TEXAS LIGNITE MINING: GROUNDWATER AND SLOPE STABILITY CONTROL IN THE NINETIES AND BEYOND[1]

by

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Abstract. As lignite mining in Texas approaches and exceeds depths of 200 feet below ground level, rising costs demand that innovative mining approaches be used in order to maintain the economic viability of lignite mining. Groundwater and slope stability problems multiply at these depths, resulting in increasing focus on how to control these costs. Dewatering costs are consistently rising for the lignite industry, as deeper mining encounters more and larger saturated sand bodies. These sands require dewatering in order to improve slope stability. Planning and analysis become more important as the number of wells grows beyond what can be managed with a simple "cookie-cutter" approach. Slope stability plays an increasing role in mining concerns as deeper lignite is recovered. Slope stability causes several problems, including loss of lignite, increased rehandle, and hazards to personnel and equipment. Traditional lignite mine planning involved a fairly "generic" pit design with one design highwall angle, one design spoil angle, and little geotechnical evaluation of the deposit. This "one mine-one design" approach, while cost-effective in the past, is now being replaced by a more critical analysis of the design requirements of each area. Geotechnical evaluation plays an increasing role in the planning and operational aspects of lignite mining. Laboratory core sample test results can be used for slope stability modeling, in order to obtain more accurate design and operational information.

Additional Key Words: dewatering, geotechnical, surface mining, Texas geology.

Introduction

Slope stability and groundwater control are issues which have become increasingly important in the "modern" era of Texas surface lignite mining, which for the purposes of this paper began in the 1970s. The lignite was shallow in the beginning, and mining was easy by today's standards. Slope stability was less of a concern at first. The pits were relatively shallow, so that slope failures which did occur were relatively minor. The overburden typically consisted of more clay and less sand than we see today, and was therefore more stable. Dewatering was often not needed because of the lesser amounts of sand.

Recovering lignite in Texas is certainly much more challenging and costly today than it was in the seventies and eighties, as mining breaks through the 200-foot-below-ground level.

This paper is intended as an overview to present ideas and promote discussion on controlling the costs of dewatering and slope stability. The author's interest stems from his more than ten-year association with the industry, first from the inside as an employee of a large surface mining company, and subsequently as a consultant to the industry.

The Effect of Geology on the Downdip Progression of Mining

Geology conspires to make Texas lignite mining more expensive as it proceeds downdip. The geologic horizons which are the lignite hosts in Texas are a mixture of fine-grained deposits, including clays, silts, and sands. The gradation of the overburden materials shifts as mining proceeds from near-surface to deeper deposits. Sand aquifer geometry also gradually changes in character: updip, the sand bodies tend to be isolated geologic occurrences in a predominant clay matrix; downdip, these sand bodies become more pervasive and tend to merge,

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thereby making the less stable sand an increasing percentage of the highwall (Henry, Kaiser, and Groat 1976).

The Increasing Role of Dewatering

Dewatering was not initially conducted in the early Texas lignite surface mining in the 70's, simply because it was not needed. This soon changed, however. Although those first miners may not have understood all the fine details about how groundwater affects slope stability, the image of large slabs of saturated sand highwall collapsing into the pit made it obvious something had to be done. Before too long, most mines had adopted dewatering as a standard and growing part of mining operations.

Today, it is common for a Texas lignite mine to have hundreds of dewatering wells, costing hundreds of thousands of dollars per year to install and operate. And the forecast is for more dewatering in the future. The importance of carefully managing this large and growing cost is becoming more obvious as it constitutes a growing part of the per-ton mining cost.

It is worth noting that the consequences of dewatering decisions made today may not show up in mining operations until up to seven years later. This is because dewatering wells are usually installed two to four years prior to mining, and the wellfields are designed, planned and budgeted years before that.

Measuring Dewatering Success

Since dewatering costs are a large and growing cost of mine operations, it becomes increasingly important to measure dewatering performance. In this era of downsizing, tracking and reporting of many operations is not being done as much as it was in the 1970s and 1980s. As more and more money is spent on dewatering, it often happens that less and less is known about how effectively this money is being spent.

So how is dewatering performance tracked? It's tracked with numbers, and usually with the easiest and cheapest numbers to obtain. The easiest - though not the best - measure of performance is simply gallons produced per time period. This is a valid and necessary method of looking at performance. It is especially useful, for instance, to look at the cost to produce a gallon of water. This requires flowmeters at key points throughout each wellfield. In the downsizing era, this is the kind of measuring effort that is being reduced or eliminated. The consequence of this is a wellfield may go through a prolonged period of poor performance because reduced tracking does not allow for timely problem detection. As mentioned above, the mining consequences of this kind of substandard performance may not be detected for years.

Another, better method of measuring dewatering performance is measuring the decrease in saturated sand thickness created by dewatering, by taking water levels in piezometers. This gets more to the heart of the matter, since the goal is not to simply produce water. This measurement, like the water production readings mentioned above, is best made on a frequent basis, by the ones who can make the best and most immediate use of the information: the technicians whose job it is to look after wellfield performance.

It is easy to forget that the ultimate goal of dewatering is not to produce water or create drawdown...it is to improve slope stability. So why don't the field technicians simply measure this ultimate yardstick of performance? Because there is no simple monthly measurement of slope stability. It can only be indirectly measured, and even the indirect methods are difficult and open to interpretation. Slope stability can be measured by an ongoing survey of slope failures occurring in the mine. Such a survey would record the volumes of failed material, the time and equipment required to overcome the failure, and any lignite lost. This type of program has been started in some Texas mines, usually as a result of a significant slope failure and subsequent focus on the problem. It can be difficult to maintain continuity in this type of program, however, as attention and resources gradually shift elsewhere.

As increasing dewatering costs and slope failures focus attention on slope stability, the Texas lignite industry must develop and maintain methods for determining the cost of slope stability. Only by developing well-documented slope stability cost information can dewatering expenditures be assessed for cost-effectiveness. The relationship between a dollar spent on dewatering and the amount of stability gained must be established. A survey such as described above can be used to establish the ongoing cost of slope stability by looking at equipment time spent in cleaning up failures, and the lost value of unrecovered lignite.

The increasing slope stability problems brought about by deeper mining focuses attention on creating solutions using methods in addition to dewatering, in order to supplement the beneficial effects of dewatering. Operational changes can certainly improve slope stability, such as moving the spoil back further with additional equipment, leveling and reclaiming spoil peaks on an accelerated schedule, preventing standing water in the spoil by pumping, and selective spoil placement. These and other changes can be implemented on a scale ranging from small changes to dramatic operational changes. It does not make sense, however, to implement changes unless the mine already has clear "baseline" documentation of the problem which the change is supposed to address. This again indicates the need for the mine to have a consistent, ongoing program in place to establish the cost of slope stability. A time-trend analysis of slope stability cost can be used when changes are implemented in order to provide for objective analysis of the cost-effectiveness of the changes in improving slope stability.

Finally, another purpose of dewatering other than slope stability should be noted: dewatering is also conducted simply to reduce groundwater inflow into the pit. This helps keep the pit dry and improve trafficability. The success or lack thereof is often measured by simply examining the highwall for obvious sources of groundwater inflow. Dewatering serves other purposes which are beyond the scope of this paper, such as improving spoil characteristics.

The Role of Slope Stability Analysis

With all the money spent on dewatering, it is ironic that we spend so little time and analysis on the heart of the matter: slope stability. Why is the well-established engineering science of slope stability analysis relatively little-used where surface mining is concerned? Some minor slope stability analysis might be done early in a mine's pre-operational phase, typically resulting in a single design slope angle being assigned to the whole mine. Slope angle adjustments are later made by operations after mining is underway, based on experience with the design angle. However, little or no slope stability analysis is typically conducted during a mine's operation, often in spite of ongoing slope stability problems.

The main reason that slope stability analysis is little used in Texas mining is that the surface mining situation presents among the most difficult applications of this potentially useful tool. The classical applications of slope stability analysis to road embankments, dams, etc. involve factors of safety of 1.2 to 1.5 or greater. (Factor of safety is defined as the force resisting failure divided by the force causing failure, such that a slope with a factor of safety less than 1.0 will by definition fail.) If the calculated factor of safety is incorrect by one or two tenths, there is usually enough margin to prevent grave consequences. Surface mining slopes, however, are temporary constructions which exist on the ragged edge of slope stability/instability. The frequent minor failures on highwall slopes clearly indicate that most of the highwall exists at a factor of safety barely above 1.0. Therefore, there are far greater consequences if a slope stability analysis is incorrect by as much as a tenth. Unfortunately, the range of uncertainties in inputs dictates that the output is often not known with the required accuracy. For example, determining that the factor of safety is 1.02 ± 0.1 is of little use.

Another reason that classical slope stability analysis is underutilized in this application is that it has little to offer concerning what we really wish to know about a slope: the percent chance that it will fail, and when it will fail. These should be the actual goals of a slope stability analysis; this is the information that users need. Calculating a factor of safety is not the same thing.

Slope stability analysis can be usefully applied if some adaptations are incorporated. The percent chance a slope will fail can actually be calculated by incorporating statistical analysis of the inputs into classical slope stability modeling. The minimum percent confidence level that a slope will not fail can be determined by using that confidence level determined for each input. For example, if the use of the 90 percent confidence level of inputs such as cohesion, angle of friction, pore pressure, etc., result in a factor of safety of more than 1.0, then there is a minimum 90 percent confidence that the slope will not fail.

This technique assumes an adequate statistical characterization of each input. This implies a significant amount of drilling, sample collecting, and testing. In cases in which these data are not available, slope stability analysis can still be usefully employed without the statistical data. In this case, the user is once again left with calculating a factor of safety which is above 1.0, but with an uncertainty which indicates that the true factor of safety may be below 1.0. In this instance, slope stability analysis should be used not to determine absolutely if a slope will fail, but to analyze the *relative* stability of a slope, compared to an existing slope in the mine. In this manner, the stability of new slope designs or new mining areas can be usefully compared to existing slopes.

It has been suggested that surveying an actual mine highwall failure and back-calculating can be used to determine the soil parameters and other factors for input into slope stability analysis. This method often won't produce correct results because there is not a unique combination of inputs which leads to a given output factor of safety. In other words, the output - the factor of safety - can be produced with many widely varying combinations of pore pressure, cohesion, etc.

Slope stability analysis will probably remain a tool only for general guidance in most Texas surface lignite mining applications, because of the complexity of the analysis, the large amount of required input data, and the frequently indeterminate nature of the input data. Charbeneau and Wright (1983) have an excellent discussion of the application of slope stability analysis to Texas lignite mining; however, it underlines the technical complexity and difficulty of this application. Slope stability analysis often cannot be used with sufficient certainty to determine absolutely if a particular slope will fail, unless a significant amount of geotechnical data on the surrounding soils is obtained. However, it can still be usefully employed to analyze the *relative* stability of a slope, compared to an existing slope in the mine.

The Role of Groundwater Modeling

Computer groundwater modeling is going to become increasingly important as mining reaches greater depths for two reasons: 1) From a permitting point of view, it will be increasingly important to assess the effects of projected larger dewatering operations on lignite-host aquifers such as the Wilcox Group, which is a major aquifer in the State of Texas (Kaiser 1985), and 2) from a practical, mining point of view, the dewatering success of large, multi-level, coalescing dewatering wellfields can no longer be reliably determined based on past experience.

Computer modeling of groundwater formerly was used mostly as a permitting tool. When it came time, years later, to actually install dewatering wells, the permitting modeling results were generally not used. An unfortunate side effect of this practice was that modeling results were never checked; that is, there were few or no studies to determine the quality of predictions made in the permit. Of course, if the actual wellfield as installed bears little resemblance to what was modeled in the permit, there is no way to check or use the modeling results generated by permitting.

Early dewatering usually involved installing wells in a surface sand that was completely isolated from other hydrologic influences, and the results were generally predictable. As mining moves downdip, hydrogeologic conditions become more complex. Current and future dewatering will involve large wellfields installed in aquifers - some of which are confined, some unconfined, and which may coalesce and influence each other in ways which are difficult to predict without computer simulation. For instance, a smaller aquifer may merge into a larger aquifer downdip in such a way as to render the small aquifer dewatering ineffective. Groundwater modeling will become a key planning tool as the effects of large dewatering wellfields become difficult to predict in any other manner.

The Importance of Customizing Wellfield Design to the Aquifer

Dewatering wellfields have been designed in the past by the use of a "cookie-cutter" approach, with a standard spacing and design. Dewatering dollars can be spent more effectively by using an approach that includes better use of existing data. Mining personnel often have available detailed maps that show the structure of a sand, including all the high and low points in the base of a sand. Rather than simply installing wells every 300 feet (for example), it is much more effective to adjust spacing so that as many wells as possible are screened in the base of the low points in the sand. Also, computer simulation often indicates a much more effective layout that may not be otherwise obvious.

Grain size analysis of the sand can be used to substantially improve dewatering well performance. The use of a single mine-wide well design, with the same slot size, etc., misses the opportunity to substantially increase well production by analyzing differences between the various sand aquifers present in the mine. Although grain size analyses of individual sands is generally not available, this information can be obtained at relatively little cost. The grain size analysis gives a quantitative, objective method for designing a well (Driscoll 1986).

The Importance of Wellfield Maintenance

There is a tendency to minimize or underestimate the importance of the field technician's role in the overall success of the dewatering program. In the downsizing era, it may be tempting to reduce wellfield maintenance. As discussed previously, the effects of such decisions to decrease maintenance will not be felt for years. The lack of wellfield performance tracking discussed earlier can lead insidiously to decreasing maintenance: if a lack of tracking means poor wellfield performance goes undetected, then there is no need to pay someone to correct a problem that no one knows exists.

A committed, experienced wellfield technician can greatly improve wellfield performance, by using production and drawdown information to quickly ferret out and solve well problems. A mine may wish to tie wellfield performance to the technician's salary, in order to help justify the expense.

Conclusions

Dewatering costs and slope stability problems are rising significantly as Texas lignite mining progresses deeper below the ground surface. Successful mining companies will manage these costs by aggressively determining the costs of slope stability, using this information to analyze dewatering expenses, and following through by measuring dewatering success. Companies can no longer afford to spend hundreds of thousands of dollars per year on dewatering without clear justifications and benchmarks for success.

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