COAL INTERNATIONAL

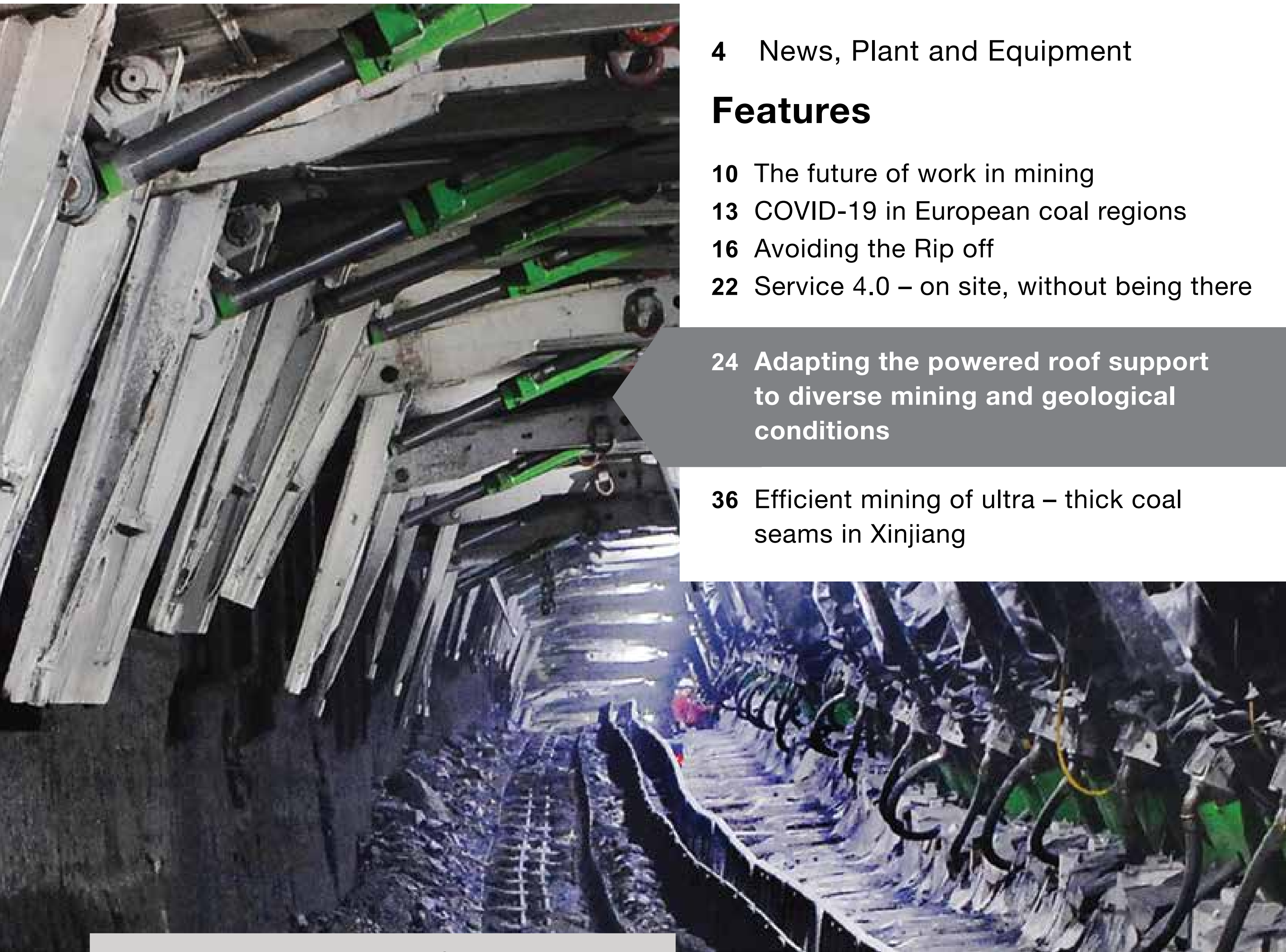
Volume 268 · Number 6

November-December 2020


NEW TD-25M
HEAVY PUSHING. NO SWEAT.
42 TONS OF PURE PERFORMANCE
WITH AN ALL-NEW FIRST CLASS CAB
SEE MORE, DO MORE WITH 33% MORE VISIBILITY
HIGH CAPACITY BLADES DESIGNED TO PUSH THE LIMITS
ENGINEERED FOR MINES, FORESTRY, LANDFILL & CONSTRUCTION
FIND OUT MORE: Email INFO@DRESSTA.COM or visit WWW.DRESSTA.COM
DRESSTA
ENGINEERED FOR YOUR BUSINESS

Volume 268 • Number 6 • November-December 2020

CONTENTS



Managing Director and Publisher: Trevor Barratt

International Sales:
Gordon Barratt +44 1909 485105 gordon.barratt@tradelinkpub.com
Gunter Schneider +49 2131 511801 info@gsm-international.eu

Graphic Designer: Sarah Beale sarah.beale@tradelinkpub.com

Published by: Tradelink Publications Ltd.
16 Boscombe Road, Gateford, Worksop, Nottinghamshire S81 7SB

Tel: +44 (0)1777 871007
Fax: +44 (0)1777 872271
E-mail: admin@mqworld.com
Web: www.mqworld.com

All subscriptions payable in advance.
Published 6 times per year, post free:

UK: £140.00 **Worldwide:** £160.00 | ISSN No: 1357-6941 | D-U-N-S No: 23-825-4721

Almost half of the producing companies set to defy climate pledge

Almost half the companies involved in the thermal coal industry are expected to defy global climate commitments by deepening their coal interests in the coming years, according to a recent report.

The study, by the green campaign group Urgewald, revealed that almost 1,000 companies should be blacklisted by investors because they remain tied to the thermal coal value chain almost four years after the Paris climate agreement came into effect.

Almost 440 of these companies plan to build coal plants, mines or other infrastructure in the years ahead, according to Urgewald's global coal exit list, which it produced alongside 30 NGO partners. Meanwhile, only 25 companies on the list have set a date to phase out their coal use.

Heffa Schücking, the director of Urgewald, said the findings should provide a wake-up call to investors who planned to continue to back companies linked to the coal industry as global governments signal a shift to cleaner energy sources.

"When we speak to the financial industry many believe that it's important to stick with these companies through the energy transition. But half of these companies aren't interested in transitioning," Schücking said.

"We are in a climate emergency and a speedy exit from coal is more urgent than ever. Our database identifies 935 companies the finance industry needs to blacklist if it is serious about fulfilling the Paris goals."

The global coal exit list includes all energy companies that either hold more than 5GW of coal-fired power plant capacity, produce 10m tons of thermal coal a year, or rely on coal for a fifth of their energy generation or revenue.

The list also includes a growing number of companies outside of the energy industry that are planning to invest in coal power alongside established energy players, or to meet their future energy needs.

The ongoing financial support for coal-fired power plants has caused the world's coal-fired power plant capacity to grow by 137GW since the Paris climate agreement came into effect, or the same amount as the coal plant fleets of Germany, Russia and Japan combined.

The pipeline for new coal-fired power plants has reached 522GW-worth of coal-fired power plants, of which half are expected to be built in China, where four of the world's top five coal plant developers are based.

China Energy plans to build 43GW of coal-power capacity followed by China Datang (34GW), China Huaneng (29GW) and China Huadian (15GW). The world's fifth most prolific coal-plant developer is India's NTPC, which has plans for another 14GW of coal-power capacity.

"Waiting for coal companies to transition is a recipe for runaway climate change," Schücking said. "Unless financial institutions speed up their exit from the industry, we will fail the most basic of all climate tests: leaving coal behind."

A worker walking by the main gate of a coal-to-oil plant in Changzhi in China's northern Shanxi province. Photograph: Fred Dufour/AFP/Getty.

Banks Mining will not challenge mine rejection

Banks Mining will not appeal against a government decision to reject its plans to develop a new coal mine in northeast England, the British company said recently.

Northumberland County Council agreed in 2016 that developer Banks could extract three-million tonnes of coal over six to seven years by cutting an open cast, or surface mine, near Druridge Bay, Highthorn.

Former minister Sajid Javid rejected the application in 2018 following a public inquiry, but Banks challenged the decision in England's high court and it was returned to central planning authorities for further consideration.

Robert Jenrick, minister for housing, communities and local government, last month again refused permission for the coal mine to be built, citing environmental concerns.

"We have concluded that issuing a challenge to it would not be the right course of action," Gavin Styles, executive director at Banks Mining, said in an emailed statement.

Styles said the company still planned to go ahead with its Dewley Hill coal mine, also in the northeast of England.

Banks Mining is seeking to extract 800 000 tonnes of coal and 400 000 tonnes of fireclay from the Dewley Hill site.

Britain is seeking to phase out coal-fired power plants by 2024 as part of efforts to meet its target of net zero emissions by 2050.

It still uses some coal in industry and for domestic fires and imported around 6.5-million tonnes of coal in 2019, government data showed. More than a third of this was from Russia.

Seaborne thermal demand set to rise over the next decade

The Minerals Council of Australia released a report related to the outlook for seaborne thermal coal in terms of demand to 2030 in the Asia Pacific region.

The report was commissioned to Commodity Insights and it states that Asian thermal coal imports are expected to grow by more than 270 million tonnes (Mt) to 1.1 billion tonnes per annum over the next decade. The market analyst says that this growth stands on the same drivers that allowed seaborne thermal coal volumes to double between 2006 and 2019, from 500Mt to 1,000Mt, rising in volume every year of that period except in 2015.

These driving factors are high electricity demand across developing nations, pushed by strong economic growth, increasing industrialization and higher electrification rates; high population growth, particularly India and Southeast Asia; significant coal-fired generation capacity commissioned in many countries; and, in some regions, an inability of domestic coal production to keep pace with demand growth, amplified by increasing demand for high-quality thermal coal, which is typical of seaborne traded coals.

According to the report, even though growth will be negative in 2020 due to the impact of covid-19, it will be followed by a solid recovery and most countries are expected to increase imports, with only Taiwan and Korea reducing volumes.

Moreover, five countries – among them The Philippines, India, and Vietnam – are forecast to increase demand by more than 30Mt.

As a commodity, such a rise illustrates the breadth of market demand growth for imported thermal coal – which is not reliant on growth from China.

https://www.mining.com/demand-for-seaborne-thermal-coal-expected-to-rise-in-the-next-decade-report/

Bayswater Power Station in New South Wales, Australia.

South Korea vows to go carbon neutral by 2050 to fight climate emergency

South Korea's president, Moon Jae-in, has declared that the country will go carbon neutral by 2050, bringing it into line with other major economies.

In a policy speech in the national assembly , Moon said South Korea, one of the world's most fossil fuel-reliant economies, would "actively respond" to the climate emergency "with the international community and achieve carbon neutrality by 2050".

He vowed to end its dependence on coal and replace it with renewables as part of its Green New Deal, a multibillion-dollar plan to invest in green infrastructure, clean energy and electric vehicles.

South Korea is the latest major economy to commit to zero emissions. The European Union set itself a similar target last year, with Japan following suit recently. China said in September it would achieve carbon neutrality by 2060.

Moon's announcement is in line with a proposal made by his ruling party before April's national assembly elections.

Its Green New Deal calls for an end to financing of overseas coal plants, and the introduction of a carbon tax, creating urban forests, recycling, establishing a foundation for new and renewable energy, and creating low-carbon industrial complexes.

Campaigners welcomed Moon's announcement, but warned that South Korea – the world's seventh-biggest emitter of carbon dioxide in 2017, according to the International Energy Agency – would have to transform its energy policy to stand a chance of reaching the zero-emissions milestone.

"South Korea is finally one step closer to aligning itself with the reduction pathway compatible with Paris climate agreement goals," Joojin Kim, managing director of the Seoul-based NGO Solutions for Our Climate, said in a statement.

"However, there is much to be done to make this declaration actually meaningful. The most urgent tasks are enhancing its 2030 emissions reduction target, presenting a clear roadmap to phase out coal by 2030, and putting a complete stop to coal financing."

Jude Lee of Greenpeace East Asia said Moon's pledge was "another important step forward. We expect that this important pledge leads the Korean industry to swiftly shift from fossil fuels to a 100% renewables-based system."

South Korea relies on coal for about 40% of its electricity generation, with renewables making up less than 6%. It still has seven coal power units under construction. It is also one of the top three public financiers of overseas coal power projects, mostly in Asia, Solutions for Our Climate said.

The country will struggle to achieve net-zero emissions "without fundamental changes in energy policy", Kim said. "South Korea must immediately stop the construction of new coal power plants, and begin replacing the existing coal fleet with renewables."

Columbia pins hopes of salvation on China

Colombia's coal industry is experiencing one of the worst crises in its recent history. The Covid-19 pandemic has compounded problems including labour strikes, criticism of its environmental and human rights standards, and a decline in sales to its traditional customers, which began at least five years ago.

In the midst of the gradual loss of European markets as they transition towards clean energy, coal companies have looked to China – the country's second largest trading partner and a coal importer – as a possible destination for part of their future production.

However, any hopes China will save the day seems a remote possibility.

Toshiba retreating from coal-fired power stations

Japanese engineering giant Toshiba Corp will not build any more coal-fired power plants and will shift to renewable energy in a bid to reduce greenhouse emissions, company president Nobuaki Kurumatani said.

However, none of its existing coal-power construction projects will be scrapped, said Toshiba, which has about 10 under way worldwide.

"We will stop accepting new orders to build coal-fired plants, and seek to cut greenhouse gas emissions by 50% by 2030," Kurumatani told reporters.

He said that the company is to increase investment in renewable energy – including infrastructure for offshore wind-power and solar-power facilities, and research and development in related fields.

The announcement comes just weeks after Japanese Prime Minister Yoshihide Suga set a 2050 deadline for the world's third-largest economy to become carbon-neutral.

Suga's target date firmed up the nation's previous climate-change commitments, as it plays catch-up with similar pledges made by other major economies.

Kurumatani said that business opportunities could arise from the Paris climate accord, which US president-elect Joe Biden has vowed to re-join after US President Donald Trump's withdrawal.

As well as selling mega solar and hydropower plants, "we plan to pour our resources into wind power and to produce cutting-edge windmills," he said.

Germany's Siemens Energy and General Electric Co of the US have made similar commitments to stop building new coal-fired power stations.

Greenpeace welcomed the move, with its climate and energy campaigner Daniel Read calling the news "heartening," but emphasizing that "much work still remains."

"A complete separation from coal, both new and existing projects, and moving wholly to renewables is the only option that makes long-term sense, both financially and environmentally," he said in a statement.

Read warned against relying on nuclear power to reach net-zero emissions by 2050, saying it is not a "viable alternative."

Japan, which is a signatory to the Paris agreement, has struggled to cut carbon emissions after shutting down reactors after the 2011 meltdown at the Fukushima Dai-ichi nuclear power plant.

Reliance on fossil fuels such as coal increased after that, as public anger over the accident pushed all of the nation's reactors offline temporarily.

Japan's 140 coal-fired power plants provide nearly a third of its total electricity generation.

Coal is the second-biggest power-generation method behind liquefied natural gas-fired plants.

Protesters hold up placards as they take part in call for action on climate change in Tokyo on 29 November last year.

The All New MAXAM Mining Haulage Tire – MS412

Gaining a strong reputation in the industry, MAXAM Mining Group continues to innovate, adding the all-new MS412 27.00R49 to their open pit mining, quarry and OTR program. Designed to meet the demanding conditions in mine sites globally, the MS412 is the result of cutting-edge engineering and ground breaking compounding technology.

The MS412 features a high net-to-gross tread pattern that provides extremely low wear rates that drastically increase tire life. MAXAM's engineers have also strategically placed stone ejectors to provide maximum protection from stone drilling, which leads to the cause of premature tire removal and out of service conditions. Engineered with tread grooves that allow for exceptional traction and heat dissipation, the MS412 delivers excellent traction in a variety of haul roads conditions. To enable high speed operation with minimum heat build-up, MAXAM has optimized the MS412's base compound to help maximize productivity for mining operations globally.

Featuring a strong all-steel casing to reduce cuts and punctures, the all-new MS412 is engineered with increased casing durability to dominate severe hauling conditions. As an innovative group, with years of expertise in the mining industry, MAXAM's engineering team has designed the MS412 with a high lug-to-void ratio for improved wear and impact protection, providing mine sites increased protection and wear on haulage tires. Similar to all large mining haulage tires in MAXAM's program, the MS412 has deep tread grooves to provide cooler running tread and longer tire life.

Delivering a premium E4 haulage tire to the industry, the MAXAM MS412 provides exceptional performance, minimum cost-per-hour and a high net-to-gross pattern for maximum tread wear. The MS412 is available in one size and available in multiple tread compounds, including the ultra-cut resistant compound, recently released and innovated by MAXAM's engineering and R&D team, the MS412 is a rugged solution that maximizes the haulage truck's resilience in the toughest mining environment.

For more information, please contact your local representative or visit www.maxamtire.com.

India-crewed ships stuck at Chinese ports

Coal is among the Australian exports reportedly targeted by China as tensions escalate between the two countries

Two Indian-crewed merchant ships carrying Australian coal have been stuck at Chinese ports for several months, union officials said recently, with the sailors becoming the latest casualties of escalating tensions between Canberra and Beijing.

Australia-China tensions had been deteriorating in recent years and worsened further when Canberra supported calls for an independent inquiry into the origins of the coronavirus pandemic.

In response, an upset Beijing has reportedly imposed trade embargoes on Australia, including on coal – a business worth some US$10 billion a year.

The Indian bulk carrier MV Jag Anand with 23 Indian crew and carrying more than 160,000 tonnes of Australian coking coal has been stuck at the Chinese port of Jingtang since mid-June after being refused permission to offload, said Abdulgani Serang, secretary of the National Union of Seafarers of India.

Another vessel, Anastasia, also carrying coal from Australia and with 18 Indians on board, has been at China's Caofeidian anchorage since 3 August, he added.

"We have a humanitarian crisis at hand. Our seafarers are being treated inhumanely," Serang told AFP.

"The ships have become floating prisons and it is taking a heavy toll on the mental and physical wellbeing of the crew."

Serang said both ships have not been allowed to unload their cargo or depart for another port.

His union has written to the Indian and Chinese governments as well as the International Maritime Organisation (IMO), pleading for an end to the crisis.

"The seafarers are just doing their job and paying a heavy price for no fault of theirs," Serang said.

"It is like a food delivery guy being hammered in a fight between neighbours."

A letter from the wife of one of the crew members, posted on Twitter tagging Indian Prime Minister Narendra Modi's account, said the "deteriorating health of crew members is also a major concern".

The Great Eastern Shipping Company, which owns the Indian vessel Jag Anand, said it had offered to send the ship to Japan at its own cost but to no avail.

"Regrettably, none of our efforts have yielded results so far," a spokesman told The Hindu newspaper.

But China's foreign ministry said in response to an AFP query about the Jag Anand that "China has never restricted it from leaving".

"The freight side did not wish to adjust the ship's transport arrangements, citing commercial rights and interests. This is the real reason behind the circumstances."

India-China ties have also worsened significantly in recent months.

In mid-June, 20 Indian soldiers were killed in a brutal, high-altitude border clash. China has not revealed how many casualties it suffered.

The nuclear-armed neighbours later sent tens of thousands of troops to the disputed frontier in the Ladakh region in the Himalayas.

New power station in O Meanchey nears finish line

Han Seng Coal Mine Co Ltd's 265MW coal-fired power station in Oddar Meanchey province's easternmost Trapaing Prasat district is nearly 60% complete, deputy provincial governor Dy Rado stated.

He said the company is actively working to have the project – expected to cost a total of $294.3 m – up and running as quickly as possible to meet the province's energy needs ahead of an expected dry season shortage of electricity supply.

The 130MW first phase is scheduled to go online by the end of next year, with the project set to be fully online by the end of 2022, he added.

"We are studying the environmental impact of a project proposal to connect [the coal plant] to East Siem Reap Substation via a 230kV transmission line," Rado said, adding that the power station would supply his province and its southern neighbour Siem Reap.

EDC Workers remove the cable power along Hanio street in Phnom Penh. Heng Chivoan

With a population of over 260,000, Oddar Meanchey has a total energy demand of 10MW, he said.

"Power from the plant will greatly benefit the people living in the province and ensure that they have the energy to improve their livelihoods and household economies," Rado said.

The government on 23 October issued final registration certificates for the project and its transmission line.

Victor Jona, the director-general of the Ministry of Mines and Energy's General Department of Energy, has said Cambodia needs an average of more than 2,000MW of electricity a year, but demand could drop to 1,800MW this year.

The future of work in mining

What will jobs look like in intelligent mining operations?

The COVID-19 crisis has exposed the siloed nature of mining companies and highlighted the need for integrated operations. This is likely to accelerate the adoption of digital technologies, artificial intelligence, and analytics in the mining industry. We examine what future mining jobs will be like in intelligent, integrated operations.

THE evolution of technology, from advanced data analytics to artificial intelligence (AI), has always had the potential to transform the mining industry by realizing operational efficiency improvements, enhancing productivity, improving safety performance, empowering employees to do more meaningful work and allowing communities to be more prosperous. Has today's crisis accelerated that trend?

In recent years, many mining companies have begun their digital journeys towards intelligent operations. Deloitte's *Tracking the trends 2020* report explored the following action points for mining companies to optimize their digital journeys and unlock sustainable value:

- Understand the amount of effort required to clean up data and upgrade technology infrastructure
- Integrate operations and governance by bringing planning and execution together in a closed loop system and integrating data across the entire value chain
- Understand the staffing and skill requirements in moving towards integrated operations centres (i.e., Nerve Centres)

The future of work in mining is not only about introducing new technologies but also about considering what role these technologies will play and what work will look like in a new organization that imbibes these new technologies. To help guide us in these uncharted territories, it is important to keep the end state in mind: "What outcomes drive value for the business?" These key business drivers can

Andrew Swart-Canada

Janine Nel-Canada

Julie Harrison-Au

help tailor and redesign the organization to ensure that technology and organizational change empower this future organization, rather than debilitate it.

To achieve the desired value-driving outcomes, it is imperative to look out several years and understand and design for how humans could interact with the technology and with each other. Companies that have had successful digital journeys so far have often placed significant emphasis on change management to shift people's behaviour and engage with their work in new ways. Mining companies looking to capitalize on these trends will need to consider the future of work as they move towards integrated operations centres (i.e., Nerve Centres) that help guide decision-making across the value chain and reduce siloed behaviour's. They should consider what skills and roles are needed to support the Nerve Centers in achieving the desired business outcomes, and whether they will build these capabilities in-house or outsource it to external partners. These organizations will need to consider the desired culture of the teams, defining what success looks like when the culture is in its desired state. The operations culture plan should be developed in line with the objectives that the organization is looking to achieve through its digital goals and vision.

To support the teams when using digital tools, it is important that principles for decision rights, escalation protocols, and role accountabilities are clearly identified. A transparent and clear understanding as to how each role contributes to the success of the organization provides the best opportunity for teams to tap into the many resources available and the collective situational awareness that this collaborative environment brings.

THE TIME FOR CHANGE IS NOW

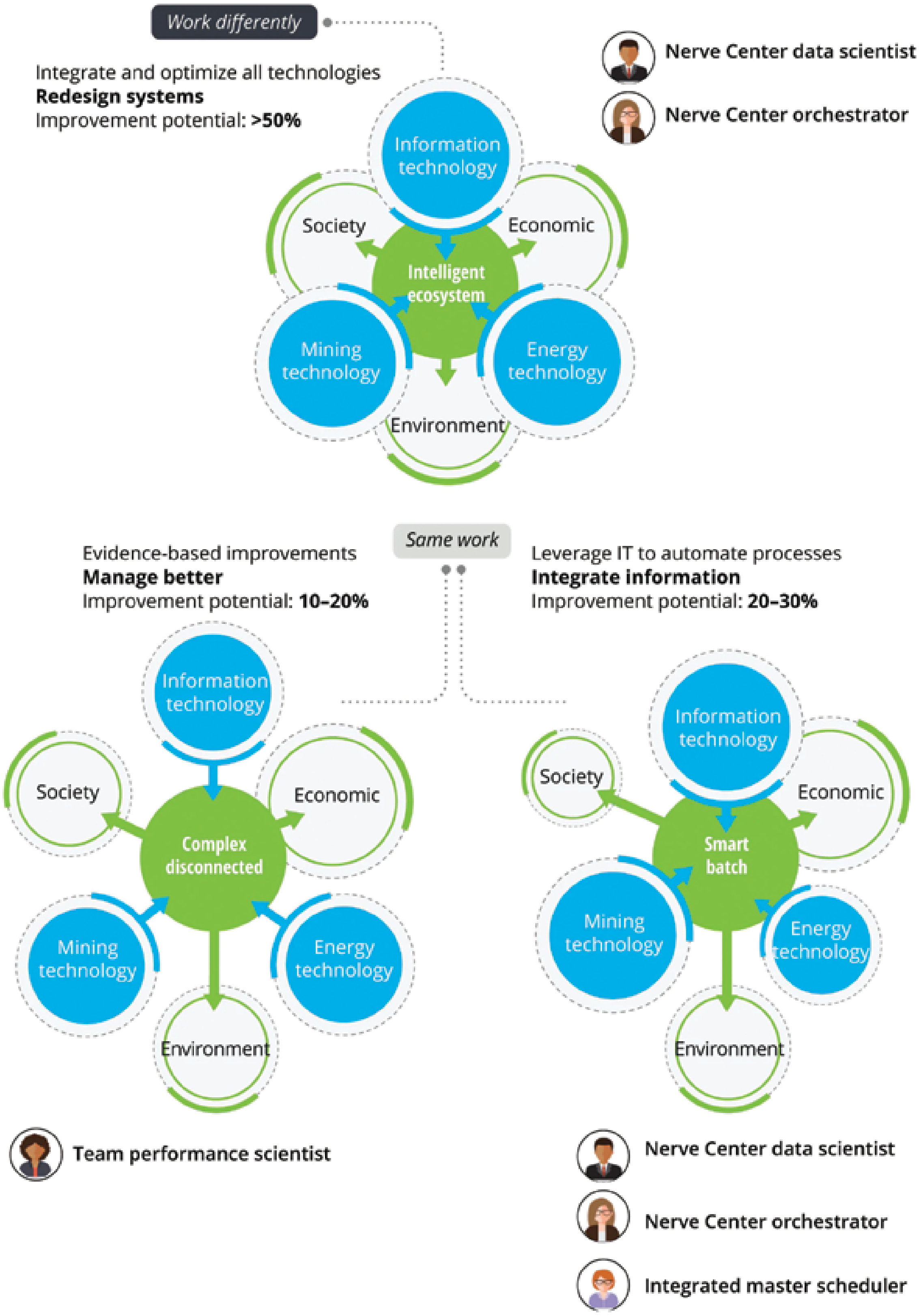
Recently, the global pandemic resulting from the novel COVID-19 virus has seen organizations around the globe change how and where work gets done in an effort to curb the spread of the virus. Energy, resources, and industrial companies are among those facing the biggest constraints in offering flexible working and remote solutions. Some operations have, however, rapidly executed secondary control rooms, equipped with the relevant hardware and network capabilities to allow seamless handover between shifts in two separate locations. Some others have executed working-from-home capabilities by creating "dispatch packs" containing laptops and communication tools, enabling workers to operate and maintain control of on-site activities from the safety of their homes. For those performing essential services and therefore unable to work remotely, operations have focused on providing epidemic protection – ensuring sanitation, personal protective equipment, and safety of the workplace environment. Some others – for instance, those working on-site to support power utilities – have halved their operational efficiency to instill social distancing and other health-related measures. Meanwhile, those who have been unable to effectively mitigate the risk have had to shut down during this time.

Nobody knows exactly what the impact of these operational lockdowns will be on the industry, but many are realizing that there is a critical, accelerated need to fundamentally rethink how value is generated and redesign how work gets done. We are now seeing some clients actively revisit technologies such as tele-remote systems, autonomous vehicles, and automation of key areas of their operation. While many of these require significant capital investment at a time when commodity prices have been hit hard, they are weighing this up against the increased flexibility and performance improvement this offers in the midst of a crisis.

Now, more than ever before, an integrated operations center has become critical for any mining organization to provide an integrated single source of the truth built on real-time tracking of operational data across the value chain, enhance decision-making through advanced analytics, enable remote management of resources where feasible, and optimize workforce allocation and utilization, among others.

To help mining clients prepare for this new normal, we have developed personas for roles we deem important in unlocking the value of intelligent mining (**Figure 1**), enabled through Nerve Centers:

- Nerve Centre orchestrator
- Nerve Centre data scientist
- Integrated master scheduler
- Team performance scientist



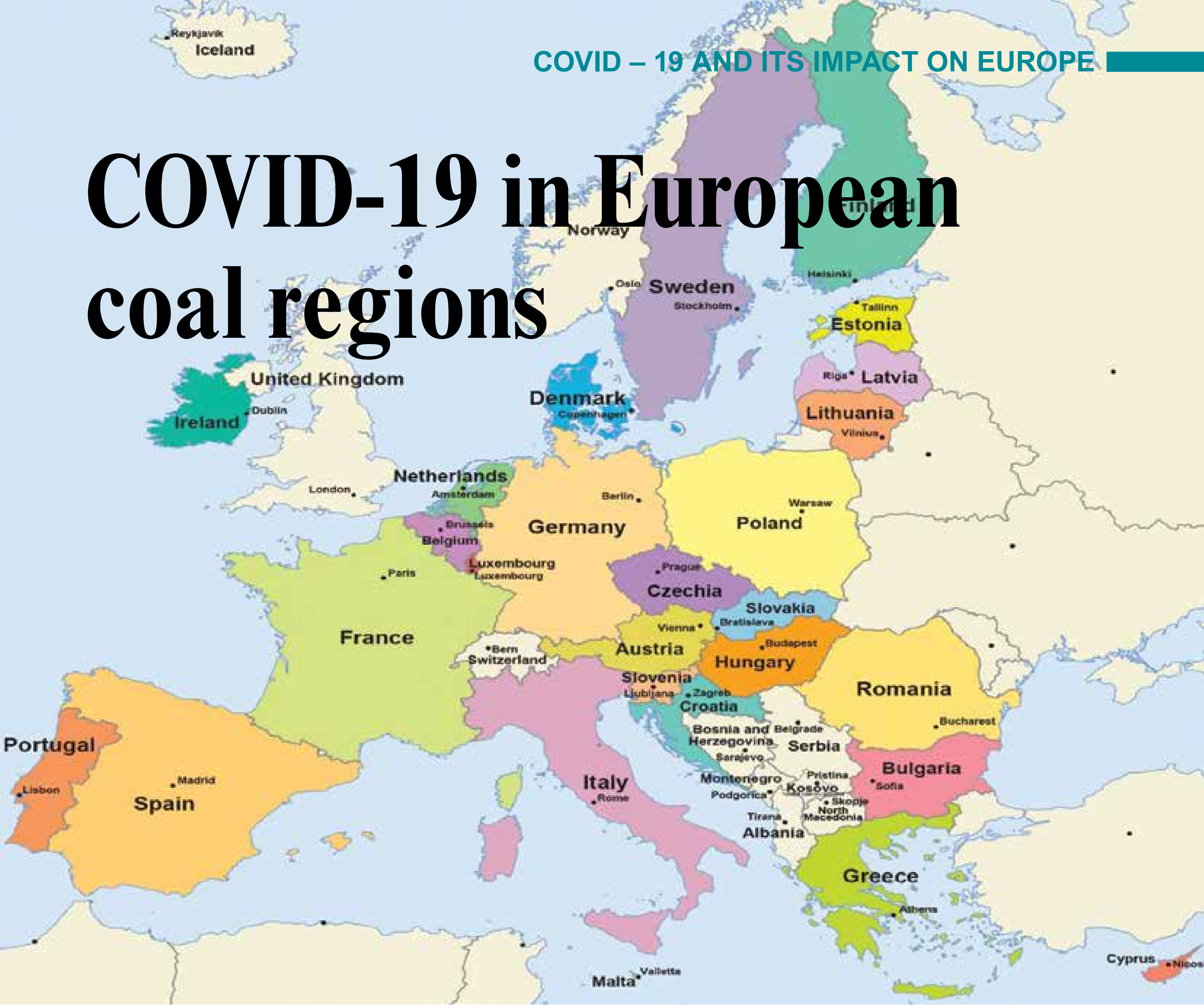
To better understand the roles of the individuals who will be interacting with exponential technologies in an intelligent mine, we explore the following different facets of these personas' profiles:

- Future roles and responsibilities within the Nerve Centre
- Skills needed to achieve new work outcomes
- Relevant digital tools typically associated with intelligent mining and a Nerve Centre
- A glimpse into what a typical day in their lives could look like

One of the hallmarks of these roles of the future is that they'll likely draw on familiar components of work but put them together in new ways to create a job that's never been done before. As mining companies continue to progress towards becoming truly intelligent mining organizations, roles will continue to evolve. Understanding how work needs to change to quickly adapt to unforeseen circumstances and leverage technology to ensure more meaningful and safe work can help the industry transform and overcome disruption.

Deloitte's Tracking the trends 2020 explores the action points

COVID-19 in European coal regions



T he coronavirus (COVID-19) pandemic has created an unprecedented situation affecting all countries, regions, and communities throughout Europe. Measures to limit the spread of the virus have caused an economic downturn followed by a reduction in energy demand, leading to severe impacts on coal power generation and mining activities and the coal and carbon-intensive regions in general.

In this difficult context, the Secretariat of the Platform for Coal Regions in Transition reached out to the affected regions with a brief survey aimed at collecting information and opinions on the main issues, challenges and experiences of Europe's coal regions resulting from the COVID-19 pandemic. The survey was open from 18 May to 7 June 2020.

25 respondents representing 21 coal and carbon-intensive regions in 10 countries1 shared the experience from their regions in this survey. The responses received from the regions offer valuable insights that we wish to share here.

IMPACTS OF THE PANDEMIC ON THE ENERGY AND COAL SECTORS

The introduction of lock-down measures and the consequential slowdown in economic activity all over Europe has reduced energy demand. Regions reliant on coal for their energy thus have seen the demand for coal fall drastically. As power plants reduce their energy output, the entire supply chain linked to the power plants has become exposed to the effects and saw a sometimes-drastic slowdown. The ensuing drop in coal prices further exacerbates the financial struggle of mining companies.

Respondents report on manifold and complex problems in the regions. The pre-existing unfavourable conditions are aggravated by the current events, leading to a combination of effects that are hard to mitigate. Indeed, the ongoing coal-phase out already presents many regions with immense challenges, for example economic diversification, or depopulation, which are now compounded by the impacts of the economic downturn.

While the situation continues to unfold, very concrete impacts on the communities in coal and carbon-intensive regions are already visible. Respondents from at least four regions confirmed that large numbers of workers have been laid-off in the energy sector, temporarily or permanently.

It was repeatedly mentioned that the pandemic not only affects the energy sector but poses a larger risk to the transition. The general economic impact also threatens the diversification efforts. Sectors that form an important part of the regional economy beyond the coal and energy sector are suffering as well. For example, Czech regions observed impacts on the tourism industry, and connected services sectors, which are important pillars of the diversified regional economy.

As off early June, respondents provided the following information on redundancies: Peat industry in the Irish Midlands laid off 200 people temporarily; Karlovy Vary coal mine company announced redundancy of 800-1000 people; Estonian oil share industry has laid off about 100 workers; In a mine in Wielkopolska around 240 layoffs are planned.

On a more positive note, positive impacts were also noted. As smaller quantities of fossil fuels are being burned, emissions have been significantly reduced and air quality improved. In specific cases, this may also help to mitigate some of the financial consequences as energy companies will need to acquire fewer CO2 emission allowances.

MEASURES BY PUBLIC AUTHORITIES AND AT COMPANY LEVEL

The coal and energy sector in a majority of regions were able to draw on the support programmes of the regional and national public authorities. Respondents listed a variety of measures ranging from government subsidies to the energy companies, special loans and new financial instruments, support directly to affected workers, special unemployment subsidies for those who lost their job, to aid to households on energy bills.

In an effort to limit lay-offs, affected companies have reduced working time as a temporary measure in at least six different regions in Poland, Spain, Czechia, Germany, Slovakia. This reduction has been accompanied by lower wages, thus easing the financial pressure on the affected companies. In several cases, such as in Polish regions, trade unions and company management have come together to successfully work out these agreements. Public administrations in affected regions may follow suit. In Upper Nitra (Slovakia) for instance, the municipal administrations have equally reduced worktime and adapted salaries for their staff.

While these such measures may have managed to reduce mass layoffs in some cases, at least seven respondents reported that collective redundancies had already been announced in response to the reduced activity levels. Among the affected regions are Upper Silesia, Upper Nitra, Wielkopolska, Karlovy Vary, as well as the peat and shale oil operations in the Irish Midlands and Estonia, respectively.

Meanwhile, many respondents highlight that a slew of measures have been introduced to ensure the health and safety of the employees. These include mandatory wearing of face masks, working from home where possible, large scale testing of workers where possible. The later measure concern primarily the Polish regions where the mines have become a hotspot for COVID-19.

In the Czech case, the energy and coal sectors and their supply chains have been considered critical infrastructure to ensure energy security. As a result, specific measures have been implemented. For example, employees of power plants stayed on their jobsites for longer periods, to avoid the risk of infected at home.

DECISIONS RELATING TO THE CLOSURE OF COAL MINES AND COAL POWER PLANTS

Asked whether public authorities or companies in the coal supply chain announced any decisions relating to the closure of coal mining activities or coal power plants, regions have diverging answers.

Four regions confirmed their intention of closing specific mining sites and plants earlier than was initially planned before the pandemic. Among them are Czech regions, Asturias, Aragon, and Silesia.

Most notable is the large-scale temporary shut-down of Polish coal mines. Recently, Poland announced that 12 of its coal mines will be closed for at least three weeks until the end of June. While closures in some regions have been motivated by the economic downturn, the latest decision of temporary closures in Poland is mostly driven by an effort to contain the spread of the pandemic. In fact, the coal mines have become a major hotspot for coronavirus infections. Silesia has registered more than a third of all COVID-19 cases identified in Poland.

On the other hand, authorities, and companies in Karlovy Vary, Western Macedonia, and West Virginia (US) consider postponing any potential closures of mining activities to avoid layoffs in the middle of the economic downturn and thus mitigate the impacts on the region.

Nonetheless, many regional representatives mentioned that no major decisions regarding the plans for coal mines and power plants had been made at this stage. Neither is the long-term fate of sites that have been closed temporarily known.

SUGGESTIONS OF GOOD PRACTICES OF MEASURES TAKEN IN RESPONSE TO THE PANDEMIC

It may be too early to assess with certainty which measures are effective in limiting the spread of virus and mitigating the economic and social shock experiences by the coal regions. Several respondents pointed out an evaluation in the medium term will be necessary to assess which measures that worked well. Nonetheless several suggestions have already been made by the regional representatives.

Generally, regions agreed on the importance of implementing adequate health and safety measures, such as wearing face masks and social distancing.

Meanwhile, the examples of close collaboration between all involved stakeholders to get to an agreement that may mitigate the effects of the pandemic on the affected communities in coal regions could serve to inspire other regions. A direct information line and involvement of all stakeholders has helped multiple regions, such as Brandenburg, implement the shut-down measures effectively.

Further ideas include the creation of a facility to provide remote psychological assistance, such as was set up in Silesia. Another inspiration comes from Asturias, where a former coal mine and its facilities are used for the storage of medicine and medical equipment. Meanwhile, a reskilling programme in the Appalachian region has adjusted its focus towards addressing urgent needs of the community, such as making masks, hospital beds and focussing on production and agriculture. In the Ruhr region, the rehabilitation and greening of former mining sites provided a useful asset in the context of the pandemic where citizens are restricted to their local environment.

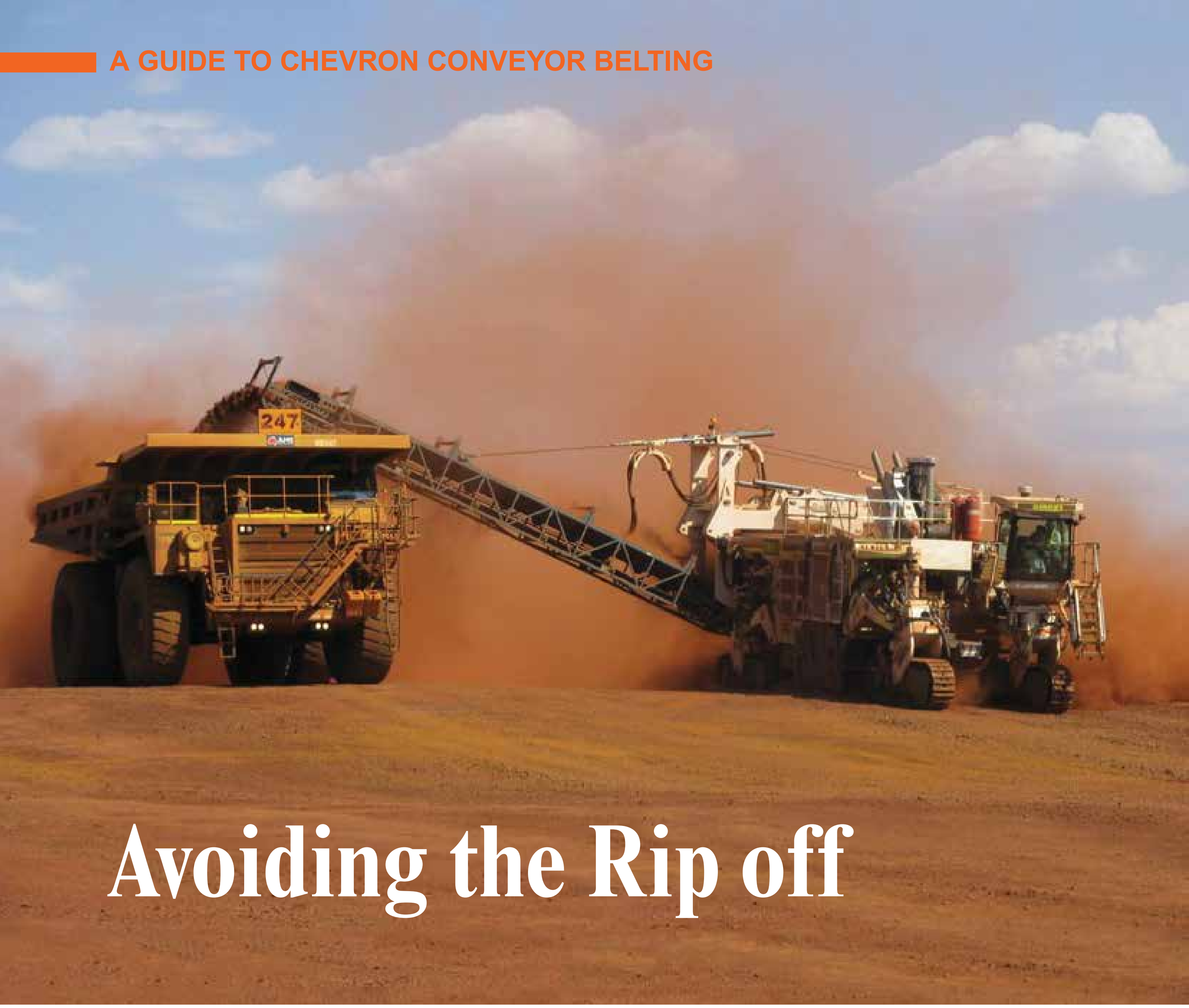
SUGGESTIONS FOR TOPICS FOR FUTURE MEETINGS AND ACTIVITIES OF THE PLATFORM

Respondents expressed a keen interest in exchanging views on how the pandemic and the ensuing economic slowdown impacted the different coal regions. Participants are interested in learning more about how each region is responding to the challenges, and what measures, tools and funds can be deployed.

Furthermore, the Platform participants are keen to learn more about the measures to be taken at European level to address the challenges in the regions. Unsurprisingly, the plans for the European economic recovery and access to emergency funding, the role of the Green Deal and the Just Transition Mechanism remain the most requested topics for the upcoming meetings.

Several more related questions could be discussed by the Platform: Regions suggested many more topics to be discussed by the Platform: achieving a sustainable economic diversification; resilience towards future shocks; securing energy supply across borders in Europe; Digitalisation of mining regions and the energy sector; exchange of best practice projects; rebuilding the competitiveness of the regions.

The Platform for coal regions in transition is an initiative by the European Commission. ec.europa.eu/coal-regions-in-transition secretariat@coalregions.eu twitter @Energy4Europe Credits © European Union, 2020



Avoiding the Rip off

Chevron profile conveyor belts are a key component on a huge variety of mobile plant and equipment. Despite the important function they fulfil, relatively little is known about them technically. As a consequence, even less is understood as to why some chevron belts are so much more efficient and less troublesome than others. Here, conveyor belt specialist Leslie David explains the different production methods, how they ultimately affect reliability and how to avoid literally being ripped off.

GETTING TO GRIPS

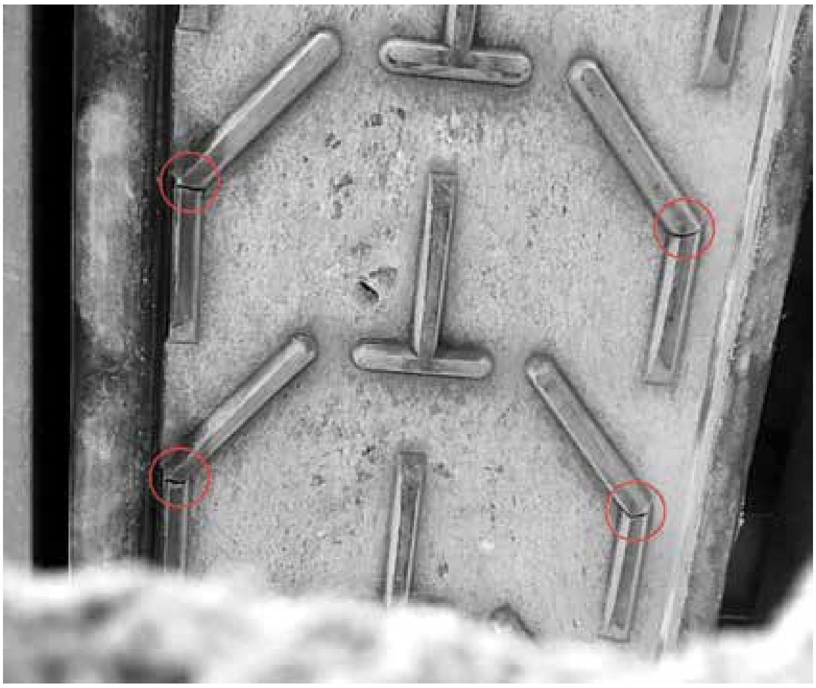
Excluding belts that have cleats fitted to them, there are essentially two types of profiled rubber conveyor belt. The most commonly used are those with chevron-patterned profiles ranging from 15mm up to 32mm in height above the belt surface. The chevrons guide and control the flow of loose materials such as sand or small size aggregates for example. The second most common type are belts with low profiles that are usually no more than 5mm.

One of the most common problems experienced by many operators affects high chevron belting because the chevron profiles can become partly detached or ripped off entirely.

With both high and low profile belts another common problem is that the profiles themselves wear down within an unacceptably short period of time. The origins of these problems are both to be found within the manufacturing processes and the rubber compounds that are used.

CONVENTIONALLY PRODUCED CHEVRON BELTING – THE ACHILLES HEEL

Because of its adaptability, most of the rubber used to make modern-day conveyor belting is synthetic. Because of the technical difficulties (and higher cost) involved in creating a synthetic rubber compound that will flow uniformly, the vast majority of chevron profile belts are effectively created using a two-stage vulcanisation process. Firstly, a belt carcass consisting of layers of fabric reinforcing ply and covered by a layer of uncured rubber compound on the top and bottom surfaces is placed in a vulcanisation press. At the same time, a mould plate is filled with uncured rubber and the base structure is then placed on top of the filled



A common problem – profiles that split and eventually detach from the base belt.

mould. Alternatively, the mould plate is extracted, filled with uncured rubber and then replaced back under the base structure. In both cases, the complete structure is then vulcanised to create the finished belt.

The key issue here is that the uncured rubber compound used to construct the base belt structure cannot be the same as the compound used to fill the moulds. This is because the rubber used in the moulds to create the actual chevron profiles has to be more malleable than the rubber used on the top and bottom cover surfaces so that it can completely fill the mould cavity.

However, this directly creates the 'Achilles heel' of all chevron belts made in this way. This is because the contact point where the two different rubber compounds join then becomes a point of weakness. The chevron profiles constantly stretch and flex under tension each time they run around a pulley or drum.

Constant flexing can cause dynamic stress fractures in conventionally produced chevron belts.

Unless the bond between the base belt carcass and the chevron profile is absolutely flawless then sooner or later dynamic stress fractures in the profile will start to occur, causing the profile to split. Especially on belts conveying hard, heavy lumps of material, the constant impact weakens the joint between the base belt and the chevron. Either way, eventually the chevron will part company with the rest of the belt.

The problem is significantly magnified on conveyors with relatively small pulley diameters, especially mobile equipment. The smaller the pulley then the higher the dynamic stress. Failure will happen even sooner if one (or both) of the rubber compounds used are not fully resistant (as per ISO 1431 testing) to the effects of degradation (surface cracking) created by chemical reactions in the rubber caused by ground level ozone and ultra violet light.

RAPID WEAR

Having to use a rubber that is sufficiently malleable (pliable) so that it will fill the mould cavities and accept the dynamical strains of belt operation often creates a second major 'belt life-threatening' weakness.

Chevrons as high as 25mm or 32mm can wear almost completely flat in a remarkably short time.

Research and experience has shown that the rubber used to make the chevrons in the conventional two-step production process almost invariably has much lower resistance to abrasive wear than would normally be acceptable. It is not unusual, especially among so-called 'economy' belts imported from Asia, that even chevrons as high as 25mm or 32mm can wear almost completely flat in a remarkably short time.

A ‘single structure’ chevron belt needs a highly specialised rubber.

The mould plate used to make a ‘Single homogenous structure‘ chevron belt.

MAKE IT ONCE, MAKE IT STRONG

The fact of the matter is that there is only one way to avoid the inherent weaknesses created by the conventional manufacturing methods that I have just described. Firstly it requires the use of a single rubber compound that has been specially engineered for both the base belt structure AND the chevrons. Secondly, it is essential that the belt is produced as a single, wholly homogenous structure. This can only be achieved using a one-step production process rather than the more conventional two-step process. In other words, making the belt once makes it considerably stronger. The inescapable truth is that a homogenous structure, even if damaged or split, is simply much stronger and more resilient against spreading damage or having profiles shear off completely when two non-identical materials (compounds) are bonded together.

That may sound straightforward to achieve but it is a surprisingly tall order. Firstly, it is extremely difficult (and more costly) to create such a versatile rubber compound. This is largely due to the huge number of different chemicals, polymers and additives that are used to create the synthetic rubber. All of the various components have to be very precisely balanced and mixed so that the final compound possesses all the necessary physical properties.

These properties include wear resistance, tensile strength and durability while at the same time also being sufficiently malleable to allow the rubber to flow smoothly and evenly into the moulds. The rubber then needs to be able to vulcanise virtually simultaneously within the mould AND the base belt structure. Not only that, the compound also needs to be fully resistant to the effects of ozone and ultra violet light (for longevity of working life) and conform to European REACH regulations so that the end product is also safe to handle.

‘SINGLE HOMOGENOUS STRUCTURE‘ CHEVRON BELTING – HOW DO THEY DO IT?

To create a single homogenous structure the base belt (at this stage comprising of only uncured rubber) is placed in the vulcanising press between the base plate of the press and a chevron mould plate positioned immediately below it. The base belt will already also have a specific quantity of uncured rubber on the top cover surface in addition to the volume of rubber needed to achieve the minimum thickness of the top cover of the base belt once it has been vulcanised. The actual amount of ‘extra’ rubber needed depends on the design and depth of the chevron pattern. The compression of the upper and lower plates then forces the additional rubber to flow into and fill the mould cavities. Vulcanisation of both the

Chevron belts with a single homogenous structure are stronger and longer-lasting by far.

base belt structure and the rubber-filled moulds then takes place simultaneously to form a single homogenous unit.

Bearing in mind the technical complexity and the higher costs involved, perhaps it is not surprising that apart from Dunlop Conveyor Belting, hardly any other manufacturer of note produces profiled chevron belt in this way. However, the significantly superior strength, reliability and much longer working life that is created by chevron belting being made in this way makes it not only worth the effort but also worth the investment.

HOW WILL I KNOW?

Even when armed with this understanding of the huge difference in strength and overall durability between chevron belts made using the conventional 'two-step' process and the 'single homogenous structure', the dilemma then is how to establish which kind is being offered by the manufacturer/supplier who is providing the quotation. Unfortunately, the only way to find out is to ask the would-be supplier and then hope that the salesperson you are speaking to actually does know the difference!

KEEPING A LOW PROFILE

'High' profile chevron belts are available in a variety of different heights, mostly 16mm, 25mm and 32mm. Some manufacturers only make the 25mm version. However, there are several belts on the market that have profile patterns that are little more than 5mm high and sometimes even less. Belting of this kind is mostly used for the transportation of packaged goods such as boxes, bags and baggage as well as bulk materials including agricultural products, oily materials, woodchips and wet sand and can successfully be used on inclines as steep as 30° in some cases.

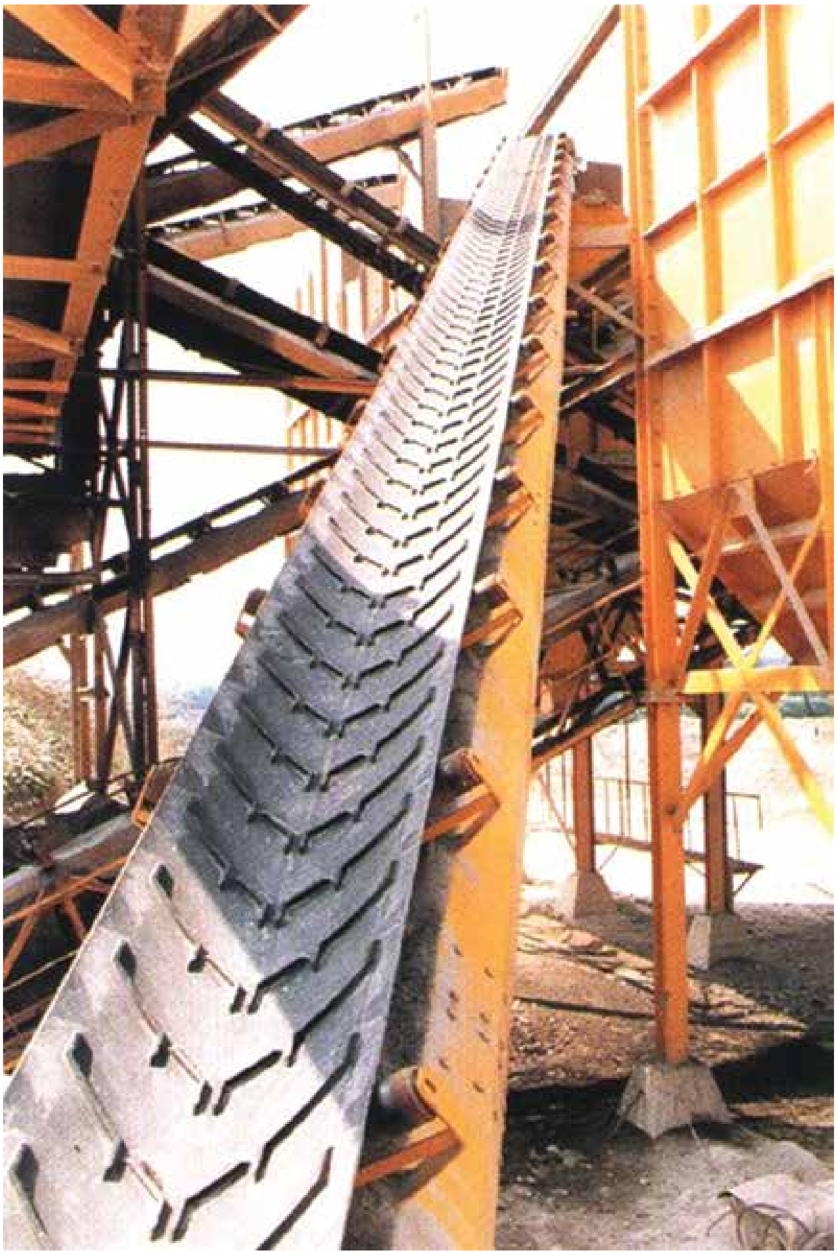
Unlike their chevron counterparts, making single, homogenous structures is relatively easy to achieve with low profiles because the rubber only has to flow a small amount compared to high chevron profiles. Yet again, the key influencer as far as performance and value is concerned is the quality of the rubber. In this case it is ability of the rubber to resist wear (abrasion) and to resist the effects of ozone & ultra violet that are the most crucial. As far as European-based quality led manufacturers like Dunlop are concerned, achieving working lifetimes as long as five years is more than possible.

DON'T BE FOOLED

When it comes to profiled belting, appearances can be very deceptive. One belt may look virtually identical to another belt and the basic specifications such as tensile strength and number of plies may also be identical. Therefore, expecting that the actual performance and working lifetime

Still going strong – a five-year old Dunlop Multiprof belt in action.

Splitting the difference in price and quality.



will be roughly the same would seem to be a reasonable assumption. However, the alarm bells should start to ring if there is a significant difference in the asking price. Actually, there is a very good reason why one belt can have a dramatically lower price compared to one of a seemingly identical specification, and that reason is very easy to explain. Ultimately, the difference in price will come down to the quality of the rubber, and it is the quality of the rubber that will have the biggest bearing on performance and the cost-effectiveness of the end product.

The rubber used for conveyor belts usually constitutes at least 70% of the material mass and therefore it is the single biggest element of cost when manufacturing a conveyor belt. Consequently, in the highly price-competitive conveyor belt market, for those who want to compete for orders based on price rather than performance and operational longevity, it becomes the single biggest opportunity for manufacturers to minimise costs. In fairness, the market for OEM's of mobile plant equipment is also very competitive. This often means that any desire to pay a higher price for a higher quality, more durable conveyor belt is set aside in the effort to keep the selling price of their machines as competitive as possible.

The harsh reality is that conveyor belts used on mobile equipment are viewed by a great many as readily disposable components that are not a reflection of the reliability of the machine itself, even though the need to regular repair and replace worn and damaged belts is expensive both in terms of lost productivity and day-to-day running costs. A cynic might also say that for some manufacturers, belt suppliers and engineers, regularly replacing belts is a highly lucrative business that would not be nearly so profitable if the belts were a lot more durable and lasted a lot longer. Fortunately, for the higher-quality belt manufacturers, not everyone thinks that way.

THE SLIPPERY SLOPE

The two most common methods used to keep rubber costs to an absolute minimum are the use of recycled rubber (usually of highly questionable origin) and the use of cheap 'bulking' fillers such as chalk to replace part of the rubber polymers in the rubber compound. Another practice is the burning of used rubber car tyres to create a cheap form of carbon black. Some 20% of rubber compound is made up of carbon black so it has a notable impact on the overall cost of making a conveyor belt. Good quality carbon black is created by a process of burning oil in a strictly controlled, low oxygen environment so that combustion is incomplete. But burning used car tyres not only pollutes the atmosphere it also means that any oils and greases contained within 'regenerated' materials compared to good quality carbon black will have a detrimental effect on the physical properties of the rubber.

KEY MESSAGES

Making profiled belts that do what they need to do and, arguably most importantly of all, give the best return on investment by providing the longest possible working life, is something very few belt manufacturers can achieve. Fortunately, although they are a very rare breed indeed, there are at least one or two still out there that continue to prove that chevron belts that are genuinely durable and last much longer than the 'cheap' imitations cost appreciably less and are much less hassle in the long run.

Leslie David

After spending 23 years in logistics management, Leslie David has specialised in conveyor belting for over 14 years. During that time, he has become one of the most published authors on conveyor belt technology in Europe.

Service 4.0 – on site, without being there

The service technician has all important information displayed in the live image of the camera via the BEUMER Smart Glasses.

Machine malfunctions and standstills that are not eliminated as fast as possible may become expensive for manufacturing companies. BEUMER Group developed the BEUMER Smart Glasses as a pioneering product that supports users quickly and easily. The BEUMER Customer Support technicians use them to take a virtual look over the shoulder of the customer's service technician to solve the problem together. This digital solution reduces travel times and costs.

With the BEUMER Smart Glasses, our customers can get in live contact with our service experts anywhere and at any time," promises Christopher Kirsch, team leader of BG.evolution. With this spin-off at the university location of Dortmund, the company brings digital innovation from outside into the company. In other words: "We are working on a customer problem with the support of start-ups to develop 'Minimum Viable Products'. These are minimally equipped prototypes whose market potential and customer acceptance we put to the acid test," explains Kirsch. This makes it easier for the BEUMER Group to decide quickly whether a new technology makes sense to develop into a finished product – such as the BEUMER Smart Glasses.

Together with their colleagues from BEUMER Customer Support and the Department for Research and Development in Beckum, the employees in Dortmund made this digital solution ready for the market. "From October 2018 to January 2019, long-term tests were carried out with various customers, including one with live testing with a long-term customer from the building materials industry. We were successful in concluding this phase," reports Kirsch. The user has been using a high-capacity palletiser BEUMER paletpac and a high-capacity packaging system BEUMER stretch hood for years.

REDUCE IDLE TIMES BY LOOKING OVER THE SHOULDER

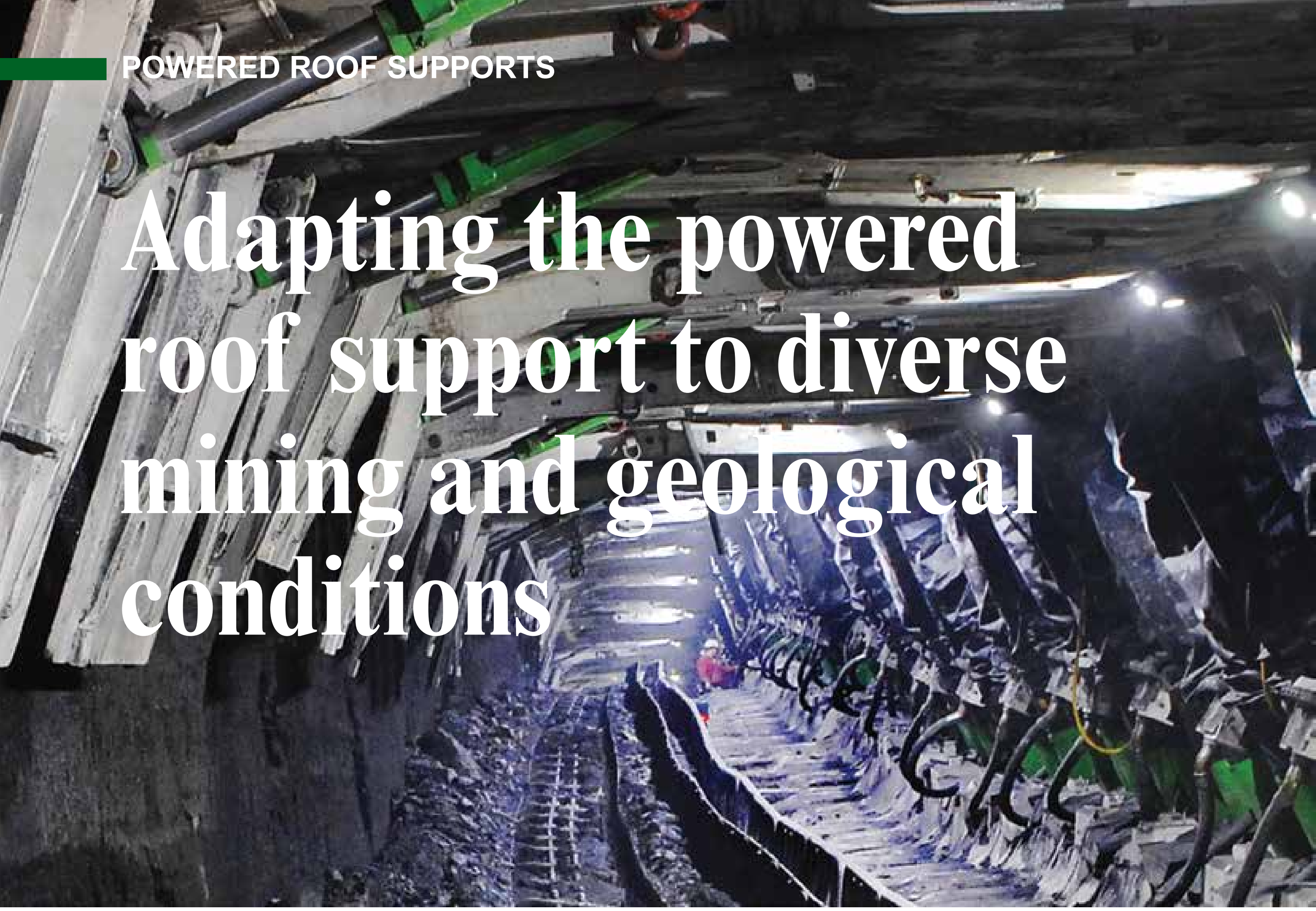
If there is a problem during operation, this may easily result in production bottlenecks. In the worst case, this results in delays of day-to-day operations. "If a machine suddenly breaks down, the problem must be solved as fast as possible," says Kirsch. This is the only way for the users to save time and money. If the users are not in a position to handle this by themselves, the BEUMER Group sends their globally located technicians to prevent longer downtimes. In addition to service technicians, Customer Support also provides qualified telephone support for trouble shooting, which is available 24/7. However, it can be challenging to successfully communicate complex problems quickly and clearly over the phone. Imagine if the customer had the opportunity to have a BEUMER technician take a quick and easy look at the problem at any time – on-site support, without actually being there. The BEUMER Smart Glasses make it possible.

JUST PUT THEM ON AND GET STARTED

The employee at the machine puts on the glasses and starts the BEUMER Support app via voice command. The employee transmits a service number and a pin code to the hotline, and the connection with image and sound is established. The BEUMER technician receives the same image as the customer. The technician can directly give instructions and display all relevant information in the field of vision. The employee has both hands free to follow the instructions of the expert and carry out the necessary actions. Faults can be solved quickly and precisely – at any time. The BEUMER experts are available around the clock, seven days a week. "Language barriers or the lack of specialised knowledge are no longer relevant for trouble shooting," explains Kirsch. "Together with the user, we can also better validate why the fault occurred based on the recorded images."

"As part of the comprehensive BEUMER Customer Support, users add the BEUMER Smart Glasses as an extension to their monthly or annual hotline service agreement. Together with BG.evolution, the BEUMER Group is currently developing further digital products under the umbrella of "Smart Solutions". "Many of our customers are already showing clear interest in the BEUMER Smart Glasses," Christopher Kirsch stated.

Providing the right environment: At BG.evolution in Dortmund, BEUMER colleagues are working on a customer problem and develop so-called minimum viable products, prototypes that feature minimum equipment, and check, if applicable, their market potential up to marketability.



Adapting the powered roof support to diverse mining and geological conditions

A powered roof support is one of the most important pieces of equipment of a longwall system. Its basic task is to ensure the safety and continuity of the mining process. The conditions of coal mining process are constantly changing and have significantly deteriorated in recent years, which in turn has also resulted in a significant increase in the requirements for mining support. As a result, it is necessary to develop an appropriate methodology that will facilitate the design and testing process of a power roof support as well as will help to select a roof support adjusted to given conditions. This article presents such a methodology. It is based on forecasted load impacting on a roof support, tests covering selected systems and elements of the section as well as legal conditions regarding the admission of the roof support to operation. This idea was developed in the form of a procedure that, by combining the three areas, should support the decision-making process in the case of different underground conditions. In terms of the expected load impacting on the support, the research team identified the most dangerous phenomena occurring in the rock mass that can generate these loads. Stand tests included impact load and permanent clamping of an excavation. The element that significantly impacts the safety of the support operation is a hydraulic leg, and therefore it was tested together with the safety system and the control system. Model tests were also carried out for the system with a safety valve. The developed concept takes into account legal conditions, which should include test results and different support operating conditions in a more flexible way. The main purpose of the work was to develop a comprehensive methodology for testing and assessing the possibility of using a powered roof support for given mining and geological conditions based on an analysis of safety and control systems. The presented approach is undoubtedly new and original, and can be widely used. It enables better adaptation of the support to given conditions. It also fits the research and activities designed to minimize the presence of miners or service workers in hazardous underground exploitation zones and to improve efficiency and boost sustainable development of the mining industry.

INTRODUCTION

The global economy remains subject to ongoing structural changes but it is still based on fossil raw materials. In particular, this applies to the energy sector. Changes in this market are mainly related to environmental protection and have resulted in the dynamic development of unconventional energy sources[1,2]. The amount of energy obtained from these sources, however, is not sufficient to cover the huge and constantly growing overall demand for energy. This in turn means that in many countries' energy is still produced from conventional energy sources, including hard coal. The most popular way of obtaining this raw material, due to its retention, is underground mining.

Strong competition on the energy raw materials market causes that mining companies strive to reduce production costs. One way to achieve this is to constantly increase the efficiency of machines such as high-performance longwall systems. Longwall shearers and plow system mine the rock mass. The output is transported by scraper and belt

Figure 1: Machines included in the longwall complex: (a) shearer and scraper conveyor in a longwall; (b) powered roof support and conveyor in a longwall.

conveyors[3-6]. The roof support controls key functions in the longwall complex such as securing the roof which is the working space in the longwall and moves the entire complex along with the progress of exploitation[7-10]. An active longwall and the machines of the longwall complex are presented in **Figure 1**.

The powered roof support secures the longwall excavation against deformation caused by the rock mass. At the same time, this type of impact is also generated by the floor and roof as well as by the cave-in area. The biggest threat to the support is generated by the roof in which the stress resulting from the imbalance in the rock mass is most often concentrated. The disturbance of this balance caused by mining activity results in various types of loads acting on the support.

The geological and mining conditions of the coal production process constantly change. Consequently, loads impacting on the roof support have different values, directions and nature (static, dynamic, quasi-static). This diversity means that the construction and technical parameters of the support must be properly selected so as to ensure full functionality necessary for the operation process. This, in turn, means that a wide range of scientific work should be focused on improving and, above all, adapting to changing conditions. The powered roof support consists of individual but cooperating sections (**Figure 1**). Each element impacts on the remaining components. Therefore, tests should include all sub-assemblies and elements of the section.

The main sub-assemblies of the section that determine its operating parameters are hydraulic cylinders, and the entire system of hydraulic supply and control. The powered roof support is a hydraulic machine, powered by high pressure, whose energy carrier is oil and water concentrate. Spragging of the support section of the powered support for the required height of the excavation and its support is conducted by hydraulic legs. They constitute a structural connection of the canopy and floor base. It can be assumed that the hydraulic legs, as the main executive elements of the support section, transfer external loads impacting on the support. At the same time, these legs are most vulnerable to damage and destruction due to the deformation effect of the rock mass. To prevent it, the leg's hydraulic feed system is protected by a safety valve. The purpose of the safety valve is to prevent the hydraulic pressure in the leg's cylinder from exceeding the allowable value.

The projected load (dynamic or static) determines the choice of type and parameters of the safety valve (response time, efficiency). It is also essential to determine the working pressure at which the safety valve will properly operate. This value is selected depending on the section design and mining and geological conditions prevailing in a given area. These conditions cannot be fully predicted due to the fact that the depth of exploitation of coal seams constantly increase. Greater depths are associated with an accumulation of various hazards and the impact previously conducted mining activities is visible. Consequently, there is a number of additional threats and hazards that occur during the coal mining process. These are mainly methane[11-14] and fire[15,16] hazards, very strongly dependent on the physical parameters of the goafs[17-19], which also act on the support. Above all, the most dangerous is the deformation effect of the rock mass which can generate various types of loads impacting on the support.

All these factors mean that the work parameters of the legs and entire sections must be adapted to such load conditions. A system that is not properly adjusted may cause a threat to the safety of miners and disruption of the operation process. This can be prevented by developing comprehensive methodology for testing the entire section and its most important components and sub-assemblies in terms of their adaptation to various load conditions to which they may be subjected during operation.

While developing this methodology, it was assumed that it would be based on three basic pillars. The first will include the analysis of phenomena that may occur in the rock mass in which the support will work and the resulting types of loads that may affect it. The second pillar includes a set of testable key systems and components, and support section components under these loads. In this case, the selection of appropriate methods and the best possible mapping during their implementation of the actual state of load is crucial. The third pillar refers to legal conditions that govern the selection and admission of the support to work in given conditions. Appropriate and quick adaptation of directives, standards, and other regulations to dynamically changing conditions in which the system operates is of key importance.

The analysis of the literature in the field of testing and selection of a powered support and the impact of the rock mass on a support is very wide and diverse, and includes various aspects related to the use of mining support in longwall excavations[20-29]. Available papers refer to individual aspects of operation, but do not include a comprehensive assessment of these conditions and a method that would define the means to adapt the system. Legal conditions that have a significant impact on the practical application of research results are also not included. It can therefore be assumed that this paper is the first presenting an attempt to combine many factors impacting on the selection of a powered roof support.

This paper presents the concepts of the test procedure and the adaptation of the powered support to various mining and geological conditions. The main purpose of the work is to develop a comprehensive methodology based on research and practical experience. The data on mining and geological conditions in a given area helps to properly select a system.

The research team made an attempt to determine the potential loads that a support may be subjected to during operation by conducting an analysis of the phenomena occurring in the rock mass and their consequences. It was used to identify the most dangerous loads the support may be exposed to.

The obtained results were used as a basis for stands tests of hydraulic legs and the remaining equipment. The tests included dynamic impact loading in the form of free-falling mass and constant displacement. The tests included safety valves and the entire hydraulic system. The model tests included the hydraulic system of the leg with particular regard to the connections of safety valves. Model tests supplement costly bench test machines that require highly specialized equipment. They also provide new data in the field of flows and related speed and pressure distributions in these systems. The research area, located in the second pillar of the developed concept, was also supplemented with tests of the support's control system.

The purpose of the research is to develop a new system for remote control of powered support sections. The use of such a system will allow control of the support from outside the longwall excavation, e.g., from a bottom gate. This, in turn, should significantly improve the safety of work in the area of direct exploitation. A special virtual system was developed to test these systems. The results of the tests carried out using this system are presented in the paper.

The third pillar, included in the presented concept, as already mentioned, refers to legal conditions regarding mining supports. The paper discusses only the essential legal acts in this field. These acts must also be considered when deciding whether a given support is suitable for underground operation.

The concept presented in the work, together with the results of specific research included in it, undoubtedly represents a new approach to research aimed at adapting powered roof supports to mining and geological conditions.

Therefore, one of the objectives is to answer the question of whether, based on the current state of knowledge, we are able to develop an effective method to select a powered roof support that will function properly in given changing mining and geological conditions. It is also important to determine the best methods and tools. It seems that this can be achieved with the use of the presented concept, including issues related to rock mechanics, fluid mechanics, mechanical engineering, computer science and control, as well as modelling, bench tests, and tests conducted in real conditions.

The presented method of research implementation, closely related to real phenomena occurring in the rock mass, constitute a new approach to testing sub-assemblies of the roof support section. It also includes a broader view of the problem of adapting roof supports to the conditions in which they will work.

Previous studies concerning roof supports did not cover such a comprehensive approach to this issue, including legal conditions. Practice shows that these conditions are very important and should take into account new research results and user's opinions. So far, the tests have included the most essential aspects but they are focused mainly on individual problems[20-25]. They do not include such a comprehensive approach as presented in this paper.

The paper discusses the individual pillars of the developed concept for adapting support to diverse mining and geological conditions, along with examples of research that has been carried out in individual areas.

It should also be emphasized that the presented concept is open and can be freely modified depending on the needs and expectations. It should also be emphasized that the material presented in the paper extends the existing knowledge in the field of testing roof supports, and is the result of existing operational problems that their users have with the roof supports.

The authors hope that this study will be an important part of the discussion on methods of testing and using the roof support as well as support the process of admitting roof supports into underground workings. It will also stimulate appropriate bodies to reflect on legal conditions regarding the design, selection and operation of roof supports. The main objective of all conducted activities, the results of which are presented in the paper, is to improve occupational safety and efficiency of the mining production process. This, in turn, is inextricably linked to the sustainable development of the entire mining industry.

2. PHENOMENA OCCURRING IN THE EXPLOITED ROCK MASS AND THEIR EFFECTS ON THE SUPPORT

The external conditions in which the powered support works mainly depend on mining and geological conditions. As mentioned in the introduction, carrying out mining processes in intact rock mass causes its imbalance[30,31] which affects excavation and the support system protecting it.

This impact may have a different character and be the result of various phenomena occurring in the rock mass[5,32-36]. A list of these phenomena and their effects on the support is shown in **Figure 2**.

Phenomena occurring in the rock mass and their sequences are presented below and in **Figure 2**[2,3,10,30,32,34-39].

1. Vibration of rock mass arises as a result of the dynamic impact of the rock mass, and its intensity, and thus the effects depend on the location of the epicentre and the geological structure of the rock centre.
2. Rapid clamping of the excavation is caused by settling of the roof. The size of settlement and its course in time

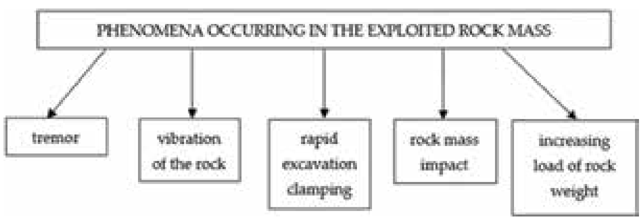


Figure 2: Division of phenomena occurring during mining operations.

varies depending on the type of seam and coal as well as the rate and method of exploitation.

3. Mass impact, a dynamic impact of the rock mass, occurs as a result of cracking of rocks around the excavation. The excavation is weighted with rock mass from deposits located above. The estimation of the mass size and its speed allows determining the energy with which the support is loaded as a result of a tremor.
4. Increasing load of rocks may occur in the case of roofs of very low strength or in which there is complete destruction of rocks. The load on the support during this process depends on the weight of the rock masses.

They are all caused by a violation of the balance in the rock mass due to mining activity.

The general model of the rock mass, disturbed as a result of the executed mining excavation, is presented in **Figure 3**.

This model in a simplified way presents phenomena that occur in the rock mass as a result of mining exploitation. The effect of this exploitation is primarily settling of rock layers lying above the exploited excavation. Settlement of layers leads to the development of deformation processes, which in the case of thick and durable layer, cause tremors. Settlement of thick sandstone layers in the adjacent layers causes them to crack. Consequently, the layers lose physical continuity but maintain geometric continuity thanks to mutual meshing of individual blocks. After exceeding the limit spread, the connected layers lose their load capacity and break down into individual blocks. This phenomenon is accompanied by an increase in the load impacting on the roof support. The course of this load depends on the nature of the phenomenon of crumbling the structure of these layers.

Most often, the course of such phenomena is dynamic. The resulting tremor releases energy that has its source both in the Earth's gravitational field and geotectonic disturbances, as well as the concentration of stress around mining excavations and components of this concentration in the form of critical rock mass exertion. The effects of these tremors obviously impact on the support, however, the effects depend on many factors and can be very different.

They decide whether the rock mass is relaxed, in a state of tremor, or rock burst (phenomena defined by and recognized in the mining industry in Poland). The latter is particularly dangerous as it consists in dynamic relaxation of the rock mass, which results in damage to the support

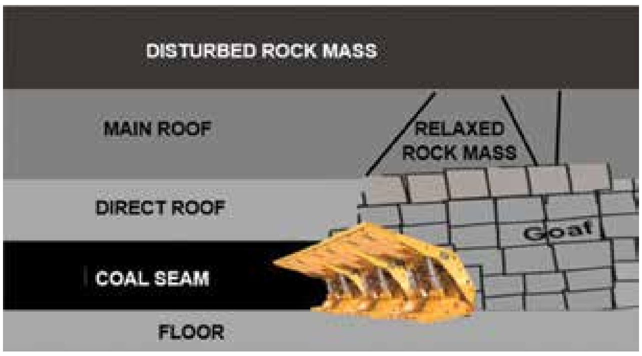


Figure 3: Model of rock mass affected by mining exploitation.

and mining excavations. Unfortunately, as a result of these phenomena, parts of the support section are very often damaged. Hydraulic cylinders and control systems are the elements that are damaged the most often.

Examples of damages in the form of torn cylinders of hydraulic actuators are shown in **Figure 4b**. Damage to the scraper conveyor (**Figure 4b**) and to excavation (**Figure 4a**) were the result of a rock burst that occurred in the area of this excavation.

(a) (b)

Figure 4: Damaged elements of the longwall complex after a rock burst: tilted scraper conveyor press (a) and torn second stage of the hydraulic leg in the powered roof support (b).

This confirms that the loads acting on the mining support are the result of the impact of the rock mass whose stability was disturbed as a result of mining processes. The variety of loads resulting from this state affecting the support and the effects they cause depends on many factors. All mining and geological conditions of a given area must be properly analysed and defined prior to selecting a powered roof support. The results of such tests should be applied when selecting individual section components, particularly the control system and the safety system of the leg.

Preventing damages to legs and their elements and maintaining the functionality of the roof support requires appropriate systems protecting against overloads. It seems that this is currently the most desirable direction of research on the development of powered roof supports. An effective safety system will allow full use of the mechanical capabilities of the support, while protecting it against the effects of overloads resulting from the dynamic impact of the rock mass.

3. TESTS OF THE SAFETY SYSTEM SECURING THE HYDRAULIC LEG OF A POWERED ROOF SUPPORT

Tests for powered supports are carried out for their individual components as well as for entire sections. They include mechanical and hydraulic systems as well as control systems. Tests are conducted in real conditions including test legs and in the form of model tests. There are also various ways of loading the tested elements and sections.

Taking into account the current state of knowledge, practical experience and requirements for powered roof supports, it can be stated that hydraulic legs are essential elements impacting on the level of effectiveness of the system. Proper control system and protection means against overloads creates opportunities to fully utilize the potential of the entire support (including individual sections) and to adapt to mining and geological conditions in which mining is carried out. The role of safety systems is also very important from an economic point of view. It should be emphasized that the powered roof support is the most expensive machine in the powered complex so it must be protected against possible damage and failure.

Taking into account the above considerations, the chapter presents the results of stand tests and model tests of the hydraulic system of the leg, with particular emphasis on the safety and control systems. Stand tests of the leg were carried out with its dynamic load and constant displacement on a fast sliding press.

The most dangerous phenomenon for the safe operation of the support and individual sections is a mining tremor. It lasts about 0.01-0.03 s and causes a short-term increase in the load of the powered roof support section[30,40]. If, as a result of tremors, the excavation or machinery are damaged, this event is classified as a rock burst. Tremors result in a very rapid increase in pressure in the working space of the leg. Damages to the leg caused by such a tremors can be prevented by installing a hydraulic safety valve in the leg. This valve must be resistant to overloads caused by dynamic loads that change over time and have an appropriate flow characteristic $Q = f(p)$. Its operation should prevent the pressure in the leg from rising above the permissible value. In terms of safety of the hydraulic leg at dynamic loads, the valve is crucial as it protects the leg against damage[20,21,41]. An example of the construction of a piston safety valve is shown in **Figure 5**.

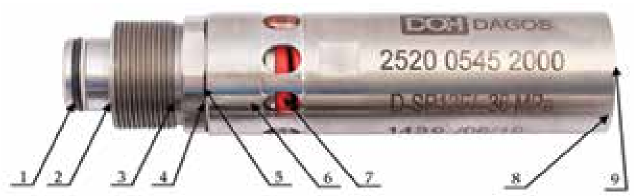
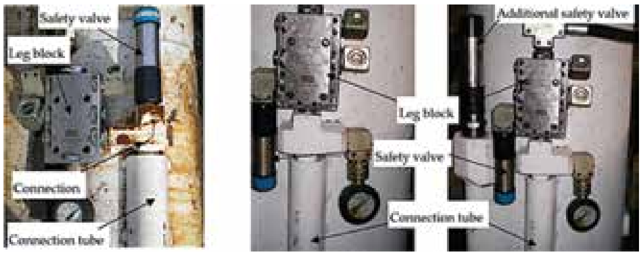


Figure 5: Construction of a piston safety valve with a gasket and spring pressure: 1-round seal, 2-connection stub, 3-round piston seal, 4- piston, 5- piston pressure plate, 6-casing, 7-spring, 8-thrust plate, 9-adjustment screw.

The of the design of this valve indicate that it is a hydraulic valve with a special design that allows opening and closing the flow in a very short time, while maintaining a very high flow. The safety valve is built into the hydraulic system to effectively protect the working space of the leg. It is usually a space under the piston for the first stage of the leg[21,41-43]. Exemplary solutions of systems protecting hydraulic legs with liquid outlet through the safety valve outside the internal hydraulic system are shown in **Figure 6**.

The role of the safety valve and the characteristics of its operation for the operational safety of the hydraulic leg and the entire support section are crucial. The valve and all additional accessories (**Figure 6**) are designed to secure the entire hydraulic system of the powered roof support. The parameters of this valve also have a significant impact on the performance characteristics of individual legs and sections as well as the entire support. Therefore, special attention was paid to the selection and installation of safety valves during the testing of the leg safety system.



(a) (b) (c)

Figure 6: Exemplary solutions of systems protecting hydraulic legs with liquid outlet outside the hydraulic system of the support; with one valve, a universal safety system (a); a system for deformation impact of the rock mass (b); a system protecting against dynamic overload (c).

The hydraulic system and the system protecting the leg against overload are key components of the longwall system. Consequently, they must be thoroughly tested before they can be admitted to operate underground.

The purpose of stand tests is to determine the work characteristics of the leg for different types of load. Such tests should, as far as possible, reflect the real conditions in which the section with the tested leg will work. The research team conducted tests during which dynamic (impulse) load on the support and static load growth were mapped.

3.1. Dynamic Test of the Protection of the Hydraulic Leg

The dynamic tests of the hydraulic leg of the powered roof support along with the safety system were carried out at a drop weight tester[8,23,40]. The leg was impacted with a free-falling impact mass[40,44-47]. The leg was initially expanded in the frame of the tester by loading it with the mass of the traverse. This reflects the static load on the leg in a mine heading, while ensuring its stability during the test. **Figure 7** presents the test stand with its main elements marked.

The tested leg was equipped with a safety valve. Its purpose was to protect its working space against pressure increase caused by mass surges. As mentioned before, the mass load reflects the mass impact of the layers and tremor in actual underground conditions (**Figure 2**). The main factors determining the effectiveness of the leg's safety system are volume of liquid contained in the piston space of the leg, its mechanical properties, cylinder deformability, size and type of a discharge valve, as well as the way it is connected to the hydraulic system.

The course of forces in a dynamically loaded leg[41,45,48] is determined as follows:

Equation 1

$$f(\mathrm{t}) = F_{max} \cdot \sin \omega t$$

where F_{max} is maximum amplitude of force in oscillatory motion (N), t is time (s), $\omega = \sqrt{\frac{k}{m}}$ is frequency of vibrations and k is the elasticity constant of the leg, and m is the mass of the leg, (kg).

The analysis of the relationship (1) indicates that the value of the modulus of elasticity directly affects the frequency of

Figure 7: Drop-weight tester for valve's opening time; 1-impact weight (20,000 kg), 2-impact guiding gear, 3-traverse blocking pin in the station frame, 4-traverse (3300 kg), 5-double-telescopic hydraulic leg, 6-tested safety valve, 7-pressure sensor, 8-height of drop.

vibration of the leg, i.e., the elongation or reduction of the duration of the system response to dynamic load. Reducing the value of the modulus of elasticity results in a reduction of vibration pulsation, i.e., also the time of rise of the load. Reducing the rise time of the load is beneficial due to the work of the discharge (safety) valve connected to the hydraulic system of the leg. Reducing the elasticity also reduces the maximum load value. This means that the liquid contained in the core space, which is an additional absorber of impact energy, increases the leg's resistance to dynamic loads.

The elasticity (k), in addition to the volumetric modulus (B), is influenced by factors such as the cross-sectional area of the liquid column (S_c) and the column height (L_c), as presented below:

Equation 2

$$k = \frac{BS_c}{L_c}$$

where B is volume modulus of elasticity, S_c is cross-sectional area of the liquid column (m^2) and L_c is height of the liquid column (m).

Stand tests were carried out on the leg which had been mounted and operated in a powered roof support in an active underground working. The method of loading the leg was based on loading it with the impact mass falling on the traverse that rested on the leg. The impact energy was determined on the basis of the impact mass and the height of its decrease. The tests were carried out for various impact energies by changing the height of the impact mass decrease. The purpose of the research was to determine the operating characteristics of the leg determining the change in pressure value in the leg's piston space over time.

Figure 8 shows the four phases of the same test during which the safety valve was opened. The impact energy in the present case was 140.0 kJ. The characteristic determined for the tested leg is shown in **Figure 9**. In the presented case a safety valve DN 19 with threaded end (M 45 × 2) was used. The crossbar weighted 3300 kg. The results of similar tests are presented in[47] where the safety valve was attached with a Stecko connector DN 12, and the crossbar weighted 1800 kg. Both tests were carried out at different positions but with similar mass impact energy. Despite the visible similarity of the registered runs, the results obtained (especially in terms of maximum pressure values) are different. In addition, equations defining the trend lines of maximum pressure values recorded in the cylinder of the leg were also determined. The reduction of these values (damping process) most accurately describes the exponential equation, which is presented in the figure together with the value of the coefficient of determination (R^2).

The results clearly show that the impact energy was high enough to open the safety valve in the leg. Analysis of the obtained characteristics allows to determine the time of this opening and the maximum pressure in the leg in relation to the pressure of the safety valve setting. This, in turn, makes it possible to assess the quality and effectiveness of the valve used. The obtained results also indicate that the mass impact load is of a pulsating nature. Consequently, the leg is loaded several times. Its shortening, due to the occurrence of a slide (due to the outflow of liquid), causes it to become more yielded. This phenomenon is very beneficial. It sets a new state of balance between the rock mass and the support. It can be assumed that a correctly selected and functional safety valve protects the hydraulic system of the leg (and the leg itself) from overloading and improves the cooperation of the support with the rock mass. Therefore, these conclusions fully justify testing of a leg with protective systems under impact loads.

(a) (b) (c) (d)

Figure 8: Phases of the tested leg loaded with mass impact (140.0 kJ); initial impact weight drop (a); the safety valve opens (b); liquid outflow from the leg (c); the safety valve closes (d).

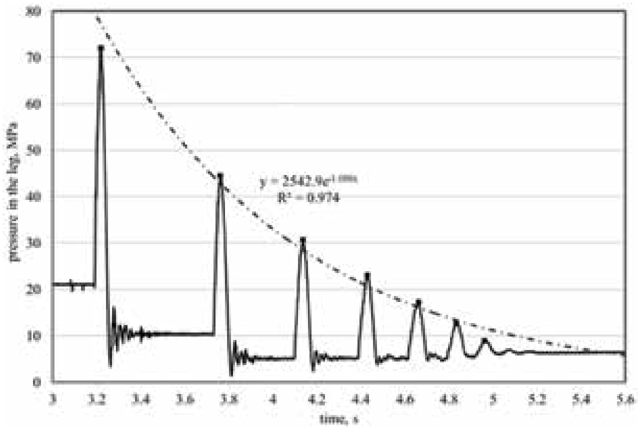


Figure 9: Performance characteristics of the hydraulic leg with a safety system loaded with a free-falling mass dropped from a height of 0.7 m (E = 140.0 kJ).

3.2. Tests of a Hydraulic Leg Loaded with Constant Displacement

A very common way of loading the support, and hence the leg, is the load resulting from the workings being clamped as a result of settling of the roof. The displacement of the roof occurs in this case at a certain speed and most often takes place in a uniform manner. In practice, this increases the pressure on the support and its displacement until it reaches a state of equilibrium. Mapping such a load condition of the support section or leg requires testing on a specialized press that allows clamping (displacement) at a constant speed. Such a machine is also known as a rapid hydraulic press.

The method of loading the leg on this press means that the pressure in the leg increases more slowly than under mass impact loads. In this case, inertial forces are therefore less important. However, exceeding the pressure value at which the safety valve is set causes its opening and outflow of liquid.

In reality, this method of loading can cause very negative effect, including serious damage. If, as a result of sliding (operation of safety valves), the pressure on the section is not reduced, the section may be damaged, and the excavation will lose its functionality. Therefore, the safety valves should be set so as to slow down the rock mass which can sometimes be quite difficult to achieve.

The research team conducted tests using the rapid hydraulic press to determine how the hydraulic leg will behave under this type of load[20,21,49]. The press was designed to carry out different types of tests. Here, the load resulting from the deformation of the roof in the longwall was successfully mapped.

(a) (b) (c)

Figure 10: Stand for tests with the use of a rapid hydraulic press; general view of the stand (a); the tested leg (b); the leg during load (c).

The leg consists of four columns, connected to a traverse, which is guided along these columns. The tests were carried out for a hydraulic leg equipped with a Repair and Manufacturing Facility (RPF) type connection and a pressure relief valve (safety valve), DOH-DAGOS type. The slide in the press took place at a constant speed of about 0.1 ms^{-1}. When the leg was clamped, the leg pressure and the size of the slide were recorded. Time courses of these quantities determine the characteristics of the work of the leg. The testing station with the leg is shown in **Figure 10** and the waveforms obtained during the tests are presented in **Figure 11**[20,21,49].

The results show that when the leg is loaded with a constant speed, the process of reaching the pressure limit at which the safety valve opens depends on the sliding speed of the press. This, in turn, causes that a valve overload is smaller than in the case of the impact load of a free-falling mass (**Figure 9**). It can also be seen that the leg slide is stable and depends on the time the load operates. In practice, this can lead to the complete sliding of the leg and loss of stability of the section and the entire support. Undoubtedly, the analysed load condition and its effects occur very often in actual workings and pose a serious threat to stability of the support system. The results obtained indicate the need for further testing of the legs and entire sections at a constant speed of slide in order to optimally select the parameters of the leg's safety system. In this case, it seems reasonable to use sequential safety valves that would allow an increase in load capacity as the size of the leg's slide.

3.3. Numerical Analysis of Flows in the Leg's Protection System

In addition to stand tests, in recent years model tests have been used increasingly to analyse many physical and chemical phenomena. Also in the field of mining support testing, these tests are increasingly used. Their undoubted advantage is the possibility of analysing many phenomena, the study of which in real or stationary conditions is practically

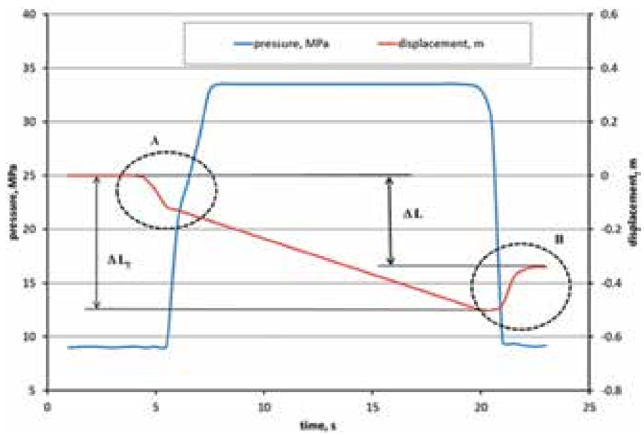


Figure 11: Time courses of the value of the displacement (slide-down) and pressure in the tested leg with spring deformation zones marked (A and B) and full slide-down (ΔLT) (own study based on[20,21,49]).

impossible or very expensive. Also the possibility of multi-variant analyses in spatial systems, taking into account time and variability of other parameters, means that they are used more and more often. In the case of powered supports, these tests can be used primarily for mechanical and flow analyses. Tests of hydraulic flows in legs are important when adapting the circuits to changing mining and geological conditions.

It can be assumed that in the process of sustainable development of powered supports and methods of testing them, model tests should be one of the basic methods used for such types of analyses.

The paper presents an example of the use of numerical fluid mechanics to analyse the flow of hydraulic fluid in a hydraulic leg and the connection supplying liquid to the safety valve at static load on the leg. The results of the analysis of rate and pressure distribution at the connections support the safe operation of the system.

The advantages of model research can be clearly seen in this type of analysis. They make it possible to trace the tested parameters practically at every point of the tested object. Acquiring such knowledge from other studies is impossible. It is also obvious that in the case of model tests, the reliability of the results obtained depends on the accuracy of the mapping of the tested object and the adopted boundary conditions. The results obtained can significantly enrich knowledge and explain the essence of the phenomena for example when analysing the flow of liquid in a hydraulic leg[20,41]. The results obtained and presented in **Figure 12** clearly show the velocity and pressure distributions, especially at the connections of this leg.

It should be emphasized that the determination of flows in the working systems of a powered roof support can be the basis for qualifying it for work in conditions of tremors and other rock mass impacts.

It is obvious that the possibilities of model testing, especially in the field of flow testing, are very large and should be widely used for testing roof supports. The use of these tests makes it possible to determine the performance characteristics of a hydraulic system, depending on many factors. One of them is the geometry of the connection's flow channels.

Therefore, in the case of powered roof supports testing, it is also reasonable to use model tests. It is important to remember that the quality of the results of model tests depend largely on the accuracy of the developed model and the correctness of the adopted boundary conditions.

However, in many cases they can be verified and validated by such methods as measuring the pressure value at selected points of the hydraulic system.

Therefore, it is fully justified to state that in the process of research on the sustainable development of the powered roof support intended for operation in variable mining and geological conditions, model tests may constitute a very important and valuable part of these tests.

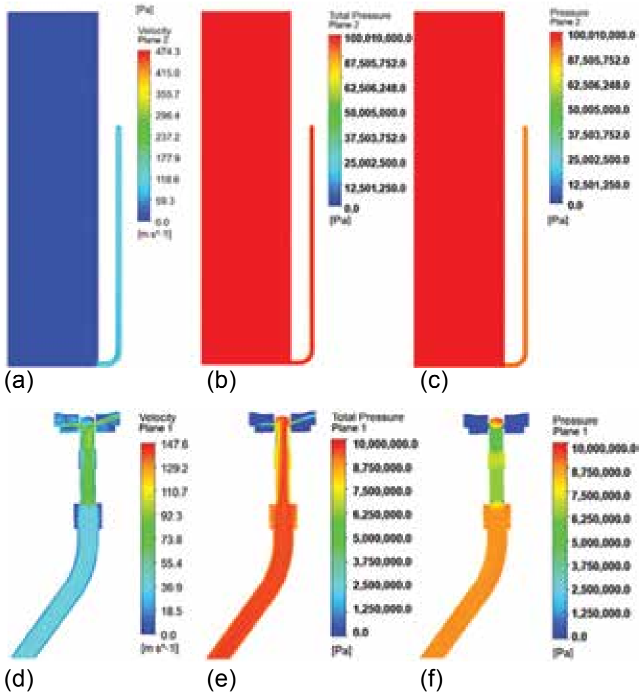


Figure 12: Distribution of velocity (a), static pressure (b) and total pressure (c) in a hydraulic leg and flow velocity (d), total pressure (e) and static pressure (f) in the connection supplying liquid to the safety valve at static load on the leg.

3.4. Research on the Development of Electro-hydraulic Control of a Powered Roof Support

In addition to mechanical and hydraulic systems, the most important system in support, in many cases, determining the effectiveness of its work is the control system. Therefore, it is obvious that scientific research on this system must be accelerated. The pursuit of unmanned operation (or with a minimal presence of people in the longwall) and the increasing use of digital data to support the roof support and the entire complex mean that the demand for more and more intelligent control systems increases.

The current level of technology does not allow for the complete elimination of miners from the longwall. This is also not to be expected in the coming years. This is mainly the result of not fully definable conditions in how underground mining is conducted. However, this does not limit the development of control systems, for which the requirements are increasing and will grow. The basic direction are works whose effect is relocation (removal) of as many activities as possible outside the mining longwall[50-53]. In this area, the role and importance of control systems is key.

Research in this area mainly includes work on the development of electro-hydraulic control. A special testing station was designed, based on a virtual controller, to facilitate tests of new control systems. It determines a number of control system parameters. Its main purpose is to determine static and dynamic performance characteristics of control hydraulics components. The station also tests systems protecting hydraulic cylinders against overload.

The station is mobile and can be used to conduct research in a variety of environments, which significantly extends the scope of research. It enables testing of control elements and visualization of the work parameters of a powered roof

(a) (b)

Figure 13: The stand for testing control and safety systems of the hydraulic system of the support during the test (b) and its basic parts (a).

support. **Figure 13** shows the station with its components and elements marked[54,55].

The scope of research carried out using the developed system is very wide. One of the problems was to determine the times for implementing the basic functions of the support. It mainly concerned the spreading and withdrawing of sections (extensions/slides of hydraulic legs mounted between floor bases and canopies). Measurements in this area included determining the time of switching on the PWM signal and full signal supply for the basic functions performed by the roof support. The operating parameters of the control system obtained for individual phases of the section operation are shown in **Figure 14**[54,55]. An analysis of measurement uncertainty was also carried out for these results.

The obtained results clearly indicate that the tested electro-hydraulic system has very short response times, which ensures fast and reliable performance of the tasks that the roof support has to perform. These results also enable comparative analysis of the control systems and their components as well as sensitivity analysis. This, in turn, enables the appropriate selection of control parameters for specific mining and geological conditions in which exploitation is to be carried out. These conditions are the basis for forecasting the load states that the mining support may be subjected to.

It can therefore be assumed that the use of virtual testing techniques for already used systems as well as new solutions and prototypes creates great possibilities for their evaluation. At the same time, the conditions to which these systems will be subject in real conditions are impossible to achieve. For this reason, the developed system and the entire test stand has great research potential. It is also an example of using modern IT systems in the mining industry. Its versatility should also be emphasized as it makes it possible to apply testing hydraulic systems in other industries.

Undoubtedly, this enables conducting multi-variant tests of hydraulic systems in a scope that would be impossible to carry out or would be very expensive and time consuming in other conditions.

4. THE CONCEPT OF A POWERED ROOF SUPPORT TESTING PROCEDURE DESIGNED TO ADAPT IT TO THE OPERATING CONDITIONS

The analysis of loads to which the mining support may be subjected during operation in underground longwall excavations as a result of the deformation impact of the rock

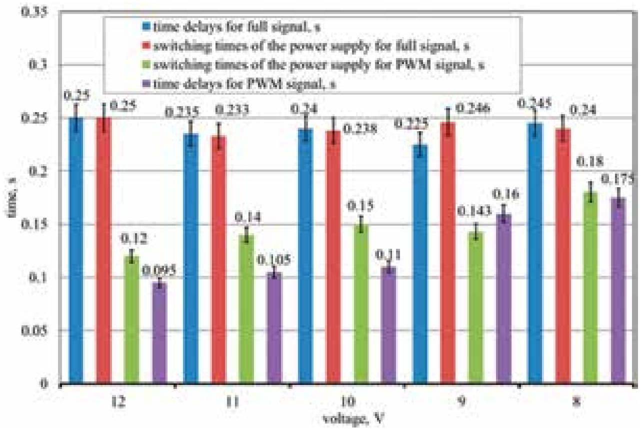


Figure 14: Switching on and lag times with the PWM and full signal for leg's sliding down mode (own study based on data from[54,55]).

mass (**Section 2**) indicates that in order to fulfil its functions, it must be properly designed, constructed and operated. Therefore, it is necessary to conduct tests of elements, sub-assemblies and entire sections of this support as much as possible. In this regard, it is necessary to use all available research methods. This is due to the fact that the role and importance of support in the mining process is very large, and in particular concerns the safety of people.

It is therefore reasonable to develop a comprehensive procedure for testing the conditions in which the support and its sub-assemblies and components will be operated in terms of adaptation to these conditions. This procedure, apart from various test methods to which the elements and sub-assemblies of the support section should be subjected, also takes into account legal conditions in the scope of approval, testing and quality control of the support[56-61]. This is a key element of the presented concept as it significantly interferes with manufacturers of the support. The most important part of this procedure is to determine the research area that will be used to implement it. It is about research methods and tools that will be included in it.

Reliable research results should be the basis for development of legal conditions. New directives and standards, and thus also certificates, should take into account, as soon as possible, the results of testing the supports and all the data and knowledge resulting from the use of the systems. They should also flexibly relate to changing operating conditions, which was included as the third pillar of the developed concept.

The whole concept is based on three pillars: research, real conditions (underground mines), and the legal regulations related to the production of supports. This comprehensive approach to analysing the state of safety and the requirements to be met by the support before it is put into service creates the opportunity to improve the safety and efficiency of the operation process.

A block diagram of the developed concept of a powered roof support approval procedure based on required safety demands is presented in **Figure 15**. As already mentioned, this procedure takes into account the mining and geological conditions in which the system will be used, which determines

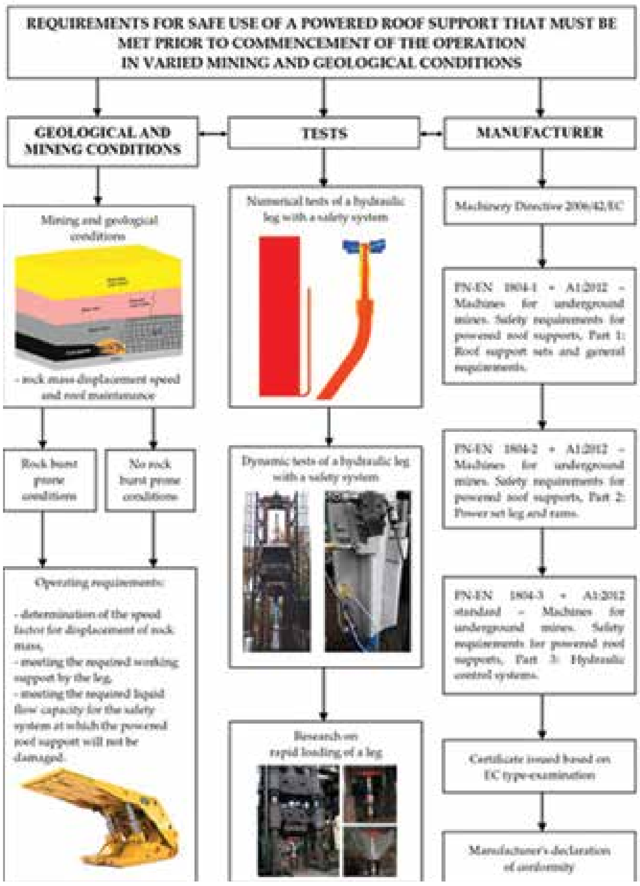


Figure 15: The concept of the procedure for admitting the powered support to be installed and operate in longwalls characterised by varied mining and geological conditions.

the method of its loading, the methods of testing safety systems designed for legs and support sections (discussed in the **Section 3**) as well as legal conditions determining the approval, discussed in **Section 2**.

It can be assumed that the presented concept covers all the most important areas in terms of safety and efficient operation of the roof support.

The conditions in which the mining roof support operates are random, therefore the developed procedure should be used for each new mining longwall separately. Each time the scope of its use should be tailored to the projected mining and geological conditions of a given area. The identification of potential loads and requirements for the maintenance of the excavation roof should be the basis for further activities and calculations. Possible structural changes and other systems should be preceded by a thorough assessment of these conditions.

The presented procedure is open and, depending on the needs and possibilities, can be supplemented with new information about the state of the rock mass, new research methods, and legal conditions.

5. CONCLUSIONS

The key component of currently used high-performance systems for mining underground coal deposits is the powered roof support. Its reliable and effective work in the field of securing mine workings enables safe and effective operation of the mining process. Changing mining and geological conditions of the mining area results in many requirements that must be meet by the roof support. These requirements increase with deteriorating environmental conditions, which is obvious when the depth of mining activities increase. Therefore, research and tests are carried out to adapt the support to such unpredictable mining conditions.

The roof support requires continuous improving. This especially refers to its individual sub-assemblies and elements. The concept of a new procedure for approving the support to work in specific mining and geological conditions presented in the paper perfectly fits the improvement process. This procedure is based on three pillars. The first includes the identification of mining and geological conditions in which mining will be carried out. This should enable forecasting of the conditions of load impacting on the roof support during mining operation. The second pillar includes comprehensive testing of sub-assemblies, systems and components of the roof support section in relation to projected loads. The purpose of these tests is to assess the safe operation of the roof support in varied conditions. The paper refers to impact mass load and load resulting from permanent displacement. The research team developed stand test methods to analyse both types of load. Model research, which was included in the proposed set of support test methods, is also especially important. The use of mechanical analyses only briefly mentioned in the paper, as well as analyses using numerical fluid mechanics (CFD), should constantly increase.

The last pillar of the developed concept are legal conditions that must keep up with the changes taking place in previously discussed pillars. These conditions determine the practical application of the results of identification of potential loads and solutions in section systems designed to meet these loads. Undoubtedly, these acts and the approach to the authorization of mining support for mining requires a separate study and discussion. It is crucial to include the latest research achievements and practical experience in the newly developed acts.

The hydraulic control systems in the support section also have very important significance as it was presented in the paper. The developed systems for testing them create great opportunities to develop and implement new effective solutions that limit the work of people in hazardous areas.

Another element that has an enormous impact on the safety of the mining operation, the roof support and the whole system is a safety valve. Its significance and results of conducted research are presented in the paper (**Section 3**). Its value in terms of safe and efficient operation of the roof support was numerously emphasized in the paper. Such valves should effectively protect the sections against overloads and damage. Therefore, safety valves were subjected to model and stand tests. Tests in an actual underground area will be conducted in the near future.

The results of presented analysis and tests show that prior to admitting the powered support to be installed and operate, a thorough analysis of the requirements for its safe use should be conducted. Such analysis should cover the entire support section, but in particular its safety system. The procedure proposed and presented in Figure 15 enables a full assessment of the possibilities of the support section and safety system for the expected conditions of its operation.

The research team managed to develop a method that is undoubtedly a new and original approach to testing and controlling the condition of the support section. It also facilitates the selection of a support that will operate properly in given changing mining and geological conditions. The presented methodology and obtained test results proves that the main objective has been achieved. The authors, thanks to appropriate research methods and tools, designed an original way of testing and controlling the condition of the section and a method for selection for various mining and geological conditions.

The open nature of this procedure is its best advantage thanks to which the procedure can be modified depending on the conditions, requirements and needs, as well as research capabilities. This applies to both manufacturers and users of the roof support. In particular, the responsible approach of contractors ordering the roof support, its potential users. Their task is to select a system that will match the conditions prevailing in a given underground area. In this case, first of all, the safety of the miners and the safety of the roof support must be taken into account. The support is the most expensive machine of the powered roof support complex and its safe use impacts the economic efficiency of the entire mining process.

REFERENCES

1. Tutak, M.; Brodny, J. Degree of Use of Alternative Sources for Energy Production for the Economical Aims in EU Countries. In Proceedings of the 17th International Multidisciplinary Scientific GeoConference SGEM 2017, Vienna, Austria, 27-29 November 2017; pp. 635-642. [Google Scholar] [CrossRef]
2. Stecuła, K.; Brodny, J. Renewable Energy Sources as an Opportunity for Global Economic Development. In Proceedings of the 17th International Multidisciplinary Scientific GeoConference SGEM 2017, Vienna, Austria, 27-29 November 2017; pp. 749-756. [Google Scholar] [CrossRef]
3. Singh, R.; Singh, T.N. Investigation into the behavior of a support system and roof strata during sublevel caving of a thick coal seam. Geotech. Geol. Eng. 1999, 17, 21-35. [Google Scholar] [CrossRef]
4. Fan, Q.; Li, W.; Hui, J.; Wu, L.; Yu, Z.; Yan, W.; Zhou, L. Integrated Positioning for Coal Mining Machinery in Enclosed Underground Mine Based on SINS/WSN. Sci. World J. 2014, 2014, 460415. [Google Scholar] [CrossRef]
5. Peng, S.S.; Chiang, H.S. Longwall Mining; John Wiley and Sons, Inc.: New York, NY, USA, 1984. [Google Scholar]
6. Barczak, T.M. Design and Operation of Powered Roof Support Systems for Longwall Mining; IC 9320; U.S. Department of Interior, Bureau of Mines: Washington, DC, USA, 1992; p. 14. [Google Scholar]
7. Axin, M. Mobile Working Hydraulic System Dynamics. Ph.D. Thesis, Universitetet Linkoöping, Linköping, Sweeden, 2015. [Google Scholar]
8. Irresberger, H.; Gräwe, F.; Migenda, P. Schreitausbau für den Steinkohlenbergbau; Verlag Glückauf: Essen, Germany, 1994. [Google Scholar]
9. Buyalich, G.; Byakov, M.; Buyalich, K.; Shtenin, E. Development of Powered Support Hydraulic Legs with Improved Performance. E3S Web Conf. 2019, 105, 03025. [Google Scholar] [CrossRef]
10. Jacobi, O. Praxis der Gebirgsbeherrschung 2. Auflage; Glückauf: Essen, Germany, 1981. [Google Scholar]
11. Szurgacz, D.; Sobik, L.; Brodny, J. Ventilation Systems in Longwall Workings with Powered Longwall Complex. In Proceedings of the Geolinks International Conference on Geosciences, Athens, Greece, 26-29 March 2019; pp. 201-209. [Google Scholar]
12. Brodny, J.; Tutak, M. Analysis of Gases Emitted into the Atmosphere during an Endogenous Fire. In Proceedings of the 16th International Multidisciplinary Scientific GeoConference SGEM, Vienna, Austria, 2-5 November 2016; pp. 75-82. [Google Scholar] [CrossRef]
13. Brodny, J.; Tutak, M. Analysis of Methane Emission into the Atmosphere as a Result of Mining Activity. In Proceedings of the 16th International Multidisciplinary Scientific GeoConference SGEM, Vienna, Austria, 2-5 November 2016; pp. 83-90. [Google Scholar] [CrossRef]
14. Tutak, M. Analysis of Varying Levels of Methane Emissions from Coal Mines in Poland. In Proceedings of the 17th International Multidisciplinary Scientific GeoConference SGEM, Vienna, Austria, 27-29 November 2017; pp. 301-308. [Google Scholar] [CrossRef]
15. Brodny, J.; Tutak, M. Determination of the Zone with a Particularly High Risk of Endogenous Fires in the Goaves of a Longwall with Caving. J. Appl. Fluid Mech. 2018, 11, 545-553. [Google Scholar] [CrossRef]
16. Tutak, M.; Brodny, J. Impact of type of the roof rocks on location and range of endogenous fires particular hazard zone by in goaf with caving. E3S Web Conf. 2018, 29, 00005. [Google Scholar] [CrossRef]
17. Tutak, M.; Brodny, J. Analysis of Influence of Goaf Sealing from Tailgate on the Methane Concentration at the Outlet from the Longwall. IOP Conf. Ser. Earth Environ. Sci. 2017, 95, 042025. [Google Scholar] [CrossRef]
18. Tutak, M. Assessment of Hydrodynamics of Gas Flow through the Porous Rock Structures. In Proceedings of the 17th International Multidisciplinary Scientific GeoConference SGEM 2017, Vienna, Austria, 27-29 November 2017; pp. 53-60. [Google Scholar] [CrossRef]
19. Brodny, J.; Tutak, M. Determination of the Zone Endangered by Methane Explosion in Goaf with Caving of Operating Longwalls. In Proceedings of the 16th International Multidisciplinary Scientific GeoConference SGEM 2016, Albena, Bulgaria, 28 June-6 July 2016; pp. 299-306. [Google Scholar]
20. Doległo, L. Analityczna Metoda Wyznaczenia Przeciążeń Zmechanizowanej Obudowy Ścianowej Powstałych w Wyniku Wstrząsów Górotowru. Ph.D. Thesis, Central Mining Institute, Katowice, Poland, 2011. [Google Scholar]
21. Gil, J. Analiza Przepływów w Układach Ograniczających Ciśnienie Przestrzeni Roboczej Stojaka Hydraulicznego w Zmechanizowanej Obudowie Ścianowej. Ph.D. Thesis, AGH University of Science and Technology, Kraków, Poland, 2014. [Google Scholar]
22. Budirskỳ, S.; Martinec, P. Influence of support resistance on roof control in single-pass thick-seam mining (4.5 m): A case history. Min. Sci. Technol. 1986, 4, 59-67. [Google Scholar]
23. Szurgacz, D.; Brodny, J. Dynamic Resistance Test for Safety Valve in Electro-Hydraulic Control System for Powered Roof Supports. In Proceedings of the 18th International Multidisciplinary Scientific GeoConference SGEM, Albena, Bulgaria, 2 July-8 July 2018; pp. 343-350. [Google Scholar]
24. Buyalich, G.; Buyalich, K.; Byakov, M. Factors Determining the Size of Sealing Clearance in Hydraulic Legs of Powered Supports. E3S Web Conf. 2017, 21, 03018. [Google Scholar] [CrossRef]
25. Buyalich, G.; Byakov, M.; Buyalich, K. Factors Determining Operation of Lip Seal in the Sealed Gap of the Hydraulic Props of Powered Supports. E3S Web Conf. 2017, 41, 01045. [Google Scholar] [CrossRef]

26. Gorodilov, L.V.; Efimov, V.P.; Kudryavtsev, V.G. Modelling the Striking Head-Impact Tool-Rock Mass Interaction. J. Min. Sci. 2013, 49, 618-624. [Google Scholar] [CrossRef]
27. Klishin, V.I.; Klishin, S.V. Coal Extraction from Thick Flat and Steep Beds. J. Min. Sci. 2010, 46, 149-159. [Google Scholar] [CrossRef]
28. Klishin, V.I.; Fokin, Y.S.; Kokoulin, D.I.; Kubanychbek, B. Mining of Thick Seams by Using Powered Supports with Controlled Coal Drawing; Nauka: Novosibirsk, Russia, 2007. [Google Scholar]
29. Goshtasbi, K.; Oraee, K.; Khakpour-yeganeh, F. Shield Support Selection Based on Geometric Characteristics of Coal Seam. J. Min. Sci. 2006, 42, 151-156. [Google Scholar] [CrossRef]
30. Kidybiński, A. Stateczność Górotworu i Obudowy Przed Łącznym Obciążeniem Statycznym i Dynamicznym; Central Mining Institute: Katowice, Poland, 2009. [Google Scholar]
31. Stoiński, K.; Szurgacz, D. Case study of rock burst which occurred during mining works – Roof support unit. Przegląd Górniczy 2017, 7, 8-17. [Google Scholar]
32. Brady, B.H.G.; Brown, E.T. Rock Mechanics for Underground Mining; Springer: Dordrecht, The Netherlands, 2005. [Google Scholar]
33. Wang, J.; Yu, B.; Kang, H.; Wang, G.; Mao, D.; Liang, Y.; Jiang, P. Key technologies and equipment for a fully mechanized top-coal caving operation with a large mining height at ultra-thick coal seams. Int. J. Coal Sci. Technol. 2015, 2, 97-161. [Google Scholar] [CrossRef]
34. Liang, Y.; Li, L.; Li, X.; Wang, K.; Chen, J.; Sun, Z.; Yang, X. Study on Roof-Coal Caving Characteristics with Complicated Structure by Fully Mechanized Caving Mining. Shock Vib. 2019, 2019, 6519213. [Google Scholar] [CrossRef]
35. Małkowski, P.; Ostrowski, Ł.; Brodny, J. Analysis of Young's modulus for Carboniferous sedimentary rocks and its relationship with uniaxial compressive strength using different methods of modulus determination. J. Sustain. Min. 2018, 17, 145-157. [Google Scholar] [CrossRef]
36. Lama, R.D.; Vutukuri, V.S. Mechanical Properties of Rocks; Trans Tech Publications Clausthal: Zellerfeld, Germany, 1978. [Google Scholar]
37. Biliński, A. Criteria of Support Selection for Longwall Workings with Natural Roof Caving; Central Mining Institute: Katowice, Poland, 1976. [Google Scholar]
38. Biliński, A.; Kostyk, T.; Prusek, S. Principles of selecting a powered roof support for longwall faces. Bezpieczeństwo Pr. Ochr. Środowiska Górnictwie 1997, 3, 7-17. [Google Scholar]
39. Dubiński, J.; Konopko, W. Tąpania – Ocena, Prognoza, Zwalczanie; Central Mining Institute: Katowice, Poland, 2000. [Google Scholar]
40. Stoiński, K.; Mika, M. Dynamics of Hydraulic Leg of Powered Longwall Support. J. Min. Sci. 2003, 39, 72-77. [Google Scholar] [CrossRef]
41. Stoiński, K. Zmechanizowane Obudowy Ścianowe do Warunków Zagrożenia Wstrząsami Górotworu; Central Mining Institute: Katowice, Poland, 2018. [Google Scholar]
42. Gil, J.; Kołodziej, M.; Szurgacz, D.; Stoiński, K. Introduction of standardization of powered roof supports to increase production efficiency of Polska Grupa Górnicza, S.A. Min. Inform. Autom. Electr. Eng. 2019, 56, 33-38. [Google Scholar] [CrossRef]
43. Stoiński, K.; Madejczyk, W. Stojaki Dwuteleskopowe z Wierconymi Płaszczami Cylindrów; Prace Naukowe. Monografie; CMG KOMAG: Gliwice, Poland, 2004. [Google Scholar]
44. Brodny, J. Determining the working characteristic of a friction joint in a yielding support. Arch. Min. Sci. 2010, 55, 733-746. [Google Scholar]
45. Brodny, J. Tests of friction joints in mining yielding supports under dynamic load. Arch. Min. Sci. 2011, 56, 303-318. [Google Scholar]
46. Szurgacz, D. Dynamic phenomena in a powered support caused shocks of the strata. Wiadomości Górnicze 2011, 10, 561-567. [Google Scholar]
47. Szurgacz, D.; Brodny, J. Analysis of the Influence of Dynamic Load on the Work Parameters of a Powered Roof Support's Hydraulic Leg. Sustainability 2019, 11, 2570. [Google Scholar] [CrossRef]
48. Stoiński, K. Praktyczne aspekty upodatnienia obudowy zmechanizowanej. Napędy i Sterow. 2006, 10, 101-107. [Google Scholar]
49. Kipczak, P. Badania Zaworu Szybkopustowego Stojaka Hydraulicznego z Przepływem Wewnętrznym dla Upodatnienia Obudowy Hydraulicznej. Ph.D. Thesis, AGH University of Science and Technology, Kraków, Poland, 2011. [Google Scholar]
50. Gumuła, S. A new concept of hydraulic mechanized supports resistant to the crumps. Arch. Min. Sci. 2005, 50, 275-288. [Google Scholar]
51. Guo, W.B.; Wang, H.S.; Dong, G.W.; Li, L.; Huang, Y.G. A Case Study of Effective Support Working Resistance and Roof Support Technology in Thick Seam Fully-Mechanized Face Mining with Hard Roof Conditions. Sustainability 2017, 9, 935. [Google Scholar] [CrossRef]
52. Hussein, M.A.; Ibrahim, A.R.; Imbaby, S.S. Load calculations and selection of the powered supports based on rock mass classification and other formulae for abutartur longwall phosphate mining conditions. J. Eng. Sci. 2013, 41, 1728-1742. [Google Scholar]
53. Shengli, Y.; Gaofeng, S.; Dezhong, K. An evaluation of longwall face stability in thick coal seams through a basic understanding of shield – Strata interaction. J. Geophys. Eng. 2019, 16, 125-135. [Google Scholar]
54. Szurgacz, D.; Brodny, J. Analysis of Powered Roof Support Operation Based on a Virtual Driver. In Proceedings of the XV International Conference Multidisciplinary Aspects of Engineering, Zawiercie, Poland, 5-8 September 2018; pp. 415-421. [Google Scholar]
55. Szurgacz, D.; Gondek, H. Tests of an Innovative Designed to Control the Powered Roof Support. In Proceedings of the XV International Conference Multidisciplinary Aspects of Engineering, Zawiercie, Poland, 5-8 September 2018; pp. 361-368. [Google Scholar]
56. Directive 2006/42/EC: Machinery (Amending Directive 95/16/EC). Available online: https://eur-lex.europa.eu/legal-content/PL/LSU/?uri=CELEX:32006L0042 (accessed on 15 November 2019).
57. Polish Standard. Maszyny dla Górnictwa Podziemnego – Wymagania Bezpieczeństwa dla Obudowy Zmechanizowanej – Część 1: Sekcje Obudowy i Wymagania Ogólne; Polski Komitet Normalizacyjny: Warszawa, Poland, 2011. [Google Scholar]
58. Polish Standard. Maszyny dla Górnictwa Podziemnego – Wymagania Bezpieczeństwa dla Obudowy Zmechanizowanej – Część 2: Stojaki i Pozostałe Siłowniki; Polski Komitet Normalizacyjny: Warszawa, Poland, 2012. [Google Scholar]
59. Polish Standard. Maszyny dla Górnictwa Podziemnego – Wymagania Bezpieczeństwa dla Obudowy Zmechanizowanej – Część 3: Hydrauliczne Układy Sterowania; Polski Komitet Normalizacyjny: Warszawa, Poland, 2012. [Google Scholar]
60. Ordinance of the Minister of Energy on Detailed Requirements for Conducting Underground Mining Operations of 23 November 2016. Available online: http://www.dziennikustaw.gov.pl/du/2017/1118/1 (accessed on 5 November 2019).
61. Budirskỳ, S. Interaction of powered supports and the strata in coal seams under a heavy roof. Int. J. Min. Eng. 1985, 3, 113-138. [Google Scholar] [CrossRef]

AUTHORS

Dawid Szurgacz and Jaraslow Brodny

Efficient mining of ultra – thick coal seams in Xinjiang

The scientific and efficient mining of ultra-thick coal seam in Xinjiang, China is faced with the problems of low exploration level and lack of theoretical research on underground mining. This paper studied occurrence characteristic of ultra-thick coal seams in Xinjiang, using field investigation and drilling exploration. Based on the variation law of support load under different roof bearing structure form and development height in multi-layer mining, classification method and mining technology selection of ultra-thick coal seam were put forward. The results indicate that: (1) The ultra-thick coal seams in Xinjiang have a distribution characteristic of more north and less south, more east and less west, mainly concentrate in East Junggar and Turpan-Harmi coalfields. The form of the ultra-thick coal seam has the remarkable characteristic of coal seams merging and bifurcating. (2) The mechanical model of the relationship between the support and surrounding rock under different roof bearing structures is established. At the early stage of multi-layer mining, the support load includes the load caused by rotary subsidence of the blocks that formed the near-stope roof bearing structure and the gravity load of rock blocks under roof bearing structure. At the later stage, the support load is mainly gravity load of loose blocks below the far-stope roof bearing structure. (3) According the roof bearing structure form, ultra-thick coal seam can be divided into three types: no stable bearing structure, (higher) beam bearing structure and arch bearing structure. In order to ensure the stability of near-stope roof bearing structure, backfill mining, longwall mining, and longwall mining early and backfill mining later should be adopted in three types ultra-thick coal seams mining respectively.

INTRODUCTION

Occurrence of ultra-thick coal seam is a common phenomenon. Coalfields with single seam thickness of more than 20 m distribute in major coal-mining countries and regions such as China, United States, Russia, Eastern Europe and Southeast Asia. The integrated coalfield with ultra-thick coal seam has the characteristics of good production conditions, low mining cost and large output. In order to mine ultra-thick coal seams scientifically, researchers have studied occurrence and genesis of the ultra-thick coal seams[1,2].

In terms of occurrence characteristics of ultra-thick coal seams, the Carboniferous ultra-thick coal seams occur from Europe to Central Asia[3], the Permian ultra-thick coal seams distribute in Gondwana[4-7], which is composed of Australia and India, and the Carboniferous-Permian ultra-thick coal seams are mainly bituminous coal with concentrated occurrence and high metamorphic degree;

Figure 1: Distribution of main coalfields in Xinjiang.

the Jurassic ultra-thick coal seams distribute along latitudes in Kazakhstan, Russia, Xinjiang and Ordos Basin in China, mainly with non-caking coal and lignite[8]; tertiary ultra-thick coal seams widely distribute around the world, but the degree of coal metamorphism is low, mainly lignite.

Traditionally, it is considered that the thick coal seam is the product of long-term equilibrium compensation between peat accumulation rate and basement subsidence rate, but it is difficult to explain the process mechanism of continuous peat deposition forming ultra-thick coal seam[9-11]. Relevant experts and scholars have studied the genesis mechanism of ultra-thick coal seam based on different examples. Diessel *et al.*[12,13] proposed the transgressive regressive sequence model of coal seam sediments, identified and divided the sequence boundary of ultra-thick coal seam, which laid a foundation for studying the genesis mechanism of ultra-thick coal seam with regional distribution. Wu *et al.*[14] studied genesis of ultra-thick coal seam in typical fault basins, and believed that the allochthonous accumulation of peat caused by storms, gravity flow and underwater debris flow played a very important role in the development of ultra-thick coal seam. They established the genetic model of allochthonous accumulation in deep water environment of ultra-thick coal seam. Shearer thought that thick coal seam is composed of several ancient peat bodies, which are separated by the interface that marks the falling water level. Based on this, Banerjee *et al.*[15] believed that ultra-thick coal seam may be a complex of multiple high-frequency sequences in the interior. On the basis of previous studies[16], Wang *et al.*[2,17] put forward genetic model of ultra-thick coal seams formed by superimposition of multiple coal seams. They believed that the formation of ultra-thick coal seams in the depression basin was the result of superposition of multiple coal seams.

There are ultra-thick coal seams in Xinjiang, Liaoning, Inner Mongolia and Yunnan of China. As well, except Laohutai coal mine in Fushun, which adopts slicing sand backfill mining, open-pit mining is usually adopted in ultra-thick coal seams. As a key coal base of 100 million tons in China, Xinjiang has four major integrated coalfields, being East Junggar, Ili, Turpan-Harmi and Kuqa-Bay coalfields[18]. The presence of ultra-thick coal seams, which are usually more than 20 m thick, is an important feature in East Junggar, Turpan-Harmi and Ili coalfields. For example, in East Junggar Coalfield, a single seam with thickness more than 80 m has been reported, and there is a ultra-thick coal seam in Shaerhu coalfield, with thickness more than 200 m. As the focus of Chinese coal resources development shifted to the western region, the coal output in Xinjiang has increased from 88.12 million tons in 2009 to 167 million tons in 2017, and will be further expanded in the future. However, at present, the area is facing the problems of low exploration level (only 46% of geological resources are identified) and lack of design and practical experience for ultra-thick coal seam underground mining. Most mines are in the planning stage. Based on distribution and occurrence characteristic of ultra-thick coal seam in Xinjiang, this paper theoretically analyses the variation characteristic of the support load under different roof bearing structures, classifies ultra-thick coal seams according to the occurrence conditions, and puts forward the appropriate mining technology. The results will provide a guideline for the mining area construction and coal mining method selection under similar mining conditions.

DISTRIBUTION CHARACTERISTIC OF ULTRA-THICK COAL SEAMS IN XINJIANG

The distribution of main coalfields in Xinjiang is shown in **Figure 1**. Coal resources mainly distribute in the north and east, accounting for 94.7% of the total forecast reserves, and there are 24 coalfields with forecast reserves of more than 10 billion tons.

The coalfields with forecast reserves of more than 100 billion tons are East Junggar coalfield, Shaerhu coalfield, Yining coalfield, Turpan coalfield and Dananhu-Wutongwozi coalfield, accounting for about 60% of the total forecast. According to the distribution and development strategy of coal resources in Xinjiang, four major coalfields, East Junggar, Ili, Turpan-Harmi and Kuqa-Bay Coalfields, are planned to be the main bases of Xinjiang coal power, “coal transportation from west to east” and coal-to-gas.

The distribution of the ultra-thick coal seams in Xinjiang is shown in **Figure 2**. There are ultra-thick coal seams in the three integrated coalfields of East Junggar, Turpan-Harmi and Ili. Reserves of ultra-thick seams and planned coal production in each coalfields are shown in **Figures 3** and **4**.

The distribution of ultra-thick coal seams in Xinjiang is characterized by more north and less south, and more east and less west, and coal seams mainly concentrate in East Junggar and Turpan-Harmi coalfields. The proven reserves of ultra-thick coal seams in the East Junggar, Turpan-Harmi and Ili coalfields account for 27.49% of the total forecast reserves in Xinjiang. As well, the reserves of ultra-thick coal seams in

Figure 2: Distribution of ultra-thick coal seams in Xinjiang.

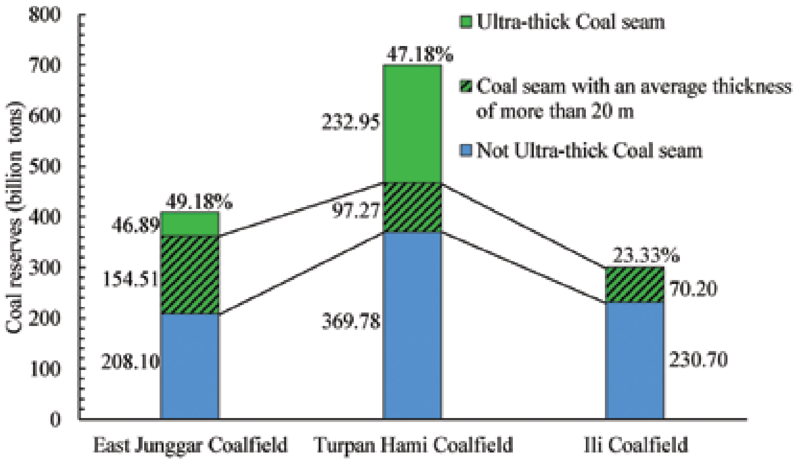


Figure 3: Reserves of ultra-thick coal seams in three coalfields.

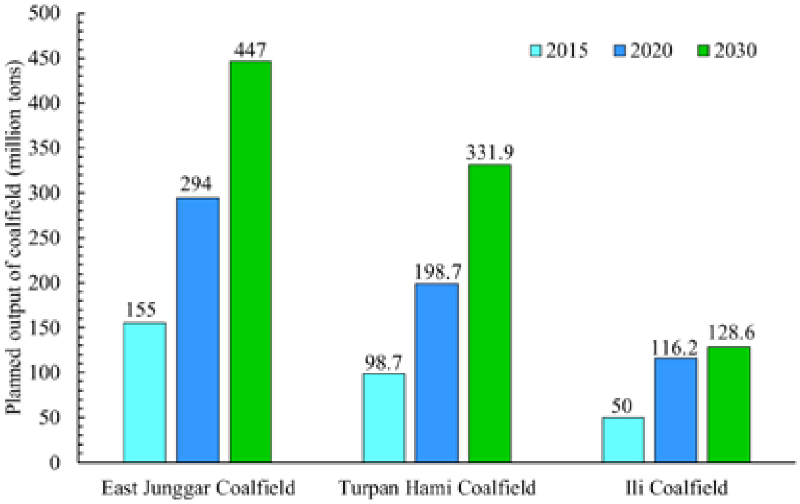


Figure 4: Planned coal production in three coalfields.

the three coalfields are 201.40 billion tons, 330.23 billion tons and 70.20 billion tons respectively, accounting for 49.18%, 47.18% and 23.33% of the forecast reserves in their respective coalfields. The planned output of East Junggar coalfield will increase from 155 million tons in 2015 to 447 million tons in 2030, an increase of 1.88 times, accounting for 49.26% of the planned output of the three integrated coalfields. It is the key development coalfield in Xinjiang coal base. In the construction process of East Junggar coal base, it will inevitably encounter the problem of ultra-thick seam underground mining.

OCCURRENCE CHARACTERISTIC OF TYPICAL ULTRA-THICK COAL SEAMS

Most ultra-thick coal seams distribute in East Junggar and Turpan-Harmi coalfield in the eastern part of Xinjiang. As well, ultra-thick coal seams with average thickness of more than 20 m are concentrated in Shaerhu coalfield and East Junggar coalfield. Therefore, taking these two typical coalfields as examples, this paper analyses occurrence characteristic of ultra-thick coal seams in Xinjiang.

Occurrence of Shaerhu Coalfield

The main structural unit of Shaerhu coalfield is Shaerhu depression in the southern depression zone, adjacent to Toksun depression and Shaerhu uplift in the north, Aydingkol slope in the west, and Wutongwozi depression in the east, as shown in **Figure 5**[19]. **Figure 6** shows contour distribution of coal seam thickness and section of eastern coal seam in Shaerhu coalfield.

The coal seam in Shaerhu coalfield is located in the middle section of middle Jurassic Xishanyao

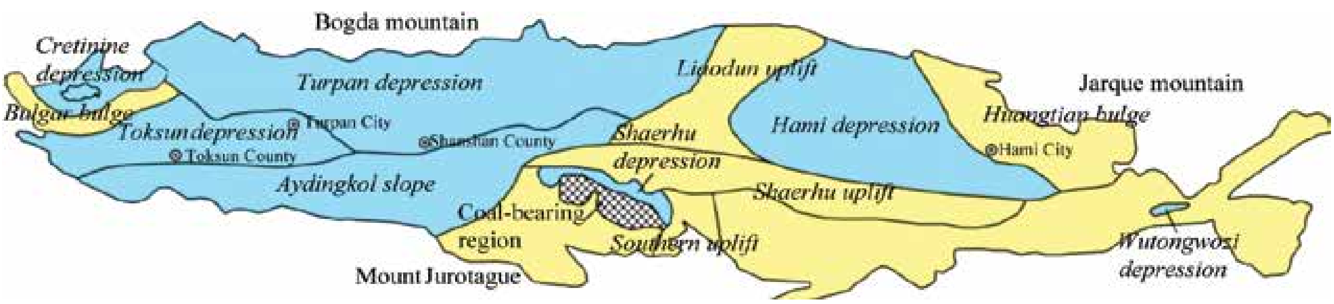
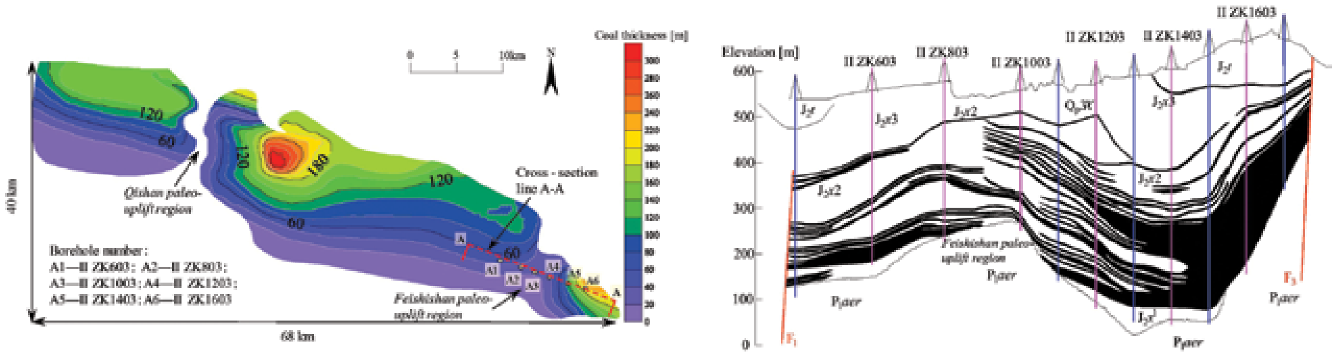


Figure 5: Shaerhu coalfield and its surrounding structural distribution.



(a) Coal seam thickness distribution in shaerhu coalfield

(b) Section A-A of eastern coal seam

Figure 6: Contour distribution of coal seam thickness and section of eastern coal seam in the Shaerhu coalfield.

formation (J2x). It can be divided into 25 coal seams, and 23 coal seams can be mined. The C8 coal seam is main mining seam with a total thickness of 1.30-267.42 m and average thickness of 96.82 m. The coal seam shows bifurcation in the southern part of coalfield, the roof is mudstone and carbonaceous mudstone, while the floor is siltstone and silty mudstone. Mudstone and carbonaceous mudstone are main lithology of roof and floor in the rest of the coalfield. The coal seam is thick in the north, thin in the south, and is deep in the north and shallow in the south. Coal seam depth is mostly within 600 m.

Occurrence of East Junggar Coalfield

The main structural unit of the East Junggar coalfield is eastern uplift of Junggar basin, with Kelameili mountain in the north, Bogda mountain in the south, and Donghaidaozi depression, Baijialhai uplift and Fukang depression from north to south in the west. East Junggar coalfield mainly has Wucaiwan, Dajing, Jiangjunmiao, Xiheishan and Laojunmiao mining areas, which are concentrated in the northern part of the coalfield with the boundary of Shaqi uplift, as shown in **Figure 7**[20,21].

The major coal-bearing strata in in East Junggar coalfield are lower Jurassic Badaowan (J$_1$b) and middle Jurassic Xishanyao (J$_2$x) formations. Badaowan formation (J$_1$b) contains group A coal with a formation thickness of 6.60-120.24 m. The formation thickness decreases from west to east along the strike, and increases from periphery to center of the basin along the trend. The lithology is mainly argillaceous siltstone, silty mudstone, fine sandstone and mudstone. The depression in front of the Bogda mountain contains 5-8 coal seams with a cumulative thickness of 26.65 m, while the depression in front of the Kelameili mountain contains 1-4 coal seams with a cumulative thickness of 7 m. Xishanyao formation (J$_2$x) contains group B coal, which is the most important coal-bearing formation in East Junggar coalfield. The formation thickness is 18-285 m, and the coal accumulation is the best when the formation thickness is 100-130 m. Dajing mining area is the coal-rich center of group

B coal. The number of coal seams in group B coal increases from east to west, and single coal seam becomes thinner. The thickness of single coal seam in Dajing mining area is up to 70-90 m. The roof and floor of coal seam are mainly fine sandstone, medium sandstone and carbonaceous mudstone, and the burial depth is 300-600 m.

Due to severe deformation of strata in the coal-bearing basin in Xinjiang, there is a big difference in the coal seam dip angle. The dip angle of ultra-thick coal seam is 0-54°, and the number and thickness of the coal seams vary greatly.

Form of Ultra-Thick Coal Seam

The study area is Dajingnan Nº. 1 coal mine, which is located at the junction of the Jiangjunmiao mining area and the Dajing mining area in East Junggar coalfield. A total of 124 boreholes are drilled in this area, and the boreholes arrangement is shown in **Figure 8**.

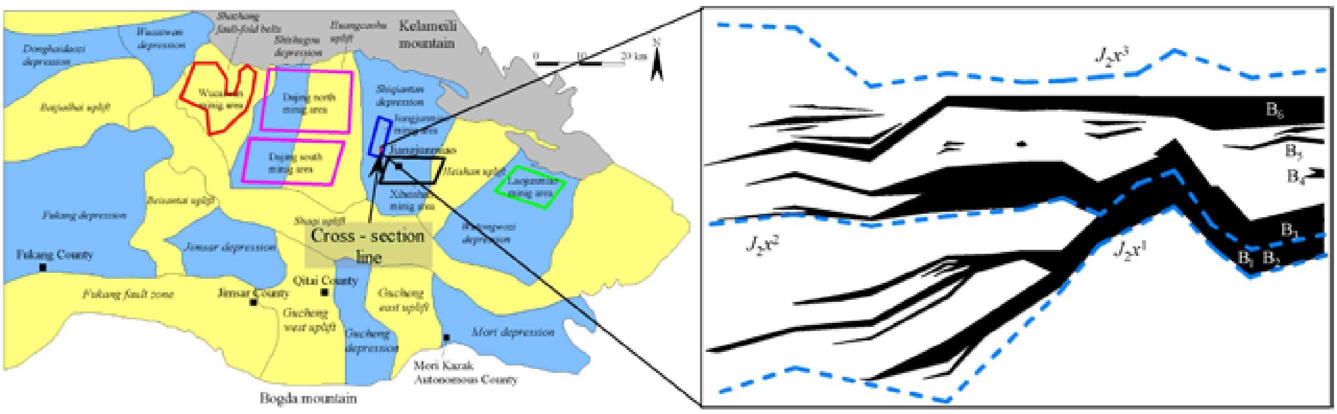


Figure 7: Structure of East Junggar coalfield and section of coal seam.

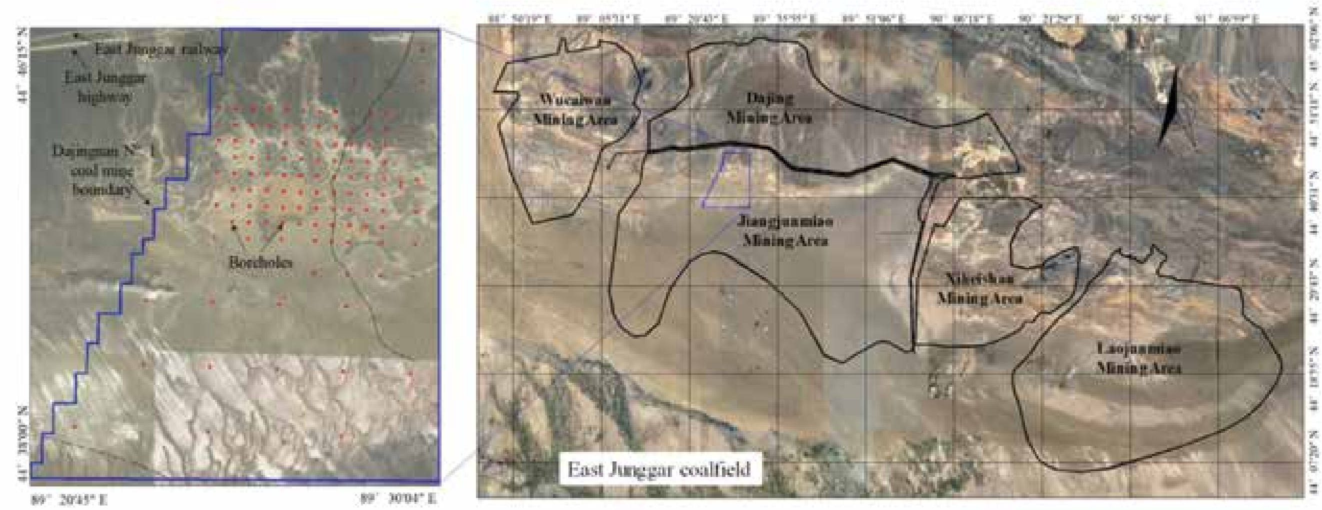
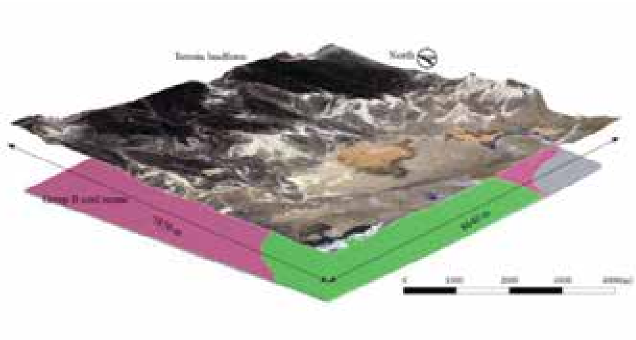
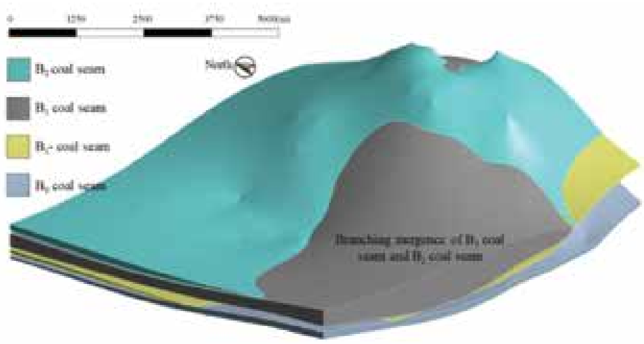


Figure 8: Boreholes arrangement of Dajingnan Nº. 1 coal mine.



(a) The form of group B coal



(b) The form of group B coal (expanded by 10 times along the thickness direction)

Figure 9: The form of group B coal in the north of Dajingnan Nº. 1 coal mine.

The form of group B coal in the mine north is obtained by processing the borehole data, as shown in **Figure 9a**. In order to easy observation, the group B is expanded by 10 times along the thickness direction, the form of group B coal after expanded is shown in **Figure 9b**.

The section of group B coal at different positions in the northern region of the mine is shown in **Figure 10**. The form of group B coal presents the characteristics of the northern coal seams merged and the southern coal seams bifurcated. As well, the thickness of the coal seam in the northwest is large, the thickness in the southeast is relatively small. The distance between the coal seams is 0-40 m.

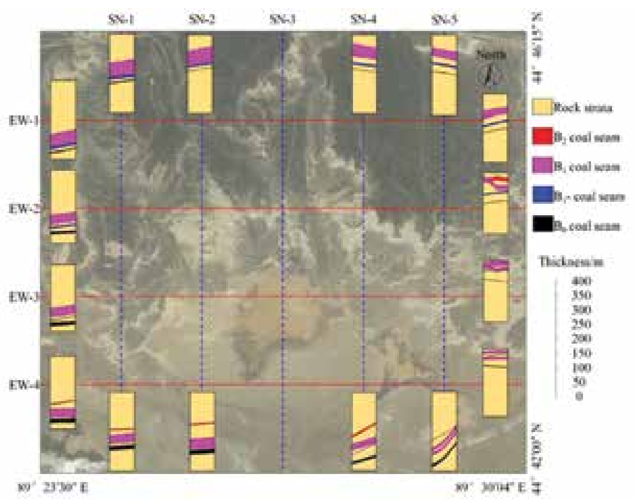


Figure 10: The section of group B coal at different positions in the mine.

It is generally believed that the formation of ultra-thick coal seam has experienced multiple sedimentary discontinuities, and it is an integration of multiple coal seams. Therefore, in the form of the ultra-thick coal seam, it has the remarkable characteristics of coal seams merging and bifurcating. As well, the form of group B in the Dajingnan Nº. 1 coal mine is verified for this.

From the perspective of coal seam form, there are two forms of ultra-thick coal seam: single ultra-thick coal seam and close distance thick coal seam group. Considering the influence of ultra-thick coal seam mining on the roof, the ultra-thick coal seam can be divided into two types: Type A, single ultra-thick coal seam and ultra-close distance thick coal seam group (the comprehensive mining thickness of the upper and lower coal seams is close to the sum of the upper and lower coal seams); Type B, close distance thick coal seam group (the comprehensive mining thickness of the upper and lower coal seams is less than the sum, the mining influence among coal seams is small). This paper focuses on the selection of mining technology for Type A ultra-thick coal seam.

CHANGE CHARACTERISTIC OF SUPPORT LOAD IN ULTRA-THICK COAL SEAM MULTI-LAYER MINING

Based on evolution process of roof bearing structure in ultra-thick coal seam multi-layer mining, the support load

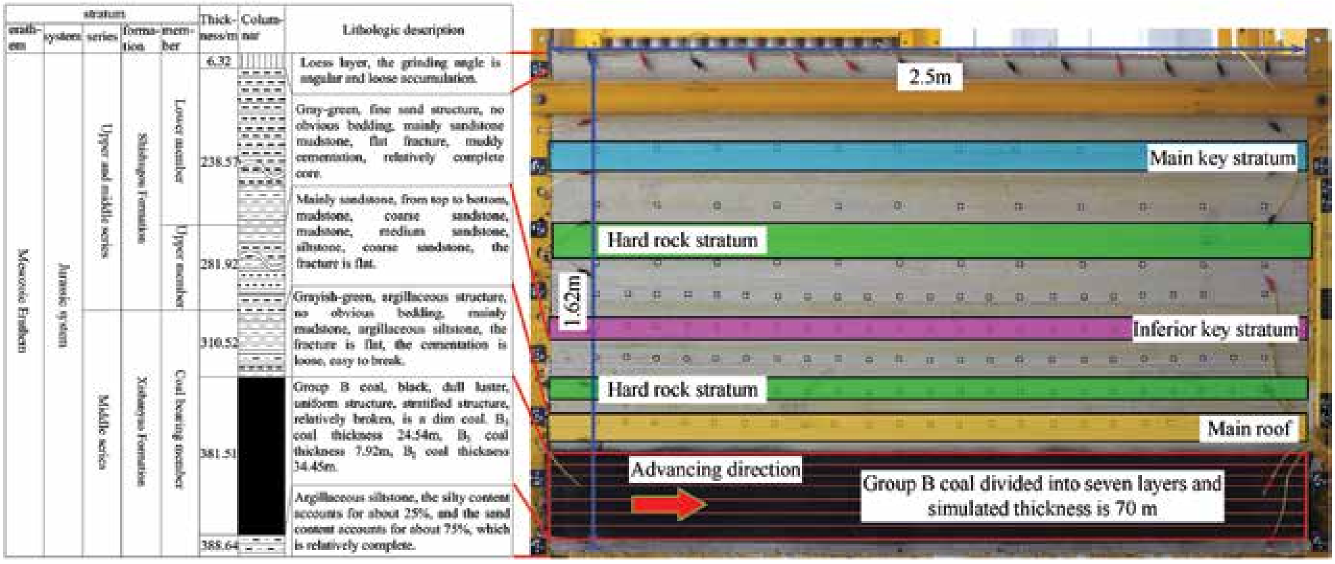


Figure 11: Stratigraphy information and physical model.

and its change characteristic under different roof bearing structures are analyzed theoretically.

Evolution Process of Roof Bearing Structure in Multi-Layer Mining of Ultra-Thick Coal Seam

The physical model is constructed for analyzing the evolution process of roof bearing structure in ultra-thick coal seam multi-layer mining, based on the occurrence conditions of group B coal at Dajingnan No. 1 coal mine. The stratigraphy information and model is shown in **Figure 11**.

It has dimensions of 2.5 m (length) by 0.2 m (width) by 1.62 m (height), with the geometric ratio of 1:240 (model to *in situ*). The length of the simulated coal seam is 415 m and the overburden thickness is 310 m. There are 92.5 m boundary pillars at both ends of the model to minimize the boundary effects. The overburden lithology is dominated by fine sandstone and mudstone. The uniaxial compressive strength of fine sandstone is 17.46 MPa, the cohesive force is 1.81 MPa, and the uniaxial compressive strength of mudstone is 14.21 MPa, and the cohesive force is 1.41 MPa. With reference to the current mining methods in the area, ultra-thick coal seam is mined in seven layers with a thickness of 10 m.

In the process of multi-layer mining, the roof bearing structure shows the evolution process of “beam structure – higher beam structure – arch structure”, as shown in **Figure 12**[22]. With the increase of total coal seam mining thickness, roof bearing structure keeps moving upward, and the height of caving zone increases. The support load changes due to the range increase of instability strata.

Change Characteristic of the Load on Support under Different Roof Bearing Structures

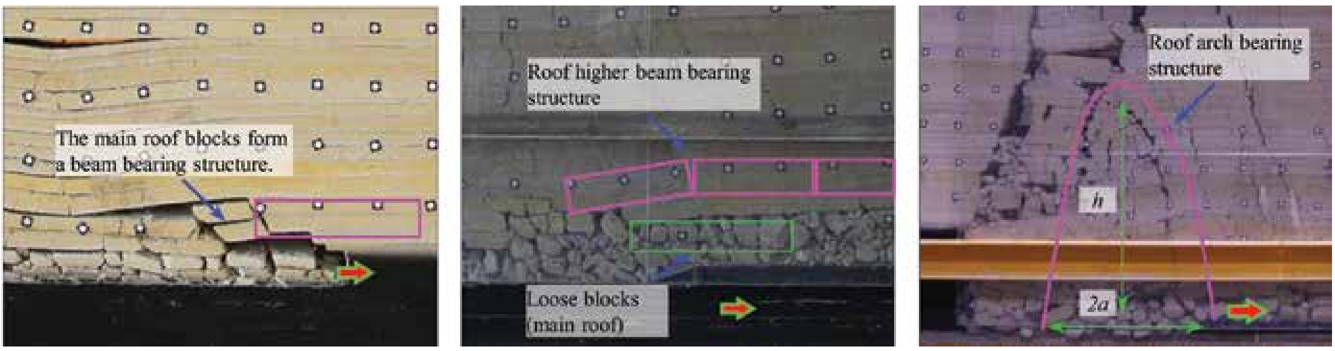
Support Load under Roof Beam Bearing Structure

At the early stage of multi-layer mining, collapse rock blocks can effectively support the overlying strata, and broken main roof blocks form a beam bearing structure. The support load is mainly the gravity load of immediate roof and top coal and the load caused by rotary subsidence of the main roof blocks, as shown in Figure 13. Considering that top coal and immediate roof are thick and the breakage length of main roof is big, the support load can be known from **Equation 1**[23]

Equation 1

$$P=\sum h_i\gamma_i l_m+\left[1-\frac{L\tan(\varphi-\theta)}{2(H-\Delta)}\right]Q$$

where P is the support load; h_i and γ_i are the thickness and volume force of the i-th stratum (top coal) under the main roof, respectively; l_m is the roof control distance; L is the periodic breakage length of the main roof. As well,



(a) Beam bearing structure (b) Higher beam bearing structure (c) Arch bearing structure

Figure 12: Evolution process of roof bearing structure in multi-layer mining.

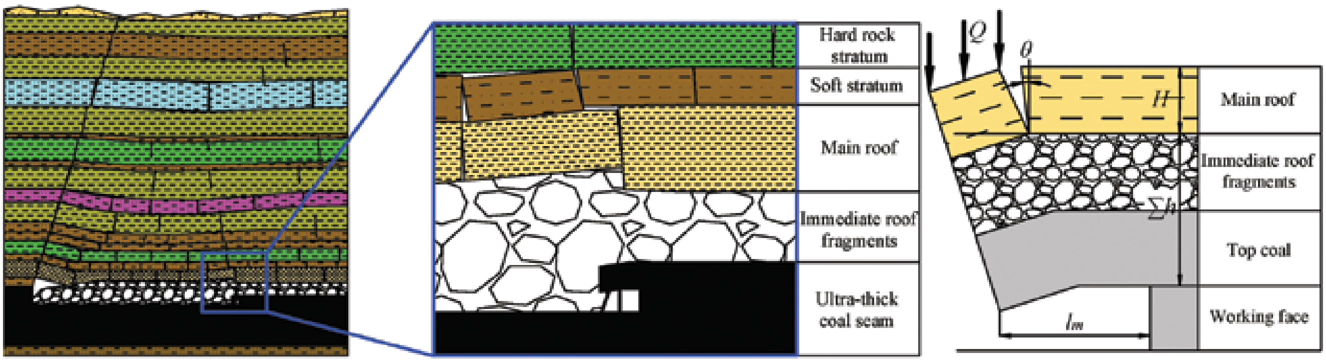


Figure 13: Relationship between support and surrounding rock under roof beam bearing structure.

θ is the main roof fracture angle; ϕ is the internal friction angle of the main roof; *H* is the main roof thickness; ∆ is the subsidence of the main roof; *Q* is the weight of the broken main roof blocks and the load on the blocks.

Support Load under Roof Higher Beam Bearing Structure

At the middle stage of multi-layer mining, the hinge of broken main roof blocks weakens, and broken blocks of the higher hard rock stratum hinge to form a higher beam bearing structure. At this time, although the hard rock stratum above the working face has been broken at early stage of mining, the broken hard rock blocks can still bear the weight of the upper rock strata in the form of cantilever beam, because of small suspension length and high strength.

The load on support is mainly resulted from the weight of blocks under the hard rock stratum and the rotation of the broken rock blocks in the hard rock stratum, as shown in **Figure 14a**. The force condition of roof is similar to that under roof beam bearing structure, and the load on support can be obtained from **Equation 1**. The corresponding main roof parameters are replaced by those of the hard rock stratum forming the higher beam bearing structure.

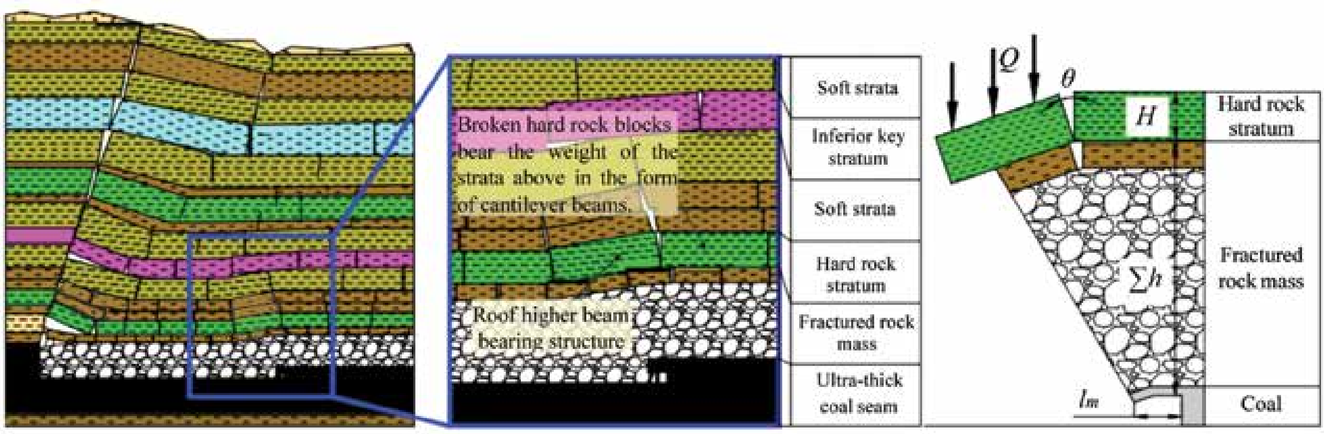
If the roof higher beam bearing structure is far away from the stope, the load generated by the rotary subsidence of the broken hard rock block is transmitted to the goaf, as shown in **Figure 14b**. The load on support is the gravity load of rock blocks under the hard rock stratum and can be obtained from **Equation 2**.

Equation 2

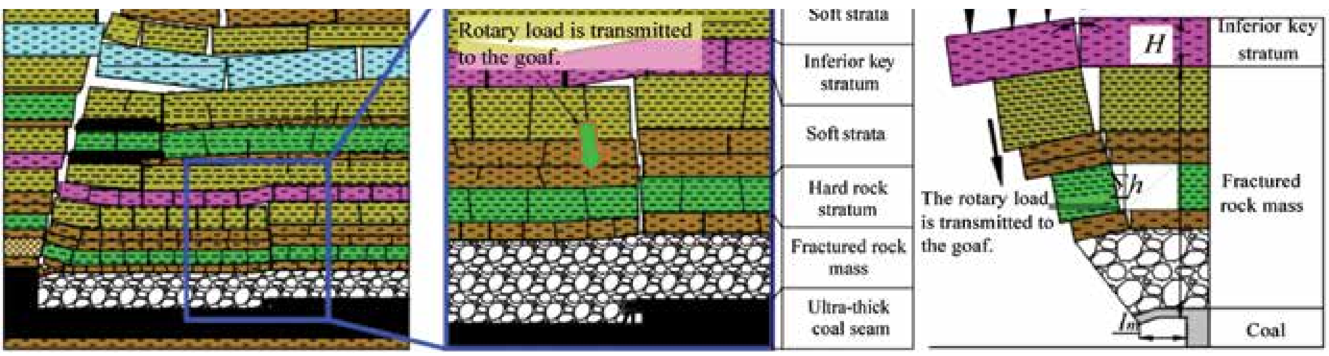
$$P = \sum h_i \gamma_i l_m$$

Support Load under Roof Arch Bearing Structure

At the later stage of mining, with the increase of mined volume of rock mass, the hinged structure within the hard rock stratum



(a) Hard rock stratum is close to stope



(b) Hard rock stratum is far from stope

Figure 14: Relationship between support and surrounding rock under roof higher beam bearing structure.

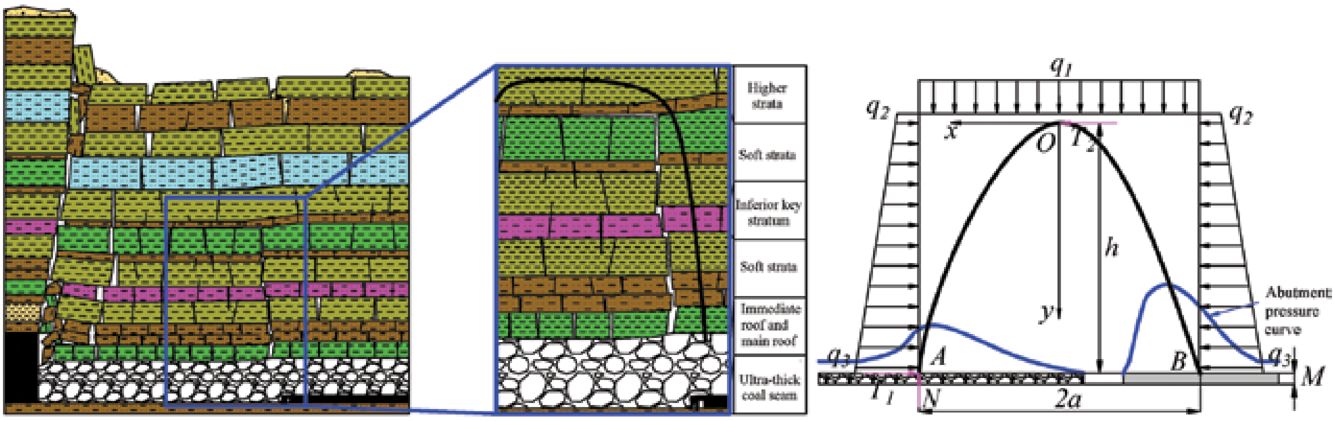


Figure 15: Relationship between support and surrounding rock under roof arch bearing structure.

fails, leading to the roof higher beam bearing structure instability. As well, roof bearing structure is gradually moved upward, the upper rock blocks are compressed together to form an arch bearing structure. The support load is mainly from the gravity load of loose blocks in the arch, as shown in **Figure 15**.

The essence of roof arch bearing structure is pressure arch *AOB*, which formed by the mutual extrusion of overburden broken rock blocks. As well, the arch foot is at peak of abutment pressure in the goaf and coal body in front of working face. Pressure arch can withstand compressive stress but cannot withstand bending stress. The loads acting on the pressure arch include weight of rock strata above the arch bearing structure (q_1) and lateral pressure (q_2 and q_3). Taking the *AO* section for analysis, the vault *O* is affected by the horizontal force T_2, and the arch foot *A* affected by the horizontal force T_1 and the supporting force *N*. The balance condition of pressure arch is that bending moment and the shear force are 0 at any point on the arch line *AOB*. According to the balance condition of the model, **Equations 3** and **4** can be obtained, and 2a is pressure arch span.

Equation 3

$$T_2 h - \frac{1}{2} q_1 a^2 - \int_0^h \left(q_2 + \frac{q_3 - q_2}{h} y \right) \mathrm{d}y = 0$$

Equation 4

$$T_2 = T_1 + \int_0^h \left(q_2 + \frac{q_3 - q_2}{h} \right) \mathrm{d}y = 0$$

Equation 5

$$T_1 = Nf = q_1 a f$$

Equation 6

$$\left(\frac{2}{3} q_2 + \frac{1}{3} q_3 \right) h^2 + 2 a q_1 f h - q_1 a^2 = 0$$

$$h = \frac{q_1 a}{q_1 f + \sqrt{q_1^2 f^2 + q_1 \left(\frac{2}{3} q_2 + \frac{1}{3} q_3 \right)}}$$

where *f* is static friction coefficient of the surrounding rock, *f* = tanϕ, and ϕ is internal friction angle of surrounding rock in the goaf.

If $q_2 = q_3 = \lambda q_1$, **Equation 7** can be obtained.

Equation 7

$$h = \frac{a}{f + \sqrt{f^2 + \lambda}}$$

With the advance of the working face, the arch span increases. When the pressure arch becomes unstable, the roof pressure is the maximum gravity load of the loose blocks in the arch, as shown in **Equation 8**.

Equation 8

$$P = \sum h_{1i} \gamma_{1i} l_m$$

where h_{1i} and γ_{1i} are the thickness and volume force of the i-th loose body layer below the roof arch bearing structure, respectively.

Support Load Change Characteristic under Different Roof Bearing Structures

The above analysis makes clear calculation method of the support load under different roof bearing structures. When it is roof beam bearing structure, roof pressure usually reaches the maximum value during the first layer mining. When under other roof bearing structure, it is necessary to determine the position of hard rock stratum that can form stable bearing structure firstly, and then determine the form of roof bearing structure by comparing with pressure arch height, the support load value can be obtained finally.

a. Discrimination of Roof Bearing Structure Form

In the rest of the layers mining, rotation angle of broken hard rock blocks can be obtained from **Equation 9**.

Equation 9

$$\sin\beta = \frac{1}{l}[M - H_1(K_{P'} - 1) - H_2(K_{P''} - 1)] = \frac{1}{l}[M - H_3(K_P - 1)]$$

where *β* is rotation angle of broken hard rock blocks; *M* is the thickness of mining layer of coal seam; H_1 and K_p'

are thickness and residual expansion of caving zone under the roof bearing structure, respectively. H_2 and Kp" are thickness and residual expansion of fissure zone under the roof bearing structure, respectively. As well, H3 and Kp are thickness and residual expansion of rock strata under the roof bearing structure, respectively. l is periodic breakage length of hard stratum.

Equation 10 can be obtained from **Equation 9**.

Equation 10

$$\frac{H_3}{M} = \left(1 - \frac{l}{M}\sin\beta\right) / (K_p - 1)$$

In Dajingnan No.1 coal mine, the slicing mining thickness is 10 m and periodic breakage length of the hard stratum is 25-30 m. When Kp is 1.1 and maximum rotation angle of broken hard rock blocks is 5-8°, it can be obtained as follow.

Equation 11

$$\frac{H_3}{M} = (1 - 3\sin\beta) / (1.1 - 1) = 5.82\text{-}7.39$$

Equation 12

$$H_3 = (5.82\text{-}7.39)\, M$$

Therefore, when there is a hard rock stratum at H_3 above the roof and H_3 < pressure arch height h, the roof bearing structure is a higher beam bearing structure, and the thickness of rock strata between the roof bearing structure and stope is H_3. When there are hard rock strata at H_3 above the roof and H_3 > pressure arch height h, the roof bearing structure is an arch bearing structure. In other cases, the height of roof bearing structure is less than H_3.

b. Support Load under Different Roof Bearing Structure

The slicing mining thickness of group B coal is 10 m in Dajingnan No.1 coal mine. The evolution process of roof bearing structure and the loading condition of the support under different roof bearing structures are shown in **Figure 16**.

In the first and second layers mining process, the form of roof bearing structure is beam bearing structure, and the load on support is the largest during the first layer mining. In the first layer mining process, as shown in the **Figure 13a**, the length and thickness of the broken main roof blocks are 27.96 m and 20 m respectively, and roof control distance is 7 m, according to engineering and geological conditions. The main roof block is subjected to gravity load of the strata under the inferior key stratum. So the maximum support load (P_1) is 10463.37 kN in the first layer mining.

Equation 13

$$P_1 = \sum h_i \gamma_i l_m + \left[1 - \frac{L\tan(\varphi - \theta)}{2(H - \Delta)}\right] Q = (9.8 \times 25 + 5 \times 17)$$
$$\times 7 + \left[1 - \frac{27.96 \times \tan 30^\circ}{2 \times (20 - 6.08)}\right] (27.96 \times 28 \times 25$$

In the third and fourth layers mining process, the roof bearing structure is higher beam structure. During the third layer mining, as shown in the **Figure 13b**, the main roof blocks collapse, and the broken hard rock blocks 37.8 m away from the stope hinge to form a roof higher beam bearing structure, and the length and thickness of the blocks are 30.53 m and 14.7 m respectively. The block of hard rock stratum is subjected to gravity load of the strata under the inferior key stratum, and the support load (P_2) is 12549.25 kN.

Equation 14

$$P_2 = h_i \gamma_i l_m + 1 - \frac{L\tan(\phi - \theta)}{2(H - \Delta)} Q = (37.8 \times 25 + 5 \times 15)$$
$$\times 7 + 1 - \frac{30.53 \times \tan 30^\circ}{2 \times (14.7 - 3.68)} (30.53 \times 35.4 \times 25) = 12549.25 \text{ kN}$$

In the fourth layer mining, the broken rock blocks in inferior key stratum form a roof higher beam bearing structure, as shown in **Figure 13c**. Since the roof bearing structure is far from the stope, the support load (P_3) is gravity load of the strata under the inferior key stratum, which is 13160 kN. Compared roof pressure with that under the roof beam bearing structure, the variation range is 25.77%.

Equation 15

$$P_3 = \sum h_i \gamma_i l_m = (72.2 \times 25 + 5 \times 15) \times 7 = 13160 \text{ kN}$$

In the fifth and the rest of the layers mining, roof bearing structure is arch structure. Based on the simulation results [21], the pressure arch span is 210 m, and the pressure arch height is 144.2 m according to Equation (7) (**Figure 13d**). The maximum support load (P4) is 25760 kN, and the maximum of support load increases by 146.19% compared with the value under the roof beam bearing structure.

Equation 16

$$P_4 = \sum h_{li} \gamma_{li} l_m = (144.2 \times 25 + 5 \times 15) \times 7 = 25760 \text{ kN}$$

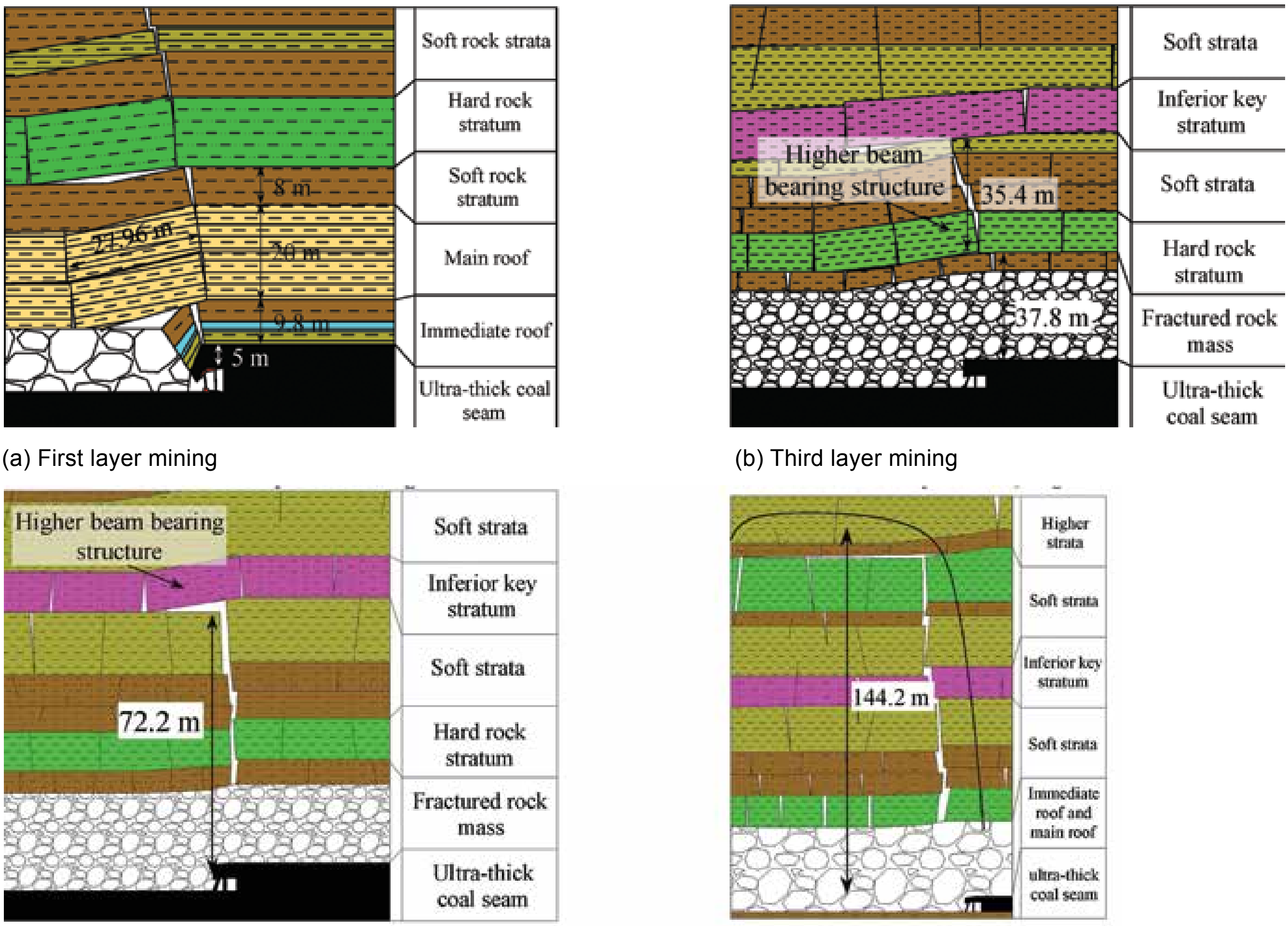
At the early stage of multi-layer mining, the form of roof bearing structure is beam or higher beam bearing structure, and the maximum support load is around 13,000 kN. At the later stage of mining, the form is arch bearing structure, the support load is close to 26,000 kN, and the current equipment is difficult to meet the needs. The variation of support load is small under beam and higher beam structure, while it increases greatly under arch structure.

CLASSIFICATION AND MINING TECHNOLOGY SELECTION OF ULTRA-THICK COAL SEAM

In order to realize safe mining of ultra-thick coal seam, this paper analyzes the height development characteristic of the roof bearing structure in multi-layer mining under different occurrence conditions, and classifies the ultra-thick coal seam with the occurrence conditions as the index. The suitable mining technologies are put forward.

Height Development Characteristics of Roof Bearing Structure in Multi-layer Mining

The dip angle of ultra-thick coal seam is between 0° and



(a) First layer mining (b) Third layer mining

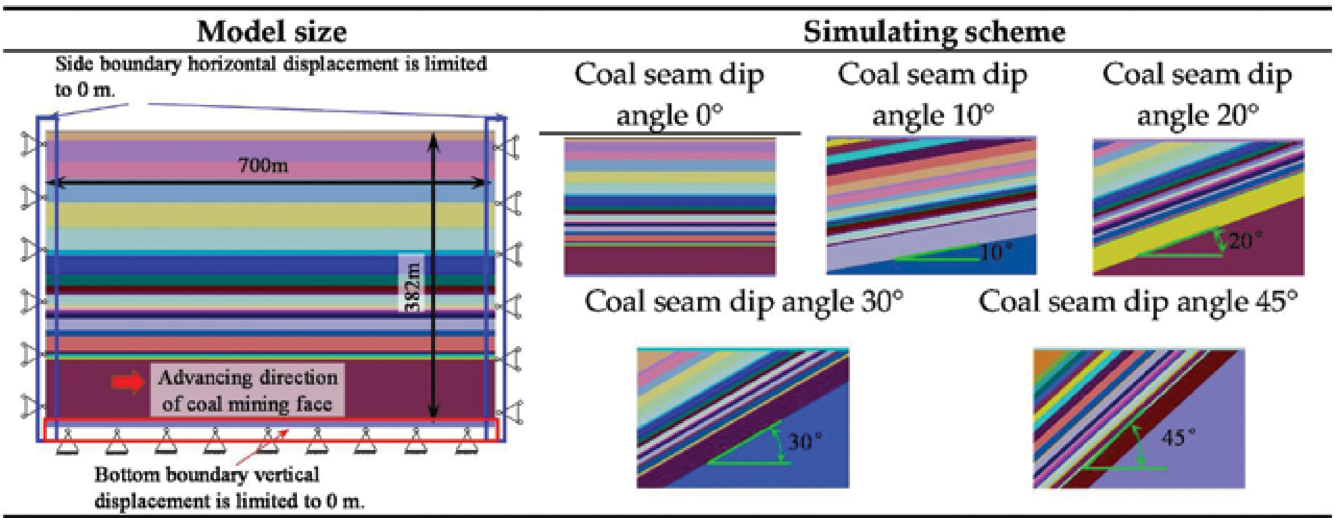
(c) Fourth layer mining (d) Fifth layer mining

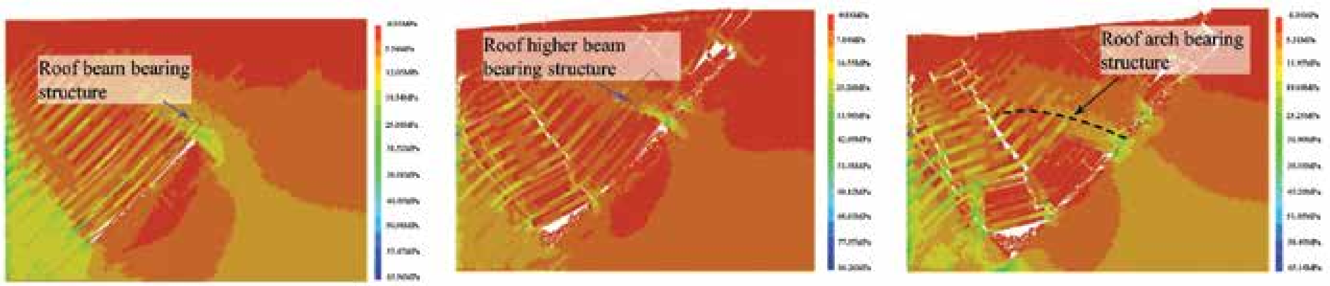
Figure 16: Loading condition of the support under different roof bearing structures.

54°, and there are differences in strata failure process under different dip angles in multi-layer mining. Based on the conditions of the group B coal at the Dajingnan No. 1 coal mine, GPU Continuum-based Discrete Element Method software (GDEM, GDEM Technology, Beijing, Co., Ltd., Beijing, China) was used to conduct numerical simulation analysis on the height development process of the roof bearing structure under different coal seam dip angles.

The model size is 700 m (length) by 382 m (height), and the vertical direction is from the coal floor to the surface. The boundary conditions are shown in Table 1, where the side and bottom boundary displacement are constrained, and the upper boundary is representing the free surface. The total thickness of the coal seam is 70 m, divided into seven mining layers. A total of 500 m of each multi-layer is extracted, and there are 100 m wide barrier pillar left to minimize the boundary effects. The dip

Table 1: Simulating scheme of roof bearing structure height development characteristics under different dip angles.





(a) 1st layer extraction (roof beam bearing structure)
(b) 4th layer extraction (roof higher beam bearing structure)
(c) 7th layer extraction (roof arch bearing structure)

Figure 17: Evolution process of roof bearing structure of inclined ultra-thick coal seam (coal seam dip angle 45°).

angles of coal seam are selected as 0°, 10°, 20°, 30° and 45°, respectively. The simulation scheme is shown in **Table 1**.

In the process of multi-layer mining of inclined ultra-thick coal seam, as shown in **Figure 17**, roof bearing structure shows the evolution process of "beam structure-higher beam structure-arch structure", which is consistent with the multi-layer mining of horizontal ultra-thick coal seam.

The position of roof bearing structure is determined by the peak position of the maximum principal stress. The change curve of roof bearing structure development height is shown in **Figure 18**.

As increase of the total mining thickness of coal seam (Mt), the roof bearing structure gradually moves up and stabilizes at 150 m (pressure arch height h) above the coal seam. Moreover, with increase of coal seam dip angle, the sensitivity of roof bearing structure increases, the stability weakens and the development speed is faster. If dip angle of coal seam is less than 20°, the roof bearing structure is relatively stable, and height of roof bearing structure develops to around 150 m above the coal seam at a total mining thickness of 70 m. If dip angle of coal seam is more than 20°, the roof bearing structure is more sensitive. When the dip angle of coal seam is 30° and 45°, the height of roof bearing structure develops to 150 m at a total mining thickness of 60 m and 40 m, respectively.

The support load is different under different roof bearing structures. In order to classify ultra-thick coal seams, roof bearing structure form is taken as the classification basis, and overlying strata thickness (H_M), roof bearing structure height (Hn) and pressure arch height (h) are taken as the classification indexes. The ultra-thick coal seams classified as shown in **Table 2**.

According to the form of roof bearing structure, ultra-thick coal seams can be divided into three types:

a. If $H_M < H_n$, ultra-thick coal seam belongs to type I coal seam. There is no stable bearing structure in the roof strata, and the support load at the later stage of mining is all or most of gravity load of overburden strata.
b. If $H_n < h$ and $H_n < H_M$, ultra-thick coal seam belongs to type II coal seam. The roof bearing structure is (higher) beam structure, and the support load is the gravity load of rock strata under the bearing structure and the load caused by the rotary subsidence of broken hard rock blocks.
c. If $H_n \geq h$ and $h < H_M$, ultra-thick coal seam belongs to type III coal seam. At the later stage of mining, the roof bearing structure is arch structure, and the load on support is mainly the gravity load of loose blocks under the arch.

Mining Technology Selection of Ultra-thick Coal Seam

At the later stage of the multi-layer mining, the roof bearing structure evolves into arch bearing structure, and the load on support rises from 13,000 kN to 26,000 kN, and the current equipment is difficult to meet. In order to reduce the stope roof pressure, suitable mining technology should be selected to control the form and height of the roof bearing structure and reduce the range of rock strata that transmits gravity load.

From the above analysis, it can be seen that the artificial controllable factor of the roof bearing structure

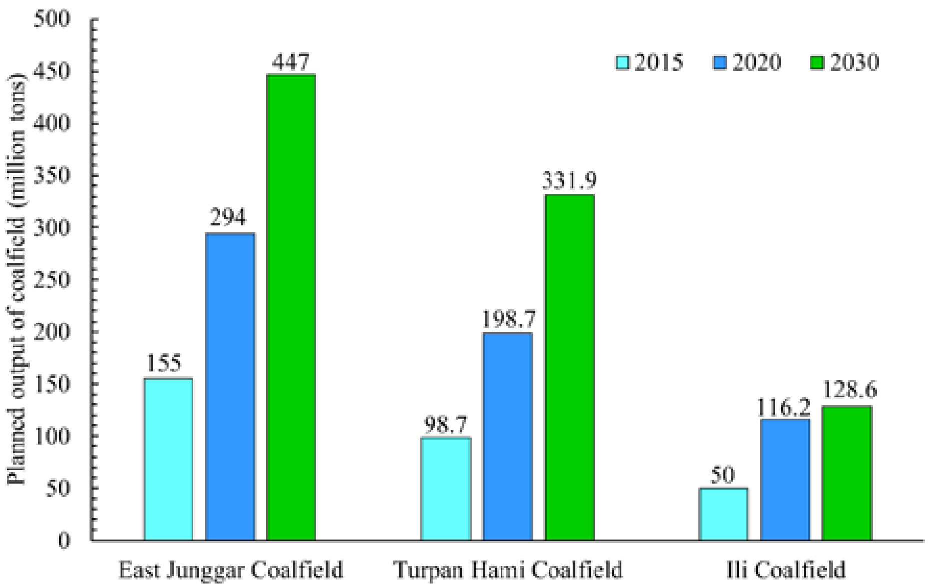


Figure 18: Change curve of the roof bearing structure development height under different dip angle coal seam.

Table 2: Classification of ultra-thick seams.

Types	Classification conditions	Roof bearing structure form	Development height of roof bearing structure (Hn)
Type I coal seam	$H_M < H_n$	no stable bearing structure	Dip angle of coal seam α ≤ 20°;
		(higher) beam bearing structure	$H_{n1} = 100M_t/(0.207M_t + 25.29)$ 22.6
Type II coal seam	$H_n < h$ and $H_n < H_M$		20° < dip angle of coal seam α < 30°;
			$H_{n2} = 100M_t/(0.268M_t + 14.36) - 44.29$
Type III coal seam	$H_n \geq h$ and $h < H_M$	arch bearing structure	30° ≤ dip angle of coal seam α;
			$H_{n3} = 100M_t/(0.288M_t + 5.02) - 101.6$

form is the slicing mining thickness in multi-layer mining of ultra-thick coal seam. The smaller slicing mining thickness of coal seam is, the smaller rotation angle of broken rock block in hard stratum is, and the more stable the (higher) beam bearing structure is. However, as the number of slicing mining layers increases, on the one hand, thick and hard rock strata separate easily along the weak structural plane, resulting in blocks secondary breakage, which reduces the stability of the bearing structure. On the other hand, production costs increase. On the premise that the slicing mining thickness can meet the production demand, shortwall mining and backfill mining should be adopted to reduce equivalent mining thickness of the coal seam, limit the movement space of roof strata, and control the roof bearing structure form and development height. Therefore, the mining technology selection for ultra-thick coal seam should be based on the principle of "ensuring the stability of near-stope roof bearing structure", so as to avoid the appearance of the roof arch bearing structure and reduce the height of higher beam bearing structure.

Combined with the occurrence conditions, mining technology and classification standards, the underground mining technology of ultra-thick coal seam with average thickness of more than 20 m is studied. The main contents are shown in **Table 3**.

a. Type I ultra-thick coal seam that is not suitable for open pit mining
There is no stable bearing structure in the roof strata, and the load on support at the later stage of mining is from gravity load of rock strata under the bearing structure of the rock mass. Therefore, in order to reduce support load, backfill mining is adopted to reduce equivalent mining thickness, improve the stability of beam bearing structure, and control the development of caving zone.

b. Type II ultra-thick coal seam
For ultra-thick coal seam with small dip angle, height of the roof bearing structure is developed slowly, and the near-stope roof higher beam structure is more stable, so longwall mining can be adopted. For ultra-thick coal seam with large dip angle, the roof bearing structure is sensitive. At the later stage of mining, it is easy to form the far-stope higher beam structure. As well, the support load is easy to suddenly increase with the instability of the roof higher beam bearing structure, backfill mining is a better choice. If the coal thickness is around 20 m, the roof bearing structure has a small development height, ultra-thick seam can be mined by longwall mining.

c. Type III ultra-thick coal seam
The backfill mining should be adopted to reduce equivalent mining thickness so as to avoid the roof arch bearing structure. On the premise of ensuring reasonable development height of the roof bearing structure, longwall mining can be adopted at the early stage and backfill mining at the later stage. If total mining thickness is large, the hydraulic support is subjected to a large gravity load of the backfilled body when the slicing backfill mining is adopted, and the remaining part of the coal seam should not be mined.

CONCLUSIONS AND PROSPECTS

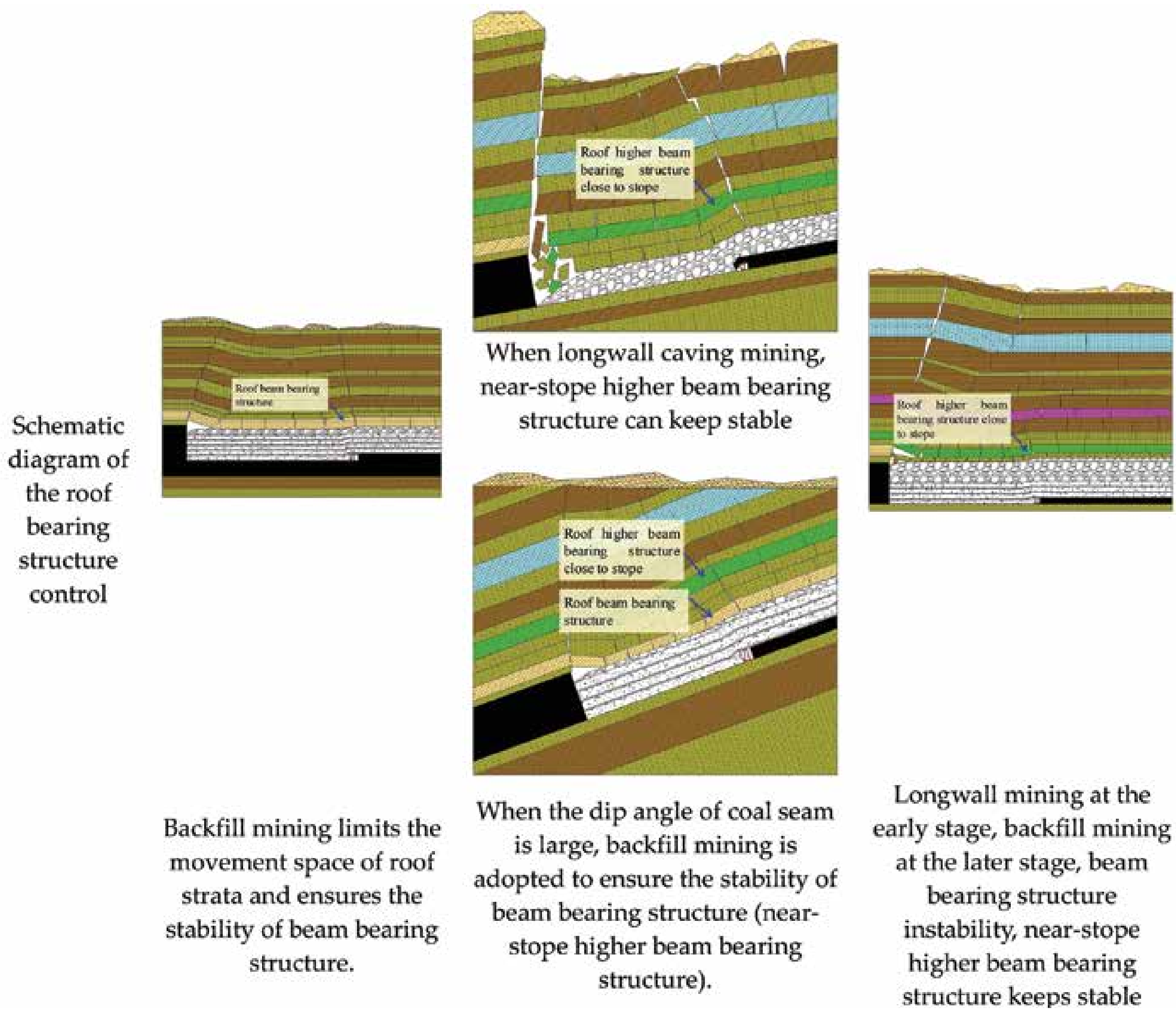
Based on coal resource exploration in Xinjiang, this paper analyzed the occurrence characteristic of ultra-thick coal seams in Xinjiang. The change characteristic of support load under different roof bearing structures in multi-layer mining of ultra-thick coal seam was studied. From the perspective of coal mining, classification and mining technology selection of ultra-thick coal seams were put forward.

The ultra-thick coal seams in Xinjiang have a distribution characteristic of more north and less south, more east and less west, mainly concentrate in East Junggar and Turpan-Harmi coalfields. The C8 coal seam of Shaerhu coal field and the group B coal seams of East Junggar coal field are the most representative ultra-thick coal seams, with coal seam thickness of 96.82 m and 70-90 m respectively, and the maximum thickness of C8 coal seam in the Shaerhu coalfield is 267.42m. The buried depth of the coal seam is between 300 m and 600 m, and the dip angle, number of layers and thickness of the coal seam change greatly. The form of the ultra-thick coal seam has the remarkable characteristic of coal seams merging and bifurcating.

Based on the evolution process of the roof bearing structure during ultra-thick coal seam multi-layer mining, the mechanical model of the relationship between the support and surrounding was established, considering different roof bearing structures. As well, the change characteristic of support load in multi-layer mining of a

Table 3: Selection of mining technology for typical ultra-thick coal seams in Xinjiang.

Types	Type I coal seam	Type II coal seam	Type III coal seam
Typical mining areas and coalfields	/	**Ili Coalfield:** The average thickness of 5# coal in Yining mining area is 21.36 m. The thickness of C1-C5 group coal in Nilka mining area is 26 m. **Turpan-Harmi Coalfield:** The thickness of 13 # coal in Toksun Heishan mining area is 32.09 m. **East Junggar Coalfield:** The average thickness of B2 coal in Jiangjunmiao mining area is 30.62 m.	**Turpan-Harmi Coalfield:** The average thickness of C8 coal in Shaerhu coalfield is 96.82 m. **East Junggar Coalfield:** The average thickness of B coal in Dajing mining area is 70 m.



typical ultra-thick coal seam in Xinjiang is studied. In the process of multi-layer mining, the roof bearing structure shows the evolution process of “beam structure-higher beam structure-arch structure”. At the early stage of multi-layer mining, the load on support is rotary subsidence load of the near-stope roof bearing structure and gravity load of rock strata under the bearing structure. At the later stage, the support load is mainly gravity load of loose blocks under the far-stope bearing structure. The change of support load is small under beam and higher beam bearing structures, while it increases greatly under arch bearing structure.

Based on the form and development height of the roof bearing structure under different occurrence conditions, classification method and mining technology selection of ultra-thick coal seam are put forward. Overlying strata thickness (H_M), roof bearing structure height (H_n) and pressure arch height (h) are taken as the ultra-thick classification indexes, and the mining technology selection principle of "ensuring the stability of the near-stope roof bearing structure" is proposed. Ultra-thick coal seam divides into three types: No stable bearing structure, (higher) beam bearing structure and arch bearing structure. In order to ensure the stability of the near-stope roof bearing structure, three types of ultra-thick coal seams should be mined by using backfill mining, longwall mining and early longwall mining, later backfill mining, respectively.

The occurrence conditions of ultra-thick coal seams in Xinjiang are complex and variable, the degree of exploration is low, and the surface ecological environment is also fragile. Large-scale mining of ultra-thick coal seams has just begun, a series of problems need to be studied systematically. In this paper, the distribution and occurrence characteristics of ultra-thick coal seams are studied. Based on the change characteristics of roof bearing structure and support load, classification of ultra-thick coal seams is proposed, and suggestion on the selection of mining technology is put forward.

In the actual mining process, it is necessary to balance relationship between the hydraulic support performance and coal recovery rate by flexibly selecting mining technology. Mining technological parameters, coal seam slicing thickness determination and measures of roof control technology are still the research focus in the field of ultra-thick coal seams reasonable and efficient mining.

REFERENCES

1. Volkov, V.N. Phenomenon of the Formation of Very Thick Coal Beds. Lithol. Miner. Resour. 2003, 38, 223-232. [CrossRef]
2. Wang, D.D.; Shao, L.Y.; Liu, H.Y.; Shao, K.; Yu, D.M.; Liu, B.Q. Research progress in formation mechanisms of super-thick coal seam. J. China Coal Society 2016, 41, 1487-1497.
3. Rošer, J.; Potocˇnik, D.; Vulic´, M. Analysis of Dynamic Surface Subsidence at the Underground Coal Mining Site in Velenje, Slovenia through Modified Sigmoidal Function. Minerals 2018, 8, 74. [CrossRef]
4. Khan, I.; Javed, A. Spatio-Temporal Land Cover Dynamics in Open Cast Coal Mine Area of Singrauli, M.P., India. J. Geogr. Inf. Syst. 2012, 4, 521-529. [CrossRef]
5. Zarlin, N.; Sasaoka, T.; Shimada, H.; Matsui, K. Numerical Study on an Applicable Underground Mining Method for Soft Extra-Thick Coal Seams in Thailand. Engineering 2012, 4, 739-745. [CrossRef]
6. Lin, N.; Sasaoka, T.; Shimada, H.; Hamanaka, A.; Matsuia, K. Numerical Analysis of Interaction Effects in Double Extra-thick Coal Seams Mining. Procedia Earth Planet. Sci. 2013, 6, 343-349. [CrossRef]
7. Islam, M.R.; Hayashi, D.; Kamruzzaman, A. Finite element modeling of stress distributions and problems for multi-slice longwall mining in Bangladesh, with special reference to the Barapukuria coal mine. Int. J. Coal Geol. 2009, 78, 91-109. [CrossRef]
8. Hu, S.R.; Lin, L.N.; Huang, C.; Chen, D.Y.; Hao, G.Q. Distribution and genetic model of extra-thick coal seams. Coal Geol China 2011, 23, 1-5.
9. Shearer, J.C.; Staub, J.R.; Moore, T.A. The Conundrum of Coal Bed Thickness: A Theory for Stacked Mire Sequences. J. Geol. 1994, 102, 611-617. [CrossRef]
10. Large, D.J.; Marshall, C. Use of carbon accumulation rates to estimate the duration of coal seams and the influence of atmospheric dust deposition on coal composition. In Strata and Time: Probing the Gaps in Our Understanding; Geological Society: London, UK, Special Publications, 2014. [CrossRef]
11. Nadon, G.C. Magnitude and timing of peat-to-coal compaction. Geology 1998, 26, 727. [CrossRef]
12. Diessel, C.; Boyd, R.; Wadsworth, J.; Leckie, D.; Chalmers, G. On balanced and unbalanced accommodation/peat accumulation ratios in the Cretaceous coals from Gates Formation, Western Canada, and their sequence-stratigraphic significance. Int. J. Coal Geol. 2000, 43, 143-186. [CrossRef]
13. Diessel, C.F. Utility of coal petrology for sequence-stratigraphic analysis. Int. J. Coal Geol. 2007, 70, 3-34. [CrossRef]
14. Wu, C.; Li, S.; Wang, G.; Liu, G.; Kong, C. The allochthonous genesis model about the extra-thick and high-quality coalbed in Xianfeng basin, Yunnan Province, China. Front. Earth Sci. China 2007, 1, 97-105. [CrossRef]
15. Holz, M.; Kalkreuth, W.; Banerjee, I. Sequence stratigraphy of paralic coal-bearing strata: An overview. Int. J. Coal Geol. 2002, 48, 147-179. [CrossRef]
16. Jerrett, R.M.; Davies, R.C.; Hodgson, D.M.; Flint, S.S.; Chiverrell, R.; Chiverrell, R. The significance of hiatal surfaces in coal seams. J. Geol. Soc. 2011, 168, 629-632. [CrossRef]
17. Li, Z.X.; Wang, D.D.; Lv, D.W.; Li, Y.; Liu, H.Y.; Wang, P.L.; Liu, Y.; Liu, J.Q.; Li, D.D. The geologic settings of Chinese coal deposits. Int. Geol. Rev. 2018, 60, 548-578. [CrossRef]
18. Zhang, D.S.; Liu, H.L.; Fan, G.W.; Wang, X.F. Connotation and prospection on scientific mining of large Xinjiang coal base. IJMME 2015, 32, 1-6.
19. Li, Y.H.; Zhao, F.H.; Nie, H.G. Jurassic coal accumulation law of main coal-bearing basins in Eastern Xinjiang; Science Press: Beijing, China, 2015.
20. Li, J.; Zhuang, X.G.; Querol, X.; Font, O.; Moreno, N.; Zhou, J.B.; Lei, G.M. High quality of Jurassic coals in the Southern and Eastern Junggar Coalfields, Xinjiang, NW China: Geochemical and mineralogical characteristics. Int. J. Coal Geol 2012, 99, 1-15. [CrossRef]
21. Zhou, J.; Zhuang, X.; Alastuey, A.; Querol, X.; Li, J. Geochemistry and mineralogy of coal in the recently explored Zhundong large coal field in the Junggar basin, Xinjiang province, China. Int. J. Coal Geol. 2010, 82, 51-67. [CrossRef]
22. Wang, X.F.; Qin, D.D.; Zhang, D.S.; Guan, W.M.; Xu, M.T.; Wang, X.L.; Zhang, C.G. Evolution characteristics of overburden strata structure for ultra-thick coal seam multi-layer mining in Xinjiang east Junggar basin. Energies 2019, 12, 332. [CrossRef]
23. Jin, Z.M. Theory and Technology of Top Caving Coal Mining; China Coal Industry Publishing House: Beijing, China, 2001; pp. 1-258.

AUTHORS

Dongdong Qin, Xufeng Wang, Dongsheng Zhang , Weiming Guan, Lei Zhang and Mengtang Xu

Biden infrastructure programs could save miners

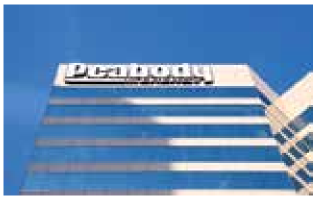
The world's largest coal producer, Peabody Energy is at risk of going bankrupt for the second time in five years. It's all a function of the demand for coal, especially now during the coronavirus. But the potential trouble is indicative of something much bigger – the transition from coal to natural gas and renewables.

The future of thermal coal used to make electricity is not bright. But metallurgical coal has a role in the production of steel. And this is where Peabody and others like Arch Resources are placing their bets. "Met" coal is used to make 70% of the world's steel and once the pandemic subsides, economic growth will resume.

And therein is the potential path forward for President-elect Biden and a possible Republican-dominated US Senate: building better bridges, ports and transmission systems is a good thing that enjoys wide support.

"Suffice to say, we've had a tough year here," Peabody's chief executive Glenn Kellow said on a conference call recently. "Market conditions have and continue to severely impact customer demand … The combined risks associated with our recent financial results, market conditions, additional collateral demands and potential credit agreement non-compliance raise substantial doubt about…our ability to continue as a going concern."

Peabody told investors that it had lost $67 million in the third quarter while coal sales fell by 23%. Meantime, revenues from the sales of met coal used to make steel fell by more than 63%. However, Kellow says that he is optimistic that this segment will pick back up – at some unknown point in time.



Japan needs to cut its addiction to meet climate pledge

Japan will need to more than quadruple the pace at which it shuts down coal plants and rapidly ramp up renewable energy capacity over the next decade to meet its new climate pledge to zero out emissions by 2050.

New Prime Minister Yoshihide Suga confirmed that the world's fifth largest emitter and third biggest economy will become the latest country to set a goal in line with the Paris Agreement to limit global warming.

It comes after China announced it would go carbon neutral by 2060 and European Union ministers agreed to a binding 2050 climate neutrality goal. Currently six countries around the world have set the mid-century in law with several more to follow, according to the Energy and Climate Intelligence Unit.

While all new long-term goals set a direction of travel for investors and have been widely welcomed, details on how they plan to get there are currently lacking.

A spokesman for United Nations Secretary-General Antonio Guterres said he looks forward to "concrete policy measures" from Japan, including a revised 2030 climate target, known in UN terms as a Nationally Determined Contribution.

Currently Japan's 2030 climate policy published earlier this year is out of kilter with the new target. The NDC isn't ambitious enough to deliver on the mid-century goal, and the government has said it'll be updated.

Coal accounts for more than a third of Japan's power needs – a share that rose after the Fukushima nuclear disaster in 2011 that led the government to mothball its atomic fleet.

Despite a government plan announced earlier this year to close 100 inefficient coal-fired power plants, Japan is still targeting coal to provide about a quarter of the nation's power needs by 2030 under its current plans.

Japan needs to "start decommissioning coal power – and as an absolute minimum, Japanese companies must stop building and financing new coal power abroad," said Eric Pedersen, head of responsible investments at Nordea Asset Management.

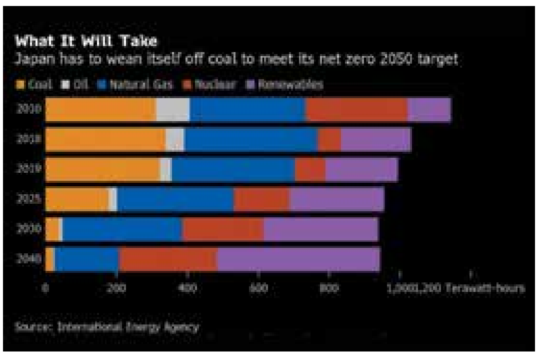
To fall in line with the Paris Agreement, Japan's use of coal would need to fall to just 4% of the energy mix by 2030, the IEA says. In that scenario, coal power capacity would drop from 51 gigawatts in 2019 to 17 gigawatts by 2040.

Japan may change its 2030 power mix goals, which are currently being reviewed by a panel of specialists and could be revised in the nation's basic energy plan next year, said Minister of Economy, Trade and Industry Hiroshi Kajiyama.

In that same Sustainable Development Scenario, renewable sources such as solar, wind and hydropower would need to account for a third of energy by 2030. By 2040, renewables would be supplying almost half of all power.

Japan's announcement marks an important shift for a country that has historically slowed progress in international climate talks, says Rachel Cleetus, policy director and lead economist at the Union of Concerned Scientists.

"We are seeing this as a hopeful sign that a pivot moment is coming and because of that we're going to want to see what the details are – what is the commitment that is going to happen by 2030," she said.



The new KOMATSU PC 3000-6 has a new cab, but that's not all. Improvements have been targeted to raise productivity. Whether it is the new hydraulic management control for faster cycle time, robust undercarriage for extended life or re-designed service points to reduce on-board maintenance time, it's there to improve on the existing superior standard of safety and reliability.

High digging performance, service friendly and extended reliability - insist on the PC 3000-6 for a profitable investment in productivity.

KOMATSU

THE NEW PC 3000-6

Optimising the detail

KOMATSU Germany GmbH
Buscherhofstrasse 10, D-40599 Düsseldorf, Germany.

KMG Warrington
8 Gawsworth Court, Risley Road, Birchwood, Warrington, Cheshire, WA3 6NJ. UK
Tel: +44 (0)1925 830344 Fax: +44 (0)1925 830058

www.komatsu-mining.de