
What is the seismic risk on the Côte d'Azur and in the Southwestern Alps ?

An earthquake is caused by the **rapid sliding** of two rock compartments located on opposite sides of a **fault**. It is the friction between these two compartments that produces waves that propagate to the surface of the globe. It is a brief phenomenon (from a few seconds for low to moderate earthquakes to a few minutes for major earthquakes) that generates vibrations called **seismic waves**. These waves **propagate from the depths of the earth towards the surface** at a very high speed (several kilometres per second). It is the **ground vibrations** that are responsible for most damage to structures (buildings, houses, bridges, infrastructure) and it is the collapse of structures that is responsible for most loss of life**. It is not currently possible to predict earthquakes, but scientific research has led to advances in our understanding of their causes and consequences.**

The level of ground vibrations (1) depends on two first-order parameters: the size of the earthquake (= the **magnitude**, which is a measure of the energy emitted by the earthquake on a scale from -2 to over 9) and the **distance** between the rupture zone and the site under consideration. The effects caused by an earthquake vary according to its characteristics :

- An earthquake of moderate magnitude can cause strong ground vibrations, but only in a small area. For example, the magnitude 5 earthquake that occurred in 2019 in the commune of Le Teil (Rhône valley near Montélimar) showed that an earthquake, even a moderate one, can produce destruction close to the rupture (2). This event has renewed interest in seismic risk research in France (3).
- An earthquake of greater magnitude will cause vibrations over a wider area (several tens or even hundreds of kilometres for a magnitude 7 earthquake). This was the case for the magnitude 7.8 earthquake at Kharamanmaras in Turkey in February 2023.
- An earthquake may cause no damage if it is located far from inhabited areas (e.g. the magnitude 6 earthquake that occurred at sea between Corsica and the mainland in 1963).

It is therefore essential to know where earthquakes are likely to occur and what their magnitude may be.

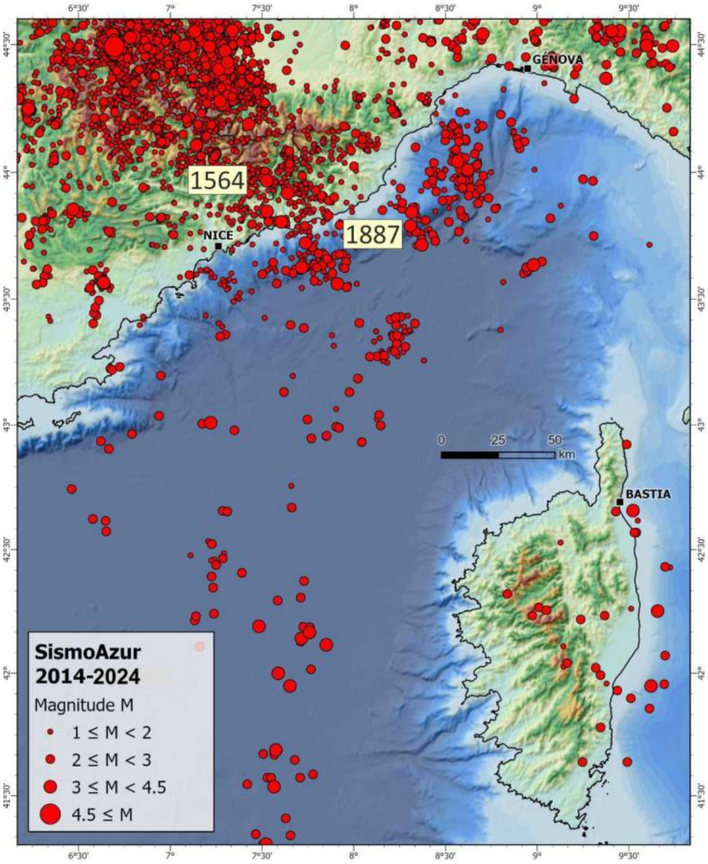
In addition to magnitude and distance, another effect must be taken into account. This is the **site effect** (4). This term refers to the amplification of seismic waves caused by superficial geological layers or topographical relief. This may seem counter-intuitive, but we now know that waves are trapped and amplified if the subsoil is ‘soft’ (made up of a few tens of metres of unconsolidated sediment) compared with soils made up of hard rock (granite or limestone, for example). So an earthquake of the same magnitude at the same distance will generate stronger surface vibrations in a valley filled with sediment than on a site made up of hard rock. An amplification effect can also exist in steep areas (this is known as the topographic site effect). This effect can occur in the Var valley (filled with several tens of metres of alluvium) and in certain villages in the hinterland of Nice perched on promontories, for example.

Seismic hazard on the Côte d’Azur

Destructive earthquakes in the past : the Côte d'Azur is one of the most seismically active areas in Western Europe. It has suffered around ten destructive earthquakes in its history. In 1564, an earthquake caused considerable damage in the hinterland of Nice, killing at least 300 people (5). In 1887, an offshore earthquake just a few kilometres off the Ligurian coast caused the death of more than 600 people, considerable damage and a tsunami of up to 2 metres. Its magnitude was estimated at between 6.7 and 6.9 (6) and (7). As the earthquake

*The (n°) and * refer to references listed at the end of the document* occurred near San Remo in Italy, it was in this area that it caused the most damage (Figure 1, photo top right). In the town of Nice, more than 50 km from the focus, the vibrations were strong enough to cause residents to camp out for several weeks for fear of aftershocks (Figure 1, photo bottom right).

It is the current reproduction of this type of earthquake that is feared the most, given its high magnitude for the region. Regardless of the number of victims, such an event could leave several thousand people homeless in the urban areas around Nice.



village de Diano Marina (Ligurie)
après le séisme de 1887

Centre ville de Nice après le séisme de 1887

Figure 1 : Map on the left : the white dots indicate the epicentres of earthquakes located from 1980 to 2013 by RENASS and the red dots the recent earthquakes from 2014 to 2024 located by the Géoazur laboratory. The approximate location of the historic earthquakes of 1564 and 1887 is indicated by a yellow rectangle. Right : Photos taken after the 1887 earthquake in Italy (top) and in Nice city centre (bottom), collection Didier Moulin.

A high level of microseismicity shows that the area is active : the current seismological networks (Epos-France network : French national seismological network, managed locally by Géoazur) detect all earthquakes of magnitude greater than 1.8 in the region (Figure 1 map). Detection at sea is less accurate due to the lack of stations. Ground vibrations are recorded by around forty sensors in the region and transmitted in near real time. This data, along with calculations of location and magnitude, is open and accessible to the public via the http://sismoazur.oca.eu/ portal managed by the Géoazur** laboratory.

Geological causes : the Mediterranean basin is the site of the **convergence of two major tectonic plates : Africa and Eurasia**. In the geological past (the last 60 million years), the convergence of these two plates led to the formation of the Alps. Over the last few million years, the boundary between these two plates has moved southwards and is now found in the Maghreb, Sicily and Calabria ranges. Today, the south of France is more than 1,000 km from the plate boundary, but is still feeling the effects of this convergence, as shown in the figure showing the seismicity of the Alpes Maritimes and Ligurian Basin (Figure 1). Recent studies have also shown that, in the Alps, the loss of the glacial load due to the **melting of the glaciers**, which began 20,000 years ago, is helping to modify the forces acting at depth on the faults that cause earthquakes.

Non-geological causes : for several years now, scientists have been detecting earthquakes triggered by non-geological processes. This can be the case when a dam is filled or emptied, when a quarry is exploited or when shale gas is extracted, for example. Any process capable of modifying the forces acting on faults a few kilometres below the surface can potentially trigger an earthquake. This is known as an **induced earthquake**. Observations currently show that these induced earthquakes are generally of low to moderate magnitude. The Vallée de la Tinée was the site of a microseismic crisis in the 2 months following storm Alex (October 2020). During this storm, the Argentera-Mercantour massif received considerable rainfall (600 mm in a few hours). It caused very serious damage and several casualties in the Roya, Vésubie and Tinée valleys. In the Tinée valley, the rainfall caused water to infiltrate deep along faults, triggering several dozen low-magnitude earthquakes in a normally aseismic area.

Active faults : earthquakes occur on faults that are said to be 'active' because they are capable of generating an earthquake in the current period. Fine bathymetry surveys at sea have identified a network of faults around 25 km off the coast, extending from Nice to Savona in Italy (Figure 2). It was this network of faults that was responsible for the destructive earthquake of 1887. If an earthquake of similar magnitude were to occur on this fault system off Nice, it would inevitably have dramatic consequences for the coastline, which is now very densely populated. It could also trigger a tsunami, which could cause additional casualties, particularly during the summer months when beaches are crowded.

On land, faults are also active, regularly generating low to moderate magnitude earthquakes. Their trace is less well known because erosion, which is more intense in land areas, tends to mask evidence of recent activity (over the last two million years). An earthquake on land could have greater consequences in the epicentral zone than an earthquake at sea, particularly if its hypocentre (the zone where the rupture is initiated at depth) is shallow (within the first 5 km of the earth's crust) and located beneath inhabited areas. This was the case in central Italy in 2016, where the village of Amatrice was devastated by a magnitude 6.1 earthquake that killed 298 people in a few of seconds when their homes collapsed.

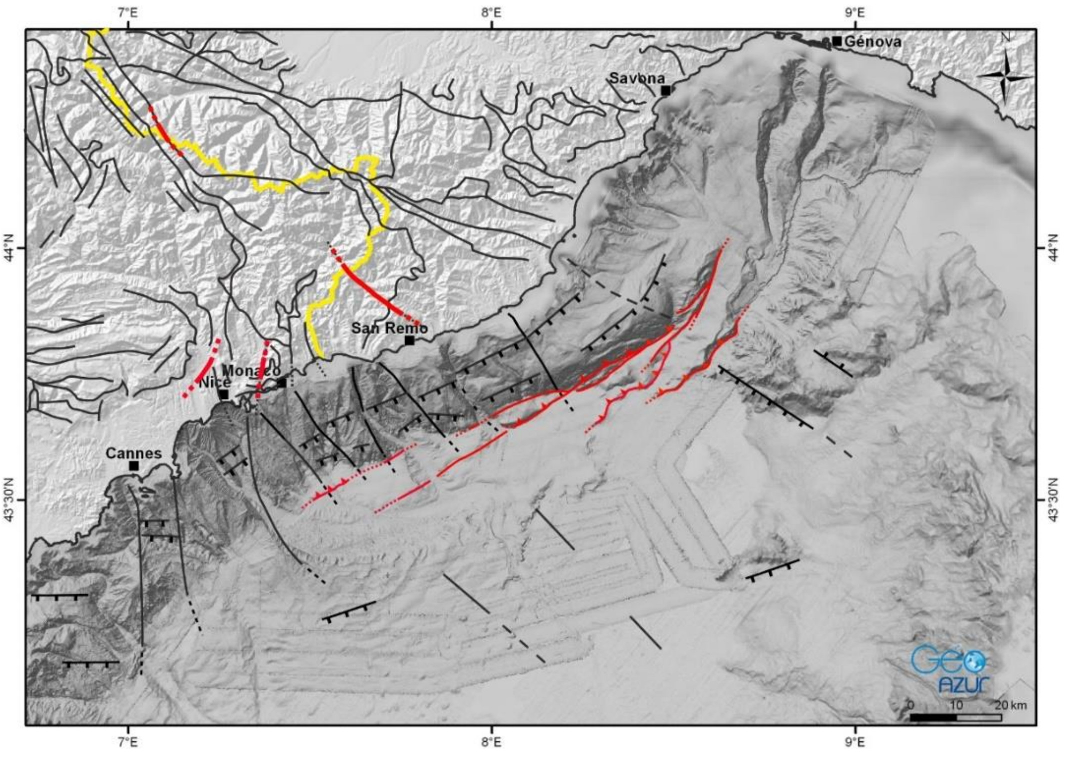


Figure 2 : Fault map of the Ligurian Basin and Southern Alps region. The grey background represents the shaded topography, including the seabed. The French-Italian border is shown in yellow, and the other lines represent the traces of the main known faults (based on maps of Nice and Gap, 1:250,000, BRGM). Active faults are highlighted in red, including the Ligurian Fault at sea (Géoazur document).

In addition to this seismic hazard, there is also a **tsunami hazard** : the Côte d'Azur and Liguria coastline has suffered two low-intensity tsunamis in recent history. The first is directly linked to the earthquake of 23 February 1887, the epicentre of which was at sea on the Ligurian fault some twenty kilometres off the coast of Imperia in Italy (Figures 1 and 2). There are eyewitness accounts of sea movements from Genoa to Toulon, with variable amplitudes of up to 2 m in a few localised areas (note that this amplitude is much smaller than that observed during the major tsunamis in Indonesia on 26 December 2004 and Japan on 11 March 2011). The second tsunami observed was not induced by an earthquake : on 16 October 1979, a huge submarine landslide followed the collapse of an embankment dam being built to extend Nice airport. Tens of millions of m^3 of material slid to the bottom of the sea, producing a tsunami that was limited to the Baie des Anges and whose maximum amplitude reached 3 m on the east coast of Cap d'Antibes.

The geological causes of earthquakes and tsunamis in our region persist for tens of thousands of years or more. So we know that there will be earthquakes in the future, but unfortunately we can't predict when.

How is this seismic hazard taken into account ?

Using information on historical earthquakes and current seismicity recorded by seismological networks, it is possible to calculate **probabilistic seismic hazard maps**. These maps indicate the value of ground acceleration that has a 10% (or greater) probability of being exceeded in a given period of time (50 years for national regulations concerning standard buildings). This probabilistic calculation is used to construct a regulatory map indicating the seismic stresses to be taken into account for new buildings in each zone (Figure 3).

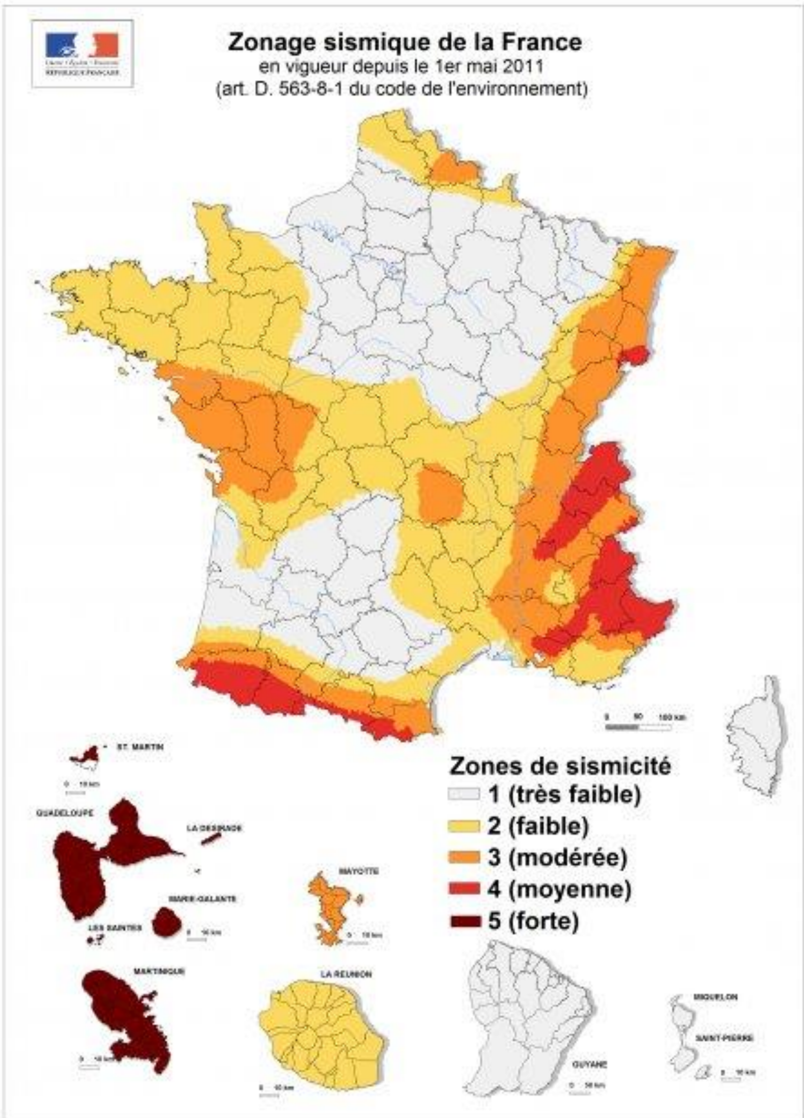


Figure 3 : Seismic zoning of France. Nice and its hinterland are located in zone 4.

Nice is in a level 4 zone (qualified as medium), which is the strongest in mainland France (level 5, which is very strong, is reached in the French West Indies). Seismic regulations also take account of site effects linked to the geology of the topsoil, by adapting the resistance of buildings to these effects. Seismic Risk Prevention Plan (PPRs - Plan de Prévention des Risques sismiques) enable regulations to be adapted to the geological and topographical conditions of a given municipality.

Studies carried out over the last twenty years by CEREMA*** in the city of Nice have resulted in a seismic microzoning map**** and a PPRs, which was approved by the Prefect of the Alpes Maritimes on 28 January 2019. Nice is now the first major French city to be microzoned.

These regulations make it possible to minimise losses in the event of a strong earthquake in recent buildings that comply with construction standards. **However, standard residential buildings constructed before the 1990s do not comply with any earthquake-resistant standards, representing 70% to 80% of Nice's housing stock.**

Conclusion

The Alpes Maritimes is a moderate seismic zone : small earthquakes are recorded every day by monitoring networks, but strong earthquakes are rare, and the seismic risk is often a little forgotten.

However, it is known that **the Côte d'Azur will be hit by a potentially destructive earthquake in the future**. Based on current knowledge, it is assumed that this earthquake will be less powerful than the one that occurred in Turkey in February 2023, for example, but for the moment **it is not possible to predict when or on which fault this earthquake will occur**. It is therefore essential to strengthen infrastructures and communication networks and to work out scenarios for the authorities in charge of rescue services in order to limit human and material damage. It is also vital to raise awareness among the general public, schoolchildren, public authorities and businesses of the urgent need to take action. It is also important to **continue to support scientific research and observation methods, which are gradually leading to a better understanding of the phenomena and reducing the uncertainties involved in calculating the impact of earthquakes.**

More informations :

Articles from popular scientific newspapers can be downloaded by clicking on the link (in French) :

(1) *https://hal.science/hal-02918385* : how to anticipate the vibrations that lead to the destruction of buildings.
(2) *https://hal.science/hal-02934441* : the origins of the Teil earthquake (Rhône Valley, November 11, 2019).
(3) *https://hal.science/hal-04717029* : a look back at seismic risk in France after the Le Teil earthquake.
(4) *https://hal.science/hal-02918390* : explanation of site effects when vibrations propagate in the ground.
(5) *https://www.azurseisme.com/Vesubie-seisme-nissart-de-1564.html* : historical data on the Vésubie earthquake (1564).
(6) *https://hal.science/hal-04717089* : scenario of the earthquake and tsunami of February 23, 1887 on the Ligurian Riviera.
(7) *https://www.azurseisme.com/-Seisme-ligure-de-1887-17-.html* : historical data ont the 1887 Ligurian earthquake.

Website (in French) :

https://sismoazur.oca.eu/#/ : real-time monitoring of earthquakes in the region recorded by monitoring networks.
https://www.azurseisme.com/ : informations on historical earhquakes in the region.
https://observaterre.fr/ : a comprehensive national site to find out more.
http://edumed.unice.fr/ : the Mediterranean Educational Observatory for teachers and students.

Scientific publications :

Cinotti, B. et al. (2019). Aléa sismique à Nice. Passer du déni à une action volontaire dans la durée. Rapport n°012485-01 du Ministère de la Transition Ecologique et Solidaire. *https://www.vie-publique.fr/rapport/272086-rapport-alea-sismique-nice*

Courboulex, F. et al. (2007). Seismic hazard on the French Riviera: observations, interpretations and simulations. Geophysical Journal International, 170(1), 387-400. *https://onlinelibrary.wiley.com/doi/10.1111/j.1365-246X.2007.03456.x*

Duval, A. M. et al. (2013). Détection des effets de site sismiques : mise au point de méthodes expérimentales et application à Nice. Bulletin du laboratoire des ponts et Chaussées n 279. *https://hal.science/hal-00850952*

Larroque, C., et al. (2001). Active and recent deformation at the Southern Alps-Ligurian basin junction. *Geologie en Mijnbouw*, *80*(3/4), 255-272. *https://www.cambridge.org/core/journals/netherlands-journal-of-geosciences/article/active-and-recent-deformation-at-the-southern-alps-ligurian-basin-junction/398C8D3A7FE6A19EB641124D9B170169*

Larroque, C. et al. (2011). Morphotectonic and fault–earthquake relationships along the northern Ligurian margin (western Mediterranean) based on high resolution, multibeam bathymetry and multichannel seismic-reflection profiles. *Marine Geophysical Research*, *32*(1-2), 163-179. *https://link.springer.com/article/10.1007/s11001-010-9108-7*

Larroque, C. et al. (2012). Reappraisal of the 1887 Ligurian earthquake (western Mediterranean) from macroseismicity, active tectonics and tsunami modelling. Geophysical Journal International, 190(1), 87-104. *https://onlinelibrary.wiley.com/doi/10.1111/j.1365-246X.2012.05498.x*

What to do in case of earthquake :

During a vibration, if you're **inside a building**, you need to move away from windows, get under - or stuck to - a solid or load-bearing element (a wall or large piece of furniture, for example), protect your neck with your hands, or get out carefully, paying attention to anything that might fall from the top of the building (balconies, chimneys, flowerpots, etc.). Positioning yourself on the ground against a solid element is a good reflex known as the “survival triangle”, providing a safer space in the event of a falling object or ceiling. If you're **outside**, you need to be careful of anything that could collapse, including electrical wires.

After an earthquake :

In the immediate aftermath of an earthquake, you should also be alert to the **risks posed by aftershocks**, the strongest of which can occur just a few minutes after the first shock. It's important to exit buildings carefully, without using elevators, and to stay informed by listening to the radio (*Radio France* in France). Unless it's an emergency, avoid phoning to avoid saturating the networks (SMS is best for brief updates), and stay where you are until it's safe to do so. The key is to assess the damage and move away from dangerous areas, and cut off gas, water and electricity if you can.

For more information, visit the Géorisques site (in French) : portail Géorisques.

* The seismic hazard is the probability that a ground acceleration value will be exceeded in a given period of time (50 years for national regulations concerning standard buildings). It is the combination of the hazard and the vulnerability of the area under study that defines the level of seismic risk.

** The Géoazur laboratory was set up at Sophia Antipolis in the mid-1990s by the Centre National de la Recherche Scientifique (CNRS) and the University of Nice, in response to a request from the Secretary of State for Major Risks to improve the observation and analysis of seismicity in the south-east of France. It is now a public geosciences research laboratory with more than 200 staff and several supervisory institutions (https://geoazur.oca.eu/fr/) : the Université Côte d'Azur, the CNRS (Centre National de la Recherche Scientifique), the OCA (Observatoire de la Côte d'Azur), the IRD (Institut de Recherche pour le Développement) and the CEREMA (Centre d'Etude et d'Expertise sur les Risques, l'Environnement, la Mobilité et l'Aménagement). Real-time seismic monitoring is carried out by a group of engineers and researchers working with the French research infrastructure EPOS-France (https://www.epos-france.fr/)

*** CREREMA: Centre d'Etude et d'Expertise sur les Risques, l'Environnement, la Mobilité et l'Aménagement.

**** Seismic microzoning is used to define small areas of homogeneous behaviour when seismic waves pass through them.

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