THK: CLB CROSSED LINEAR BEARING SEISMIC ISOLATORS

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REZUMAT. Acest text prezintă noua tehnologie de izolare seismică denumită CLB (Crossed Linear Bearing). Sunt descrise specificaţiile şi caracteristicile de construcţie, sunt ilustrate exemple de izolare seismică şi aplicaţii funcţionale şi sunt redate date experimentale. Începând cu anul 1994, angajarea Japoniei în dezvoltarea unor sisteme antiseismice diversificate axate pe caracteristicile specifice ale structurilor ce trebuie protejate şi ale zonelor în care acestea se construiesc a condus la stabilirea unei sinergii importante între departamentele de proiectare ale principalelor companii japoneze şi centrul de cercetare-dezvoltare al firmei THK, menită să conducă la elaborarea unor noi tehnologii şi soluţii de izolare seismică efectivă pentru următoarele cazuri: clădiri uşoare; clădiri turn; izolare seismică cu perioadă de oscilaţie lungă; izolare seismică pentru obiecte individuale, cum sunt obiectele de artă, mici sau mari, vitrinele muzeelor, instalaţiile de calcul sau pelefonice, echipamentul medical.

Cuvinte cheie: izolare seismică, sarcini uşoare, încărcări tensoriale, perioade lungi, moştenire culturală.

ABSTRACT. This text highlights the new seismic isolation technology called CLB (Crossed Linear Bearing). It describes specifications and building characteristics, provides examples of seismic isolation and application functionalities and shows experimental data. Since 1994, the constant commitment by Japan to develop diversified anti-seismic systems based on the precise needs of the structures to protect and the areas where they were built has led to the creation of important synergy between the research institutions of leading Japanese companies and THK's centre for research and development.Their goal has been to develop new technology and solutions to allow seismic isolation to be effective in the following cases: lightweight buildings; towering buildings; seismic isolation with long oscillation periods; seismic isolation for single object, like art objects, whether small or large, museum displays, computer and telephone installations, medical equipment.

Keywords: seismic isolation, lightweight loads, tensile loads, long periods, cultural heritage.

1. SPECIFICATIONS AND BUILDING CHARACTERISTICS OF CLB SEISMIC ISOLATORS BY THK

1.1. Operating principle

Linear guide with recirculating ball technology apply the same principle as rotary bearings to obtain linear motion (Fig. 1). They include three main elements: the rails, blocks and rolling elements. Raceways are obtained from the rails and blocks on which the inserted balls roll, allowing the relative motion between the two elements. Assembling the guides at right angles causes multi-directional motion over the surface (Fig. 2.).

The function of the CLB seismic isolators is to separate the ground displacement over the horizontal surface from the main structural masses elevated from the foundation in order to drastically restrict acceleration and therefore the strength transmitted from the seism to the building (Fig. 3).

1.2. Vertical compressive and tensile load capacity

The rails and blocks have been obtained with special hardened and tempered steel strips that have undergone a surface hardening heat treatment through induction. The raceway hardness obtained is 61 HRC (± 1 HRC). The ball raceways are ground to ensure low friction and wear and tear of the balls. THK's CLB seismic isolators are available by catalogue with strokes up to +/-600 mm, a vertical compressive load capacity of 226 to 61190 kN and a vertical tensile load capacity of 24 to 8680 kN.

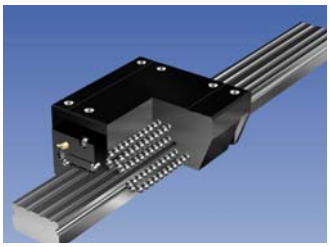


Fig. 1. Linear guide with recirculating steel ball technology.



Fig. 2. CLB seismic isolator.

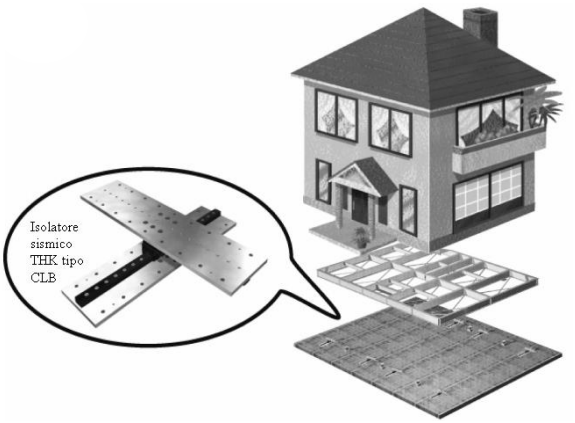


Fig. 3. Base-isolated building.

The balls roll on raceways with a circular arc and a radius of curvature (Rp) slightly greater than the radius (Rs) of the balls (Rp = 1.04 Rs) so they have a support surface that provides a load capacity 13 times greater than that provided if they were on a flat surface (Fig. 4). For example, the single THK block series CLB780 uses balls with a diameter of 30.16 mm (72 of which are in the loading zone) and has a radial compressive capacity equal to 7800 kN. The CLB isolator guides have 4 or 6 ball circuits (depending on the model). 2 or 4 of these are located on the upper part of the guide at a 90° angle of contact and sustain compressive radial loads while the other 2 are positioned to the side with a 45° angle of contact and allow sustaining radial tensile loads (Fig. 5). CLB isolators maintain a constant load capacity for the entire stroke.

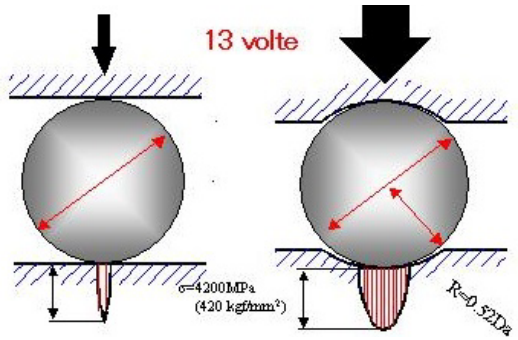


Fig. 4. Load capacity comparison between balls on a flat surface and on a raceway with a circular arc.

1.3. Horizontal rigidity

Thanks to the characteristics of the rolling elements and the mechanical processing used, CLB isolators have a friction coefficient μ of 5/1000 to 8/1000 of the applied load, which remains constant during the entire displacement of the project. The following is a practical example: a constant side force of 5 kg can move a 1 t mass resulting in displacement of 1000 mm (Fig. 6 and Fig. 7) shows the relationship between the friction coefficient, the frictional resistance force and the displacement of isolator CLB61 subjected to a load equal to 592 kN.

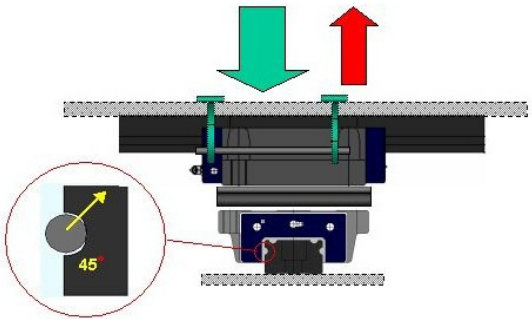


Fig. 5. CLB isolators have compressive and tensile load capacity.

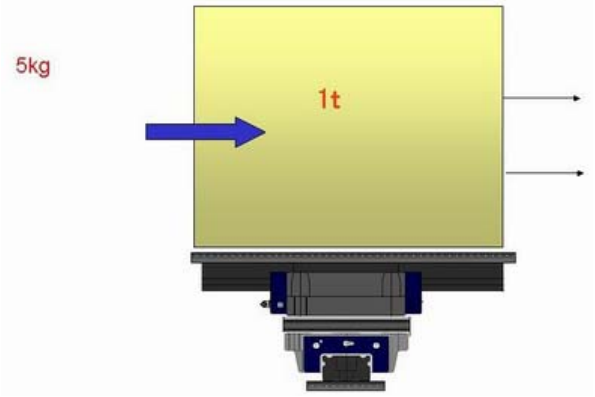


Fig. 6. Frictional resistance force of CLB isolators.

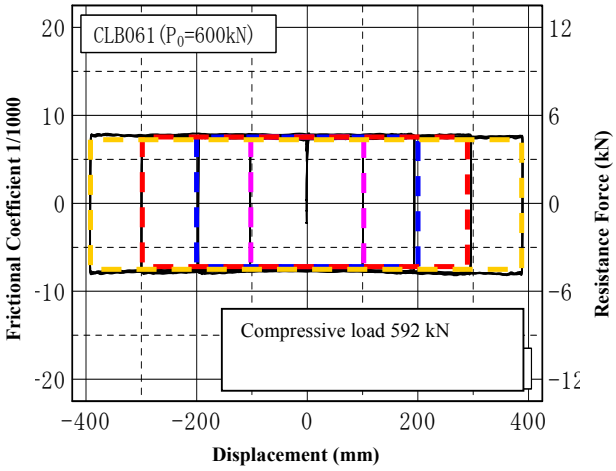


Fig. 7. The friction coefficient remains constant as horizontal displacement varies.

Practical experiments have demonstrated how when factors such as direction and speed of sliding, air temperature and atmospheric pressure change, the maximum variation of the friction coefficient is 0.002 of the nominal value. The calculation formulas for each isolator model are available upon request.

Thanks to the aforementioned characteristics, the horizontal rigidity Kc of a CLB isolator subjected to a load P for displacement δ is on average less than 0.01 kN/m. This value can be calculated with the following equation:

$$Kc = P\mu / \delta$$

1.4. Quality and functional consistency

THK factories manufacture devices whose quality standards comply with ISO 9001 requirements. When manufacturing mechanical components, this means that each part is built and assembled in compliance with processing and systematic control procedures, from the acceptance of the incoming material to its transformation (which occurs by following precise tolerances during each processing phase) and the assembly of the individual components. Each piece is marked and can be identified through an inspection certificate, which tracks all processing control phases and is stored in THK's factories for 10 years. The result is the production of devices that always ensure the same functional characteristics and performance.

1.5. Operating life

CLB isolators are designed to maintain their efficiency over a long period of time. Following is a list of measures implemented to prevent any event that could impact operating life.

Protection against corrosion: CLB devices are built with martensitic steel alloy and are treated on the surface. Treatment in a chromium-enriched atmosphere is performed on sizes up to CLB99 in an APC kiln. Larger sizes are coated with 3 epoxy resin based layers. Raceways and balls are protected by a synthetic layer of urea-based grease called AFA, which, in addition to being a lubricant, is also an antioxidant.

Protection against dirt from entering the recirculating ball area: the blocks are protected with special front seals that adhere to the rail profile. A moulded sheet is positioned on the rails to prevent dirt from settling on them.

Ageing of rubber shim between the blocks; this rubber is obtained with a special, durable mixture. Accelerated deterioration tests were performed by simulating ageing equivalent to 60 years of useful life on a CLB133 isolator subjected to a load of 1300 kN. Expected subsidence due to creeping was calculated at 0.235 mm.

1.6. Assembly

A rubber shim positioned between the 2 guides constituting the isolator is used to combine precision mechanical components with building components. Its purpose is to compensate planarity errors normally present on the surfaces of building components where the isolators are assembled. CLB isolators are provided with 2 steel plates fastened on the upper and lower guides, respectively. They have holes on the outer edge so they can be bolted to corresponding anchor plates, which must be suitably connected to the sub-structure while considering any tensile loads they will sustain (Fig. 8). The precision alignment values to comply with during assembly are available from THK.

1.7. Periodic inspections and maintenance

In order to maintain correct and long-lived functionality, inspection and periodic maintenance plan on the seismic isolation devices is needed. After having commissioned the isolation system, we recommend performing a first inspection and creating a register where dimensional and visual assessments can be noted. These data must be stored and used as reference parameters for subsequent checks.

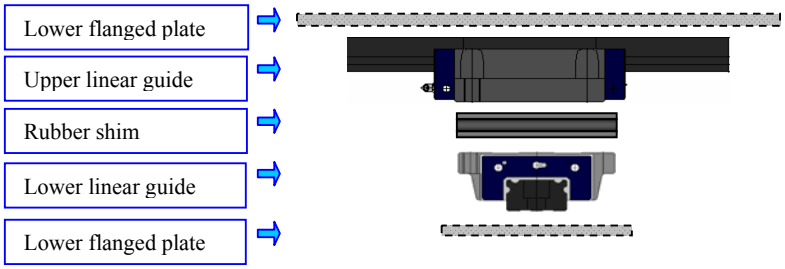


Fig. 8. CLB isolator composition.

Afterwards, we recommend performing inspections every 5 years or each time a disaster occurs, such as a seism, flooding, fire or a landslide that causes the building to tilt. The following checks should be performed and recorded:

Isolator dimensional assessments: height, block position, planarity;

Visual assessments: verify lack of obvious faults such as breaks, buckling and corrosion, check the state of lubrication of the raceways, clean the system and ensure there are no objects that may restrict or prevent the correct functioning of the devices. It is a good idea to take pictures.

Recirculating ball isolators require limited maintenance if they are used in the conditions provided for. Any interventions must be planned based on the results of the 5-year inspections and must be performed by qualified personnel. We recommend changing the grease every 10 years, in the blocks using lubricator nipple and on the raceways using a trowel.

2. EXAMPLES OF SEISMIC ISOLATION AND APPLICATION FUNCTIONALITIES

2.1. Long periods of oscillation - lightweight buildings and structures

CLB seismic isolators perform the function of supporting vertical loads but they do not dissipate energy nor recentre after displacement due to their low horizontal rigidity. To prevent residual displacement at the end of a seism and excessive building displacement that would make the connection to ground systems and separation joints with adjacent buildings difficult, it is always necessary to use auxiliary devices to dissipate seism energy and to bring the building back to its original position. The following is an analysis of the main application advantages of CLB isolators in consideration of the aforementioned characteristics.

The process of designing for seismic isolation requires analysing the response spectrum of the structure to isolate and defining acceleration based on possible earthquakes with the aim to calculate the period T during which the mass structure M oscillates. (Fig. 9).

Then the equivalent rigidity Keq is calculated with the following equation:

$$T = 2\pi\sqrt{M / Keq}$$

from which

$$Keq = (2\pi / T)^2 xM$$

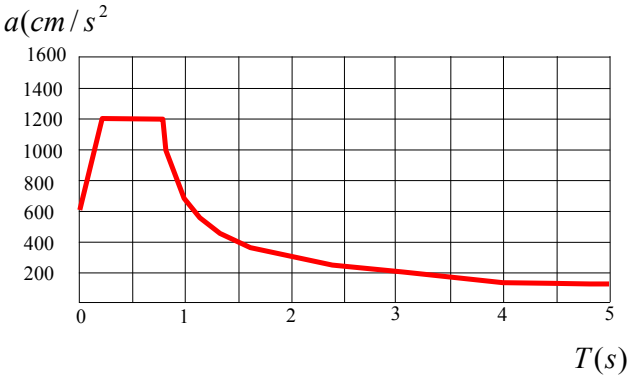


Fig. 9. Seismic response spectrum of the building.

Keq is the summation of the horizontal rigidities of all isolation devices applied.

$$Keq = \sum K$$

The horizontal rigidity Kc of a CLB isolator subjected to a load P for displacement δ is calculated with the following equation:

$$Kc = P\mu / \delta$$

Notice how, as the friction coefficient μ is near 0.01, very contained horizontal rigidity values are obtained.

The horizontal rigidity of an HDRB (High Damping Rubber Bearing) device is calculated with the following equation:

$$Kh = GA / t$$

where G is the shear modulus of rubber, A is the cross-section of the isolator and t is its total height. Remember that the choice of the cross-section A is based on the load and the horizontal displacement to which the rubber isolator is subjected in the event of a seism. This may determine high overall horizontal rigidity, especially in an area of high seismicity where significant displacement is expected, and thus reduce the effectiveness of the isolation system.

This infers how the use of the appropriate mix of CLB isolators with other rubber devices allows to achieve long periods, especially in the case of lightweight buildings or structures whose structural mass weighing on each isolator is particularly contained. For example, small one or two-storey family homes, roofs and industrial and chemical plants, just to name some of the projects realised. This way, the design engineer can choose the combination of devices that allows obtaining the optimum period T for the safety of the people and buildings and the objects they contain.

The same functional peculiarities are also widely used in buildings of medium height, such as hospitals, schools and residences, with the purpose of lengthening the oscillating period. On this subject, refer to the calculation example shown in Table 1 and Fig. 10, which compares

the seismic isolation of a building that only has rubber isolators and that obtained with a mix of rubber and CLB isolators.

Table 1. **Example of calculation**

Type of structure	Iron structure	
Height	19.05 m	
Building mass	1,795 t	
Isolation devices	8 natural rubber elastomeric devices, 4 rubber devices with a lead nucleus	8 CLB250 recirculating ball devices, 4 rubber devices with a lead nucleus
Equivalent horizontal rigidity Keq	11200 kN/m	4933 kN/m
Period T	2.515 s	3.789 s
Displacement	0.200 m	0.280 m

2.2. Vertical tensile loads - towering buildings and structures

CLB isolators are widely used in Japan due to their resistance to vertical tensile loads. This is typical of towering buildings subjected to overturning moments due to lateral inertia during seisms. In these cases, the recirculating ball isolators are primarily located in the perimeter and are appropriately chosen in multiple configuration including several rails and blocks to take advantage of suitable load capacity (Fig. 11). Tensile phenomena often occur in proximity of stairways or lift-shafts, just to name a few.

2.3. Seismic response tests on isolated buildings

THK has performed a large number of laboratory tests in Japan to analyze the seismic response of buildings isolated at the base with CLB isolators compared with equivalent structures that have a fixed base. By simulating disastrous earthquakes, a drastic reduction of the acceleration transmitted to the building was demonstrated, therefore proving the effectiveness of seismic isolation. The phenomenon is particularly obvious if measured at the upper floors, where the acceleration of the seism is amplified (Fig. 12 and Fig. 13).

2.4. Cultural heritage, museum displays, computer and telephone installations, medical equipment

The concept of isolation to obtain seismic protection is also applicable to objects and mobile structures contained inside buildings in the event they are deemed to be resistant to collapse.

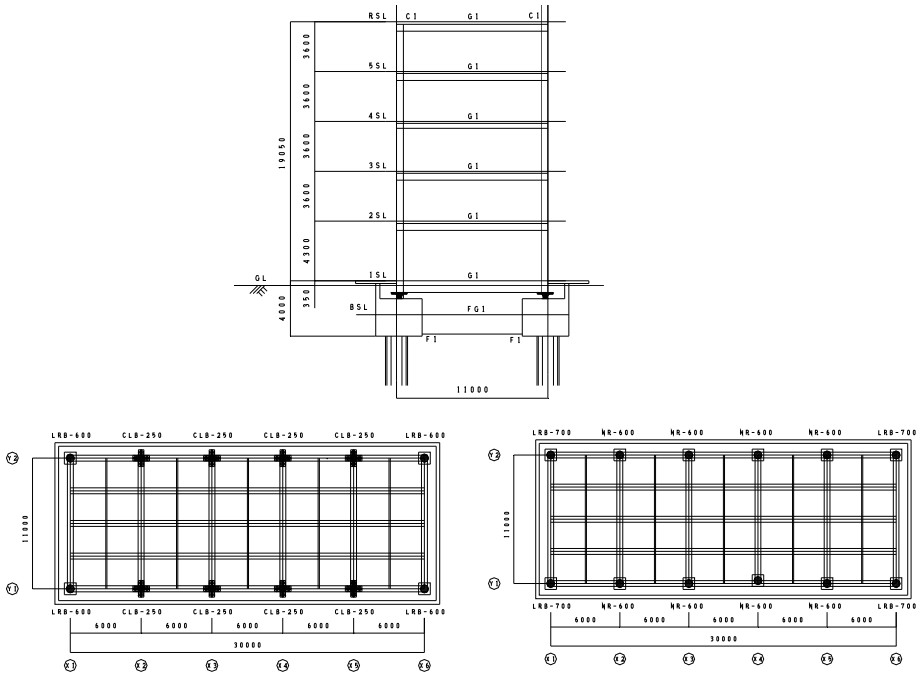


Fig. 10. Application of seismic isolators.



Fig. 11. CLB Seismic isolators for towering buildings.



Fig. 12. Laboratory test.

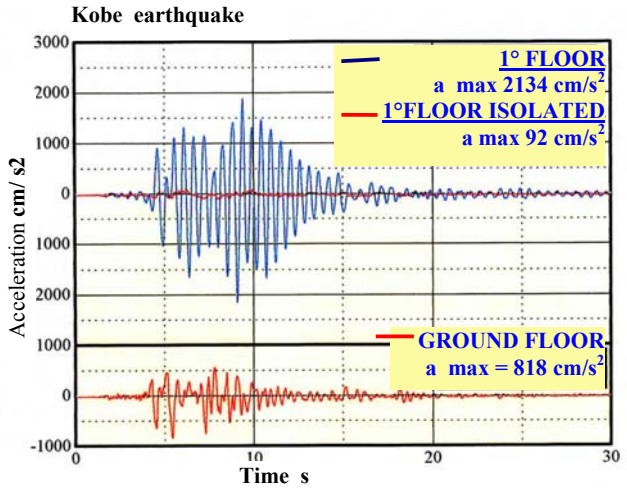


Fig. 13. Laboratory test result Measurement of the response acceleration at the first floor of an isolated building compared to the same building with a fixed base.

A topical subject is the protection of the artistic, cultural and historic heritage, which includes statues and works of art at times preserved in museum displays. Other examples include computer and telephone installations, as well as sophisticated medical equipment in hospitals. Just think of the strategic importance of being able to guarantee the continuity after a seism of the countless activities tied to these technologies. CLB seismic isolation, using linear guides with recirculating ball technology, effectively addresses these technical and functional challenges tied to isolating single property. There are technical similarities in the design approach to isolating electronic and medical equipment or art objects, as they require low lateral resistance to oscillate for long periods and to reduce the acceleration transmitted by the seism. For this reason, THK developed and presented (in April 2007) a range of tables for seismic isolation called TSD, which are ready to be commissioned and can be used for many purposes. TSD tables are composed of 2 overhanging surfaces connected to each other by 4 pairs of linear guides located at the corners of the table. They free the two levels during horizontal movements. Several springs ensure the table is recentred after displacement due to a seism (Fig. 14). Oscillation experiments have been performed by simulating the 1995 Kobe earthquake using a TSD-1000 table with a load equal to 800 kg and acceleration of 8.24 m/s^2. The response acceleration measured on the table was 1.05 m/s^2, that is approximately 1/8 of that exerted at the base of the table (Fig. 15).

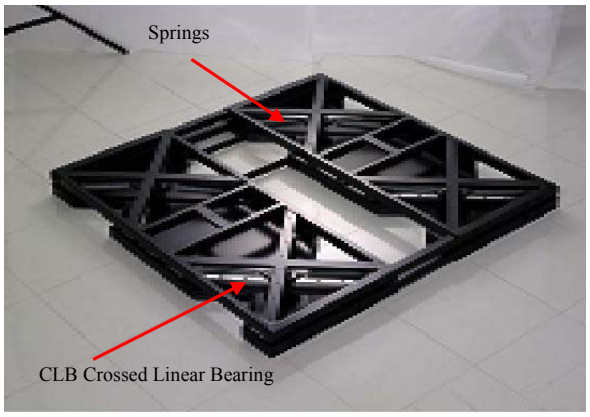
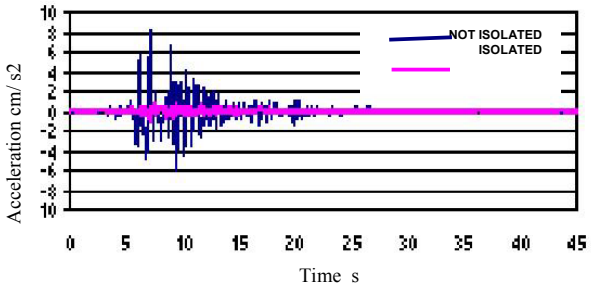


Fig. 14. Internal structure of THK'S TSD seismic isolation table.

Simulation of earthquake with an applied load equal to 800 kg



. 15. Simulation of earthquake: the response acceleration on the table is about 1/8.

3. CONCLUSIONS

Seismic isolation using CLB with linear guides recirculation steel ball technology is an innovative device that has quickly spread in Japan and has been integrated within the realm of rubber devices. This is further evidence that the current scientific and technological knowledge can be used to protect against an earthquake by isolating new buildings as well as existing ones, with particular regard to strategic facilities that precisely in the event of an earthquake must guarantee continuity of service, such as hospitals, schools, industrial and telecommunications installations, as well as private buildings built in areas with high seismic risk. A far-sighted assessment also finds seismic isolation convenient from an economic standpoint in addition to safety. An intense research and development is underway, including spreading an anti-seismic culture. It involves professors and researchers, universities, design engineers, associations of engineers, private companies and organizations including "GLIS Isolamento ed altre Strategie di Progettazione Antisismica" (which THK is a member of).

The general hope is to widen the expertise of the professionals in the industry, to increase political and economic commitment, along with public awareness so the citizens can make an informed decision as to how to protect themselves from earthquakes.

In this context, THK is highly committed to numerous initiatives sharing the same goals.

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