CEMENTED BACKFILL IN TWO ITALIAN MASSIVE OREBODIES

By
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ABSTRACT

Mining of the massive complex sulphides orebodies of Campo Pissano and San Benedetto (Southern Sardinia, Italy), dates back to before Christ, though their exploitation with modern technology was only resumed in the middle of the last century. The increasingly adverse economic conditions and the weakness of both country rock and mineralization were concurrent in forcing the Company's management to develop suitable high-productivity stoping methods. In the framework of a project financed in part by the Commission of the European Communities, and carried out in cooperation with the Universities of Cagliari (Italy) and Clausthal (Germany), a cemented backfill stoping method was developed. The concrete mix preparation and placement facilities, study of the cement mixes and endeavours to optimize the methods are described. The monitoring system for measuring stress evolution within the emplaced backfill is illustrated together with the successful replacement of part of the Portland cement with fly ash as binding agent in the mixes is discussed and a cost analysis provided.

INTRODUCTION

Sardinia, an Italian island about 350 km west of the Italian peninsula in the Tyrrhenian sea, has been an important mining district for over two thousand years mostly for its zinc- and lead sulphides orebodies. However, over the last two decades, the rising labour costs, the decrease in grade of run-of-mine ore and the dramatic fall of base-metal prices resulted in the closure of a number of mines. The strive towards greater profitability of existing mines has prompted the companies to develop and optimise completely automated stoping methods. Typical examples of this are the mines of Campo Pissano and San Benedetto where the potentials of stoping methods with cemented backfill have been investigated within the framework of a project supported by the Commission of the European Communities. The present paper is concerned with the results achieved so far.

THE CAMPO PISANO AND SAN BENEDETTO MINES

GEOLGY AND GEOGRAPHY OF THE MINES

The Campo Pissano and San Benedetto mines are located in south-western Sardinia. The

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geology of the area is characterized by Middle and Lower Cambrian outcrops with three main formations one of which, the "Connessa Formation", is locally known as "Metalliciferous", on account of the fact that the major metal sulphides and/or oxides containing orebodies are located therein (Fig. 1). The country rock of the Connessa Formation is exclusively carbonate: shaded dolomite, grey dolomite and "waxy" limestone.

At Campo Pisano, in the orebody where stoping is currently being carried out, the mineralization is prevalently composed of pyrite, sphalerite and minor amounts of galena and is often fragile. The country rock at the foot wall of the orebody contains oxidized matter and grey dolomites; the latter are fractured and incoherent in the vicinity of the contact, becoming continuous far from it. The plan section of the mass reveals an elongated shape, the major axis running in an E-W direction. Its surface area increases considerably with depth, ranging from about 1200 m² at the - 49 m a.s.l. elevation to about 10,000 m² at the -165 m a.s.l. elevation. The mass dips northwards, dip varying considerably with depth, from subvertical in the upper parts to less than 45° in the lowest parts (Fig. 2).

Above the elevation -39 m a.s.l. (the latter being the lowest elevation that can be dewatered by the pumping station) the reserves

![Fig. 1 - Geologic map of Iglesias area.](image-url)
amount to 2,200,000 Mg assaying 9% Zn, and 0.45% Pb (in addition to a strong occurrence of pyrite, estimated at 3%).

Fig. 2 - Campo Plazano Mine. Vertical projection on a plane through the S-W axis of shaft N.1.

The orebody currently being mined at San Benedetto is massive, and hosted in a carbonate country rock of the basal part of the Metalliferous that is predominantly grey, massive dolomite. The dolomite alters to yellow dolomite in a layer some metres thick at the footwall contact and especially at the hanging wall contact, with a marked deterioration in mechanical properties. In the zones where stoping is presently being carried out, the run-of-mine ore occurs in the form of massive sulphides with a calcite matrix, originally the filling of karstic cavities. This mineralized rock exhibits very poor mechanical properties, exerts considerable pressure and does not permit unsupported cavities wider than 4 to 5 metres to be opened.

The plan section of the orebody is roughly elliptical: its major axis ranges from 100 to 150 m in length and runs from N-E to S-W; its minor axis is from 20 to 40 metres long. Dip is N-W, fairly regular and about 60°. The mineable reserves amount to about 900,000 Mg of sulphides assaying 9.1% Zn and 0.3% Pb.

ACCESS WAYS

In addition to the shafts that were used in the past for hoisting and personnel access, and where the equipment is still efficient, ramps 5 m high and 4.5 m wide, with the portals on surface have recently been excavated - and are in progress; they are presently used as main access and haulage ways.

STOPING

The stoping method used at both Campo Plazano and San Benedetto mines is known as "underhand cut-and-fill stoping by horizontal slices in descending order".

Stoping is carried out as follows: a drift is driven from the ramp, located at a distance ranging from 10 to 20 metres from the orebody, through the country rock, crossing the whole plan section of the orebody (Fig. 3); the cross-cuts, that are in effect the stopes, are then driven from the drift at an angle ranging from 60° to 90°. These cross-cuts are 5 m wide and 4 m high and reach the contact of the orebody with the country rock. The height of the stopes is also the thickness of the horizontal slice that is thus generated when all the stopes are mined out. The roof consists of the cemented backfill emplaced in the overlying slice.
The method consists of the following steps:
* blasting of the ore and haulage of the muck;
* preparation of the backfill mixes;
* delivery of the mixes from the preparation plant to the underground stopes;
* emplacement of the backfill into the cavities left by stoping.

The optimization of the overall procedure involves, therefore, optimizing each step and its correct integration with the other steps.

The general objective was attained through a process of successive approximations. This process entailed the preparation of cohesive cemented backfills whose strength was designed according to the requirements of orebody and country rock stability. Fig. 4 shows an isometric view of the stoping method.

Fig. 4 - Campo Pisano Mine. Isometric view of stoping method.

THE CEMENTED BACKFILL

Similarly to stoping, backfilling is carried out in practically the same way at both Campo Pisano and San Benedetto; hence,
the description of the whole operation will be the same for both mines.

**THE CONCRETE MIX PREPARATION PLANT**

The plants and delivery systems are practically identical for both mines. The sketch of a typical plant is shown in Figure 5: it consists of five bins (1), each with a total capacity of 220 m$^3$, where the various aggregate components and fly ash are stored. Each bin is equipped with a feeder that is operated from a control panel. The feeders deliver the required amounts of size fractions of aggregate and binders to a conveyor belt (2). The dry mix is transferred to a skip (3) which delivers it to the mixer (4), together with the Portland cement coming from silo (5). Water is added in the required amounts to the mixer and the concrete mix thus prepared, once its desired homogeneity is achieved, is discharged into the underlying pumpump (6). The control room, that is not shown in the sketch, provides the plant operator with all the data concerning the various mix components. In this way, the plant operator can constantly and accurately determine the mix composition. The operating capacity of the plant is 200 m$^3$ of concrete mix per 8-hour shift.

**THE CONCRETE MIX DELIVERY SYSTEM**

The mix is conveyed to the stopes by means of suitable piston pumps, and a 125-mm diameter pipeline. One pump is installed at the surface, near the mixing plant. In both mines, the mix delivery pipe consists of a vertical branch installed in a shaft, connecting the surface to the stoping area. This vertical branch is 280 m long at Campo Pisano, and 160 m long at San Benedetto.

The pipeline discharges the concrete mix into a second mixer located at the shaft station underground; this mixer restores the homogeneity of the mix, that is usually altered by the unavoidable segregation during its fall. A second piston pump, similar to the one installed at the surface, delivers the mix to the stopes through another 125-mm pipeline.

**COMPLETED BACKFILL CHARACTERISTICS**

A compressive strength of 10 MPa was considered sufficient on the basis of experience acquired prior to project start up.

The philosophy underlying the mix design is summarized by the flow-chart of Fig. 6.

Based on investigations carried out by the researchers of the Mining and Mineral Dressing Department of the University of Cagliari (IMUDUC) (Manso et al. 1983; 1984) as well as information provided in the literature (Collepardi, 1980; Thomas, Mantel

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and Netley, 1979; Grassholm, 1983), part of the cement in the mixes was successfully replaced with fly ash. A "reference concrete" was prepared having the following characteristics:

- Maximum particle size of aggregates: 20 mm
- Workability: from 20 to 24 cm slump
- Water: 230 cm$^3$ m$^{-3}$
- Average strength: 20 MPa

The binders

Conventionally, Portland cement is used as binder in concrete manufacture and this material does not pose any problem from the strictly technological viewpoint. However, to achieve the compressive strengths often required even by such simple structures as cemented backfills, such large proportions of Portland cement may be required that costs may become prohibitive.

Therefore, the resort to cheaper though equally effective substitutes of Portland cement was considered imperative for the economy of the stoping methods. The effectiveness of fly ash, blast furnace slags and amorphous as partial substitutes of Portland cement was investigated.

Cemented backfill sampling and testing

Samples of the mixes were taken at regular intervals. The slump tests were carried out on site. Most of the strength testing was performed either by means of a standard compression testing machine installed in the Civil Engineering Department of the Engineering Faculty of Cagliari University or at the Company’s Central Testing Laboratory, located at Campo Pisano.

THE MONITORING SYSTEM

A monitoring system for measuring the stresses within the cemented backfill was installed at points suitable for characterizing the evolution of the loads acting thereon. It consisted of two sets of type 8-40/40-05-400-24-EI total pressure cells manufactured by Glutazl Co. together with the required ancillary equipment.

The first set - monitoring system MS1 - consists of six vertical and three horizontal cells (Fig. 7) located in the
middle of the central crosscut of the seventh
slice of Campo Pisan Mine, at the -115 m
a.s.l. elevation. The second system (mon-
toring system M32) was placed in slice No. 8
in July 1991: five cells are vertical and two
cells are horizontal. Fig. 8 shows the
locations of the two sets in the respective
slices.

Fig. 8 - Campo Pisan Mine. Location of cells
M31 and M32.

RESULTS AND DISCUSSION

MIX DESIGN AND CEMENTED BACKFILL CHARACTERISTICS

Several mix compositions consisting of
various combinations of the components
available in the Edessa mining district
were tested in the laboratory as well as in
the field. Table 1 lists four mix types. The
standard mix composition “B” was subsequently
adopted, where Portland cement was partially
replaced by the fly ash from a nearby thermo-
electric power station. It provided a very
satisfactory performance with a compressive
strength that was higher than 10 MPa and a
workability that ensured a troublefree flow
through the delivery pipelines.

Table 1
Cement mix compositions tested at S.I.M. mines

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>MIX</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>kg·m⁻³ of mix</td>
</tr>
<tr>
<td>Bauxites Gravel</td>
<td>1100</td>
</tr>
<tr>
<td>Muscovite float</td>
<td>764</td>
</tr>
<tr>
<td>Sand</td>
<td>60</td>
</tr>
<tr>
<td>Fly ash</td>
<td>150</td>
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<tr>
<td>Type 325 pozolnic cement</td>
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<tr>
<td>Water</td>
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</tr>
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</table>

The regularity of operation of the
preparation and emplacement system, thus
achieved, allowed to steadily attain its top
emplacement capacity of 200 m³ per 8-hour
shift, with considerable cuts in costs and
improvements in stope organization compared
to the earlier stages of the operation (Table
2). Worthy of note was the abolishment of

Table 2
Campo Pisan Mine. Technical-economic comparison of cemented backfill operation during three semesters of the project.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>Semester of project</th>
</tr>
</thead>
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<tr>
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<td>1</td>
</tr>
<tr>
<td>Backfill emplaced</td>
<td>m³ per min hour</td>
</tr>
<tr>
<td>Compressed air (*)</td>
<td>m³ per m³</td>
</tr>
<tr>
<td>Compressed air costs</td>
<td>ITL : m⁻³</td>
</tr>
</tbody>
</table>

(*) For removing concrete obstructions in the delivering pipeline. Expressed as cubic meter free air per cubic meter backfill.

11th International Conference on Ground Control in Mining, The University of Wollongong, N.S.W., July 1992.

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Intermediate fill fences in the crossovers. In effect, fill fences represent a major cost item, since their construction is labour-intensive.

**MONITORING OF STRESS EVOLUTION WITHIN THE EMPLACED CEMENTED BACKFILL.**

At the time of writing only data provided by System MS1 can be considered significant and these are shown in Table 3.

So far 14 series of data have been collected. The time interval between two successive series ranges from 3 to 31 days, depending on the progress of stopping in slice No. 9, that underlies slice No. 7 where MS1 was placed. Figs. 9 and 10 graphically summarise the evolution of stresses shown in Table 3.

**Fig. 9 – The evolution of stress.**

Surprisingly enough, following the fifth reading, i.e. 139 days after the installation of MS1, no significant variation was recorded.

Hence, it seems that neither the setting of the cemented backfill in the depleted slopes of slice No. 7, nor the cavities left...

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**Table 3**

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<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<td>62600</td>
<td>62602</td>
<td>62606</td>
<td>62598</td>
<td>52504</td>
<td>52505</td>
</tr>
<tr>
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<td></td>
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<td></td>
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<td></td>
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<td></td>
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<td>0.955</td>
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<td>0.134</td>
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<td>0.134</td>
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</tr>
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</table>

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by the stopes of slice No. 3 have produced any variations in the stress distribution within the cemented backfill.

RESULTS OF NUMERICAL CALCULATIONS

Stresses in backfill beams under their own weight

The Finite Element Programme FEM has been used to investigate the stresses occurring in backfill beams under their own weight. Two models have been developed, representing backfill beams: 24 m long, 4 m wide and 4 m and 2 m high respectively. No external forces were introduced.

The material properties were chosen as follows:
- Specific gravity 27,000 N m^{-3}
- Young's Modulus 10,000 MPa
- Poisson's Ratio 0.2

The total displacement values depend on Young's modulus, estimated here as 10,000 MPa.

The results have been compared with analytical solutions for calculating the maximum bending stresses in beams under their own weight resting on two end points. Table 4 shows the results of both the numerical and analytical calculations. The FEM calculations show lower values than the analytical solutions. This can be explained by the fact that FEM has always been implemented on partly undercut beams 24 m long, whereas beams with a length equal to the undercut length were considered in the application of the analytical solutions.

Figure 11 shows a graphical representation of the results.

Fig. 11 - Graphical representation of results of FEM calculations of stresses occurring in backfill beams under their own weight.
Comparison of in-situ measurements with results of numerical calculations

An attempt was made to simulate, using the Finite Element Method, slope undercutting at Campo Flaminio Mine, where in situ measurements are being carried out. For this purpose, a model of a 40 m long and 4 m high backfill beam, that initially is only loaded by its own weight and subsequently by the next overlying backfill block, was developed.

The horizontal and vertical stresses in the block were calculated by the FEM program at the point where the pressure cells are installed. Five different phases were investigated:

- backfill block resting on ore over its entire length with no load from the overlying backfill (phase 1);
- backfill block resting on ore over its whole length with load from the next overlying backfill slice (phase 5);
- backfill block undercut at one end (phase 7/8);
- backfill block undercut at one end as well as in the middle (phase 9/12);
- backfill block undercut in the middle; other end resting on backfill (phase 13).

The volumic mass of the backfill was taken as 2,500 kg/m$^3$, Young's modulus as 10,000 Pa and the Poisson ratio as 0.2. It was assumed that the backfill beam under investigation is loaded by the next overlying backfill with a height of 4 m from phase 5 onward (not in phase 1). It was also assumed that the backfill is free to move in a horizontal direction on the underlying ore, or rock, whereas this is not so for the ends of the backfill beam, as movement is impeded by the neighbouring backfill or country rock. The results of the FEM calculations are shown in Fig. 12.

![Graphical representation of results of FEM calculations of stresses produced in backfill by undercutting.](image)

The results of the FEM calculations are, at least in part, in good agreement with the in-situ measurements. With the FEM, maximum horizontal stresses of more than 0.3 MPa (compressive stress in lower part of backfill) and 0.2 MPa (tensile stress in the upper part) have been calculated, when the backfill is undercut. Measured values are actually smaller and this may be attributed to friction at the sides of the backfill block. For phase 13, the FEM-calculation shows a decrease in stress values that is also in agreement with the in-situ measurements.

Therefore it can be said that even a two-dimensional Finite-Element-Model provides fairly reliable values for the stresses in the backfill beams in underhand-cut-and-fill mining. A three-dimensional model would likely afford more accurate results.

The backfill that is undercut in an underhand-cut-and-fill method consisting of
horizontal slices mined by stopes, practically parallel galleries, is mainly loaded by its own weight, at least straight after undercutting. Subsequently, the load increases but can nevertheless be assumed to be equivalent to that acting on the next overlying backfill slice. Probably, an arching effect keeps the lower part of the backfill almost free from the load of the overlying backfill mass or country rock. This means that no excessive stresses occur. In particular, only minor tensile stresses (by bending of the backfill "beam") are exerted, provided the backfill is homogeneous and stoping is done in a continuous manner.

Consequently, only moderate backfill strength is required, provided the backfill layer is thick enough and the backfill is homogeneous.

It was furthermore shown that the Finite-Element-Method can be used quite successfully for estimating the stresses in backfill which is undercut, at least for calculating the range of stress values. This is important especially for investigating the stoping sequence and complicated geometrical situations. The method is however open to improvement.

Interaction between backfill and country rock

For estimating the loads acting on the backfill and for predicting subsidence over the mined area, a model is required that represents a fairly large portion of the orebody, at least the actual stoping area.

In this investigation a numerical model was developed, that was based on the situation of the San Benedetto Mine.

The model covers 80 m in horizontal and 80 m in vertical direction of the orebody and represents a (two dimensional) cross-section of its area, which is actually mined by the underhand-cut-and-fill method with cemented backfill.

Several boundary conditions or loading situations (external loads) were examined. It was found that the stresses in the cemented backfill are rather low. This bears out the assumption of an arching effect and compares favourably with the in-situ measurements of the stresses in the backfill.

CONCLUSIONS

At both the Campo Plano and San Benedetto Mines massive, irregularly shaped orebodies are mined. In both deposits the ore and the wall rock are characterized by poor mechanical strengths and consequently it is not possible to open up large stopes. Mining has to be done under a stable roof, which can only be realized artificially, and surface subsidence must be avoided. Therefore, only a stoping method where the cavities are completely filled can be implemented. For obvious safety reasons, the stopes must be provided with stable roof. The only stoping method which complies with these requirements appears to be an underhand-cut-and-fill method with cemented backfill.

Provided the slices are accessible via a ramp system, the method can be highly mechanized using drill jumbos and LHD equipment.

A backfill mix was designed composed of low cost aggregates, Portland cement partly...
replaced by fly ash, and water. For cemented backfill the most important parameters are strength and workability and these have both been optimized as a result of an exhaustive preliminary testing programme. With the mix ingredients employed, a compressive strength of 10 MPa was steadily attained after 28 days. Workability, together with an accurately designed geometry of the delivery system, made it possible to exploit the full mixing plant capacity, i.e. 200 m³ per 8-hour shift.

Under the specific conditions at the Campo Pianese and San Benedetto Mines, the pumping backfill system appears to be the most suitable method of transportation from both the technical and economical points of view. Particularly attractive features of this method are its high flexibility, the relatively simple infrastructure required underground, and the low labour requirements.

In-situ measurements so far have shown unexpectedly small stress values in the backfill. However, similar findings have emerged also at the Herrandon Mine, in the French Massif Central (Collierier, personal communication 1991), where a similar stoping method has been under test for some years. This may be attributed to the fact that the stresses in the backfill are only due to the load exerted by the backfill slice's own weight and at the most by the immediate overlying backfill slice. Even during undermining, the stresses show no excessive values at least for several months afterwards. In addition, no failures of the artificial roof of the stopes have been observed even with free spans of up to 10 m.

Comparison of numerical calculations, in particular with the Finite-Element-Method, and in-situ measurements have shown that this method is useful for estimating the stresses in the backfill during mining. The Finite-Element-Method can therefore be used to optimize the stoping and backfilling sequence. It also seems possible to optimize the stope geometry with this method. However, the method is only applicable if continuity and homogeneity of the emplaced backfill is assumed. Hence, this is a practical condition for reliable and successful backfilling.

With cemented backfill, subsidence can be eliminated. The application of numerical calculations revealed that an arching phenomenon takes place, which distributes the load from the overlying backfill and rock to the country rock located laterally with respect to the orebody thus considerably relieving the immediate stoping area from most of the load exerted by the overlying material.

Although most of the above conclusions refer to the Campo Pianese Mine, it seems that they also hold for the San Benedetto Mine, owing to the fact that the two orebodies are very similar.

The cemented backfill method is, as a rule, expensive. However, if the overall economy of the operation is taken into account, then it is probably the most convenient.

ACKNOWLEDGMENTS

This work was funded partly by the Commission of European Communities (Contract No. MAIM - 0057 - I(A)).
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