Prefabricated underground shelters for critical infrastructure or human protection made of green concrete

Wars in conjunction with forced global military build-up and the increasing threat of terrorism have led to a massive increase in demand for shelters. For the quick reconstruction of transformer stations that were originally installed above ground and destroyed by the war in Ukraine, Ukrainian local authorities requested underground shelters.

The German Federal Government also recognised in its Security Strategy 2023: "Our critical infrastructures are increasingly the target of significant threats and disruptions."

Above-ground, practically unsecured transformer station in Germany

The conventional construction of underground shelters often takes several years, as very complex and cost-intensive special civil engineering measures are often required before the actual construction of the shelters can begin, depending on the ground conditions.

Prefabricated elements have been used in building construction for a long time to reduce construction times. Industrial prefabrication is significantly more efficient and assembly times on the construction site are many times faster. No concrete setting times need to be observed on the construction site, as is usual with in-situ concrete construction, and the full static load-bearing capacity is immediately available.

Prefabricated parts from industrial prefabrication, known as segmental “Tübbing” elements, have also been used for a long time in mining and tunnelling for the construction of both, vertical shafts and horizontal tunnels. The elements consist of circular segments made of various materials, primarily cast steel, rolled steel plates and reinforced concrete.

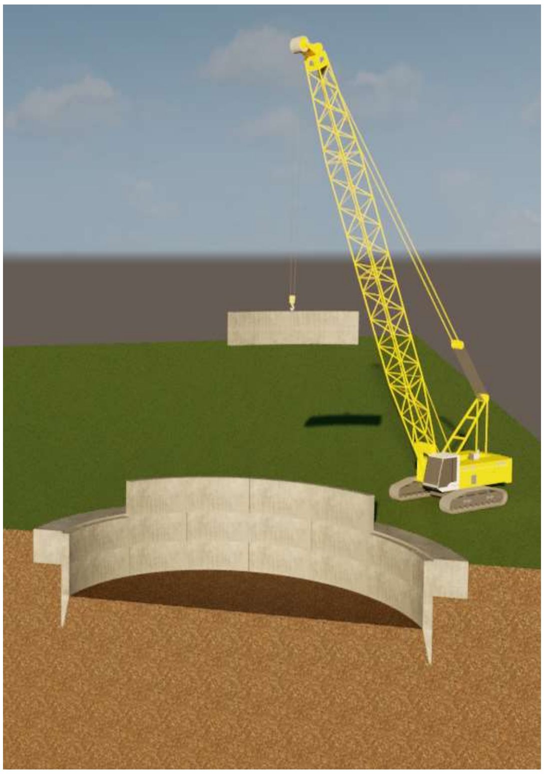
Long construction times cannot be accepted for human protection and also for the underground reconstruction of transformer stations, which are an important component of the power supply. One problem here is the necessary depth of the structures. Static requirements and the presence of groundwater can massively increase the effort and therefore the construction time.

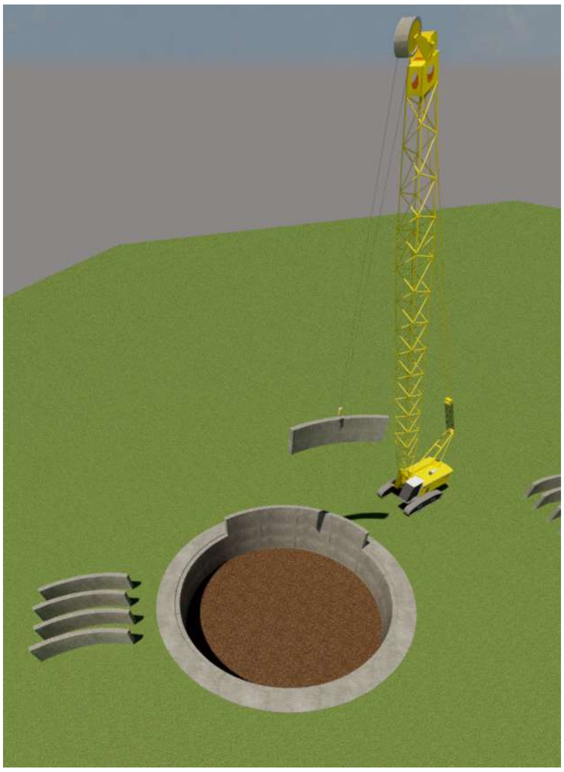
The following concept was developed to solve the problems described.

The requirements for the size and subsequent use of the shelter buildings can vary greatly, so different geometric shapes can be considered, but a circular shape is preferable from the structural point of view. The following solution is based on circular shelter structures, but rectangular structures or structures with other geometries can also be realized using the same approach.

The lowering method (without a pressurized air chamber, as is common in the caisson method) is the preferred installation method, as it is the fastest method regardless of the ground conditions and groundwater level. This method does not require an excavation pit, the structure replaces the necessary support and is lowered by the excavation/pumping of the soil and by its own weight.

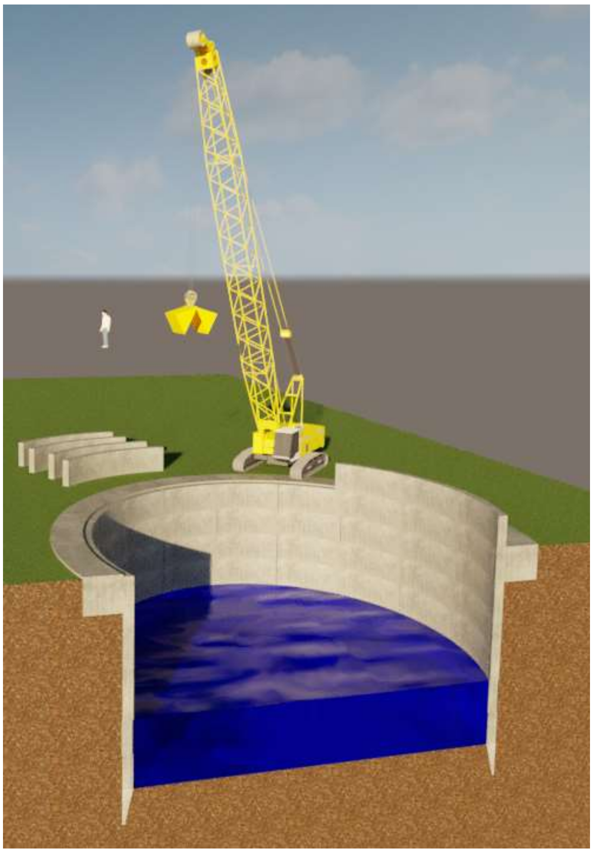
From the construction process point of view, the diameter of the structures should be between 2.0 and 24.0 meters. Depending on the transport and crane capacities, precast rings can be used in the small diameter range and precast circular segments in the larger diameter range. The underside segments are provided with a cutting edge.





Depending on the required depth of the shelter building, soil can be excavated within the building to a depth of around 30-40 meters using a cable excavator, in dry excavation or in groundwater in wet excavation. Greater depths are generally uneconomical, as the excavation intervals become too long with increasing depth. For harder soil types and greater depths, the use of a slurry pump in combination with a technique for breaking up the soil, as used in floating excavators, is recommended. This often requires the groundwater that is already present or the addition of water. The soil is removed mechanically, usually with rotating excavation tools, or with high-pressure or ultra-high-pressure water jets. The water-soil mixture is then pumped out. The major advantage of this method is the continuous excavation and removal of the soil compared to discontinuous cable excavator operation. This is associated with a further reduction in construction time. In contrast to the cable excavator technique, however, pumping requires an additional soil separation system.

The weight of the industrially prefabricated rings or circular segments, which are assembled into watertight rings before being lowered, allows the structure to sink slowly. The sinking of the structure can be controlled by removing the soil and using holding devices. As soon as the last ring installed has reached ground level, excavation is interrupted and the next rings are installed.

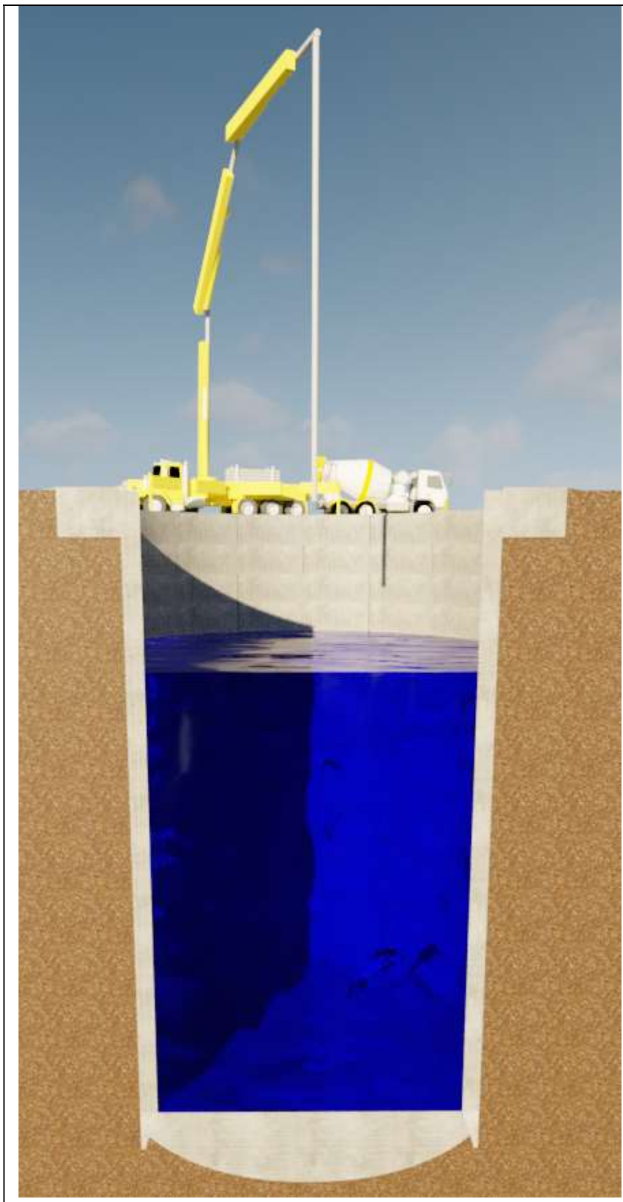
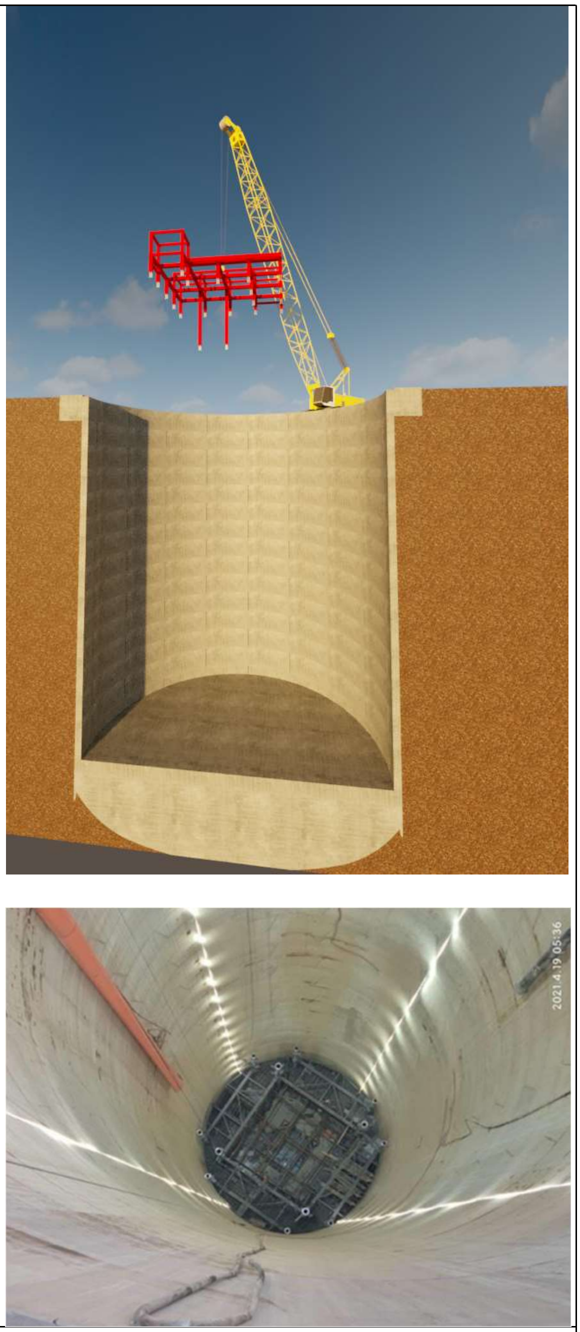


Soil excavation with cable excavator in groundwater

Soil excavation with milling / pumping technology for greater depths (Herrenknecht AG)

Once the planned depth of the shelter building has been reached, the lowering process ends and an underwater concrete base is installed. For this purpose, the precast segments in the lower area of the structure are prepared during production to accommodate steel reinforcement and for watertight "interlocking" with the underwater concrete base. After the underwater concrete base has hardened, the water can be pumped out of the structure.

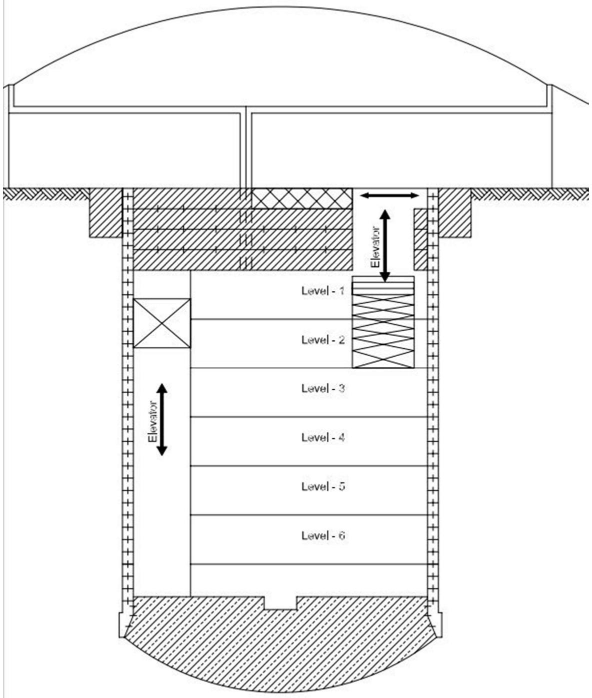
The internal installations are carried out before the shelter top of the protective structure is completed. Similar to the industrial prefabrication of the outer walls of the shelter, the floor levels, any partition walls and the lift/staircase construction, ventilation pipes and pipes for irrigation and drainage are also manufactured as modules.

	
Installation of the underwater concrete base	Installation of the shelter interior modules

The installations are prefabricated in transportable units according to the modular principle, lowered into the open structure and connected together there. This results in a further reduction of the construction time.

Once the interior work on the shelter has been completed, the shelter roof is also assembled from prefabricated elements. Depending on the subsequent use of the underground shelter, further escape routes and supply and disposal lines can be constructed as horizontal tunnels in addition to the main access shaft.

Installation of the shelter roof



Possible installation variant with several levels and covered with the excavated material

The shelter roof can later be used as a foundation for a building or covered with the excavated soil.

If covering with soil is considered, the main access shaft is also built over with prefabricated semi-circular segments and led out of the soil cover.

With the method described, underground shelters can be constructed at depths of over 100 meters, regardless of the groundwater and geology.

Advantages of the construction method:

- Significant reduction in construction time
- Multifunctional use due to modular construction principle
- Safety requirements can be customized thanks to flexible prefabricated part thicknesses and large depths
- Space requirements can be easily adapted thanks to greater depths / more levels
- Deep shelter buildings are significantly more cost-effective than conventional construction methods
- Extremely small space requirement, therefore also easy to use in city centers
- Shelters can be built at a later stage and can also be connected to existing buildings via tunnels in city centers
- Elimination of temporary excavation pit support and more effective precast element production significantly reduce emissions

Decarbonization through modified construction technology and production of the concrete segment elements using "green concrete" according to the Wismar method.

The significantly reduced use of construction process technology, the elimination of temporary construction pit shoring and the more effective production of prefabricated parts already reduce emissions considerably compared to the conventional construction of shelters.

The use of conventional concrete would continue to generate very high emissions. Around 600 - 800 tons of concrete are required for a 10-meter-deep shelter structure with a shaft diameter of 12 meters. The Wismar process is therefore to be used in the production of precast elements. The aim of the process is to produce recycled cement from old crushed concrete using an energy-saving low-temperature process. Emissions during cement production are mainly generated during the production of cement clinker. Around two thirds of these are caused by the release of CO_2 from the raw materials used (calcination of limestone) and one third by the burning of the fuels. In the Wismar process, calcination is eliminated and the energy required for production is only around one third of the cement clinker combustion.

- **Process step I**: Shredding the concrete to extract the crushed concrete sand.
- **Process step II**: Further mechanical processing of the crushed concrete sand enriches the cement paste content in the ultra-fine fraction.
- **Process step III**: Thermal treatment produces an independent hydraulic binder, the RC cement, from the finest fraction.

By using RC gravel in combination with RC cement, the Wismar process can achieve a complete environmental cycle.

The process has already been demonstrated on a laboratory scale at Wismar University of Applied Sciences; the strength development of RC cement is comparable to that of Portland cement. The use of RC gravel, which is a by-product of RC cement production, results in higher compressive strengths due to its coating with microfine, hydraulically active binder particles.

The next step is the implementation of a pilot project to demonstrate the performance of "green concrete" and the realisation of a closed cycle concept for the production of segment elements for the construction of underground shelters for critical infrastructure.

Another effect that has not yet been investigated in detail is the possibility of utilising the previously unused exhaust heat from the above-ground transformer stations in an underground, closed structure for the local/district heating supply.

Responsible:

Prof. Jens Hölterhoff Construction Management / Construction Technology

Prof. Winfried Malorny Building Construction Materials Technology