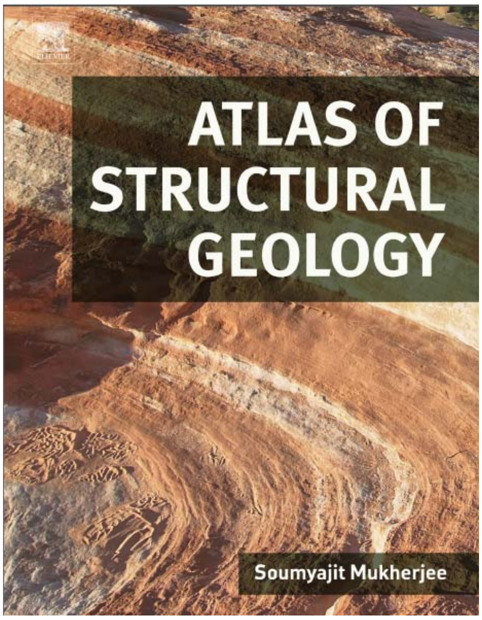

Geological features in ancient buildings – archaeoseismology

In: Mukherjee, S. (ed.) (2015): Atlas of Structural Geology. Elsevier, Amsterdam, pp. 153-155, figs 6.52-6.55.

Miklós Kázmér
Department of Palaeontology, Eötvös University
Budapest, Hungary
mkazmer@gmail.com

The instrumental record of seismic activity is less than hundred years old, while the recurrence of major earthquakes is measured on a centennial to millennial scale. Archaeoseismology aims to extend this record throughout the period characterized by man-made structures. Ancient buildings bearing particular features of damages provide evidence for past earthquakes. These allow to determine parameters (date, intensity, epicentre, magnitude) of causative seismic events. Terms of structural geology are used in describing the damages produced by seismic loading. Examples of secondary, off-fault damages, produced by seismic shaking, are shown below.

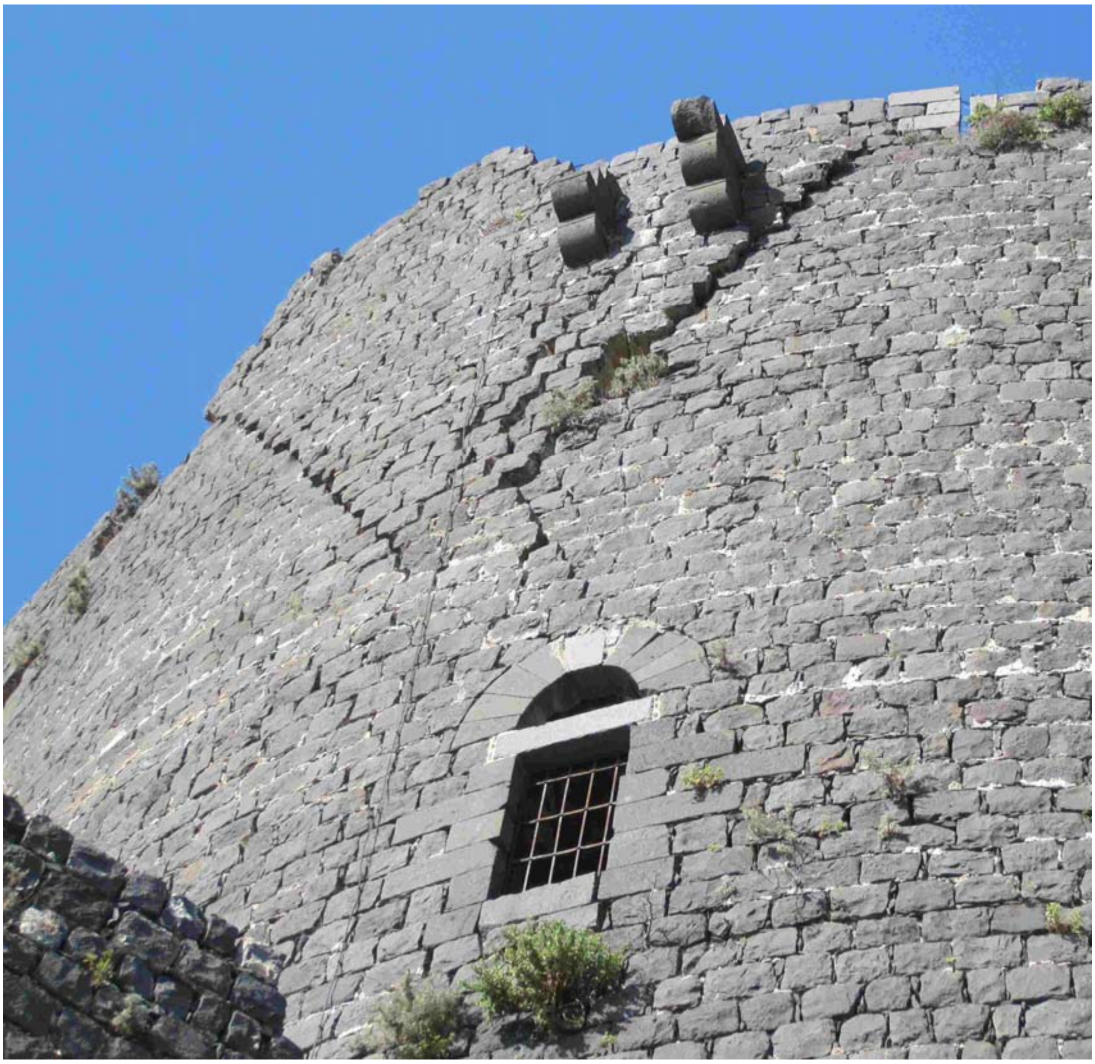

Fig. 6.52. **V-shaped, extruded block bordered by conjugate faults**. A wedge-shaped block of masonry, ca. 7 × 7 m, shifted toward 240° azimuth by ~20 cm during the largest known earthquake in the Near East, in 1202 AD. Donjon of al-Marqab citadel, Syria, built by the Hospitaller knights in late 12th century. Built of Roman concrete (rubble in lime), the external and internal walls are faced by dressed basalt blocks. Walls are up to 5 m thick, diameter of the tower is 20 m. Between floors – where the extruded wedge is – the building is compact. Al-Marqab, south of Baniyas on the Mediterranean coast, Syria (35° 09' N, 35° 56' E). Photo #1798.

Supporting references

Kázmér, M., 2014. Damages to ancient buildings from earthquakes. In: Beer, M., Patelli, E., Kouigioumtzoglou, I., Au, I. S.-K. (Eds.), Encyclopedia of Earthquake Engineering, Springer, Berlin (accepted)

Further reading:

Kázmér, M., Major, B., 2010. Distinguishing damages of two earthquakes – archeoseismology of a Crusader castle (Al-Marqab citadel, Syria). In: Sintubin, M. Stewart, I., Niemi, T., Altunel, E. (Eds.), Ancient Earthquakes. Geological Society of America Special Paper, 471, 186 –199.

Fig. 6.53. **Distributed left-lateral strike-slip deformation** in the Roman theatre of Baelo Claudia, Gibraltar Straits, Spain (36° 05' N, 5° 46' E). There are conspicuous displacements visible on the wall of the staircase and between the blocks forming the arch in the foreground. Displacement is larger upwards (max. 10 cm), indicating seismic shaking: the top part of the building oscillated with higher amplitude than the lower part, attached to the foundation.
The town along the northern coast of Gibraltar Straits, flourished during 1st to 4th century AD. After an earthquake of intensity IX-X MSK about 350-395 AD the city was abandoned. Active faults nearby and a landslide within the area of the Roman town contributed to the damages. Scale: stairs on the left are 20-25 cm high. Photo #8375.

Supporting references

Kamh, G.M.E., Kallash, A., Azzam, R. 2008. Factors controlling building susceptibility to earthquakes: 14-year recordings of Islamic archaeological sites in Old Cairo, Egypt: a case study. Environmental Geology 56, 269-279.

Karakhanian, A.S., Trifonov, V.G., Ivanova, T.P., Avagyan, A., Rukieh, M., Minini, H., Dodonov, A.E., Bachmanov, D.M., 2008. Seismic deformation in the St. Simeon monasteries (Qal'at Sim'an), northwestern Syria. Tectonophysics 453, 122-147.

Grützner, C., Reicherter, K., Hübscher, C., Silva, P.G., 2012. Active faulting and neotectonics in the *Baelo Claudia* area, Campo de Gibraltar (southern Spain). Tectonophysics 554-557, 127-142.

Further reading

Silva, P.G., Borja, F., Zazo, C., Groy, J.L., Bardají, T., De Luque, L., Lario, J., Dabrio, C.J., 2005. Archaeoseismic record at the ancient Roman city of *Baelo Claudia* (Cádiz, south Spain). Tectonophysics 408, 129-146.

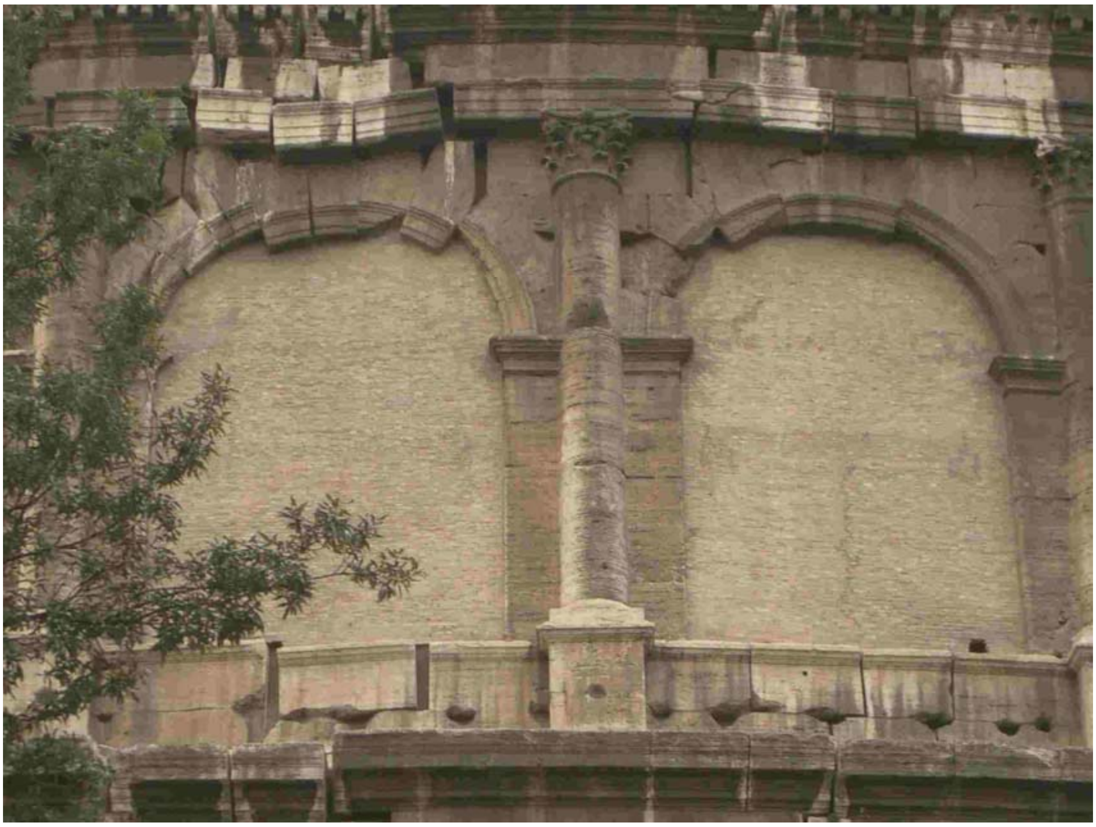

Fig. 6.54. **Dropped keystones and adjacent blocks in the arches of the Colosseum, caused by earthquake shaking.** The feature is a miniature analogue of rifting: extension produced open fissures, normal faulting, subsidence and tilting of blocks.

The Flavian amphitheatre in Rome, Italy, (worldwide known as Colosseum) was built between 70 and 76 AD (41° 53’ N, 12° 29’ E). The external wall is composed of travertine blocks originally connected by iron pins and cramps embedded in lead, without mortar. Holes of uniform size between the blocks were made to steal the lead in times of scarce supply. Several earthquakes between 508 AD and 1703 AD affected Rome and the Colosseum. Heterogeneity of the soil beneath the foundations (lake sediments below the northern part as opposed to an abandoned bed of the river Tiberis below the southern part) yielded uneven vibration and settlement during earthquakes. This is why the southern perimeter wall of the Colosseum collapsed. The photo shows severely damaged arcades #23 and #24 between the collapsed and intact portions of the external wall on the eastern end of the amphitheatre. These were closed by a brick wall during a restoration effort in 1805-1807, preserving the arches in their damaged form. Photo #9338

Supporting references

Marco, S., 2008. Recognition of earthquake-related damage in archaeological sites: Examples from the Dead Sea fault zone. Tectonophysics 453, 148-156.

Kamai, R., Hatzor, Y.H., 2008. Numerical analysis of block stone displacements in ancient masonry structures: A new method to estimate historic ground motions. International Journal for Numerical and Analytical Methods in Geomechanics 32, 1321-1340.

Korjenkov, A.M., Mazor, E., 2003. Archeoseismology in Mamshit (Southern Israel): Cracking a millennium-old code of earthquakes preserved in ancient ruins. Archäologischer Anzeiger 2003/2, 51-82.

Further reading:

Pau, A., Vestroni, F., 2008. Vibration analysis and dynamic characterization of the Colosseum. Structural Control and Health Monitoring 15, 1105-1121.

Fig. 6.55. **Rotated blocks** within the sea wall of the crusader castle, Tartous, coastal Syria (39° 53’ N, 35° 52’ E). The fortress, built in the 12th century by the knights of the Temple, suffered the greatest damage probably during the 1202 AD earthquake. Blocks are ca. 70 cm high. The counterclockwise rotation of four blocks together (left block towards the viewer) was caused by E-W strong seismic motion. There is a right-lateral strike-slip fault on the northern side of the leftmost blocks. Vertical component of seismic waves allowed the blocks to rotate when the overburden was momentarily relieved, and seismic loading overcame friction. Photo #4682.

Supporting references

Korjenkov, A.M., Mazor, E., 1999. Seismogenic origin of the ancient Avdat ruins, Negev desert, Israel. Natural Hazards 18, 193-226.

Rodríguez-Pascua, M.A., Pérez-López, R., Silva, P.G., Giner-Robles, J.L., Garduño-Monroy, V.H., Reicherter, K., 2011. A comprehensive classification of earthquake archaeological effects (EAE) for archaeoseismology. Quaternary International 242, 20-30.

Similox-Tohon, D., Sintubin, M., Muchez, Ph., Verhaert, G., Vanneste, K., Fernandez, M., Vandycke, S., Vanhaverbeke, H., Waelkens, M., 2006. The identification of an active fault by a multidisciplinary study at the archaeological site of Sagalassos (SW Turkey). Tectonophysics 420, 371-397. Erratum: 435, 55-62.

Further reading:

Meghraoui, M., Gomez, F., Sbeinati, R., Van der Woerd, J., Mouty, M., Darkal, A.N., Radwan, Y., Layyous, I., Al Najjar, H., Darawcheh, R., Hijazi, F., Al-Ghazzi, R., Barazangi, M., 2003. Evidence for 830 years of seismic quiescence from paleoseismology, archaeoseismology and historical seismicity along the Dead Sea Fault in Syria. Earth and Planetary Science Letters 210, 35-52.