Modeling the impact of subsoil strain on buildings

Too Much to Bear

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Everybody knows the parable about two houses, one built on sand and another on solid rock. This just goes to show that even thousands of years ago, people realized how crucially a building's safety depends on whether it rests on the proper subsoil

All the loads affecting a building are "collected" by the elements of its structure - like roofs and ceilings, bearing walls, door heads, beams and pillars - and transmitted to the ground by its foundation. Hence, the ideal subsoil should be rigid and strain-resistant. However, such subsoil is not always available.

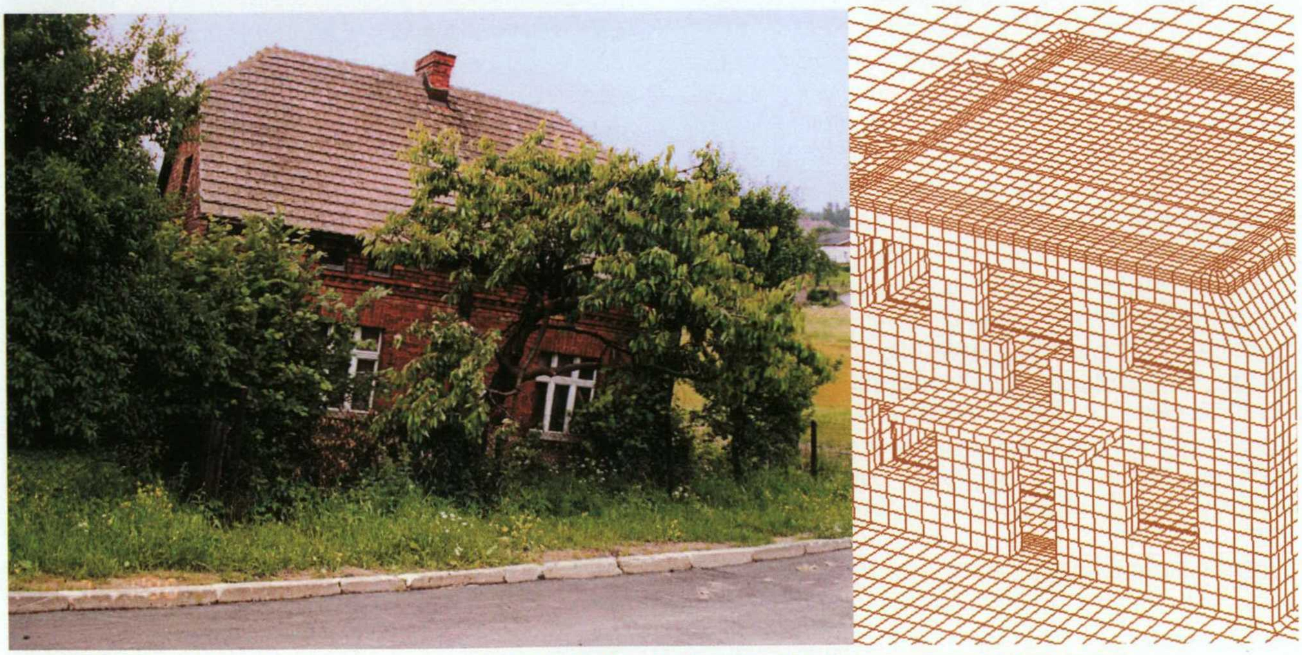
Our planet has long geological history. As a result, the typical subsoil is stratified, including both hard (strong) and soft (weak) rock layers. Soft and easily deformable soils are often incapable of bearing the load of a heavy structure. Probably the best-known example of a building set on inadequate subsoil is the famous belfry tower in Pisa. Nevertheless, potentially damaging strains in the subsoil can also result from human activities. Such occurrences are typically related to various kinds of excavation. So-called mining damage is particularly common in the vicinity of underground mines.

On strained ground

At the Polish Academy of Sciences' Strata Mechanics Research Institute in Kraków, we have developed a state-of-the-art numerical subsoil model for simulating the interaction between a building or another structure and the underlying ground. This model was based on the ABAQUS finite element method package.

We begin the process of modeling the influence of subsoil strains on a building by collecting as much information about the actual state of affairs as possible. If the building already exists, precise measurements are taken and the overall condition of the structure is assessed. This includes collecting data about the materials used in the building. Alternatively, if the structure is still being designed, the input data for our model is taken from technical documentation. The parameters of the soil are obtained through geological survey. Typically a number of boreholes are required to investigate the sequence of strata and to acquire specimens for soil property analysis in the laboratory. This is the most important stage of work, as even the best numerical model will produce unreliable results if it is fed erroneous information.

Jan Leśniak



The typical building damage wrought by ongoing mining operations can be forecast using a four-dimensional computer model of subsoil strain

The data input stage usually begins with sketching the geometry of the system. This can be easy or difficult, depending on the complexity of the building's solid shape. For the subsoil, however, the problem is much more complex. This is because geological strata, unlike buildings, are of infinite dimensions. To limit the calculation to a reasonable level, such dimensions are simplified. The idea of so-called infinite elements is that they "concentrate" the solution around the loaded areas, and make it disappear while receding from the "center".

Time flows – and earth flows too

The next stage of modeling involves choosing the proper law of materials, that is, determining the behavior of a material (e.g. reinforced concrete, brick wall or soil) under the influence of a load. Some materials, especially soils, also change with time. This is taken into account when the law of materials is being formulated. The algorithm developed by our Institute involves both elastic and plastic behavior of soils, as well as their rheological properties (the factor of time).

This soil-related procedure works in the following way: in the initial state, mostly geostatic stresses are present in the strata, resulting from the dead weight of the soil. Due to load imposed on the subsoil, it begins to deform. This is at first an elastic strain, then followed by yielding (plastic flow). It can be either a consolidating process, with compaction hardening the soil, or a cohesive (loosening) one, with softening. Additionally, our model simulates the mechanism of soil creep, which is time-dependent. This makes it possible to correctly forecast the behavior of the strata, to anticipate any slow-running processes that would not manifest any symptoms until many years had passed.

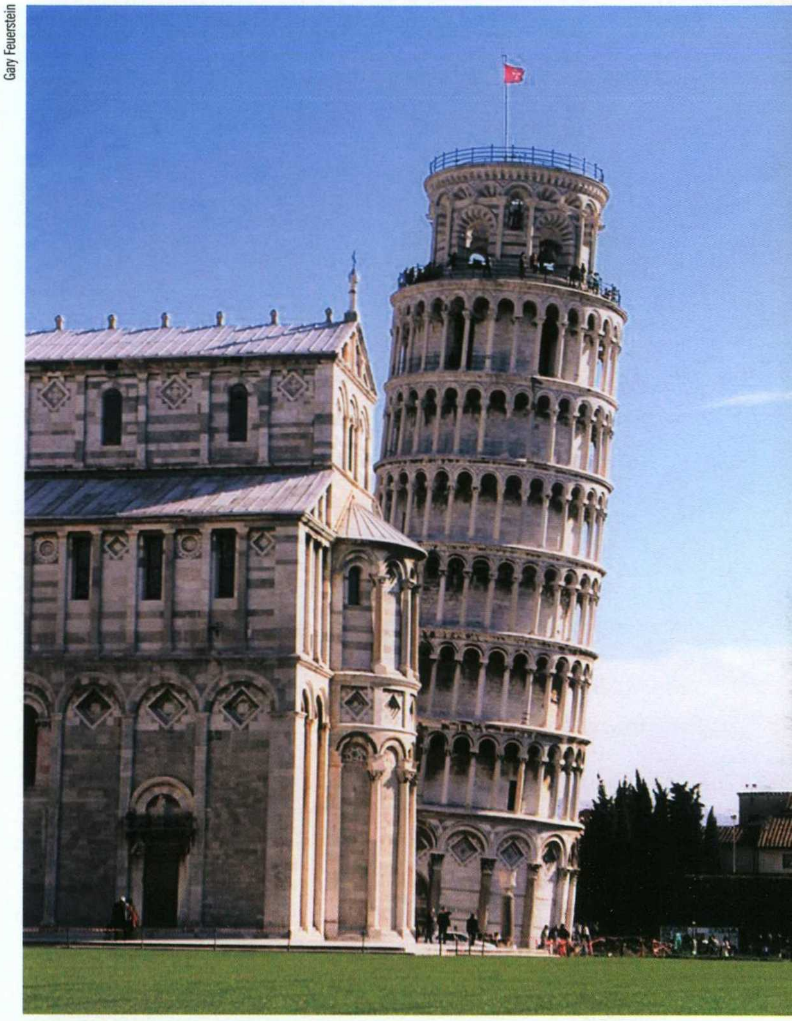
The foundation connects the building to the subsoil and transfers the entire load from the construction to the ground, and conversely, everything that affects the subsoil is transmitted through the foundation to the building structure. It is therefore essential to describe the conditions present where the foundation contacts the soil with the highest possible precision. A full transmission of interaction has been assumed in a direction perpendicular to the contact surface, whereas tangential interactions are transferred by means of friction. There is also the possibility of slips, which often occur where the building contacts the soil.

Virtually undermined

The greatest challenge lies in properly modeling the processes that cause strains to appear in the strata (e.g. water infiltration, quicksand, mining trough, active fault, etc.). Our Institute specializes in solving problems related to mining damage. For this purpose, we developed a specialized numerical algorithm which simulates the process of a mining trough forming in the subsoil beneath a building. Such a trough is initiated within the strata and changes with time.

Once the data have been entered into the computer and a finite element mesh has been fully created, a series of arduous calculations begins. Several hundred thousand algebraic equations need to be solved. The results provide an answer as to whether the given building is prone to damage, or even collapse. If it is the case, the values of the stresses, strains and displacements so obtained allow the proper building structure protection or subsoil reinforcement to be correctly designed. ■

Gary Feuerstein



The famous leaning tower of Pisa is a perfect example of how subsoil strain can affect buildings

Further reading:

Florkowska L., Walaszczyk J. (2004). *On the possibilities of computer modeling in the interaction between a building and actively deforming mining ground.* Archives of Mining Sciences 49, Special Issue, 83-98.

Florkowska L. (2003). *Selected problems of interaction between buildings and the ground.* Prace IMG PAN, Rozprawy, monografie, 3 [in Polish].