Efficiency of modified concrete in lining in underground structures

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Abstract. The authors discuss an efficient concrete technology toward highest advance rates in tunneling in unstable rocks at minimized labor input.

1. Introduction

Review of Russian and foreign experience gained in underground constructions shows that overall efficiency of support installation in mines has grown slightly in the last years but falls far behind the advance rate. The practice of underground construction indicates that the type, technology and mechanization of roof support govern the rate of tunneling.

This study aims to justify optimized parameters for construction of underground structures in unstable rocks by the opencast method with cemented paste backfill using modified quick-hardening mixtures to ensure reduction in labor cost, financial expenditures and time of construction.

2. Construction and support of underground structures: State-of-the-art

Underground structures can be constructed using the opencast method and without support in pits with sidewalls cut at a slope of repose and in pits with reinforced sidewalls. Cutting of pits with sidewalls at a slope of repose is the simplest and the most economic solution but is heavily constrained, especially in the conditions of narrow-space urban development [1]. The major constraint is the depth of a pit. In deeper pits, it is necessary to make flatter slope, and the pit area and volumes of extracted soil essentially grow, which makes this approach inexpedient or even impossible in case of a limited space. Another complication is groundwater as underground construction requires water depression to be undertaken in this case. Thus, pits with sidewalls at a slope of repose are usually arranged in the absence of urban development and in case of deep level of groundwater.

Support design and technology for pits in case of underground construction should meet some requirements such as: stability of pit walls during and after total extraction of soil; withstanding of load from the structure; water impermeability if water depression is impossible or economically inexpedient; re-usability of support elements in case of temporal reinforcement; the support should not block the pit, extraction of soil or backfill, and erection of other structures; saving of materials, labor and time; preservation of surface and underground objects in operation in the influence zone of underground structure construction; environmental standards (permissible rates of noise, vibration) and environmental protection. To this effect, sidewalls of pits and trenches are supported using modified concrete mixes.
New-generation concretes are described in [2]. Concrete technologies have been greatly advanced through extensively investigated and practically approved science of concrete modification using admixtures-modifiers intended to improve properties of concretes and concrete mixes.

Methods and means capable to maximize underground construction rates are discussed in [3]. Monolithic lining using concrete in horizontal and inclined tunnels in complicated geological conditions is combined with temporary support meant to take up loads exerted by enclosing rock mass. This is only possible if concrete rapidly develops strength mainly dependent on the strength of paste matrix. The main factor to govern duration of support installation cycle is a time period within which concrete placed in a formwork changes from plastic to solid state. Based on the studies into the rate of hydration of cements manufactured by different plants, the highest kinetics of structure formation is a feature of cements manufactured at Pervomaisky and Verkhnebakansky Cement Plants in Novorossiysk in Russia. High placeability of cements is only achieved with superplastifiers.

The rate of strength development in modified early-curing concretes used in underground structures is analyzed in [3]. Regarding development of strength in concrete, the most effective admixtures should exert integrated effect on a binder. The tests of increment in plastic strength of cement grout of normal density were carried out with integrated admixtures such as Relamix M2, Relamix SL, Poliplast-1MB, Superplast ultra D5 and some others. From the test results, the most effective admixtures are D5 and Relamix T-2.

Installation of monolithic concrete lining is a specific, difficult and long process. This is connected with design features of a framework, space-limited operation front, impossibility of vibro-compaction and duration of mixture placement, especially in the crown of roof. In this case, sustained fluidity of cement mixture for 30–40 min is a critical factor. Mie construction mostly uses flowing concrete with cone slump to 17 cm; for this reason, the above-specified time interval is of particular concern as the high water/cement ratio result in much longer time of initial and final setting.

The authors of this paper accomplished testing of normal density mixtures at a cement : sand ratio of 1: 3 and at constant sand size in the range of 1.61–1.67. In the plastic strength test, we placed the mixtures in three rings with a diameter of 100 mm and a height of 40 mm; the bending and compression tests were carried out on 32 beams made of the test cement mixtures. The test results are compiled in Table 1 and in Figure 1. All modified mixtures exhibited a considerable increase in the plastic strength over a curing time from 2 to 6 h.

These studies were carried out for monolithic concrete lining installation in Almaty Metro.

In application of high-early-strength concrete, intensification of structure formation during early curing of concrete is accompanied by a decrease in concrete fluidity, and the increased time of mixing during placement leads to a decrease in strength. Thus, it is required to assess ‘vitality’ of cement mixtures by investigating the influence of mixing time before cement placement in frameworks on structural and mechanical properties of the mixtures.

Table 1. Test results of modified cement-and-sand mixtures

| No. | Admixture | Content, % | Plastic strength, kPa, at curing time, h |
|-----|-----------|------------|----------------------------------------|
|     |           |            | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1   | No admixture | -          | 5.5 | 9.6 | 22.3 | 48.1 | 157 | 272 | 369 | 486 | 618 |
| 2   | UP-5      | 4          | 12 | 18.3 | 127 | 272 | 414 | 594 | 981 | 1262 | 1579 |
| 3   | Extra     | 3          | 76 | 171 | 284 | 388 | 582 | 796 | 1007 | 1239 | 1594 |
| 4   | D-11      | 3          | 18 | 64.8 | 86.3 | 126 | 297 | 511 | 826 | 1141 | 1512 |
| 5   | D-5       | 4          | 11 | 58 | 76.3 | 106 | 182 | 387 | 604 | 874 | 1581 |
Figure 1. Kinetics of increment in plastic strength: (a) normal density cement grout composed of cements manufactured at different cement-and-sand factories; (b) modified mixtures; (c) modified mixtures at mixing time of 20 min.

The tests were carried out at the mixing times of 10, 20 and 30 min. Immediately after mixing, the beam and ring frameworks were filled with the test mixtures. Placement time was 8–10 min; that is, the maximum time to stabilization of the mixtures was 40 min as per the earlier set condition.

The test result show that the increase in the mixing time to 20 min greatly intensifies the processes of hydration (Table 2), which is proved by the increment in the plastic strength of the mixtures by 3–5 times at curing time of 6 h.
Table 2. Test results of modified cement-and-sand mixture at mixing time of 20 min

| No. | Admixture | Content, % | Plastic strength, kPa, at curing time, h |
|-----|-----------|------------|-----------------------------------------|
|     |           |            | 1 | 2 | 3 | 4 | 5 | 6 |
| 1   | No admixture | -          | 4.8 | 11.2 | 32.2 | 265.4 | 457.3 | 1267 |
| 2   | UP-5      | 4          | 101 | 148 | 267 | 522 | 934 | 1414 |
| 3   | Extra     | 3          | 216 | 374 | 744 | 1358 | 1784 | 2079 |
| 4   | D-11      | 3          | 147 | 184 | 356 | 764 | 1248 | 2201 |
| 5   | D-5       | 4          | 54.4 | 192 | 383 | 726 | 1169 | 2483 |

The analysis of the research findings shows that the highest hydration rates are ensured by admixtures Extra, D-11 and D-5. On the other hand, the mixtures with modifiers Extra and D-11 considerably thicken by the time of placement and consolidate more difficulty, moreover, at curing time of 6 h, the plastic strength of the mixtures with Extra and D-11 is lower than with D-5.

In the ultimate compression tests of the normal density mixtures in the form of beams, 5–8 half-beams were compressed to fracture per test series so that the measurement error was not higher than 10%.

The test results showed that the highest strength of structure formation and, accordingly, the highest strength characteristics are exhibited by the Portland cement mixture with modified D-5. At the same time, the rate of hardening in the period from 9 to 24 h was insufficient, while the maximum loads on the lining were expected in that very time span.

Thus, based on the heat release tests in hydration of binders, the influence of the hardening accelerators on the kinetics of structure formation in the modified cement mixture with admixture D-5 was determined with a view to manufacturing a mixture with high rate of structure formation in the period of 12–18 h after addition of water to the mixture.

3. Conclusions

1. It has been found that the maximal stress depends on the value of the confining pressure, thickness of lining, rock cohesion, and on the time change of the mechanical characteristics of modified concrete.

2. The developed efficient modified concretes ensure the increment in the strength by 20 times in curing for 12 h and by 7 times in curing for 1 day as compared with admixture-free concretes.

3. The presented research findings show that the highest rate of structure formation and, accordingly, the highest strength characteristics belong to the Portland cement mixture with modifier D-5. However, this mixture has insufficient rate of hardening over the period from 9 to 20 h when the maximal load on the concrete lining are expected.

4. Modeling in PLAXIS 2D reveals that pit sidewalls lined with the modified concrete mixture is capable to sustain loading and pressures.

References

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