Current Design and Maintenance Practice in Salt Mine Shafts

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ABSTRACT

Deterioration of a salt mine shaft can result in the permanent loss of a mine for production purposes. Although this phenomenon has never occurred in North America there have been several near misses. In addition, many mine shafts have required, or will require, costly and prolonged production shutdowns for maintenance or major modifications. Other shafts require expensive maintenance programs on a regular basis.

The major maintenance problems common to all salt shafts result from the solubility of the ore, the corrosive action of brine and the visco-elastic properties of salt. Other problems originate from the overlying strata which may contain large volumes of water, corrosive water, gas and unstable horizons.

This paper describes several case histories of deterioration problems in salt mine shafts. The type and extent of the damage is illustrated and the two steps taken to correct the damage are described.

INTRODUCTION

This paper describes three specific maintenance problems in salt mine shafts and suggests methods of eliminating or reducing their impact in new shafts through changes or modifications in design. These problems are concrete corrosion, structural failure of concrete due to salt squeeze, and leakage in the interface between the concrete lining and the host salt.

CONCRETE CORROSION

Several salt mines in the northeastern United States suffer from a corrosive atmosphere in their shafts. The corrosive atmosphere originates from formation water leaking through the concrete lining. This water contains hydrogen sulphide and sulphate and chlorides of sodium and magnesium. The corrosive action is in the form of acid attack on the cement paste and on the limestone aggregate on the face of the concrete wall. The action is relatively slow and the face of the concrete wall recedes at a rate in the order of 1/8 inch per year.

The deterioration of a concrete wall has not caused any recent major maintenance problems involving lost production. However, considerable cost has been encountered in one mine where the flow of corrosive water has been kept to a minimum through an ongoing program of maintenance grouting.

As long as the corrosive water continues to come in contact with the concrete, the deterioration of the concrete will continue and eventually either 1) the attachment of furnishings and services to the concrete wall will fail, or 2) if the concrete wall is required for structural or hydraulic support, the concrete thickness required for such support will no longer exist, and the concrete will fail.

No shaft in North America known to the writer is currently in either stage 1 or 2. No shaft appears to be in danger of reaching either stage in the near future.

Any maintenance or preventative procedure to correct this problem must be aimed at preventing the corrosive water from coming in contact with the concrete. Such procedures could entail the following.

1. *Sealing the corrosive water within the surrounding rock formation or behind the shaft wall by means of grouting.* This solution is very practical at shallow depths, especially where the water's sources are confined to a narrow zone. At greater depths with higher pressures, thicker water-bearing zones, or complex fissure patterns, the effectiveness of grouting can be limited. However, if the volume of flow can be reduced, then the rate of corrosive action on the concrete is reduced. The value of such a reduction should be a factor when considering the cost of a regular maintenance grouting program
2. *Controlling all water flow in a piping system and conveying it to the mine level or a pump station.* In some circumstances this procedure can be the cheapest and easiest solution. However, it does require constant maintenance to ensure that block-

ages are cleared or piped. In addition, corrosion of the piping system can be a problem. This solution has proven to be impractical in several shafts for a combination of the above problems and the large number of small leaks over an extensive vertical height of concrete wall

3. *Applying a protective coating to the concrete wall to prevent the corrosive water from contacting the face of the concrete.* This procedure was applied successfully to a salt mine shaft in the 1920s, several years after construction. The contractor chipped several inches from the face of the concrete wall over a height of several hundred feet, inserted pipes to control the flow of water through the concrete, and constructed a brick wall with mortar in the annular space between the brick wall and the concrete lining. The brick has a ceramic facing resistant to the corrosive action of the water. The pipe inserts are connected to a drain pipe that leads to the mine level. Currently, at other shafts, the use of a corrosion resistant coating is under consideration
4. *Replacing all or part of the lining in the wet zone with an impermeable lining with the structural strength to withstand the hydrostatic pressure.* In an extreme case this solution would require a cast iron tubbing and cost several millions of dollars to construct.

The design required in any new shaft that penetrates a zone of corrosive water should ensure that the water is not permitted to contact concrete susceptible to its attack. Such designs are as follows:

1. *Use of an impermeable lining with a seal at the top and bottom of the wet zone to prevent any migration of water above or below in the interface between the lining and the formation.* In the extreme case this lining could be a combination of welded steel, concrete and bitumen. In shallow applications combinations of concrete, plastic membranes and careful construction may be adequate. This design is the best solution to the problem for the obvious reason that if construction is successful the corrosive water does not contact the concrete wall and no drainage or pumping is required
2. *Use of a piping system to conduct all the water from the interface between the concrete wall and the formation to a pump station on the mining level.* This system must ensure that the water will not come in contact with the face of the concrete. It calls for the careful placement of panning (back sheets) during construction in the interface between the concrete and the rock formation, and conducting the water from the interface through the concrete in pipe inserts. With this solution maintenance of the piping system and pumping of the water are required for the life of the shaft
3. *If it is assumed that no solution to the problem will be 100% effective, use of a corrosion resistant cement and concrete mix if available and feasible.* If the cement and mix is not adequate, then corrosion resistant coatings should be investigated.

STRUCTURAL FAILURE OF CONCRETE DUE TO SALT SQUEEZE

A discussion of the conditions and pressures that cause plastic flow in salt is beyond the scope of this paper. It is sufficient to note that plastic flow which exerts pressures of a magnitude to cause concrete shaft wall failure is not normally encountered at depths shallower than 1500 feet. In addition, even at shallower depths mining operations can induce extremely high stresses around a mine shaft. The resulting salt flow can squeeze the concrete wall and cause structural failure of the concrete.

When concrete failure has reached the stage of crack formation but has not yet commenced to spall, repairs have been effected by rock bolting through the concrete and anchoring in the salt. If the rock bolts are installed at close centers and are supplemented with steel straps and mesh, spalling can be prevented and a permanent repair effected if further flow is minimal. If further flow is excessive, then replacement of the wall over the affected zone may be necessary.

The accepted designs to prevent structural failure due to salt squeeze can be one or any combinations of the following:

(a) omitting any type of lining if it is not required for structural strength, hydraulic sealing, prevention of solutioning or other damage, etc.
(b) delaying construction of the lining for at least several weeks following excavation to permit the initial squeeze or convergence to take place
(c) designing the wall with sufficient structural strength to overcome the stress caused by plastic flow
(d) when it is not feasible to design sufficient wall strength, inserting a material between the salt and the concrete that will flow with the salt without exerting harmful pressure on the concrete wall. Styrofoam has been employed for this purpose.

LEAKAGE IN THE INTERFACE BETWEEN THE CONCRETE LINING AND THE HOST SALT

This problem is the most serious shaft hazard facing the operators of mines in salt domes near the Gulf of Mexico.

The problem exists because it is necessary to construct a seal to prevent water from the alluvium (and consequently, the Gulf of Mexico) from entering the mine through the shaft. Unfortunately every shaft in the coast area penetrates from a saturated alluvium directly into the salt dome and consequently there is no insoluble and impermeable layer in which to construct a seal. The seal, therefore, must be constructed in the interface between the concrete lining and the host salt. Any leakage in this interface will dissolve salt and enlarge the leakage path, giving rise to a situation with potentially catastrophic consequences.

At the five Gulf Coast mines in existence up to a few years ago there were 17 shafts. Of these 17 there were at least 11 shafts where leakage through the seal occurred and maintenance was required. In many shafts maintenance has been required almost annually. Leakages are more prevalent in shafts where the depth of alluvium over the salt dome is in excess of 150 feet.

There is one case on record where a shaft at one of the Gulf Coast mines collapsed completely when a leakage enlarged a flow path and permitted inflow of the overlying alluvium into the shaft. Three years were required to rebuild the shaft and restore production at the mine.

The dangers posed by leakage in another shaft has caused a production loss in excess of six months to permit construction of a lining extension.

Other leakages and maintenance grouting programs have caused production losses varying from several days to several weeks. In many cases, however, maintenance grouting programs have been performed on weekends or nonproduction shifts, and no production time has been lost.

The maintenance procedures for the repair of these leakages are as follows:

1. Diligent adherance to a thorough and regularly scheduled shaft inspection procedure in order to detect a leakage anywhere in the shaft while it is still in the range of 1 to 5 gallons per hour. At this stage frequent observations are made in order to accumulate as much data as possible to design a program to investigate the source of the leak and seal it off.
2. Sealing of most leakages by grouting with either cement or chemical grout, or both. A pattern of small diameter holes are normally drilled through the concrete wall to intercept the flow path of the leakage and to determine the extent of the flow path or solution channeling behind the concrete lining
3. Some leakages are the result of inadequate seal length due to a vertical flow path in the salt that is not in contact with the concrete lining. The leakage is observed in the salt wall many feet below the bottom of the concrete wall. In this situation the problem has been corrected by extending the concrete wall to a sufficient depth to cover the leakage and to construct a seal below it.

The general practice in shaft design at Gulf Coast mines is to continue the concrete liner at least 150 feet into the salt below the alluvium and to construct the seals within this 150 feet. At some mines the owner has specified that the shaft be fully lined from surface to the mining level, a distance up to 800 feet below the salt contact. Seal designs vary in type of material, size, physical shape and numbers. The most common materials are bitumen, Dowell sealant, chemical grouts and cement grouts.

The design and construction of a seal area that will be free of leakage for the life of a mine shaft is theoretically possible, provided that

1. There is no anomaly in the salt which will permit a flow path to develop from the top of the dome to below the seal area and connect with the shaft (there are cases on record where such flow paths have developed 10 and 20 years after a shaft construction. The location and nature of such an anomaly has not been determined even after the leakage occurred)
2. Mining operations do not cause stress, vibration or movement that will cause damage to the seals.

In summary, the seal area in Gulf Coast salt mine shafts is the source of a potentially catastrophic occurrence. The probability of such an occurrence can be reduced in new shafts through close attention to design and construction methods. However, a vigilant inspection program is mandatory because there is no way to guarantee the permanent integrity of the seal. Experience has shown that if a leakage is detected as soon as it occurs, repairs can be effected before the leakage path can enlarge to create a condition where the mining operation is at risk.