

Overview of Base Isolation Technique for Earthquake Resistant Buildings

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ABSTRACT: An overview of earthquake resistant building with base isolation technology is given in this paper which elaborates the construction, working principle and design structure of base isolation system. Base Isolation is a state-of-the-art design strategy that substantially decouples (isolates) a building from the damaging effects of earthquake ground motion. It can be used to dramatically reduce earthquake forces by factors of 5 to 10 on mid-rise buildings (2-15 stories tall), and make a Magnitude 8.0 earthquake seem like a much less damaging Magnitude 5.5 event. Base isolation, also known as seismic or base isolation system, is a collection of structural elements which should substantially decouple a superstructure from its substructure resting on a shaking ground thus protecting a building or non-building structure's integrity. Base isolation is the most powerful tool of the earthquake engineering pertaining to the passive structural vibration control technologies. It is meant to enable a building or non-building structure to survive a potentially devastating seismic impact through a proper initial design or subsequent modifications. In some cases, application of base isolation can raise both a structure's seismic performance and its seismic sustainability considerably. Contrary to popular belief base isolation does not make a building earthquake proof as there is no such thing.

I. INTRODUCTION

Why Earthquake Resistant Structural Design: Buildings or structures are usually designed to bear only vertical loads. However, in the event of an earthquake, the ground shakes to & fro. This motion of the ground, imposes an additional horizontal load on the Building which it is unable to withstand unless specifically so designed; hence the damage. Surprisingly, the additional cost to make a building/structure earthquake resistant is very low, usually about 5% of the structural cost of the building which comes out to be not more than 1-2% of the total cost of the building.

How to build: A number of methods have been developed to build earthquake-resistant structures. These techniques range from extremely simple to fairly complex. For small- to medium-sized buildings, the simpler reinforcement techniques include making the structure ductile when subjected to earthquake. This ductility is achieved using properly placed reinforcement and providing support walls called shear walls. Shear walls, made of reinforced concrete (concrete with steel rods or bars embedded in it), help strengthen the structure and help resist rocking forces.

Sometimes, the buildings are protected using medium-sized devices that act like shock absorbers between the building and its foundation. These devices called base isolators, are usually bearings made of alternate layers of steel and an elastic material such as synthetic rubber. Also base isolators absorb some of the sideways motion that would otherwise damage a building.

Base isolation design

International Journal of Innovative Research in Science, Engineering and Technology

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Description of Base Isolation: Base Isolation is a state-of-the-art design strategy that substantially decouples (isolates) a building from the damaging effects of earthquake ground motion. It can be used to dramatically reduce earthquake forces by factors of 5 to 10 on mid-rise buildings (2-15 stories tall), and make a Magnitude 8.0 earthquake seem like a much less damaging Magnitude 5.5 event. A base-isolated structure is one supported by isolation elements--generally bearings or sliders--that are typically placed between the building and its foundation. An appropriate analogy would be the relationship between automobiles and their suspension system of springs and shock absorbers, which cushion the occupants from a bumpy ride.

The following illustrations shows the effects of an earthquake acting on both a base-isolated building and a conventional, fixed-base building. During an earthquake, the ground beneath each building begins to move. In figure 1, isolators placed between the bottom of each column and its foundation, prevent most of the horizontal movement of the ground from being transmitted to the structure, and dissipate the energy imparted to the building by earthquake. The building feels less force and moves uniformly (like a rigid box) in a slow controlled fashion, resulting in substantially reduced damage to the structure and its contents.

The conventional approach to earthquake resistant design of buildings depends on providing the building with strength, stiffness and inelastic deformation capacity which are strong enough to withstand a given level of earthquake-generated force. This is generally accomplished through the selection of an appropriate structural configuration and the careful detailing of structural members, such as beams and columns, and the connections between them.

But in contrast, we can say that the basic approach to more advanced techniques for earthquake resistance is not to strengthen the building, but to reduce the earthquake-generated forces that is put on the building. The most important advanced techniques of earthquake resistant design and construction are:

- Base Isolation Energy
- Dissipation Devices Active Control Systems

II.BASE ISOLATION

This is the most widely used method against earthquake damage. A base isolated structure is supported by a series of bearing pads which are placed between the building and the building's foundation. A variety of different types of base isolation bearing pads have now been developed, including ones called lead-rubber bearings.

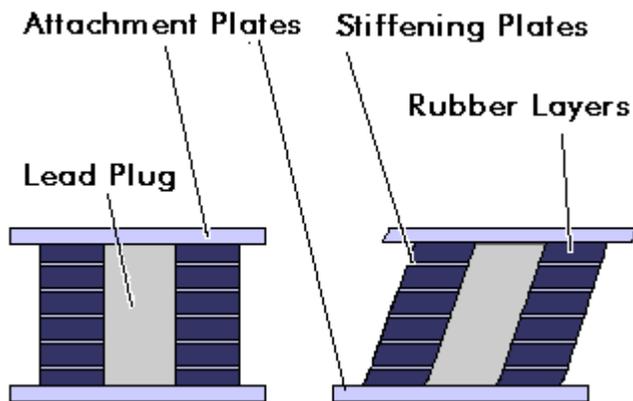


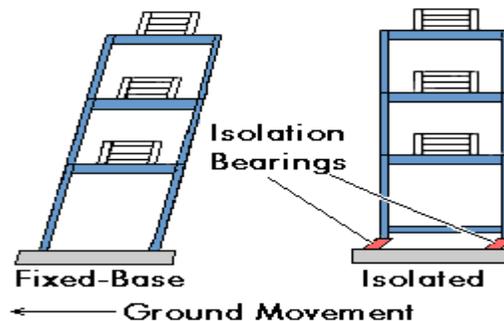
Fig.2 A lead-rubber bearing is made from layers of rubbers sandwiched together with layers of steel. In the middle of the bearing is a solid lead "plug." On top and bottom, the bearing is fitted with steel plates which are used to attach the bearing to the building and foundation. The bearing is very stiff and strong in the vertical direction, but flexible in the horizontal direction.

As a result of an earthquake, the ground beneath each building begins to move. In Figure 3, it is shown moving to the left. Each building is undergoing displacement towards the right, which is due to inertia. In addition to displacing to the right, the un-isolated building is also changing shape into more of a parallelogram from a rectangular. This is the process of deforming. And of course, the primary cause of earthquake damage is deformation which the building goes through as a result of inertial force acting on it.

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III. WORKING PRINCIPLE

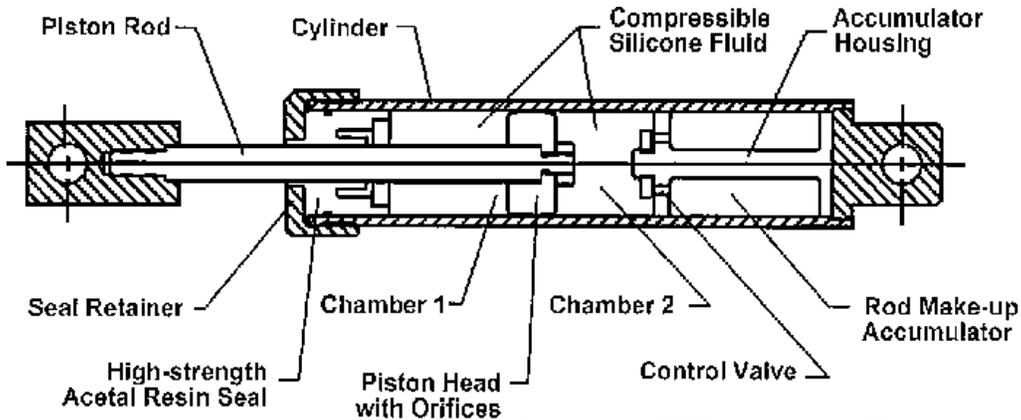
To get a basic idea of how base isolation works, first examine the (fig b). This shows an earthquake acting on base isolated building and a conventional, fixed-base, building. As a result of an earthquake, the ground beneath each building begins to move. In (fig b) it is shown moving to left. Each building responds with movement which tends towards the right. The buildings displacement in the direction opposite the ground motion is actually due to inertia. The inertia forces acting on a building are the most important of all those generated during an earthquake.

In addition to displacing towards right, the un-isolated building is also shown to be changing its shape from a rectangle to a parallelogram. We say that the building is deforming. The primary cause of earthquake damage to buildings is the deformation which the building undergoes as a result of the inertial forces upon it.

The base-isolated building, though is still displacing, retained its original rectangular shape. Only the lead-rubber bearing supporting the building are deformed. The base-isolated building escaped the deformation and damage--which shows that the inertial forces acting on the base-isolated building have been reduced. Experiments and observations of base-isolated buildings in earthquakes have been shown to reduce building accelerations to as little as 1/4 of the acceleration of fixed-base buildings

Since the rubber isolation bearings are highly elastic, they don't suffer any damage. The lead plug in the middle of the example bearing experiences the same deformation as the rubber. However, it also generates heat as it does so. In other words, the lead plug reduces, or dissipates, the energy of motion--i.e., kinetic energy--by converting that energy into heat. And by reducing the energy entering the building, it helps to slow and eventually stop the building's vibrations sooner--in other words, it damps the building's vibrations.

IV. SECOND TYPE OF BASE ISOLATION

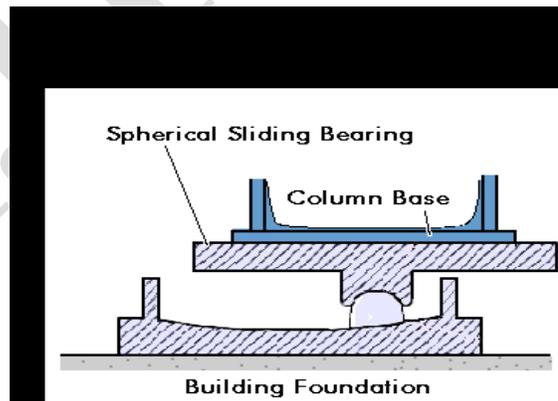


Spherical sliding isolation systems are another type of base isolation. The building is supported by bearing pads that have a curved surface and low friction. During an earthquake the building is free to slide on the bearings. Since the bearings have a curved surface, the building slides both horizontally and vertically.

The forces needed to move the building upwards limits the horizontal or lateral forces which would otherwise cause building deformations. Also by adjusting the radius of the bearings curved surface, this property can be used to design bearings that also lengthen the buildings period of vibration.

A second type of base-isolation is called Spherical Sliding Isolation Systems. With this, the building is supported by bearing pads that have a curved surface and low friction. During an earthquake, the building is free to slide on the bearings. Since the bearings have a curved surface, the building slides both horizontally and vertically (See Figure 4). The force needed to move the building upwards limits the horizontal or lateral forces which would otherwise cause building deformations. Also, by adjusting the radius of the bearing's curved surface, this property can be used to design bearings that also lengthen the building's period of vibration.

The concept of base isolation is explained through an example building resting on frictionless rollers.



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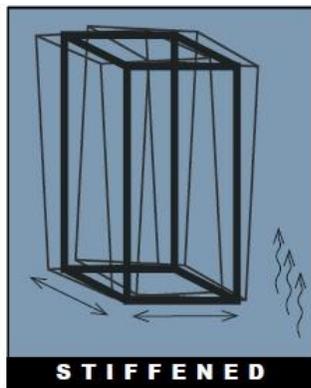
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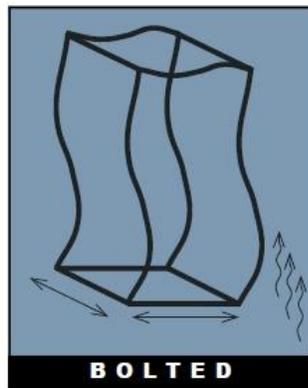
When the ground shakes, the rollers freely roll, but the building above does not move. Thus, no force is transferred to the building due to the shaking of the ground; simply, the building does not experience the earthquake.

Now, if the same building is rested on the flexible pads that offer resistance against lateral movements, then some effect of the ground shaking will be transferred to the building above. If the flexible pads are properly chosen, the forces induced by ground shaking can be a few times smaller than that experienced by the building built directly on ground, namely a fixed base building. The flexible pads are called base-isolators, whereas the structures protected by means of these devices are called base-isolated buildings. The main feature of the base isolation technology is that it introduces flexibility in the structure.

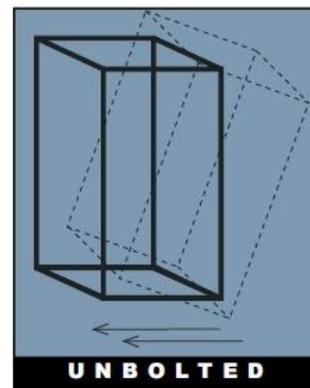
Traditional Earthquake Mitigation Techniques



Shock and vibrations sent into and contained within stiffened frame.

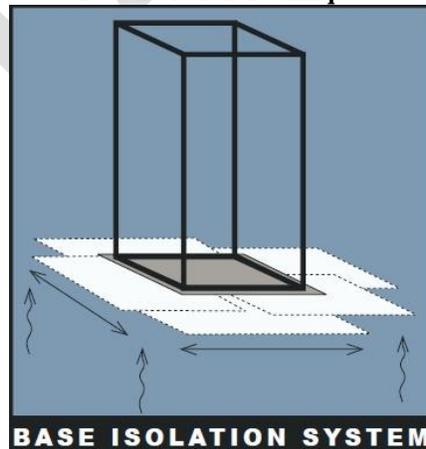


Stresses on cabinet frame and travel of shock and vibrations.



Reaction of a cabinet to seismic ground motion.

Base Isolation Technique



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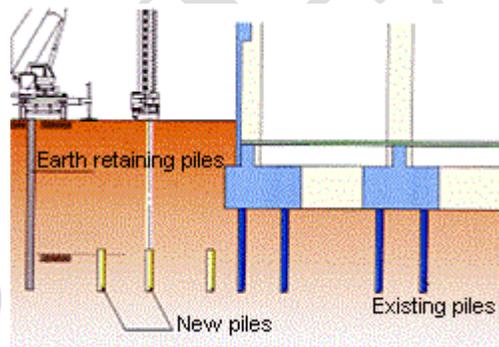
Due to the flexibility in the structure, a robust medium-rise masonry or reinforced concrete building becomes extremely flexible. The isolators are often designed, to absorb energy and thus add damping to the system. This helps in further reducing the seismic response of the building. Many of the base isolators look like large rubber pads, although there are other types that are based on sliding of one part of the building relative to other. Also, base isolation is not suitable for all buildings. Mostly low to medium rise buildings rested on hard soil underneath; high-rise buildings or buildings rested on soft soil are not suitable for base isolation.

Lead-rubber bearings are the frequently-used types of base isolation bearings. A lead rubber bearing is made from layers of rubber sandwiched together with layers of steel. In the middle of the solid lead "plug". On top and bottom, the bearing is fitted with steel plates which are used to attach the bearing to the building and foundation. The bearing is very stiff and strong in the vertical direction, but flexible in the horizontal direction.

Construction procedure for the Building-Moving Base Isolation Improvement Method :

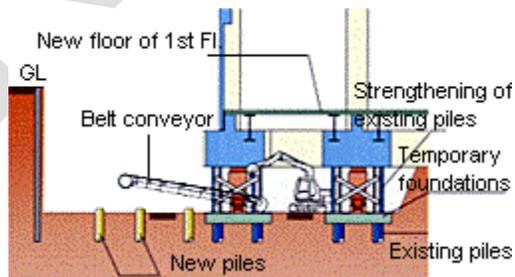
(1) Earth retaining and pile work

Earth retaining H-shaped steel piles will be put in place to prevent collapse of the ground surrounding the site where the building is to be moved. Some 44 new piles will be put in place where the building is to be moved.



(2) Excavation work

The earthen floor slab of the first floor will be broken up, and a new structural slab laid, strengthened with beams. Excavation will be carried out while strengthening existing piles on the base under the existing building and the new site of the building.



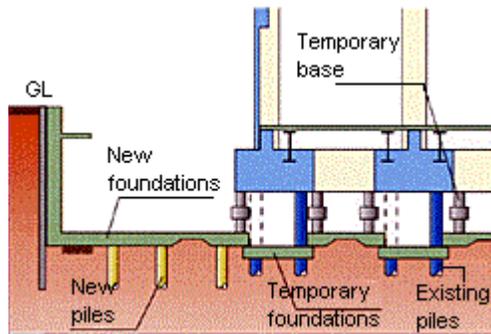
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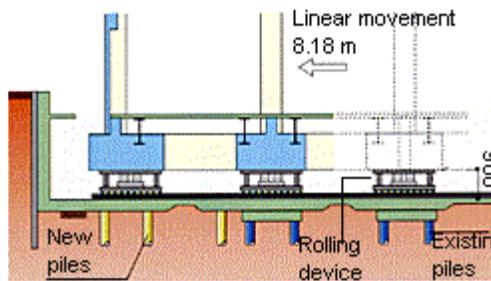
(3) Cut existing piles and construct foundations

Foundations in areas except around existing piles will be constructed. A temporary base will be installed, the existing piles cut, and then new foundations constructed around existing piles.



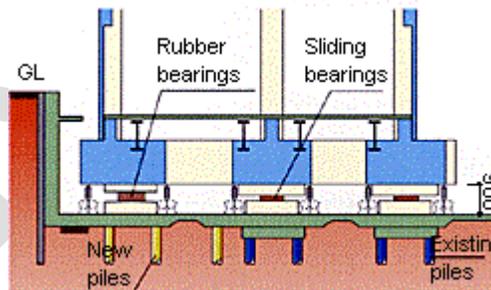
(4) Building-moving work

A roller-lift device will be installed, and the temporary base removed. The building will then be moved approximately eight meters by eight 50-ton propelled hydraulic jacks on the transfer roadbed. The stroke of the jacks is 20 centimeters, and they require approximately five minutes to extend. After the building moves 20 centimeters, the jacks will be reset, and this process repeated.



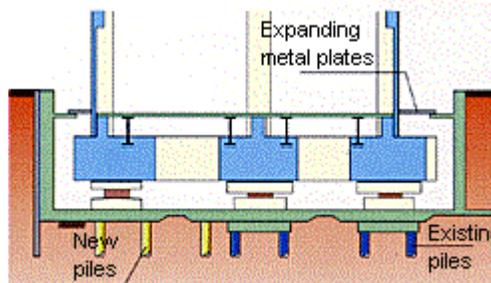
(5) Base isolation work

After installing a temporary base and removing the rolling device, the base isolation system - rubber bearings (diameter 600 millimeters, seven locations), sliding bearings (diameter 450 to 30 millimeters, 11 locations) and oil dampers (four locations) will be installed under the existing foundations, with the gap to be filled in with concrete, and the temporary base removed.



(6) Completion

The remaining retaining walls will be completed, and the surrounds of the building closed off with expanding metal plates.



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Energy Dissipation Devices

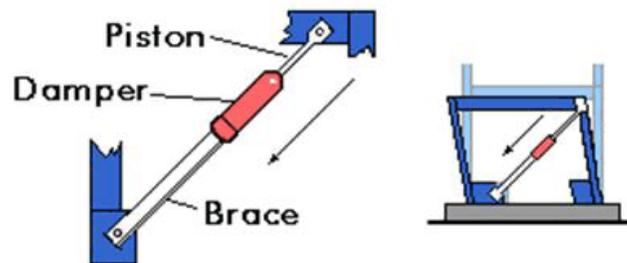
Another major new technology for improving the earthquake resistance of buildings involves energy dissipation. During an earthquake, a certain amount of energy is transferred to the building. While buildings can dissipate, or damp, this energy, the capacity to do so before becoming deformed or damaged is quite limited.

A building dissipates energy either by undergoing large-scale movement or by sustaining increased strains in key building elements such as columns and beams. Both of these processes eventually result in some degree of damage. Structural engineers can greatly decrease the seismic energy entering the building, and thus decrease building damage, by equipping a building with additional devices that have high damping capacity.

A number of damping devices have been developed. What follows are some representative examples:

- Friction Dampers utilize frictional forces to dissipate energy
- Metallic Dampers utilize the deformation of metal elements within the damper
- Viscoelastic Dampers utilize the controlled shearing of solids
- Viscous Dampers utilize the forced movement (orificing) of fluids within the damper

Damping devices are often installed as part of bracing systems. Figure 5 shows one type of damper-brace arrangement, with one end attached to a column and one end attached to a floor beam.



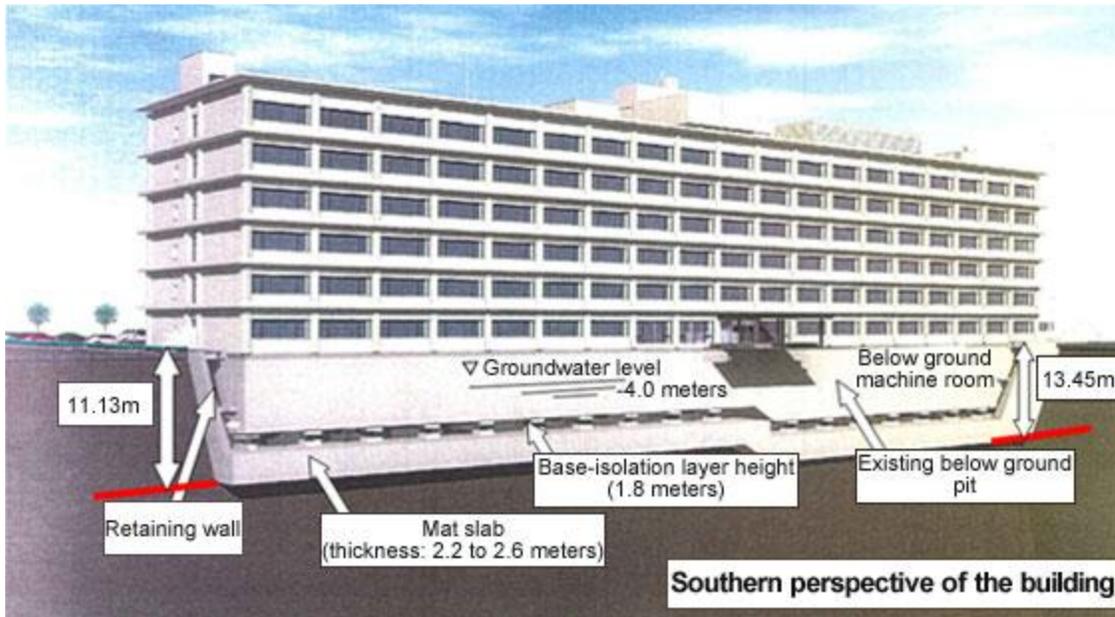
Damping Device Installed with Brace

Spread foundation building: this is the type of building which is constructed together with the foundation directly on the ground, without using deep in-ground piles to support the structure. There are two types of spread foundations: "mat foundations" and "footing foundations." This particular building has a "mat foundation."

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Below-floor excavation work



Base isolation mat slab construction

[Outline of base isolation work using the Foundation Base Isolation Retrofitting Method]

In order to install base isolation devices underneath the spread foundation of the "Geographical Survey Institute Joint Government Building," it is necessary to construct a new foundation (mat slabs). Therefore, the Foundation Base Isolation Retrofitting Method used in this project involved press-fitting 470 steel pipes to temporarily support the weight of the building, and then constructing a new foundation (mat slabs) to enable installation of the base isolation devices. Careful attention is required in the process of installing "temporary piles," so ground property and other detailed prior checks are carried out to avoid the building from tilting and to prevent any deformation. The "temporary piles" are removed after installation of the base isolation devices. This is the first time in the industry where base isolation retrofitting work on this type of spread foundation (mat foundation) building using "temporary piles" has been carried out on such a large scale.

DOI: 10.15680/IJIRSET.2014.0311133

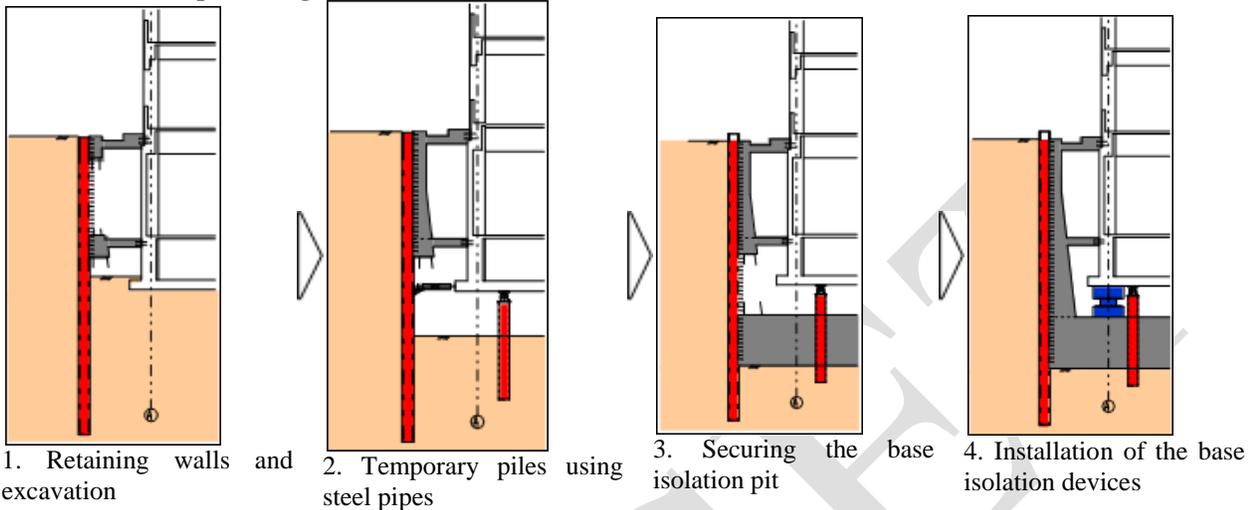
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(Construction step drawings)



<Construction steps>

1. Retaining walls and excavation
Retaining walls were installed around the building before the excavation work began on the building side.
2. Temporary piles using steel pipes
About 470 steel pipes were carefully installed underneath the entire foundation one after the other with fine tuning to temporarily support the weight of the building of around 45,000 tons.
3. Securing the base isolation pit
A pit was secured underneath the existing building to construct a new foundation (mat slabs; thickness: 2.2 to 2.6 meters) to enable installation of the base isolation devices.
4. Installation of the base isolation devices
The base isolation devices, including laminated rubber bearing, were installed, and after the mat foundation was jacked-down the "temporary piles" were removed.

The construction steps from one to four were carried out at four places that could be excavated around the building at the same time, while maintaining the building level by constantly using a settlement gauge and actual measuring of the surveying. From this project, the company has collected the technology required for the optimum method of base isolation retrofitting work on an existing building with a spread foundation where it is difficult to insert piles deeply into the ground. This knowhow will have wide-ranging use in the future.

IV.RESULTS AND DISCUSSIONS

RESPONSE OF BASE ISOLATED BUILDINGS

The base-isolated building retains its original, rectangular shape. The base isolated building itself escapes the deformation and damage-which implies that the inertial forces acting on the base isolated building have been reduced. Experiments and observations of base-isolated buildings in earthquakes to as little as ¼ of the acceleration of comparable fixed-base buildings.

Acceleration is decreased because the base isolation system lengthens a buildings period of vibration, the time it takes for a building to rock back and forth and then back again. And in general, structures with longer periods of vibration tend to reduce acceleration, while those with shorter periods tend to increase or amplify acceleration.

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Reducing Earthquake Damage:

Earthquakes are likely, knowing how to build can help reduce injury, loss of life, and property damage during an earthquake. An earthquake-resistant building has a number of special structural features. Interior support walls called shear walls, made of reinforced concrete, strengthen the structure and help resist rocking forces. Shear walls in the center of a building form a shear core. Cross-bracing reinforces walls with diagonal steel beams. Base isolators act as shock absorbers, and a moat allows a building to sway.

V.CONCLUSION

Earthquakes, though tragic, also provided with the momentum to the process of improvements in seismic design codes and construction practices. It is important to bear in mind that there is no such thing as an earthquake proof building. But a properly engineered tall architectural building should be able to withstand the maximum credible earthquake for its area without collapse, and lesser seismic events without major structural damage. Today, there are various types of softwares, like 2D and 3D animation software, Revit, and design drafting software which increase productivity in building design and construction and help builders, engineers and customers to preview how the building would look like after construction. The evolution of Building Information Model (BIM) has tremendously changed the shape of construction industry improving visualization, quickening retrieval of information, increasing coordination of construction documents, embedding and linking of vital information such as vendors for specific materials, location of details and quantities required for estimation and tendering. With the help of CAD architectural designing and drafting and 3D architectural rendering, we can draw, design and preview the tall architectural building able to withstand the maximum credible earthquake for its area without collapse.

It is possible to make modifications to a building to make it earthquake resistant. The nine layers overlapped cubic building with buttresses, a roof, and cross braces was 83% more stable than the plain nine layer building. The nine layers overlapped cubic building with cross braces, a roof and a marble base isolator was 226% more stable than a plain nine layer building. The base isolator is more effective at stabilizing the building than the buttresses because it actually absorbs more of the earthquake's energy. Using of this technology we can reduce the damage of building, human and other living things. The life and property are important to everyone, so earthquake resistant buildings very useful to save.

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