A SUCCESSFUL METHOD OF RECLAIMING SUBSIDENCE
IN ABANDONED MINING AREAS

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ABSTRACT

Old mine openings present hazards to the public and liabilities to the property owners. Many makeshift attempts have been devised to solve the problems of old mine openings and mine subsidence, but few have been successful.

This document will describe a method of plugging mine shafts, ventilation raises and mine cave subsidence which has been designed, tested and found to be successful, meets environmental requirements and has not failed in over 150 reclamation sites.

Engineering design parameters were first applied by the writers to the plugging of mine openings in 1992. The design was inspired by the expandable thermos bottle cork which expands into the fragile throat of the vacuum bottle and seals it off. The concept was adapted to the mine openings with old mine tires as the cork. The compound polymer-steel toroid structural unit (loader tire) is designed to compensate for poor anchor points, loose rock, a tensional component in the stresses and when compressed and allowed to expand into the cavity, applies considerable pressure on the sides of the cavity, stabilizing the opening. This is a dynamic structural design component, capable of moving with the rock as the strain is taken up and the latent stresses in the rock are relieved.

Once the opening is stabilized using the toroid plug, a three step, matte, mesh and cloth geotechnical solution can be applied and finished with backfill, topsoil and seeding to complete the reclamation.
INTRODUCTION

Old mine openings present hazards to the public and liabilities to the property owners. Many makeshift attempts have been devised to solve the problems of old mine openings and mine subsidence, but few have been successful.

This document will describe a method of plugging mine shafts, ventilation raises and mine cave subsidence which has been designed, tested and found to be successful, meets environmental requirements and has not failed in over 150 reclamation sites.

The use of concrete has been used in some instances but this method has serious shortcomings. The specific applicability and inapplicability of concrete plugging is discussed.

HISTORY

In the past, mines were worked while economic parameters were favorable and when the economics were no longer viable the mine was abandoned. Often the openings were merely boarded up and surface installation locked up as the operator walked away, leaving everything as it stood on the last day of production. Often these closures were considered temporary at the time but the mines never reopened and the properties fell into disrepair and then eventually into rubble. Today, these practices are no longer acceptable and reclamation planning and funding for reclamation is required to be in place before mining can begin. However there are hundreds of old mines which are not protected by the new reclamation regulations and there are many hazards and liabilities associated with these properties. Photo #1 shows a typical portal feature that has reopened. These features are common in mining areas.

Over the years many mine openings, which were not open through to surface, at the time of the closure of the mine, have now caved through to surface and are manifest as holes with apparent bottomless cavities underneath into which an unwary hiker, curious explorer, spelunker, dirt-biker, ski-dooer or hunter might fall.
Some attempts have been made to fill these openings with gravel, brush, old cars, old fridges or whatever was available. Figure #1 show a typical procedure that has been used for many years to "plug" and cover old mine entries. A common alternative was to completely refill the cavity left by the mining but that would often require tens of millions of tonnes of material and is not considered practical. Attempts to block the opening using the previously mentioned materials are seldom successful as the brush and trees rot, the cars and fridges rust, water washes the fines past the blockage and inevitably the holes open up again. Attempts have been made using concrete to seal these openings. These concrete plugs are very expensive, and whereas they look good, there are fundamental flaws in the design concept that makes these plugs at the best, suspect. The concern with respect to concrete plugging is addressed later.

Engineering design parameters were first applied by the authors to the plugging of mine openings in 1992. The design was inspired by the expandable thermos bottle cork, which expands into the fragile throat of the vacuum bottle and seals it off. The concept was adapted to the mine openings with old heavy equipment tires functioning as the cork. The compound polymer-steel toroid structural unit (loader tire) is designed to compensate for poor anchor points, loose rock, a tensional component in the stresses. When compressed and allowed to expand into the cavity, applies considerable pressure on the sides of the cavity, stabilizing the opening. This is a dynamic structural design component, capable of moving with the rock as the strain is taken up and the latent stresses in the rock are relieved.

Once the opening is stabilized using the toroid plug, a three stage matte, mesh and cloth geotechnical solution can be applied and finished with backfill, topsoil and seeding to complete the reclamation. Figure 2 shows all of the components of the toroid plug technique.

There are numerous instances where the old mine workings are near towns today, as is the case in the Crownest Pass area of Alberta. These towns have grown out of the old mining camps and the highways servicing the mines have remained and communities have
developed to occupy the old mine areas. Several of these areas exist in the Canadian Rockies where the early coal mines have now been abandoned for 50 years. Two of these are the Crowsnest Pass and the Canmore areas of Alberta, but these are only two of many.

PROCEDURE

The following outlines the procedure by which a flexible, expandable, plug is inserted into the old mine workings and through modern geotechnical methods the subsidence is sealed off and the ground stabilized.

Equipment

The equipment used for the work depends on a field evaluation of the feature being addressed as well as the limitations placed on the work either by the physical practicalities of the site or by specific requests or limitations required by the client. The most usual and useful component is the backhoe as shown in Photo 2. A Cat 325 tracked excavator with thumb, or equivalent, is used for excavation, placing the plug, backfilling, contouring the hole and where applicable removing the access. Support equipment normally includes a dump truck for the transportation of materials, a 4X4 pickup for the transportation of personnel and small supplies and a quadtrack, all terrain vehicle (ATV), which is convenient for close access and speeds up the work, but is not essential in all cases. The ATV is also used in the seeding and fertilizing operations and is mounted with an automatic electric seeder and bin. In areas too rugged for the ATV a hand held seeder is required.
Supplies:

A supply of used tires from large scale earth moving equipment is the basic ingredient necessary for this technique. Mine truck, scraper or loader tires are suitable for the design and assembly of the plug. Although the number varies widely, in general between three and fifteen tires are required per open hole. A supply of used highway truck tires is required for the construction of the matte. Between 15 and 100 per reclamation site is a usual requirement. A supply of geotechnical mesh sufficient to cover the constructed matte is needed. Rolls of mesh come in 14 foot widths and the patch should be two meters longer and 2 meters wider than the hole that is being covered. A supply of geotechnical cloth is required. The cloth comes in 12 foot wide rolls and should be cut to cover the mesh. A supply of 5/16" galvanized wire cable is required. Although cable comes in any length, a 2000 foot spool is convenient for handling. Approximately 30 meters of cable and 8 clips are required for every three of the large tires in the plug. In addition the tire matte requires $2[(w -1)(L) + (w)(L-1)]$ meters of cable, where "w" is the width of the matte in meters and "L" is the length of the matte in meters. A supply of 5/16" Crosby cable clips is required. The number of clips required is $[(w -1)(L) + (w)(L-1)]$. To finish the job a supply of suitable grass seed and appropriate fertilizer for reclamation is needed.

METHOD

One of the procedural problems that has to be addressed is the fact the ground around an area of subsidence is nearly always unstable. That is, the cave-ins, caved in because the ground was broken and had insufficient strength to hold the opening. The rock around these cave-ins is usually still moving as the rock adjusts to the removal of the ore.

The solution is to design a plug as shown in Photo 3 for structural support at a depth where there is better structural integrity in the mine opening and to build the rest of the barrier above that. Various ideas revolving around the use of concrete, structural steel, etc were assessed but: with ground that has already moved the use of concrete does not seem to be a
suitable answer in most cases; Concrete is a static structural unit, incapable of adjusting to the latent strain naturally occurring in the rock. Since the ground has moved and is moving it is necessary that the plug be designed to reflect this.

What is required is a dynamic, expandable, flexible plug that would expand to fill the hole even if a minor amount of movement continued to occur and more material sloughed away from the sides of the opening after the plug was in place. The solution came in the form of recycled open pit mine equipment tires. The large loaders, scrapers and trucks, used in the open pit mines and construction projects require new tires at regular intervals often before the tread is worn away. If the sidewalls or cording is damaged the tire is no longer useable nor reclaimable and most mines and many contractors have stock piles of these unrecyclable tires for which they have no use. These damaged and unusable tires are still very strong and proved ideal for the purpose of providing a suitable plug for underground mine openings.

Mine openings come in various sizes. It is therefore necessary to adapt the use of the recycled tires to the size of the hole. Many of the openings can be successfully plugged by arranging the tires in a stack of four to six tires, which are then cabled together with galvanized 5/16th inch steel cable. The tires are then compressed with the use of the excavator bucket and thumb and are ready to be forced into the hole. The cables are used to hold the plug together in a manageable unit for handling and are not meant to provide a structural component. The compressed stack is then forced into the opening and allowed to expand to fill the hole. In the case of large holes several of these stacks may be required and in the case of small holes one or two tires when compressed may be all that will fit into the opening. The force that the excavator is able to exert upon the stack, with the weight of the machine and the hydraulics of the bucket and thumb, provide a compression in the stack which would be difficult to achieve by any other method and is sufficient to provide a stable, structural plug. Ideally the plug is placed in the opening before the area around the hole is disturbed. Experience has shown that, excavating before the plug is in place only increases the size of the problem and makes the plugging operation more difficult.

With the plug secure, a layer of material is placed above the plug to create a platform. Any available material will do, as this thin layer is placed only to provide a working platform on which the workmen can safely stand to complete the next step. While excavating the material to cover the plug the excavator operator will cut back the edge of the hole to create a one meter wide ledge to be used as a "hitch" or anchor on which to set the next layer, the matte. This platform should be fairly planar but does not necessarily have to be flat. Salvage and stockpiling of the topsoil for later use, should be attempted during this part of the operation as this will enhance the final result and make the establishment of ground cover much easier.
The next layer is referred to as the matte. The matte is made up of a number of highway truck tires linked together by cable and sufficiently large to cover the area of subsidence and a minimum of one meter onto stable rock on all sides. As shown in Photo 4, each tire is cabled independently to is neighbor by a 5/16th galvanized steel cable and clamped with Crosby cable clips. In the matte the cables are a part of the structure, but since the strength of the repair is established in the plug, this layer is not required to carry massive loads but is rather designed to support the mesh and cloth and stop the flow of fines into the hole. The tires are arranged in a square pattern with each tire being secured to the four tires around it. With the matte in place a firm foundation is set for the next layer, the mesh.

The mesh is a commercial geotextile material used universally to stabilize difficult ground conditions. It consists of a 1.5" X 1.5" square mesh of polypropylene plastic and comes in 14 foot rolls, 200 feet in length. This material can be cut with a sharp knife to fit the matted area. This mesh is then simply placed on top of the matte and secured by placing heavy objects, usually rocks, at the corners. In practice the mesh catches on the cable clamps used on the matte and is difficult to move once it is placed on top of the matte.

The next layer is a commercial geotextile material referred to as cloth. This material has the consistency of carpet underlay, is 0.5 centimeter thick and is made from fine polypropylene fiber. The cloth allows water to pass through but stops the fines and provides the final structural support for the reclamation. This material is very strong and will carry the weight of a bulldozer without tearing.

The next layer as shown in Photo 5, is composed of gravel or broken rock or whatever material is available and is applied to a depth of at least one meter. A good percentage of fines is preferred in this layer to promote the growth of ground cover and provide material for tree roots. At this point the contour of the final reclamation is established with drainage leading surface water away from the hole and diverting any flow of water which may be directed toward the opening.
The final layer is topsoil which was salvaged from the initial excavation. This topsoil should be at least 15 centimeters and preferably 30 centimeters thick in order to provide a good growing medium and allow the establishment of ground cover.

The final step is the reintroduction of suitable vegetation to the area and finally to seed and fertilize the area with suitable ground cover to kickstart the regrowth cycle.

**CONCRETE PLUGS**

Concrete as shown diagrammatically in Figure 3, has been used to plug mine shaft subsidence in some cases. It is felt that the use of concrete for shafts and other vertically oriented features is inadvisable and some comments are appropriate to clear up some misconceptions with respect to the use of concrete for this purpose.

Engineering design of concrete structures requires the recognition that concrete has virtually no strength in tension. Whenever a tensional component appears in the design of a concrete structure, reinforcing steel is required to be set into the concrete, sufficient to carry that tensional component. In order to be certain that these tensional components are fully understood and compensated for, a complete evaluation of the forces and loads applied to the: concrete must be measured and understood, so that the tensional component can be designed for and the appropriate reinforcing steel can be installed in the concrete, in the right orientation and with adequate tensional strength to withstand these forces.
In the case of mine subsidence it is extremely difficult and very expensive to evaluate the stresses inherent in the breakdown of a mine opening or the residual stresses left in the rock from the original mining of the opening and the surrounding rock, and this evaluation of the stresses, is a prerequisite of any engineering design.

The other problem with respect to the use of concrete to stabilize mine subsidence is the need to establish a solid foundation on which to set the concrete beam which makes up the main structural member of the plug. In most situations the mine opening is already spalling and caving and the sides are unstable and opening with cracks. It is difficult to imagine how a stable foundation can be achieved under these circumstances.

Because of the problems stated above, an adequate concrete plug must be so massively over designed as to be beyond any design aspect at all.

The cost of an adequate concrete plug in a typical mine subsidence will be in the order of $20,000 to $50,000 per site depending on the availability of concrete and the access required for the delivery of large amounts of concrete to the opening. Some mine stabilization programs have been installing concrete plugs for half this figure but without the stress analysis, reinforcing steel, or the massive over design required for a safe repair. For these reasons the propriety of concrete plugs is questionable.

**COSTS**

The cost of the method outlined here is one of the more attractive aspects to an otherwise rather ugly situation. Costs vary tremendously depending on the location of the hole, the size of the hole, accessibility of the hole and proximity to towns etc. For the average of over 150 sites reclaimed to date, the costs per site is under $5,000 per hole.

**Itemized costs are as follows:**

The cost of heavy equipment tires is usually made up only of the loading and haulage costs from the source, often a nearby mines. The cost of tires used in the construction of the matte is usually negligible being made up of the haulage costs from the nearest city land fill where they are usually set aside as being unrecyclable.
Geotextile mesh can be purchased for about C$2.50 per square meter with the average hole requiring 20 to 30 square meters. Geotextile cloth can be purchased for about C$2.50 per square meter with the area covered the same as above. Although there is a wide variance in the capability of equipment operators, it has been found that a willing and capable operator can easily adapt to this specialized work. The rental of the excavator with operator is about C$150/hour.

Mobilization and demobilization of equipment will require the use of a low boy and costs will depend on haulage distances to the site.

Rental of the 4X4 pick up is usually about C$100/day
Rental of the ATV with seeder etc. is usually about C$100/day
The cost of seed and fertilizer is about C$300 per hectare.
The cost of accommodation for the crews should be in the order of C$200/day. On a multi-hole project the crews should be able to reclaim one hole per day.

For a single hole, preparation, mobilization and organization of equipment can take two or three days with the actual work requiring a day to complete.

RESULTS

To date, over 150 holes have been repaired, many between occupied homes in the Bellevue, Blairmore, Coleman and Canmore areas of Alberta, and many more within the city limits of these towns, adjacent to schools, within areas frequented by children, as well as near to trails used by dirt-bikers, skidoosers and hikers who frequent the neighboring hills adjacent to these towns. This method has proven to be successful in all cases to date. In no case has the plug shifted or the integrity of the reclamation been lost.

CONCLUSIONS

This method of plugging and reclaiming mine subsidence is not about throwing a bunch of old tires into the hole until it is blocked. This method is about using the unique properties of the tires to design a plug that when compressed and inserted properly into the opening it expands and forms a structurally competent barrier to block further subsidence and to contribute to the support of the unstable ground around the mine opening. The subsequent steps in the method are focused on blocking the movement of fines and controlling the drainage. This portion of the work follows the traditional ground stabilization methods used wherever ground stability is a problem.
The success of this method has been tested in over 150 sites. Several sites have been tested in the extreme. Many sites located in the towns are now used as playgrounds for neighborhood children. Many have been tested by the regular passage of vehicles. Most have been tested by the passage of livestock, horses and cattle as well as wild game animals such as deer and elk. One, to our knowledge, has been tested by the passage of a D9 tractor and other heavy equipment while the area was undergoing seismic surveys. No failures have occurred in the six years that we have been using this method.

WE DO NOT RECOMMEND THAT THESE PLUGS BE TESTED IN THIS WAY BUT WE ARE NOT SURPRISED THAT THEY HAVE WITHSTOOD THESE TESTS. WE DO NOT RECOMMEND THAT THESE SITES BE USED FOR PERMANENT ROADWAYS OR THAT THE SITES BE USED FOR BUILDINGS AS COMMON SENSE WOULD DICTATE FOR ANY AREA THAT IS UNDERMINED.

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