Foreva Solutions

Seismic repair and strengthening of existing buildings

IMPROVE, PRESERVE, SECURE

FREYSSINET
SUSTAINABLE TECHNOLOGY

The Freyssinet Group

Freyssinet brings together **an unrivalled set of skills in the specialist civil engineering sector**. It implements solutions with high added value in two major fields: construction and repairs.

Freyssinet is involved in numerous major projects on five continents,
making it the world leader in its specialist areas of:

- prestressing;
- construction methods;
- cable-stayed structures;
- structural accessories;
- repairs;
- structural reinforcement and maintenance.

Freyssinet is highly involved in sustainable development issues, and has set up a number of initiatives, particularly to reduce the environmental impact of its projects and enhance its social responsibility policy.

Freyssinet is a subsidiary of the Soletanche Freyssinet group, a world leader in the soils, structures and nuclear sectors.

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FREYSSINET
SUSTAINABLE TECHNOLOGY

An integrated seismic prevention and protection solution for existing buildings, from the structural repair and reinforcement specialist.

With sixty years of experience in concrete repair, reinforcement and protection techniques, including designing and manufacturing earthquake protection devices. As a general contractor for special works Freyssinet offers you guaranteed turnkey services.

We make our expertise and know-how available to contracting authorities for seismic compliance, strengthening and repair projects on existing buildings and residences.

Services

1. **Assistance with earthquake risk assessments**
   - Selecting seismic action;
   - Preliminary study of structure vulnerability.
2. **Technical and financial assessment of strengthening options**
   - Assistance with selecting the protection level;
   - Formulating technical performance objectives for the reinforced structure.
3. **Strengthening design study**
   - Assistance with collecting data specific to the structure, soil and seismic action;
   - Devising the strengthening strategy in accordance with architectural requirements.
4. **Performance of strengthening studies and work**
   - Numerical modelling and dynamic analysis of the reinforced structure;
   - Design and supply of seismic strengthening devices;
   - Performance of strengthening work on the structure and foundations.

Areas of application

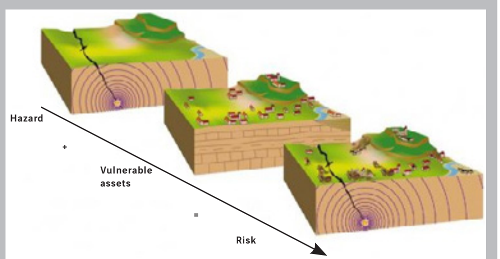
- **Public buildings**
- **Commercial buildings**
- **Industrial buildings**
- **Historic monuments**
- **Residential buildings**
- **Office buildings, hotels**
- **Community centres**
- **Sports facilities**

Seismic risk

The earthquake risk is the combination of a seismic hazard and the vulnerability of the people, property and activities on a single site.

The seismic hazard

The seismic hazard is the probability, for a given site, of being exposed to an earthquake with given characteristics, within a given period of time.



The vulnerability of socio-economic assets

The scale of the damage considered acceptable to an isolated building or a group of buildings depends on the vulnerability of the assets (economic, heritage, social, etc.) and their importance within the society both pre & post seismic event (hospitals, schools, etc.).

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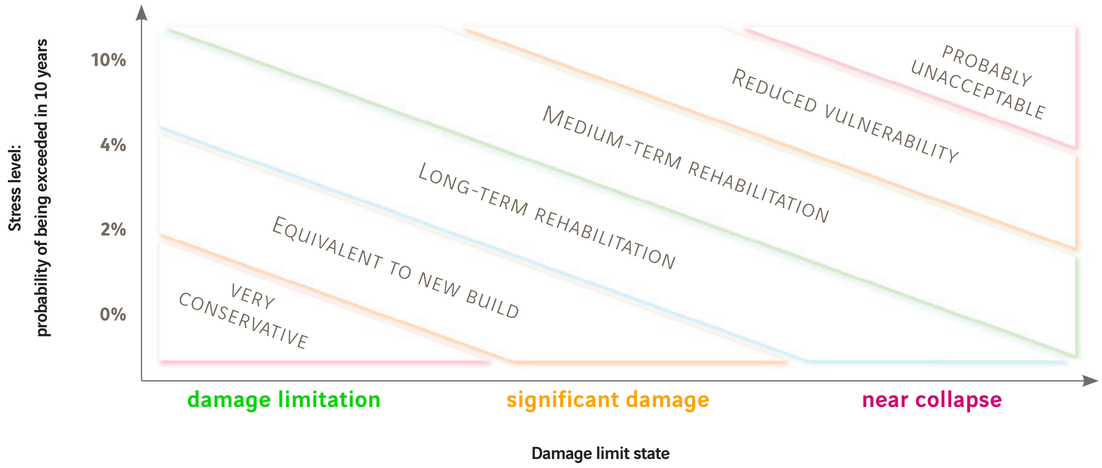
OBJECTIVES OF THE STRENGTHENING/REPAIR

Safeguarding users is the main objective of the various types of rehabilitation. Other objectives also come into consideration depending on the socio-economic importance and the residual service life of the structure; these include maintaining emergency services (hospitals, barracks, etc.), protecting equipment (major industrial facilities), conserving the national heritage (historic monuments), safe evacuation of the building, etc.

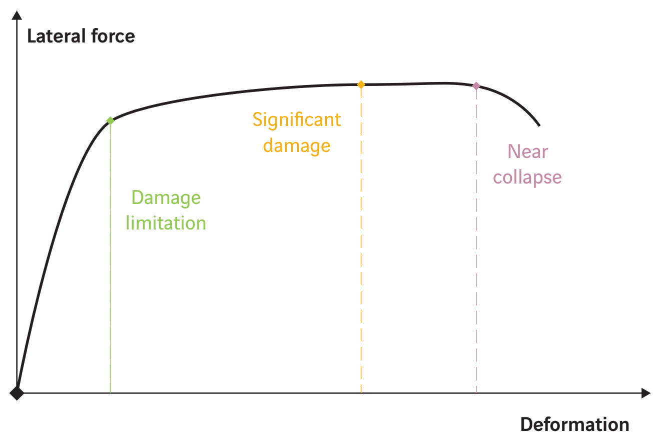
Freyssinet helps contracting authorities translate their objectives into technical performance requirements to be met by the strengthened or repaired structure.

The level of protection is the intersection between a level of seismic stress and a damage limit state of the structure:

Protection level = Damage limit state x Stress level



Damage limit states *(with reference to Eurocode 8, for example)*



Limit State of Damage Limitation

The structure is only lightly damaged. Materials have been prevented from significant yielding and retain all of their strength and stiffness properties.

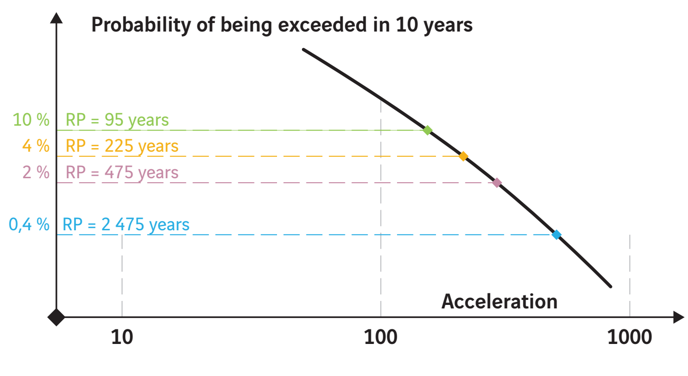
Limit State of Significant Damage

The structure is significantly damaged, but has some residual lateral strength and stiffness. Vertical elements are capable of sustaining vertical loads. The structure can sustain after-shocks of moderate intensity.

Limit State of Near Collapse

The structure is heavily damaged following an earthquake. It would not sustain an after-shock.

Stress level *(with reference to Eurocode 8, for example)*



The selection of the return period for the seismic action determines the seismic acceleration applied to the structure. The following reference return periods (RP) are generally envisaged: 2,475 years, 475 years, 225 years and 95 years.

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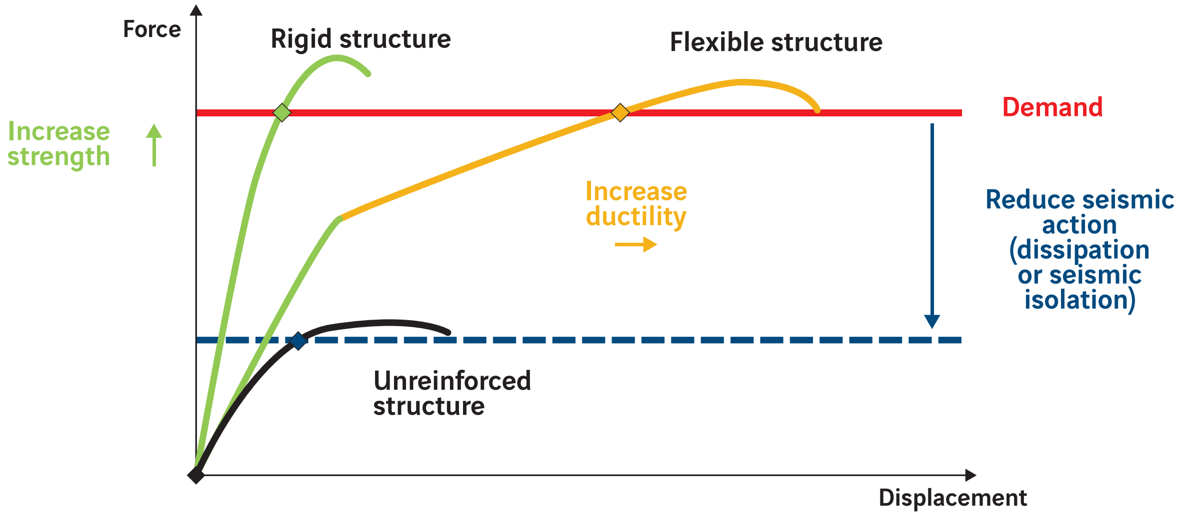
STRENGTHENING STRATEGIES

The repair or strengthening strategy must be appropriate to the type of structure. For example, during an earthquake, very tall reinforced concrete portal frame structures are relatively flexible and work in bending, whereas low concrete wall structures work mainly in shear.

Structure capacity curve



Increasing the strength of rigid structures

To reduce the vulnerability of low-ductility buildings, it is often more cost-effective to make them stronger so that they can withstand greater seismic forces, rather than trying to improve their ductility. Strengthening solutions are often accompanied by an increase in the weight and stiffness of the existing structure, and therefore increase the seismic forces to which it is subjected. However, rigidity can help to protect non-structural accessories, which cannot tolerate significant deformation of the building.

Increasing the strength and ductility of flexible structures

Flexible structures can be strengthened by increasing their strength, particularly by means of additional cross-bracing, or by increasing their ductility, for example by introducing plastic hinges. Increasing ductility consists of making the building more deformable before failure, without increasing the forces to which it is subjected, in such a way as to distribute the seismic action over the entire building and make better use of its resilience. When plastic hinges are introduced, they help to increase the structure's dissipation capacity.

Dissipating the energy transmitted to the structure

Whether rigid or flexible, structures can be fitted with damping devices that are able to dissipate a large part of the seismic energy transmitted to them. Harnessing forces of several tens or even hundreds of tonnes over strokes measured in centimetres, they can contribute to significant financial savings by reducing the work carried out on the structure.

Isolating the structure from its foundations

The seismic action placing stress on a building can be reduced by dynamic isolation of the structure from its foundations, advantageously combined with a damping device. This solution amounts to placing a "filter" between the ground and the building that only lets through part of the energy resulting from the seismic action. The dynamic isolator offsets the frequency of the structure, which works in the horizontal direction as a relatively low-frequency oscillator. This arrangement is particularly effective for rigid structures.

The level of protection that can be obtained in this way is significantly higher than the level required by the seismic rules for normal-risk structures. Structures remain operational, even after violent earthquakes. There is little or no damage to non-structural elements and equipment, which can be extremely costly (in the case of hospitals, for example).

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Foreva Solutions
The Freyssinet turnkey service guarantee

INCREASING THE STRENGTH OF THE STRUCTURE

Shotcrete reinforcing elements

Dry process shotcreting is used to strengthen wall ties in structures, create shells or increase the strength of existing elements with or without the addition of reinforcements, by encasing columns and beams, strengthening shear walls, increasing floor thickness, etc.

Foreva® Shotcrete can be used in enclosed spaces by containing the working areas. This means that it is also suitable for work inside the building.

Composite reinforcing elements

Reinforcing elements are used to strengthen reinforced concrete columns by confinement, beams in bending, in-plane shear walls, etc. They are also used to reinforce existing wall ties.

These reinforcing elements have the advantage of not adding weight and only slightly stiffening the structure, which prevents amplification of the seismic forces experienced by the structure and overloading of the foundations in particular.

The Foreva® TFC carbon fibre fabric reinforcement solution can be used in conjunction with Foreva® WFC 100 and Foreva® WFC 300 patented carbon fibre braids, which respectively use a short braid anchored in resin or a long braid anchored in grout.

Restoring concrete after an earthquake

Structures damaged after an earthquake often show some degree of cracking and peeling. The concrete is restored locally by grouting the cracks and reprofiling using Foreva® TP Inject and Foreva® REP respectively.

1 - Beam strengthening with Foreva® Shotcrete
2 - Slab strengthening with Foreva® TFC composite
3 - Strengthening with braces

Increasing the strength of the structure

Prestressed diaphragm wall reinforcing elements

Freyssinet produces prestressed diaphragm walls by means of external prestressing tendons anchored in additional headers or capping.

The tendons can be arranged horizontally, in which case they connect opposite sides of the building, or vertically in order to compress the transverse shear walls of a façade.

The vertical prestressing tendons are also used to anchor the structure to its foundations when it is subject to an overturning moment.

The introduction of additional forces in the structure and foundations due to prestressing may require reinforcement, and must therefore be checked.

Bracing with external buttresses

Bracing with reinforced concrete buttresses on one or both sides of the building enables it to withstand horizontal seismic forces and ensure that loads are transferred to the foundations. The buttress footings also serve to strengthen the structure's foundations.

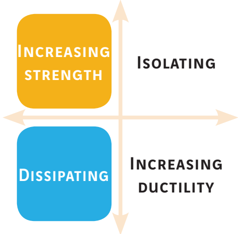
The benefit of this type of reinforcement is that it only requires external work, avoiding disruption to activities inside the building. It can be advantageously combined with the installation of horizontal prestressed wall ties.

Bracing with reinforced concrete shear walls

New reinforced concrete shear walls must often be built in addition to modifying the block diagram of the structure during an earthquake, in order to ensure the stability of load-bearing elements and continued load transfer.

Transverse shear walls can be outside or inside the building, and can be advantageously used in conjunction with prestressed wall ties to improve performance.

1 - View before repair - Sophia Antipolis office building
2 - Addition of buttresses secured to the structure by three levels of external prestressing (Sophia Antipolis)



Strengthening with cross-bracing

Bracing in the horizontal plane using struts makes it possible to transmit the lateral actions experienced by the building to the vertical bracing elements and distribute them more evenly.

The struts must withstand the horizontal forces in that plane on every storey of the building, and transfer the dynamic loads to the foundations.

Strengthening with struts fitted with energy-dissipation devices

Freyssinet's solution consists of combining additional bracing with Transpec™ FVD anti-seismic devices. These viscous fluid energy-dissipation devices have very high damping capacity and are particularly efficient over very short strokes. Their damping capacity offsets the increased stiffness resulting from the addition of braces.

Strengthening with struts fitted with hysteretic damping devices

When a multi-storey building is equipped with additional bracing over its entire height, struts working in parallel have to resist the same force, whatever their respective movements.

Freyssinet supplies struts fitted with hysteretic damping devices and a system for progressive post-elastic stiffening in the operating range, making it possible to equalise the forces in the struts.

Foundation strengthening solutions

When the foundation system used to transmit the vertical and horizontal forces from the building to the ground is inadequate, it can be strengthened by underpinning:

- reinforcing the footings, by linking the stay plates or piles with reinforced concrete stringers, or by brace and prestressed tie rod systems;
- with Freyssinet micropiles, even in very confined spaces through the use of compact drilling equipment;
- with anchor tie rods when the weight of the structure is insufficient to ensure stability.

1 - Cross-bracing
2 - Struts fitted with hydraulic dampers
3 - Detail of a hydraulic damper fitted to a strut

Increasing the ductility of the structure

The ductility of the structure is increased by strengthening joints working in the elastic range but having weaknesses, and confining plastic hinge zones.

Strengthening joints

In order to overcome inadequate reinforcement layout or design faults in the beam-column joints (lack of transverse confinement reinforcements), joints can be reinforced with hoop rings made using Foreva® TFC carbon fibre strips, recessed additional reinforcements, or dry process Foreva® Shotcrete.

Confining plastic hinge zones

The confinement of plastic hinge zones is advantageously strengthened by application of a composite carbon fibre fabric reinforcement, Foreva® TFC.

Encasing columns

The ductility of reinforced concrete columns in portal frame structures can be increased without introducing additional stiffness by means of confinement encasing using Foreva® TFC carbon fibre reinforcing strips. For large sections, the reinforcing strips are advantageously anchored to the facing using Foreva® WFC 100 carbon fibre braids.

Strengthening corner columns

Due to the horizontal shear forces that they have to balance and the low vertical load they bear, the corner columns are the most vulnerable. The ends of the columns can be strengthened using Foreva® TFC carbon fibre strips or additional pinning reinforcements.

1 - Local confinement of columns using Foreva® TFC composite reinforcements
2 & 3 - Strengthening external beam-column joints using Foreva® TFC composite reinforcements and Foreva® WFC 300 braids

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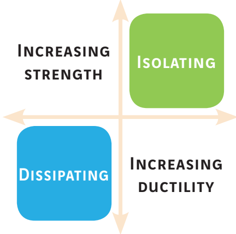
ISOLATING THE STRUCTURE FROM ITS FOUNDATIONS



Banded elastomeric bearings

The horizontal flexibility of banded elastomeric bearings and their high distortion capacity under vertical loads makes it possible to isolate the structure from movements in the foundations. Due to their elasticity, these bearings recentre the structure after an earthquake.

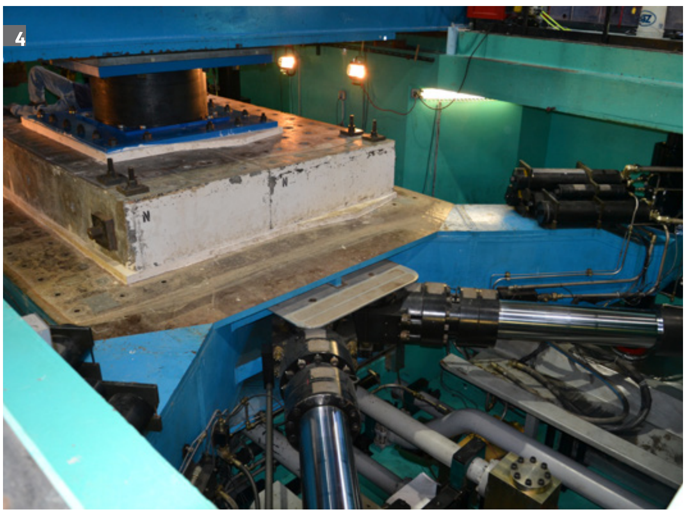
Additionally, dynamic isolators can also have a damper function to dissipate a portion of the seismic energy. In this case, they are either made from a material with a high degree of internal damping (HDRB type) or fitted with a lead insert (LRB type), which deforms under distortion. These types of bearing require no maintenance; they must be inspected after strong earthquakes.

In order to increase the energy dissipation at the connection between the structure and its foundations, dynamic isolation can also be combined with Transpec™ FVD viscous fluid dampers, making it possible to achieve internal damping cœfficients in excess of 50%.

Pendulum bearings

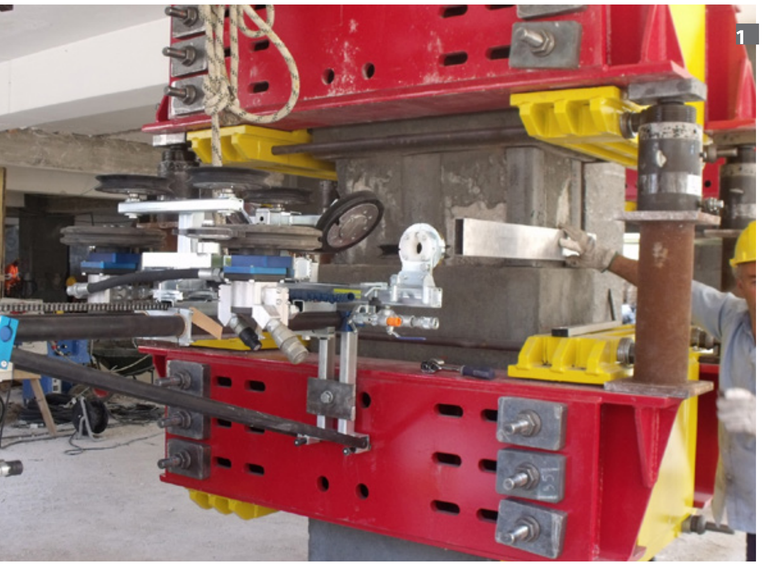
Pendulum bearings allow the structure to move relative to the foundations along a spherical surface, the radius of which determines the natural frequency of the isolated structure. After an earthquake, the bearings recentre the structure.

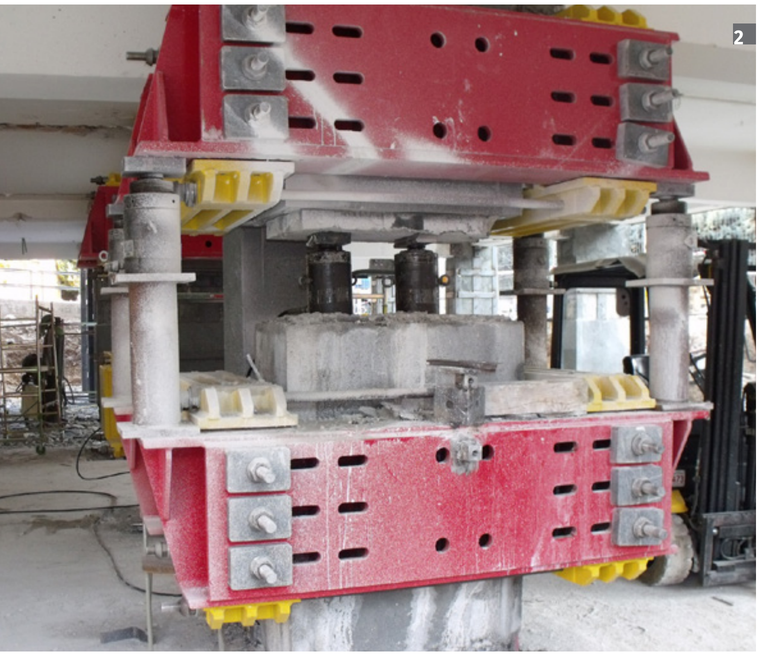
In addition, the friction between the bearing disc and the sliding surface dissipates some of the seismic energy.

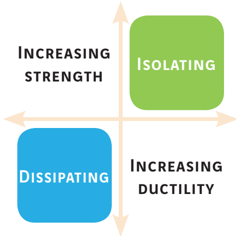


1 - Banded elastomeric isolator during installation
2 - Transpec™ FVD damper
3 - Pendulum damper
4 - Dynamic distortion test on a banded elastomeric bearing

ISOLATING THE STRUCTURE FROM ITS FOUNDATIONS







Inserting dynamic isolators

In order to house the dynamic isolators under the building's floor, if the structure cannot be raised permanently, special arrangements must be made to insert and load them:

- recreating recesses between the walls and floor;
- cutting the columns and inserting the isolators.

Freyssinet installs temporary structures to relieve the load from the areas to be treated without destabilising them, creates the recesses and performs cutting operations, locally reinforces structural elements, installs the seismic isolation devices and then loads them by means of precision jacking of the structure using specialist equipment.

Installation of horizontal bracing

The isolated building may sometimes require bracing in the plane of the columns, or even the installation of a sufficiently rigid, strong floor in order to evenly distribute the movements at the base.

1 - Securing the metal beams using prestressing bars and relieving the column of its load by jacking
2 - Sawing the column
3 - Reinforcing and concreting the plinths, inserting the bearings and packing. Restoring the load to the column by lowering the jacks
4 - View of the isolated building before recommissioning

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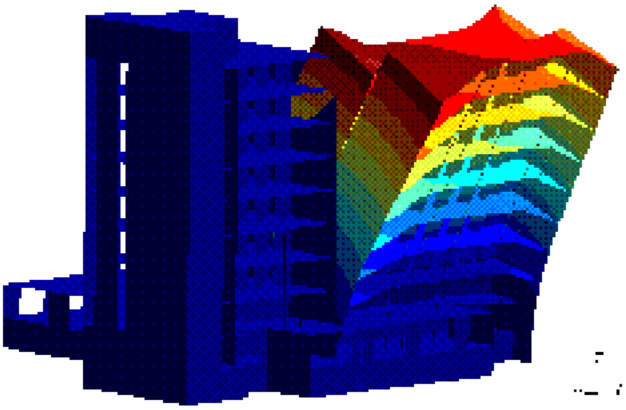
SPECIALIST CONSULTANCY



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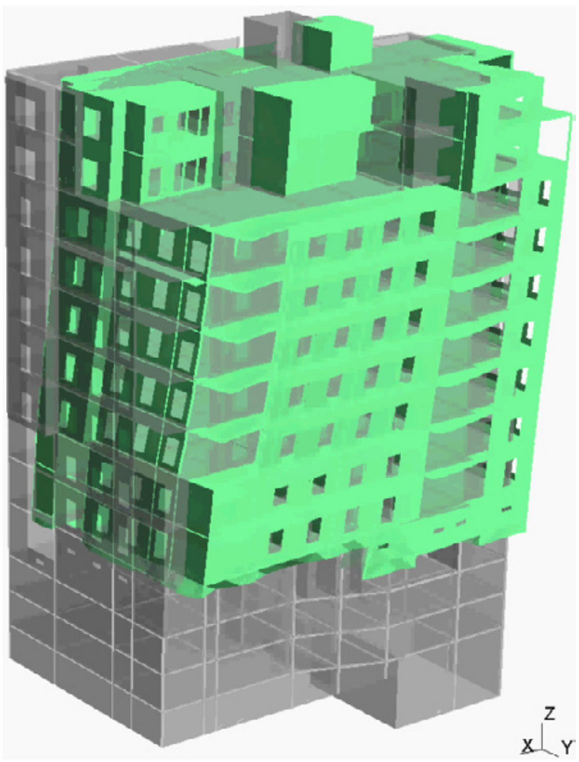

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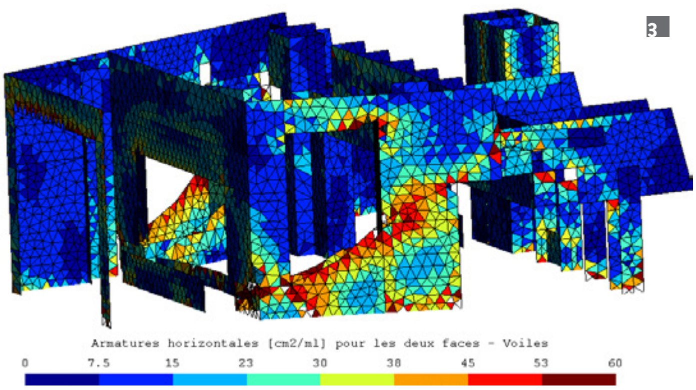

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Inspections and surveys

The best strengthening and/or repair solution can only be chosen following a detailed diagnostic process, which provides information about the strength of the existing building or its residual seismic capacity.

At the contracting authority's request, Freyssinet can perform the seismic diagnosis, which is broken down into four areas:

- The structure (geometry and actual weights, reinforcements, loads, materials, irregularities, fragility, etc.);
- The soil (type, dynamic impedance, liquefaction risk, etc.);
- The seismology on the site (characterisation of seismic action, site effect, site-specific spectrum, etc.);
- The environment (interaction with existing structures).

Numerical forward modelling

Due to their architectural design, buildings often require complex numerical modelling in order to understand their seismic behaviour.

Freyssinet gives contracting authorities access to its specialist numerical analysis consultancy, which has developed its own structural modelling software to produce timely, reliable studies of even the most irregularly-shaped structures, before and after strengthening.

With expertise in numerical modelling of inelastic nonlinearities and earthquake protection devices, the consultancy can produce a dynamic analysis of the strengthened building using simplified or complex methods.

1 - Study of the seismic behaviour of a group of buildings
2 - Modelling of the dynamic isolation of the upper and lower (underground) parts of a building
3 - Local analysis of the stresses induced by the effects of an earthquake

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Over 60 locations worldwide

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Publication: 02/2013 - R I 7 - Printed in France