Sinking of a New Shaft and Watertight Relining of an Old Shaft at the Heilbronn Rock Salt Mine

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ABSTRACT

The Heilbronn rock salt mine, which operated for nearly 90 years with only one shaft, was provided with a second shaft of 238 m depth and an internal diameter of 5.0 m in 1971/72. Cement was injected into the water-bearing open seams of the overthrust mountain in four sections, one time from the surface and three times from the shaft bottom.

Shaft sinking was done conventionally by blasting work, loading by grabs and bucket extraction. During this work a circular wall made out of preformed concrete blocks was carried along to secure the wall face of the rock. Remarkable is the lining in the water-bearing overthrust mountain. The watertight lining, consisting of a reinforced concrete cylinder (50 cm) and a steel plate cylinder (9 mm) was mounted onto a wedge-shaped foundation ring at a depth of 139 m. A ring joint between this composite cylinder and the masonry connected to the rock was at last poured with asphalt to reach a total watertightness in the horizontal and vertical direction and to protect the steel plate cylinder against corrosion.

This lining method, first used in coal mines with unstable strata, was also used when repairing the shaft in Heilbronn. The masonry of this shaft, which was finished in 1885, was penetrated right from the beginning by approximately 120 liters of water per minute coming out of the surrounding rock. This water was controlled, collected and pumped to the surface via a pipe duct. In the course of the general reconstruction of the shaft the water inflow could be prevented successfully.

Shaft No. 2 was equipped with a skip conveyor of 1000 t/h capacity. Shaft No. 1 with a skip conveyor of 300 t/h capacity.

INTRODUCTION

Rock salt is a raw material which occurs in substantial quantities and can be mined economically in the Federal Republic of Germany. Total annual production is about nine million tons of rock salt in solid form. The Südwestdeutsche Salzwerke AG (South-West German Salt Mines Company) owns two mines at Heilbronn and Kochendorf, and their production of about three million tons represents a third of this total.

The Heilbronn rock salt mine has been in operation for almost a century. The first shaft was sunk in 1884 and 1885, and for 87 years only one single shaft connected the underground working with the surface. An exception was made to the usual insistence on two exits to the surface for safety's sake; this was done primarily because of the fear of the mine's flooding if the water-bearing strata could not be reliably and permanently sealed off when a new shaft was being sunk. After all, sixteen German salt mines (potassium and rock salt) were lost by flooding in the course of sinking new shafts before the turn of the century and during the first third of the present century.

However, improvements in methods of sinking and of lining shafts have meant that this consideration has become less important during recent decades.

A further reason why the Heilbronn mine was able to operate with only a single shaft for such a long time was the good condition of its masonry lining and furnishings. In addition, there were three different types of human carrier facilities in this one shaft.

By the beginning of the 1970s, however, this situation was no longer acceptable, above all because the production capacity of the mine could not match its sales potential. Another factor was that the mine's ventilation could not be improved any further because of the high air flow resistance in the shaft. As a result, diesel-powered equipment could only be used within tight limits.

SINKING THE 'FRANKEN' SHAFT IN 1971-72

In 1971 the Südwestdeutsche Salzwerke AG decided to sink a second shaft only 180 metres from the existing shaft. The proximity of the two shafts was justified by the favourable access to the mill, both above and below ground.

Geological Conditions. Even though the new shaft was to be close to the old one, it was considered wise to make a core hole in the centre of the new shaft to investigate the strata. The expense was justified because the overburden was known to be composed of heavily water-bearing strata. When the Heilbronn shaft was being sunk the water inflow reached 2.5 m^3/min. At the nearby Kochendorf mine, a distance of only six kilometres away, there was a water inflow of more than 20 m^3/min. The attempt to pump this water away was unsuccessful and resulted only in drying out all the wells for several kilometres around. This indicates an interconnected water system covering a large area.

The test boring and the sinking of the shaft itself provided a geological cross-section with the following strata (Figure 1):

Quaternary:	0–9 m	Pleistocene gravels
Triassic:	9–36 m	mudstones and clayey sandstone of the lower Keuper (upper Trias)
	36–122 m	dense limestone, fractured in places of the upper Muschelkalk (middle Trias)
	122–173 m	fractured dolomite and compact anhydrite of the middle Muschelkalk (middle Trias)
	173–210 m	rock salt of the middle Muschelkalk
	210–238 m	mudstone, anhydrite, dolomite.

Based on the analysis of the core, the water tests and the geophysical measurements, the following factors formed the most important criteria for the choice of methods for sinking and lining the shaft:

1. Heavily water-bearing and unstable strata from 0–9 m depth
2. Stable strata from 9 m to the planned final depth of 238 m
3. Groundwater is present, particularly on fissures and joints, especially at depths of 9–30 m and 90–110 m
4. 40 m thickness of dry strata in the anhydrite formation above the rock-salt deposits; a minimal amount of residual dampness, under no pressure, in a leached-out layer immediately above the rock salt.

Sinking and Lining the Shaft. The information given above led to a decision to sink the shaft by conventional drilling and blasting. Grouting of the water-bearing layers was designed to reduce the inflow of water whilst the shaft was being sunk through the overburden, until the watertight lining could be installed.

By this method there was always the danger that inadequate grouting could lead to an inrush of water into the shaft. Use of the freezing process would have avoided any

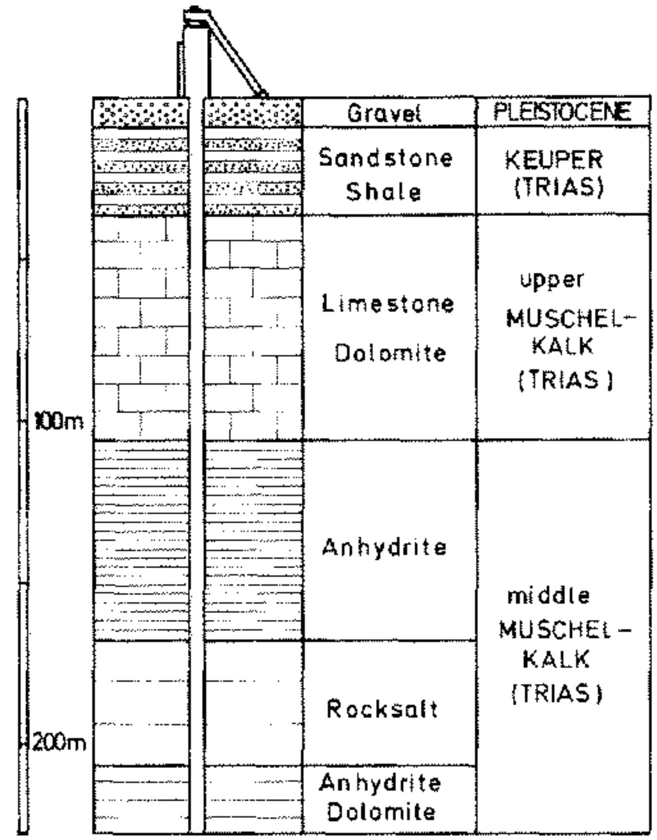

Figure 1. Geological profile of the two shafts at Heilbronn.

danger of this occurring, but this method was not used because of its greater cost. The proportional cost of cementing compared to freezing was about 1:1.4. Partial freezing of the water-bearing gravels down to a 9-metre depth was also rejected for reasons of cost.

In order to make the shaft watertight before it entered into the rock salt deposits, it was first sunk only to the dry anhydrite above the rock salt. This section was then lined with the permanent watertight lining. After the watertight lining was in place the dry strata, including the salt formation, were penetrated to a final depth of 238 m and lined with precast concrete blocks.

Sinking Work to 136/153 m. A circular wall of sheet piles of 7.2 m diameter was first installed into the 9-metre layer of gravel, down as far as the first solid measures of the Keuper formation. The gravel was removed by a deep cut bucket shovel in the first five metres, and by the cactus grab of the sinking equipment below that.

The shaft was sunk with a diameter of 7.0 to 7.2 m, from a depth of 9 m to 136 m. This section was lined with precast concrete blocks of 30 cm thickness and a watertight special lining of 67 cm thickness. The inside diameter was thus 5.0 m.

When sinking a grouted shaft, excavation work is usually carried out with heavy pneumatic jack hammers in order to avoid vibration from blasting. In the present case this was not done because the rock strength of approximately 100 to 120 N/mm^2 meant that it was not an economical proposition.

Sinking work was carried out by the blasting method with a three-armed drill jumbo, a cactus grab and two buckets of 1.5 m^3 capacity each. The depth of one pull was about 3.4 m. About 107 blast holes were drilled and 140 kg of explosive used for each cut. Four or five men worked on the shaft bottom, four shifts per day.

Two possible methods of pre-grouting the various strata were discussed. The whole section of the shaft through the water-bearing strata from 9 m to 130 m depth could be pre-grouted under pressure from the surface. Alternatively this could be done in sections, corresponding to the progress of the sinking work, and taking into account the individual aquifers. This latter method was preferred and was in fact adopted. In the present case it was felt that the latter was both a more flexible and a more economical solution.

The flexibility of this method was repeatedly used to the number of grout holes to the individual hydrological conditions especially at depths where heavily water-bearing layers were present (0–20 m and 92–110 m). In a dry intermediate section between 110 m and 115 m, no grouting at all was applied. The pressure grouting was thus applied in sections, according to the actual hydrological conditions. In addition the vertical overlap between the first and second grout cover was kept to 1 m only, because previous borings had shown that no inflow of water was to be expected at this point.

First Grout-Cover (0–60 m). Grouting was carried out in four sections (Figure 2). Drillings were made from the surface to a depth of up to 60 m. The diameter of the injection curtain was 10.3 m, with a horizontal spacing between the drill holes of 1.8 m. This distance was subsequently reduced to 0.9 m by drilling intermediate boreholes to a depth of 20 m, because of the unexpectedly large amount of cement which was accepted to this depth.

Despite the high degree of hardness caused by the sulphate in the water of these strata (1.5 g SO_4/l up to 5.5 g/l in places) the use of cements with high sulphate resistance was not considered for this pressure-grouting. A more reasonably priced blast furnace cement was sufficient, since the pressure-grouting was only needed to form a temporary barrier against the inflow of water until the watertight lining could be installed. Cement of normal granulation could also be injected, because this material penetrated well into the fissures of the surrounding strata. Only in one exceptional case was there a need for small quantities of special cement and chemicals.

There was considerable acceptance of cement in the layers between 9 m and 20 m depth, which consisted primarily of mudstone and dolomite seams. There was noticeably less acceptance in the deeper strata. In the first

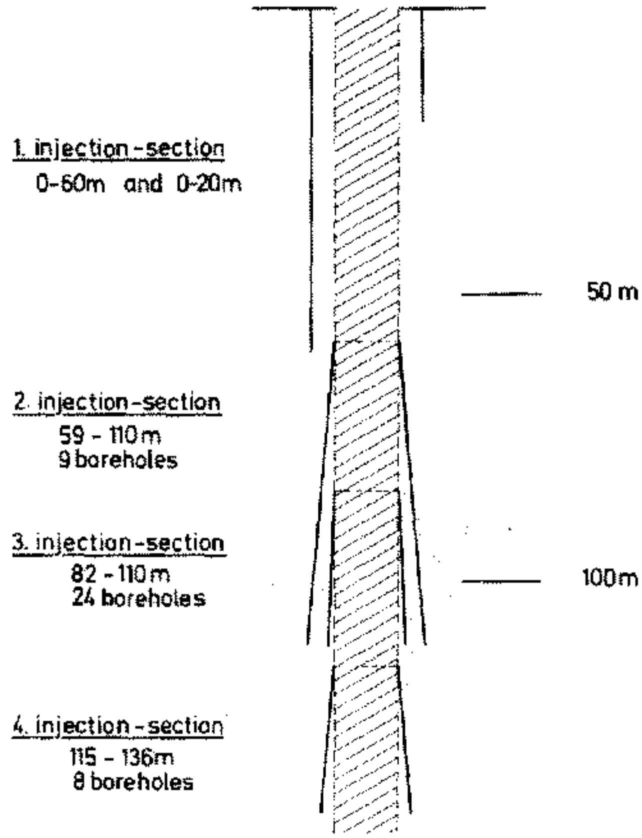

Figure 2. Grouting sections for sinzing the Franzen shaft.

grouting section from 9 m to 60 m depth more than 300 tons of cement was used.

During sinking operation some small inflow of water was noted from certain areas, despite the grouting which had been carried out. Subsequent pressure-grouting of these areas from the shaft itself reduced the inflow to a maximum of 15–20 l/min. The sinking progress was not reduced by this inflow.

This small inflow of water should not be seen as failure in the grouting process. It could indeed have been possible to reduce the actual inflow of water considerably by carrying out the initial pressure-grouting even more carefully, but this would have meant an unjustifiable expenditure of time and money. In any event, the vibration from subsequent blasting operations could have opened new cracks, even after the most careful pressure-grouting, thus allowing an admittedly lower inflow of water into the shaft.

The surrounding strata were generally stable enough to allow 8 to 12 m of shaft wall to stand without any need for rock bolting or wire meshing to safeguard against rock fall.

The 30-cm-thick concrete blocks were used to line the shaft while sinking it. This kind of lining was chosen because of its strength to allow pressure-grouting or wall drying in case of a major water inflow. Shotcrete would not have been adequate.

Second and Third Grout-Cover (59–110 m). After the shaft had been sunk to a depth of 59 m without any particular difficulty, thanks to the protection of the first injection curtain, nine more drill holes were sunk from the shaft bottom to a depth of 110 m. Water entered one drill hole at a rate of 120 l/min at 0.6 N/mm^2; the inflow of water into the other eight drill holes was also considerable, between 3 and 40 l/min. Because this water came from a depth of 92–100 m, the shaft could be sunk a further 23 m, after the grout holes had been pressure-grouted with about 3.5 tons of cement.

From the shaft bottom at a depth of 82 m the water-bearing fissured ground, at 92–100 m depth, was carefully injected with cement and other grouting materials through a total of 24 grout holes. After this, the critical zone could be penetrated without any great inflow of water. As this was being done the main water channel could be seen at the shaftwall; this was a fissure of up to ten metres in height and seven centimetres in width, largely filled with cement.

The great variation between the discharge of water from the drill holes and the sometimes minimal acceptance of cement into the grout holes was a further confirmation that the water in the surrounding strata was practically only in fissures. Under such conditions the efficacy of pressure-grouting as a sealing method is, without doubt, less than the sealing by the freezing process, because a large number of grout holes is required before all the fissures have been penetrated and pressure-grouted.

Fourth Grout-Cover (115–136 m). In the last grout cover from 115 to 136 m there were no significant quantities of water intercepted, contrary to the Kochendorf shaft 6 km away, where the dolomite seam lying directly above the anhydrite was responsible for the greatest inflow of water of 20 m^3/min.

The Watertight Lining. The following lining (Figure 3) was planned for a depth of 0–139 m:

1. For a depth of 0–133 m, precast concrete-block lining bonded to the rock in sections whilst the shaft was being sunk
2. Construction of the foundation for the special watertight lining at depths of 136 to 139 m
3. The special watertight lining, from the outside,
   - a 17-cm wide annulus for subsequent filling with asphalt
   - a 9-mm thick sheet steel cylinder
   - a 50-cm. thick cylinder of reinforced concrete

To prevent water from building up around the foundation, particular care was taken to form a seal at the base of the lining. This was done by installing several layers of Colcrete concrete, resin concrete and a cold-mix bitumen

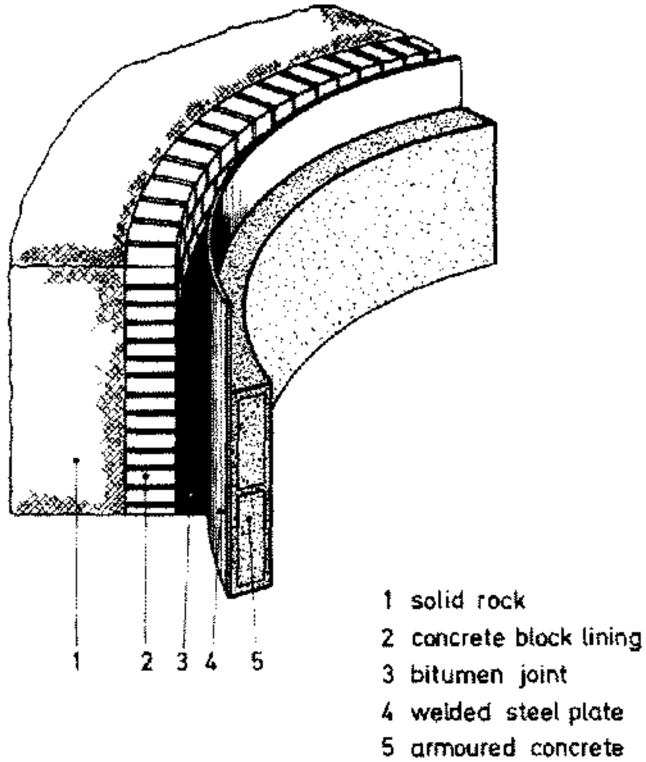

Figure 3. Watertight lining of the Franzen shaft.

(Figure 4). It is anticipated that the viscous asphalt will close any joints and cracks which might open up, thus preventing any vertical migration of water. Also the outer surface of the sheet steel cylinder is protected against corrosion.

A special 24-m-high five-level platform was used to install the watertight lining (Figure 5). To enable this to be lowered from the surface in one operation, the shaft was sunk to a depth of 153 m; this was 14 m deeper than the bottom of the foundation that was to support the watertight lining. This "cellar" was also used as a sump whilst the special lining was being installed and took the water that flowed into the shaft through the annulus, which had not yet been filled with asphalt. As a result there was no need for this water to be pumped continuously to the surface at this stage of operation.

The special lining was installed in the following way. The sheet steel cylinder was made up on the surface from four prefabricated segments, and lowered in vertical sections of 3 m and of 2 × 3 m = 6 m, respectively. In place they were correctly aligned and welded together. Twelve hours later the reinforcement for the inner concrete wall was installed and the concrete placed at intervals of 12 m vertical height.

An eight-man shift was needed for the installation of the sheet-steel lining. Eight men were also occupied to install the reinforcement, the concrete and the brackets that

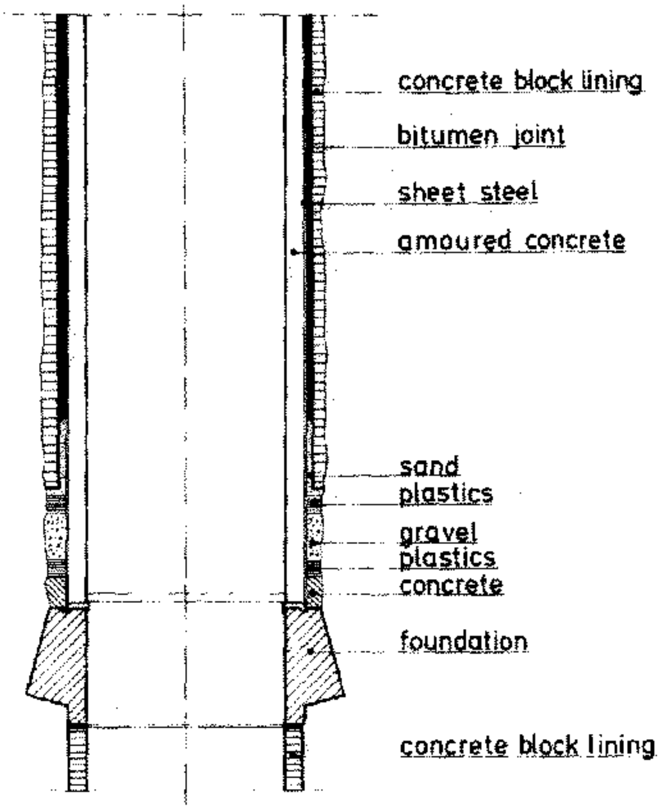

Figure 4. Foundation section of the watertight shaft lining.

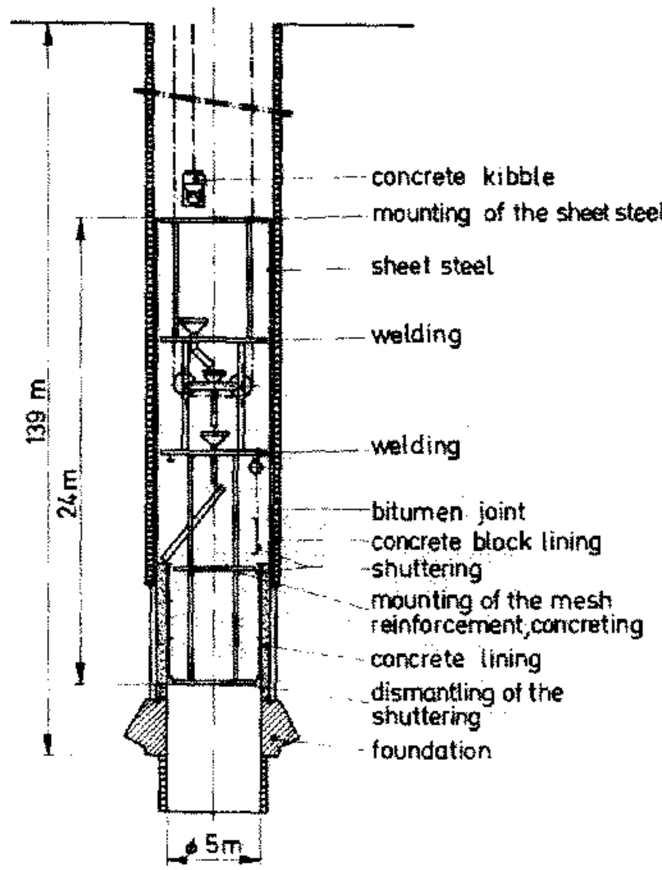

Figure 5. Five-level platform for installing the watertight lining.

were installed to support the guides. The average speed of the special lining installation was 3.5 m of sheet-steel lining and 3.2 m of inner reinforced concrete per 12-hour shift.

The annulus between the concrete block lining and the sheet steel lining which was being built upward, served as a vertical run-off for the continuing inflow of water, whilst the special lining was being installed. The water was able to pass into the sump through a drainage pipe that was fitted to the bottom of the special lining. Finally this pipe was plugged, and the annulus was immediately filled with hot asphalt. The specific gravity of the asphalt was 1.3 kg/l. It was made by admixing powdered limestone to bitumen. This specific gravity ensures that in addition to the hydrostatic water pressure from the surrounding strata, the ring-shaped column of asphalt can also take up a certain amount of rock pressure. The temperature at which the asphalt was poured was between 140°C and 180°C. As a result of varying thermal expansion, the sheet steel cylinder expanded more than the inner concrete, the difference being about 5 mm at the top of the lining column. The level of asphalt sank by more than 3.5 m in the first two days after pouring because of contraction during cooling and fissures being filled. The rate of sinking of the asphalt level later slowed to about 1 cm per day and ceased entirely after six months.

Further Sinking Work, from 156 m to 238 m. After the watertight lining had been completed, and the sump of the shaft pumped out, further sinking work could continue under dry conditions without putting the rock salt deposits at risk. As in the area of the shaft between 139 m and 156 m, the shaft was here excavated to a diameter of about 5.6–5.8 m. It was given a concrete block lining of 30 cm thickness. Here too the inside diameter was 5.0 m.

Between 160 and 170 m depth further sealing was necessary when a minimal amount of residual dampness was encountered in the leached-out layer of clay and anhydrite immediately above the salt deposits.

A deliberate decision was taken not to extend the watertight lining used in zones above 136 m down to this area. Other data had shown that only a minimal amount of residual dampness, under no pressure, was present in the leached-out layer. This was sealed off by means of plastic sheetings 2 mm thick and 12.5 m high, which were placed between a brick lining bonded to the rock and the concrete blocks on the inside of the shaft. In the event pressure-grouting becomes necessary in the future, grouting pipes were provided at the top and bottom of this sealing.

Expenditure. Materials used were, in round figures:

180,000	concrete blocks and clinker bricks
800	tons mortar and pressure-grouting cement
1,400	tons ready-mixed concrete
44	tons reinforcement
190	tons sheet steel
670	tons bitumen
11	tons explosive.

A total of about 9,500 man-shifts were needed from the time the sinking-head gear was set up to the time it was dismantled.

For the sinking operations alone, the average excavation rate was 4.3 m^3 per man shift; at the most this figure reached 5.5 m^3 per man shift. For the installation of the concrete block lining which was bonded to the rock, average progress was 2.0 m^3 per man shift.

Fifteen months had been estimated for construction of the shaft. One of the factors that had not been quantifiable in advance was the amount of grouting that would have to be carried out. Including the time needed for the installation of the necessary furnishing such as guides, inset steelworks and power cable, completion time was about eighteen months. The project was finished in October 1972.

After more than ten years in operation, this shaft, which was given the name 'Franken,' has met all the demands required of it, especially as far as the impermeability of the lining of the overburden is concerned.

The production equipment installed later comprises two 20-ton skips and has a capacity of more than 1,000 tons per hour.

WATERTIGHT RELINING OF THE HEILBRONN SHAFT IN 1981-82

For reasons that are no longer apparent, the first shaft of the rock salt mine at Heilbronn, sunk in 1884-85, was given no watertight lining; this lining would have been tubbings, the only generally-used form of watertight lining at the time. Instead, the shaft was lined with a clinker masonry. The water that flowed in principally from three areas at the 42 m, 97 m and 127 m levels was collected in pipework running through the masonry, so that the masonry would not be destroyed by the hydrostatic pressure of water in the surrounding strata. The water then flowed through a drop pipe into a sump, from where it was pumped to the surface.

The total inflow of water was about 100 l/min. This was not critical from a safety point of view, because both the water inflow and its subsequent pumping to the surface presented no insoluble technical problems. Water only entered the drift system from the shaft at a time shortly before the end of the World War II, when the mine was in the combat zone. Power was lost to the pumps for a few days, and the water which overflowed began to attack the safety pillars by dissolving the salt.

The salt content of the water in the shaft was about 8 g NaCl/l. In the course of almost one century, more than 40,000 tons of dissolved salt was removed. There was always the possibility that salt was being dissolved out of some as yet unnoticed place in the deposits.

In 1981 the Südwestdeutsche Salzwerke AG decided to stop this "water industry" for the remaining years of production at the Heilbronn shaft. This was to be done by the installation into this shaft of the same sort of watertight lining that had proved its worth at the 'Franken' shaft.

First of all the old pit head gear was dismantled and replaced with a partially-completed new head gear. All operations in the shaft were carried out with this, and the existing hoisting machinery. The head gear was later completed for the hoisting of rock salt.

A three-deck stage was used to remove the wooden furnishings in the shaft from the bottom upward. The same stage was subsequently extended by two further decks and used to install the special watertight lining.

Several investigations were carried out into how the shaft could be sealed off yet retain its inside diameter of 5.0 m. To do this the old brick lining would have had to be removed; it would also have been necessary to enlarge the diameter of the unlined shaft by means of a ripping operation. But these measures would have made it impossible to control the water in the surrounding strata. Special work

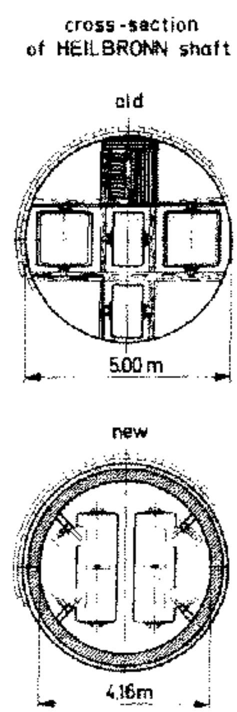

Figure 6. Cross-section of the Heilbronn shaft before and after repair.

such as cement grouting would not only be expensive and time-consuming, but it would also have been impossible to guarantee that the salt deposits would not be adversely affected by an inflow of water entering from the higher strata during repair.

These considerations made it clear that the watertight lining would have to be placed inside the old brick lining. As a result, the inside diameter was unavoidably reduced from 5.0 m to 4.16 m.

After the old furnishings had been removed, drainage continued with two sets of pipework, and the new lining was installed from the bottom upward. From 224 to 142 m depth, in the dry layers of the anhydrite and rock salt deposits, the lining consists of reinforced concrete. In the upper anhydrite layer, at 142 m depth, excavation was carried out by careful blasting and expensive chipping work with heavy pneumatic hammers for the wedge-shaped rim for the foundation. The base for the watertight lining was constructed after this.

As in the 'Franken' shaft, this special lining consists of asphalt joint, sheet steel cylinder and inner reinforced concrete. Only the dimensions of the lining materials are different. From the outside, they are:

- 10 cm annulus, filled with asphalt
- 10 mm sheet-steel cylinder
- 30 cm reinforced concrete.

According to the installation schedule for the watertight relining, the steel construction firm was given twelve hours in which to install and weld the sheet steel lining. In the next twelve hours the reinforcement was to be fitted in place, the concrete forms to be moved into the new position and then concrete placed. A sheet metal ring of 4.76 m diameter consists of four segments, each 6 m in height and 10 mm thick. Six metres of steel plate lining and interior concrete were completed each day. Including the delays involved in starting and finishing these operations, the average progress was 4.5 m per day.

Whilst the steel plate and concrete were being installed, the water present in surrounding strata had to be diverted through the annulus between the old masonry and the steel plate lining, through a drain pipe attached to their lower end. The drain pipe was plugged just before the asphalt was poured. About 360 m^3 of asphalt was used, with a specific gravity of about 1.3 kg/l.

Sixteen months was necessary for renovations of the shaft, including the removal of the old furnishings.

As with the 'Franken' shaft, the lining of the 'Heilbronn' shaft proved absolutely impermeable to the water from surrounding strata.

In 1982 the 'Heilbronn' shaft was equipped with new skip winding, running on steel guide rails. The old and new cross sections of the shaft are shown in Figure 6. Despite the reduction of the inside diameter from 5.0 to 4.16 m, renovation has permitted a more efficient use of the full inside diameter of the shaft. In this way, the payload of the skips was increased from five to ten tons; in addition, the removal of the many fittings from the old shaft and the smooth wall of the new shaft have improved the situation as far as ventilation is concerned.