METHOD OF PROTECTING A BUILDING OR GROUP OF BUILDINGS FROM SEISMIC WAVES USING GELIFYING POLYMERS

Publication Classification

Int. Cl.
E02D 31/08 (2006.01)
E02D 27/34 (2006.01)
E04B 1/98 (2006.01)
E04H 9/02 (2006.01)

U.S. CL.
CPC .................. E02D 31/08 (2013.01); E04H 9/021 (2013.01); E02D 27/34 (2013.01); E04B 1/985 (2013.01)

ABSTRACT

A method for protecting a building or a group of buildings from the horizontal components of the seismic waves, including: forming a trench around all or part of the periphery of the building or group of buildings, or an excavation under the building, and filling the trench or the excavation with at least one pregelled polymer, or of at least one polymer and/or of a mixture of polymerizable monomers that can undergo gelation in the trench.
Figure 5 (top view)
METHOD OF PROTECTING A BUILDING OR GROUP OF BUILDINGS FROM SEISMIC WAVES USING GELIFYING POLYMERS

FIELD OF THE INVENTION

[0001] Buildings constructed in seismic zones are subject to increasingly strict regulations.

[0002] These regulations relate to the actual structure of the buildings, but also to the mechanical systems for compensating movements and for construction on a seismic isolation system enabling the movement of the building superstructure (namely the building part that is supported by the isolators) to be quasi disconnected from that of the ground.

BACKGROUND OF THE INVENTION

[0003] Most seismic isolation systems act only in the horizontal plane, because the horizontal earthquake components are usually the most dangerous for a structure and also to avoid rocking of the superstructure, which is difficult and costly to be controlled. If a building is protected by a horizontal seismic isolation system, its superstructure shall be and remain fully free to move laterally to the design displacement of the isolators, which varies from some tens of centimeters in Europe to one meter or more in highly seismic areas, as Japan or California. In addition, for some isolators kinds (e.g. rubber bearings, curved surface sliders) a free movement of a few centimeters of the superstructure shall be ensured in the vertical direction too, because the horizontal deformation of the aforesaid isolators also induces a (limited) vertical movement of the superstructure itself.

[0004] For buildings, all these tasks are usually achieved thanks to transverse structural gaps, which separate the isolated building from the surrounding ground or from adjacent constructions (both seismically isolated and conventionally founded). At present, such gaps are empty spaces, which shall remain empty during the entire building life. This is frequently a difficult condition to guarantee, especially years after the building erection, due to lack of adequate maintenance, and, more generally, low perception of seismic risk in several countries.

[0005] In addition, the seismic regulation prescribes that structural gaps of adequate width exist between adjacent buildings even in case of both absence of seismic isolation systems, to avoid hammering between such buildings during an earthquake, as a consequence of the different vibrational behavior of such buildings. However, such a condition is not respected by many existing constructions.

[0006] Last but not least, the results of recent studies shall be taken into account, which have been carried out for deflecting seismic waves by means of isolating holes provided around a sensitive building. These holes of large dimensions (3 meters in diameter and 5 meters deep) have the property of deflecting the waves originating from the epicenter, which then do not reach the building to be protected. This technique is described in patent application FR 2 964 580.

[0007] Such a device for protecting a building on all four sides requires a large area around the building, and deflecting the waves can increase the amplitudes received by the buildings nearby. In addition, to remain efficient, the isolating holes shall remain free from earth or rigid materials, which is frequently difficult to ensure for the necessary long time.

SUMMARY OF THE INVENTION

[0008] The problem to be solved is therefore to develop a method for protecting a building or a group of buildings from the horizontal components of the seismic waves, which, as mentioned, are usually the most dangerous for a structure (usually, only in epicentral areas the effects of the vertical component may be very important).

[0009] For this purpose, the applicant has developed a method consisting of using a gelifying polymer for absorbing the horizontal components of the seismic waves that may impinge on the vertical walls of the foundations.

[0010] In other words, the invention relates to a method for protecting a building or a group of buildings from the horizontal components of the seismic waves, comprising:

[0011] forming a trench around all or part of the periphery of said building or group of buildings, or an excavation under the building,

[0012] filling the trench or the excavation with at least one pregelled polymer, or of at least one polymer and/or of a mixture of polymerizable monomers that can undergo gelation in the trench.

[0013] It has been found that the use of a gelled polymer is beneficial for absorbing the horizontal components of the seismic waves that may impinge on the vertical walls of the foundations. This gel may called a gel-based dissipative and re-centering polymer.

[0014] The gel will damp the energy brought by the waves while re-centering the building during the earthquake and once the earthquake it phased out.

[0015] According to the invention, the trench is formed around all or part of the periphery of a building against the foundations.

[0016] According to another alternative, the trench is formed around all or part of the periphery of a building or a group of buildings at a distance from a building or a group of buildings.

[0017] According to another alternative, the trench is formed between two adjacent buildings. This alternative is particularly useful for example in historical quarter where buildings are not equipped with anti-seismic protection and where streets between buildings are narrow.

[0018] The method of the invention ensure the continuing efficiency of the trench, in terms of attenuation property of the ground motion to protect a building or a structure or group of buildings (e.g. an entire ancient residential quarter) for which there is neither intent nor possibility to put seismic isolators under them or to sufficiently strengthen them using other retrofit techniques, or to avoid hammering between adjacent buildings due to the absence of sufficiently wide structural gaps.

[0019] According to another alternative, an excavation is formed under the building, preferably, along seismic isolators, in order to create the necessary damping and re-centering element of the seismic isolation system.

[0020] The method of the invention is used alone or in combination with other anti-seismic protection. They may pre-exist before using the method of the invention. Anti-seismic protections are for example seismic isolators, flexible footing at the base of the building, elastomeric isolators, sliders, rotating ball or sphere bearings, tubes, sand.

[0021] Moreover the method of the invention can be conveniently used to upgrade existing seismic isolation systems in case there is a seismic reclassification of the territory. Indeed such seismic reclassification leads to increase the
maximum horizontal deformation capability of the isolators and, consequently, the trench width next to the building, which is not always possible to implement. Then the filling of gel into the existing empty trench surrounding an equipped building will not require to modify the trench, nor to replace the existing isolators, in the case that they cannot be laterally deformed as required by the revised seismic hazard values.

[0022] In the specific case of upgrading existing seismic isolation systems on a building already surrounded by an empty trench enabling its displacement when the earthquake occurs, the gel poured into it will enable to meet more stringent seismic classification by avoiding to increase the gap width and/or replacing the isolators. A subsequent advantage is that it protect the gap itself from the insertion in it of earth or other rigid materials that may hinder, in the future, the free motion of the seismically isolated superstructure.

[0023] In all cases, the gelled or gellable polymer is a natural or synthetic hydrophilic polymer that absorbs large amounts of water, called superabsorbent or SAP polymers.

[0024] When the polymer is pregelled, the gel is prepared before the trench, by mixing at least one SAP polymer with water. The trench is then filled with the partially or fully swollen polymer.

[0025] In another embodiment, the gels are formed in situ in the trench. In this case, the trench is filled with at least one polymer and/or with crosslinkable monomers that can gel in situ.

[0026] To do this:

[0027] either the trench is filled with an uncrosslinked hydrophilic polymer previously dissolved in water, to which a crosslinking agent is added. In this case the polymer gels in the trench;

[0028] or the trench is filled with a mixture of hydrophilic monomers previously dissolved in water, to which a crosslinking agent and a catalyst are added. In this case, the monomers polymerize and then crosslink to give polymers that swell in contact with water.

[0029] According to the invention, the SAP polymers are obtained for example from non-ionic, anionic and/or cationic monomers.

[0030] Generally and preferably, the SAP polymers used in the invention are crosslinked and are derived from polymerization of the following water-soluble monomers, without technical limitation:

[0031] Anionic monomers. They are advantageously selected from the group comprising monomers possessing a carboxyl function such as acrylic acid, methacrylic acid, and salts thereof, monomers possessing a sulfonic acid function such as 2-acrylamido-2-methylpropanesulfonic acid (ATBS) and salts thereof;

[0032] Non-ionic monomers. They are advantageously selected from the group comprising acrylamide, acrylamide derivatives such as N-alkylacrylamide as well as the N,N-dialkylacrylamides. It is also possible to use vinylformamide, N-vinylpyrindine, N-vinylpyrrolidone, hydroxyalkyl acrylates and methacrylates, (meth)acrylates bearing chains of the alkoxy and ACMO (acryloyl morpholine) type.

[0033] Cationic monomers. They are preferably selected from the group comprising the diallyldialkylammonium salts such as dialyl dimethyl ammonium chloride (DADMAC) and dialkylaminoaalkyl acrylates and methacrylates, in particular dialkylaminoaethyl acrylate (ADAME) and dialkylaminoaethyl methacrylate (MA-DAME), as well as their acidified or quaternized forms.

[0034] In a preferred embodiment, the polymers are crosslinked copolymers of acrylamide and partially or fully sulfated acrylic acid and preferably contain between 40 and 90 mol % of acrylamide and between 10 and 60 mol % of partially or fully sulfated acrylic acid.

[0035] Substitution of a proportion of the acrylamide with neutralized acrylic acid makes it possible to increase the swellability of the SAP polymers, for example to reduce the amount of polymer required.

[0036] The SAP polymers can also be associative, i.e. can in addition contain hydrophilic monomer units, partially or fully hydrophobic monomer units. The SAP polymers are thus crosslinked and associative. In the case when the SAP polymer is crosslinked and contains partially or fully hydrophobic monomer units, the gel will tend to be harder.

[0037] The hydrophilic monomers with hydrophobic character are for example ethoxylated alkyl (meth)acrylates or ethoxylated alkyl (meth)acrylamides.

[0038] Generally speaking, all the polymers used for the invention can be protected with bactericides. In practice, a bactericide is added to the gel or to the polymer and/or to the crosslinkable monomers.

[0039] These gels can also be obtained from crosslinked natural polymers such as guar gums crosslinked with borates or zirconium salts. These products are more susceptible to biodegradation and must be protected with large amounts of bactericides.

[0040] Generally speaking, all the polymers used for the invention can be protected with bactericides. In practice, a bactericide is added to the gel or to the polymer and/or to the crosslinkable monomers.

[0041] In the trench, the SAP polymers are preferably fully swollen.

[0042] The trenches can be excavated directly against the foundations or at a certain distance from the building or the group of buildings between 1 and 50 m, preferably between 2 and 10 m.

[0043] Generally a continuous trench is excavated all around the building or the group of buildings, i.e. on the entire periphery of the building or the group of buildings. It is called a peripheral trench. A trench may be excavated between two adjacent buildings.

[0044] Generally a continuous trench is excavated all around the building or the group of buildings, i.e. on the entire periphery of the building or the group of buildings. It is called a peripheral trench. A trench may be excavated between two adjacent buildings.

[0045] In the case when the method according to the invention is employed when the building is under construction, the trenches are made by constructing two walls parallel to the foundations at a distance of 0.2 to 1 metre from the foundations.

[0046] In the case when the method according to the invention is employed for protecting an existing building or the group of buildings, the trenches are made using trenching machines.

[0047] These trenching machines are of several types:

[0048] Wheeled trenching machines, permitting maximum depths of 1 m 20/1 m 50 with a very narrow passage: 10 to 20 cm.

[0049] Chain-type trenching machines that can go to a depth of 8 meters on loose ground. The width of the
trench is dictated by the rigidity of the arm and the minimum is from 20 to 40 cm, with certain trenching machines going up to 1 metre or more.

[0050] The trenching machines are of very varied designs, with power from 50 to 1500 hp depending on the type of ground (earth, stony earth, limestone, rock, etc.), the depth and width of the trench. They are often used in agriculture for burying irrigation pipes.

[0051] In practice, the width of the trench is between 20 and 100 cm, preferably between 30 and 60 cm. The depth of the trench is between 1 and 10 meters, preferably between 3 and 6 meters. They can be determined by special tests.

[0052] In an improved embodiment, concrete walls are cast all the way along the walls of the trench in the direction of the length if the walls have sufficient rigidity.

[0053] In order to increase the seismic protection of the building(s) to be protected, it is also possible to make at least one second series of trenches at the periphery of the building(s) and also fill them with absorbent gel.

[0054] For practical reasons, the gel-filled trenches are covered by elements which shall permit free circulation of people and vehicles around the building(s), but which, in case of seismic isolation of the building, shall not hinder the free lateral motion of its seismically isolated superstructure. In case of seismic isolation these elements shall be, for example, thin metal plates fixed on one side only. In absence of seismic isolation they may also be heavier and consist of concrete slabs too.

[0055] The gel can, if necessary, be easily removed by section by means of a truck or brought back up to level with a fresh injection of gel. As a result, the easiness and limited cost of gel replacement will reduce maintenance cost of the system while ensuring a life expectancy compatible with code requirements.

[0056] The gel can be put in place by several methods, which will be summarized in the following examples, and the appended drawings illustrate the invention and its advantages.

**BRIEF DESCRIPTION OF THE DRAWINGS**

[0057] FIG. 1 shows an embodiment of the invention, in which the gel-based dissipative and re-centering polymer is positioned in a trench around a building and against the foundations of the building having a seismic isolation system under the building.

[0058] FIG. 2 shows another embodiment of the invention, in which the gel-based dissipative and re-centering polymer is positioned in a trench around a building and some meters away from the foundations of the building having a seismic isolation system under the building.

[0059] FIG. 3 shows another embodiment of the invention, in which the gel-based dissipative and re-centering polymer is positioned in a trench around a building and some meters away from the foundations of the building, said trench being deeper to compensate the absence of seismic isolation system under the building.

[0060] FIG. 4 shows another embodiment of the invention, in which the gel-based dissipative and re-centering polymer is positioned in an excavation formed along isolators under the building. The excavation is formed in parallel with flat surface sliding or rolling or even other type isolators.

[0061] FIG. 5 shows the top view of another embodiment of the invention, in which the gel-based dissipative and re-centering polymer (5) is positioned in a trench (4) between two adjacent buildings (1).

**DETAILED DESCRIPTION OF THE INVENTION**

[0062] FIG. 1 shows, schematically, a building (1) equipped with seismic isolators, such as elastomeric isolators, sliders, rotating ball or sphere bearings, tubes, sand, (2). According to the invention, a trench is excavated into the ground (3) at the periphery of the building (4) located against the foundations of the building, into which the gelled or gellable polymer is poured (5). The building is then protected from horizontal seismic waves as a result of damping function to absorb the energy of vibrations while re-centering the building, namely bringing it putting the building back into its original position once waves have disappeared during and after the earthquake (6).

[0063] In the specific case of upgrading existing seismic isolation systems (2) on a building already surrounded by an empty trench (4) enabling its displacement when the earthquake occurs, the gel poured into it (5) will enable to meet more stringent seismic classification by avoiding to increase the gap width and/or replacing the isolators (7).

[0064] In the embodiment in FIG. 2, the trenches (4) are excavated at a distance from the building (1) having seismic isolators under its base (2) and a gap (7) between ground and side wall. The building is better protected from horizontal seismic waves.

[0065] In the embodiment in FIG. 3, the trenches (4) are excavated at a distance from a building or a group of buildings (1) which is not equipped with isolator. Seismic waves attenuation will further protect the building where the use of seismic isolators or retrofit by means of other techniques is are neither wanted nor possible.

[0066] In the embodiment in FIG. 4 the gel-based dissipative and re-centering polymer (5) is poured into an excavation (8) under the building to create a damping and re-centering element in a seismic isolation system, where the isolators (9) are flat surface metal-PTFE sliding devices (which are of limited cost and provide only horizontal motions of the isolated superstructure). The structural gap (10) around the isolated building is filled by polymer gel (10).

[0067] Finally, FIG. 5 shows the case of a damping and re-centering gel inserted between adjacent buildings to prevent hammering. In that case, the polymer is positioned in a trench (4) between two adjacent buildings (1).

**Example 1**

Placement of a Superabsorbent Polymer

[0068] A superabsorbent polymer, in this instance an acrylamide/sodium acrylate/ATBS Na terpolymer (70%-25%/5), with grain size less than 5 mm, is swollen with water in a dissolving tank to about 150 to 200 times its volume. It is then transported by truck to the site, where it will be pumped to fill trenches 4 m deep and 40 cm wide around a sensitive building (FIG. 1 or 2).

**Example 2**

Preparation and Use of a Gel Obtained from a Mixture of 2 Solutions

[0069] Two solutions are prepared:

[0070] The first A contains:

<table>
<thead>
<tr>
<th>Solution A</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>200 kg</td>
</tr>
<tr>
<td>50% Acrylamide</td>
<td>9600 kg</td>
</tr>
</tbody>
</table>
[0073] Methylene-bis-acrylamide (MBA) 300 kg
[0074] Triethanolamine 300 kg
[0075] The second B contains:
[0076] Water 9900 kg
[0077] Sodium persulphate 297 kg
[0078] These two solutions are pumped and mixed and then the mixture is injected into the trench, in which polymerization takes place, forming a vibration-absorbing rigid gel (FIG. 1 or 2).

Example 3

[0079] An acrylamide/sodium acrylate mixture (70-30 mol %) in solution at 50% and containing 3% of triethanolamine and 3% of MBA is transported in a tanker truck. At the site, a solution of 300 kg of sodium persulphate dissolved in 990 kg of water is added to this mixture. This permits in situ polymerization with a gel of good consistency.

[0080] A biocide, Protectol HT (triazine), is added in a small amount (0.01 wt %) for product stability.

[0081] A trench made 10 meters from the building and having the dimensions 5 meters deep and 50 cm wide is filled with the prepared gel.

[0082] The building is separated from the subjacent ground by a flexible footing, usually of rubber, and at the side walls by a trench containing gel. It has exceptional seismic performance.

[0083] The use or production of superabsorbent gels can be modified by a person skilled in the art for adapting to the local conditions.

1. A method for protecting a building or a group of buildings from the horizontal components of seismic waves, comprising the steps of:
   forming a trench around, or an excavation under, all or part of a periphery of said building or group of buildings, filling the trench or the excavation with at least one pregelled polymer, or of at least one polymer and/or of a mixture of polymerizable monomers adapted to undergo gelation in the trench.

2. The method according to claim 1, characterized in that the trench is formed against foundations of said building or group of buildings.

3. The method according to claim 1, characterized in that the trench is formed at a distance from the building or group of buildings.

4. The method according to claim 1, characterized in that the gelled or gellable polymer is a superabsorbent polymer.

5. The method according to claim 1, characterized in that when the polymer is pregelled, the trench is filled with the partially or fully swollen polymer.

6. The method according to claim 1, characterized in that when the trench or excavation is filled with at least one gellable polymer, said polymer is an uncrosslinked hydrophilic polymer previously dissolved in water, to which a crosslinking agent is added.

7. The method according to claim 1, characterized in that when the trench or excavation is filled with crosslinkable gellable monomers, said monomers are hydrophilic and are previously dissolved in water, and a crosslinking agent and a catalyst are added to the mixture.

8. The method according to claim 1, characterized in that the polymers are obtained from monomers selected from the group consisting of:
   a. Anionic monomers selected from the group consisting of monomers possessing a carboxyl function, monomers possessing a sulphonic acid function.
   b. Non-ionic monomers selected from the group consisting of acrylamide, acrylamide derivatives, vinylformamide, N-vinylpyridine, N-vinylpyrrolidone, hydroxyalkyl acrylates and methacrylates, (meth)acrylates bearing chains of the alkoxy and ACMO (acyrlyl morpholine) type.
   c. Cationic monomers selected from the group consisting of diallyldialkyl ammonium salts, dialkylaminooalkyl acrylates and methacrylates, in particular dialkylaminooalkyl acrylate (ADAME) and dialkylaminooethyl methacrylate (MADAME), as well as their acidified or quaternized forms.

9. The method according to claim 1, characterized in that the crosslinking agents are selected from polyfunctional monomers, aluminium citrate, zincium lactate, and titanates.

10. The method according to claim 1, characterized in that a bactericide is added to the gel or to the polymer and/or to the crosslinkable monomers.

11. The method according to claim 1, characterized in that the trench is excavated at a distance from the building between 1 and 50 m.

12. The method according to claim 1, characterized in that the width of the trench is between 20 to 100 cm, and the depth of the trench is between 1 and 10 meters.

13. The method according to claim 1, characterized in that the trench is excavated on the entire periphery of the building.

14. The method according to claim 2, characterized in that the trenches are made by constructing two walls parallel to the foundations at a distance of 0.2 to 1 metre from the foundations.

15. The method according to claim 1, characterized in that the trench is excavated at a distance from the building between 2 and 10 m.

16. The method according to claim 1, characterized in that the width of the trench is between 30 and 60 cm, and the depth of the trench is between 3 and 6 meters.

* * * * *