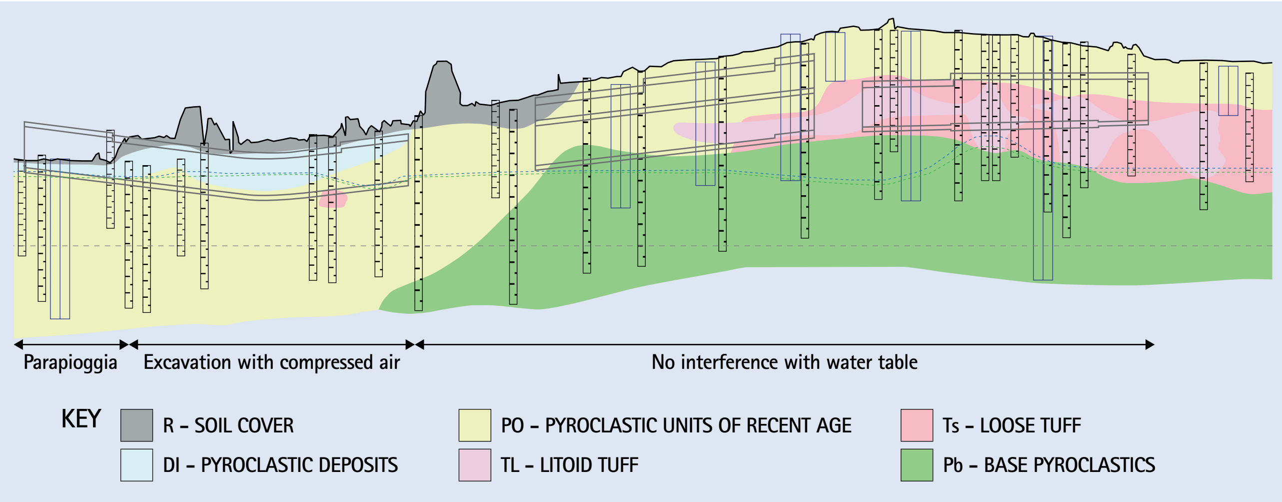
KEEPING UP THE PRESSURE

A cut-and-cover tunnel in Italy will make use of high pressure compressed air in what engineers are claiming is a first for the Mediterranean country. **Paola De Pascali** spoke with Andrea Pigorini, the head of infrastructure engineering at Italferr, and a spokesperson for for Salini Impregilo, to find out more



Above: ***Profile of the geology along the tunnel alignment***

IT'S NEVER TOO LATE TO try something new. The Casalnuovo tunnel, which will be built partially below the water table, will be the first cut-and-cover tunnel in Italy to be built using high-pressure compressed air techniques. The 1.1km-long structure will be built top-down and the use of hyperbarics are to create a dry base during construction.

The tunnel will form part of the high-speed rail (HSR) line between Naples and Bari, which itself forms part of the Scandinavia-Mediterranean Corridor of the Trans-European Network (TEN-T). TEN-T is a grand plan to build an integrated multimodal transport network to move people and goods across Europe. The Naples-Cancello section will cost 400M (USD 445M), while the whole project Naples-Bari will be EUR 6.2bn (USD 6.86bn) and run for some 180km, with newly-built line comprising 120km of this. Trains will reach speeds of 250km/h.

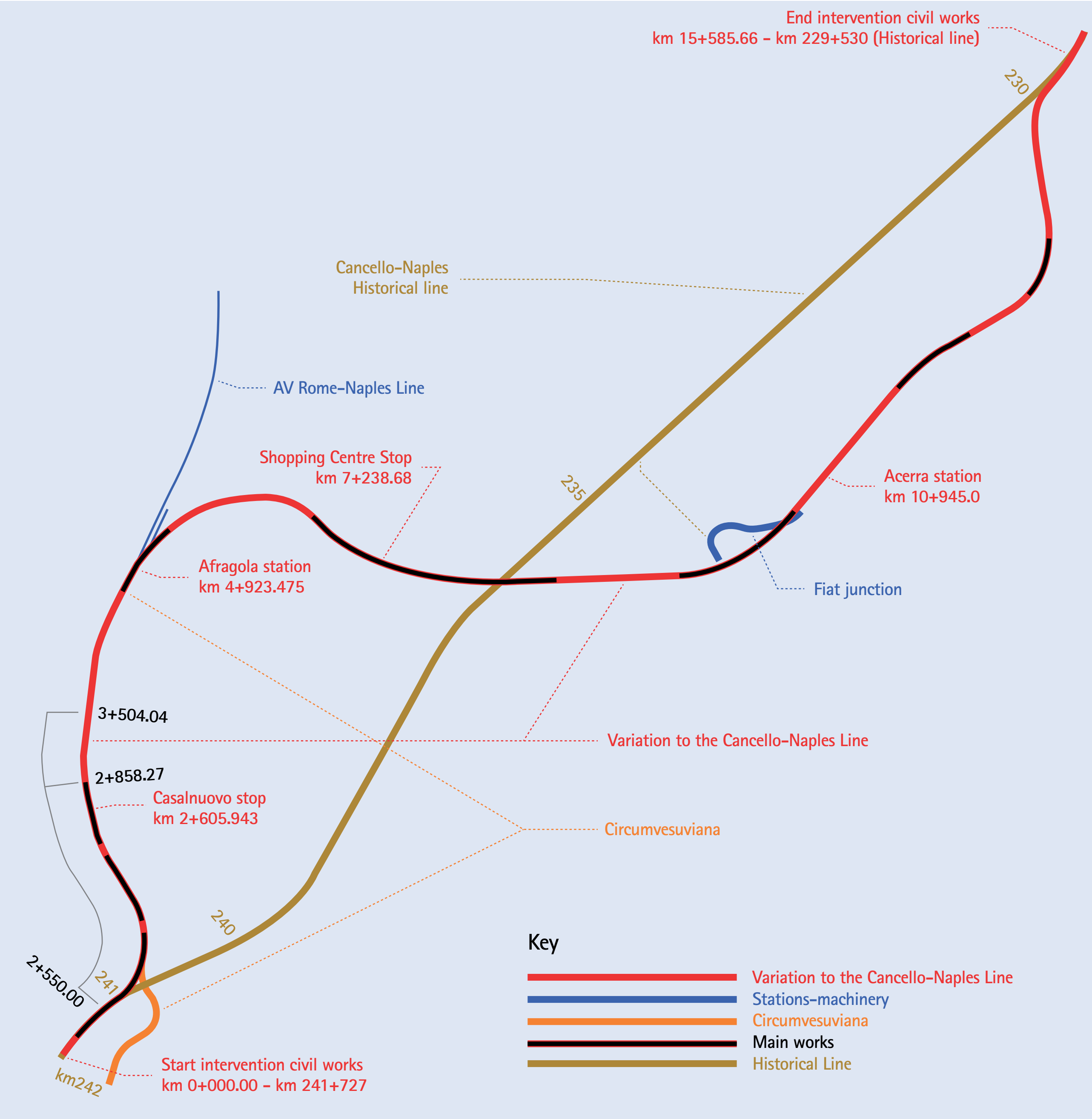
Due to the need to pass through the Apennines, more than 50% of the line will be located underground, with some 82km in bored tunnels and 6km in cut-and-cover.

The project is owned by the Italian state railway (Rete Ferroviaria Italiana from Gruppo Ferrovie dello Stato Italiane) with Salini Impregilo and Astaldi as contractors. The final design has been completed, with some aspects being checked by a group of designers comprising Systra, Systra-Sotecni and Rocksoil. It is due to be completed in December 2026, but the Casalnuovo tunnel is expected to complete in 2023.

GEOLOGICAL CONDITIONS OF THE PIANA CAMPANA

The Casalnuovo tunnel is to be built within the Naples area. The flat area around Naples (nestled between the Tyrrhenian Sea, the Massico Mountain, the mountains of Caserta and the famous Vesuvius) is called the Piana Campana. The Piana Campana is a geologically young (30,000-39,000 years) structural depression, filled with sedimentary and volcanic deposits of the plio-quaternary age. The northern, southern and eastern margins are constituted by Mesozoic carbonate soils and by Miocene, calcareous and siliciclastic soils between the Burdigalian and the upper Tortonian (Miocene). These soils derive from the deformation of the western-most areas characterised by carbonate sediments.

The Piana has been progressively filled by marine deposits, alluvial and marsh, by the volcanic products of Campi Flegrei and those of the Somma-Vesuvio complex.



***Above:* General layout map of the network**

The lithostratigraphic units that are found along the alignment of the cut and cover tunnel itself are: soil, pyroclastic deposits, young pyroclastic units, lithoid tuff, loose tuff, base pyroclastics.

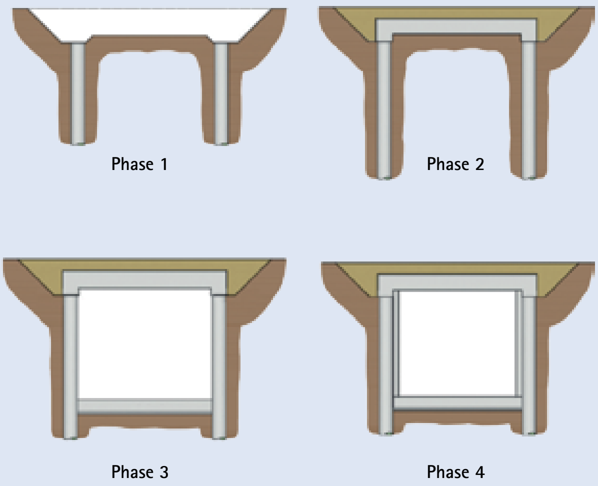
The main aquifer is located in the Base Pyroclastics, which are at the top level by the Ignimbrite Campana (Litoid and Loose Tuff). In the upper layer, where the tunnel will be excavated, there is a superficial aquifer connected with the deeper one.

The average permeability ranges from 10-3 to 10-6m/s.The tunnel stretch interfering with the ground-water is mainly excavated in DI and PO units, which can be classified respectively as silty-clayey sands and clayey-silty sands and medium to coarse sands with silt and gravel derived from volcanic deposits. Salini Impregilo carried out permeability coefficient tests to design the structures accordingly. This is vital as the ground is more permeable to the air than the thicker water, and the air can push into the ground.

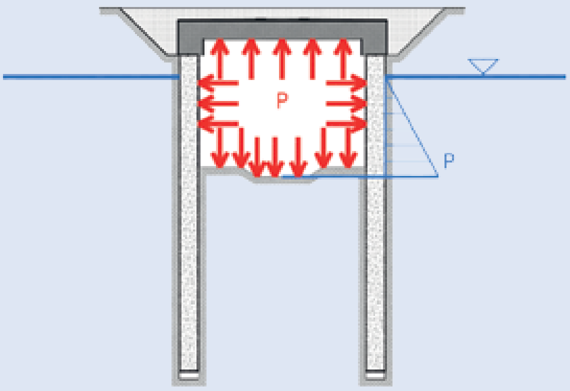
The final design includes a study on the geological, geomorphological and hydrogeologic and seismic situation. Several analyses have been done including 50 surveys that include continuous coring, test pits and 18 piezometers to follow up and redefine the lithological, stratigraphic and hydrogeological reconstructions.

CONSTRUCTION METHODOLOGY

The Casalnuovo Gallery has a rectangular single-barrel cross section (double track width = 10m) and double-barrel sections



Above: The tunnel will be constructed following the top down method which foresees the following phases: Excavation to the diaphragm wall execution level and realisation of the diaphragm walls; Cast of the r.c. roof slab and backfilling above the roof slab; Excavation below the roof slab, between the diaphragm walls, to the foundation level and cast of the bottom slab; Cast of the lining walls and finishes installation



Above: In order to perform the excavation and the cast of internal structures in dry condition, a pressure higher than the atmospheric one is applied in the tunnel after the execution of the backfilling, before the start of digging operations. The pressure value to be applied is equal to the corresponding value of hydrostatic pressure acting on the excavation bottom due to the water head at that time.After the internal structures are casted and sealed it is possible to deactivate the internal air pressure

separated by a central septum of 1.1m (second barrel width = 8.6m). The tunnel will be built top-down, with the following procedure:

- Excavation of the diaphragm wall; execution level and building the diaphragm walls;
- Casting of the reinforced concrete roof slab and backfilling above the roof slab;
- Excavation below the roof slab, between the diaphragm walls, to the foundation level and cast of the bottom slab;
- Cast of the lining walls to finish the installation.

Specifically, the tunnel will be built with the 'Milan Method', which means means doing lateral and central diaphragm walls first and then a cover slab. After that, tunnel excavation will be performed. The hydraulic thrust will be countered by the hyperbaric pressure through air injection from outside. On 200m of 1.3km-long tunnel, the ground water pressure will be countered by counterthrust of a primary slab.

The main issue related to the Casalnuovo tunnel is the ground water table that is located few metres below the surface in high permeability pyroclastic deposits. The first idea was to execute a jet-grouting plug as temporary waterproofing with high pressure execution of jet-grout columns. This technique has been changed by a technical proposal done by the contractor Salini Impregilo, during the tender phase that proposed the compressed-air system.

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The internal pressure represents an additional load acting on the structure in the temporary phase that should be considered in structural analyses. This does not require a strengthening of the structure. Assuming the air pressure is kept steady during the whole excavation process, it reduces the internal actions associated to the temporary phase.

While the compressed air system is active, the whole equilibrium toward possible uplift has to be checked. The internal pressure, determined to be sufficient to counteract the water pressure at the bottom of the excavation, can lead to structure uplift in case of insufficient backfilling. This condition should be taken into account performing a specific check, which should consider the internal pressure of the air, the weight of the structure, the backfilling load, the anchoring strength of the diaphragm walls in the ground.

On 700m of the whole route, vibrocompacted columns will be installed in gravel, due to liquefiable strata at the ground level.

Table 1: Comparison between jet grouting and compressed air

	Jet Grouting	Compressed Air
Watertightness in the construction phase	Partial: due to the impossibility of a comprehensive field test, it is quite likely that there will be a water inflow path.	Perfect: all the water inflow paths are counteracted by the air pressure.
Environmental impact	Possible: the chemical components of the jet grouting mixture could pollute the ground water.	None: no chemical substances are introduced in the ground.
Management of unexpected water levels	Difficult: the jet grouting plug is sized in the design phase and can manage ground water fluctuation limited to the assumed safe factors.	Easy: it is sufficient to increase the air pressure to counteract a higher water head.
Costs	High costs due to soil treatment works.	The higher cost of the necessary construction plant is offset by the elimination of the soil treatment.
Works duration	A long time is needed for soil improvement works and there are possible delays during excavation due to the (only) partial water-tightness, which could require integrative grouting.	The technology requires a construction process industrialized in every phase: this need leads to a longer time for the installation of the machinery and the start of the excavation followed by a very fast advance.

WATER INGRESS

In terms of water ingress, it has to be considered that three sides of the tunnel are closed by the upper slab and by the diaphragm walls so the water inflow is only possible from the bottom of the excavation until water proofing membrane and final concrete lining are completed.

The excavation will be constructed in 40m-long compartments, which are hydraulically isolated by transversal diaphragm walls. To keep the water away from the excavation works, it is necessary to calculate the pressure and airflow inside the tunnel. Calculations to this effect were done during the design phase. About 100m^3 per minute of air has to be supplied to the tunnel during excavation by means of three compressors (the compressors provide an inflow of 50m^3/min each, so there is a spare compressor in case of failure).

Pigorini explains that they aim also to mechanise the whole excavation process as much as possible, for example by using conveyor belts for the muck out instead relying on trucks, to avoid air leaks.

Waterproofing is essential to avoid water ingress and air leaks. The side diaphragm walls are to be carried out with seal joints through water-stops and metallic sheet piles and the diaphragm walls are waterproofed by means of PVC membrane.

The upper slab also is waterproofed from the outside.

Following the waterproofing, concrete is cast for the final lining of the box. The progression is to be gradual, ensuring a complete seal of each compartment before advance.

COMPRESSED AIR

Andrea Pigorini, head of infrastructure engineering at Italferr, says that in recent years compressed air has rarely been used to excavate bored or cut-and-cover tunnels at all. “This method has been used in Austria, Germany and UK but not in Italy,” Pigorini says. “It was considered a high health risk for the people working at pressure.”

At the Casalnuovo tunnel the use of compressed air was allowed under a few key conditions. For example, the hyperbaric pressure to control the water inflow was limited to less than 1 bar, and there was careful examination of health implications.

A spokesperson for Salini Impregilo adds that compressed air techniques are more reliable and sustainable than jet-grouting because it doesn’t affect the ground water. There are no effects on subsidence and water-tightness.

Pigorini admits that working in high hyperbaric conditions is ‘risky’. “First of all you need to discharge the nitrogen from the blood and for that, shifts have to be adjusted accordingly,” he says. “But this tunnel is just below the ground level. There is at most 7m of water to hold up and it’s therefore necessary to get an over pressurise by between 0.7 and 1 bar to prevent any water ingress from the bottom of the excavation. These modest pressures allow work for nearly eight hours without decompression (in most cases).

“Workers can access hyperbaric areas only if their physical condition is good. For example they can’t work if they get a cold or they have a blocked ear.”

If a worker doesn’t feel well, he or she needs to go through the decompression chamber process. There is an emergency procedure to follow. In general, the philosophy has been to reduce personnel required in the working area.

Reference

Lunardi, G., Cassani, G., Bellocchio, A., Nardone, C., Cafaro, M., Ghivarello, G., Sorge, R., Carriero, F., Cut and cover excavation in hyperbaric condition: an innovative solution applied for Napoli-Cancello high speed railway (Gallerie e Grandi Opere Sotterranee n.129, March 2019)