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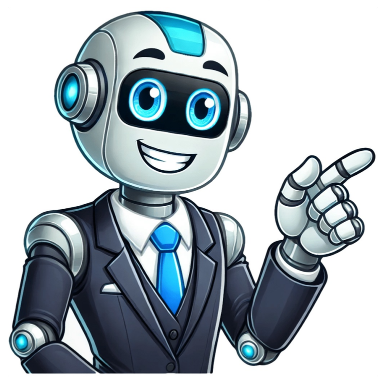

The Bronze Age saw the rise of several successful civilizations, including a few that managed to build impressive cities with ordered grids and sophisticated plumbing. Now, scientists think that tectonic activity may have contributed to the demise of some of these ancient cultures. For example, research conducted at the city of Megiddo (now part of present-day Israel) suggests that a massive earthquake may have devastated the city, leading to the sandwich-like layers found in excavations. And a series of earthquakes may have brought down the Harappan civilization (in what's now Pakistan), which disappeared suddenly in 1900 B.C.E. We're just as susceptible today to the aftereffects of powerful earthquakes. When exposed to the sudden lateral forces produced by seismic waves, even modern buildings and bridges can fail completely and collapse, crushing the people in, on and around them. If anything, the problem has become worse as more people live in urban environments and as structures have grown. Luckily, over the last few decades, architects and engineers have devised a number of clever technologies to ensure that houses, multidwelling units and skyscrapers bend but don't break. As a result, the building's inhabitants can walk out unharmed and start picking up the pieces. On the next few pages, we've assembled 10 of these temblor-thwarting technologies. Some have been around for several years. Others, like the first item in our countdown, are relatively new ideas that are still being tested. Engineers and seismologists have favored base isolation for years as a means to protect buildings during an earthquake. As its name suggests, this concept relies on separating the substructure of a building from its superstructure. One such system involves floating a building above its foundation on lead-rubber bearings, which contain a solid lead core wrapped in alternating layers of rubber and steel. Steel plates attach the bearings to the building and its foundation and then, when an earthquake hits, allow the foundation to move without moving the structure above it. Now some Japanese engineers have taken base isolation to a new level. Their system actually levitates a building on a cushion of air. Here's how it works: Sensors on the building detect the telltale seismic activity of an earthquake. The network of sensors communicates with an air compressor, which, within a half second of being alerted, forces air between the building and its foundation. The cushion of air lifts the structure up to 1.18 inches (3 centimeters) off the ground, isolating it from the forces that could tear it apart. When the earthquake subsides, the compressor turns off, and the building settles back down to its foundation. The only thing missing is the theme song from the "Greatest American Hero." Another tried-and-true technology to help buildings stand up to earthquakes takes its cue from the auto industry. You're familiar with the shock absorber -- the device that controls unwanted spring motion in your car. Shock absorbers slow down and reduce the magnitude of vibratory motions by turning the kinetic energy of your bouncing suspension into heat energy that can be dissipated through hydraulic fluid. In physics, this is known as damping, which is why some people refer to shock absorbers as dampers. Turns out dampers can be useful when designing earthquake-resistant buildings. Engineers generally place dampers at each level of a building, with one end attached to a column and the other end attached to a beam. Each damper consists of a piston head that moves inside a cylinder filled with silicone oil. When an earthquake strikes, the horizontal motion of the building causes the piston in each damper to push against the oil, transforming the quake's mechanical energy into heat. Damping can take many forms. Another solution, especially for skyscrapers, involves suspending an enormous mass near the top of the structure. Steel cables support the mass, while viscous fluid dampers lie between the mass and the building it's trying to protect. When seismic activity causes the building to sway, the pendulum moves in the opposite direction, dissipating the energy. Engineers refer to such systems as tuned mass dampers because each pendulum is tuned precisely to a structure's natural vibrational frequency. If ground motion causes a building to oscillate at its resonance frequency, the building will vibrate with a large amount of energy and will likely experience damage. The job of a tuned mass damper is to counteract resonance and to minimize the dynamic response of the structure. Taipei 101, which refers to the number of floors in the 1,667-foot-high (508-meter-high) skyscraper, uses a tuned mass damper to minimize the vibrational effects associated with earthquakes and strong winds. At the heart of the system is a 730-ton (660-metric-ton), gold-colored ball suspended by eight steel cables. It's the largest and heaviest tuned mass damper in the world. In the world of electricity, a fuse provides protection by failing if the current in a circuit exceeds a certain level. This breaks the flow of electricity and prevents overheating and fires. After the incident, you simply replace the fuse and restore the system to normal. Researchers from Stanford University and the University of Illinois have been experimenting with a similar concept in the quest to build an earthquake-resistant building. They call their idea a controlled rocking system because the steel frames that make up the structure are elastic and allowed to rock on top of the foundation. But that by itself wouldn't be an ideal solution. In addition to the steel frames, the researchers introduced vertical cables that anchor the top of each frame to the foundation and limit the rocking motion. Not only that, the cables have a self-centering ability, which means they can pull the entire structure upright when the shaking stops. The final components are the replaceable steel fuses placed between two frames or at the bases of columns. The metal teeth of the fuses absorb seismic energy as the building rocks. If they "blow" during an earthquake, they can be replaced relatively quickly and cost-effectively to restore the building to its original, ribbon-cutting form. In many modern high-rise buildings, engineers use core-wall construction to increase seismic performance at lower cost. In this design, a reinforced concrete core runs through the heart of the structure, surrounding the elevator banks. For extremely tall buildings, the core wall can be quite substantial -- at least 30 feet in each plan direction and 18 to 30 inches thick. While core-wall construction helps buildings stand up to earthquakes, it's not a perfect technology. Researchers have found that fixed-base buildings with core-walls can still experience significant inelastic deformations, large shear forces and damaging floor accelerations. One solution, as we've already discussed, involves base isolation -- floating the building on lead-rubber bearings. This design reduces floor accelerations and shear forces but doesn't prevent deformation at the base of the core-wall. A better solution for structures in earthquake zones calls for a rocking-core wall combined with base isolation. A rocking core-wall rocks at the ground level to prevent the concrete in the wall from being permanently deformed. To accomplish this, engineers reinforce the lower two levels of the building with steel and incorporate post-tensioning along the entire height. In post-tensioning systems, steel tendons are threaded through the core wall. The tendons act like rubber bands, which can be tightly stretched by hydraulic jacks to increase the tensile strength of the core-wall. You may think of water or sound when considering the topic of waves, but earthquakes also produce waves, classified by geologists as body and surface waves. The former travel rapidly through Earth's interior. The latter travel more slowly through the upper crust and include a subset of waves -- known as Rayleigh waves -- that move the ground vertically. This up-and-down motion causes most of the shaking and damage associated with an earthquake. Now imagine if you could interrupt the transmission of some seismic waves. Might it be possible to deflect the energy or reroute it around urban areas? Some scientists think so, and they've dubbed their solution the "seismic invisibility cloak" for its ability to render a building invisible to surface waves. Engineers believe they can fashion the "cloak" out of 100 concentric plastic rings buried beneath the foundation of a building [source: Barras]. As seismic waves approach, they enter the rings at one end and become contained within the system. Harnessed within the "cloak," the waves can't impart their energy to the structure above. They simply pass around the building's foundation and emerge on the other side, where they exit the rings and resume their long-distance journey. A French team tested the concept in 2013. As we discussed earlier in the countdown, the plasticity of materials presents a major challenge to engineers trying to build earthquake-resistant structures. Plasticity describes the deformation that occurs in any material when forces are applied to it. If the forces are strong enough, the material's shape can be altered permanently, which compromises its ability to function properly. Steel can experience plastic deformation, but so can concrete. And yet both of these materials are widely used in almost all commercial construction projects. Enter the shape memory alloy, which can endure heavy strains and still return to its original shape. Many engineers are experimenting with these so-called smart materials as replacements for traditional steel-and-concrete construction. One promising alloy is nickel titanium, or nitinol, which offers 10 to 30 percent more elasticity than steel [source: Raffiee]. In one 2012 study, researchers at the University of Nevada, Reno, compared the seismic performance of bridge columns made of steel and concrete with columns made of nitinol and concrete. The shape memory alloy outperformed the traditional materials on all levels and experienced far less damage [source: Raffiee]. It makes sense to consider earthquake resistance when you're building a new structure, but retrofitting old buildings to improve their seismic performance is just as important. Engineers have found that adding base-isolation systems to structures is both feasible and economically attractive. Another promising solution, much easier to implement, requires a technology known as fiber-reinforced plastic wrap, or FRP. Manufacturers produce these wraps by mixing carbon fibers with binding polymers, such as epoxy, polyester, vinyl ester or nylon, to create a lightweight, but incredibly strong, composite material. In retrofitting applications, engineers simply wrap the material around concrete support columns of bridges or buildings and then pump pressurized epoxy into the gap between the column and the material. Based on the design requirements, engineers may repeat this process six or eight times, creating a mummy-wrapped beam with significantly higher strength and ductility. Amazingly, even earthquake-damaged columns can be repaired with carbon-fiber wraps. In one study, researchers found that weakened highway bridge columns cocooned with the composite material were 24 to 38 percent stronger than unwrapped columns [source: Saadatmanesh]. While engineers make do with shape memory alloys and carbon-fiber wraps, they anticipate a future in which even better materials may be available for earthquake-resistant construction. And inspiration for these materials may likely come from the animal kingdom. Consider the lowly mussel, a bivalve mollusk found attached to ocean rocks or, after it's been removed and steamed in wine, on our dinner plate. To stay attached to their precarious perches, mussels secrete sticky fibers known as byssal threads. Some of these threads are stiff and rigid, while others are flexible and elastic. When a wave crashes on a mussel, it stays put because the flexible strands absorb the shock and dissipate the energy. Researchers have even calculated the exact ratio of stiff-to-flexible fibers -- 80:20 -- that gives the mussel its stickiness [source: Qin]. Now it's a matter of developing construction materials that mimic the mussel and its uncanny ability to stay put. Another interesting thread comes from the south end of spiders. We all know that, pound for pound, spider silk is stronger than steel (just ask Peter Parker), but MIT scientists believe that it's the dynamic response of the natural material under heavy strain that makes it so unique. When researchers tugged and pulled on individual strands of spider silk, they found the threads were initially stiff, then stretchy, then stiff again. It's this complex, nonlinear response that makes spider webs so resilient and spider thread such a tantalizing material to mimic in the next generation of earthquake-resistant construction. And what about developing countries, where it's not economically feasible to incorporate anti-earthquake technologies into houses and office buildings? Are they doomed to suffer thousands of casualties every time the earth shakes? Not necessarily. Teams of engineers are working all over the world to design earthquake-resistant structures using locally available or easily obtainable materials. For example, in Peru, researchers have made traditional adobe structures much stronger by reinforcing walls with plastic mesh. In India, engineers have successfully used bamboo to strengthen concrete. And in Indonesia, some homes now stand on easy-to-make bearings fashioned from old tires filled with sand or stone. Even cardboard can become a sturdy, durable construction material. Japanese architect Shigeru Ban has designed several structures that incorporate cardboard tubes coated with polyurethane as the primary framing elements. In 2013, Ban unveiled one of his designs -- the Transitional Cathedral -- in Christchurch, New Zealand. The church uses 98 giant cardboard tubes reinforced with wooden beams [source: Slezak]. Because the cardboard-and-wood structure is extremely light and flexible, it performs much better than concrete during seismic events. And if it does collapse, it's far less likely to crush people gathered inside. All in all, it makes you want to treat the cardboard tubes nestled in your toilet paper roll with a little more respect. When the 2011 Virginia earthquake struck, I was about 55 miles (89 kilometers) from the epicenter. It produced a locomotive-like rumbling and moved the earth in an unsettling way that's hard to describe. In the small towns of Louisa and Mineral, near my mother's house, a couple of structures collapsed, and many more experienced significant damage. While the quake itself was frightening, what was more disturbing was our collective sense that, being so far from the Ring of Fire and the constant threat of tectonic activity, we were somehow insulated from these kinds of events. Makes me wonder if the building codes in Virginia have been updated to incorporate some of these earthquake-resistant technologies. Related Articles "Advanced Earthquake Resistant Design Techniques." Multidisciplinary Center for Earthquake Engineering Research (MCEER). 2010. (Aug. 26, 2013) Colin. "Invisibility cloak could hide buildings from quakes." New Scientist. June 26, 2009. (Aug. 26, 2013) Etienne. "Ancient civilizations shaken by quakes, say Stanford scientists." SpaceDaily. Dec. 17, 2001. (Aug. 26, 2013) Rebecca. "Japanese Home-Levitation System Could Protect Buildings From Earthquakes." Popular Science. March 1, 2012. (Aug. 26, 2013) Rebecca. "Stretchy, Sticky Mussel Fibers Inspire New Types of Tough Waterproof Adhesives." Popular Science. 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"Seismic Invisibility Cloak Could Hide Buildings From Earthquakes." Popular Science. June 26, 2009. (Aug. 26, 2013) Nidhi. "Super-strong mussel fibers could inspire earthquake-proof buildings." NBC News. July 23, 2013. (Aug. 26, 2013) Kalee. "Robust, or Risky? What Makes an Earthquake-Resistant Building." Popular Mechanics. (Aug. 26, 2013) Brian. "Japan a leader in engineering earthquake-proof structures, helping to limit damage." Washington Post. March 12, 2011. (Aug. 26, 2013) Logan. "The Earthquake-Resilient Building." Popular Mechanics. Sept. 30, 2010. (Aug. 26, 2013) Zach. "Concrete Gets Flexible." Discover Magazine. Aug. 6, 2005. (Aug. 26, 2013) The ground shakes forcefully, objects crash to the ground, and everything sways as the earth suddenly becomes restless. Yet, somehow amid the abrupt chaos, buildings continue to stand, unaffected by an earthquake's impact. But how? That's the question we sought to answer when we reached out to Bill Gray, expert builder and jack of all trades at LMC Building & Construction Ltd in Kaikoura, New Zealand. And seeing as the entire island of New Zealand is an earthquake zone, Bill had all the information we were looking for on building earthquake-proof buildings and earthquake-proof houses. In this interview, Bill shares his personal experience with a magnitude 7.8 earthquake as well as insights on the techniques, materials, building designs, and skilled processes that go into the construction of earthquake-resistant buildings and houses. Check it out. Bill: New Zealand has around 14,000 to 15,000 a year, and most of these seismic activities are unable to be felt. Only about 150 to 200 quakes are large enough to be felt. On Nov 14, 2016, just after midnight, Kaikoura was struck by a magnitude 7.8 earthquake. It lasted for over two minutes and the damage was major. The roads in and out of Kaikoura were impassable and closed to the general public for five weeks. The main north-south train line was out of action for weeks. Damage to property was severe, and it has taken until this year to complete the repair process. From personal experience, when the earthquake struck, it was impossible to stand without holding on. Two minutes seems like a lifetime when your house is violently shaking and everything above floor level is being thrown onto the ground. I could watch the concrete floor in our house twisting and turning like waves on a lake. It was impossible to get out of the house, so I just held on. Bill: Earthquakes, by nature, are either a sideways shaking or an up-and-down shaking (or a combination of both). They're unpredictable, and at their worst, can cause widespread damage and destruction. Houses built now aren't necessarily designed to withstand earthquakes without damage but are designed to save lives. Better structural engineering is also helping houses withstand major damage, but first and foremost, they're designed to remain standing although the damage may be severe, so they don't injure. Building earthquake-proof structures to withstand the effects of seismic forces has led to a change in the way we construct reinforced concrete floors with rib raft concrete floors becoming the norm. This involves excavating down to a solid platform (removing the soil) and then adding a compacted hardfill up to the level required. We then pour a 300 mm (11.8 inches) concrete slab on top of this compacted hardfill. Before pouring, pods of polystyrene 1.2 meters by 1.2 meters (3 feet by 3 feet) are placed with 100 mm (3.9 inches) gaps to provide a concrete rib when poured both ways under the topping slab. The ribs, slab and outside concrete are all bolstered with reinforcing rods. This creates a concrete "raft" that can move around on top of the hardfill if an earthquake occurs. The advantage of this kind of concrete foundation is that it can be leveled after an earthquake without cracking up or breaking. It also takes pressure off the rest of the house, as the movement allows for less energy to pass up into the building itself. The next area of major change has been the way we brace the walls of the house. The bracing must meet a certain criterion, be distributed through the house to act as a shock absorber, and stop the building from twisting under earthquake forces. There are several ways this can be achieved, but the most common is using a gypsum board and a designated screw pattern. Each end of the bracing unit is tied to the floor with designed hold down brackets that meet the bracing requirements. Ceiling diaphragms are also used as bracing units, and this is applied much the same as wall bracing, using gypsum board and a designated screw pattern. The exterior walls are usually lined with plywood and may be used as bracing. In all cases, it's the screw/nail patten that will determine whether a particular area of ply will be a bracing unit or just acting as a rigid air barrier. Bill: There are several factors that happen in an earthquake that all affect buildings. On sloping ground and hillsides, there is a risk of slips and rockfalls. On flat ground, a high water table can cause liquefaction where water is forced to the surface, provoking surface flooding. Slumping may occur, causing land to spread and crack open or forcing land together creating lifting. Some areas can be affected by tsunamis. All these potential natural disasters have to be taken into consideration when it comes to house design. Bill: As mentioned earlier, the main focus when building houses in earthquake zones is saving lives, and it's secondary to building an earthquake-resistant building. Cost is also a factor because an earthquake resistant house costs more. Housing in New Zealand is particularly expensive already just to meet the cost of surviving an earthquake and our particular climate conditions. Lightweight roof structures such as light steel or iron roofs make for less stress when a house is shaken by an earthquake. Brick cladding is used quite extensively, as it's an economical building product and inflexible during an earthquake. With the use of a rigid air barrier such as ply, the house itself can still withstand a fair shake even if the bricks crack apart. Wood, fiber cement products, iron, and various other products are used as exterior wall claddings. Internally, gypsum board is the lining of choice, as it lends itself to not only giving a smooth wall finish but is strong enough to withstand a good shake and is easily repaired if required. Bill: Building houses here is more along the lines of creating a safe environment rather than structural benefits. Most customers are not aware that the house they live in is designed to also save them if a major earthquake happens. Our design process at the start of the build is almost always about aesthetics and livable space. Once the client is happy with that, we then have to fit the various requirements of the building code into that design. There is no shortcut here. You will not be able to build until all the criteria are met. Building costs here run around $2,500 to $3,000 New Zealand dollars per square meter on top of land costs. Building is an expensive operation, even for a typical home, with the unseen costs being earthquake and climate protection. Bill: The pandemic has created its own headaches for the building industry, but you have to remember that all of New Zealand is basically an earthquake zone. We have been relatively unscathed throughout the pandemic due to several factors. We are an island nation, so a closed border is easier to maintain. Those same factors also cause headaches when it comes to procuring materials for building. We import so many products as we don't have the facilities here, but with a closed border, materials have been harder to procure. There are now long waiting lists for basic building materials from timber and roofing to TVs and appliances. Bill: Buildertrend, for us, has become that hammer in your nail pouch that you use all the time without putting much thought into it. We are a fairly small operation with 10 of us on the team and, of course, all the trades and others required to build a house. Buildertrend allows us to keep everyone informed of where everything is at. Our schedules are changing all the time due to material shortages, weather issues, sub-trade availability, and various other factors, and yet, we manage to keep the show running and clients informed through Buildertrend. Coupled to that is having all the info on hand wherever we are. Issues are resolved quickly as we can get info from the site to the person concerned. With the structural installation requirements being so detailed, we are able to have all the installation instructions online and provided for the job so there are few hold-ups, and we can work from anywhere there is a connection. Building for the extreme is made easier with the use of tech. If you're looking for a better system that will improve the way you tackle your toughest construction jobs, schedule a demo today. Earthquakes are powerful natural disasters, and one cannot build a completely earthquake-proof building. However, earthquake-resistant buildings are completely possible. Earthquake-resistant buildings are built with the goal of maximizing life safety, minimizing damage, and maintaining functionality. Though there are multiple hacks available to make your building earthquake-resistant, this article highlights five fundamental steps that are highly recommended to build buildings earthquake-resistant. The following factors will make your building super earthquake-resistant: Solid foundation Structural reinforcement Non-structural component reinforcement Flexible utility lines Seismic dampers A solid foundation ensures that the forces of an earthquake are distributed evenly throughout the building and no cracks or structural failure occur, resulting in the collapse of the building. How to Lay a Strong Foundation: Choose an ideal site for your buildings. Locations with good bedrock provide firm soil conditions. Employ grouting or other soil compaction techniques to harden loose or sandy soil in your building site. Build a deep foundation using piling techniques like driving steel or concrete piles into the ground. This will help the foundation to carry the building's weight more stably. The structure of the building must be built in a way to absorb and dissipate the forces of the earthquake. This will prevent the building from crumbling. How to Reinforce the Building's Structure: Use Reinforced Concrete: Concrete is weak with tension. Reinforcing the concrete using steel rebar embedding, known as Reinforced Cement Concrete (RCC), allows the building to bend slightly but prevents the building from cracking during an earthquake. Use Structural Steel: Structural steel can provide a higher protection than concrete as it is very strong and ductile and would make a good earth-quake resistant component. Placement of Shear Walls: Shear walls are made of thick reinforced concrete and placed strategically to resist the lateral forces of an earthquake. Using Braced Frames: Braced frames are structures with diagonal braces and are made of steel or concrete. They act as trusses and hold the building, offering stability and preventing excessive lateral movement. Using Diaphragms: Diaphragms are rigid horizontal elements like floors and roofs that prevent the earthquake forces from concentrating only on vertical structures like walls and roofs. They help distribute the earthquake forces to be distributed evenly throughout the building structure. Just as focusing on the building's structure is important, it is equally important to focus on non-structural components of the building, like shelves, cabinets, furniture, light fixtures, and others. During an earthquake, unsecured furniture, things on the shelves, appliances, and others might fall and cause injury, cause accidents, and even block doorways. How to Reinforce Non-Structural Components of the Building: You can prevent the non-structural components from falling or crashing during an earthquake by: Anchoring furniture, shelves, and cabinets to walls with essential anchoring components. Strapping water heaters, microwave ovens, and other electrical appliances to the walls using appropriate strapping elements. Utility lines for drinking water, drainage, and electricity also get exposed to the forces of an earthquake and may get damaged. Using flexible pipelines can help prevent the lines from rupturing and minimize the risk of fires or leakages. How to Employ Flexible Utility Lines: You can use braided metal hoses or reinforced plastic for water lines For wiring you can use flexible electrical conduits. Seismic dampers are exclusively designed to protect buildings and their occupants from earthquakes. They absorb the shock due to the earthquakes and dissipate them. How to Employ Seismic Dampers: There are two kinds of seismic dampers available: Hydraulic Dampers: They are pressurized oil that moves through the structure, absorbs the earthquake's energy, generates heat, and prevents the seismic movement from directly affecting the building. Viscous Dampers: They are special fluids that absorb that absorb the energy of the earthquake tremors and reduce the shaking of the building. As the saying goes, "Prevention is better than cure." Building your building earthquake-resistant is indeed a wiser initiative. In addition to implementing the steps mentioned above, regular maintenance of the building can help you identify and take any preventive measures before an earthquake. Also, consult a qualified structural engineer to assess the condition of your building and take the necessary measures to make your building earthquake-safe. In this article, we will discuss 16 ways to make a building earthquake proof. A building with capabilities to resist the effects of earthquakes is called an earthquake-proof building.Making building earthquake-proof results decrease in loss of lives, properties, etc. A. Increasing Earthquake Resistivity of Small Buildings By taking some precautions and measures in site selections, building planning, and construction, small buildings can be made earthquake resistant. 1. Site selectionThe building constructions should be avoided on:a) Near unstable embankmentsb) On the sloping ground with columns of different heights2. Building PlanningSymmetric plans are safe compared to unsymmetrical plans. Hence we should go for square or rectangular plans rather than L, E, H, and T shapes. Rectangular plans should not have a length more than twice of width.3. FoundationThe width of the foundation must not be less than 750 mm for single-story buildings and not less than 900 mm for multi-story buildings.(Note: Storey in British English and story in American English)The depth of the foundation should not be less than 1.0 m for soft and 0.45 m for rocky ground.Before laying the foundation, remove all loose materials, including water from the trench and compact the bottom. After the laying of the foundation, back-filling and compacting of the foundation should be done.4. MasonryIn the case of stone masonry:1. Place each stone flat on its broadest face.2. Place the length of stone into the thickness of the wall to ensure interlocking inside and outside faces of the wall.3. Voids should be filled with the small chips of the stones with minimum possible mortar.4. The stone should be broken to make it angular so that it has no rounded face.5. At every (600 -700) mm distance use through stones.In the case of brick masonry:1. Use properly burnt bricks only.2. Bricks should be placed with their groove mark facing up to ensure a better bond with the next course.In the case of concrete masonry:1. Place rough face towards top and bottom to get a good bond.2. Blocks should be strong.3. Brush the top and bottom faces before laying.The length of the wall must be restricted to 6 m. Cross walls make the masonry stronger. It is better to build partition walls along the main walls interlinking the two.5. Doors and windows openings1. Walls with too many doors and windows near to each other may collapse early. Windows should be kept at the same level.2. The total width of all openings in the wall should not exceed one-third of the length of the wall.3. Doors should not be placed at the end of the wall. They should be at least 500 mm from the cross wall.4. Clear width between two openings should not be less than 600 mm.6. Roof1. In slopy roofs with a span greater than 6 m use trusses instead of rafters.2. Building with a 4-sided sloping roof is stronger than that with two-sided sloping since gable walls collapse early.7. ChhajjasRestrict chhajjas or balcony projections to 0.9 m. For larger projections use beams and columns.8. ParapetMasonry parapet walls can collapse easily so it is better to build parapets with bricks up to 300 mm followed by iron railings.9. Concrete and mortarUse river sand for making mortar and concrete. It should be sieved to remove pebbles. Silt must be removed by holding it against the wind.Coarse aggregate of size more than 30 mm should not be used. Aggregates should be well-graded and angular. Before adding water cement and aggregate should be dry mixed thoroughly.10. BandsThe following R.C. bands should be provided:-a) Plinth bandb) Lintel bandc) Roof bandd) Gable bandFor making R.C. bands, the minimum thickness is 75 mm and at least two bars of 8 mm diameters are required. If the wall size is large, vertical and diagonal bands also may be provided.11. RetrofittingRetrofitting simply means, scientifically preparing a structure or building so that all elements of a building act as an integral unit. It is generally the fastest and most economical way to achieve the safety of the building. The following are some of the methods for retrofitting:-1. Anchor roof truss to walls with brackets.2. Provide bracing at the level of purlins and bottom chord members of trusses.3. Gable wall is strengthened by inserting a sloping belt on the gable wall.4. Strengthen corners with seismic belts.5. Anchor floor joints to walls with brackets.6. Improve story connections by providing vertical reinforcement.7. Introduce tensile strength against vertical bending of walls by providing vertical reinforcement at all inside and outside corners.8. Encase wall openings with reinforcement.12. Selection of Materials As far as possible highly ductile materials should be given priority as compared to others. B. Increasing Earthquake Resistivity of Big Buildings Tall buildings are subjected to heavy horizontal forces due to inertia during the time of the earthquake. Hence they need shear walls. Shear walls should be provided evenly throughout the buildings in both directions as well as from bottom to top. Apart from providing shear walls, the given following techniques are also used for making tall buildings earthquake-resistant:This is an idea behind isolation to detach (isolate) the building from the ground in such a way that earthquake motions are not transmitted up through the building, or at least greatly reduced.The concept of base isolation is explained through an example of a building resting on a roller. When the ground is shaking, the roller freely rolls but the building above does not move. If the gap between the building and the vertical wall of the foundation pit is small, the vertical wall of the pit may hit the wall. Hence 100% frictionless rollers are not provided in practice. The building is rested on flexible pads which offer resistance. This helps in reducing some effects of ground shaking on the building. The flexible pads are called base-isolator, whereas the structures projected utilizing these devices are called base-isolated buildings.2. Using seismic dampersAnother method for controlling seismic damage in buildings is by installing seismic dampers in place of structural elements, such as diagonal braces.When the seismic energy is transmitted through them, dampers absorb part of it and thus dampen the motion of the building. There are 3 types of seismic isolation bearings:-a. High-density rubber bearingb. Laminated rubber bearingsc. Friction pendulum bearings C. New Techniques: Earthquake Proof Buildings Following techniques are some techniques for making earthquake-resistant buildings are discussed below:-1. HaunchesAs we know joints are most vulnerable during an earthquake and most the structures fail due to the failure of joints. Thus by increasing the strength of joints, some resistance can be achieved. Strength of joints can be gained or achieved by simply using high strength or fiber reinforced concrete, or just by the increasing section near joints or providing haunches. This might work as a knot as in bamboo. And thus provide stiffness to the joints.2. Hollow foundationAs we all know secondary and love types of waves are the most destructible among other earthquake waves. And the secondary waves can not pass through water media. Thus the provision of a hollow type raft foundation filled with water can be used for reducing some destructible effects of the earthquake. It may be filled with some viscous fluid, worked as a damper to reduce earthquake effects.Two belts are to be provided within a bituminous layer in between. In experimental setups, it was found that the damage to the building decreased very much. Key Principles of Earthquake-Resistant DesignEngineers use several principles to create structures capable of enduring seismic forces:1. Flexibility Over RigidityBuildings that are too rigid are prone to cracking and breaking under stress. Flexible designs, in contrast, allow structures to move with the ground rather than against it, reducing the likelihood of catastrophic failure.2. Energy DissipationDamping systems and materials with high energy-absorbing capacities reduce the amount of force transferred to the building. By dissipating seismic energy, these systems minimize damage and extend the building's lifespan.3. Lightweight ConstructionHeavier buildings experience greater seismic forces due to their mass. Using lightweight yet strong materials, such as engineered timber, lightweight concrete, or composites, reduces the overall force exerted during an earthquake.4. ReinforcementStructural elements like: • Cross-bracing: Diagonal supports that create a triangular framework to resist lateral forces. • Shear walls: Vertical walls that stiffen a structure and counter horizontal forces. • Diaphragms: Rigid floor systems that transfer lateral loads to vertical supports.These elements work together to enhance a building's lateral stability.Technologies Used in Earthquake-Resistant BuildingsThe effectiveness of earthquake-resistant designs relies on advanced engineering technologies:1. Base IsolationThis technique separates the structure from the ground using flexible bearings, such as lead-rubber or sliding bearings, which absorb seismic vibrations. Base isolation enables the building to "float" above the moving ground. • Example: New Zealand's Parliament Building uses lead-rubber bearings to mitigate seismic forces.2. Tuned Mass Dampers (TMDs)Large pendulum-like devices installed in tall buildings counteract swaying during earthquakes. TMDs are designed to move in opposition to seismic forces, stabilizing the structure. • Example: Taipei 101 in Taiwan features a 660-tonne tuned mass damper, a prominent engineering marvel visible to visitors.3. Cross-Bracing and Shear WallsThese structural reinforcements distribute seismic forces more evenly across the building, preventing concentrated stress points that can lead to failure. • Example: San Francisco's Transamerica Pyramid incorporates cross-bracing for enhanced seismic stability.4. Energy-Absorbing FoundationsShock-absorbing materials or systems embedded in a building's foundation dissipate seismic energy before it impacts the structure above. • Emerging Technologies: Materials like shape-memory alloys and special polymers are being researched to improve energy absorption.Notable Earthquake-Resistant BuildingsThe ingenuity of engineers and architects is showcased in several iconic structures designed to withstand earthquakes:1. Taipei 101, Taiwan • Features: A massive tuned mass damper and a deep foundation anchored into bedrock. • Seismic Benefits: Able to withstand both earthquakes and typhoons.2. Tokyo Skytree, Japan • Design Inspiration: Traditional Japanese pagodas, known for their seismic resilience. • Unique Feature: A central column acting as a damping mechanism.3. The Burj Khalifa, UAE • Seismic Features: A Y-shaped foundation and a reinforced core primarily designed for wind but offering seismic resistance as well.Steps in Designing Earthquake-Proof BuildingsThe process of creating earthquake-resistant structures is multifaceted, involving collaboration across various disciplines: 1. Feasibility Studies • Assess seismic risks, including fault line proximity and soil conditions. • Evaluate local building codes and regulations. 2. Collaborative Design • Engineers, architects, and seismic experts work together to balance functionality, aesthetics, and safety. 3. Simulation and Testing • Advanced modeling software simulates seismic events to optimize designs. • Physical shake-table tests expose prototypes to controlled seismic forces. 4. Construction • Precision in execution ensures that all safety measures function as intended.Costs and BenefitsCost Considerations: • Retrofitting older buildings: $30–$100 per square foot. • New earthquake-resistant buildings: Typically 10–20% more expensive than traditional designs.Long-Term Benefits: 1. Saving Lives: The primary objective is to reduce casualties. 2. Economic Resilience: Protecting infrastructure minimizes repair costs and downtime. 3. Sustainability: Earthquake-resistant buildings are more likely to remain functional, reducing the environmental impact of reconstruction.Future Directions in Earthquake EngineeringWith advancements in materials science, AI-driven design tools, and real-time monitoring systems, the future of earthquake-resistant buildings looks promising. Research continues into: • Smart Materials: Materials that adapt to seismic stress in real time. • Seismic Sensors: Networks of sensors to monitor and predict structural responses during earthquakes. • Community Resilience: Urban planning strategies that integrate seismic safety at a citywide scale.Earthquake-resistant buildings represent a blend of innovation, science, and foresight. From the tuned mass damper of Taipei 101 to the reinforced core of the Burj Khalifa, these structures are a testament to human ingenuity in adapting to nature's challenges.As seismic technology evolves, societies worldwide are better equipped to protect lives and livelihoods. By investing in these resilient designs, we can build a safer and more sustainable future. By Emily Newton When professionals design and construct buildings, they assess how to reduce risks. Following the applicable codes is one way to do that. Besides the international building codes that regulate the design, construction, alteration, and maintenance of new commercial and residential buildings, there are seismic codes. These are provisions that ensure structures can withstand earthquake forces. Buildings made to withstand earthquakes may not look remarkable from the outside. However, numerous aspects make them more resilient during these disasters. Here are five of them: 1. An Appropriate Foundation Creating a flexible foundation for a building could help it stay standing during an earthquake. One option is to build the structure on top of pads that separate the building from the ground. Then, the pads move, but the building stays still. Another similar possibility, described in a 2019 research paper, is to place a solid foundation slab made of reinforced concrete and crisscrossing strips atop an intermediate cushion of sand. This approach also included a trench around the foundation for further protection. Since this foundation design kept the building's base away from the soil, it was more resistant to seismic forces. 2. Seismic Dampers Earthquake-resistant buildings also need features to help absorb shocks. People more commonly refer to them as seismic dampers. Engineers worked with NASA to develop damper systems for swing arms on its rockets in the 1960s. It chose a gas-driven shock isolation system first, then eventually progressed to a fluidics-based system that's still used today during space station launches and for earthquake-proofing buildings. Seismic dampers absorb destructive energy, protecting the building from sustaining it. Generally, the larger the damper's diameter, the more force it can handle. One manufacturer of these dampers sells products to withstand from 25 to 1,100 tons and sells customized options, too. Another approach involves putting a thin layer of graphene on top of a natural rubber pad. Researchers believe this will be a low-cost damper option for commercial and residential buildings. 3. A Drainage Mechanism Pooled water can create structural complications. That's why parking garages often have double-tee load-bearing structures with a twist that lowers one corner — a feature called warping. Engineers achieve positive drainage with 1.5 percent minimum slopes across the diagonal toward floor drains. Drainage is also crucial to help structures tolerate earthquakes. When the disasters occur in places with loose, sandy soils, the shaking can result in a phenomenon called liquefaction. It makes buildings sink or move to one side, and sewage pipes may rise to the surface. When the soil solidifies again after an earthquake, the buildings stay in their sunken, tilted positions. However, earthquake drains help collected water escape, preventing liquefaction. They are prefabricated pieces wrapped in a filtering fabric. Each drain measures between 3 and 8 inches in diameter. A successful installation requires a grid-style placement. Depending on the size of the area prone to liquefaction, a building may need hundreds or thousands of drains. 4. Structural Reinforcement Engineers and designers have various methods for strengthening a building's structure against potential earthquakes. Many of those redirect seismic forces. For example, shear walls and braced frames transfer lateral forces from the floors and roof to the foundation. Then, diaphragms are rigid horizontal planes that move lateral forces to vertical-resistant parts of the building, such as a building's walls or framework. There are also movement-resistant frames. Those possibilities make a building frame's joints rigid while letting the other parts move. Shorter buildings have less flexibility than taller ones. Thus, engineers typically realize they must provide more structural reinforcement for structures that are only a few stories tall versus skyscrapers. 5. Material With Adequate Ductility Ductility describes how well a material can tolerate plastic deformation before it fails. Thus, materials with high ductility can absorb large amounts of energy without breaking. Structural steel is one of the most ductile materials, while brick and concrete are low-ductility materials. Researchers have also developed creative solutions that show how structural steel is not the only earthquake-resistant material worth considering. For example, scientists engineered a fiber-reinforced concrete with properties similar to steel. They called the material eco-friendly ductile cementitious composite. Experiments showed applying a 10-millimeter-thick layer to interior walls protected them from damage during a 9.0-magnitude simulated quake. Projects are also underway to build earthquake-resistant residences in nations that lack the resources for safely built houses made from materials that people may need to import or lack the skills to use correctly — such as concrete and bricks. A civil engineering company showed how people in Indonesia could construct earthquake-resistant homes almost entirely from bamboo. The roofs feature corrugated sheets made from recycled Tetra Pak, a lightweight material that reflects heat. Thoughtful Decisions Can Save Lives Tens of thousands of earthquakes happen globally every year. Although some cause minor or no damage, others lead to collapsed buildings, loss of life and tremendous disruptions to local economies. The above list is not all-encompassing, but it includes five things that should come up in every conversation about helping a building resist earthquakes. When architects, construction workers and other professionals protect a structure against seismic activity from the start, they'll contribute to safer, more sustainable and more productive communities. Emily Newton is the Editor-in-Chief of Revolutionized Magazine. She has over three years experience writing articles in the industrial sector. Our planet is covered by tectonic plates that are slowly moving around, pushing into or sliding past one another along boundaries called faults. Friction sometimes causes two of these plates to get stuck to each other at spots along a fault. Tension builds up over years, decades or even centuries until suddenly the fault snaps. The two sides lurch past each other, unleashing an earthquake.From the place where the fault ruptures, seismic waves ripple outward in all directions. When they reach Earth's surface, they can set buildings or any other structures shaking—violently and destructively if the quake is strong and close enough, as were the two massive temblors that struck Turkey and Syria on February 6, which was followed by a large aftershock on the same day.These quakes killed more than 45,000 people, many of them in collapsed buildings. Though earthquakes can't be prevented or predicted, science does have some ways to protect buildings—and the people inside them. Scientific American spoke with several earthquake engineering experts to learn more about how using the right building methods can prevent homes, offices and other structures from succumbing to the capricious movements of the Earth.On supporting science journalismIf you're enjoying this article, consider supporting our award-winning journalism by subscribing. By purchasing a subscription you are helping to ensure the future of impactful stories about the discoveries and ideas shaping our world today.What happens to a building during a quake?Imagine you're driving a car down the road, and you suddenly need to stop. As you slam on the brakes, those groceries sitting on the passenger seat (and anything else not strapped down) will fly through the air in the same direction and at the same speed as the car was originally going. This is because of inertia—an object's tendency to stay at rest or to maintain a uniform speed and path until some other force acts on it. That same tendency is what puts a building at risk during an earthquake.During a quake, the ground beneath a building moves quickly back and forth. But because the building has mass, it has inertia. "The earthquake is shaking the ground, and the building is trying to stay put," says Ertugrul Taciroglu, a structural engineer at the University of California, Los Angeles. But once it does start moving, the building wants to keep going in whatever direction the earthquake has pulled it—essentially, it is always lagging behind the ground motion. These lags generate horizontal inertial forces on the building, causing any vertical columns and walls to deform at an angle (creating a parallelogram shape if one were looking at a side view of a rectangular building). When a building has multiple stories, each story is holding up the weight of those above it. That means lower stories have to bear larger inertial forces than those above. If walls and columns are not properly designed or reinforced, they may not be able to support the weight they once held.The larger an earthquake is and the closer it is to the surface —and the nearer a building is to the fault rupture—the larger the inertial forces will be on that building during a quake. The type of ground a building is sitting on can also play a role: compared with hard rock, looser soils magnify ground motions.How do we build buildings so they don't collapse during an earthquake?To keep a building intact when an earthquake hits, it needs to be constructed to resist horizontal inertial forces. Exactly how that can be done depends on the building material being used. Let's focus on two of the most common: concrete and steel. Much of the building stock in the affected area of Turkey used these materials.Under normal circumstances, concrete is a great material for holding the weight of a building because it performs well under what engineers call compression. A concrete building can easily last for decades if it only has to support its own weight. Yet the quake-generated inertial forces that set vertical walls and columns swaying put the concrete into tension, the opposite of compression. Although the forces are trying to stretch the concrete out, "it doesn't give. It doesn't let the building form move but tries to hold on really tight, and it generates these inertial large forces," says Perry Adebar, a structural engineer at the University of British Columbia. The stressed concrete columns and walls can eventually crack and fail because they can no longer support the weight above them.Concrete is still one of the most widely used building materials in the world, in part because it is cheap and abundant and because it has an ability to bear structural weight. To make concrete more suitable for seismically active areas, engineers add steel (in the form of rebar), which is much more flexible. "You have to put steel in wherever you're going to have tension," Adebar says.Steel behaves elastically when subjected to a certain amount of tension. Think of tugging gently on the bottom of a wire coat hanger and seeing it bounce back into shape when you let go. But when subjected to larger amounts of tension, such as in a very strong quake, steel "becomes plastic and deformed," Adebar explains. Think of pulling hard enough on the bottom of the coat hanger that it bends out of shape. In the case of a building during an earthquake, "that's just exactly what you want," Adebar says, because the deformed steel has effectively absorbed those inertial forces but can still hold up weight.Doesn't that mean the building is damaged?In a large earthquake, yes. Steel-reinforced concrete buildings can still sustain considerable damage, possibly to the point that they will be unusable after the quake. This has to do with the way governments set building codes, which tell engineers how to design a building to withstand a certain level of earthquake shaking. Codes, including those in the U.S. and Turkey, generally require that a building achieves what is called "life safety" under a given maximum expected earthquake in an area. "Our seismic codes are only a minimum requirement," says Sissy Nikolaou, research earthquake engineer at the National Institute of Standards and Technology. "You just want these buildings at least to give you the chance to get out of it alive when the big one happens, under the assumption that they may be seriously damaged." The situation is akin to a car that crumples in a crash: the vehicle absorbs the impact to protect passengers, but it is totaled.There are, of course, different standards for buildings or other infrastructure that are considered critical and that need to keep functioning after a quake—for example, hospitals. Experts such as Nikolaou are also beginning to rethink the life-safety standard so that more structures are usable after an earthquake. Doing so could avoid situations where people are kept out of their homes for months or years. Many people in Turkey now face this possibility, with tens of thousands of buildings deemed at risk of collapse from damage sustained in the February 6 quakes.There are ways to keep buildings habitable after an earthquake. Some methods involve smarter designs with common materials such as steel-reinforced concrete. It can also require more technological approaches, such as "base isolation." With this technique, a building is not rigidly attached to its foundation. Instead it sits atop flexible structures that decouple it from the foundation—and therefore from shaking ground. This type of system adds to construction costs, though, and some building owners would be unable or unwilling to pay for it. In the U.S., it has been used to protect crucial structures such as hospitals and to retrofit historic buildings while preserving their original architecture. Some hospitals in Turkey had base-isolation systems and withstood the recent quakes there.Why might a building fail even if it is built to earthquake codes?Buildings are designed to withstand a certain level of shaking, based on the seismic risks in their location. A building in Los Angeles, for example, would be built to withstand a larger earthquake than one in New York City. But seismologists don't always know exactly how big of an earthquake a fault can produce. "The major difficulty in engineering design is the uncertainty about the future earthquakes, because we don't know what will happen precisely," Taciroglu says. The bigger the magnitude, the rarer the quake. Some of the biggest may only happen every few hundred or thousand years—but modern seismic measurements only go back a few decades. Many seismologists thought the East Anatolian Fault—the one involved in the Turkey-Syria quakes—was likely to produce a maximum magnitude of 7.4 or 7.5. But the February 6 earthquake was a 7.8—about four times bigger on the logarithmic scale of earthquake magnitudes. So it is possible that some structures built to code in Turkey may simply have experienced more force than they were built to withstand, Taciroglu says.Building codes also evolve as science's understanding of earthquake risk and engineering change, so a building that was been built to code at the time it was constructed might not meet updated standards. Retrofitting such buildings is often cost-prohibitive. Taciroglu says this is likely the reason many of the buildings in Turkey were severely damaged or collapsed.Human error can also come into play. It may range from intentional, profit-driven cuttings of corners to honest mistakes that can happen at various points in the design or building process—and that aren't revealed unless something like a massive earthquake comes along. Since earthquakes literally shake a structure back and forth, the key to building a resilient structure is designing the building to transfer those shaking loads to the foundation as quickly as possible. Buildings that cannot transfer those loads quickly have to be strong enough to take the beating or they will crumble.What Techniques Lead to an Earthquake-Resistant Structure?When an earthquake hits, the structures that survive have three characteristics in common: they are stiff, strong, and ductile. These are the most common features that give a building these characteristics. Many buildings use a combination of these features to ensure a building is still standing even after a big one hits.Avoid Columns on the Ground FloorMany multistory structures utilize the ground floor as a parking garage or have a living area with many open areas. While aesthetically pleasing or functional, those designs tend to have worse outcomes when an earthquake hits. The columns cannot withstand the shaking.Dampen the ShockIn the same way that shock absorbers are key to offroad and bumpy driving, shock absorbers can be used to minimize the impact of earthquakes on buildings too.When used on a building, shock absorbers are typically added to each floor of a building. The shock absorbers help to dissipate the shaking energy from an earthquake, so that the building's structure doesn't have to redirect all of the force back to the building's foundation.Shear WallsBuildings are constructed to support the weight of a building from gravity. When an earthquake hits, the forces on the building start to change direction which can be disastrous if the building cannot handle those loads. Shear walls are designed specifically to handle these loads, and are often made from diagonal steel cross braces. Shear walls can support the compression and tension that occurs during an earthquake and push those loads to the building's foundation.Go with the FlowFor skyscrapers, a popular technique is to use a pendulum that moves opposite the earthquake's movements to dissipate the energy. These systems are engineering marvels that utilize a large ball suspended from steel cables that connect to a hydraulic system at the top of the building. Moving against the earthquake helps keep the entire structure stable even when the ground is shaking.DiaphragmsIntegral to horizontal structures, diaphragms are designed to distribute sideways forces that occur during an earthquake. These features are built into floors and the roof to connect to the building's vertical elements. The diaphragms also help to absorb stress and torsion from the building during twisting.Reinforced ConcreteSteel reinforced concrete structures are very good at withstanding intense earthquakes. Unreinforced concrete buildings are another story. The shaking from an earthquake will cause concrete to crack and crumble unless it has steel to reinforce and strengthen it.The steel in the concrete pulls double duty: it makes the wall more ductile and also anchors the wall to the foundation. This anchoring helps make the wall an effective shear wall, allowing it to redirect shaking forces into the building's foundation.Strong ConnectionsReinforced concrete has a naturally strong connection between the walls and foundation. Wood frame construction is incredibly ductile but must be properly anchored to the foundation. If the connections between the wall and foundation are weak, the building can move and shift during an earthquake.