Dmytro Usenko
O.O. Dovzhenko, research supervisor
V.V. Strilets, language adviser
Poltava National Technical Yuri Kondratyuk University, Poltava, Ukraine

Resonance during seismic activity and city destruction

Earthquakes are among the most impressive and formidable natural phenomena. They are a real disaster for the residents of high seismic areas. Towns and villages turned into ruins, a lot of people killed, significant damage – this is a terrible tribute that earthquakes annually collect from the humans. For a long time, people have not understood the nature of earthquakes. In ancient times cities and even states died from severe tremors. Therefore, it is not surprising that the study of earthquakes and their consequences are a subject of many research works.

Earthquake is associated with tremors caused by tectonic processes occurring inside the Earth. Our planet consists of the inner and outer cores, mantle and crust. The crust and upper part of the mantle create a cold solid layer called lithosphere. The lithosphere is composed of tectonic plates. The convection forces of the mantle make the plates move in different directions. Most of the earthquakes occur at the junction of plates.

The plates are in constant motion. Friction of the plates rubbing against each other leads to tension between them. As a result of this movement the potential energy is accumulated, which is suddenly released, turning into the energy, that changes the structure of rocks in the earthquake source.

When the plates connect, one of them starts to crawl over another. This is done for millennia resulting in mountain formation. Where plates drift apart, the volcanic lava from the mantle creates a new section of the crust. The boundaries of these plates are under water.

Other plates slowly and simultaneously move in opposite directions. Some of them collide. In the places of collision the potential energy is accumulated which is later released in the form of an earthquake.

The point beneath the Earth’s surface where the earthquake starts is called a hypocenter. The point which is above the hypocenter and situated on the ground is called an epicenter.

The energy released as a result of an earthquake is divided into three types. Primary P-waves are felt like a sudden shock, secondary S-waves arrive a few seconds after P-waves and are felt like longer transverse vibrations. Surface waves diverge from the epicenter arriving after the P and S waves. Love waves (L-waves) make the Earth’s surface swing in different directions. Rayleigh waves (R-waves) cause the rotational movement of particles from the top to the bottom. These two types of surface waves lead to the largest damage. The cause of the earthquake is the rapid shift of the crust at the time of plastic or brittle deformation of strained rocks in the earthquake source. Most sources of earthquakes are near the Earth’s surface. The displacement is caused under the action of elastic forces during the discharge process that is - reducing the elastic deformation of the entire area of the plate and shifting to the equilibrium.

Some buildings have seismic protection. However, there are cases when the buildings without protection survive during the earthquake, while most of the others are destroyed. Surprisingly, these cases are not uncommon. High and seemingly fragile ancient structures sustain earthquakes, whereas modern and stable-looking buildings fall down. Why does it happen?

Earthquakes generate seismic waves that pass through the land. Like ocean waves, they have crests and troughs. The wave frequency is associated with a period of time necessary for the passage of one wave.

Houses have different resonance frequency and different natural oscillation period. Imagine your child on a swing. The swing with short ropes completes one cycle much faster than that with long ones. The same principle applies to buildings of different heights. Each building is like an inverted pendulum. Higher buildings have longer periods of oscillation. In addition, the period is also affected by the ground, on which the house is built: a shorter period occurs on the soft soil while a longer one – on the stone surface.

Professor Kwon from Massachusetts University conducted an experiment relating to this phenomenon. He used a simplified model of three buildings – of 14, 9 and 5 floors. At first, the installation models a low-frequency earthquake (4 Hz), which is devastating for the 14-storey building (42 meters in height). At this time, other buildings remain intact.

Then the platform creates shocks equal to the 6.35 Hz-intensity earthquake, destroying the 9-storey house (27 meters in height). Similarly to the previous case, damage is observed only in the building, the natural frequency of which coincides with the installation that is the earthquake, and is in resonance with it.

At the final stage the platform imitates the high-frequency earthquake (11.35 Hz), which destroys homes and building of low heights, or 5 floors (15 m), entering into resonance with them.

High-frequency waves having short period amplify in rock formations, and cause moderate and weak earthquakes, such as in Amatrich. Low-frequency waves with long period which amplify in sedimentary rocks are formed during large earthquakes, such as the infamous earthquake in Nepal that overthrew Dharahara Tower in 2015. When the resonance frequency of the soil coincides with that of the building, the latter undergoes the greatest possible fluctuations and gets the most damage. The stiffness and mass distribution along the building height also have a big impact on the probability of damage.

Ancient buildings need to be modernized and made more resistant to earthquakes. Do not forget about the cumulative effect, as ancient buildings survived many earthquakes and may have accumulated strain preventing them from sustaining a weak earthquake. New buildings resistant to resonance with surface fluctuations should be designed after a thorough study of the history of earthquakes in the region.