SIGURNOSNI RIZICI I MJERE ZAŠTITE PRI POVRŠINSKOM MINIRANJU

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Izvorni naučni rad

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Sažetak:
Miniranje na površinskim kopovima predstavlja jedan od najsloženijih i najrizičnijih procesa u rudarskoj praksi, gdje sigurnost ljudi i infrastrukture direktno zavisi od pravilnog planiranja, tehničke kontrole i poštivanja propisanih mjera zaštite. Ovaj rad daje sistematičan prikaz rizika koji prate sve faze površinskog miniranja, od bušenja i punjenja bušotina do detonacije i postdetonacione inspekcije, te definira ključne tehničke i organizacione mjere za njihovu prevenciju. Posebna pažnja posvećena je eksplozivnim, seizmičkim i akustičkim utjecajima, čija se kontrola vrši primjenom empirijskih modela, seizmičkog monitoringa i adekvatnog projektovanja minskih polja. U radu su analizirani relevantni zakonski propisi, međunarodni standardi i evropske direktive koji uređuju rukovanje eksplozivima, sigurnosne udaljenosti i obavezne postupke nadzora. Uloga geofizičkih metoda posebno je naglašena kao važan alat u planiranju sigurnih miniranja, jer iste omogućavaju identifikaciju nestabilnih zona i precizno određivanje geoloških parametara koji utiču na raspodjelu energije eksplozije. Dobijeni rezultati ukazuju na potrebu integrisanog pristupa koji povezuje tehničke, zakonske i organizacione mjere, čime se postiže viši nivo sigurnosti, efikasnosti i kontrole nad neželjenim efektima miniranja u površinskim eksploatacionim radovima.

***Ključne riječi:** miniranje na površini, mjere zaštite, eksplozivni rizici, seizmički utjecaji, neeksplodirana sredstva, sigurnosne zone, geofizičke metode, zakonski propisi, organizacioni rizici*

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1. Uvod

Miniranje na površini bilo da se izvodi na trasama, gradilištima, infrastrukturnim zonama ili eksploatacionim lokalitetima predstavlja jednu od najrizičnijih faza tehničkih operacija, s obzirom na prisustvo eksplozivnih materijala, dinamične sile, fragmentaciju stijenske mase i neposrednu izloženost radnika potencijalno štetnim utjecajima [1-3]. Zbog toga, mjere zaštite na radu u ovom segmentu zahtijevaju strogu tehničku, organizacionu i zakonsku kontrolu.

Prema podacima Administracije za sigurnost i zdravlje u rudnicima (Mine Safety and Health Administration-MSHA), svaka faza miniranja od skladištenja i transporta eksploziva do detonacije i pregled nakon provedenog miniranja mora biti regulisana preciznim protokolima kako bi se spriječile nesreće, povrede i štete na opremi [4]. Zaštita na radu ne podrazumijeva samo korištenje lične zaštitne opreme, već i sistemsku primjenu procedura koje obuhvataju planiranje, obuku, tehničku kontrolu i zakonsku usklađenost [5-8]. Poseban značaj imaju procedure za istraživanje incidenata, koje omogućavaju identifikaciju uzroka rizičnih događaja i definisanje korektivnih mjera, čime se direktno doprinosi sigurnijem radu na rizičnim radnim mjestima [9].

Kodeks dobre prakse za sigurnost miniranja (Blasting Safety Code of Practice) za površinske operacije naglašava da je procjena rizika temeljni korak u definisanju zona opasnosti, odabiru eksploziva, pripremi radne platforme i određivanju sigurnosnih udaljenosti [10]. U površinskom miniranju, svaka operacija mora biti prethodno analizirana kako bi se identificirali i procijenili svi potencijalni rizici povezani s geološkim uvjetima, prisustvom infrastrukture, meteorološkim faktorima i prethodnim incidentima fragmentacije stijenske mase. Ova sistemska analiza omogućava planiranje sigurnih procedura i minimiziranje opasnosti za radnike i okolinu [11].

Istraživanja su pokazala da zadržavanje radnika u zoni odbacivanja stijena tokom detonacije uzrokuje više od 40 % svih povreda u površinskom miniranju, što naglašava potrebu za strožijim procedurama i učinkovitijom kontrolom sigurnosti [12]. U modernim tehničkim sistemima miniranja, sigurnost radnika i kontrola detonacija sve više se oslanjaju na digitalne alate. Ovi sistemi omogućavaju praćenje zona miniranja u realnom vremenu, automatsko blokiranje pristupa opasnim područjima i senzorski nadzor nad detonacijom, čime se smanjuje rizik ljudske pogreške i povećava ukupna sigurnost operacija [13,14].

MSHA dodatno propisuje obaveznu inspekciju prostora na kojem je izvršeno miniranje nakon detonacije, zabranu ulaska u zonu miniranja prije signala „all clear“, te primjenu vizualnih i zvučnih upozorenja kao obaveznu proceduru [15].

Za provođenje sigurnog postupka bušenja i miniranja posebna pažnja mora se posvetiti označavanju zona miniranja, pravilnom transportu eksploziva, tretmanu neeksplodiranih sredstava i obaveznoj kontroli nakon detonacije. Ove mjere imaju za cilj smanjenje rizika od povreda uzrokovanih sekundarnim urušavanjem stijena, odbačenim stijenskim fragmentima i neeksplodiranim sredstvima te osiguranje zaštite radnika i sigurnog izvođenja miniranja [16].

U površinskim rudarskim i građevinskim radovima poseban izazov predstavlja postizanje precizne fragmentacije stijenske mase bez oštećenja korisnog materijala ili okolne infrastrukture. To zahtijeva pažljivo balansiranje između efikasnosti miniranja i sigurnosti radnika. Pravilna priprema bušotina, kontrola količine eksploziva i primjena odgovarajuće metode aktivacije minskog polja sa preciznom vremenskom sinhronizacijom ključni su faktori u smanjenju rizika od odbačenih stijenskih fragmenata i drugih nesreća, te istovremeno doprinose optimiziranju proces miniranja [17].

Zakonski okvir u Bosni i Hercegovini, kao i u zemljama EU, propisuje obaveznu izradu Elaborata o zaštiti na radu, koji mora sadržavati procjenu rizika, plan evakuacije, opis lične zaštitne opreme, te tehničke mjere za sprječavanje neželjenih efekata miniranja [18,19].

Uloga geofizičkih metoda u planiranju miniranja sve više dobiva na značaju. Seizmička karakterizacija podzemlja, georadarske prospekcije i elektromagnetna mjerenja omogućavaju detaljno mapiranje pukotinskih sistema, preciznu identifikaciju nestabilnih zona te i optimizaciju položaja bušotina. Time ne samo da se povećava efikasnost miniranja, već se značajno smanjuje rizik od neželjenih efekata, poput odbačenih stijenskih fragmenata, vibracija i sekundarnih urušavanja [20-24].

U konačnici, posebne mjere zaštite na radu pri miniranju na površini nisu samo tehnički izazov, već i etička obaveza izvođača, nadzora i projektanata. Svaka greška u planiranju, komunikaciji ili izvođenju može rezultirati ozbiljnim posljedicama po zdravlje radnika.

Ovaj rad ima za cilj da identifikuje i analizira ključne rizike pri miniranju na površinskim kopovima, te da predstavi tehničke i organizacione mjere zaštite u skladu sa važećim propisima i standardima. Fokus je na kontroli eksplozivnih i seizmičkih utjecaja, tretmanu neeksplodiranih sredstava i primjeni geofizičkih metoda radi unapređenja sigurnosti i efikasnosti miniranja.

2. Opis postupka miniranja

Miniranje na površinskom kopu tehničkog kamena obuhvata niz precizno definisanih operacija koje se moraju izvoditi u skladu s tehničkim normama, sigurnosnim protokolima i zakonskim propisima. Da bi se osigurala potpuna usklađenost sa važećim zakonodavstvom i tehničkim standardima, neophodno je prethodno razmotriti zakonski okvir koji definiše obaveznu dokumentaciju, mjere zaštite i tehničke zahtjeve za izvođenje miniranja.

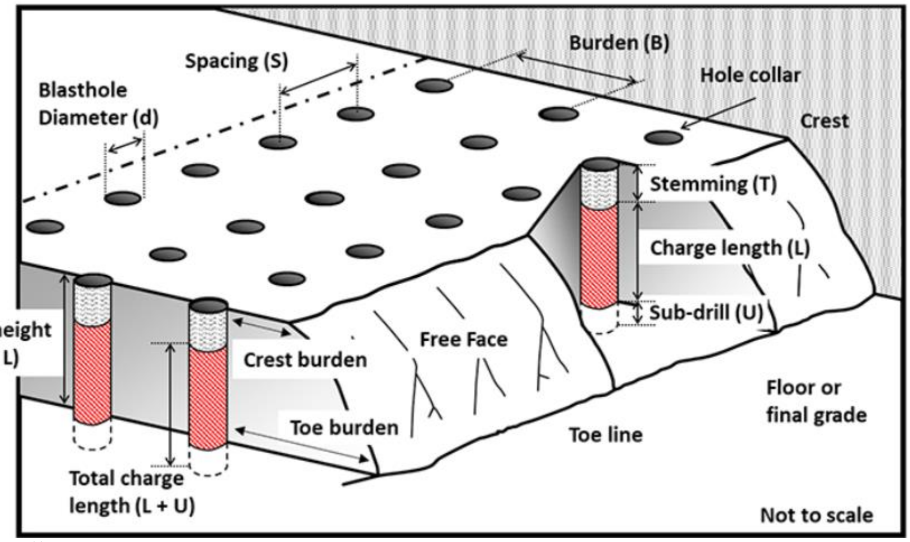
2.1 Zakonski propisi i standardi za površinsko miniranje

Za svako miniranje na površinskom kopu tehničkog kamena obavezna je izrada Plana miniranja, koji mora sadržavati sve tehničke, sigurnosne i organizacione mjere u skladu sa važećim propisima. Prema Pravilniku o tehničkim normativima pri rukovanju eksplozivnim sredstvima i miniranju u rudarstvu [25], Plan mora uključivati tehničke parametre miniranja, vrstu i količinu eksploziva, način aktivacije, sigurnosne udaljenosti, mjere zaštite na radu, geološke i geofizičke podatke, opis radova, mjere zaštite od neželjenih efekata poput vibracija, urušavanja i rizika od neželjenog raspršivanja stijenskih komada, kao i obaveznu inspekciju zone miniranja nakon detonacije, pregled eventualnih neeksplodiranih sredstava i izdavanje signala za nastavak radova nakon potvrde da je zona sigurna.
Usklađivanje domaćih propisa sa evropskim zakonodavstvom dodatno osigurava tehničku i pravnu validnost postupka miniranja. Direktiva 92/91/EEZ propisuje minimalne zahtjeve za sigurnost i zdravlje radnika u industriji ekstrakcije mineralnih sirovina, uključujući obaveznu procjenu rizika, tehničku kontrolu eksploziva i evakuacijske mjere [26]. Direktiva 2013/29/EU zahtijeva da eksplozivna sredstva budu tehnički dokumentovana, označena i praćena kroz sistem upravljanja sigurnošću [27], dok Direktiva 2014/28/EU definiše nadzor nad eksplozivima za civilnu upotrebu i njihovo stavljanje na tržište [28].
Primjena međunarodnog standarda EN ISO 45001:2018 omogućava sistematsko upravljanje zdravljem i sigurnošću na radu u svim fazama procesa miniranja, od planiranja do pregleda minskog polja nakon miniranja [29]. Tehnički standard EN 13631-10:2003 dodatno definiše metode ispitivanja eksploziva u vezi sa fragmentacijom, vibracijama i sigurnosnim udaljenostima [30].
Plan miniranja mora biti izrađen i odobren prije početka operacija, a njegova primjena je obavezna u svim fazama miniranja. Usklađenost sa navedenim propisima predstavlja osnovu za tehnički ispravno, zakonski dozvoljeno i sigurnosno kontrolisano izvođenje miniranja.
Primjena zakonskih propisa, tehničkih normi i sigurnosnih procedura u oblasti miniranja potvrđena je kroz više stručnih radova koji dokumentuju primjenu kontrolisanog miniranja u složenim inženjerskim uslovima. Ovi primjeri iz prakse obuhvataju tehničku pripremu, izvođenje i postdetonacione mjere, uz dosljednu primjenu važećih propisa i standarda sigurnosti [31-33].

2.2 Priprema terena, bušenje punjenje eksplozivom i povezivanje

Prije početka miniranja, neophodno je izvršiti geološku i geofizičku karakterizaciju terena radi identifikacije pukotinskih sistema, nestabilnih zona i optimalnog rasporeda bušotina [34]. Seizmičke metode, georadar i elektromagnetna mjerenja omogućavaju precizno mapiranje strukture stijenske mase [35]. Raspored, međusobni razmak i dubina bušotina definišu se u skladu s lokalnim geofizičkim parametrima, strukturom stijenske mase i tehničkim ciljevima miniranja, uzimajući u obzir zahtjeve fragmentacije, stabilnosti i sigurnosne udaljenosti.

Bušenje se izvodi vertikalno ili pod blagim nagibom, uz kontrolu odstupanja od projektovane osi. Svaka bušotina mora biti označena, očišćena od ostataka, te provjerena na dubinu i eventualne blokade prije punjenja eksplozivom. Zabranjeno je bušenje u prethodno korištene bušotine ili u blizini neeksplodiranih sredstava [36]. Punjenje bušotina izvodi se patroniranim ili nepatroniranim eksplozivima, pri čemu se mora poštovati omjer mase eksploziva i zapremine izdvojenog stijenskog materijala kako bi se osigurala kontrolisana fragmentacija i ograničilo seizmičko djelovanje. Eksploziv se ne smije nasilno utiskivati, a alat koji se koristi prilikom punjenja minskih bušotina mora biti izrađen od drveta ili plastike i ne smije stvarati varnice. Inicijatori (detonatori) povezuju se serijski ili paralelno, a primjena sistema s vremenskom sinhronizacijom omogućava preciznu kontrolu redoslijeda paljenja radi smanjenja vibracija i optimizacije fragmentacije [37]. Na slici 1 prikazan je šematski raspored bušotina s označenim tehničkim parametrima miniranja.



Slika 1. Šematski prikaz rasporeda bušotina sa označenim parametrima: prečnik bušotine (d), rastojanje između bušotina (S), linija najmanjeg otpora (B), dužina punjenja (L), dužina čepa (T), probušenje/dodatna dubina bušotine (U) i visina etaže (H) [38].

2.3 Evakuacija i detonacija

Zona miniranja mora biti fizički ograđena, jasno označena tablama upozorenja i pod stalnim nadzorom ovlaštenih radnika koji učestvuju u procesu miniranja. Minimalna udaljenost evakuacije određuje se na osnovu prethodnih incidenata s izletnim kamenom, uz primjenu sigurnosnog faktora 1,5 puta najveće zabilježene udaljenosti odbačenog fragmenta. Ova udaljenost može se aproksimirati izrazom:

$$D = 1{,}5 \cdot R_{max}$$

gdje je R_{max} najveća zabilježena udaljenost odbacivanja fragmenta stijenske mase ustanovljena prilikom eksperimentalnog probnog miniranja. Navedeni izraz predstavlja empirijsku aproksimaciju koja se koristi u nedostatku preciznih mjerenja ili numeričkih modela, te služi kao praktičan kriterij za definisanje sigurnosne zone evakuacije.

Prije detonacije, obavezno je emitovanje zvučnog signala u tri faze: upozorenje, priprema i detonacija. Detonacija se smije izvršiti isključivo po nalogu odgovorne osobe, nakon potvrde da je zona u potpunosti evakuirana, da su svi električni i mehanički spojevi ispravni, te da meteorološki uvjeti omogućavaju sigurno izvođenje miniranja. U slučaju prisustva olujnih nepogoda, jakog vjetra ili smanjene vidljivosti, postupak miniranja mora se odgoditi do uspostavljanja povoljnih uslova [39].

2.4 Pregled zone miniranja nakon detonacije

Nakon izvođenja miniranja, radna zona se ne smije napuštati dok se ne emitira zvučni signal koji nedvosmisleno označava završetak operacije. Ova mjera ima za cilj sprečavanje prijevremenog ulaska osoblja u potencijalno opasno područje. Po završetku miniranja, obavezno je izvršiti detaljan vizuelni pregled kompletnog minskog polja, uključujući odminiranu masu, pristupačne dijelove radilišta i sve površine koje su bile izložene djelovanju eksploziva. Pregled se vrši radi provjere prisustva zaostalih eksplozivnih sredstava, procjene stabilnosti terena i identifikacije eventualnih deformacija ili pomjeranja stijenske mase [40].

U slučaju sumnje na prisustvo neeksplodiranog sredstva (NES), pristup zoni miniranja dozvoljen je isključivo stručno osposobljenom osoblju koje raspolaže odgovarajućom zaštitnom opremom i primjenjuje propisane sigurnosne postupke. Svaka intervencija mora biti dokumentovana, a daljnje aktivnosti se mogu nastaviti tek nakon što se potvrdi da je područje sigurno za rad [41].

3. Identifikacija rizika

Miniranje na površini uključuje niz složenih i potencijalno opasnih operacija koje generišu različite vrste rizika. Efikasna identifikacija i klasifikacija tih rizika predstavlja osnovu za primjenu odgovarajućih mjera zaštite na radu. Rizici se mogu sistematizirati u četiri glavne kategorije: mehanički, eksplozivni, seizmički/zvučni i organizacioni.

3.3 Mehanički rizici

Mehanički rizici u površinskom miniranju proizlaze iz interakcije radnika s tehničkim sistemima, dinamičnim radnim okruženjem i nestabilnim stijenskim materijalom. U kontekstu bušenja, punjenja i pripreme fronte, najčešće identificirane mehaničke prijetnje uključuju kontakt s rotirajućim dijelovima bušačke opreme, padove s visinskih etaža, te udare od odlomljenih blokova stijenske mase. Ovi rizici su inherentni procesu, ali se njihova učestalost i intenzitet značajno povećavaju u uslovima neadekvatne tehničke kontrole, nedostatka prostorne segregacije i odsustva sistemske zaštite.

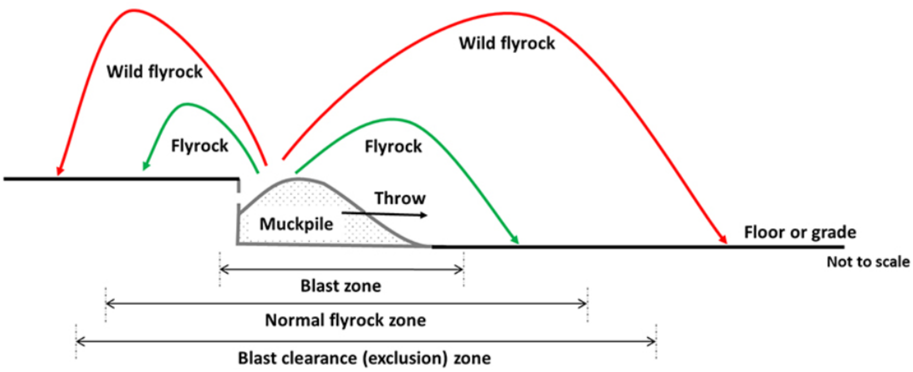
Prema OSHA regulativi (29 CFR 1910.212), tehnički sistemi moraju biti projektovani i održavani na način koji onemogućava direktan kontakt s pokretnim dijelovima, dok se radna zona mora fizički i proceduralno izolovati tokom aktivnih operacija. Empirijska istraživanja ukazuju da je upravo nepostojanje barijera i neadekvatna signalizacija najčešći uzrok mehaničkih povreda u rudarstvu i građevinarstvu [12,42].

Lična zaštitna oprema, iako formalno obavezna, ne može kompenzirati sistemske propuste u organizaciji rada. Studije pokazuju da reflektirajuća odjeća, zaštitne kacige i obuća s čeličnim vrhom imaju preventivni učinak samo u kombinaciji s tehničkom kontrolom pristupa i obukom osoblja [43]. U tom smislu, mehanički rizici se ne mogu tretirati izolovano, već zahtijevaju integraciju tehničkih, organizacionih i edukativnih mjera u okviru sveobuhvatnog sistema upravljanja sigurnošću.

3.4 Eksplozivni rizici

Eksplozivni rizici predstavljaju najkritičniju kategoriju opasnosti u procesu površinskog miniranja, s obzirom na neposrednu energiju oslobađanja, nepredvidive efekte detonacije i mogućnost sekundarnih incidenata. U tehničkoj i sigurnosnoj literaturi, najčešće identificirani eksplozivni rizici uključuju: preranu detonaciju, prisustvo neeksplodiranih sredstava (tzv. misfire), nekontrolisano odbacivanje stijenskih fragmenata (flyrock), te prekomjernu količinu eksploziva u odnosu na projektovane parametre.

Nekontrolisano razbacivanje fragmenata stijenske mase izvan predviđene zone miniranja, posebno je opasno zbog svoje prostorne nepredvidivosti i kinetičke energije. Empirijski podaci ukazuju da fragmenti mogu dostići udaljenosti veće od 300 metara od epicentra detonacije, pri čemu se bilježe slučajevi teških povreda i fatalnih ishoda [12,42]. U tom kontekstu, prostorna distribucija rizika mora biti precizno definisana, uz primjenu sigurnosnog faktora i prethodnih terenskih mjerenja. Prostorna raspodjela rizika usljed nekontrolisanog odbacivanja stijenskih fragmenata tokom miniranja prikazana je na slici 2, koja ilustrativno definiše zonu miniranja, sigurnosnu zonu evakuacije i moguće putanje odbačenih fragmenata stijenske mase.



Slika 2. Zona odbačenih stijenskih fragmenata pri miniranju – prostorna distribucija rizika i sigurnosnih granica [44]

Za procjenu incidentnog pritiska zračne eksplozije koristi se empirijski izraz poznat kao Kingery–Bulmash model [45]:

$$P = \frac{K \cdot Q^{1/3}}{R}$$

gdje je:

P - pritisak, izražen u bar.,
Q - količina eksploziva, u kg,
R - udaljenost od epicentra, u m' i
K - empirijski koeficijent, zavisan od vrste eksploziva i geometrije detonacije.

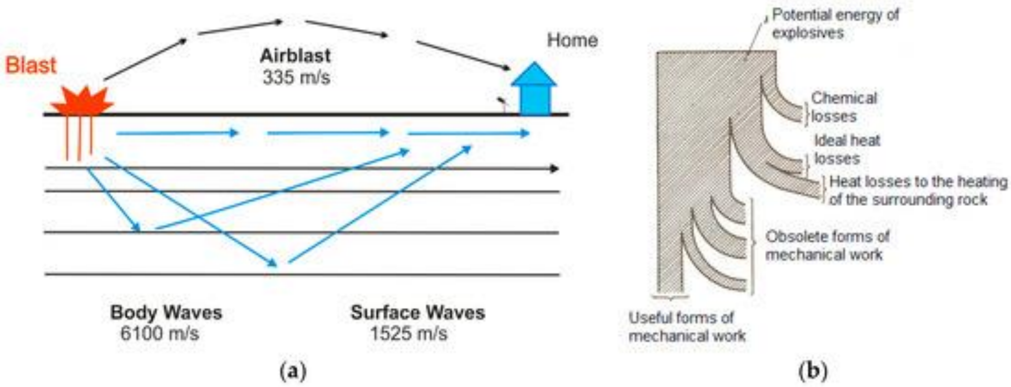
Ova formula se koristi u planiranju zone miniranja, posebno u blizini infrastrukture, naseljenih područja ili osjetljivih objekata. Neeksplodirana sredstva predstavljaju latentni rizik koji zahtijeva specijalizovanu intervenciju. Prema smjernicama MSHA, zona u kojoj se sumnja na prisustvo neeksplodiranih sredstava mora biti izolovana, a pristup dozvoljen isključivo stručno obučenom osoblju sa odgovarajućom zaštitnom opremom i tehničkom podrškom.

3.5 Seizmički, vibracioni i akustički rizici

Detonacija eksploziva u površinskom miniranju generiše seizmičke i zračne talase koji se šire kroz tlo i atmosferu, pri čemu dolazi do interakcije s okolnim objektima, infrastrukturom i ljudskim organizmima. Ovi talasi mogu uticati na stabilnost građevinskih struktura, integritet podzemnih instalacija, te izazvati fiziološke i psihološke reakcije kod radnika i stanovništva u blizini zone miniranja [46-49].

Vibracije tla prenose se u objekat putem temelja i podruma, dok zračni udar djeluje na zidne i krovne površine. Rezultantno podrhtavanje može izazvati zveckanje predmeta, pomjeranje opreme i osjećaj unutrašnje buke, koja kod ljudi izaziva alarmantne reakcije, iako sama buka ima zanemariv utjecaj na konstrukcijsku stabilnost [47-49].

U nastavku teksta, na slici 3a prikazan je mehanizam širenja seizmičkih i zračnih talasa generisanih detonacijom eksploziva. Talasi se prostiru radijalno od epicentra, pri čemu dolazi do diferencirane interakcije s tlom ili objektom. Slika 3b prikazuje energetsku bilancu eksplozije, gdje se jasno vidi da se samo manji dio oslobođene energije troši na drobljenje stijenske mase. Većina oslobođene energije prenosi se kroz neželjene efekte, kao što su širenje usitnjene mase te generisanje seizmičkih i zračnih talasa [50].



Slika 3. (a) Širenje seizmičkih i zračnih talasa tokom miniranja; (b) Šema energetske bilance tijekom miniranja [51]

Prema tehničkim smjernicama, dozvoljeni nivo vibracija na granici zone miniranja iznosi maksimalno 5 mm/s za stambene objekte, odnosno 10 mm/s za industrijske strukture [52]. Praćenje stvarnih vrijednosti vrši se seizmičkim monitoringom putem geofona, čime se omogućava prilagođavanje parametara miniranja u realnim uslovima [53]. Za tehničku procjenu seizmičkog utjecaja koristi se standardizovana empirijska formula [54]:

$$PPV = K \cdot \left(\frac{D}{Q^{1/2}}\right)^{-n}$$

gdje je:

PPV – maksimalna brzina vibracija, u mm/s,
D – udaljenost od epicentra eksplozije, u m',
Q – količina eksploziva po odgodi, u kg i
K,n – koeficijenti koji zavise od lokalnih geoloških uslova i vrste eksploziva.

Vrijednosti se određuju terenskim mjerenjem, najčešće metodom najmanjih kvadrata, čime se omogućava lokalna kalibracija modela i precizno planiranje miniranja u osjetljivim zonama [54].

Pored seizmičkih i vibracionih efekata, detonacija eksploziva generiše i zračni udar (airblast), koji nastaje usljed naglog širenja plinova iz eksplozije. Ovaj impulsni talas može izazvati oštećenje staklenih površina, poremećaj u radu elektronske opreme, te negativan utjecaj na sluh radnika. Preporučeni prag zračnog udara iznosi 120 dB za industrijske zone, dok se za naseljena područja preporučuje maksimalno 115 dB [55]. Akustički rizici se kontrolišu primjenom zvučnih barijera, pravilnim tempiranjem detonacije i obaveznim korištenjem zaštite za sluh.

3.6 Organizacioni rizici

Organizacioni rizici predstavljaju ključan faktor u sigurnosnoj analizi miniranja, jer se odnose na sistemske propuste u planiranju, komunikaciji i izvršenju operacija. Najčešći izvori ovih rizika uključuju nedostatak obuke, nejasnu raspodjelu odgovornosti, lošu komunikaciju među timovima, te neusklađenost sa važećim zakonskim propisima.

Prema Pravilniku o tehničkim normativima pri rukovanju eksplozivnim sredstvima i miniranju u rudarstvu [25], izvođač je dužan osigurati prisustvo ovlaštenog lica za rukovanje eksplozivima, evidentirati stručno osposobljavanje radnika, te obezbijediti fizičku zaštitu zone miniranja putem signalizacije i barijera. Iako evakuacione procedure nisu eksplicitno propisane, tehnički elaborat mora sadržavati mjere koje osiguravaju sigurnost radnika u zoni miniranja.

U domaćoj literaturi se ističe da su organizacioni propusti, posebno u fazi pripreme i koordinacije, čest uzrok odstupanja u sigurnosnim parametrima miniranja. Nedostatak formalizovanih procedura, neadekvatna komunikacija među timovima i nepostojanje jasnih operativnih uputa mogu dovesti do grešaka koje se u eksplozivnim operacijama manifestuju s ozbiljnim posljedicama [56].

4. Zaključak

Miniranje na površinskim kopovima predstavlja jednu od najzahtjevnijih i najrizičnijih faza tehničkih operacija u rudarskom i infrastrukturnom sektoru. Uspješno upravljanje rizicima koji proizlaze iz ovog procesa zahtijeva sistemsku integraciju zakonskih propisa, tehničkih normi, organizacionih mjera i geofizičkih metoda. Svaka faza, od planiranja i bušenja do detonacije i postdetonacione inspekcije, mora biti precizno definisana i kontrolisana kako bi se osigurala sigurnost radnika, stabilnost radne zone i zaštita okoline.

Analizom ključnih kategorija rizika utvrđeno je da eksplozivni, seizmički i organizacioni faktori imaju dominantan utjecaj na sigurnost operacija. Eksplozivni rizici, poput nekontrolisanog odbacivanja stijenskih fragmenata i prisustva neeksplodiranih sredstava, zahtijevaju primjenu empirijskih modela, tehničkih barijera i specijalizovanih procedura. Seizmički i akustički utjecaji moraju se kvantitativno pratiti i kontrolisati putem geofona i standardizovanih proračuna, dok organizacioni propusti, naročito u fazi pripreme i koordinacije, predstavljaju latentni izvor nesreća koji se može prevenirati uspostavljanjem jasnih procedura formalizacijom procedura i obukom osoblja.

Usklađenost sa Pravilnikom o tehničkim normativima pri rukovanju eksplozivnim sredstvima i miniranju u rudarstvu, kao i sa evropskim direktivama i međunarodnim standardima, predstavlja osnovu za zakonito i tehnički validno izvođenje miniranja. Primjena geofizičkih metoda, poput seizmičke tomografije i elektromagnetne prospekcije, omogućava preciznu karakterizaciju stijenske mase, identifikaciju nestabilnih zona i optimizaciju rasporeda bušotina, čime se direktno doprinosi smanjenju rizika i povećanju efikasnosti.

Zaključno, sigurnost pri miniranju nije samo tehnički izazov, već i profesionalna i etička obaveza svih učesnika u procesu. Samo dosljednom primjenom validiranih podataka, usklađenih procedura i multidisciplinarnog pristupa moguće je ostvariti kontrolisane, efikasne i sigurne minerske operacije u složenim inženjerskim uslovima.

1. Literatura

1. Bajpayee, T. S., Rehak, T. R., Mowrey, G. L., & Ingram, D. K. (2004). Blasting injuries in surface mining with emphasis on flyrock and blast area security. *Journal of Safety Research, 35*(1), 47–57. https://doi.org/10.1016/j.jsr.2003.07.003
2. Kecojevic, V., & Radomsky, M. (2005). Flyrock phenomena and area security in blasting-related accidents. *Safety Science*, 43(9), 739–750. https://doi.org/10.1016/j.ssci.2005.07.006
3. Valjevac, M., Bektašević, E., Gutić, K., Sakić, N., & Sikira, D. (2024). Exploitation and processing of technical stone from quarries Plješevac near Kiseljak. *Journal of Faculty of Mining, Geology and Civil Engineering, University of Tuzla*, 12, [Professional Paper]. https://doi.org/10.51558/2303-5161.2024.12.12.23
4. Mine Safety and Health Administration. (2002). *Module 11: Transportation, use, and storage of explosives*. U.S. Department of Labor. Retrieved from https://arlweb.msha.gov/safetypro_in_a_box/IG%2043%20OJT%20training%20modules%20surface%20MNM/Module%2011%20Transportation%20use%20and.%20storage%20of%20explosives.PDF
5. Festić, E., & Imamović, A. (2021). Značaj edukacije i opšti uslovi za bezbjedan transport opasnih materija prema ADR-u. *Zaštita i sigurnost*, 1(2), 95–106.
6. Bektašević, E., Gutić, K., Valjevac, M., & Sakić, N. (2025, April). The role and importance of preventive safety measures at work during the production and processing of technical stone at the quarry. In *15th Scientific/Research Symposium with International Participation „METALLIC AND NONMETALLIC MATERIALS“*, Bosnia and Herzegovina.
7. Bektašević, E., Gutić, K., Valjevac, M., & Konta, J. (2024, December). Unapređivanje mjera zaštite na radu u kamenolomima pri proizvodnji i preradi tehničkog kamena. *Rudarsko-geološki glasnik*, Hrvatsko rudarsko-geološko društvo Mostar, 49–61. ISSN 1840-0299.
8. Chen, X.-k., Zhu, H.-l., & Chen, J.-q. (2011). *Hazard identification and control in the pre-blasting process*. *Journal of Coal Science and Engineering (China), 17*(3), 331-335. https://doi.org/10.1007/s12404-011-0320-0
9. Imamović, A., Softić, S., Kablar, O., & Oruč, M. (2022). Značaj procedure istraživanja incidenta za sigurniji rad na rizičnim radnim mjestima. *Zaštita i sigurnost*, 2(1), 22–31**.**
10. Manitoba Labour and Immigration. (2006). *Code of practice for the use of explosives*. Workplace Safety and Health Division. Retrieved from https://www.gov.mb.ca/labour/safety/pdf/cop_useof_explosives.pdf
11. Strzałkowski, P., Woźniak, J., Górniak-Zimroz, J., & et al. (2025). Identification and systematics of safety hazards in surface rock mining. *Scientific Reports, 15*, 30492. https://doi.org/10.1038/s41598-025-16437-z

12. Bajpayee, T. S., Rehak, T. R., Mowrey, G. L., & Ingram, D. K. (2004). Blasting injuries in surface mining with emphasis on flyrock and blast area security. *Journal of Safety Research, 35*(1), 47–57. https://doi.org/10.1016/j.jsr.2003.07.003
13. Engineer Live. (2023). *Better blasting: Improving safety in mining operations*. Retrieved October 1, 2025, from https://www.engineerlive.com/content/better-blasting
14. Identec Solutions. (2023). *Blasting safety in daily mining operations*. Retrieved October 1, 2025, from https://www.identecsolutions.com/news/blasting-safety-in-daily-mining-operations
15. Mine Safety and Health Administration. (n.d.). *Blasting safety*. U.S. Department of Labor. Retrieved October 1, 2025, from https://www.msha.gov/safety-health/safety-health/safety-health-materials/safety-topics/blasting-safety
16. National Institute for Occupational Safety and Health. (2006). *Blast area security: Flyrock safety* (NIOSH Report No. 2007-112). U.S. Department of Health and Human Services. https://www.cdc.gov/niosh/docs/mining/UserFiles/works/pdfs/2007-112.pdf
17. Orica. (2010). *Safety of blasting with electronic detonators*. Orica Technical Bulletin. https://www.orica.com/ArticleDocuments/2606/200415_Safety%20of%20Electronic%20Detonators%20for%202010%20ISEE%20Lownds%2C%20Steiner.pdf.aspx
18. Vlada Federacije Bosne i Hercegovine. (2020). *Zakon o zaštiti na radu*. Službene novine Federacije BiH, broj 17/20. https://fbihvlada.gov.ba/bosanski/zakoni/2020/Zakoni/17.htm
19. Vijeće Europske unije. (1989). *Direktiva 89/391/EEZ o uvođenju mjera za poticanje poboljšanja sigurnosti i zdravlja radnika na radu*. Službeni list Europske unije, L 183, 1–8. https://eur-lex.europa.eu/legal-content/HR/TXT/?uri=CELEX%3A31989L0391
20. Reynolds, J. M. (2011). *An introduction to applied and environmental geophysics* (2nd ed.). Wiley-Blackwell.
21. Bektašević, E., Antičević, H., Gutić, K., & Sikira, D. (2024). Determination of the depth of the rock mass damage zone around the excavation profile by blasting with seismic cross-hole tomography in the „Šubir“ tunnel on the Zagreb-Split motorway. *Nauka+Praksa*, (27), 13–19. https://doi.org/10.62683/NiP27.13-19
22. Bektašević, E., & Gutić, K. (2025). Seismic impact assessment of blasting on surrounding population using geophysical methods. *Engineering and Technology Journal*, 10(4), 4468–4475. https://doi.org/10.47191/etj/v10i04.12

23. Bektašević, E., Antičević, H., Gutić, K., & Sikira, D. (2024). Application of seismic methods for determining the depth of the rock mass damage zone around the excavation profile by blasting. *Global Journal of Engineering and Technology Advances*, 18(3), 139–151. https://doi.org/10.30574/gjeta.2024.18.3.0051
24. Husejnagić, E., Bektašević, E., Osmanović, F., Žutić, Đ., Konta, J., & Hasić, E. (2016). Geofizičko-seizmička ispitivanja vještački izazvanih potresa i njihov uticaj na sigurnost i stabilnost objekata na PK Koritnik-Breza. In *Zbornik radova petog međunarodnog naučno-stručnog savetovanja*, Savez građevinskih inženjera Srbije, Sremski Karlovci (pp. 205–222).
25. Službeni list SFRJ. (1988). Pravilnik o tehničkim normativima pri rukovanju eksplozivnim sredstvima i miniranju u rudarstvu.
26. European Commission. (1992). *Council Directive 92/91/EEC on the minimum requirements for improving the safety and health protection of workers in the mineral-extracting industries through drilling*. https://eur-lex.europa.eu/eli/dir/1992/91/oj/eng
27. European Parliament and Council. (2013). *Directive 2013/29/EU on the harmonisation of the laws of the Member States relating to the making available on the market of pyrotechnic articles*. https://eur-lex.europa.eu/eli/dir/2013/29/oj/eng
28. European Parliament and Council. (2014). *Directive 2014/28/EU on the harmonisation of the laws of the Member States relating to the making available on the market and supervision of explosives for civil uses*. https://eur-lex.europa.eu/eli/dir/2014/28/oj/eng
29. International Organization for Standardization. (2018). *ISO 45001:2018 – Occupational health and safety management systems – Requirements with guidance for use*. https://www.iso.org/standard/63787.html
30. European Committee for Standardization. (2003). *EN 13631-10:2003 – Explosives for civil uses – High explosives – Part 10: Verification of initiation methods*. https://standards.iteh.ai/catalog/standards/cen/9b294e02-391f-47cd-85fe-60101faf6341/en-13631-10-2003
31. Bektaševič, E., Kadrić, R., Nikolić, M., Gutić, K., & Kadrić, S. (2023). Excavation of the foundation of piers S1L and S1R of the Vranduk I bridge by controlled blasting on the motorway route: Zenica Municipality Northern Administrative Boundary – Zenica North. *Electronic Collection of Papers, Faculty of Civil Engineering, University of Mostar*, 26, 9–26. https://doi.org/10.47960/2232-9080.2023.26.13.9
32. Bektaševič, E., Kadrić, R., Gutić, K., & Kadrić, S. (2023). Primjena kontrolisanog miniranja pri iskopu ulaznog portala desne tunelske cijevi tunela „Vranduk“ na koridoru Vc. *Zbornik radova GEO-EXPO 2023*, Društvo za geotehniku u Bosni i Hercegovini, 163–172. https://doi.org/10.35123/GEO-EXPO_2023_17

33. Bektaševič, E., Antičević, H., Osmanović, F., Kadrić, S., Žutić, Đ., & Konta, J. (2023). Tehnologija miniranja pri iskopu evakuacionog tunela „Vranduk II" na magistralnoj cesti M-17. *Elektronički zbornik radova Građevinskog fakulteta Sveučilišta u Mostaru*, 49–60. https://doi.org/10.47960/2232-9080
34. Ilić, M. (2017). Application of results of geological exploration of deposits of solid mineral raw materials in mining. *Tehnika – Mining, Geological and Metallurgical Engineering*, *72*(2), 204–211. https://doi.org/10.5937/tehnika1702204I
35. Bektašević, E., Strelec, S., Sakić, N., & Gutić, K. (2025). Multichannel surface wave analysis in the context of shallow geophysical investigations. Academia Engineering, 2(3). https://doi.org/10.20935/AcadEng7876
36. Occupational Safety and Health Administration (OSHA). (2024). *1926.905 - Loading of explosives or blasting agents.* U.S. Department of Labor. Retrieved from https://www.osha.gov/laws-regs/regulations/standardnumber/1926/1926.905
37. Tang, H.-L., Liu, X., Yang, J., & Yu, Q. (2023). Experimental Study on the Influence of Delay Time on Rock Fragmentation in Bench Blasting. *Applied Sciences*, *13*(1), 85. https://doi.org/10.3390/app13010085
38. Szendrei, T. & Tose, S.. (2024). Flyrock in surface mining Part II - Causes, sources, and mechanisms of rock projection. Journal of the Southern African Institute of Mining and Metallurgy. 123. 557-564. 10.17159/2411-9717/2583/2023.
39. Božić, B. (1998). *Miniranje u rudarstvu, graditeljstvu i geotehnici*. Varaždin: Geotehnički fakultet Sveučilišta u Zagrebu.
40. Bektašević, E. (2022). *Blasting: Examples of surface blasting and tunnel construction with occupational safety measures*. LAP LAMBERT Academic Publishing.
41. QNJAC. (2020). *Post-blast inspection guidance for quarries*. Quarries National Joint Advisory Committee. https://minex.org.nz/training/toolbox/the-post-blast-inspection.pdf
42. Kecojevic, V., & Radomsky, M. (2005). *Flyrock phenomena and area security in blasting-related accidents*. Safety Science, 43(9), 739–750. https://doi.org/10.1016/j.ssci.2005.07.006
43. ISEE. (2022). *Personal Protective Equipment in Blasting Operations*. International Society of Explosives Engineers.
44. Little, T. N. (2007). *Flyrock risk*. In *Proceedings of EXPLO2007: Blasting—Techniques and Technology* (pp. 35–43). Australasian Institute of Mining and Metallurgy.
45. Kingery, C. N., & Bulmash, G. (1984). *Airblast parameters from TNT spherical air burst and hemispherical surface burst* (ARBRL-TR-02555). U.S. Army Ballistic Research Laboratory. Retrieved from https://apps.dtic.mil/sti/pdfs/ADA955203.pdf

46. Bektašević, E., & Gutić, K. (2025). *Seismic impact assessment of blasting on surrounding population using geophysical methods*. *Engineering and Technology Journal, 10*(4), 4468–4475. https://doi.org/10.47191/etj/v10i04.12
47. tagg, M. S., & Siskind, D. E. (1987). *Effects of blast vibration on construction material cracking in residential structures* (p. 43). Bureau of Mines Technology Transfer Seminar, Chicago, MI, USA.
48. Siskind, D. E., & Stagg, M. S. (1987). *Blast vibration measurements near structures* (pp. 46–50). Bureau of Mines Technology Transfer Seminar, Chicago, MI, USA.
49. Hustrulid, W. A. (1999). *Blasting principles for open pit mining* (Vol. 2). CRC Press.
50. Malbašić, V., & Stojanović, L. (2017). *Determination of seismic safety zones during the surface mining operation development in the case of open pit „Buvač“*. In *Proceedings of the 6th International Symposium MEP 17* (pp. 138–144), Vrdnik, Serbia, June 21–24.
51. Malbasic, V., & Stojanovic, L. (2018). Determination of Seismic Safety Zones during the Surface Mining Operation Development in the Case of the „Buvač“ Open Pit. *Minerals*, *8*(2), 71. https://doi.org/10.3390/min8020071
52. Husejnagić, E., Bektašević, E., Osmanović, F., Žutić, Đ., Konta, J., & Hasić, E. (2015). *Geofizičko-seizmička ispitivanja vještački izazvanih potresa i njihov uticaj na sigurnost i stabilnost objekata na PK Koritnik–Breza*. *Rudarsko-geološki glasnik*, Hrvatsko rudarsko geološko društvo, Mostar, 67–82. (ISSN 1840-0299).
53. Bektašević, E., Frljak, N., Sarajlić, M., Konta, J., & Lapandić, E. (2013). *Komparativni pregled uticaja prirodnih i vještački izazvanih potresa na primjeru „Rudnika krečnjaka Breza“–Breza*. *Rudarsko-geološki glasnik*, Hrvatsko rudarsko geološko društvo, Mostar, 70–77. (ISSN 1840-0299).
54. Boon, C. W., & Ooi, L. H. (2015). *Rock blasting — peak particle velocity against distance*. In Proceedings of the 11th International Symposium on Rock Fragmentation by Blasting (FRAGBLAST 11), Sydney, Australia. Australian Centre for Geomechanics. Dostupno na: https://papers.acg.uwa.edu.au/d/1508_23_Boon/23_Boon.pdf
55. Gregurović, N. (2013). *Kontrola seizmičkih efekata pri opreznim miniranjima u urbanim sredinama* [Diplomski rad, Geotehnički fakultet Sveučilišta u Zagrebu]. Repozitorij GFV. https://repozitorij.gfv.unizg.hr/islandora/object/gfv%3A75/datastream/PDF/view
56. Katalinić, M. (2021). *Netipične vrijednosti kod mjerenja seizmičkih utjecaja miniranja* [Diplomski rad, Rudarsko-geološko-naftni fakultet, Sveučilište u Zagrebu]. Repozitorij RGNF. https://zir.nsk.hr/islandora/object/rgn%3A1783/datastream/PDF/download

Popis slika

Slika 1. Šematski prikaz rasporeda bušotina sa označenim parametrima: prečnik bušotine (d), rastojanje između bušotina (S), linija najmanjeg otpora (B), dužina punjenja (L), dužina čepa (T), probušenje/dodatna dubina bušotine (U) i visina etaže (H).

Slika 2. Zona odbačenih stijenskih fragmenata pri miniranju – prostorna distribucija rizika i sigurnosnih granica.

Slika 3. (a) Širenje seizmičkih i zračnih talasa tokom miniranja; (b) Šema energetske bilance tijekom miniranja.

SAFETY RISKS AND PROTECTIVE MEASURES IN SURFACE BLASTING

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Original scientific paper

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Abstract:
Surface blasting represents one of the most complex and high-risk processes in mining practice, where the safety of people and infrastructure directly depends on proper planning, technical control, and compliance with prescribed safety measures. This paper provides a systematic overview of the risks accompanying all phases of surface blasting from drilling and borehole charging to detonation and post-detonation inspection and defines key technical and organizational measures for their prevention. Special attention is devoted to explosive, seismic, and acoustic impacts, which are controlled through the application of empirical models, seismic monitoring, and appropriate blast-field design. The paper analyzes relevant legal regulations, international standards, and European directives governing the handling of explosives, safety distances, and mandatory supervision procedures. The role of geophysical methods is particularly emphasized as an important tool in the planning of safe blasting operations, as they enable the identification of unstable zones and precise determination of geological parameters influencing the distribution of explosion energy. The obtained results indicate the need for an integrated approach that connects technical, legal, and organizational measures, thereby achieving a higher level of safety, efficiency, and control over undesirable effects of blasting in surface exploitation operations.

Keywords: *surface blasting, protective measures, explosive risks, seismic impacts, unexploded ordnance, safety zones, geophysical methods, legal regulations, organizational risks*

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1. Introduction

Surface blasting, whether carried out along road alignments, construction sites, infrastructure zones, or exploitation areas, represents one of the most hazardous phases of technical operations due to the presence of explosive materials, dynamic forces, rock mass fragmentation, and the direct exposure of workers to potentially harmful effects [1–3].

Therefore, occupational safety measures in this segment require strict technical, organizational, and legal control. According to data from the Mine Safety and Health Administration (MSHA), every stage of the blasting process from the storage and transport of explosives to detonation and post-blast inspection must be regulated by precise protocols to prevent accidents, injuries, and equipment damage [4]. Occupational safety does not only imply the use of personal protective equipment but also the systematic implementation of procedures that include planning, training, technical supervision, and legal compliance [5–8]. Special importance is given to incident investigation procedures, which enable the identification of the causes of hazardous events and the definition of corrective measures, thereby directly contributing to safer working conditions in high-risk environments [9].

The Blasting Safety Code of Practice for surface operations emphasizes that risk assessment is the fundamental step in defining danger zones, selecting explosives, preparing the working platform, and determining safety distances [10]. In surface blasting, each operation must be analyzed in advance to identify and assess all potential risks associated with geological conditions, nearby infrastructure, meteorological factors, and previous incidents of rock mass fragmentation. This systematic analysis enables the planning of safe procedures and the minimization of hazards to workers and the environment [11].

Research has shown that retaining workers within the rock-throw zone during detonation accounts for more than 40% of all surface blasting injuries, highlighting the need for stricter procedures and more effective safety control [12]. In modern blasting systems, worker safety and detonation control increasingly rely on digital tools. These systems enable real-time monitoring of blasting zones, automatic restriction of access to hazardous areas, and sensor-based detonation supervision, thereby reducing the risk of human error and increasing overall operational safety [13,14].

MSHA further prescribes mandatory post-blast site inspection, prohibition of entry into the blasting area before the “all clear” signal, and the use of visual and audible warnings as standard procedures [15].

To ensure safe drilling and blasting operations, particular attention must be given to marking blasting zones, proper transport of explosives, handling unexploded ordnance, and mandatory post-detonation inspections. These measures aim to reduce the risk of injuries caused by secondary rock collapses, flying rock fragments, and unexploded materials, ensuring worker safety and controlled execution of blasting [16].

In surface mining and construction works, achieving precise rock fragmentation without damaging valuable material or nearby infrastructure presents a particular challenge. This requires a careful balance between blasting efficiency and worker safety. Proper borehole preparation, control of explosive quantities, and the application of suitable blast-field initiation methods with precise timing synchronization are key factors in minimizing the risk of flyrock and other accidents, while simultaneously optimizing the blasting process [17].

The legal framework in Bosnia and Herzegovina, as well as in EU countries, prescribes the mandatory preparation of a Safety Protection Study, which must include a risk assessment, evacuation plan, description of personal protective equipment, and technical measures for preventing adverse blasting effects [18,19].

The role of geophysical methods in blasting design is gaining increasing importance. Seismic subsurface characterization, ground-penetrating radar (GPR) surveys, and electromagnetic measurements enable detailed mapping of fracture systems, precise identification of unstable zones, and optimization of borehole placement. This not only enhances blasting efficiency but also significantly reduces the risk of adverse effects such as flyrock, vibrations, and secondary collapses [20–24].

Ultimately, specific occupational safety measures in surface blasting are not only a technical requirement but also an ethical obligation for contractors, supervisors, and designers. Every error in planning, communication, or execution can result in serious consequences for worker safety.

The aim of this paper is to identify and analyze key risks associated with surface blasting operations and to present the corresponding technical and organizational protection measures in accordance with current regulations and standards. The focus is on the control of explosive and seismic impacts, treatment of unexploded ordnance, and the application of geophysical methods to improve the safety and efficiency of blasting operations.

2. Description of the Blasting Procedure

Blasting at a surface quarry for technical stone involves a series of precisely defined operations that must be carried out in accordance with technical standards, safety protocols, and legal regulations. To ensure full compliance with applicable legislation and technical standards, it is essential first to consider the legal framework that defines mandatory documentation, safety measures, and technical requirements for performing blasting operations.

2.1 Legal Regulations and Standards for Surface Blasting

For every blasting operation at a surface quarry for technical stone, it is mandatory to prepare a Blasting Plan that must include all technical, safety, and organizational measures in accordance with applicable regulations. According to the Rulebook on Technical Standards for the Handling of Explosives and Blasting in Mining [25], the Plan must include technical blasting parameters, the type and quantity of explosives, the initiation method, safety distances, occupational safety measures, geological and geophysical data, a description of the works, measures for protection against undesirable effects such as vibrations, collapses, and the risk of rock scattering, as well as a mandatory post-detonation inspection of the blasting zone, examination of potential unexploded charges, and issuance of clearance signals for resuming work once the area is confirmed to be safe. The harmonization of domestic regulations with European legislation further ensures the technical and legal validity of the blasting process.

Directive 92/91/EEC prescribes minimum requirements for the safety and health of workers in the extractive industries, including mandatory risk assessment, technical control of explosives, and evacuation measures [26].

Directive 2013/29/EU requires that explosive materials be technically documented, labeled, and traceable through a safety management system [27], while Directive 2014/28/EU defines the supervision of explosives for civil use and their placement on the market [28].

The application of the international standard EN ISO 45001:2018 enables systematic management of occupational health and safety in all stages of the blasting process, from planning to post-blast inspection of the blast site [29].

The technical standard EN 13631-10:2003 further defines methods for testing explosives concerning fragmentation, vibrations, and safety distances [30]. The Blasting Plan must be developed and approved before the commencement of operations, and its implementation is mandatory throughout all stages of blasting. Compliance with these regulations forms the basis for technically sound, legally permitted, and safely controlled blasting operations.

The implementation of legal regulations, technical standards, and safety procedures in the field of blasting has been confirmed through numerous professional studies documenting the application of controlled blasting in complex engineering conditions. These case studies encompass technical preparation, execution, and post-detonation measures, with consistent adherence to current regulations and safety standards [31–33].

2.2 Site preparation, drilling, charging and connection

Prior to blasting, it is necessary to perform geological and geophysical characterization of the site to identify fracture systems, unstable zones, and the optimal layout of boreholes [34]. Seismic methods, ground-penetrating radar, and electromagnetic measurements enable precise mapping of the rock-mass structure [35]. The arrangement, spacing, and depth of boreholes are defined in accordance with local geophysical parameters, rock-mass structure, and the technical objectives of blasting, taking into account fragmentation requirements, stability, and safety distances. Drilling is performed vertically or with a slight inclination, with control of deviation from the designed axis. Each borehole must be marked, cleared of debris, and checked for depth and possible obstructions before charging with explosives. Drilling into previously used boreholes or near unexploded ordnance is prohibited [36]. Borehole charging is carried out with cartridge or non-cartridge explosives, respecting the ratio of explosive mass to the volume of the separated rock mass in order to ensure controlled fragmentation and limit seismic effects. Explosives must not be forcibly rammed, and tools used when charging blast holes must be made of wood or plastic and must not produce sparks. Initiators (detonators) are connected in series or parallel, and the use of timing-synchronized systems enables precise control of firing sequences to reduce vibrations and optimize fragmentation [37]. Figure 1 shows a schematic layout of boreholes with indicated technical blasting parameters.

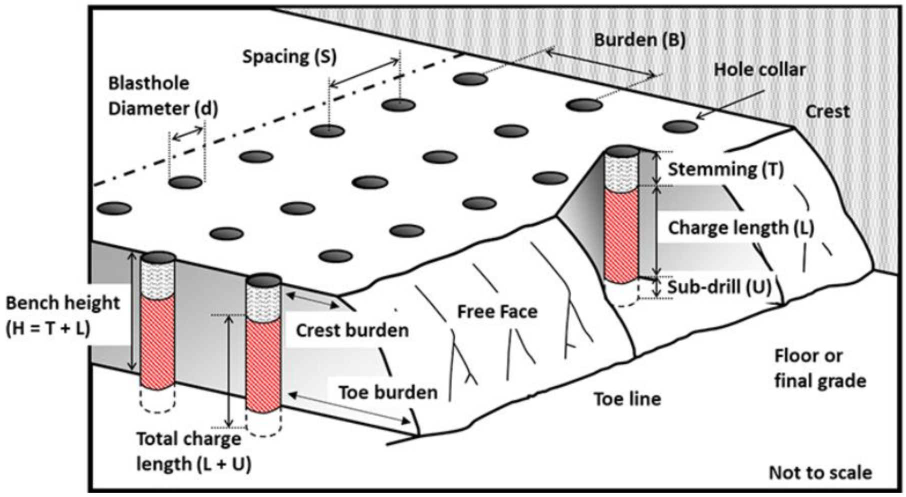

Figure 1. Schematic diagram of the borehole layout with indicated parameters: borehole diameter (d), spacing between boreholes (S), line of least resistance (B), charge length (L), stemming length (T), pre-drill/additional borehole depth (U), and bench height (H) [38].

2.3 Evacuation and detonation

The blasting zone must be physically fenced, clearly marked with warning signs, and kept under constant supervision by authorized personnel involved in the blasting process. The minimum evacuation distance is determined based on previous incidents of flyrock, applying a safety factor of 1.5 times the greatest recorded distance of a thrown fragment. This distance can be approximated by the expression:

$$D = 1{,}5 \cdot R_{max}$$

where R_{max} is the greatest recorded distance of rock-fragment ejection determined during experimental trial blasting. The given expression represents an empirical approximation used in the absence of precise measurements or numerical models, and serves as a practical criterion for defining the evacuation safety zone.

Prior to detonation, an audible signal must be emitted in three stages: warning, preparation, and detonation. Detonation may be carried out only on the order of the responsible person, after confirmation that the area has been completely evacuated, that all electrical and mechanical connections are functional, and that meteorological conditions allow safe execution of the blast. In the event of severe weather, high winds, or reduced visibility, the blasting procedure must be postponed until favorable conditions are reestablished [39].

2.4 Post-Blast Inspection of the Blasting Zone

After blasting operations, the work area must not be vacated until an audible signal clearly indicates the completion of the operation. This measure aims to prevent premature entry of personnel into a potentially hazardous area. Upon completion of blasting, a detailed visual inspection of the entire blast site must be carried out, including the blasted rock mass, accessible parts of the work area, and all surfaces exposed to explosive effects. The inspection is conducted to check for the presence of residual explosive materials, assess ground stability, and identify any potential deformations or displacements of the rock mass [40].

In case of suspected unexploded ordnance (UXO), access to the blasting zone is permitted only to professionally trained personnel equipped with appropriate protective gear and following prescribed safety procedures. Every intervention must be documented, and further activities may continue only after confirmation that the area is safe for work [41].

3. Risk Identification

Surface blasting involves a series of complex and potentially hazardous operations that generate various types of risks. Effective identification and classification of these risks form the basis for implementing appropriate occupational safety measures. Risks can be categorized into four main groups: mechanical, explosive, seismic/acoustic, and organizational.

3.1 Mechanical Risks

Mechanical risks in surface blasting arise from the interaction of workers with technical systems, dynamic work environments, and unstable rock material. In the context of drilling, charging, and face preparation, the most frequently identified mechanical hazards include contact with rotating parts of drilling equipment, falls from elevated benches, and impacts from dislodged rock blocks. These risks are inherent to the process, but their frequency and severity significantly increase under conditions of inadequate technical control, lack of spatial segregation, and absence of systematic protection.

According to OSHA regulations (29 CFR 1910.212), technical systems must be designed and maintained to prevent direct contact with moving parts, while the work area must be physically and procedurally isolated during active operations. Empirical studies indicate that the absence of barriers and inadequate signaling is the most common cause of mechanical injuries in mining and construction [12,42].

Personal protective equipment, although formally mandatory, cannot compensate for systemic shortcomings in work organization. Studies show that reflective clothing, protective helmets, and steel-toe footwear provide preventive benefits only when combined with technical access control and personnel training [43].

In this sense, mechanical risks cannot be addressed in isolation but require the integration of technical, organizational, and educational measures within a comprehensive safety management system.

3.2 Explosive Risks

Explosive risks represent the most critical category of hazards in surface blasting due to the immediate energy release, unpredictable effects of detonation, and potential for secondary incidents. In technical and safety literature, the most frequently identified explosive risks include premature detonation, the presence of unexploded ordnance (misfire), uncontrolled ejection of rock fragments (flyrock), and excessive explosive quantity relative to the designed parameters.

Uncontrolled scattering of rock fragments beyond the intended blasting zone is particularly dangerous due to its spatial unpredictability and kinetic energy. Empirical data indicate that fragments can reach distances exceeding 300 meters from the detonation epicenter, with recorded cases of severe injuries and fatalities [12,42].

In this context, the spatial distribution of risks must be precisely defined, applying safety factors and previous field measurements. The spatial distribution of risks due to uncontrolled flyrock during blasting is shown in Figure 2, which illustratively defines the blasting zone, the evacuation safety zone, and potential trajectories of ejected rock fragments.

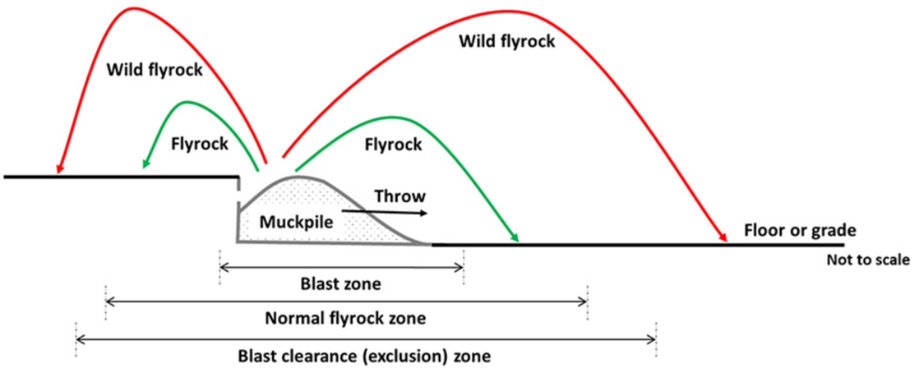

Figure 2. Zone of ejected rock fragments during blasting – spatial distribution of risk and safety boundaries [44].

To estimate the incident overpressure from an air blast, an empirical expression known as the Kingery–Bulmash model is used [45]:

$$P = \frac{K \cdot Q^{1/3}}{R}$$

where:

P – pressure, expressed in bar,
Q – amount of explosive, in kg,
R – distance from the epicenter, in m, and
K – empirical coefficient, dependent on the type of explosive and detonation geometry.

This formula is used in planning the blasting zone, especially near infrastructure, populated areas, or sensitive facilities. Unexploded ordnance (UXO) represents a latent risk requiring specialized intervention. According to MSHA guidelines, areas suspected of containing unexploded ordnance must be isolated, and access is permitted only to professionally trained personnel equipped with appropriate protective gear and technical support.

3.3 Seismic, Vibrational, and Acoustic Risks

Detonation of explosives in surface blasting generates seismic and air waves that propagate through the ground and atmosphere, interacting with surrounding structures, infrastructure, and human organisms. These waves can affect the

stability of buildings, the integrity of underground installations, and induce physiological and psychological reactions in workers and nearby populations [46–49]. Ground vibrations are transmitted to structures via foundations and basements, while the air blast impacts walls and roof surfaces. The resulting shaking can cause rattling of objects, displacement of equipment, and an internal noise sensation, which may trigger alarmed reactions in people, even though the noise itself has negligible impact on structural stability [47–49].
In the following text, Figure 3a illustrates the propagation mechanism of seismic and air waves generated by explosive detonation. The waves radiate outward from the epicenter, interacting differently with the ground or structures.
Figure 3b shows the energy balance of the explosion, highlighting that only a small portion of the released energy is used for rock fragmentation. The majority of the energy is transmitted through undesired effects, such as the dispersion of fragmented material and the generation of seismic and air waves [50].

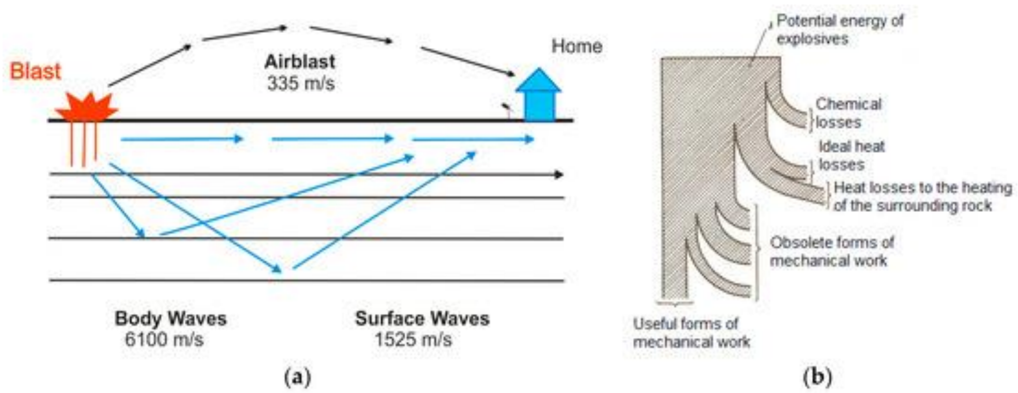

Figure 3. (a) Propagation of seismic and air waves during blasting; (b) Schematic representation of the energy balance during blasting [51].

According to technical guidelines, the permissible vibration level at the boundary of the blasting zone is a maximum of 5 mm/s for residential buildings and 10 mm/s for industrial structures [52]. Monitoring of actual values is performed through seismic monitoring using geophones, which enables the adjustment of blasting parameters under real conditions [53]. For the technical assessment of the seismic impact, a standardized empirical formula is used [54]:

$$PPV = K \cdot \left(\frac{D}{Q^{1/2}}\right)^{-n}$$

where:

PPV – peak particle velocity, in mm/s,

D – distance from the explosion epicenter, in m,

Q – amount of explosive per delay, in kg, and
K, n – coefficients dependent on local geological conditions and the type of explosive.

The values are determined through field measurements, most commonly using the least squares method, enabling local calibration of the model and precise blasting planning in sensitive zones [54].

In addition to seismic and vibrational effects, explosive detonation generates an airblast, which occurs due to the rapid expansion of gases from the explosion. This impulsive wave can cause damage to glass surfaces, disrupt electronic equipment, and negatively affect workers' hearing. The recommended airblast threshold is 120 dB for industrial zones, while a maximum of 115 dB is advised for residential areas [55]. Acoustic risks are mitigated through the use of sound barriers, proper timing of detonations, and mandatory hearing protection.

3.4 Organizational Risks

Organizational risks represent a key factor in the safety analysis of blasting, as they relate to systemic failures in planning, communication, and execution of operations. The most common sources of these risks include lack of training, unclear allocation of responsibilities, poor inter-team communication, and non-compliance with applicable legal regulations.

According to the Rulebook on Technical Standards for the Handling of Explosives and Blasting in Mining [25], the contractor is obliged to ensure the presence of an authorized person for handling explosives, to record the professional training of workers, and to provide physical protection of the blasting zone by means of signage and barriers. Although evacuation procedures are not explicitly prescribed, the technical documentation must include measures that ensure worker safety within the blasting area.

Domestic literature emphasizes that organizational shortcomings, especially in the preparation and coordination phase, are a frequent cause of deviations from the safety parameters of blasting. Lack of formalized procedures, inadequate communication among teams, and absence of clear operational instructions can lead to errors that, in explosive operations, manifest with serious consequences [56].

4. Zaključak

Blasting at surface quarries represents one of the most demanding and high-risk phases of technical operations in the mining and infrastructure sectors. Effective management of the risks arising from this process requires a systematic integration of legal regulations, technical standards, organizational measures, and geophysical methods. Each phase, from planning and drilling to detonation and post-blast inspection, must be precisely defined and controlled to ensure worker safety, stability of the work area, and environmental protection.

Analysis of the key risk categories indicates that explosive, seismic, and organizational factors have a dominant impact on operational safety. Explosive risks, such as uncontrolled flyrock and the presence of unexploded ordnance, require the application of empirical models, technical barriers, and specialized procedures. Seismic and acoustic impacts must be quantitatively monitored and controlled using geophones and standardized calculations, while organizational shortcomings, particularly in the preparation and coordination phases, represent latent sources of accidents that can be prevented through the establishment of clear procedures, formalization of protocols, and personnel training.

Compliance with the Rulebook on Technical Standards for the Handling of Explosives and Blasting in Mining, as well as with European directives and international standards, provides the foundation for legally and technically valid execution of blasting operations. The application of geophysical methods, such as seismic tomography and electromagnetic surveys, enables precise characterization of the rock mass, identification of unstable zones, and optimization of drill hole layouts, thereby directly contributing to risk reduction and operational efficiency.

In conclusion, safety in blasting is not only a technical challenge but also a professional and ethical obligation for all participants in the process. Only through consistent application of validated data, harmonized procedures, and a multidisciplinary approach is it possible to achieve controlled, efficient, and safe mining operations under complex engineering conditions.

1. Literatura

57. Bajpayee, T. S., Rehak, T. R., Mowrey, G. L., & Ingram, D. K. (2004). Blasting injuries in surface mining with emphasis on flyrock and blast area security. *Journal of Safety Research, 35*(1), 47–57. https://doi.org/10.1016/j.jsr.2003.07.003
58. Kecojevic, V., & Radomsky, M. (2005). Flyrock phenomena and area security in blasting-related accidents. *Safety Science*, 43(9), 739–750. https://doi.org/10.1016/j.ssci.2005.07.006
59. Valjevac, M., Bektašević, E., Gutić, K., Sakić, N., & Sikira, D. (2024). Exploitation and processing of technical stone from quarries Plješevac near Kiseljak. *Journal of Faculty of Mining, Geology and Civil Engineering, University of Tuzla*, 12, [Professional Paper]. https://doi.org/10.51558/2303-5161.2024.12.12.23
60. Mine Safety and Health Administration. (2002). *Module 11: Transportation, use, and storage of explosives*. U.S. Department of Labor. Retrieved from https://arlweb.msha.gov/safetypro_in_a_box/IG%2043%20OJT%20training%20modules%20surface%20MNM/Module%2011%20Transportation%20use%20and.%20storage%20of%20explosives.PDF
61. Festić, E., & Imamović, A. (2021). Značaj edukacije i opšti uslovi za bezbjedan transport opasnih materija prema ADR-u. *Zaštita i sigurnost*, 1(2), 95–106.
62. Bektašević, E., Gutić, K., Valjevac, M., & Sakić, N. (2025, April). The role and importance of preventive safety measures at work during the production and processing of technical stone at the quarry. In *15th Scientific/Research Symposium with International Participation „METALLIC AND NONMETALLIC MATERIALS“*, Bosnia and Herzegovina.
63. Bektašević, E., Gutić, K., Valjevac, M., & Konta, J. (2024, December). Unapređivanje mjera zaštite na radu u kamenolomima pri proizvodnji i preradi tehničkog kamena. *Rudarsko-geološki glasnik*, Hrvatsko rudarsko-geološko društvo Mostar, 49–61. ISSN 1840-0299.
64. Chen, X.-k., Zhu, H.-l., & Chen, J.-q. (2011). *Hazard identification and control in the pre-blasting process*. *Journal of Coal Science and Engineering (China), 17*(3), 331-335. https://doi.org/10.1007/s12404-011-0320-0
65. Imamović, A., Softić, S., Kablar, O., & Oruč, M. (2022). Značaj procedure istraživanja incidenta za sigurniji rad na rizičnim radnim mjestima. *Zaštita i sigurnost*, 2(1), 22–31.
66. Manitoba Labour and Immigration. (2006). *Code of practice for the use of explosives*. Workplace Safety and Health Division. Retrieved from https://www.gov.mb.ca/labour/safety/pdf/cop_useof_explosives.pdf
67. Strzałkowski, P., Woźniak, J., Górniak-Zimroz, J., & et al. (2025). Identification and systematics of safety hazards in surface rock mining. *Scientific Reports, 15*, 30492. https://doi.org/10.1038/s41598-025-16437-z

68. Bajpayee, T. S., Rehak, T. R., Mowrey, G. L., & Ingram, D. K. (2004). Blasting injuries in surface mining with emphasis on flyrock and blast area security. *Journal of Safety Research, 35*(1), 47–57. https://doi.org/10.1016/j.jsr.2003.07.003
69. Engineer Live. (2023). *Better blasting: Improving safety in mining operations*. Retrieved October 1, 2025, from https://www.engineerlive.com/content/better-blasting
70. Identec Solutions. (2023). *Blasting safety in daily mining operations*. Retrieved October 1, 2025, from https://www.identecsolutions.com/news/blasting-safety-in-daily-mining-operations
71. Mine Safety and Health Administration. (n.d.). *Blasting safety*. U.S. Department of Labor. Retrieved October 1, 2025, from https://www.msha.gov/safety-health/safety-health/safety-health-materials/safety-topics/blasting-safety
72. National Institute for Occupational Safety and Health. (2006). *Blast area security: Flyrock safety* (NIOSH Report No. 2007-112). U.S. Department of Health and Human Services. https://www.cdc.gov/niosh/docs/mining/UserFiles/works/pdfs/2007-112.pdf
73. Orica. (2010). *Safety of blasting with electronic detonators*. Orica Technical Bulletin. https://www.orica.com/ArticleDocuments/2606/200415_Safety%20of%20Electronic%20Detonators%20for%202010%20ISEE%20Lownds%2C%20Steiner.pdf.aspx
74. Vlada Federacije Bosne i Hercegovine. (2020). *Zakon o zaštiti na radu*. Službene novine Federacije BiH, broj 17/20. https://fbihvlada.gov.ba/bosanski/zakoni/2020/Zakoni/17.htm
75. Vijeće Europske unije. (1989). *Direktiva 89/391/EEZ o uvođenju mjera za poticanje poboljšanja sigurnosti i zdravlja radnika na radu*. Službeni list Europske unije, L 183, 1–8. https://eur-lex.europa.eu/legal-content/HR/TXT/?uri=CELEX%3A31989L0391
76. Reynolds, J. M. (2011). *An introduction to applied and environmental geophysics* (2nd ed.). Wiley-Blackwell.
77. Bektašević, E., Antičević, H., Gutić, K., & Sikira, D. (2024). Determination of the depth of the rock mass damage zone around the excavation profile by blasting with seismic cross-hole tomography in the „Šubir“ tunnel on the Zagreb-Split motorway. *Nauka+Praksa*, (27), 13–19. https://doi.org/10.62683/NiP27.13-19
78. Bektašević, E., & Gutić, K. (2025). Seismic impact assessment of blasting on surrounding population using geophysical methods. *Engineering and Technology Journal*, 10(4), 4468–4475. https://doi.org/10.47191/etj/v10i04.12

79. Bektašević, E., Antičević, H., Gutić, K., & Sikira, D. (2024). Application of seismic methods for determining the depth of the rock mass damage zone around the excavation profile by blasting. *Global Journal of Engineering and Technology Advances*, 18(3), 139–151. https://doi.org/10.30574/gjeta.2024.18.3.0051
80. Husejnagić, E., Bektašević, E., Osmanović, F., Žutić, Đ., Konta, J., & Hasić, E. (2016). Geofizičko-seizmička ispitivanja vještački izazvanih potresa i njihov uticaj na sigurnost i stabilnost objekata na PK Koritnik-Breza. In *Zbornik radova petog međunarodnog naučno-stručnog savetovanja*, Savez građevinskih inženjera Srbije, Sremski Karlovci (pp. 205–222).
81. Službeni list SFRJ. (1988). Pravilnik o tehničkim normativima pri rukovanju eksplozivnim sredstvima i miniranju u rudarstvu.
82. European Commission. (1992). *Council Directive 92/91/EEC on the minimum requirements for improving the safety and health protection of workers in the mineral-extracting industries through drilling*. https://eur-lex.europa.eu/eli/dir/1992/91/oj/eng
83. European Parliament and Council. (2013). *Directive 2013/29/EU on the harmonisation of the laws of the Member States relating to the making available on the market of pyrotechnic articles*. https://eur-lex.europa.eu/eli/dir/2013/29/oj/eng
84. European Parliament and Council. (2014). *Directive 2014/28/EU on the harmonisation of the laws of the Member States relating to the making available on the market and supervision of explosives for civil uses*. https://eur-lex.europa.eu/eli/dir/2014/28/oj/eng
85. International Organization for Standardization. (2018). *ISO 45001:2018 – Occupational health and safety management systems – Requirements with guidance for use*. https://www.iso.org/standard/63787.html
86. European Committee for Standardization. (2003). *EN 13631-10:2003 – Explosives for civil uses – High explosives – Part 10: Verification of initiation methods*. https://standards.iteh.ai/catalog/standards/cen/9b294e02-391f-47cd-85fe-60101faf6341/en-13631-10-2003
87. Bektaševič, E., Kadrić, R., Nikolić, M., Gutić, K., & Kadrić, S. (2023). Excavation of the foundation of piers S1L and S1R of the Vranduk I bridge by controlled blasting on the motorway route: Zenica Municipality Northern Administrative Boundary – Zenica North. *Electronic Collection of Papers, Faculty of Civil Engineering, University of Mostar*, 26, 9–26. https://doi.org/10.47960/2232-9080.2023.26.13.9
88. Bektaševič, E., Kadrić, R., Gutić, K., & Kadrić, S. (2023). Primjena kontrolisanog miniranja pri iskopu ulaznog portala desne tunelske cijevi tunela „Vranduk“ na koridoru Vc. *Zbornik radova GEO-EXPO 2023*, Društvo za geotehniku u Bosni i Hercegovini, 163–172. https://doi.org/10.35123/GEO-EXPO_2023_17

89. Bektaševič, E., Antičević, H., Osmanović, F., Kadrić, S., Žutić, Đ., & Konta, J. (2023). Tehnologija miniranja pri iskopu evakuacionog tunela „Vranduk II“ na magistralnoj cesti M-17. *Elektronički zbornik radova Građevinskog fakulteta Sveučilišta u Mostaru*, 49–60. https://doi.org/10.47960/2232-9080
90. Ilić, M. (2017). Application of results of geological exploration of deposits of solid mineral raw materials in mining. *Tehnika – Mining, Geological and Metallurgical Engineering*, *72*(2), 204–211. https://doi.org/10.5937/tehnika1702204I
91. Bektašević, E., Strelec, S., Sakić, N., & Gutić, K. (2025). Multichannel surface wave analysis in the context of shallow geophysical investigations. Academia Engineering, 2(3). https://doi.org/10.20935/AcadEng7876
92. Occupational Safety and Health Administration (OSHA). (2024). *1926.905 - Loading of explosives or blasting agents.* U.S. Department of Labor. Retrieved from https://www.osha.gov/laws-regs/regulations/standardnumber/1926/1926.905
93. Tang, H.-L., Liu, X., Yang, J., & Yu, Q. (2023). Experimental Study on the Influence of Delay Time on Rock Fragmentation in Bench Blasting. *Applied Sciences*, *13*(1), 85. https://doi.org/10.3390/app13010085
94. Szendrei, T. & Tose, S.. (2024). Flyrock in surface mining Part II - Causes, sources, and mechanisms of rock projection. Journal of the Southern African Institute of Mining and Metallurgy. 123. 557-564. 10.17159/2411-9717/2583/2023.
95. Božić, B. (1998). *Miniranje u rudarstvu, graditeljstvu i geotehnici*. Varaždin: Geotehnički fakultet Sveučilišta u Zagrebu.
96. Bektašević, E. (2022). *Blasting: Examples of surface blasting and tunnel construction with occupational safety measures*. LAP LAMBERT Academic Publishing.
97. QNJAC. (2020). *Post-blast inspection guidance for quarries*. Quarries National Joint Advisory Committee. https://minex.org.nz/training/toolbox/the-post-blast-inspection.pdf
98. Kecojevic, V., & Radomsky, M. (2005). *Flyrock phenomena and area security in blasting-related accidents*. Safety Science, 43(9), 739–750. https://doi.org/10.1016/j.ssci.2005.07.006
99. ISEE. (2022). *Personal Protective Equipment in Blasting Operations*. International Society of Explosives Engineers.
100. Little, T. N. (2007). *Flyrock risk*. In *Proceedings of EXPLO2007: Blasting—Techniques and Technology* (pp. 35–43). Australasian Institute of Mining and Metallurgy.
101. Kingery, C. N., & Bulmash, G. (1984). *Airblast parameters from TNT spherical air burst and hemispherical surface burst* (ARBRL-TR-02555). U.S. Army Ballistic Research Laboratory. Retrieved from https://apps.dtic.mil/sti/pdfs/ADA955203.pdf

102. Bektašević, E., & Gutić, K. (2025). *Seismic impact assessment of blasting on surrounding population using geophysical methods*. *Engineering and Technology Journal, 10*(4), 4468–4475. https://doi.org/10.47191/etj/v10i04.12
103. tagg, M. S., & Siskind, D. E. (1987). *Effects of blast vibration on construction material cracking in residential structures* (p. 43). Bureau of Mines Technology Transfer Seminar, Chicago, MI, USA.
104. Siskind, D. E., & Stagg, M. S. (1987). *Blast vibration measurements near structures* (pp. 46–50). Bureau of Mines Technology Transfer Seminar, Chicago, MI, USA.
105. Hustrulid, W. A. (1999). *Blasting principles for open pit mining* (Vol. 2). CRC Press.
106. Malbašić, V., & Stojanović, L. (2017). *Determination of seismic safety zones during the surface mining operation development in the case of open pit „Buvač“*. In *Proceedings of the 6th International Symposium MEP 17* (pp. 138–144), Vrdnik, Serbia, June 21–24.
107. Malbasic, V., & Stojanovic, L. (2018). Determination of Seismic Safety Zones during the Surface Mining Operation Development in the Case of the „Buvač“ Open Pit. *Minerals*, *8*(2), 71. https://doi.org/10.3390/min8020071
108. Husejnagić, E., Bektašević, E., Osmanović, F., Žutić, Đ., Konta, J., & Hasić, E. (2015). *Geofizičko-seizmička ispitivanja vještački izazvanih potresa i njihov uticaj na sigurnost i stabilnost objekata na PK Koritnik–Breza*. *Rudarsko-geološki glasnik*, Hrvatsko rudarsko geološko društvo, Mostar, 67–82. (ISSN 1840-0299).
109. Bektašević, E., Frljak, N., Sarajlić, M., Konta, J., & Lapandić, E. (2013). *Komparativni pregled uticaja prirodnih i vještački izazvanih potresa na primjeru „Rudnika krečnjaka Breza“–Breza*. *Rudarsko-geološki glasnik*, Hrvatsko rudarsko geološko društvo, Mostar, 70–77. (ISSN 1840-0299).
110. Boon, C. W., & Ooi, L. H. (2015). *Rock blasting — peak particle velocity against distance*. In Proceedings of the 11th International Symposium on Rock Fragmentation by Blasting (FRAGBLAST 11), Sydney, Australia. Australian Centre for Geomechanics. Dostupno na: https://papers.acg.uwa.edu.au/d/1508_23_Boon/23_Boon.pdf
111. Gregurović, N. (2013). *Kontrola seizmičkih efekata pri opreznim miniranjima u urbanim sredinama* [Diplomski rad, Geotehnički fakultet Sveučilišta u Zagrebu]. Repozitorij GFV. https://repozitorij.gfv.unizg.hr/islandora/object/gfv%3A75/datastream/PDF/view
112. Katalinić, M. (2021). *Netipične vrijednosti kod mjerenja seizmičkih utjecaja miniranja* [Diplomski rad, Rudarsko-geološko-naftni fakultet, Sveučilište u Zagrebu]. Repozitorij RGNF. https://zir.nsk.hr/islandora/object/rgn%3A1783/datastream/PDF/download

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Figure 1. Schematic diagram of the borehole layout with indicated parameters: borehole diameter (d), spacing between boreholes (S), line of least resistance (B), charge length (L), stemming length (T), pre-drill/additional borehole depth (U), and bench height (H).

Figure 2. Zone of ejected rock fragments during blasting – spatial distribution of risk and safety boundaries.

Figure 3. (a) Propagation of seismic and air waves during blasting; (b) Schematic representation of the energy balance during blasting.