Earthquakes

What are earthquakes?

An earthquake, as the word itself describes, is a quake or a movement of the Earth, also known as seism from the Greek word that means shock or tremor. The Earth is a planet that is "alive", it moves continually under our feet due to its internal dynamics and the tectonic processes. In fact the coasts of America and Europe separate a few centimetres every year. Normally the movements take place in a continuous imperceptible manner, however at times, due to the resistance opposed by the rocks, the thrust and tectonic deformations accumulate progressively like loading a spring. When the resistance of the rocks is exceeded, suddenly there is a break, and a movement along the surface of the fracture: this provokes a sudden release of energy that then spreads inside the Earth, producing a series of vibrations, the seismic waves, till they reach the surface. It is here that we note the often destructive, at times catastrophic effects of the earthquakes. The points where the rocks break and move are known as faults, the surfaces may at times be immense, kilometres long, where different rocks and also entire continents, pushed by the tectonic forces, come into contact with one another, and are deformed up to the final breakage. The size of the faults varies greatly - from enormous scars that cut across our entire planet, marking the points of contact between the various lithospherical plates, to small surfaces of only few square metres. The energy of an earthquake, however, not only depends on the extension of the surface but also on the amount of movement and the amount of energy that had accumulated before the breakage. Generally, however, seisms of a greater intensity are located near the larger faults. Together with these, usually smaller superficial movements occur, which may provoke seisms of a minor intensity, at times as a consequence of a more important seism, as in the case of the ground settling after shocks that follow the main event. The earthquake that occurred some days ago in Indonesia could in fact be of this type, a secondary movement, even though of great intensity, following the very big earthquake in December. Very active faults, that move continually, may seem dangerous because they generate a large number of small earthquakes, however the faults that do not move much and therefore get "loaded" very slowly with large quantities of energy are the ones that must be feared most.

Why here?

Studying the distribution of the bigger seisms, with the patient collection of thousands of data, in the Sixties, a map was created for the entire planet. This map shows that the earthquakes are not distributed at random, but the more frequent ones, with the greatest intensity, are distributed in very precise belts. Comparing this map with the map of the margins of the lithospherical plates or layers (the large rigid blocks, which the most superficial part of our planet is subdivided into, that move, and drift on the underlying plastic mantle), it can be seen that the distribution of the earthquakes, almost perfectly outlines the limits of the plates. However there is even more : if the earthquakes are divided according to the depth in which they occurred and the energy that was released, it can be seen that the more superficial and less powerful earthquakes are located near the ocean ridges (diverging plate margins) where the plates separate from each other and where the crust is thinner (3-5 km) and, breaking, allows magma to rise from the Earth's mantle, and the formation of submarine volcanoes. The deeper earthquakes, the ones that release a greater quantity of energy, instead, are located in the areas where the plates collide (converging plate margins) : in this case the margin of one of the two plates is forced to slide under the other one, in a process called subduction, till, slowly heated, it is reabsorbed by the mantle in a kind of large "recycling" circuit of the lithosphere. Earthquakes in these areas are the result of the friction and deformations that the forced sliding of a plate under the other one produces, and the maximum depth of these earthquakes indicates the depth where the subducted plate is still rigid enough to break, thus giving origin to a seism : the maximum depth registered for these earthquakes is 640 km. Through a study of the earthquakes in these areas, it is possible to "follow" the sliding process of a strip of lithosphere towards the mantle : earthquakes are distributed along an inclined plane called the Wadati-Benioff plane, whose name comes from the researchers who first identified it, drawing the profile of the descending plate almost perfectly.

It is therefore clear that the distribution of earthquakes is surely not a casual event and there are areas of our planet in which these events more than a risk are a certainty. For this reason it should not surprise us if seisms are repeated in

the same areas. What happened in South East Asia is simply the consequence of the collision of the Pacific Ocean plate and the complex system of small plates to be found between Indonesia and the Philippines. Along the western coasts of Indonesia is one of the deepest trenches in the planet, the Java Trench, near which the subduction of the plates one under the other takes place, leading to the formation of the islands of the Indonesian archipelago.
Observing the atlas, we can understand where the lithosphere plates collide and one of the two slides below the other. In fact if one observes the Pacific coasts it is possible to see numerous groups of islands with a typical arc shape, characterized by strong seismicity and intense volcanism; this indicates the presence of subduction plates. It is not a chance that volcanoes and earthquakes are often connected: the presence of an active volcano implies a constant high seismic risk. The study of the Earth's surface therefore gives us precious elements and proofs of a possible seismic and volcanic risk.

Measuring the released energy

In Italy, the energy that is released by an earthquake is often calculated using the "Mercalli scale" (actually it is a modified Mercalli-Cancani-Sieberg scale). It is one of the first scales that were elaborated in order to evaluate the intensity of seisms, when more precise instruments were still not available (the first version of the Mercalli scale dates back to mid 1800) even though it is still commonly used today. However this is not a real "measurement" of the energy that it is released. In fact it is based on an assessment of the damages caused by the earthquake. These certainly depend greatly on the intensity of the seism, but are also conditioned by geological factors (such as the type of rocks or the presence of loose sediments, the types of constructions that have been affected, population density, advance warning given, the time in which the earthquake occurred (it is well known that at night there is a greater number of victims), and also if the population is used to the experience of earthquakes (during the recent tsunami in South East Asia, many people were saved due to the awareness of some Japanese tourists who, knowing the phenomenon well, advised those who were present to move away from the beach) : a seismic event of the same intensity in a town with a high population density without antiseismic constructions will certainly cause greater damages than in a city with few inhabitants or built with suited antiseismic criteria. For this reason seismologists discourage people from using this scale, and prefer to use other types of scales that are more objective, as for example the Richter magnitude scale. This scale, which was adjusted by Richter and Gutemberg in the Forties, is obtained by measuring the maximum amplitude of the waves drawn by the seismographs. This amplitude, is used with suitable formulas to calculate the quantity of energy that was actually released by the earthquake. It is a scale that potentially does not have a maximum level because it only measures the intensity of earthquakes that have occurred : the highest level ever recorded was 9.5 in 1960 in Chile. However nothing prevents even greater earthquakes from taking place. The Richter scale is a logarithmic scale, therefore a degree of difference in magnitude is equivalent to a wave amplitude that is approximately 10 times greater and energy that is released that is 30 times greater, two degrees are equivalent to an amplitude 100 times greater and an energy 900 times superior and so on. Therefore you can see how the energy of earthquakes can be very different and in some cases, can be frightful. To have a vague idea of the energy that is involved, it suffices to think that an earthquake of magnitude 9 has an energy of 2×10^{18} joule, where the energy used every year in the entire USA amounts to 6×10^{19} joule!

Energy released on the surface

The energy released by an earthquake propagates into the rocks of the Earth's crust and lithosphere through two types of seismic waves – P waves or primary waves, so-called because they are the first ones to reach the seismographs, and S waves or secondary waves, which are slower. P waves are compression waves, similar to sound waves. When the internal waves reach the Earth's surface, they are modified and propagate using different mechanisms. These are the waves that we feel and the ones that provoke the greatest damage. Normally undulatory or sussultatory types of vibrations are felt. The latter, which have a strong vertical component, are the ones that potentially cause most damage. Together with the moving waves, often earthquakes are accompanied by strong rumbling: this is the effect of the propagation in the air of the compression waves. These low-frequency sounds, often infra-sounds that are near the limit of the auditory threshold , in fact often produce that particular feeling of alarm and anxiety that can even be felt during mild earthquakes, that makes one immediately distinguish between a seismic tremor and the passage, for example, of a train, with equally intense vibrations. At times particularly sharp ears can hear these sounds of the Earth even many days before : some animals, for example, dogs, pigs, fish and snakes are particularly sensitive to these sounds and can help foresee earthquakes.

The duration of the vibrations in general, is a few seconds, at times some minutes (the earthquake of these days in Indonesia, lasted approximately three minutes) : the gravity of the destructions that take place depends to a great extent also from the duration of the tremors. Generally an earthquake is not an isolated event, but it is preceded and followed by a series of tremors of minor intensity. Repeated tremors or settling tremors often continue for months.

Apart from vibrations, an earthquake generally also produces other effects, that contribute to making the situation even more dramatic. At times large amounts of water vapour are released and perturbations in the electromagnetic field take place : this can produce optical phenomena, such as light “domes”, or electric phenomena such as lightning storms. At times gases are freed, often containing sulphur, and produce bad smelling fumes. The movements of the Earth’s surface can also violently dislocate large masses of air, thus interacting with the atmospheric phenomena. In 1969, during an earthquake in Japan, a temporary rise, of 1.6 km, of the mass of air was observed, above the epicentre, at a height of 330 km.

Not only earthquakes

Earthquakes have a very strong destructive power, on one hand due to the direct effects of the vibrations, on the other because they can provoke numerous undesired effects, at times of a magnitude that is even greater than the damages provoked by the tremors. Very strong earthquakes can induce dramatic modifications in the landscape, setting off landslides, opening fissures in the ground, deviating watercourses and consequently causing floods and triggering off or summing to volcanic eruptions. Geysers of sand and mud, liquefied by the vibrations, may form, and their jet may reach over 6 metres in height. In the urban centres, destruction caused by seisms may lead to the breaking of gas pipes or oil pipelines, may provoke short circuits, causing fires or explosions. Many of the victims recorded, are due to the fires. When the hypocentre is in the sea, some types of movements may cause the feared tsunami waves, whose devastating effect is still under our eyes with the dramatic images of what occurred in South East Asia some months ago.

Some statistics

Every year, seismographs all over the world record over 600,000 tremors of intensities below 2 of the Richter scale, that can be perceived only by instruments. Other 300,000 earthquakes with an intensity between 2 and 2.9 can be felt only by persons who are particularly sensitive. 49,000 more earthquakes with a magnitude between 3 and 3.9, are felt by those who live near the epicentre, while 6,000 tremors, of intensities between 4 and 4.9 provoke minor damages. For the higher intensities, that always provoke damages, approximately 1,000 are of an intensity between 5 and 5.9, 120 between 6 and 6.9, approximately 14 with a magnitude between 7 and 7.9, while earthquakes with an intensity between 8 and 8.9 occur every 5-10 years. Fortunately, earthquakes of a magnitude greater than 9 are rare, approximately 1-2 times in a century. But these are only statistics, or annual averages – in South East Asia two seisms of a great intensity took place (greater than 9 and approximately 8.7) in around 3 months, which completely distorted the statistics, and this does not exclude that similar events might take place again in the short term.

Locating an earthquake

The hypocentre is the point, deep in the Earth, where the breakage that provoked the earthquake occurred. The epicentre is the equivalent point on the Earth’s surface. Normally the area of the epicentre is the one in which the most severe damages are recorded, while the intensity of an earthquake decreases as one goes further away. By studying the time it takes the waves to reach particular stations placed at different distances from the epicentre ,it is possible to determine the position of the hypocentre precisely, and also to identify the mechanism of movement that produced the earthquake. The seisms of a greater intensity naturally produce waves that can be felt very far away, at times they cross the entire planet and bounce several times along the various internal “layers” of the Earth. At times, on the occasion of the more powerful earthquakes, the Earth continues to oscillate for a number of days and the effects are so significant that some of the terrestrial parameters may be changed, as for example the inclination of the axis, as apparently occurred with the event of the 26th December. However, these are events that do not bear any consequences on life on the planet, and if the events are measured by the instruments, they are not felt by most living beings. The information collected during earthquakes of great intensity, have enabled the study and understanding of how the Earth is made inside, determining its structure in concentric “shells”, based on the type of waves and the speed at which these propagate in different materials. Disastrous and catastrophic events on the other hand can, at times, offer precious insights in the study of the behaviour of our planet, and enable us to build forecasting models for the future. For this reason, rescue teams work to bring aid to the affected populations alongside teams of seismologists and geophysicists who are always, silently, at work to better understand the behaviour of our restless planet.

The course of history

Earthquakes are linked to geologic and tectonic situations and therefore tend to recur in time and in the same areas, often in a similar manner. It is very important, therefore to collect the historical data of seismic events that date as far back as possible in time. Some geological studies also enable the reconstruction of seismic events of the even more remote past, through studies, for example, of particular forms of the ground, ancient landslides, or the breakage of concretion inside caves. In this manner, maps of the seisms of the past are drafted for every region, enabling the creation of general seismic risk maps, which illustrate the so-called seismic zoning. For each area it is important to note the intensity of the different seisms that occurred in succession, in order to determine the “periodicity” of the seisms of greater intensity. In practice, the statistics of the more intense events are elaborated, and a forecast is made determining after how many years an earthquake of a certain magnitude has occurred. The earthquakes of a greater intensity generally have a longer periodicity, that can be measured in years or decades or centuries. It cannot be exactly forecasted when an earthquake will take place but it is known that it will occur within a certain amount of time, so the more time passes, the greater the probabilities that certain events might take place. If the Earth remains quiet, therefore, it must not mean we can stay off-guard – but rather, the contrary! A classic example is the San Andreas Fault in California, one of the most studied seismic zones. The San Andreas Fault is over 1000 km long and 32 km deep. It is where the North American plate clashes with the Pacific plate – here the calculation of the periodicity for a recurring seism of great intensity is estimated to be 100-150 years. The last event of a great intensity occurred in 1857, therefore it is increasingly probable that a strong earthquake might take place now or in a few years time. Therefore the wait has begun for what the Californians call “The Big One”. Other studies have highlighted an increase in the microseismicity and deformations around the zone of the fault, these are all precursory signs of a subsequent important movement : it is therefore estimated that there is a 60% probability that a violent earthquake may occur in the next 30 years. The Big One is awaited, hoping everything is ready to face it!

Seismic zoning

If the periodicity of earthquakes in a particular zone is known, all human constructions must bear it in mind and opportune defences must be carried out, first of all the realization of anti-seismic constructions. Examples of anti-seismic constructions are extremely old, as may be observed, for example, in the walls built by the Incas in Cuzco, Peru. An anti-seismic construction, naturally, cannot resist against all possible earthquakes – in order to be truly safe, it is sufficient (and necessary) that it is able to resist an earthquake of the highest intensity registered in the region. An earthquake of an unusual intensity, however, although not very probable, may still occur, thus thwarting all the preventive efforts – for this reason, for those living in areas with a strong seismic activity, it is necessary to learn to live with a certain degree of risk. An example of this can be seen in a country like Japan, that is prepared and equipped to face most of the earthquakes, which however at times incur severe damages, notwithstanding the rigorous building regulations. Notwithstanding all the precautions, therefore, it is practically impossible to eliminate seismic risk. Furthermore, in many zones, including many areas in Italy, the criterion used to adapt anthropic structures to the seisms of maximum intensity ever recorded, would entail prohibitive costs for all human structures. Therefore the periodicity of the major earthquakes is taken into consideration. If this interval is very long, in other words hundreds of years, or even many decades, it might be economically more advantageous to build with less restrictive criteria, bearing well in mind however that the duration of the construction will not be able to exceed the periodicity of the more intense seism. This is particularly true for structures that are not designed to last in time, as for example a dam or a bridge, which however generally require updating after a few years and a great amount of maintenance. It is this criterion that will enable the construction of the much discussed bridge over the Strait of Messina. Simple, isn't it? Unfortunately in this approach there is a terrible illusion, the periodicity that is calculated using statistics, is an average; on average, there are, let us say, two seisms of magnitude 7 in a century – one every 50 years. Therefore, what is the conclusion? Nothing is certain, as in the case of the numbers of State lottery game, the same number can be extracted twice in a row, and then not be extracted for several months, likewise two earthquakes of magnitude 7 may occur in two months, and then nothing else for the following 100 years. Therefore to decide the level of risk that is acceptable and the resistance criteria for the constructions in order to colonize an area calls for very delicate choices. Building with anti-seismic criteria is very expensive, and it is even more so to redesign existing structures, therefore in purely economic terms it could be more advantageous to let a scarcely probable event take place without having taken adequate measures or having taken measures that are not sufficiently efficient, and then reconstruct, according to the statistics perhaps, once every 100 years… The problem is to succeed in evaluating the probability factor correctly, and on the other hand consider the weight of the social costs : the loss of human lives, in fact, has no price, not even once every 100 years…

Is a forecast possible?

Apart from the forecasts that can be made on the basis of statistics, the analysis of events that took place in history, have shown that the movements that generate an earthquake usually are not sudden, but are preceded by a series of premonitory signs, and if these are noted in time, they can help to foresee the onset of the event. Unfortunately, however, these signals are often feeble and can only be recorded instrumentally, and often they are hardly noted. Furthermore none of these can exactly forecast the date and time of an earthquake, which makes it very difficult to programme the alarms and the necessary evacuation of the population, sometimes even many months before the event. Quite often cases of alarms given immediately, perhaps too early, were later withdrawn because they were apparently without foundation, and were then followed by the pre-announced seismic event. At times the uncertainty of the forecast is considered a negative forecast, in a field in which a conditional response is a must, just as it should be for patience. In fact which one of us would be ready to abandon his home and job for a few months because "perhaps" there could be an earthquake in the vicinity?

Among the more common premonitory signs, which are also the most confirmed signs, there is an increase in the low intensity earthquakes, the so-called microseisms, that can only be recorded instrumentally, accompanied by deformations in the crust, the opening of small fractures, movements along the faults at times marked by an increase in the number of small landslides, some variations in the property of rocks, such as an increase in electric conductivity due to the formation of microfractures, the liberation of particular gases such as radon, caused by the microfractures, the increase in the level of the water table, that is easy to monitor by checking the water levels in the wells. The problem is that often these phenomena do not occur together and they almost never are of an intensity that is high enough to attract attention, and even worse, many very intense seisms occur without even one truly apparent precursory symptom. Many animals, and at times, some people, are able to feel the nearing of an earthquake, probably because they are sensitive to the variations in the electromagnetic field that precede an earthquake, or because they can hear the infrasounds that are tied to the propagation of seismic waves. Here, though, we are entering the field of "premonitory signs" more than forecasts, therefore, if no instrumental monitoring systems are present, it is difficult to rely on the state of agitation of Fido the pet dog or of the fish in the garden pond : it is difficult to analyze whether it is all due to the nearing of an earthquake or only because of a wandering kitten in the neighbourhood.

Therefore it is quite difficult to make accurate forecasts, specially in precise terms of hours or days. In China, one of the greatest earthquakes ever registered was forecasted 5 years before, however this was not sufficient to save the 250,000 persons who lost their lives, perhaps because of the long, excessive lapse of time between the alarm and the event.

International alarms

In Italy there is a network of stations for monitoring seismic events, managed by public research organisms and universities. In particular, the Istituto Nazionale di Geofisica (Italian Geophysics Institute) manages the 32 national monitoring stations distributed across the Italian territory and connected in real time to the central office in Rome. Since 1981 there is a National Group that studies the problems inherent to defence from earthquakes, promoted by the Council of Ministers, while the Servizio Sismico Nazionale (Italian Seismic Service) has the task of monitoring the application of the seismic law that regulates building laws in seismic environments. A seismic classification of the entire territory has been elaborated and is also updated constantly, over 8000 municipalities have been subdivided into 3 different levels of seismic hazard, which involve precise building restrictions for constructions and anthropic structures. Together with the Civil Protection Office, intervention plans have been laid out in case of particularly severe seismic events.

Seismic monitoring networks in many countries worldwide are, or should be, in constant contact with each other, so as to establish an efficient connecting and warning network. Often these warning systems are efficient, as for example in the case of the tsunami monitoring and warning system for the Pacific, while in other cases coordination is very difficult, as it was dramatically seen in the events that took place in December 2004. The recent earthquake in the same area instead, showed, how with a minor level of cooperation and a minor financial commitment it was possible to warn the populations of the entire area of the risk of a tsunami. The fact that subsequently, this time, whimsical nature did not create a “killer wave”, surely must not be an invitation to stand off-guard!

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