

The Long Dig

von Burkhard Bilger

The people of Allmannsweier, Germany, have never really grown used to the giant mechanical worms outside their village. You might say that the worms crept up on them. When the worms first appeared, almost thirty years ago, they were just little machines, a few yards long, built by a local engineer named Martin Herrenknecht. Now they're among the largest land vehicles on earth. Their hangars loom above the tobacco fields south of Allmannsweier like vast white cocoons. "If we had known how much room they would need, we might not have let them come," the owner of the town's upholstery shop told me. (He happened to be Herrenknecht's older brother.) "But they are here. What can we do?"

Allmannsweier lies along the southern Rhine, in the rich bottomland between the Black Forest and the Vosges Mountains. It was founded more than a thousand years ago, by a tribe of Germanic farmers called the Allemanni, and could still pass for a medieval village. Its half-timbered houses are huddled around an onion-domed church, their haylofts now suspended over BMWs. The only other hint that the local economy has changed - that the town is full of engineers-is a tidiness that verges on the obsessive, even by the standards of southern Germany. Every window seems to have a flower box, every traffic circle its freshly painted lines and sans-serif signs. The streams are flanked by neat rows of beeches and poplars, their branches dotted with crows. The birds were protected after the Second World War, one villager told me: "Now we have to shoot them. There are too many."

Over the years, the locals have developed an uneasy, symbiotic relationship with their primary employer. Herrenknecht AG is now the largest maker of tunnelling machines in the world. Its taxes alone have made Allmannsweier wealthy, and about a quarter of the town's seven hundred adults work at the factory. Many of the top engineers grew up in the area, and new local talent is continually fostered by internships, apprenticeships, and a high-school vocational course paid for by the company.

On sunny spring mornings, kindergarten classes sometimes take field trips to the factory, to see the worms and draw them with colored pencils. The machines are assembled under arched steel cranes and in cavernous halls that-smell of carbide and ionized air. Their cylindrical sides are painted grub white-the better to glow in the darkness of a tunnel beneath a mountain-and their cutting heads are bright primary colors. The smallest, machines, used to dig tunnels for utility lines or water pipes, are as little as four inches in diameter. The largest, used to dig subway, train, and highway tunnels, are almost a third of a mile long and fifty feet wide. They contain some ninety thousand moving parts and weigh more than nine million pounds. Were all the kindergartners in a class to stand on one another's shoulders, like acrobats in a Chinese circus, they wouldn't reach the top.

"It is a nice toy," Herrenknecht told me one afternoon, standing under a twenty-three-million-dollar unit bound for Caracas. "If you want to buy it for Christmas, I give you five per cent off." He patted the worm's steel

flanks and grinned up at its blunt teeth. He looked tiny beside it-like one of the short-tempered dwarfs in "The Hobbit," gazing up at Smaug the dragon. He had a barrel chest and hairy forearms, fierce blue eyes, and an owl's head, tufted with gray and white. He stood with his legs spread wide, his hands clenched at his sides, and communicated mostly in nods and shrugs. When he did speak, it was in an oddly clipped English - he'd spent most of his time in Oberschule "shooting the teacher lady with nails," he said-the explosive sound of which he seemed to enjoy. "You must fight to get the stone out of the tunnel. You must fight!"

Herrenknecht, who is sixty-six, believes that few places can't be improved by a good-sized hole. To see a map of his company's projects is to envision the planet as a porous thing - a cosmic loofah - inhabited by an increasingly hivelike humanity. At any given moment, close to a thousand Herrenknecht worms are burrowing under mountains, rivers, and cities on almost every continent. They have tunneled along the San Andreas Fault, under the Yangtze River and beside the Bosphorus, through catacombs in Rome and petrified pilings in Cairo. "We are changing the world," Herrenknecht told me. "We are putting it in tunnels. That is my vision."

Engineers build cities; the rest of us just live in them. According to population figures from the United Nations, this year marks a turning point in human history: for the first time, more people live in urban areas than in rural ones, and the disproportion grows every year. Whether we walk to work or ride a bicycle, commute along river bluffs or via concrete tunnels, our movements are increasingly dictated from afar-spatial equations solved by technicians we don't know, hunched over the planet like eager boys above a model-railroad set.

"The process of urbanization now seems unstoppable," Herrenknecht declared last year, with obvious relish, in a company newsletter. There are already more than three hundred cities around the world with more than a million inhabitants, "and the number of such megacities is increasing rapidly." If developed countries are to avoid gridlock, the newsletter went on to suggest, their cities have to grow down as well as up. Every skyscraper needs a corresponding subway tunnel, every country a high-speed rail system to connect its urban centers. "This frontier can only be conquered by bold, innovative and confident engineers, companies, planners, investors, politicians and governments," Herrenknecht concluded. "Together we are building the future."

That a villager from Allmannsweier should help shape the world's megacities is partly an accident of birth order. Herrenknecht's mother was a seamstress, his father an upholsterer. They both came from large farming families-there were twelve siblings on his father's side, thirteen on his mother's-and were married just as the Second World War began. Two of Herrenknecht's uncles died in Stalingrad; a third survived by boiling birch bark for soup. After the war, his parents were often so poor that they had to barter tobacco for food, or scavenge for grain in cut-over fields. They could afford to have only two children, and Martin was the second. "It is in the Black Forest always the same," he told me. "The older brother takes care of the father's business. There is no discussion."

His brother, Dieter, remembers things a little differently. "School cost money, and there wasn't enough for both of us," he told me one afternoon, in the upholstery shop. "There was only enough for one." Dieter is a taller,

graver version of his little brother. He showed me his parents' ledgers from the forties, written in a spidery hand. The Herrenknechts spent twelve to fourteen hours a day in the shop, slowly turning it into a prosperous business, and expected a similar work ethic of their sons. (Their father used to tell them that when he was growing up his family had only five pairs of wooden shoes for twelve children; those who woke up last went barefoot.) Martin worked in the shop from the age of six, but he was too impatient for handiwork-he was given to occasional fits of rage with a hammer, I was told - and too ambitious. "I wanted to be an engineer, a mechanical engineer," he said. "That was my dream, since I was four. To build something, create something. To push."

Herrenknecht had a good head for numbers - "In calculating, he was Spitze," Dieter told me. After earning an engineering degree from the University of Konstanz, he took jobs in Switzerland, Canada, and Mannheim, Germany, designing road-construction machinery and managing work sites. Then, in 1971, he was hired to help direct a tunnelling project in the central Alps, beneath Switzerland's Seelisberg.

Tunnelling is less a profession than a calling, Herrenknecht says. "To do it only fifty per cent? No chance." After six months, most workers either flee for other jobs or stay underground the rest of their lives-transfixed by the scale and complexity of the work, the sheer hubris of punching a hole through a mountain. The machines are so large that they have to be disassembled before shipment, loaded onto flatbed trucks, then transferred to river barges or ocean freighters. In China, where Herrenknecht is now excavating subways in seven cities, new roads have had to be laid, bridges erected, and canals dredged merely to get the machines to the work sites.

For five years, Herrenknecht spent almost every waking hour beneath the Seelisberg, descending before dawn and reemerging after nightfall. His tunnelling machine, nicknamed Big John, was a balky thing that at first could barely manage a metre a day. The air was dense, hot, and dotted with dust, the noise unrelenting. "It was fantastic," he remembers. "You had to go through hell to survive. But without this tough working I wouldn't have the company today."

When the project was over, Herrenknecht went home. He borrowed twenty thousand dollars from his mother, rented a three-room apartment in the nearby city of Lahr, and hired a pair of engineers to help him build a small machine of his own design. The leading tunnelling companies of the time - Wirth, in Germany; Lovat, in Canada; Memco and Robbins, both in the United States; and Mitsubishi, in Japan - specialized in machines for either hard or soft soils. Herrenknecht wanted his to be omnivorous. During the next thirty years, he built "mixshield" machines that could chew through granite or sand, under eight thousand feet of compressed soil or twelve atmospheres of ocean water. He built micro-tunnelling machines that could slip under city streets steered by remote control. The more difficult the conditions, the more they enticed him. As Werner Suhm, the head of the company's utility-tunnelling division, put it, "There is no ground on this nice planet that Herrenknecht cannot cut."

The defining project of Herrenknecht's career - and one of the greatest public works of any kind-is the Gotthard Base Tunnel, not far from the Seelisberg. The tunnel, which has been under construction since 2002, will run from the village of Erstfeld, in central Switzerland, to Bodio, in the

southeast, a distance of more than thirty-five miles. When completed, in 2017, it will be the longest traffic tunnel in the world; it is also one of the most geologically challenging. Its closest rivals are Japan's Seikan Tunnel, which opened in 1988, and the English Channel Tunnel, or Chunnel, which opened in 1994. The Seikan Tunnel is thirty-three miles long and crosses a rocky seabed between the islands of Honshu and Hokkaido. The Chunnel is thirty-one miles long and passes through a layer of chalk as soft as an Oreo's filling. The Gotthard crosses nine geological zones, none of them fully understood. It cuts through granite and quartz, along fault lines and beneath a sugarlike layer of dolomitic marble—a sand trap to anything going through it. Compared with the Gotthard project, Herrenknecht believes, the Chunnel was child's play.

The Gotthard Massif is one of the Continent's great divides. It separates north from south, German from Italian, the African tectonic plate from the European. Four major rivers and four mountain ranges meet there, in a series of peaks that rise to more than ten thousand feet. It is the only Alpine range, Goethe wrote, "that deserves to be called royal." To one side, the Rhine flows north to Rotterdam; to the other, the Rhone flows south to Aries. Even the weather, seems to part ways at this point: to cross the Gotthard is almost always to pass from sunshine into rain, or vice versa.

For the Swiss, the Gotthard has been both a gateway to Europe and a bulwark against it. Lacking a common language or religion, they've fixed their identity on geography, with the Gotthard as its central axis. "If you look at the Alps, there is only one spot in the whole half circle where you can cross in one step," the Swiss historian and journalist Helmut Stalder, the author of "Mythos Gotthard," told me. "In every other part, in Italy or France, you have to cross two mountain chains." It was here, around 1230, that the vertiginous Devil's Bridge was flung across the Schollenen Gorge, opening the first trade route to Lombardy. And it was here, in 1291, that farmers in three valleys banded together against the Hapsburgs, giving rise to the Swiss Confederacy and the legend of William Tell. "The Gotthard is like a collective reference point for Swiss history," Stalder said. "It is something very deep in the soul of this nation."

The Gotthard Pass rises to just under seven thousand feet, meandering between bare peaks and over scree-covered slopes. In the fifteen-hundreds, a mule train could reportedly cross it in a week. Once the path was widened, in the eighteen-thirties, a horse-drawn carriage could make the trip in less than two days. By then, though, Switzerland needed more than carriages to keep pace with modern Europe. While Germany and France had grown into industrial powers, the Swiss were still mostly farmers and craftsmen. Their dries were landlocked and girdled with mountains-walled off from the factories and steelworks of Dortmund and the Ruhr Valley. They had little coal or iron of their own, and the railroads had largely passed them by. If they wanted to be more than a "deserted island," the Swiss railroad magnate Alfred Escher declared, they had no choice but to dig a railroad tunnel at the Gotthard Pass - a modern equivalent of the Devil's Bridge.

Tunnelling was still a clumsy, haphazard art. For almost two thousand years, nothing in Europe had equalled the milelong passage that the Romans dug from Naples to Pozzuoli, heating the volcanic rock with bonfires and dousing it with cold water to crack it. Then, in 1825, the engineer Marc Brunei began digging a tunnel beneath the Thames, in London. Brunei was

inspired by a worm that he'd seen boring through ship's timbers on the Chatham docks. It ingested the wood as it went, excreting a shell-like substance that lined the tunnel walls behind it. Brunel's version of this - adapted by engineers ever since - was a giant tunnelling machine. The front was a cast-iron frame honeycombed into thirty-six cells. Each cell had room for one miner and was faced with wooden boards. The miners would remove one board at a time, dig six inches with a pick or a shovel, and replace the board. When they were done, the frame was shoved forward with jacks, and the exposed walls were reinforced with concrete.

"It was a horrible job," Robert Hulse, the director of the Brunei Museum, in London, told me. The Thames was one of the filthiest rivers in the world, laced with industrial waste and raw sewage, and the tunnel lay less than twenty feet below its bed. It was subject to continual leaks and floods, and suffused with fetid marsh gases that would periodically combust, ignited by the gas lamps that lit the tunnel. "Imagine working in this vile hole, showered in sewage, with jets of flame coming out," Hulse says. "The gases would burn for days on end sometimes, and the frame would get so hot that if you touched it you would be burned." Near the end, the miners had to work in two-hour shifts - not because their employers took pity on them but because their brains could no longer function on so little oxygen. Even so, Hulse says, some were carried out senseless or straitjacketed and raving.

The Thames tunnel was a disaster by almost any measure. It took eighteen years to build - six times longer than originally planned - and never made back its investment. (When foot traffic waned, at a penny toll per crossing, the owners brought in minstrels, magicians, and sword swallowers, to no avail.) Still, the tunnel was a wonder of its time - "To walk under the Thames in 1843 was like walking on the moon," Hulse says - and it inspired similar schemes on the Continent. In 1870, miners finished digging a nearly eight-mile-long tunnel through Mont Cents, connecting the French and the Italian Alps. Two years later, in Switzerland, an engineer named Louis Favre took up Alfred Escher's challenge and agreed to build a railroad tunnel across the Gotthard Pass. The digging would take eight years, Favre promised. For every day that he raced ahead of schedule, he would get a fivethousand-franc bonus; for every day that he fell behind, he would pay five thousand francs - and the fines would double after six months.

Conditions at Gotthard were even tougher than under the Thames. To cross the massif, the railroad had to climb more than two thousand feet, through a series of tight, helical tunnels, then cut straight through the mountain for more than nine miles and descend through more helical tunnels on the other side. The tunnel was often knee-deep in water from hidden springs and fissures, and filthy with dung from draft horses. Temperatures hovered around eighty-six degrees - perfect for incubating bacteria. The miners' technique was simple: they hammered holes in the rock with pneumatic drills, then stuffed them with sticks of dynamite. But accidents were common (dynamite had been patented only five years earlier), and the compressed air for the drills would have been better used to ventilate the tunnels. In the end, some two hundred men died of disease, caveins, and other mishaps, and more than four hundred and fifty were seriously injured. Most were poor Italians, who crowded into the Swiss villages in such numbers that some had to sleep in cow stalls. They

eventually organized a strike, and at a protest rally some of them threw rocks, prompting the local militia to open fire, killing four.

The work went on. Starting at opposite ends of the pass, two tunnelling teams burrowed toward each other through the mountain. On February 28, 1880, at six-thirty in the evening, a miner on the southern side struck the rock with his drill and blasted through. The miners on the other side were baffled at first, then began to dance and shout. Some tried to grab the drill bit in celebration, but it was still so hot that it burned their hands.

The breakthrough was miraculously precise - the two tunnels were offset by only a foot - but the tunnel wasn't completed for another year and a half. Favre, in any case, wasn't around to rack up more fines. Seven months before the breakthrough, he'd collapsed from a stroke while inspecting the tunnel. Perhaps because he had died among them, the miners set aside their grievances for a moment and granted him the honor of first passage. Before shaking hands across the breach, they took a picture of the engineer and passed it, hand to hand, down the length of the tunnel.

The Gotthard tunnel was the Swiss Suez Canal, Helmut Stalder says: "Before it, Switzerland was a dead end; then, from one day to another, it was the heart of the Continent." The railroad brought in technology and raw materials. It took isolated villages, each running on its own church dock, and put them all on the same timetable. And though it was largely the work of foreigners - the helical tunnels, for instance, were designed by a German named Robert Gerwig - its success helped give rise to the legend of Swiss precision and engineering. "Behind it, there came whole industries - constructing locomotives and wagons and huge diesel motors," Stalder says. "It was a fundamental change of identity. In Europe, we say, the railway was the plow of modernity. It went through the agricultural landscape and brought modernity behind it."

Not everyone welcomed the change. The railroad was "a work of the Devil," one conservative politician from Lucerne declared. It was puncturing Switzerland's defenses, exposing it to bad influences. Decades earlier, Schopenhauer had cautioned that "the Alps and their dwarflike inhabitants were a natural shield against the hordes of Germanic lummoxes, beer bellies, and professors." The new tunnel seemed to confirm his fears. "The newspapers were all saying, 'What are we opening ourselves up to?'" Judith Schueler, a Dutch historian who has written a book on the Gotthard called "Materializing Identity," told me. "What will modernity bring?"

The answer was a new kind of nation: neutral yet militant, cosmopolitan yet isolationist - a crossroads, heavily fortified. By the Second World War, the Gotthard Pass had become so strategically important that the Swiss concentrated their troops in the mountains around it, leaving the cities sparsely defended. "How do you tell people that the Army leaves them behind to go defend some goats?" Stalder says. "You say, 'In the Middle Ages, they protected the Gotthard, and we have to do it now.'" It's a collective memory that also helps to form a nation.

Crossing the Alps has since become even more essential to European trade. Nearly four hundred miles of tunnels wind through Switzerland, and their capacity still can't meet the need. As the European Union has opened borders, the freight traffic on roads has doubled every eight years, and increased more than tenfold since 1980. A potato grown in Poland may be sliced into fries in Italy and eaten in Belgium, crisscrossing Switzerland

along the way. A million and a half trucks now traverse the Swiss Alps every year - freight traffic has largely shifted from rail to road - many with flammable loads, and traffic jams at the major tunnels can stretch for miles.

Nine years ago, on the morning of March 24, 1999, a Belgian driver named Gilbert Degrave was halfway through the Mont Blanc tunnel when he noticed smoke leaking from the back of his truck. Degrave was carrying twelve tons of flour and nine tons of margarine. The two substances had somehow caught fire during the drive - perhaps from a discarded cigarette - and by the time Degrave stopped, the truck was burning uncontrollably. Before firefighters could reach the blaze, the flames had spread to other cars and trucks, igniting their tires and fuel tanks. The tunnel acted as a giant chimney: cool air rushed in one end and out the other at a steep gradient, fanning the fire. Some passengers stayed in their cars and rolled up their windows. Others fled for the exit on foot and were overcome by toxic fumes: rather than pump the smoke out, the tunnel's ventilation system drew air in. The fire went on to burn for two days and reach temperatures of eighteen hundred degrees. By the time the tunnel was cool enough to reenter, thirty-nine people had died. "The sights in the tunnel are unimaginable," one French firefighter said. "There are heavy trucks which have melted into the tunnel floor until they are no higher than a car. Many of the bodies have been incinerated. All that remains are a few blackened bones."

The Mont Blanc fire was the worst of its kind in Alpine history, but not for long. The following year, a funicular caught fire while passing through a tunnel on the way to Austria's Kitzsteinhorn glacier, killing a hundred and fifty-five people. The year after that, two trucks collided in the Gotthard Road Tunnel, which opened in 1980 and runs roughly parallel to the railway tunnel. The crash ignited a blaze so intense that an eight-hundred-foot stretch of the tunnel's ceiling collapsed, killing eleven. As the damaged tunnels were closed for repairs, their traffic was diverted to other routes, which were already congested. The best alternative was to shift some of the burden back to trains: that would both cut the cost of transport and dramatically reduce the risk of accidents. But the old mountain railroads were too slow and steep for heavy freight. To cross the Alps, a high-speed train would require a new kind of tunnel—one that would burrow through the very bottom of the mountains.

The Swiss had been contemplating such a project since the early sixties but had balked at the cost—more than ten billion dollars, by current estimates. Finally, after a series of contentious public referendums, digging began on two new tunnels in 2002. The Lotschberg Base Tunnel, completed on schedule last year, runs for twenty-one miles through west-central Switzerland, linking the rail lines from Bern to Milan. The Gotthard Base Tunnel is fourteen miles longer and runs farther to the east, linking Zurich to Milan. The Lotschberg was relatively easy to dig: the granite and schist it traverses are hard but consistent. The Gotthard, however, lies at the very edge of the feasible. It will be the world's deepest traffic tunnel as well as the longest, and will run on a nearly flat gradient from Zurich, with a mile and a quarter of rock pressing down upon it. When it's finished, Stalder says, the Alps will disappear: "That is the result. Flat. For the international traffic, Switzerland will be Holland."

The northern end of the Gotthard Base Tunnel begins as a deep trench, carved into the palisades of Mt. Bälmeten. Great piles of gravel rise beside it, next to steel sheds, mud-spattered trucks, and a zigzagging network of conveyor belts. The site looks like a cement factory, which it essentially is. By the time the tunnel is complete, some two thousand miners will have taken more than three hundred million cubic feet of rock out of the mountains-the equivalent of five pyramids of Cheops, the Swiss transit authority likes to say. Some of the rock is being dumped into nearby Lake Lucerne, where it will form an artificial island for nesting birds. Much of the rest - about four million pounds a day - is crushed into gravel, mixed with cement, and stuffed back into the hole in the form of concrete, shoring up, the tunnel walls with the mountains, own matter.

The trench ends in a pair of circular openings, like the double barrel of a shotgun. The two tunnels run in parallel, about a hundred and fifty feet apart, and are connected about every thousand feet so that passengers can escape from one to the other in case of fire. Each opening is about thirty feet in diameter and is flanked by massive concrete retaining walls. It's a purely functional piece of architecture made fantastical by its epic scale.

When Martin Herrenknecht and I arrived on foot one morning, trailing a team of engineers in blaze-orange smocks, we looked like members of some odd mythological quest. I half expected to find a pair of giant stone gates barring our way, etched with runes or dire Latin inscriptions. But there were just the two gaping holes. Herrenknecht grinned and quickened his pace. He was wearing a bright-yellow hard hat-he's rarely photographed without one-and seemed to grow more relaxed the deeper he descended underground.

In the near distance, we could hear the low grumble of the worm at work in the mountain. To speed construction, the miners were excavating the tunnel from five points at once. While Herrenknecht's machines bored in from either end, and from two valleys along the sides, other workers were drilling and blasting their way out from areas where the ground was too unstable for tunnelling machines. A team of South African gold miners had been brought in to cut a vertical shaft at Sedrun, in the northern section. The shaft had been fitted with an elevator twice the height of the Empire State Building, and the miners were working their way toward the other teams.

To the south, the Herrenknecht worms had begun by toiling through a long, undulating layer of kakirite - a sodden, crumbly material compressed between layers of granite. "You might as well call it shit," Herrenknecht told a reporter. As the machines chewed through it, the ceiling and walls caved in behind them, leaving cavernous spaces that had to be filled with concrete. For months in 2003, the machines had advanced as little as eight inches a day - at that pace, the tunnel would have taken seven hundred years to complete - before breaking through to granite again.

Here in the north, conditions were better. The rock was a sturdy gray gneiss, streaked with black. It was once a type of granite, when the Alps were young, but had been weakened by heat and compression as the mountains piled on top of it. "It is easy to dig," Michele Moos, the red-haired manager of the site, told me. To cut the rock, the tunnelling machine had to apply only about seventy-five bars of pressure to its cutting head-about a thousand pounds per square inch. "The toughest rock in the south takes three hundred bars," she said.

We filed into the hole, feeling the thrum of the worm's engines through the soles of our feet. Digging had just begun in the eastern barrel of the tunnel, and the miners were backed up nearly to the entrance. The end of the machine was an open framework of steel beams, threaded with catwalks, conveyor belts, stepladders, and ventilation tubes. We climbed up inside it, led by Herrenknecht, and made our way toward the front, ducking under water pipes and squidlike tangles of power lines. The air, so close to the surface, was cool but uncomfortably humid. Water leached in constantly from the mountain above, leaving the walls slick and the ground puddled with gray muck. Like the rock, much of the water was continually collected, cleaned, and recycled - the tunnellers used about half a million gallons a day to mix concrete and cool down their equipment.

When we'd gone about a hundred yards, we came to a small white cabin with Plexiglas windows. Inside, a row of computer screens showed the machine's speed, cutting pressure, and position within the mountain. If the worm was a vehicle, this was the driver's seat. By varying the pressure to a set of pistons along the flanks, known as the Gripper, the operator could steer up and down or from side to side. (When he retired, Herrenknecht said, this was the job he wanted.) The system was equipped with lasers, G.P.S., and ground-probing radar, and could be astonishingly accurate. In the southern section of the tunnel, two Herrenknecht worms were less than two inches out of alignment after tunnelling for nearly nine miles.

The roar of the machinery, muffled inside the cabin, now seemed to redouble. As we shuffled down the catwalk, it began to tremble underfoot, then lurch and shake as if trying to buck us off. An acrid taste of burning oil rilled my mouth, and the walls seemed to flex and heave around us. Herrenknecht grabbed my arm and pointed to the pistons thrust into the walls on either side, wedging the worm into the tunnel. "Bilger! Feel the power!" he shouted. "More than three hundred and fifty bars of pressure to the Gripper!" The machine was driven by ten electric motors, each with three hundred and fifty horsepower. (The entire site consumed about as much energy as a city of thirty thousand.) But the rock here was soft enough that the machine was operating at only quarter power. "If it was at one hundred per cent, the machine would go into the next tunnel," Moos said.

Herrenknecht stepped onto a platform at the front of the machine and stood with his fists on his hips. "It is excellent work!" he shouted. He pointed to another set of pistons, angled forward from the Gripper, that were driving the cutting head into the rock. The head was fitted with blunt disks, seventeen inches wide, made of an obdurate alloy of manganese, steel, and chromium. (The alloy's exact composition was a company secret, Herrenknecht had told me in Allumansweiler: "It's private like my toothbrush, or like my girlfriend.") As the cutting head turned, the crushed stone fell into spokelike dividers inside it, was funnelled onto a conveyor belt along its axis, and carried to dump trucks waiting outside. By the time the cutting head pulled back and the engines cut off, the teeth were red hot. "You can put an egg on them," Herrenknecht said. "Sunshine up."

The tunnel was suddenly silent. With a low rumble, the back half of the worm ratcheted forward two metres and planted its legs. The Gripper slid forward an equal distance and braced itself against the wall. Then the engines ignited for the next attack

The base of the Alps is like the bottom of the ocean. To tunnel through it is to grope in the dark, under lethal pressure, in a thin pocket of air. It's impossible to know exactly what lies ahead, so miners depend on soil probes, core samples, and test drilling-the geological equivalent of peepholes. Relying on ten years' and dose to two hundred million dollars' worth of testing, geologists have set a winding course for the Gotthard Base Tunnel, avoiding the highest peaks and the most perilous soil. They've identified some ninety "disruption zones" along the path - areas of fractured rock and abundant groundwater, where a machine might get stuck or swamped. (In one area, near Sedrun, the marble is so finely ground and under such terrific pressure that it came surging up through the test shafts like seltzer.) Still, most of the time, a miner's best bet is just to keep on digging. "Once you excavate the hole, it tends to close up, because the mountain is pressing on it," Matthias Neuenschwander, the former resident engineer of the southern section of the tunnel, told me. "You need to go as fast as possible. There isn't much tactics in that."

One June day three years ago, five miles south of the village of Amsteg, two worms were working their way south through a layer of granite and gneiss more than a mile underground. They'd gone about five miles without incident, when the end of one shaft collapsed without warning. The miners had hit a pocket of hydrothermally disintegrated stone. It had been formed nearly a hundred million years ago, when the African and European tectonic plates collided, thrusting the Alps out of the ocean. In the process, a blast of superheated steam had struck the rock, dissolving the natural cements that bound it together. What was left was a powdery gravel saturated with water. Within minutes, it had cascaded through the machine, seizing up the cutting head and motors. The miners spent a week trying to dig the worm out with buckets and shovels, but the walls simply caved in around it again. The machine was stuck

Miners are a moody lot, prone to poor morale when a project stalls. At the Gotthard, they dig around the dock in eighthour shifts, separated by eight hours of maintenance work. Many have families abroad and see them only on vacations and long weekends. Although fatalities are relatively rare - the Gotthard project has had seven so far - the work is hard on the body. "There are accidents, all sorts of accidents," Moos admitted after our visit, over herring and white asparagus at a nearby Gasthof. "Things fall onto people, or they are just not paying attention. Some have problems with their ears from the noise, some with their lungs from the quartz dust. And the shaking isn't good for your back"

Under the circumstances, Herrenknecht's motivational style tends toward the military: equal parts intimidation, gruff humor, and appeals to his workers' esprit de corps. He is one of them. When I asked if it wasn't hard to spend so much of your life in tunnels, his eyes narrowed to glimmering slits and he gave a tight shake of the head: "It's fascinating, the underground." As for the physical toll, "It's good for your health!" he said, clapping Moos on the back. "You don't need a massage! We can invite all the people from the city to get shaken." Moos laughed, and said, "Yes, it is like wellness to work there: hot like the sauna, mud like the clay bath, vibration like the Power Plates. It makes your thighs strong."

Herrenknecht leaves his employees both tremendous latitude and little room for indecision. "Martin doesn't like nervous people," Achim Kühn, the

company's director of marketing, told me later. "He really hates them. Stay calm. Give him the feeling that you can solve the problem. Then everything is O.K."

A few years ago, when Herrenknecht's utility-tunnelling division was just getting started, one of its machines lost power while burrowing under an Autobahn in Bremen. Herrenknecht called in Werner Suhm, the head of the division. "He said, 'If you don't go in there and repair this shit, I give up the business and you are fired,'" Suhm told me. "So I went in myself with an electrical cable."

The tunnel lay forty feet underground. It was a foot and a half wide, a hundred and fifty feet long, and choked with service lines. By the time Suhm had crawled halfway down it, the entrance behind him looked three inches wide. "I was scared. I'm still scared," he told me. "How do I get out? How do I get out? I could smell my own stuff." It took Suhm half an hour to reach the machine and plug in the cable, and nearly two hours to crawl out again. Backward.

At the Gotthard, when the tunnel caved in south of Amsteg, the situation was more desperate. The machine was miles from any entrance and too deep to dig out from the surface. Although the miners could escape back out through the tunnel, the worm couldn't reverse. It was stranded like a submarine in the Mariana Trench.

Luckily, half the tunnel was still dear. Its eastern shaft, though only a hundred and thirty feet away, had narrowly skirted the disruption zone. The miners there began by tunnelling well past the stranded machine; then they sent in rescue teams from two directions at once. The first came in from the side, drilling and blasting a narrow tunnel toward the stranded machine. Another team dug around from the front till it was directly in the machine's path. Once in place, the first team injected the gravelly material with cement and a chemical gel, turning it into a lump of concrete four stories high. The second team drove rows of pipes into the ground above the concrete, forming a steel umbrella that would prevent any further cave-ins. Finally, the concrete was blown dear. Five months after the initial collapse, the machine was freed.

The Gotthard was originally scheduled to open in 2012. As of this summer, it is five years late and three billion dollars over budget. Still, more than three-quarters of the tunnel has been excavated, and engineers say the most difficult sections are behind them. The Swiss, once prone to hand-wringing over the tunnel's progress, have shifted into celebratory mode. When the twentyone-mile Lotschberg Base Tunnel-for now, the longest land traffic tunnel in the world-opened, last year, the tracks were blessed by a Catholic bishop and a Protestant minister. The first trains to pass through were filled with politicians and journalists, dining on Gruyere and Bündnerfleisch, and greeted with fireworks, brass bands, and crowds of children waving Swiss flags.

"That is Switzerland," Herrenknecht told me. "They take the challenge. If it money-wise increases, they get crazy. But they have enough power,, experience. So they overrun the cost by five or ten per cent! If we build the technique, we build the future."

Because the Gotthard is only one of several hundred of Herrenknecht's projects, he spends a good deal of his time in the air. The company keeps a pair of private jets for site visits, one a Cessna Sovereign with a range of

thirty-two hundred miles, and Herrenknecht has two full-time pilots on call. The tunnels lie in some of the world's roughest terrain, and landing conditions can be dicey: snow-swept runways in the Himalayas, broken tarmac in Kazakhstan. To visit the southern end of the Gotthard tunnel, for instance, Herrenknecht has to fly into a military airport in Lugano: a wheeling approach, without radar, between ten-thousandfoot peaks, then a stomach-roiling drop through the clouds, at four thousand feet per minute, across a glacial lake, and onto an abbreviated runway. The experience is sometimes "a little bit bumpy," he admits, but it's worth it for the time saved. He likes to return home at night to his bed in Allmannsweier.

"Bilger! This morning I cannot talk," he told me one day, as we were boarding one of his jets, bound for Barcelona. "I will read the paper." He plopped into the seat across from me and shook open a copy of the *Frankfurter Allgemeine*. Reporters are an annoyance to Herrenknecht, Achim Kühn had warned me. He isn't in the habit of guarding his words, and some of his more inflammatory comments-about the weakness of the German welfare state, for example, or the laziness of its workers - could be quoted disapprovingly. The only reason Herrenknecht agreed to see me, Kühn suspected, was that my parents had grown up near the Black Forest and I spoke a dialect similar to his. Nevertheless, we mostly stuck to English, and he was always` grousing about having to shuttle this American around. At one point, when we were flying above the Alps, he threatened to charge me two hundred dollars for the view.

On the flight to Barcelona, fortunately, Herrenknecht had brought his wife along - perhaps to distract me. Paulina Ariza-Suarez Herrenknecht is a small, ebullient Colombian, with freckled cheeks, round glasses, and a short black bouffant. The two met at a hotel in Miami in 1978 - he was on a rare twoday holiday, she had missed her tour bus to Disney World - and began an improbable intercontinental courtship. "I hadn't been looking for a friend," she told me. "But he was very kind. It was dear that he was a very honest person - there was no doubletalk. And I found his eyes interesting. They were so awake. They seemed to say that he could do anything." She was twenty-eight and he was thirty-six.

After Miami, Herrenknecht wrote several letters to Paulina in Caracas, where she was working as a switchboard operator, tour guide, and part-time nanny. When she was slow to respond - "I didn't think he was serious" - he tracked her down through an international operator. Eventually, after more phone calls and letters, Herrenknecht persuaded her to come to Germany for an extended visit.

It was a disaster. Allmannsweier was in bloom when Paulina arrived - it was late summer - and Herrenknecht took her around the village to introduce her to the shopkeepers and his relatives. But the weather soon turned chill and gray, the people less welcoming. When Herrenknecht went back to work, Paulina found herself alone in his apartment, without a job, friends, or more than a few words of German. "The people were never bad to me," she says. "They were, in away, kind. They just weren't interested. You can come if you want, but no one needs you here." By the following winter, she was flying home to South America, three months pregnant.

Herrenknecht spent the next year and a half trying to get her back. He sent letters at first, then money when his daughter was born. He twice flew out to visit her, and to ask her to marry him. Finally, in the summer of 1982, she

agreed. She has since made her peace with Allmannsweier, she says: "This is probably the best land in the world. The people are very intelligent, very laborious." Her German has become fluent, and she has had two more children with Herrenknecht, all now grown: her elder daughter is an industrial designer, her second daughter is a stewardess, and her son is studying mechanical engineering. If anything, it's her husband who sometimes seems ambivalent about his home town.

"Martin needs some fixed points in his life, and Allmannsweier is definitely the most important one," Kuhn told me. Yet some locals complain that Herrenknecht has "lifted off" - he drives a silver Porsche Carrera around town - and he is often irritated by the town's stodginess. "There is one person on the Ortschaftsrat" - the village council - "I think he would kill him if he could," one local told me. Two years ago, Herrenknecht offered to build a funeral pavilion for the town cemetery, at his own expense. The council members accepted the offer, but only if they could tinker with the design. Herrenknecht told them to take it or leave it. "So we still don't have a funeral house, and people get wet in the rain," Renate Malter, the town's Protestant minister, told me. On another occasion, the council insisted that Herrenknecht cover the roof of a new factory with grass, to replace the green space that had been lost to it. Herrenknecht, in turn, threatened to put a herd of plastic cows on the building.

"There is a little warfare between them," Matter told me, when I visited her at the parsonage. "The council has to show that it has a little power. Then Herrenknecht gets angry when they won't give him what he wants." He is not a very diplomatic person, she acknowledged, but he can be very generous. Her husband, Axel, smiled and added, "Der liebe Gott hat dem Herrenknecht einen Dickkopf gegeben" ("The Good Lord gave Herrenknecht a fat head" - a stubborn streak.) "But this fat head, this strong will, he needs. Without it he could not do what he does."

These days, Herrenknecht seems most at home among the Spanish. While the Swiss sweat over every centime, and the Germans recently cancelled their plans for a high-speed magnetic levitation train in Munich, the Spanish have embraced mass transit with a kind of crazed exuberance. Barcelona, Bilbao, Madrid, and Valencia are all expanding their metro lines, and new systems are being laid in Granada, Gijon, and Malaga. Spanish trains were once among the slowest in Western Europe - the Madrid-to-Barcelona line felt as if it were being hauled by mules. Now dozens of new rail tunnels are being driven through the mountains, connecting the major cities in a wheel-and-spoke pattern, radiating out from Madrid. If all goes as planned, the system will comprise more than six thousand miles of track by 2020, making it the largest high-speed rail project in Europe.

"I see for Spain a great future," Herrenknecht told me. We had landed in Barcelona and were being driven to a site northwest of the city, to see its newest subway tunnel. "Before, you always thought they are a holiday people," he said. "They have siesta. Now they are the hardest-working population in Europe - the absolute top. Spain is the new Switzerland."

Barcelona has more than a million and a half inhabitants, yet it's hemmed in by mountains on one side and the Mediterranean on the other. Rush-hour traffic often comes to a standstill downtown - "It's like a strap on your heart," Herrenknecht said - so the city is investing in public transportation. The new subway line will run for twenty-eight miles, dipping and rising

between stations, connecting the suburban north to the industrial south and to the airport. The soil along the way is a loose mixture of clay and sand, and lies almost entirely under the water table - it's never more than two miles from the sea. "If you dig a hole, it doses up again behind you," Georg Siebert, one of Herrenknecht's chief engineers, explained, when we arrived at the site. "It's just like a hole in the seashore."

To keep the tunnel from collapsing, the miners were using one of Herrenknecht's Earth Pressure Balance machines. This had a sealed cutting head that injected the soil with a thick foam - its sharp ammonia scent filled the air. The foam stabilized the soil long enough for it to be excavated, then the miners lined the exposed walls with watertight concrete rings. The rings were carted down the tunnel in curved segments, on an automated trolley. Each segment was six feet wide and one foot thick, and weighed around fifteen thousand pounds. When it was ready to be installed, a robotic arm lifted it up with a vacuum plate and swung it into place along the wall. The segments fit together almost seamlessly: six segments to the circle, and a keystone on top. Like Brunei's shipworm, the machine was a self-contained factory, leaving a ready-made tunnel behind it.

Compared with Switzerland, everything here seemed to be moving at double time. The miners were paid bonuses for speed and for working on Sunday. They had no patience for interruptions - they glanced at our party with barely concealed annoyance - and no need for perfection. The trolley tracks at Erstfeld were perfectly straight; here they meandered a little, like strands of pasta, so the trolley wobbled as it ran. "The Spanish want speed," Herrenknecht said, grinning. "It is an excellent character, but they want speed." At some sites, he said, the Spanish hired two companies to dig each barrel of a tunnel, so the project would turn into a race. This tunnel had only one shaft, wide enough for two trains, but the miners were still working at a record pace. They'd installed twenty-two rings in the past twelve hours alone - a distance of a hundred and thirty-two feet.

Subways, once an astonishment of urban life, are becoming commonplace. Herrenknecht has more than a hundred machines tunnelling under cities worldwide, and orders for dozens more. Two of the machines recently completed new shafts for the Los Angeles light rail system; another will spend the next few years boring an enormous tunnel around Moscow, with room for a four-lane highway above and a subway below. "This is our bread-and-butter business," Kuhn said. "If you are not a leader here, you have it tough."

The new tunnels will be good both for cities and for the environment, Herrenknecht says. Traffic will decrease, as will pollution and fuel consumption. Congested roads will give way to parks and pedestrian plazas. And yet in Barcelona, rattling back down the tunnel on the trolley, it was hard not to think that something was being lost. Even if Herrenknecht's vision comes true, and the roads that have been relieved of traffic don't simply encourage more people to start driving, city dwellers will spend more and more time underground. Rooms with a view will give way to rooms with no view at all.

In nine years, when the Gotthard Base Tunnel is finished, it will cut an hour off the trip between Zurich and Milan. It will streamline European trade and shield a dozen Swiss villages from the roar of passing trains, and many more from the noise and exhaust of congested highways. But for those

sitting on the trains it will also turn a singularly breathtaking ride-up and over snow-dusted peaks and plummeting gorges-into a dim and desolate, one. The world, as Helmut Stalder said, is becoming flat.

By that evening, we were back in Germany. Paulina had never been to Barcelona, and she'd heard that it was the most beautiful big city in Europe. But Herrenknecht had a lecture to prepare, and he wanted to go home. Much as he admired the Spanish and their energy, Barcelona's traffic drove him to distraction. "Every day sitting in the car. Not working. Wasting time. Waiting in a queue to go to the office. I could not do it," he said. "No, I am happy if I am home to see the pheasant and the deer in my garden."

Over the weekend, news had come in from other projects abroad. There was trouble in India, Herrenknecht said, where a subway in Delhi wasn't advancing as quickly as planned, and the press was full of rumors about one of the machines he was building for Moscow. The deal had been struck that spring with Roman Abramovich, and it bore the oligarch's grandiose mark. The Russian worm would be half again as large as any machine yet built, and four times the size of those which dug the Chunnel. When it was done digging under Moscow, the British press speculated, Abramovich hoped to send it to the province of Chukotka, where he was the governor, to dig a tunnel across the Bering Strait to Alaska. (Abramovich denied the rumor.) Herrenknecht smiled at the thought: fifty miles under a frozen sea, through untested soil in the remote Arctic. "I would approach it from both sides," he said, grabbing the air with his hands. "Start with two machines from each side and two machines in the middle. Make an island with excavation material. No problem."

In the meantime, there were other mega-projects to complete. A Herrenknecht machine was scheduled to dig an extension to New York's No. 7 line in 2009, and the Yangtze River tunnel was nearly finished, at four and a half miles long. Its two shafts would each contain a three-lane highway, connecting the city of Shanghai to the island of Changxing, then travelling on, by bridge, to the city of Dongtan.

For Herrenknecht, the Yangtze project was a way of coming full circle. Dongtan, its indirect beneficiary, was being billed as the world's first eco-city. Designed by the engineering firm Amp and scheduled to be completed in 2020, it would consist of three self-sustaining communities with a total population of five hundred thousand. It would be ringed by wetlands and organic farms and threaded with footpaths and bicycle lanes. Solar power, wind power, bioenergy, and recycled waste would provide all the electricity, and only cars with zero tailpipe emissions would be allowed in town.

"If it's green, no problem, I could live there," Herrenknecht said, and I wasn't surprised. Dongtan was a city after his own heart. It was designed by engineers and built by the world's fastest-growing superpower. It was perfectly modern, admirably efficient, yet not so different from the villages that Europeans built a thousand years ago. It was a place a lot like Allmannsweier.

Quelle: The New Yorker, 15. September 2008.