element and an upper sliding element between which two or three intermediate elements are arranged, provided with spherical surfaces defining a spherical joint. During an earthquake, the spherical joint allows the relative rotation and the movement of the lower part with respect to the upper part. The spherical joint also allows to transfer the vertical compression loads and transverse loads occurring during a seismic event from the supported structure to the foundations. The spherical joint of the seismic isolator described in the above-mentioned patent application may be applied to multi-directional supports as well as to mono- and bi-directional supports. Concerning bi-directional supports in particular, the above-mentioned patent application describes a very simple and inexpensive solution, wherein the lower sliding element and the upper one are designed as rails arranged along two directions of movement substantially perpendicular to each other.

[0006] A problem of seismic isolators based on spherical joints, and particularly of those of the bi-directional type, is that such spherical joints must necessarily be dimensioned on the basis of the loading conditions of the most stressed direction and therefore they are unnecessarily oversized with respect to the less stressed direction, resulting in a consequent increase in the manufacturing costs.

[0007] Moreover, the manufacturing of spherical surfaces is rather complex and expensive both due to the geometry and to the hardness of the materials employed such as, for instance, stainless steel. In case the sliding surfaces of the spherical joints are manufactured by superimposing thin stainless steel plates to a base structure, it is very difficult to obtain spherical caps of good quality. Document DE-A-102005060375 shows a sliding pendulum seismic isolator which part by comprises the features of the preamble of the independent claim 1.

[0008] It is therefore an object of the present invention to provide a bi-directional sliding pendulum seismic isolator being able to overcome said disadvantages. Said object is achieved with a bi-directional sliding pendulum seismic isolator, whose main features are disclosed in claim 1, while other features are disclosed in the subsequent claims.

[0009] The bi-directional sliding pendulum seismic isolator according to the present invention includes a rail-shaped lower sliding element and a rail-shaped upper sliding element that are substantially perpendicular to each other and have cylindrical concave surfaces opposite to each other. Between the lower and upper sliding elements a first and a second intermediate element are arranged, which slide along said cylindrical concave surfaces of the sliding elements by means of corresponding cylindrical convex surfaces.

[0010] The first intermediate element is provided with a cylindrical concave surface opposite to its cylindrical convex sliding surface and having the axis perpendicular to the axis of the cylindrical concave surface of the lower sliding element. Similarly, the second intermediate element is provided with a concave surface opposite to its cylindrical convex sliding surface and having the axis perpendicular to the axis of the cylindrical concave surface of the upper sliding element. Between the first and the second intermediate element a third intermediate element is arranged, having a lower surface and an upper surface that are both cylindrical convex surfaces and have their axes perpendicular to each other. The three intermediate elements constitute a joint having the shape of a cylindrical double saddle that allows the movement and the relative rotation between the rail-shaped sliding elements.

[0011] The main advantage of the isolator according to the present invention is that, thanks to the particular cylindrical double-saddle design, it is possible to dimension the joint arranged between the rail-shaped sliding elements in function of the actual load conditions as well as the movements and the rotations foreseen in the two sliding directions, thus avoiding a useless oversizing and above all optimizing the design solutions.

[0012] Saving material allows to manufacture a cheaper joint with respect to known spherical joints, resulting in a notable reduction of the manufacturing costs of the isolator.

[0013] Another advantage of the isolator according to the present invention is that the manufacturing of the joint with cylindrical sliding surfaces is remarkably easier and cheaper than the manufacturing of spherical surfaces, thus being able to achieve sliding surfaces of optimum quality in a relatively easy way, both directly working metal surfaces of hard materials such as stainless steel and in the case of coverings with thin plates, which further contributes to the optimization of the isolator costs.

[0014] These and other advantages of the bi-directional sliding pendulum seismic isolator according to the present invention will become clear to those skilled in the art from the following detailed description of an embodiment thereof with reference to the attached drawings, wherein:

- figure 1 shows a perspective view of a bi-directional sliding pendulum seismic isolator according to the present invention;
- figure 2 is a sectional view of the isolator of figure1 along line II-II;
- figure 3 is a detail III of figure 2;
- figure 4 is a sectional view of the isolator of figure 1 along line IV-IV;
- figure 5 is a detail V of figure 4; and
- figure 6 is a perspective exploded view of the isolator of figure 1.

[0015] Referring to the above-mentioned figures, there is seen that a bi-directional sliding pendulum seismic isolator according to the present invention conventionally includes a rail-shaped lower sliding element 1 and a rail-shaped upper sliding element 2 substantially perpendicular to each other. Lower and upper sliding elements 1, 2 are respectively provided with a cylindrical concave sliding surface 1a facing upward and a cylindrical concave sliding surface 2a facing downward. Between the lower and upper sliding elements 1, 2 a first and a second intermediate element 3, 4 are arranged, each having a cylindrical convex sliding surface 3a, 4a suitable to allow them to slide respectively along cylindrical concave surfaces 1a, 2a of lower and upper sliding elements 1, 2. A third intermediate elements 5 is arranged between the first and second intermediate element 3, 4.

[0016] According to the novel aspect of the present invention, the first intermediate element 3 is provided with a cylindrical concave surface 3b opposite to its cylindrical convex sliding surface 3a and having the axis perpendicular to the axis of the cylindrical concave surface 1a of the lower sliding element 1. Similarly, the second intermediate element 4 is provided with a cylindrical concave surface 4b opposite to its cylindrical convex sliding surface 4a and having the axis perpendicular to the axis of the cylindrical concave surface 2a of the upper sliding element 2. The third intermediate element 5 has a lower surface 5a and an upper surface 5b that are both cylindrical convex surfaces and have their axes substantially perpendicular to each other.

[0017] When the isolator is assembled, the lower surface 5a and the upper surface 5b of the third intermediate element 5 are in contact with surfaces 3b, 4b of the first and second intermediate element 3, 4, respectively, and allow a relative rotation between the intermediate elements 3, 4.

[0018] Thus, elements 3, 4 and 5 constitute a joint having the shape of a cylindrical double saddle that allows relative rotations and movements of the lower and upper sliding elements 1, 2 in the two sliding directions defined by the isolator. The curvature radiuses of the cylindrical surfaces may be different in the two sliding directions, in order to better fit the actual movements and rotations of the superstructure.

[0019] In order to withstand the horizontal loads occurring during a seismic event, coupling means are provided between the lower and upper sliding elements 1, 2 and the intermediate elements 3, 4 and 5 in the transverse direction. Such coupling means are, for example, lateral guides formed on the sliding elements 1, 2 and on the intermediate elements 3, 4, 5 and arranged along the movement direction allowed by the single coupling.

[0020] In the illustrated embodiment, the first sliding element 1 is provided with guides 1b 1c along its sides suitable for retaining the first intermediate element 3 in the transverse direction. On the contrary, the transverse constraint between the upper sliding element 2 and the second intermediate element 4 is made up of a pair of guides 4c, 4d fixed on the second intermediate element 4 itself. Similarly, the third intermediate element 5 is constrained to the first and second intermediate element 3, 4 by means of guides 3c, 3d and 4e, 4f respectively formed thereon.

[0021] Preferably, the sliding surfaces 1a, 3a; 2a, 4a; 3b, 5a; 4b, 5b are covered with plates made of controlled friction materials that are combined between them so as to minimize the wear. Alternatively, it is possible to directly manufacture the sliding elements in controlled friction materials. Controlled friction materials suitable for the application to isolators are, for instance, stainless steel and polymeric materials chosen among, for example, polyethylene, polyamidic resins and PTFE suitably modified and/or filled.

[0022] Moreover, it is possible to employ controlled friction materials having different friction coefficients in the two sliding directions of the isolator, allowing to optimize the seismic response in the two movement directions, as well as to lubricate the sliding surfaces.

[0023] In the illustrated embodiment, the cylindrical concave surfaces 1a, 2a of the lower and upper sliding elements 1, 2 are covered with mirror polished stainless steel plates S and the cylindrical convex surfaces 3a, 4a of the first and second intermediate element 3, 4 are covered with plates T made of polyethylene. On the contrary, the third intermediate element 5 is entirely made of stainless steel with the cylindrical convex surfaces 5a, 5b being mirror polished and slidable on polyethylene plates T that are respectively arranged in suitable seats formed in the cylindrical concave surfaces 3b, 4b of the first and second intermediate element 3, 4.

[0024] The isolator according to the present invention also preferably comprises a plurality of anchoring elements 6, for example metal plates having a central hole, arranged at the base of the lower and upper sliding elements 1, 2 at their ends. Anchoring elements 6 serve to fix the lower and upper sliding elements 1, 2 to the superstructure and to its foundations by using, for instance, screws 7 engaging the threaded holes of anchor bars 8 buried in concrete.

[0025] It is clear that the above-described and illustrated embodiment of the isolator according to the invention is only an example susceptible of numerous variations. In particular, it is possible to use other controlled friction materials well known to those skilled in the art for covering the sliding surfaces. Moreover, as far as the sliding surfaces made of metal materials are concerned it is possible to use special materials such as chrome-nickel steel in order to provide high characteristics of hardness and to minimize wear.

Claims

1. A bi-directional sliding pendulum seismic isolator comprising:

a rail-shaped lower sliding element (1) and a rail-shaped upper sliding element (2) substantially perpendicular to each other, said lower and upper sliding elements (1, 2) being provided with a cylindrical concave surface (1a) facing upward and a cylindrical concave surface (2a) facing downward, respectively,
a first and a second intermediate element (3, 4) arranged between said lower and upper sliding elements (1, 2) and each provided with a cylindrical convex sliding surface (3a, 4a) suitable to allow the sliding of the first and second intermediate elements (3, 4) along said cylindrical concave surfaces (1a, 2a) of the lower and upper sliding elements (1, 2),
a third intermediate element (5) arranged between the first and second intermediate elements (3, 4), and
coupling means in the transverse direction suitable to withstand the horizontal loads occurring during a seismic event, **characterized in that** said first intermediate element (3) has a cylindrical concave surface (3b) opposite to its cylindrical convex sliding surface (3a) and having the axis perpendicular to the axis of the cylindrical concave surface (1a) of the lower sliding element (1),
said second intermediate element (4) has a cylindrical concave surface (4b) opposite to its cylindrical convex sliding surface (4a) and having the axis perpendicular to the axis of the cylindrical concave surface (2a) of the upper sliding element (2), and
said third intermediate element (5) has a lower surface (5a) and an upper surface (5b) that are both cylindrical convex surfaces and have their axes substantially perpendicular to each other, said lower and upper cylindrical convex surfaces (5a, 5b) of the third intermediate element (5) being respectively in contact with the cylindrical concave surface (3b) of the first intermediate element (3) and the cylindrical concave surface (4b) of the second intermediate element (4), and being suitable to allow a relative rotation between the intermediate elements (3, 4).

2. An isolator according to the previous claim, **characterized in that** said coupling means in the transverse direction are lateral guides (1b 1c, 4c, 4d, 3c, 3d, 4e, 4f) formed on and/or fixed to the sliding elements (1, 2) and the intermediate elements (3, 4) and arranged along the movement direction allowed by the single coupling.

3. An isolator according to one of the previous claims, **characterized in that** the sliding surfaces (1a, 3a; 2a, 4a; 3b, 5a; 4b, 5b) are covered with plates made of controlled friction materials.

4. An isolator according to the previous claim, **characterized in that** said controlled friction materials are stainless steel and polymeric materials chosen among polyethylene, polyamidic resins and PTFE modified and/or filled.

5. An isolator according to claim 3, **characterized in that** said controlled friction materials have different friction coefficients in the two sliding directions of the isolator.

6. An isolator according to claim 3, **characterized in that** the cylindrical concave surfaces (1a, 2a) of the lower and upper sliding elements (1, 2) are covered with mirror polished stainless steel plates (S) and the cylindrical convex surfaces (3a, 4a) of the first and second intermediate element (3, 4) are covered with polyethylene plates (T), and **in that** the third intermediate element (5) is entirely made of stainless steel, its cylindrical convex surfaces (5a, 5b) being mirror polished and slidable on polyethylene plates (T) arranged in suitable seats formed in the cylindrical concave surfaces (3b, 4b) of the first and the second intermediate element (3, 4), respectively.

7. An isolator according to one of the previous claims, **characterized by** further comprising a plurality of anchoring elements (6) arranged at the base of the lower and upper sliding elements (1, 2) at their ends, said anchoring elements (6) being suitable to allow the fixing of the lower and upper sliding elements (1, 2) to the superstructure and to its foundations.

8. An isolator according to the previous claim, **characterized in that** said anchoring elements (6) are metal plates provided with a central hole.

Patentansprüche

1. Erdbebenisolator mit bidirektional schiebendem Pendel, umfassend:

- ein unteres, schienenförmiges Gleitelement (1) und ein oberes, schienenförmiges Gleitelement (2) in gegenseitiger, rechtwinkliger Anordnung, wobei die besagten, unteren und oberen Gleitelemente (1, 2) mit einer zylindrischen, konkaven Oberfläche (1a) versehen sind, die nach oben gerichtet ist, sowie jeweils mit einer zylindrischen konkaven Oberfläche (2a), die nach unten gerichtet ist,
- ein erstes und ein zweites Zwischenelement (3, 4), welche zwischen den besagten unteren und oberen Gleitelementen (1, 2) angeordnet sind und jeweils mit einer zylindrischen, konvexen Gleitfläche (3a, 4a) versehen sind, die geeignet sind, um dem ersten und zweiten Zwischenelement (3, 4) das Gleiten entlang der besagten zylindrischen, konkaven Oberflächen (1a, 2a) der oberen und unteren Gleitelemente (1,2) zu erlauben,
- ein drittes Zwischenelement (5), welches zwischen dem ersten und zweiten Zwischenelement (3, 4) angeordnet ist,
- ein Kopplungsmittel in der Querrichtung, welches geeignet ist, den horizontalen Lasten während eines seismischen Ereignisses zu widerstehen, **dadurch gekennzeichnet, dass**
- das besagte erste Zwischenelement (3) seiner zylindrischen konvexen Gleitfläche (3a) gegenüber liegend eine zylindrische konkave Oberfläche (3b) aufweist, deren Achse rechtwinklig zu der Achse der zylindrischen konkaven Oberfläche (1a) des unteren Gleitelements (1) ist,
- das besagte zweite Zwischenelement (4) seiner zylindrischen konvexen Gleitfläche (4a) gegenüber liegend eine zylindrische konkave Oberfläche (4b) aufweist, deren Achse rechtwinklig zu der Achse der zylindrischen konkaven Oberfläche (2a) des oberen Gleitelements (2) ist,
- das besagte dritte Zwischenelement (5) eine untere Oberfläche (5a) aufweist sowie eine obere Oberfläche (5b), welche beide zylindrische konvexe Oberflächen sind, und deren Achsen im Wesentlichen rechtwinklig zueinander sind,
- die besagten unteren und oberen zylindrischen konvexen Oberflächen (5a, 5b) des dritten Zwischenelements (5) in Kontakt mit der zylindrischen konkaven Oberfläche (3b) des ersten Zwischenelements (3) bzw. der zylindrischen konkaven Oberfläche (4b) des zweiten Zwischenelements (4) sind und geeignet sind, um eine Relativverdrehung zwischen den Zwischenelementen (3, 4) zu erlauben.

2. Isolator nach dem vorhergehenden Anspruch, **dadurch gekennzeichnet, dass** das besagte Kopplungsmittel in der Querrichtung aus lateralen Führungen (1b, 1c, 4c, 4d, 3c, 3d, 4e, 4f) besteht, welche an den Gleitelementen (1, 2) und an den Zwischenelementen (3, 4) angeformt und/oder befestigt sind und sich entlang der von der einzigen Kopplung zugelassenen Bewegungsrichtung erstrecken.

3. Isolator nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** die Gleitflächen (1a, 3a; 2a, 4a; 3b, 5a; 4b, 5b) mit Platten belegt sind, welche aus Materialien mit kontrollierter Reibung hergestellt sind.

4. Isolator nach dem vorhergehenden Anspruch, **dadurch gekennzeichnet, dass** die besagten Materialien mit kontrollierter Reibung rostfreier Stahl sowie Polymerwerkstoffe sind, ausgewählt aus Polyethylen, Polyamid-Harzen und modifiziertem und/ oder gefülltem PTFE.

5. Isolator nach Anspruch 3, **dadurch gekennzeichnet, dass** die besagten Materialien mit kontrollierter Reibung in den beiden Gleitrichtungen des Isolators unterschiedliche Reibungskoeffizienten aufweisen.

6. Isolator nach Anspruch 3, **dadurch gekennzeichnet, dass** die zylindrischen konkaven Oberflächen (1a, 2a) des unteren und oberen Gleitelements (1, 2) mit spiegel-polierten Platten (S) aus rostfreiem Stahl bedeckt sind, und die zylindrischen konvexen Oberflächen (3a, 4a) des ersten und zweiten Zwischenelements (3, 4) mit Platten (T) aus Polyethylen bedeckt sind, und **dadurch**, dass das dritte Zwischenelement (5) vollstandig aus rostfreiem Stahl hergestellt ist, wobei dessen zylindrischen, konvexen Oberflächen (5a, 5b) spiegelpoliert sind und auf den Platten (T) aus Polyethylen verschiebbar sind, welche ihrerseits in geeigneten Sitzen aufgenommen sind, die in den zylindrischen konkaven Oberflächen (3b, 4b) des ersten bzw. zweiten Zwischenelements (3, 4) eingeformt sind.

7. Isolator nach einem der vorhergehenden Ansprüche, ferner **gekennzeichnet durch** eine Mehrzahl von Verankerungselementen (6), welche an der Basis der unteren und oberen Gleitelemente (1, 2) an deren Enden angeordnet sind, wobei die besagten Verankerungselemente (6) geeignet sind, um die Festlegung des unteren und oberen Gleitelements (1, 2) an der oberen Struktur und an ihren Fundamenten zu erlauben.

8. Isolator nach dem vorhergehenden Anspruch, **dadurch gekennzeichnet, dass** die besagten Verankerungselemente (6) Metallplatten sind, welche mit einem zentralen Loch versehen sind.

Revendications

1. Isolateur sismique à pendule coulissant bidirectionnel comprenant :

    un élément coulissant inférieur en forme de rail (1) et un élément coulissant supérieur en forme de rail (2) sensiblement perpendiculaires entre eux, lesdits éléments coulissants inférieur et supérieur (1, 2) étant prévus avec une surface concave cylindrique (1a) orientée vers le haut et une surface concave cylindrique (2a) orientée vers le bas, respectivement,
    un premier et un deuxième élément intermédiaire (3, 4) agencés entre lesdits éléments coulissants inférieur et supérieur (1, 2) et chacun prévu avec une surface coulissante convexe cylindrique (3a, 4a) appropriée pour permettre le coulissement des premier et deuxième éléments intermédiaires (3, 4) le long desdites surfaces concaves cylindriques (1a, 2a) des éléments coulissants inférieur et supérieur (1, 2),
    un troisième élément intermédiaire (5) agencé entre les premier et deuxième éléments intermédiaires (3, 4), et
    des moyens de couplage dans la direction transversale appropriés pour résister aux charges horizontales se produisant pendant un évènement sismique, **caractérisé en ce que** :

        ledit premier élément intermédiaire (3) a une surface concave cylindrique (3b) opposée à sa surface coulissante convexe cylindrique (3a) et ayant l'axe perpendiculaire à l'axe de la surface concave cylindrique (1a) de l'élément coulissant inférieur (1),
        ledit deuxième élément intermédiaire (4) a une surface concave cylindrique (4b) opposée à sa surface coulissante convexe cylindrique (4a) et ayant l'axe perpendiculaire à l'axe de la surface concave cylindrique (2a) de l'élément coulissant supérieur (2), et
        ledit troisième élément intermédiaire (5) a une surface inférieure (5a) et une surface supérieure (5b) qui sont les deux surfaces convexes cylindriques et ont leurs axes sensiblement perpendiculaires entre eux,
        lesdites surfaces convexes cylindriques inférieure et supérieure (5a, 5b) du troisième élément intermédiaire (5) étant respectivement en contact avec la surface concave cylindrique (3b) du premier élément intermédiaire (3) et la surface concave cylindrique (4b) du deuxième élément intermédiaire (4), et étant appropriées pour permettre une rotation relative entre les éléments intermédiaires (3, 4).

2. Isolateur selon la revendication précédente, **caractérisé en ce que** lesdits moyens de couplage dans la direction transversale sont des guides latéraux (1 b, 1 c, 4c, 4d, 3c, 3d, 4e, 4f) formés sur et/ou fixés sur les éléments coulissants (1, 2) et les éléments intermédiaires (3, 4) et agencés le long de la direction de déplacement autorisée par le couplage unique.

3. Isolateur selon l'une quelconque des revendications précédentes, **caractérisé en ce que** les surfaces coulissantes (1a, 3a ; 2a, 4a ; 3b, 5a ; 4b, 5b) sont recouvertes par des plaques réalisées avec des matériaux à friction contrôlée.

4. Isolateur selon la revendication précédente, **caractérisé en ce que** les matériaux à friction contrôlée sont l'acier inoxydable et les matériaux polymères choisis parmi le polyéthylène, les résines polyamides et le PTFE modifié et/ou rempli.

5. Isolateur selon la revendication 3, **caractérisé en ce que** lesdits matériaux à friction contrôlée ont des coefficients de friction différents dans les deux directions de coulissement de l'isolateur.

6. Isolateur selon la revendication 3, **caractérisé en ce que** les surfaces concaves cylindriques (1a, 2a) des éléments coulissants inférieur et supérieur (1, 2) sont recouvertes par des plaques en acier inoxydable polies miroir (S) et les surfaces convexes cylindriques (3a, 4a) des premier et deuxième éléments intermédiaires (3, 4) sont recouvertes avec des plaques de polyéthylène (T) et **en ce que** le troisième élément intermédiaire (5) est entièrement fabriqué à partir d'acier inoxydable, ses surfaces convexes cylindriques (5a, 5b) étant polies miroir et pouvant coulisser sur les plaques en polyéthylène (T) agencées dans des sièges appropriés formés dans les surfaces concaves cylindriques (3b, 4b) des premier et deuxième éléments intermédiaires (3, 4) respectivement.

7. Isolateur selon l'une quelconque des revendications précédentes, **caractérisé en ce qu'**il comprend en

outre une pluralité d'éléments d'ancrage (6) agencés à la base des éléments coulissants inférieur et supérieur (1, 2) au niveau de leurs extrémités, lesdits éléments d'ancrage (6) étant appropriés pour permettre la fixation des éléments coulissants inférieur et supérieur (1, 2) à la superstructure et à ses fondations.

8. Isolateur selon la revendication précédente, **caractérisé en ce que** lesdits éléments d'ancrage (6) sont des plaques métalliques dotées d'un trou central.

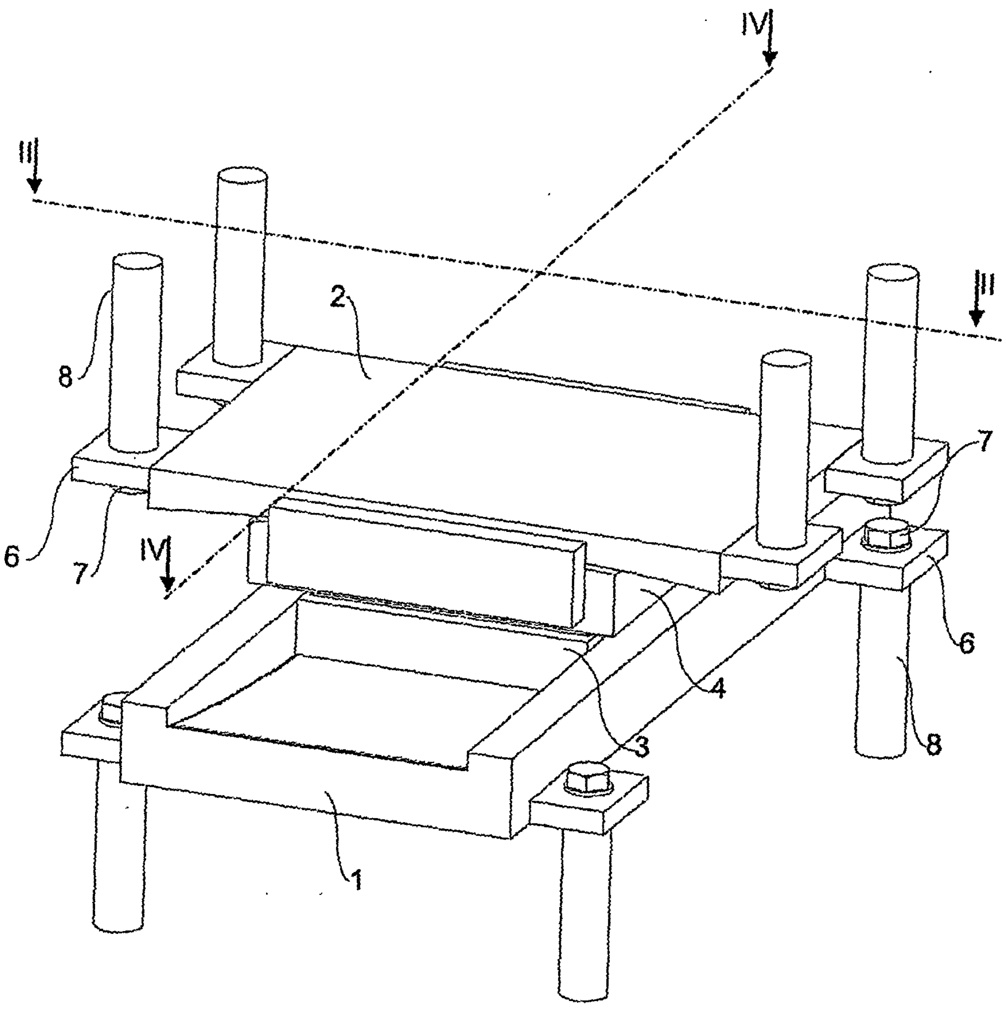

Fig.1

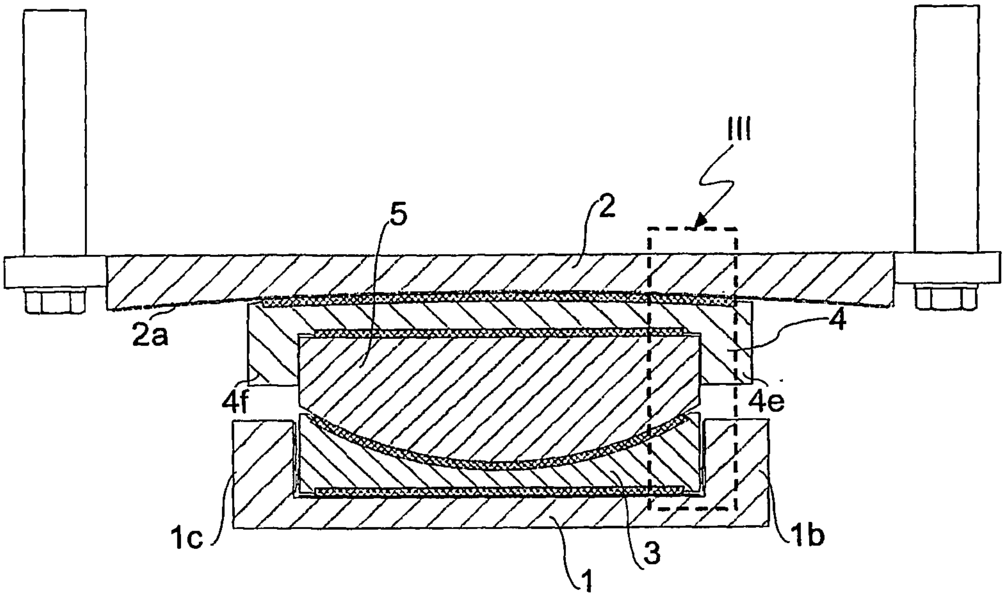

Fig.2

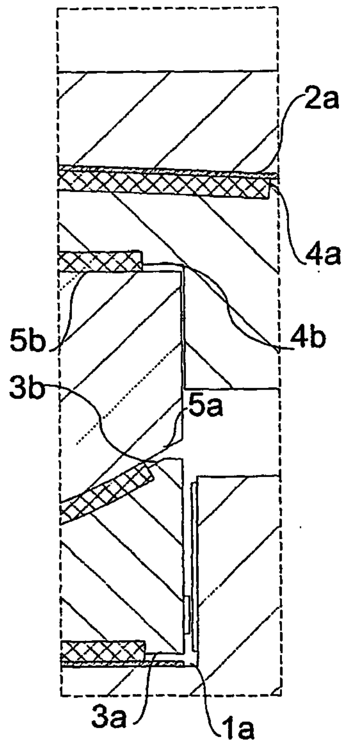

Fig.3

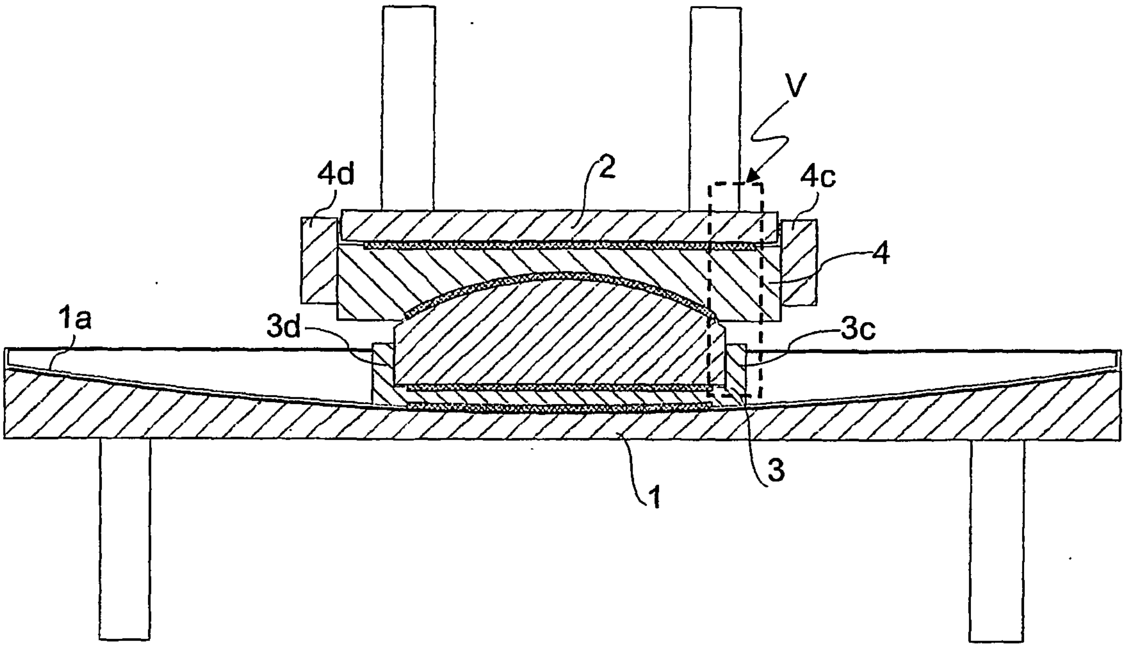

Fig.4

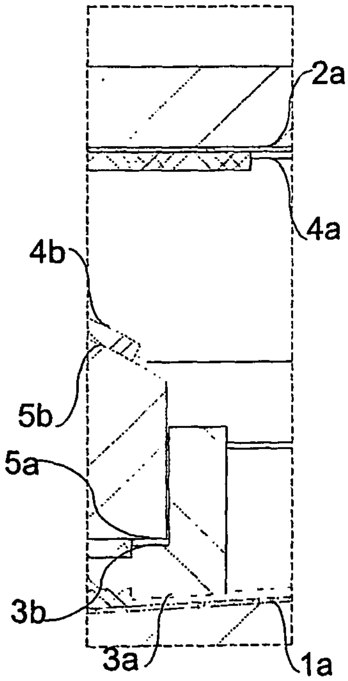

Fig.5

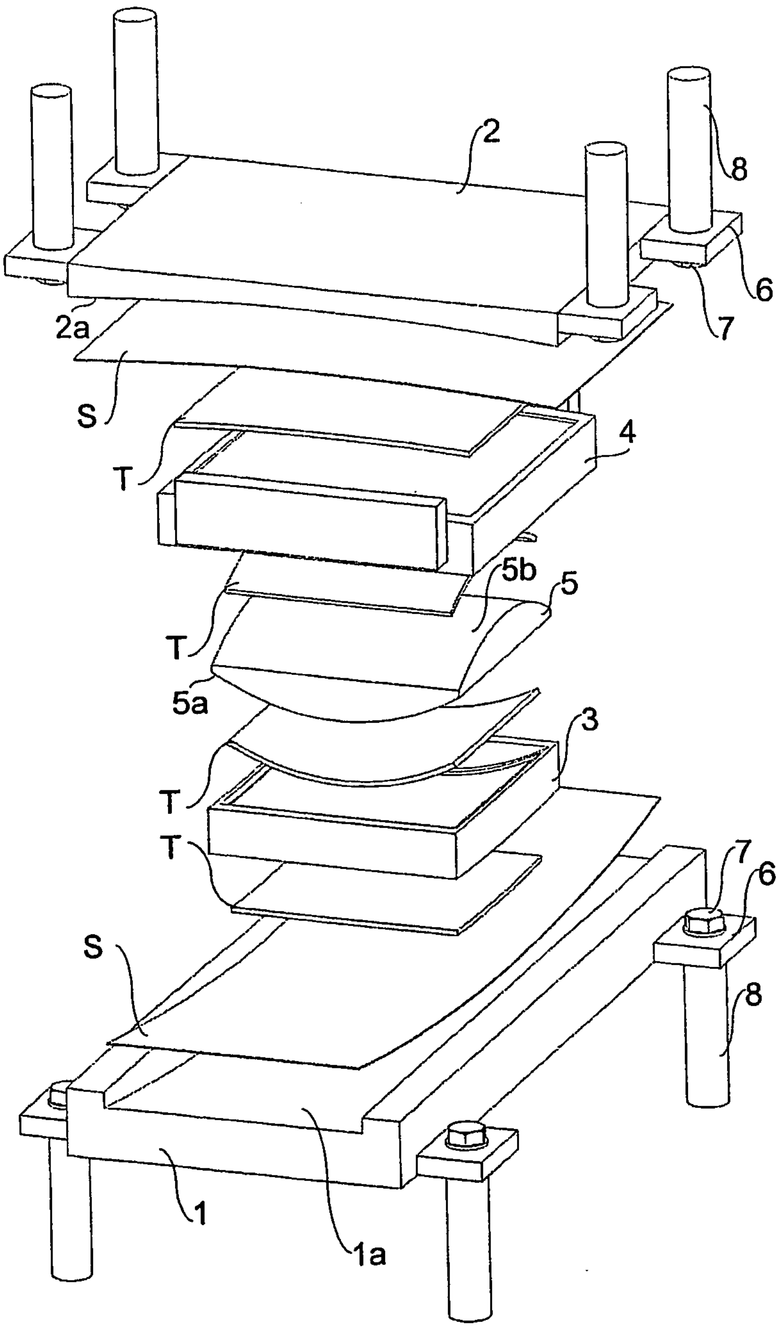

Fig.6

REFERENCES CITED IN THE DESCRIPTION

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