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# Geotechnical Analysis of Mine Shaft Lining Cost Benefits

**Binay Kumar Samanta***

*Department of Mining Engineering, Indian Institute of Technology (Indian School of Mines), Dhanbad, India*

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***Corresponding author**: Binay Kumar Samanta, Department of Mining Engineering, Indian Institute of Technology, Dhanbad, India

**Abstract**

Construction of mine vertical shafts or pits for winding men and materials from deep underground mines costs very heavily and is getting deferred. Underground production is declining the world over, while remaining reserves are at great depth. Strong legislations are already there for safety, ventilation, and environment and but there is some scope for cost-saving for mine authority. Designing and coding original model programs by collecting actual field data to run the programs to determine cost-benefit at different depths with standard diameters. Most companies are avoiding deep mining projects, because of the exorbitant cost of shaft sinking. As per the experience of the researcher, pre-split blasting and shotcrete lining can be much faster and cheaper, so model programs have been designed with the right-field cost and technical data, as exemplified in this paper. The future of deep pit mining will be assured with the successful adoption of the method.

Keywords: Geo-mechanical properties; Shaft Collar; Emerging Methods; Cost Saving, Coding Programs; Shaft Lining.

**Abbreviations:** RMR: Rock Mass Rating; RSR: Rock Structure Rating

## Introduction

In the year 2015-16, out of total coal production of 639.234MT, production from underground mines was 46.412 MT (7.26 % share). In the year 2020-21, the total production of raw coal in India was 716.084MT. In India with the progressive depletion of shallow deposits, there is no option but to deepen the existing shafts or sink new shafts, to mine coals and reduce the import burden.

Various studies of geo-mechanical properties of Indian coal-measure rocks reveal that compressive, tensile, and shear strengths [1] are 2 to 3 times higher than European coal-measure rocks. In India during British rule, hundreds of shafts were sunk in Jharia and Raneeganj coalfields, without any lining, except brick walling up to shaft collar or rock-head. Some of these shafts are winding men or materials even today, with precautions of checking and occasional side dressing or side bolting. As a result of exploration carried out up to the maximum depth of 1200m by the GSI, CMPDI, SCCL, MECL, etc., a cumulative total of 319.02 billion tons of Geological Resources of Coal have so far been estimated in the country as of 1.4.2018. Most of the mines are working to a depth below 300m and mining deep seams, where about 70% of the remaining coal reserve is present but are shelved for the higher cost.

Some high-capacity shafts, with monolithic concrete lining, rigid guides, and skip winding were constructed in the sixties. For example, at Sudamdih, Moonidih in Jharia coalfields and Banki, Surakhachar in Western coalfields, and in the eighties at Satgram, JK Nagar, Jhanjra of Raniganj coalfields and Pootkee, Bhalgora of Jharia coalfields and others. The exorbitant cost of construction of such shafts, followed by heavy losses suffered by these mines, are the reasons for deferment [2] of further deep mining projects. So, the researcher has developed a model program 'scl' to determine the cost-benefit of shotcrete compared to the monolithic concrete lining in shaft sinking.

## Materials and Methods

The circular shape is the most stable for pits, as per the theory of structures and sandstone is quite competent rock, but weak or carbonaceous shale or the presence of faults and slips, may cause unpredictable spalling and accidents. In old shafts, usually such weak zones are protected by wire netting or steel plating and then by side bolting [3]. Since rigid guides are mounted on buntons anchored on shaft walls; dynamic loading and vibrations are transmitted to it, lining is necessary to prevent bed separation of rocks and spalling or other failures [4].

The responsive behavior of the shotcrete lining can be analyzed within the convergence-confinement method. The response curve for the shotcrete support can be calculated. Shaft design is by testing of rocks along the section of the shaft, samples gleaned from the cores taken from a borehole in the designed location. The test is made on cylindrical samples, usually of dimensions length: diameter of 1:1, after grinding and lapping of the end surfaces [5]. Static tests are comparatively simpler and cheaper to perform, such as Young's Modulus = axial stress/strain, Modulus of Rigidity = Shear stress/shear strain, Poisson's Ratio = Lateral strain/longitudinal strain, etc. A comparison of dynamic and static properties of sandstone, given by Roberts of English coal measure rocks, is shown in table 1.

**Table 1:** Dynamic and Static Loading.

| Test Type loading | Stress Rate $Kg/cm^2/sec$ | Failure Stress $Kg/cm^2$ | Failure Strain Micro-cm | Mod. Elast $Kg/cm^2$ |
|---|---|---|---|---|
| Dynamic | 1400000 in 3.7 | 220 | 610 | 640,000 |
| Static | 1800000 | 80 | 410 | 190,000 |

Static properties of rocks are usually lower than dynamic ones. It has also been observed that horizontal stress is much less, compared to vertical stress, in shaft walls. Permissible stress (in kg/sq.cm) on concrete, according to National Building Code, 1970 of Indian Standards Institution, New Delhi, with Factor of Safety of 3 is given in table 2. Tests of concrete blocks at Central Institute of Mining, Fuel Research, CIMFR Dhanbad [6] showed Bulk Density- 2.14g/cc; Young's Modulus- 0.5GPa; Compressive strength- 8.26KPa; Tensile Strength- 0.95KPa. It could be observed from the table 1 that most of Indian coal measure rocks are stronger than permissible stress in concrete. Tensile strength is given by T=2W/ (p*d*L), where W-applied load, d- diameter, L- length of core sample. Strengths of Indian coal measure rocks; and concrete is shown in table 3. Shear strength could be obtained from Mohr's envelope or by cylindrical punch into rock specimens and is given by: S=W/p*d*t,

where, W-punch load at failure, d-punch, and t-thickness of rock disc.

**Table 2:** Permissible Stress on Concrete (M-150 means maximum stress of 150 $kg/cm^2$ or 15 $N/mm^2$).

| Grade of Concrete | Comp. Stress | Shear stress | Bending stress |
|---|---|---|---|
| M-100 | 30 | 3 | 7 |
| M-150 | 50 | 5 | 10 |
| M-250 | 70 | 7 | 13 |

**Table 3:** Strengths of Indian Coal Measure Rocks and Concrete.

| Type of rocks Coal-measure | Comp. Strength KPa | Tensile Strength KPa | Shear Strength KPa | Protodeakonov Index |
|---|---|---|---|---|
| Massive sandstone | 61.1 | 24.5 | 23.8 | 7.25 |
| Laminated Sandstone | 36.9 | 15.5 | 8.6 | 5.76 |
| Siltstone | 43.3 | 13.2 | 13.7 | 3.81 |
| Argillaceous shale | 26.8 | 7.1 | 6.7 | 1.54 |
| Carbonaceous shale | 19 | 6.1 | 4.5 | 1.2 |
| Coal | 7 | 5.5 | 2.5 | 0.8 |
| Concrete (M-200) | 7 | 1.3 | 0.7 | 1.47 |

## Shaft Lining Methods

Types and properties of strata determine the shaft lining methods. Mud brick, Cement brick, steel tubing, monolithic, RCC are the most usual methods. In case of very weak strata, cementation or freezing techniques are applied before lining. For decreasing ventilation resistance in mine shafts, pre-split technique of blasting should be adopted in competent Indian coal measure rocks for smooth round surface and minimum exposure to weak planes.

Costly monolithic concrete lining, minimum 30cm thick could be replaced with shotcrete for thin lining after pre-split blasting, a much cheaper method. In most Indian conditions, shaft lining [6] is only required for protecting against weak or brecciate zones, slips, faults and preventing exposure to weathering and spalling, in weak or bad zones.

Shaft lining should be computed from rock classification and primary and secondary stresses for which Bianiweski [7] formulae are useful. Vertical stress is given by:


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$V=C/(k*n)$ in KPa, for Kilopascals (1 KPa=10 kg/cm$^2$)

Where C= comp. strength in KPa, k= (1-SinA)/(1+SinA), A-apparent friction angle = arc tan f, f=strength factor=C/10 roughly, D-diameter of shaft in m, $n=1/2(D+1)^{1/3}$.

Horizontal stress is given by H=kV

There are other sophisticated electronic stress measurement instruments to check these formulae.

Characteristic Impedance [8] of a medium is computed from density and bar wave velocity. All other dynamic properties could be determined from geophysical formulae. Approximate values of the above rock properties of European coal-measure rocks, including Rock Mass Rating (RMR) is shown in table 4. Shotcrete is applied by pressure monitor, with thicker slurry 1:2 (Cement: Sand), on the surface to be lined and is different from grouting, which is usually performed. Batching and mixing plant at surface with water pumped and mixed with cement and other constituents and could be sent down the shaft, through pipeline for applying shotcrete from the suspended scaffold. Shotcrete thickness (t) is based on RSR (Rock Structure Rating), which range from 40 for very hard igneous rocks, to 7 for soft rocks [9]. RSR for sedimentary type coal-measure rocks is around 25 and it is given by:

$t = D/150(65 - RSR)$ and $RSR = 0.77*RMR + 12.4$

Where, t-thickness of shotcrete in inches, and D-diameter of shaft/ tunnel in ft. RSR could be computed from experimental derivation. Figure 1 displays the section across a vertical shaft for pre-split blasting and lining with fiber reinforced shotcrete. Shotcrete is also known as sprayed concrete and is being increasingly applied in thickness up to about 75mm, to rock surface, with concrete chips up to 12mm. Materials for shotcrete include Calcium Chloride, Sodium Hydroxide, and Sodium Silicate for accelerating setting and resins for sticking to the wall [10].

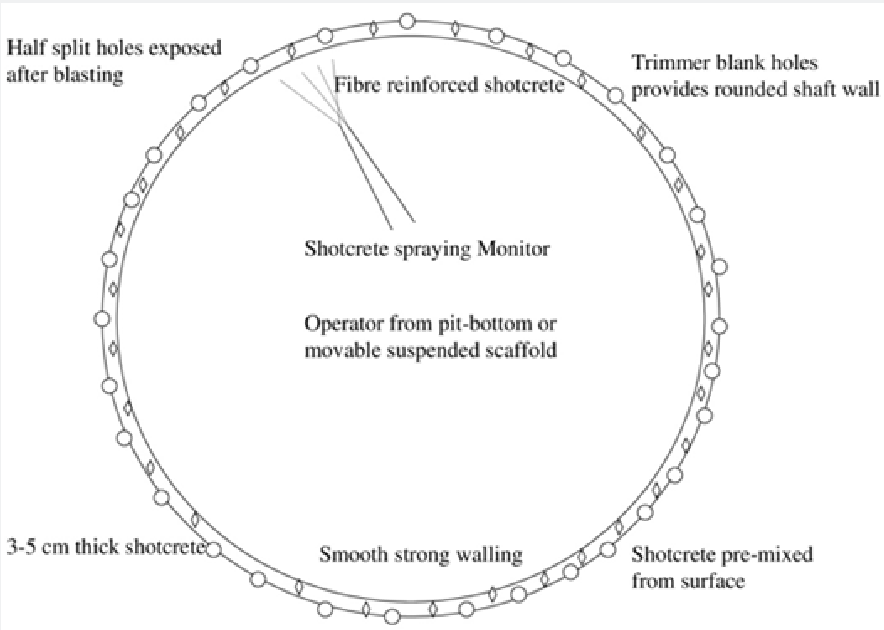


**Figure 1:** Presplit Blasting & Shotcrete Lining.

**Table 4:** Strength Calculation Variables.

| Rock Type | RMR Strength | Description of rock | Comp. Strength in Kpa | Str.factor Arc Tan f k (A) |
|---|---|---|---|---|
| High Strength-Good | Oct-40 | Sandstone | 80-150 | 78-86 .007 |
| Medium Strength-Fair | 10-Apr | Siltstone | 30-80 | 71-78 .02 |
| Moderate Loose-Poor | 4-Jan | Shale, coal | Oct-40 | 50-71 .01 |


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There could be a substantial volume of rebound, which could be controlled to 10% with proper equipment and adjustment. The velocity of shotcrete could be increased to 100m/s to fill cracks and crevices. The scaffold could be extended by an additional sliding plate for reusing immediately by applying manually, with rubber gloves or a trowel from the rebounded concrete in the gaps of the lining or for smoothening. The shotcrete thickness should be enough to prevent cracks and keep the lining flexible and amenable to slight strata movement [11].

## Choice of Method

The majority of shafts are being sunk today with drill and blast technique and the Shotcrete method is being increasingly applied for staple pits and tunnels, but rarely for shaft sinking. Shafts can be unlined or partially lined up to the rockhead with a brick wall or RCC. Bad patches are usually strengthened by:

a) Rock- bolting with wire-netting or steel plates,

b) Tubbing or shaped segments,

c) Cement injection grouting,

Earlier trials of Shotcrete were with small steel wire or fiber reinforcement, and the results were encouraging. Shotcrete has been tried successfully in coal mines, where conventional supports failed for:

1) Preventing spalling or collapse of coal pillars,

2) Gallery roof stabilization,

3) Shaft pillar and wall stabilization

The shotcrete method consists of spraying on the wall, at high pressure, with a nozzle monitor from a hanging scaffold by a mixture of cement, sand, fine stone chips, adhesive resin, quick setting, chemicals, etc. in the right proportions. In very watery conditions, 'Chemgrout' in liquid form should be sprayed first, which gels quickly and makes the wall, impervious to water. Then a Chemgrout tank with mixer and hoses should be installed on the scaffold. A brand name AM-9, consisting of an aqueous solution of Dimethyl Aminopropionitrile and Ammonium Persulphate can be used [12].

## Techno-Economics

The smooth and even outer surface of a shaft is obtained by pre-splitting, a blasting technology, reducing the cost of shaft lining. Precise and accurate blast-hole drilling with an outer row of closely spaced alternately charged. It also causes some of the shock waves generated by the blast to be reflected, which reduces shattering in the wall of the shaft. For the lining of the smooth pre-split wall, the wet with small fiber pieces in Shotcrete from the surface mixer should be much cheaper, as no shuttering, suspending ropes, winches, etc. are required [13].

Macro-synthetic fibers are completely immune to the corrosive combination of weak acids, salt, and oxygen, and to contaminants within ground water and the concrete itself. The thickness of the shaft lining will be in the range of 5-10cm, according to design, as compared to 30cm and above thickness for the monolithic lining. So, for a designed finished diameter of a shaft, a less excavated section for drilling and blasting is required. Realistic cost-benefit fiber-reinforced shotcrete in shaft sinking, designed for high-capacity winding with rigid guides, as compared to the monolithic concrete lining, different cost components are analyzed with actual field data.

According to sanctioned rates of a mine of a coal company, on tender, shaft-sinking cost of relevant items given below, deepening by 41.85m, 4.42m diameter; total cost ₹14 million of which rock excavation cost was ₹5.08 million for 1900m$^3$, coal excavation cost ₹1.69 million for 450m$^3$, compared to arrive at probable cost-saving, with shotcrete: -

1) Purchasing and installing 3 winches including shade- ₹1.4 million + rope- ₹3 million + power- ₹2 million + maintenance- ₹2 million + shuttering (material + construction)- ₹4 million = ₹25 million approx.

2) Monolithic concrete lining- @ ₹3,750/m$^3$ approx.

3) Additional excavation for lining @ ₹7368/m$^3$ approx.

4) Centering of shuttering and concreting time.

Other extra costs of lining, like concrete mixing plant, pipelines, except shotcrete monitor, are common for both. Similarly, other operations, like the installation of winders, scaffolds, winches, compressors, substations, and service buildings would be the same. Sinking operations like drilling, blasting, excavation, fabrication, and fitting of buntons, pipes, cables, ventilation ducting etc. would also be the same. But the cycle times would be faster [8] with a savings rate and so there would be more cost savings [14].

Equipment for shaft lining include mixers, chutes, pipelines, platform, monitors etc. Present shaft sinking cost with monolithic lining is more than ₹100000 per m of the completed shaft. The progress of excavation could be faster with the deployment of Cactus Grab or other mechanized loading for cheaper cost in the long run.

With the shotcrete method, additional costs would be: -

1) Drilling of outer blank holes in between charged holes in the outermost trimmer ring of shot holes for pre-split blasting, say ₹10/m.

2) Explosive charge per round would be less, as blank holes would join to create a free face, with a smooth shaft wall

3) Other experimental costs are expected, according to geotechnical properties at shaft site.


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## Model for Cost Benefit

Keeping the various variables in view, a computer program was coded, to calculate cost-benefit at different diameters and depths, with shotcrete system, vis-à-vis monolithic lining realistically. The model Flowchart of model program 'scl' is shown in figure 2. The model run makes some projections and coded in this program are 'netsave'- expected net saving, 'conlicst'- saving in concrete lining cost, 'exvcst'- saving in excavation cost, 'wincst' - saving in winch and shuttering cost, 'slcst'- shotcrete lining cost, 'diam'- diameter of the finished shaft, 'depth'- of the shaft in m, etc. By realistic input of data, a sample program run with different diameters and depths showing the cost-benefit by applying shotcrete lining compared to monolithic concrete lining is displayed in table 5.

**Table 5:** Java Program Run-Shotcrete Shaft Lining Benefit.

| Diameter of shaft in meters and all costs in rs. Millions | | | | | | |
|---|---|---|---|---|---|---|
| DIAM | DEPTH | EXC-COST | CLIN_COST | SCLN_COST | SAV_COST | NET_SAV |
| 5.0 | 100 | 182.26 | 18.98 | 5.98 | 49.74 | 293.76 |
| 5.0 | 150 | 273.39 | 28.47 | 8.97 | 74.61 | 315.64 |
| 5.0 | 200 | 364.53 | 37.96 | 11.96 | 99.48 | 337.52 |
| 5.0 | 250 | 455.66 | 47.45 | 14.95 | 124.35 | 359.40 |
| 5.0 | 300 | 546.79 | 56.94 | 17.94 | 149.22 | 381.28 |
| 5.0 | 350 | 637.92 | 66.44 | 20.93 | 174.09 | 403.16 |
| 5.0 | 400 | 729.05 | 75.93 | 23.92 | 198.96 | 425.04 |
| 5.0 | 450 | 820.18 | 85.42 | 26.90 | 223.83 | 446.92 |
| 5.5 | 100 | 216.26 | 20.77 | 6.57 | 57.79 | 301.23 |
| 5.5 | 150 | 324.39 | 31.16 | 9.85 | 86.69 | 326.84 |
| 5.5 | 200 | 432.53 | 41.54 | 13.14 | 115.59 | 352.45 |
| 5.5 | 250 | 540.66 | 51.93 | 16.42 | 144.48 | 378.06 |
| 5.5 | 300 | 648.79 | 62.32 | 19.70 | 173.38 | 403.68 |
| 5.5 | 350 | 756.92 | 72.70 | 22.99 | 202.28 | 429.29 |
| 5.5 | 400 | 865.05 | 83.09 | 26.27 | 231.17 | 454.90 |
| 5.5 | 450 | 973.18 | 93.48 | 29.56 | 260.07 | 480.51 |
| 6.0 | 100 | 253.17 | 22.56 | 7.16 | 66.43 | 309.27 |
| 6.0 | 150 | 379.75 | 33.84 | 10.74 | 99.64 | 338.91 |
| 6.0 | 200 | 506.34 | 45.13 | 14.31 | 132.86 | 368.54 |
| 6.0 | 250 | 632.92 | 56.41 | 17.89 | 166.07 | 398.18 |
| 6.0 | 300 | 759.51 | 67.69 | 21.47 | 199.28 | 427.81 |
| 6.0 | 350 | 886.09 | 78.97 | 25.05 | 232.50 | 457.45 |
| 6.0 | 400 | 1012.68 | 90.25 | 28.63 | 265.71 | 487.08 |
| 6.0 | 450 | 1139.26 | 101.53 | 32.21 | 298.93 | 516.72 |
| 6.5 | 100 | 292.98 | 24.35 | 7.75 | 75.64 | 317.90 |
| 6.5 | 150 | 439.47 | 36.53 | 11.62 | 113.47 | 351.85 |
| 6.5 | 200 | 585.96 | 48.71 | 15.49 | 151.29 | 385.80 |
| 6.5 | 250 | 732.45 | 60.88 | 19.37 | 189.11 | 419.74 |
| 6.5 | 300 | 878.94 | 73.06 | 23.24 | 226.93 | 453.69 |
| 6.5 | 350 | 1025.43 | 85.24 | 27.11 | 264.75 | 487.64 |
| 6.5 | 400 | 1171.92 | 97.41 | 30.98 | 302.58 | 521.59 |
| 6.5 | 450 | 1318.41 | 109.59 | 34.86 | 340.40 | 555.54 |
| 7.0 | 100 | 335.70 | 26.14 | 8.33 | 85.44 | 327.11 |
| 7.0 | 150 | 503.55 | 39.22 | 12.50 | 128.16 | 365.66 |


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| | | | | | | |
|---|---|---|---|---|---|---|
| 7.0 | 200 | 671.40 | 52.29 | 16.67 | 170.88 | 404.21 |
| 7.0 | 250 | 839.25 | 65.36 | 20.84 | 213.60 | 442.76 |
| 7.0 | 300 | 1007.09 | 78.43 | 25.01 | 256.32 | 481.32 |
| 7.0 | 350 | 1174.95 | 91.51 | 29.17 | 299.04 | 519.87 |
| 7.0 | 400 | 1342.79 | 104.58 | 33.34 | 341.76 | 558.42 |
| 7.0 | 450 | 1510.64 | 117.65 | 37.51 | 384.48 | 596.97 |

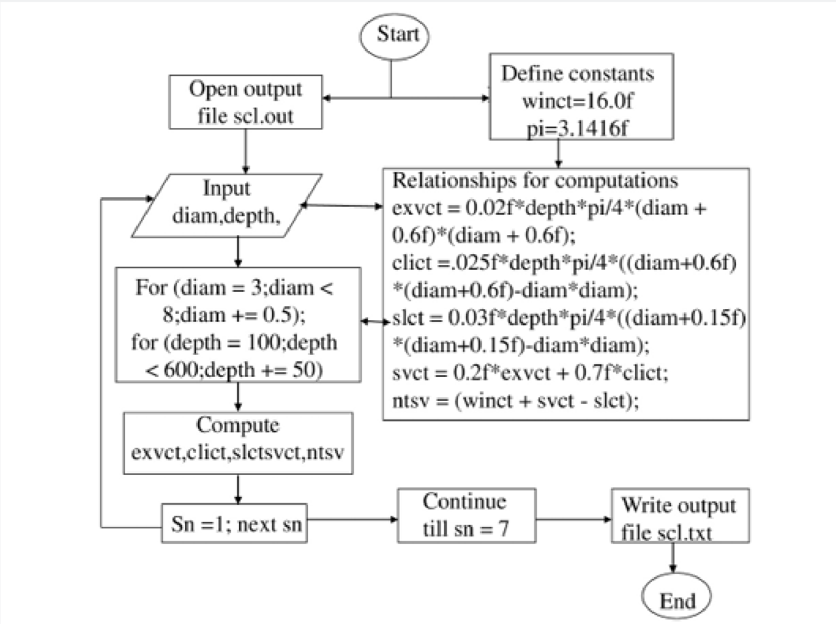


**Figure 2:** Flowchart of Shotcrete Lining.

## Results

Rigid guides in shafts for winding with skips and cages exert additional dynamic strains, which would require more fiber reinforcement. Fiber reinforced shotcrete mix made on the surface, sent down a pipeline, with a flexible range at the bottom to be operated by a spraying monitor from the movable suspended scaffold or pit bottom. Great advantage of the shotcrete method of lining is that it could be applied at any level, by moving the scaffold, as no shuttering is required [4]. The wet shotcrete method is expected to be more successful, as the dry method will cause a lot of airborne dust and health hazard in the confined space of a pit [15].

The salient points of the module are:

1) In the program run, net savings have been computed, from ₹29.38 million for 5mΦ, 100m depths; to ₹59.69 million, for 7mΦ, 450m depth, compared to conventional monolithic concrete lining in shafts.

2) Cost benefit projected is considerable, even discounting the time saved in lowering of shuttering with thick monolithic concreting.

3) Quick setting chemicals in admixture in shotcrete could help thereby shortening the cycle time of shaft sinking.

## Discussions

The first shaft for coal production in India was made at Bogra, in Raneeganj coalfield, of 9ft. diameter, sunk as the inevitable mode of entry @ ₹2.50/ft, reportedly in 1830. For deep seams, possibilities were examined for economic and effective alternative safe methods, in view of advances in Rock Mechanics. For example, the deepest shafts in India at Kolar Gold fields and even Chinakuri Colliery are only lined up to the rock-head and the rest of the shaft is unlined and satisfactorily functioned. But the winding capacity of these shafts is limited to roughly 500tpd (tones per day), in single-tub cages and 900tpd in tandem cages, as these shafts are provided with rope guides. With higher clearance between cages and walls and high speeds are possible, as also with skip winding.

Measurement of load, stress, and strain could be done with Bourdon type Pressure Gauge, Photo-electric transducer, Load cells, Dial gauges, Linear Potentiometer, mechanical Extensometer, electric strain gauge, inductance gauge, etc. Compressive strength is determined on a hydraulic Universal Testing Machine,


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by applying load gradually, till fracture of the sample and is calculated on Max load/x-section of the sample, in kg/sq.cm. The accuracy of results will depend upon calibration of the machine, end-contact conditions, size and proportion of the test piece, pore fluids, direction of bedding plane, rate of loading, anisotropy, heterogeneity, and several samples tested. Compressive strength could be determined from various other indirect methods like Protodeakonov co-efficient, drilling rate in stone, in-situ method, etc.

There will be hardly any time lost for lowering and centering of shuttering, as also cement and other material requirements would be roughly 20% of the monolithic method. Cycle time would be drastically reduced and faster progress of sinking and quicker completion of a shaft could be easily achieved.

## Conclusions

Considering all these factors, the actual cost-benefit could be much higher than projected.

1) With the Pre-split type of blasting creating a smooth round shaft wall, cement consumption would be less.

2) Viable opencast mining reserves are getting exhausted; deeper coal reserves can be more economically exploited by this method of entry.

3) Shotcrete method has been tried in small-scale repair and support in tunnels and pits successfully. Further research is going on for improving the viability of the method in complete shaft lining.

4) Underground mining could be with less investment and high winding capacity, which is a limitation in existing pits.

5) With shotcrete lining of high-capacity pits and high production machinery, at great depths, the future of underground mining should be bright.

6) With major shaft sinking works shelved for decades could be rescheduled and prioritized by this method.

7) With a model run of 'scl' will determine the benefit of lowering project construction costs and at the same time increasing the production capacity of coal mine projects.

8) The advantages expected of shotcrete lining are:

a) Planes of weaknesses covered with smooth shaft-wall.

b) Lining cost by Shotcrete thickness required would be less.

c) No need for shuttering, suspension, centering, required for monolithic lining.

Shaft-sinking cost and time will be much less than for the monolithic concrete lining method.

## References


1. Sinha Amalendu (2012) R&D for Sustainable Mining in India- The Way Forward. 4th Asian Mining Congress, Kolkata, (MGMI).
2. Jha NC (2012) Sustainable Development of Indian Coal Industry-Daunting Challenges. 4th Asian Mining Congress, Kolkata, (MGMI).
3. Singh UK, Samanta BK (2019) Prospects of Shotcrete Shaft Lining for Underground Sustainable Mining. IIT (ISM): Indian Institute of Technology.
4. Samanta BK (1999) Feasibility of Shot Crete Lining in Shafts (with a program in C). Mine tech 16(1-2): 34-43.
5. Singh UK (2003) Stabilization of Shaft Pillar by Fiber Reinforced Shotcrete: A Case Study, National Seminar on Geomechanics and Ground Control, India.
6. Samanta BK (2003) Blasting Efficiency and Vibration Damage Control. National Seminar on Explosives and Blasting, Institution of Engineers.
7. Naseri S, Bahrani N (2021) Design of Initial Shotcrete Lining for a Mine Shaft Using Two-Dimensional Finite Element Models Considering Excavation Advance Rate, Geotechnical and Geological Engineering 39: 4709-4732.
8. Erasmus A, Swanepoel, CD, Munro D, Hague I, Northcroft I, et al. (2001) Shotcrete lining of South Deep shafts. The Journal of The South African Institute of Mining and Metallurgy 101(4): 169-176.
9. Bernard E Stefan (2009) Design of Fiber Reinforced Shotcrete Linings with Macro-Synthetic Fibers. Proceedings of Shotcrete for Underground Support XI; Engineering Conferences International Year.
10. Monsberger Christoph M, Lienhart Werner (2021) Distributed fiber optic shape sensing along shotcrete tunnel linings: Methodology, field applications, and monitoring results, Journal of Civil Structural Health Monitoring 11: 337-350.
11. Glasserman P, Staum J (2003) Resource Allocation among Simulation Time Steps. Operation Research, USA.
12. Panigrahi DC (2012) Sustainable Mining and Environment-The Indian Context. 4th Asian Mining Congress, Kolkata, (MGMI).
13. Samanta BK, Samaddar AB (2002) Formulation of Coal Mining Projects by Expert System. Journal of Mines, Metals and Fuels pp. 202.
14. Samanta BK (2002) Coal net- A Developing Intranet, XXXVII National Convention of Computer Society of India 42: 251-260.
15. Sarkar BN, Samanta BK (1993) Mine Mechanization with Machine Safety and System Safety. XIII World Congress on Occupational Safety and Health, New Delhi.



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