Mine backfill

Author: Prof. Dr. habil. Heinz Konietzky
(TU Bergakademie Freiberg, Geotechnical Institute)

1   Introduction

Backfill is mainly used to fulfil one or several of the following tasks:

- Reduction of surface subsidence
- Prevention of sinkholes
- Prevention of rock bursts or induced seismicity
- Support of mined-out area
- Prevention of pressure on working face
- Secondary excavation of minerals (pillar removal)
- Preservation of natural barrier systems
- Reduction of groundwater flow into the excavations
- Prevention of subsequent illegal access to abandoned mines
- Extension of the lifetime of a mine
- Reduction of thermal impact and gas release

2   Backfill types, technologies and properties

According to the placement and the consistency of the backfill the following types can be distinguished:

- Pneumatic backfill: dry backfill is placed via pneumatic conveying through pipes
- Hydraulic backfill: liquid backfill is placed via pipes, belts or trucks
- Paste backfill: pasty backfill is characterized by high solid content (> 65%) transported through pipes by hydraulic pressure
- Mechanical backfill: dry granular material is placed via belts, chuts, pipes or trucks in the excavations (just gravity driven)
- Big bags: Big bags filled with dry or only slightly wetted backfill material are placed in the excavations

Another kind of classification system distinguishes between cemented and uncemented backfill. The first one can be transported and placed by gravity or pumping, the second one by pneumatic or slinger stowing.

Material used as backfill can be quite different and covers for instance concrete, surface quarry material, mine dumps, mill tailings, fly ash, slag, sand, waste rock etc. Often it is a mixture of several materials and depends on availability, costs, environmental impact and requested properties. Also, arbitrary waste incl. toxic waste can act as backfill material under certain restrictions.

Hydraulic and pasty backfill delivers high strength and stiffness after curing, but needs binder like cement or fly ash that makes this type of backfill more expensive. Also, special equipment (mixer, pumps, pipelines) are necessary. A potential other drawback might be, that hydraulic backfill brings additional water into the mine and construction of dams may

be necessary to isolate the backfilled excavations and to avoid outflow. The properties of backfill are determined by the following parameters (Moser, 2016):

- Mineralogy of ingredients
- Grain size distribution
- Type and amount of binder
- Type and amount of additives
- Water content
- Water-binder-ratio
- Porosity / density
- Cohesion and friction
- Permeability
- Viscosity / consistency
- Weight-volume-ratio

The specification of certain requirements on the backfill is mainly based on geomechanical calculations and dimensioning. Based on these requirements the intended backfill material has to be investigated by lab tests. Depending on the backfill type some of the following tests are used:

- Sieve analysis or sedimentation tests (grain size distribution)
- Gravimetry, volumetry (density)
- Triaxial or uniaxial compression tests (strength and stiffness)
- Oedometer tests (volumetric compaction)
- Vicat needle tests (setting time, strength)
- Uniaxial or triaxial creep tests (rheological behaviour, long-term strength and stiffness)
- Permeability tests (hydraulic behaviour)
- Slump test (rheological behaviour)

Please note, that these macroscopic properties depend on micro-properties like particle size and particle shape as well as on chemical reactions and used additives, especially in case of hydraulic and paste backfill. Simple, but specific test apparatuses used for backfill beyond the classical rock and soil mechanical equipment are shown in figures 3 and 4.

Exemplarily, Shen et al. (2017) describe in detail the geomechanical and chemical parameter determination for fly ash backfill used in abandoned mines including application and monitoring. Also exemplarily, Panchal et al. (2018) provide a description of paste fill characteristics based on detailed lab investigations. They show how composition of backfill components influence the behaviour (rheology, strength, stiffness).

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Fig. 1:   Different types of backfill, left: paste fill; right: rock fill (Sivakuga et al. 2015)

Fig. 2:   Porous brick dam for hydraulic backfill (Sivakuga et al. 2015)
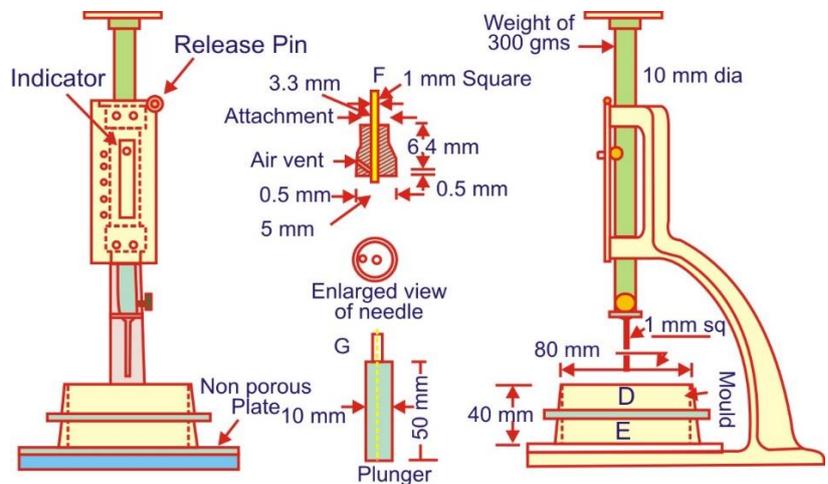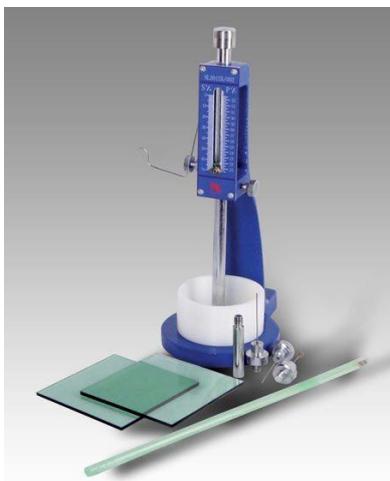
Fig. 3:   Vicat needle test apparatus (company material)
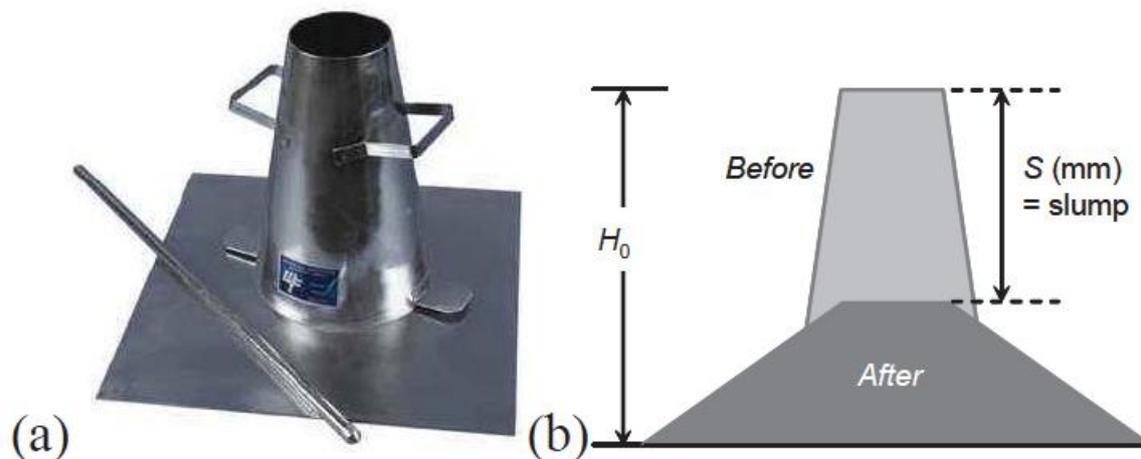
Fig. 4:   Slump test to determine rheological parameter for paste fill (Belem & Benzaazoua, 2004)

3   Planning and quality control

Backfill has to fulfil certain tasks and should therefore meet certain minimum requirements. These requirements are mainly defined in terms of strength, stiffness, rheology and hydraulics. Fig. 5 illustrates a recommended planning scheme to find the optimum backfill system.

To control the adherence of certain properties, lab and field testings are performed. Quality control comprises all phases of the backfill process including check of ingredience, mixing, placement and final properties. In most cases (especially for hydraulic and paste backfill) retained samples are produced and tested in the lab. Some quick and preliminary checks can be performed using indicators, like obtained from density, Vicat needle (fig. 3) or slump tests (fig 4). Testing can be subdivided into: qualification test, quality control test and retesting. The costs of backfill can represent up to about 25 % of the overall mining costs and binders contribute to more than 50 %.
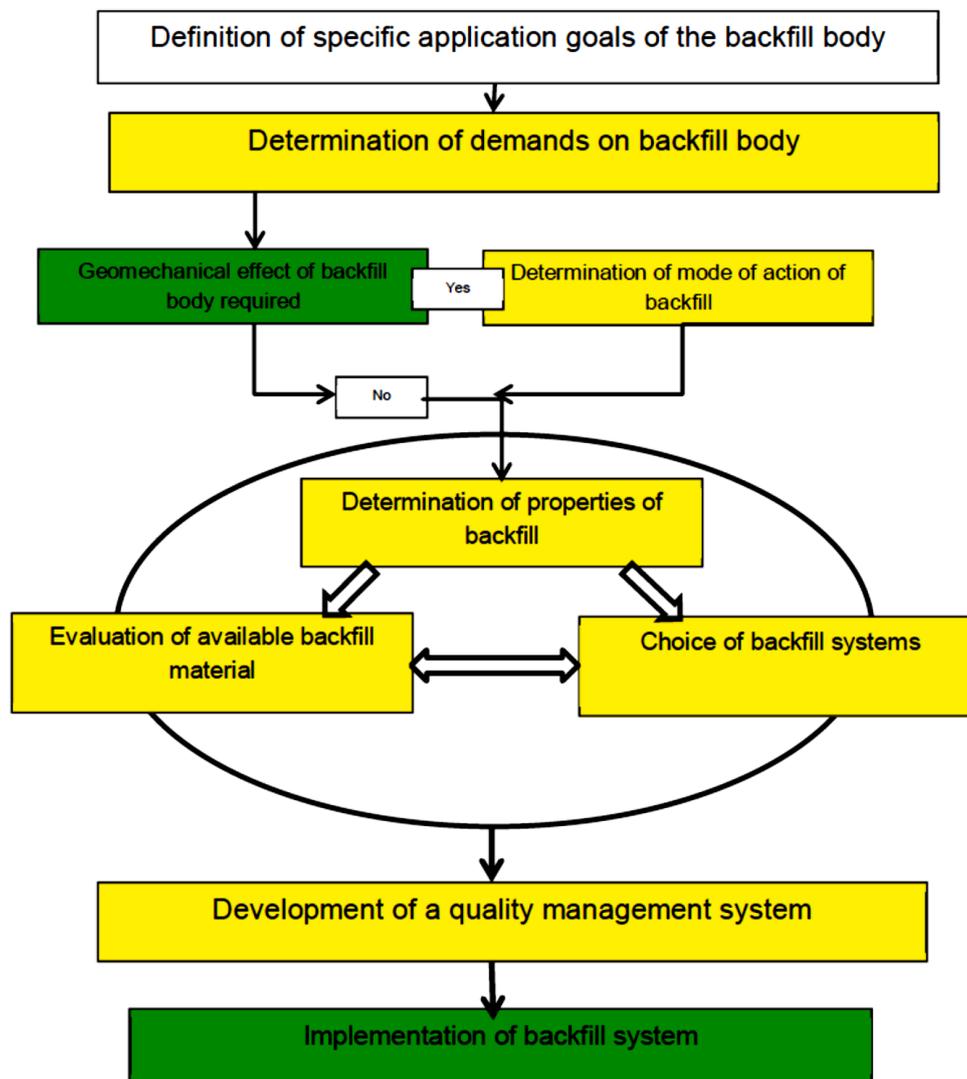
Fig. 5:   Planning scheme cycle of a backfill system (Moser, 2014)

4   Selected applications

The application of backfill is quite diverse. For each project a specific and local solution has to be developed. The following sub-chapters give just a few examples.

4.1   Shaft backfilling

In most cases abandoned shafts have to be backfilled with ballast. Commonly, coarsed grained material (broken rocks, ballast) are used. Grain size distribution, grain shape and bulk density (influenced by backfilling technology) of ballast influence frictional and compaction behaviour. Discrete Element Method (DEM) can be used to predict the ballast behaviour as shown by fig. 6. Figures 7 and 8 show that the so-called 'Silo-Effect' acts, which limits the stresses inside the ballast and to the shaft walls to a certain value. This value depends on characteristics of the ballast.

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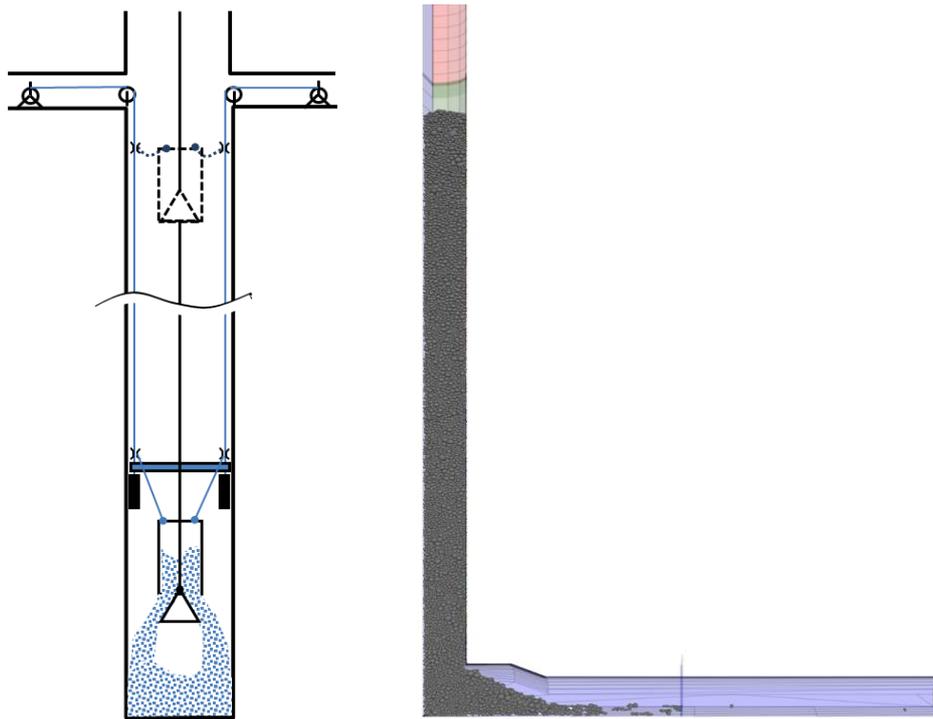
Fig. 6:   Ballast inside a shaft. Left: sketch to illustrate placement technology; Right: DEM simulation of filled shaft with connected shaft bottom (Nguyen, 2016)
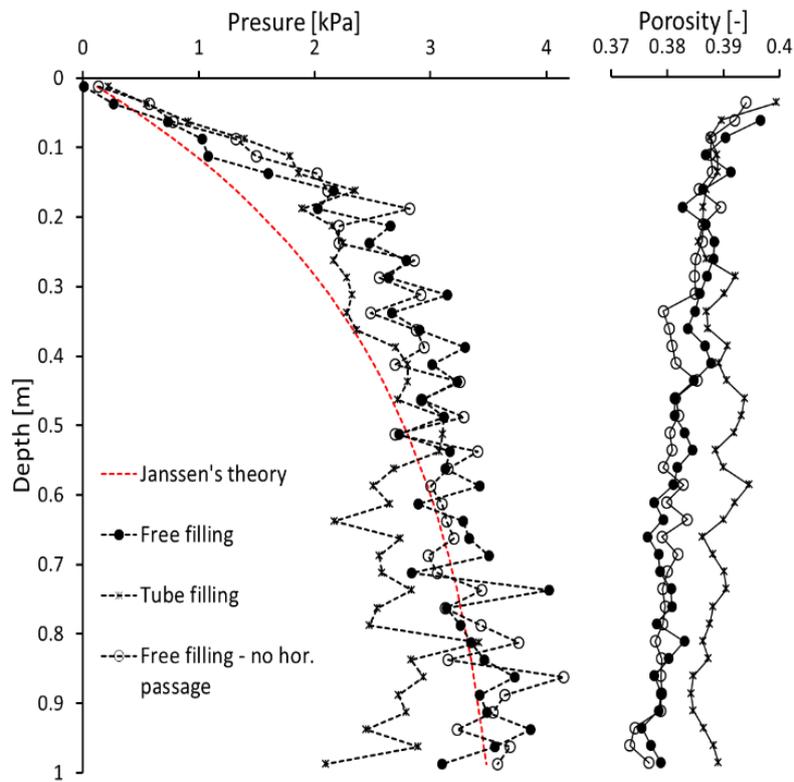
Fig. 7:   Pressure and porosity profile obtained by DEM simulations in comparison to Janssen's silo theory (Nguyen, 2016)

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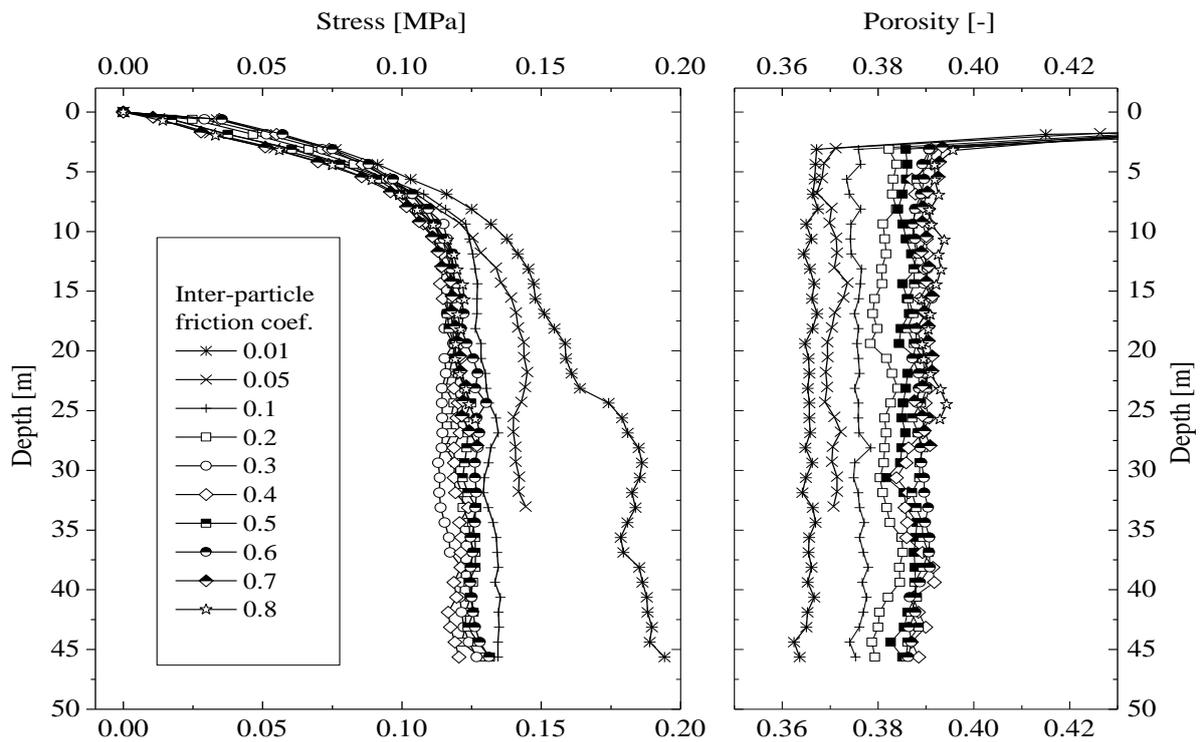
Fig. 8:   Influence of frictional behaviour of ballast on stress and porosity profile along the shaft (Nguyen, 2016)

4.2   Backfilling in potash and salt mining

To minimize subsidence, to avoid rock bursts and to maximize mineral extraction, special hydraulic backfill is used in potash and salt mining (e.g. Fliss et al. 2011). Fig. 9 illustrates the backfilling process in case of backfilling long chambers. In a similar way rooms can be backfilled and in a second step the remaining pillars can be excavated, so that the backfill acts as stabilizing element and substitutes the rock mass. In potash and salt special attention has to be paid to the fluids to minimize solution processes (e.g. drainage, water management, chemical composition, use of saturated brines etc.). A hydraulic backfill with high content of rock salt with $MgCl_2$ brine leads to a long-term stable backfill with high stiffness (Young's modulus > 20 MPa).

Crushed salt is the most used backfill material in salt mines. With particle diameter less than about 60 mm initial porosity obtained by pneumatic backfilling is in the order of 35 %. A long-term stable backfill for potash mines with MgCl brines is the so-called Sorel-concrete or MgO-concrete, based on Mg-Si-hydrates (see also Walling and Provis, 2016).
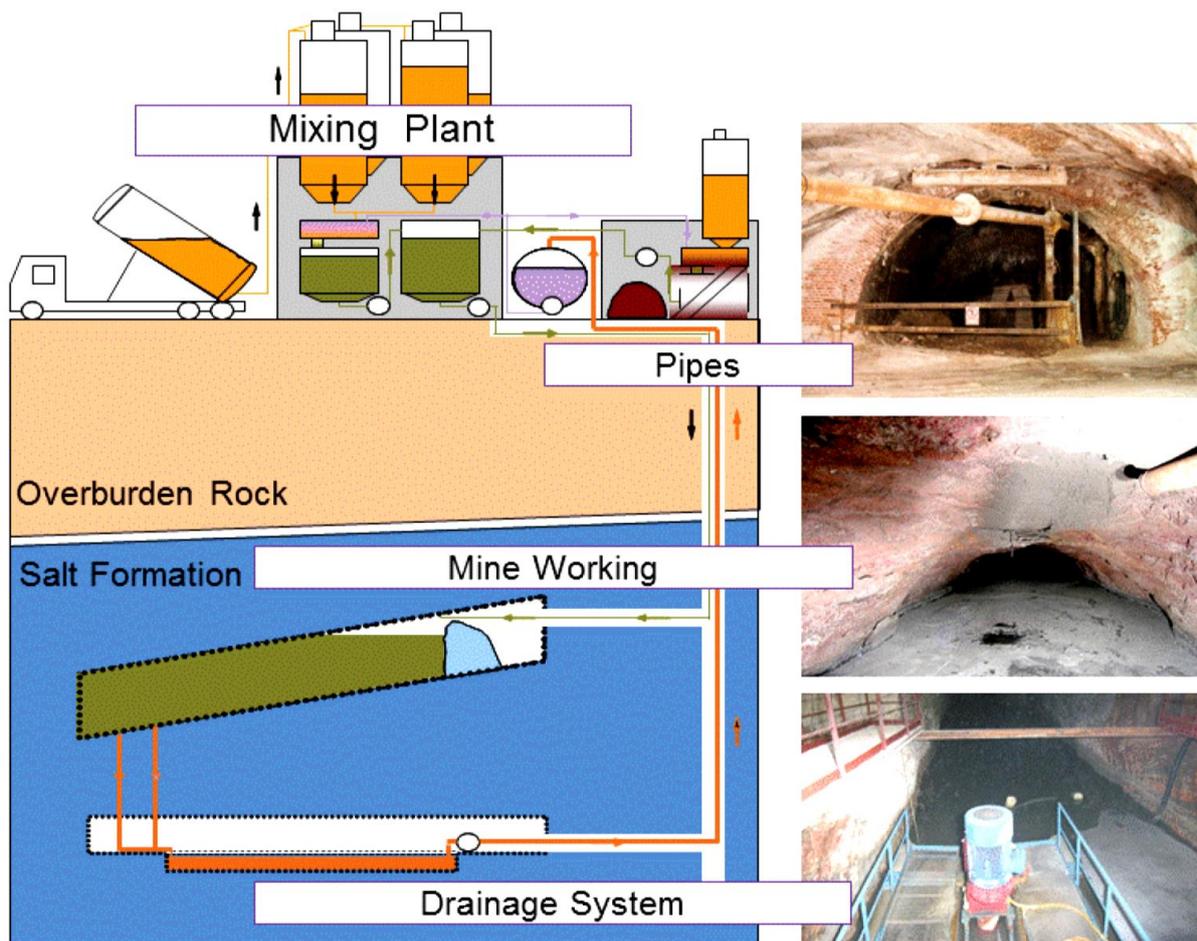
Fig. 9:   Principle sketch of hydraulic backfilling in potash mining industry (Fliß et al. 2011)

4.3   Backfilling in radioactive waste repositories

In principle backfill in radioactive waste repositories has to fulfil the same functions, but with significantly higher demands in respect to all components: mechanics, hydraulics, thermic, geochemistry and lifetime (Dixon and Keto, 2009). Backfill for underground nuclear repositories should consider the following specific aspects:

- Minimization of development of excavation disturbed zone (EDZ)

- Sealing effect

- Absorption effect to restrict radionuclide movement

- Extreme long-term stability of mechanical, thermal, hydraulic and chemical functionality of backfill

For underground nuclear repositories clay-aggregate backfill with swelling potential is considered, e.g. bentonite or bentonite-sand mixtures in form of pellets or bricks.
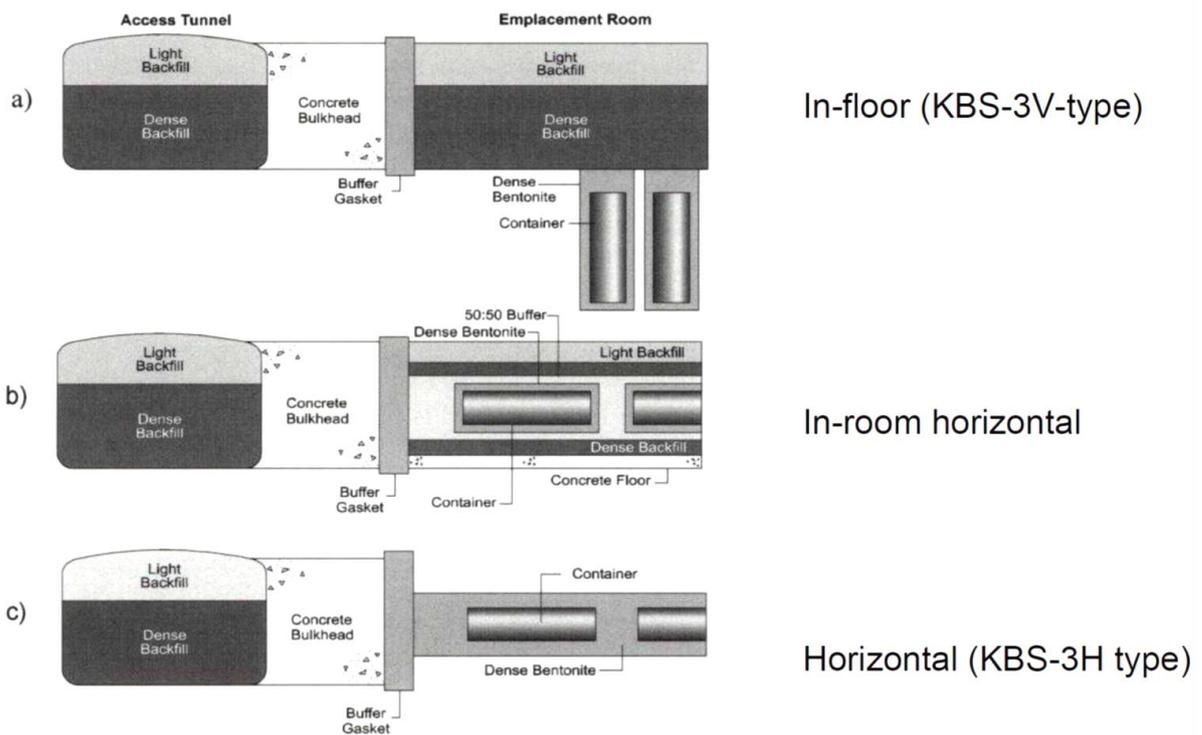
Fig. 10: Backfilling according to the Canadian concept (Dixon & Keto, 2009)
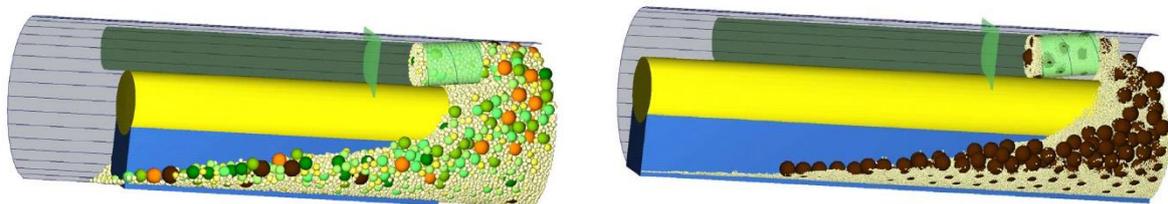
Fig. 11: Simulation of backfilling a horizontal drift with bentonite pellets of different grain size distributions (Left: Fuller; Right: bi-modal) using a crew conveyor (Konietzky & te Kamp 2000)

4.4   Backfilling in coal room and pillar mining

The bursting of coal pillars can be avoided if rooms between pillars are partially backfilled, so that they are supported. Even partial backfilling leads to a more pronounced 3-dimensional stress state inside the pillar. This reduces the areas where plastification take place and increases the elastic volume in the inner part (core) of the pillar. Backfill increases the pillar strength (loading capacity). Fig. 12 illustrates the numerical simulation procedure to investigate the effect of partial backfilling on pillar stability. Figures 13 and 14 shows exemplary specific results for an underground coal mine with room and pillar excavation scheme. It documents, that under these specific conditions cohesive backfill below 40 % of excavation height has only minor effect, but beyond this percentage the effect is significant.

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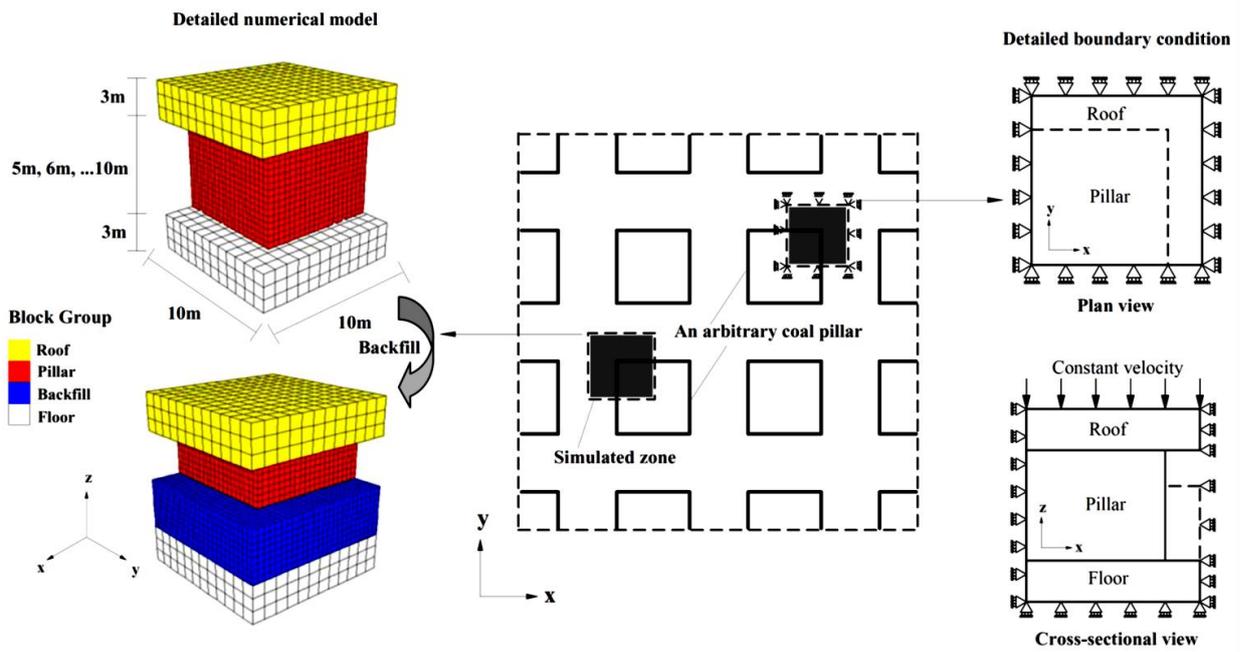
Fig. 12: Numerical model set-up to investigate backfill effects (Yaodong et al., 2011)
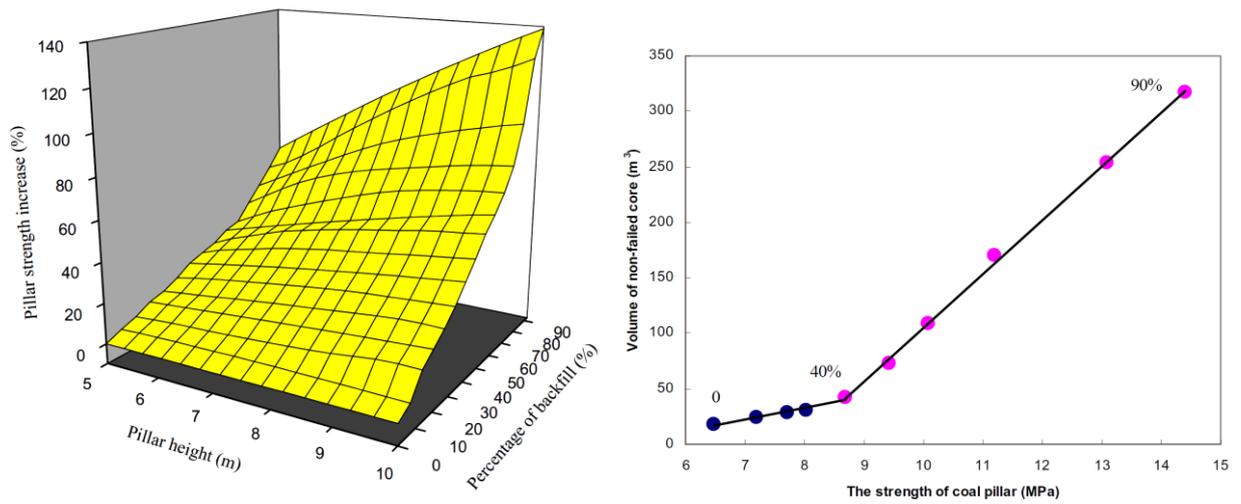
Fig. 13: Left: Pillar strength increase by different percentage of backfill; Right: Volume of elastic core in relation to pillar strength (Yaodong et al., 2011)
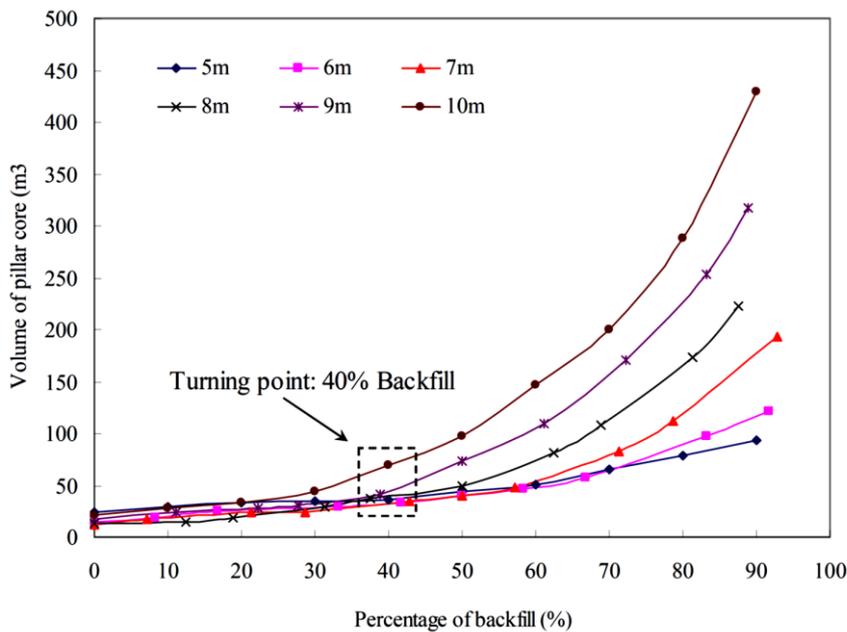
Fig. 14: Volume of elastic pillar core in dependence on the degree of backfill and mining height between 5 and 10 m (Yaodong et al. 2011)

4.5 *Backfilling in longwall coal mining*

Chang et al. (2014) document a backfill technology for longwall coal mining. They consider a 7 m thick and slightly dipping coal seam 450 m below surface. Length of working face is 102 m and strike length 1150 m. By applying a paste backfill technology (see figures 16 and 17) the following results were obtained:

- Improvement of coal recovering rate from 45 % to 95 %
- Reduction of surface subsidence to maximum of 35 mm (see fig. 15)
- Backfilling ratio > 97 %

Feng et al. (2015) present a similar backfill scheme for longwall coal mining as illustrated in fig. 18 and 19.
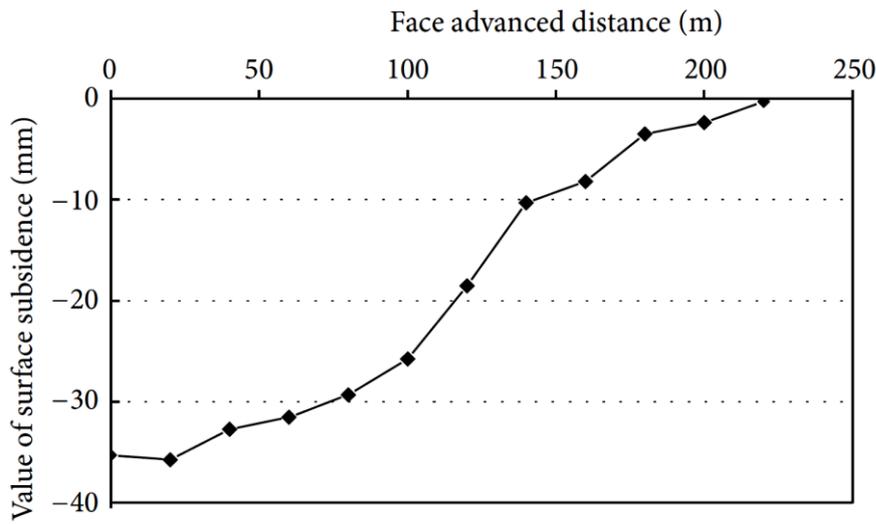
Fig. 15: Subsidence by using backfill technology according to Chang et al. (2014)
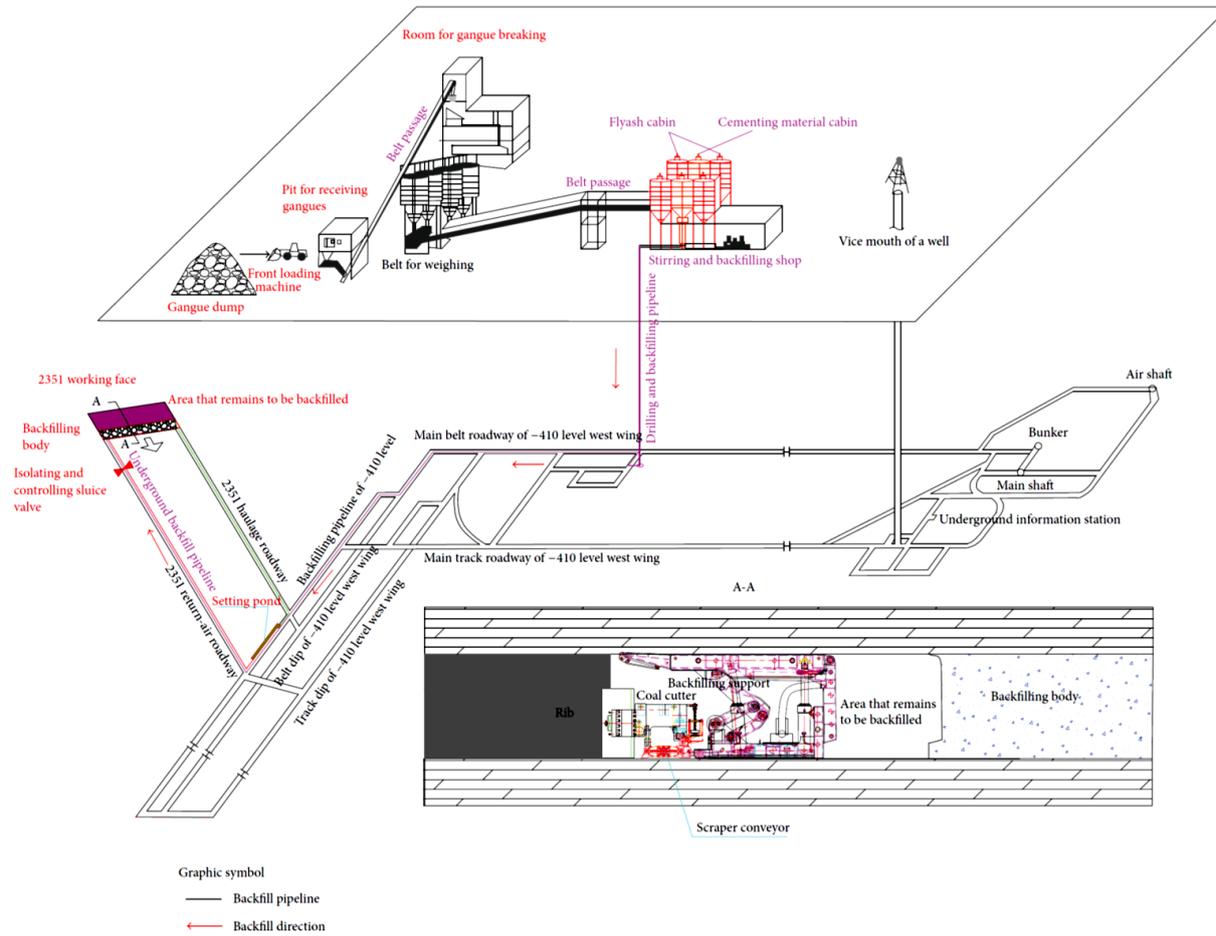
Fig. 16: Sketch of backfill technology (Chang et al., 2014)
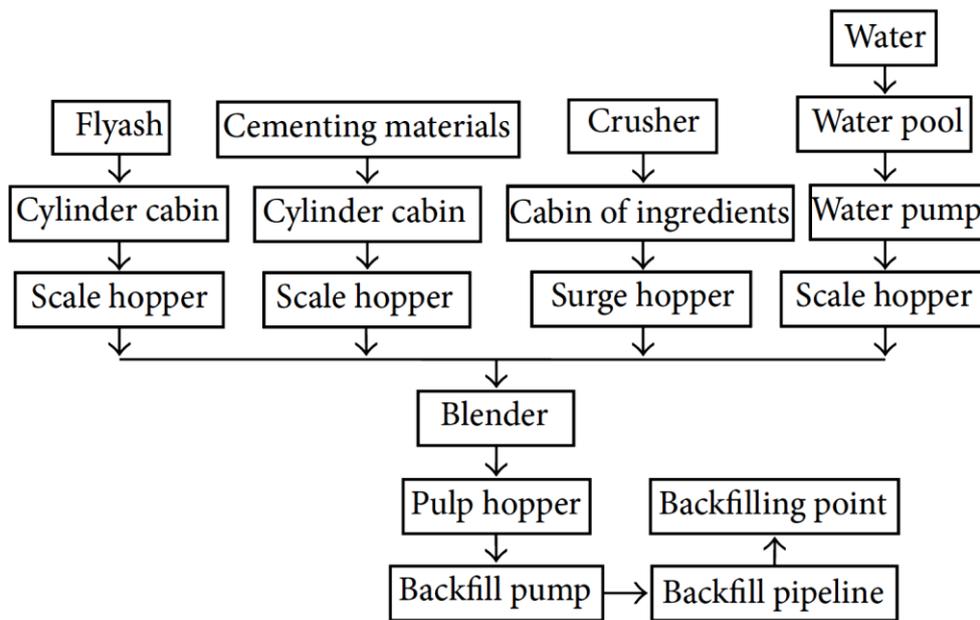
Fig. 17: Scheme of backfill technology (Chang et al., 2014)
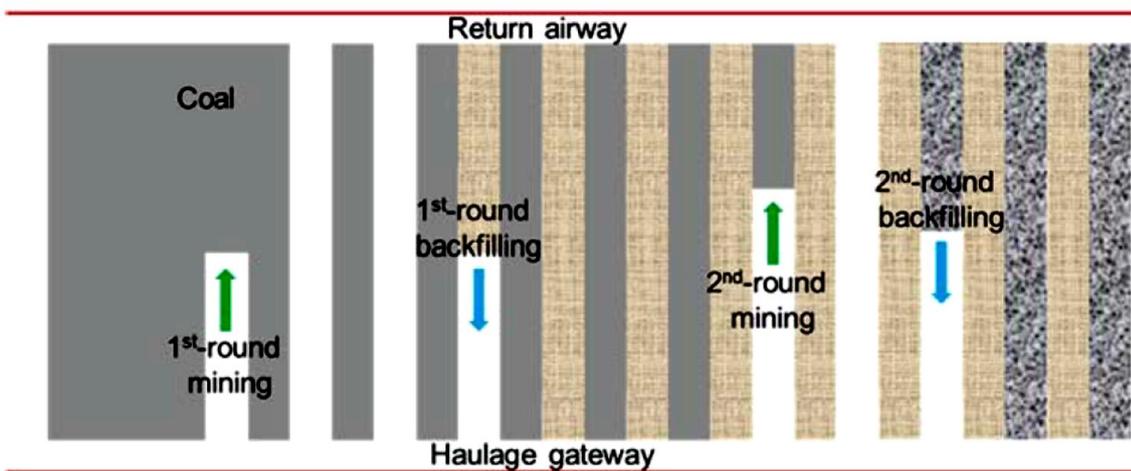
Fig. 18: Plane view of longwall mining excavation and backfill scheme (Feng et al., 2015)
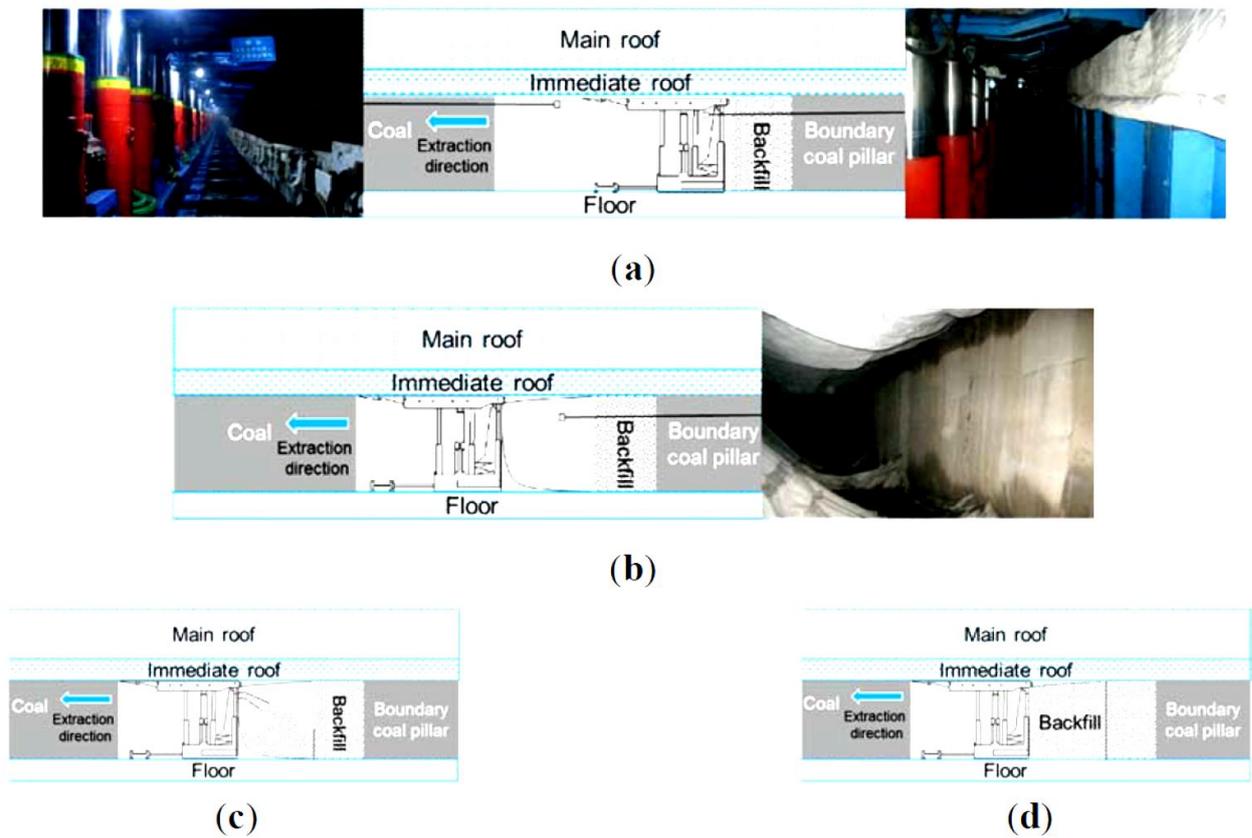
Fig. 19: Longwall mining excavation scheme as in operation in the Yulin colliery of Shanxi Province, China; (a) to (d) illustrate consecutive excavation and backfill steps (Feng et al., 2015)

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5   References

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