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SELECTING THE SUITABLE ROCK EXCAVATION METHOD OF HARD ROCK REMOVAL FOR CONSTRUCTING A GROUND LEVEL SERVICE RESERVOIR AT HILL TOP IN URBAN POPULATION

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Abstract: A best-suited method for rock excavation at the hilltop has been identified in the present paper for construction of a Ground Level Service Reservoir (GLSR) in a densely populated urban area. At the foothill, several residential houses are located at 70 meters from the excavation boundary. Due to presence of hard granitic rock, the previously adopted method using a non-explosive silent cracking agent combined with hydraulic rock breakers and excavators became inefficient in achieving the required production targets. Hence, various alternative rock excavation methods were evaluated considering two key factors, timely completion and safety of nearby structures.

Various rock-breaking techniques such as hydraulic rock breakers, static expansion agents, plasma blasting and heat-assisted splitting were reviewed thoroughly, but they found to be time-consuming and inadequate for completing the project within the time schedule. The use of explosives and controlled blasting method emerged as the only viable option provided the emanating ground vibrations, noise, and flyrock are maintained within permissible limits. Based on data from different sites with similar geological conditions, a vibration prediction equation was developed and accordingly, appropriate controlled blasting patterns along with an optimized excavation methodology were proposed to ensure safe rock excavation within the designated timeframe.

Keywords: Rock excavation, Controlled blasting, Ground vibrations, Ground Level Service Reservoir (GLSR), Non-explosive rock breakage methods

1 INTRODUCTION

In order to ensure uninterrupted availability of drinking water in Ranchi city, the capital of Jharkhand, the State Government has initiated the Jharkhand Urban Water Supply

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Improvement Project (JUWSIP). Ranchi, governed by the Municipal Corporation comprising of 55 wards within approximately 174 km² area.

The water demand of Ranchi is projected to rise sharply, reaching 401.36 MLD by 2035 and 556.81 MLD by 2050. Although a 114 MLD water treatment plant has been commissioned in 2018 under the AMRUT scheme of the Ministry of Housing and Urban Affairs to improve the water supply in Ranchi's northwestern and southern sectors, many challenges still persist. These include low per capita availability, irregular supply hours, insufficient pressure in peripheral areas and uneven distribution of water across zones (Government of Jharkhand Report, 2021).

The service-level indicators of 2022 (Table 1) indicate that the household water connection coverage and per capita supply are still below the prescribed urban service benchmarks (Urban Development & Housing Department Notification, 2022). To address this, the State Government proposed to develop an upgraded water supply system consisting a 213 MLD Water Treatment Plant (WTP), a 28.8 ML Ground Level Service Reservoir (GLSR) and a 489,268 m long distribution network for 60,932 household connections (Government of Jharkhand Report, 2021). This system is expected to enhance the existing infrastructure and meet the city's growing demand.

Table 1 Water Supply Service Levels for Ranchi City, Jharkhand

Sl. No.	Indicator	Benchmark	Status for 2021-22	Target for 2022-23
1	Coverage of water supply connections	100 %	60	65
2	Per capita supply of water	135 LPCD*	73	80
3	Extent of metering of water connections	100 %	28	40
4	Extent of non-revenue of water	20 %	38	35
5	Continuity of water supply	24 Hours	3	3
6	Efficiency in redressal of customer complaints	80 %	99	100
7	Quality of water supplied	100 %	100	100
8	Cost recovery in water supply services	100 %	7.8	45
9	Efficiency in collection of water supply related charges	90 %	30	45

*LPCD is for Liters per capita per day

Under this new water supply system, a Ground Level Service Reservoir (GLSR) is to be constructed at the top of a Hill, Bharamtoli Hill in the northern side of the Ranchi city (Figure 1). The construction of GSLR at a slightly higher elevation level would be benefitted due to following reasons:

a. Gravity-assisted distribution: The gravity-driven distribution from a higher elevation level would minimize the dependence on energy-intensive pumping and therefore, improve the efficiency.

b. Improved water pressure: The natural height would provide better pressure throughout the network thereby ensuring consistent service even during peak demand conditions also.

c. Emergency supply: During power outages or pump failures, gravity flow will maintain the water supply for critical services such as firefighting and sanitation.

d. Reduced contamination risk: Elevated reservoirs would be less vulnerable to ground-level contamination ensuring safer and cleaner water.

Figure 1. View of the GLSR construction site on top of Bharamtoli Hill (Source: Google Earth)

The hill is surrounded by many residential houses and hutments at the foothill on the north, west, and east sides. The reservoir would be divided into two compartments, covering an area of 100 m x 100 m with a tank size of 70 m x 70 m. The highest elevation level (EL) of the hill is 700 m, and excavation of hard rock is planned down to 687 m EL to construct the reservoir. The proposed maximum and minimum water levels within the GLSR are 693.00 m and 687.00 m, respectively, while the foothill's elevation is 629 m. The layout plan, illustrating the GLSR and nearby structures, is shown in Figure 2.

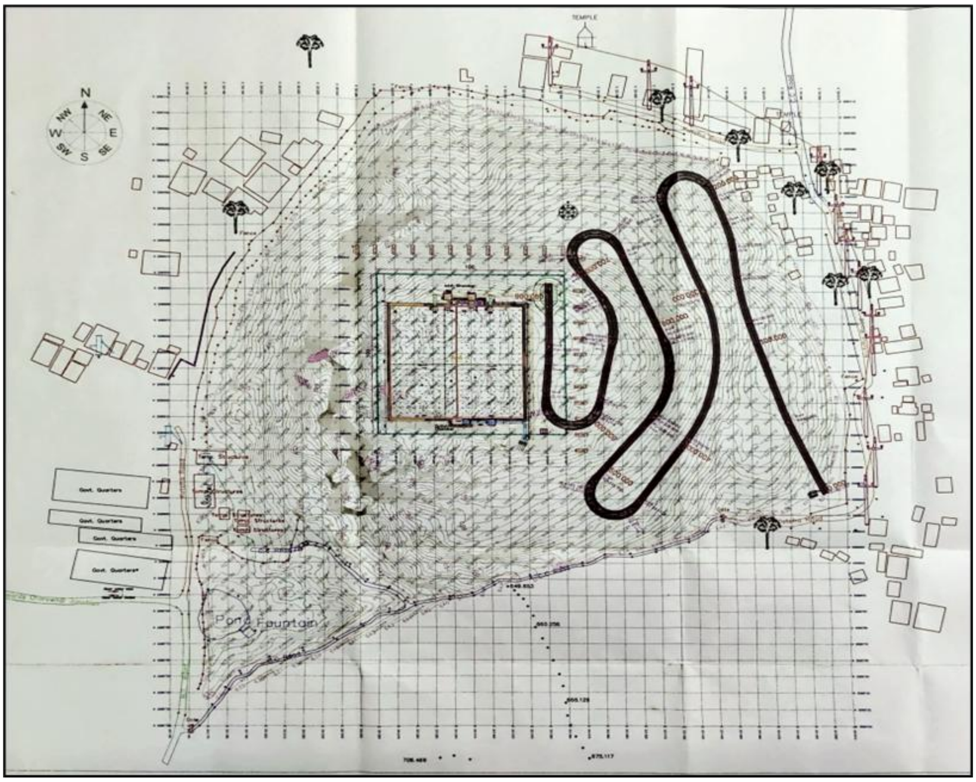

Figure 2. Plan view of the proposed GLSR showing different structures at the foothill

Due to its location in a densely populated area, the hard rock excavation at the hilltop is being carried out by using chemical expansive powder poured into shot holes drilled by jackhammer drilling machines. Once cracks develop after a considerable time duration, the subsequent excavation work is done by hydraulic excavators and rock breakers. However, this method produces very low daily output, posing risks to meet the construction schedule. To expedite the progress, alternate rock excavation techniques were investigated, and a detailed study was taken to identify the most effective, safe and timely rock excavation method for constructing the GLSR in time without endangering nearby residential structures. The paper provides a comprehensive analytical review of various rock breakage techniques and their evaluation to identify the safest and most effective method for hard rock excavation at the GLSR construction site on Bharamtoli hill.

2 SITE DETAILS AND GEOLOGY OF THE AREA

The GLSR construction site is situated on top of the Bharamtoli Hill in the northern part of Ranchi. Ranchi lies in the southern section of the Chhotanagpur Plateau (CNP), which forms the eastern extension of the Deccan Plateau. The city's primary water supply comes from major reservoirs created by damming the Kanke, Rukka, and Hatia channels.

The landscape of Jharkhand is predominantly influenced by the Chhotanagpur Plateau and its associated geomorphic divisions. Extending from the state's western region to its eastern boundary with West Bengal, the CNP exhibits a wide range of landform features. The Ranchi Plateau, the largest part of this formation, has an average elevation of approximately 700 meters above mean sea level (DOM&G, Government of Jharkhand, 2010). Geologically, the Ranchi Plateau rests primarily on hard crystalline rocks such as gneisses and granites, which are remnants of the ancient consolidated crust formed during the Archaean era more than 1,200 million years ago. The bedrock also includes schists and quartzites, together constituting the dominant lithological units of the region's hills and plateau areas (Pathak, 2012). From the peak of Bharamtoli Hill (Figure 3), rock samples were collected and analyzed at the Rock Mechanics Laboratory, CSIR-CIMFR, Dhanbad, to determine its various physico-mechanical properties. The hill consists mainly of granite, a very hard rock, and the results of these tests are summarized in Table 2.

Figure 3. A view of the type of rock observed on top of the Bharamtoli Hill

Table 2 Different physico-mechanical properties of the rock strata of the Bharamtoli Hill

Rock Type	Density (Dry)		Uniaxial Compressive Strength		Tensile Strength		Young's Modulus		Poisson's Ratio	
	Kg/m^3	Avg.	MPa	Avg.	MPa	Avg.	GPa	Avg.		Avg.
	2646		90.07		9.47		12.24		-	
Granite	2640	2643	59.04	76.37	7.37	8.83	9.15	11.51	0.34	0.29
	2644		79.99		9.66		13.13		0.23	

3 EXISTING PRACTICE OF ROCK BREAKAGE

The top of Bharamtoli Hill is composed of hard granite rock. The hill's top Elevation Level (EL) is 700 m, while excavation for construction of the GLSR is required down to EL 687 m, resulting in an average excavation depth of about 9 m. Currently, rock removal is performed using non-explosive methods. The process involves the use of a powdery expansive agent known as Echocrack, which initiates controlled fractures in the granite. L&T Komatsu PC 200 hydraulic rock breakers are then employed to break the rock mass along the cracks formed by the non-explosive agent.

To create these cracks, holes of 32 mm diameter are drilled using Jack Hammer Hydraulic drilling machines (Figure 4). The holes typically range from 1.2 to 1.5 m in depth, with a spacing of 0.20 to 0.30 m between them (Figure 5). The non-explosive chemical powder is then mixed with water in an appropriate ratio and poured into the drilled holes, leaving the top 0.3–0.4 m unfilled. This remaining portion is then packed tightly with the drill cuttings (Figure 6).

The diluted chemical gradually expands within the holes and generates an internal pressure which in turn, fractures the rock and produces cracks along the drilled hole lines. The cracking process generally takes 12-24 hours but, does not produce any noticeable displacement of the rock mass. Once the cracks are developed, hydraulic rock breakers are used to further reduce the rock to the required size (Figure 7).

Six numbers of Jack Hammer Drilling Machines of 32 mm hole diameter are used to drill the holes and are employed for about 8 hours per day. Following the complete process of drilling, charging, and crack formation, approximately 50–70 m^3 of rock is broken daily. As of the site visit date, around 8,000 m^3 of rock has been excavated from Bharamtoli Hill within a 7 months duration.

The GLSR project, including related distribution works, is scheduled for completion within 36 months. The total volume of rock to be excavated is estimated at 44,000 m^3 across an area of 100 m x 100 m. After seven months of excavation, an estimated 36,000 m^3 of rock remains. At the current removal rate of roughly 60 m^3 per day, an additional 600 days will be needed to complete the excavation (36,000 ÷ 60 = 600).

Thus, to completely excavate the balance volume of rock, 600 days are still required with this method. Therefore, a comprehensive technical review of the alternate rock-breaking methods with an increased focus on explosive and blasting method is in underway to determine the most efficient and safe method of rock breakage to ensure timely completion while maintaining the structural integrity of nearby residential areas at the base of the hill.

Figure 4. Use of 32 mm diameter Jack Hammer Drilling Machine for drilling of holes

Figure 5. Drilling pattern of holes (20-30 cm spacing)

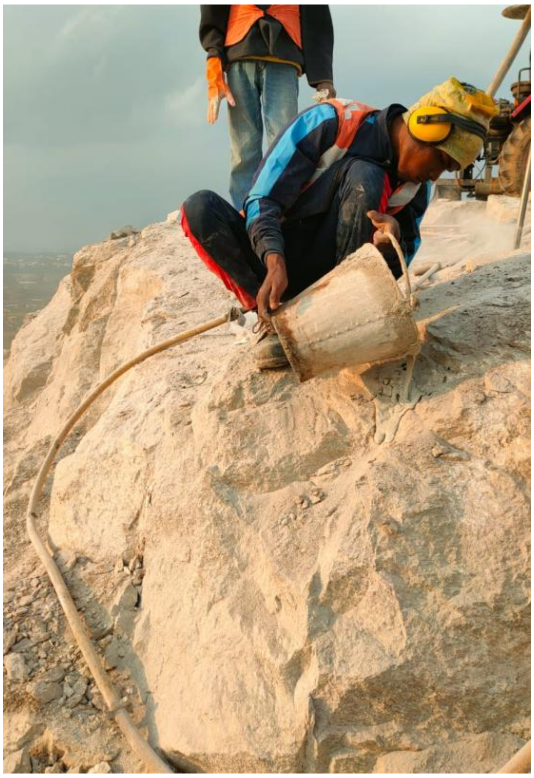

Figure 6. Pouring of non-explosive chemical in the hole

Figure 7. Use of Hydraulic Rock Breakers to break the cracks generated by the non-explosive agent

4 ASSESSMENT OF SAFE METHOD OF ROCK BREAKAGE

4.1 Different methods of rock breakage

Several methods are used for rock breakage in mining and civil engineering projects, depending on site-specific factors such as rock type, geological conditions, production requirements, equipment availability, proximity to structures, and potential environmental impacts. The most common methods include the following:

4.1.1 Explosive and blasting method

The use of explosives and blasting is the primary technique for rock breakage in most mining and civil engineering operations due to its high productivity at relatively lower cost compared to other methods. Despite advancements in mining technologies, blasting continues to be the most widely adopted rock breakage method throughout the world.

In this method, holes of required depth are drilled into the rock surface according to production requirements. These holes are then charged with commercially available explosives up to a certain depth and the balance hole is stemmed properly. After making proper connections with delay detonators, the shot is safely detonated from a secure location. The resulting fragmented rock is subsequently excavated using heavy earth-moving machineries. Although this method is economical and efficient, it may cause undesired effects such as ground vibration, noise, air overpressure, flyrock, dust, and fumes (Al-Bakri & Hafni, 2021).

4.1.2 Non-explosive methods

Non-explosive methods are widely employed in rock breakage at sensitive sites such as populated areas, high-risk zones, road excavation projects, and locations with complex environmental conditions. These techniques can be broadly classified into mechanical, chemical, and electrical methods (Zhou & Feng, 2018). Mechanical methods use large equipment such as hydraulic splitters, hydraulic breakers, and boring machines to fracture or cut the hard rock. Chemical methods involve the use of agents like static expansion compounds, carbon dioxide crackers, and metal burners. Electrical methods employ technologies such as plasma blasting and thermal splitting to break rock. A summary of various non-explosive rock breakage methods is presented in Table 3.

Table 3 Comparison of different non-explosive rock breakage methods

Type		Economy	Application / scope	Advantage	Disadvantage
Mechanical	Hydraulic Splitting Machine	Normal	Mines, gemstones, etc.	Safe to use, generates minimal vibration, environmentally friendly	Mechanical parts wear quickly, relatively low efficiency
	Hydraulic Breaker	Normal	Municipal works, mountainous terrain, ice breaking, demolition	Safe and eco-friendly	Prone to wear, unsuitable for medium-hard rock
	Boring Machine	Higher	Coal mines, tunneling projects	Safe, environmentally sound, delivers good quality results	Subject to wear, structurally complex, maintenance-intensive
Chemical	Static Expansion Agent	Low	Quarries, concrete structures	No flying debris, vibration-free, environmentally safe	Performance affected by rock type and climate, low efficiency
	Carbon Dioxide Cracker	Low	Quarries, coal mines, concrete	Very safe, produces minimal vibration	Standards lacking, some safety risks remain
	Metal Burners	Higher	Gemstone mining	No flying fragments, no toxic gases	Generates waste metal, reactive metals can be hazardous
Electrical	Plasma Blasting	Normal	Dismantling, Municipal Engineering	High safety, low vibration, no flying debris	Equipment costly, produces limited rock fragmentation
	Heat Splitting Rock	Normal	Supplemental rock breakage	Very effective on hard rock	Only suitable as a secondary method

4.2 Evaluation of safe rock breakage method

After a comprehensive review of various rock breakage techniques and their respective advantages and limitations, it has been determined that, under the present conditions at the GLSR construction site, all non-explosive methods, such as mechanical type hydraulic rock breakers, chemical-based static expansion agents, electrical plasma blasting, and heat-induced rock splitting are inefficient for the required scale. These methods are considerably slow, time-consuming, and unable to deliver the necessary daily output of fractured rock essential for completing hard rock excavation within the scheduled timeframe. Furthermore, several of these non-explosive techniques are either impractical or currently unavailable in Indian conditions. Hence, the adoption of explosive-based blasting methods has become indispensable to achieve the project's objectives within the desired timeline. Nevertheless, a safety assessment of this method is imperative, particularly for ensuring the protection of structures situated at the foothill area.

Blasting with explosives provides a rapid and effective means for breaking large rock masses. However, it carries potential risks and disturbances if not designed and executed with careful consideration of all relevant parameters. Properly controlled blasting operations can significantly accelerate the excavation process while maintaining their impacts such as ground vibrations, air overpressure, noise, and fly rock within permissible limits defined by Indian regulatory authorities. Therefore, a detailed evaluation of the blasting impacts, with a particular focus on ground vibrations affecting nearby foothill structures, is essential before finalizing the design parameters for the GLSR construction site.

4.2.1 Assessment of impact of ground vibrations in explosive and blasting method

Several studies on controlled blasting have been undertaken by the CSIR–Central Institute of Mining and Fuel Research (CSIR–CIMFR) using small-diameter blast holes (approximately 32 mm) drilled in comparable rock formations. One such investigation was conducted in the Western Ghats along the Konkan Railway alignment, where controlled blast trials were carried out to excavate hard rock outcrops. The rock was weathered type highly jointed hard massive granite having density of 2555 kg/m3 and compressive and tensile strengths 72.80 and 13.36 MPa respectively. Ground vibration levels generated from these blasts were systematically monitored at varying distances from the blasting site. The statistical analyses of the vibration data obtained from these trial blasts has formed the basis on assessing the influence of blast-induced ground motions on nearby foothill structures in the present research.

It is well established that Peak Particle Velocity (PPV) is primarily governed by two variables, distance from the blast source (d) and the maximum explosive charge detonated per delay (Qmax) (Singh et al., 2020). Among these parameters, Qmax is generally considered the key factor in blast design for vibration control. To account for the combined influence of these parameters, the concept of Scaled Distance (SD) is introduced, as expressed in Eq. 1:

$$SD = \frac{d}{\sqrt{Q_{max}}} \tag{1}$$

In practice, the precise form of the PPV–SD correlation differs from site to site, but is usually expressed as a power-law relationship of the form:

$$PPV = a(SD)^b \tag{2}$$

Here the parameters a and b are site-specific empirical constants. The coefficient *a* represents the degree of seismic energy transmitted into the ground, which depends on factors such as confinement and the explosive characteristics, whereas *b* reflects the geological attenuation of vibrations with distance (Dowding, 1985). These constants are typically determined through regression analysis of multiple field measurements. By log-transforming Eq. 2, the relation takes the linear form shown in Eq. 3.

$$\log[PPV] = b \cdot \log[SD] + \log[a] \quad (3)$$

In this representation, the slope corresponds to site factor b, while the intercept is related to log[a]. A reliable regression line (high R^2, low error) enables prediction of PPV values for specified distances and charge weights (Birch & White, 2013).

Based on this established empirical approach, a site-specific predictive equation was derived from CSIR–CIMFR vibration data collected during the Konkan Railway blasting study. The regression analysis was performed using Blastware software (Instantel Inc., Canada), resulting in Eq. 4. The corresponding regression plot is illustrated in Figure 8.

$$V = 1003.1 \cdot \left[\frac{D}{\sqrt{Q_{max}}}\right]^{-1.278} \quad (4)$$

Coefficient of Determination = 0.844, Standard Deviation = 0.144.

In India, vibration safety limits are regulated by the Directorate General of Mines Safety (DGMS), Dhanbad, which specifies allowable PPV thresholds for different categories of structures, depending on their construction type, sensitivity, and functional importance. For instance, reinforced concrete industrial buildings are permitted relatively higher vibration limits, while heritage structures and multi-storey residential buildings, due to their vulnerability, are subject to much stricter permissible limits (refer to Table 4).

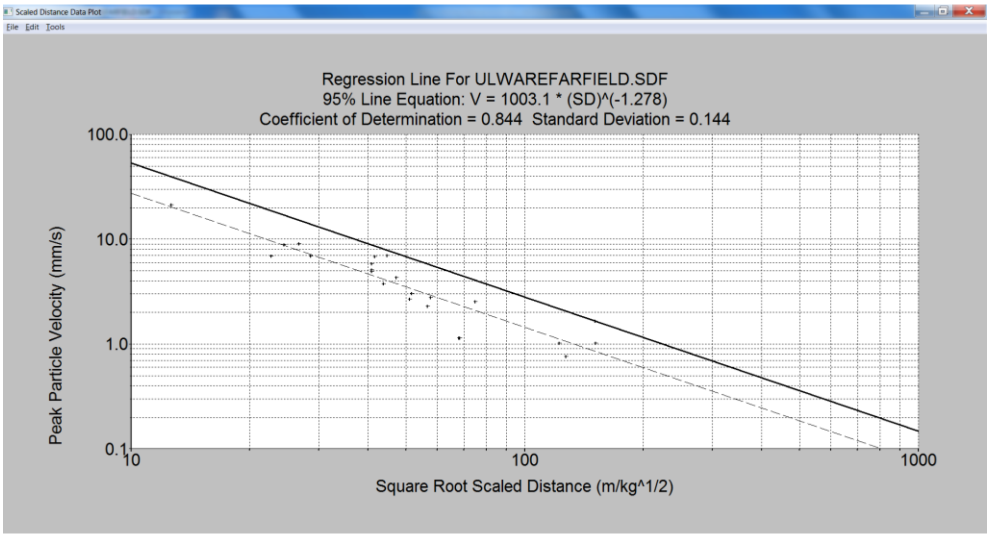

Figure 8. Plot of recorded ground vibration data with respect to scaled distance using Blastware software (Instantel Inc., Canada)

Table 4 DGMS ground vibration standards (DGMS, 1997)

Type of structure	Dominant excitation frequency		
	< 8 Hz	8-25 Hz	>25 Hz
(A) Buildings/structures not belonging to the owner			
Domestic houses/structures (Kuchcha, brick & cement)	5 mm/s	10 mm/s	15 mm/s
Industrial buildings	10 mm/s	20 mm/s	25 mm/s
Objects of historical importance and sensitive structures	2 mm/s	5 mm/s	10 mm/s
(B) Buildings/structures belonging to owner with limited span of life			
Domestic houses/structures	10 mm/s	15 mm/s	25 mm/s
Industrial buildings	15 mm/s	25 mm/s	50 mm/s

With the help of established ground vibration predictor equation, the magnitudes of ground vibrations at different distances from the blasting face with varying quantities of maximum explosive charge per delay have been calculated and are given in Table 5. From the table, it can be found out that at a distance of 50 m from the blasting face, if the maximum charge per delay is 1.0 kg only, the PPV would be 6.8 mm/s. However, if we increase the distance to 70 m, the PPV with the same charge per delay would be 4.4 mm/s, but with the charge per delay of 1.5 kg and 2 kg, they will be 5.7 mm/s and 6.8 mm/s respectively. This indicates a direct relation of PPV with the distance and maximum explosive charge per delay used in a blast.

Table 5 Predicted magnitudes of ground vibrations at different distances with different Qmax values using the established predictor Equation 4

Distance [m]	Predicted values of ground vibration, PPV [mm/s]				
	Qmax - 1.0 kg	*Qmax - 1.5 kg*	*Qmax - 2.0 kg*	*Qmax - 2.5 kg*	*Qmax - 5.0 kg*
50	6.8	8.8	10.5	12.1	18.9
60	5.4	6.9	8.3	9.6	15.0
70	4.4	5.7	6.8	7.9	12.3
80	3.7	4.8	5.8	6.7	10.4
90	3.2	4.1	5.0	5.7	8.9
100	2.8	3.6	4.3	5.0	7.8
110	2.5	3.2	3.8	4.4	6.9
120	2.2	2.9	3.4	4.0	6.2
130	2.0	2.6	3.1	3.6	5.6
140	1.8	2.4	2.8	3.3	5.1
150	1.7	2.2	2.6	3.0	4.6

4.2.2 Blasting restricted zones for different Q_{max} and threshold PPV levels

Blasting restricted zones have been established for different maximum explosive charge per delays (Q_{max}) and for various vibration threshold levels recommended by the Regulatory Body in India. These zones, within which blasting activities are prohibited, are illustrated in Figure 9.

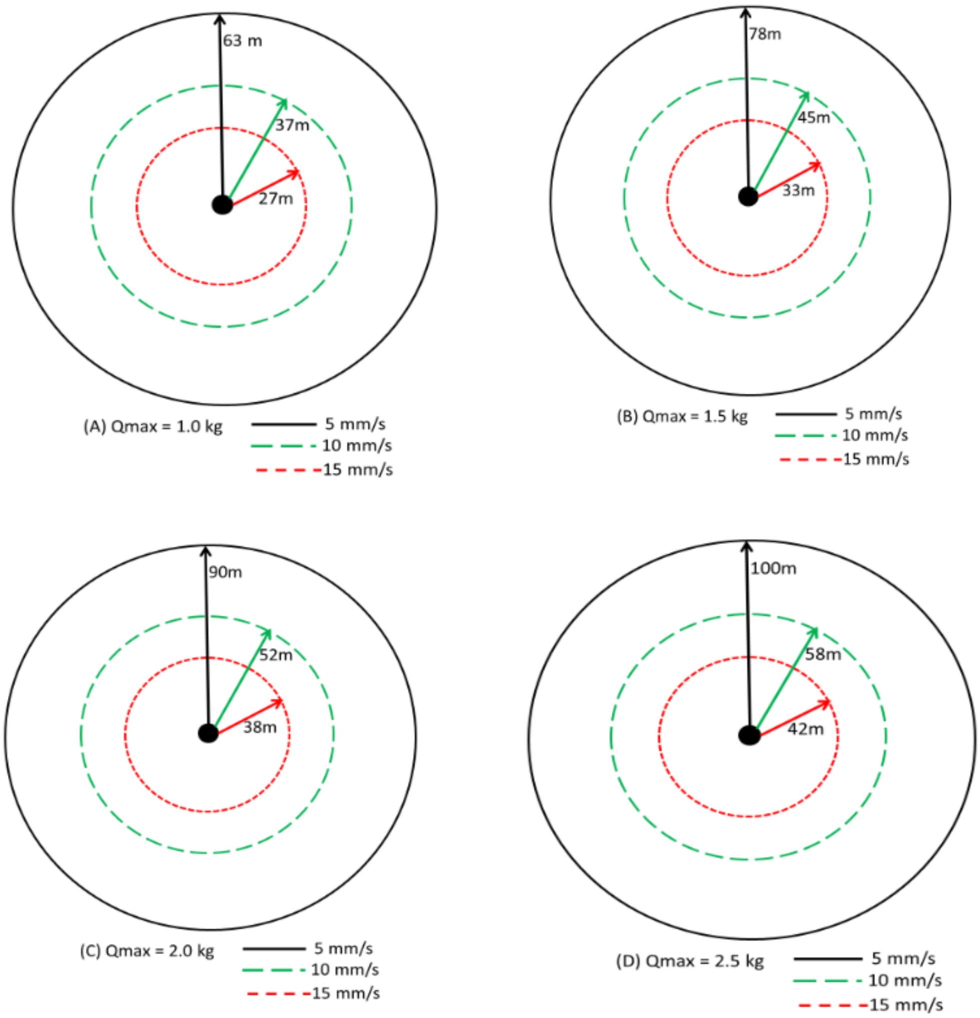

Figure 9. Blasting Restricted Zones for different threshold vibration levels (PPV) and maximum charge per delay (Q_{max})

It is evident from Figure 9 that when the threshold vibration level is set to the lowest value, that is, 5 mm/s, the blasting restricted zones, within which blasting activities cannot be performed, extend to 63 m, 78 m, 90 m, and 100 m for maximum charge per delay (Qmax) values of 1.0 kg, 1.5 kg, 2.0 kg, and 2.5 kg, respectively. Field observations at the GLSR construction site revealed that the nearest residential house is located approximately 70 m from the proposed GLSR boundary. Therefore, only a maximum charge per delay of 1.0 kg can be safely used to maintain vibration levels below 5 mm/s. Any charge per delay exceeding 1.0 kg would result in vibration magnitudes greater than 5 mm/s, as also indicated in Table 5.

The predicted ground vibration magnitudes at various distances from the blasting site, corresponding to different Qmax values, are presented in Table 4. It should be noted that the data used for these predictions were recorded at nearly the same elevation level as the blasting face. In the current scenario, however, controlled blasting for the GLSR construction will take place at the peak of Bharamtoli Hill, creating an elevation difference of more than 55 m between the blasting area and residential houses located at the foothill. Consequently, the actual vibration magnitudes resulting from controlled blasting operations are expected to be lower than those predicted by the established equation.

Based on the evaluation of ground vibration levels corresponding to various explosive charge per delay values, the delineation of blasting restricted zones for different PPV and Qmax levels, and the significant elevation difference between the GLSR site and nearby residential structures, it can be concluded that controlled blasting operations for hard rock excavation can be carried out safely without causing damage to surrounding houses and public infrastructure.

5 DEVELOPED CONTROLLED BLASTING METHODOLOGY AND BLASTING PARAMETERS

The methodology for hard rock excavation with controlled blasting technique should be as follows.

- Based on the capacity of the drilling machine and sensitiveness of the area, the complete excavation height varying between 696 - 687 m EL, (average 9 m) should be divided into six benches of 1.5 m each. The excavation should be carried out in a sequence from top to bottom. The entire width of the excavation of each layer/bench should be divided into many blasting patches depending on the number of the holes and location of the blasting face from the residential houses. The plan and sequence of excavation is shown in Figure 10.
- For excavation of rock in each layer, the controlled blasting should be conducted using the suggested design patterns given in Figure 11 and detailed in Table 6. With the help of suggested controlled blast design patterns, the throw of the blasted muck will be restricted within 5 m distance from the place of blasting.
- In order to prevent any flyrock during blasting operations, blasting mats of sufficient strength shall be placed over the entire blasting patch and on 1.5 m additional length.
- The final blasting should be carried out after taking proper shelter and giving sufficient warning to the surrounding inhabitant.

• Blast induced ground vibrations should be monitored at the nearest residential houses/structures situated at the foothill in order to assess the actual impacts of blasting and based on the results, the controlled blasting parameters should be modified.

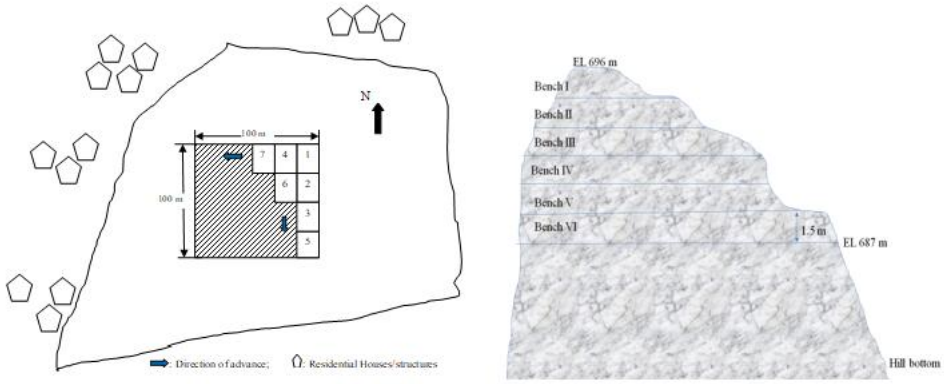

Figure 10. Plan and sequence of excavation of hard rock for conducting controlled blasting

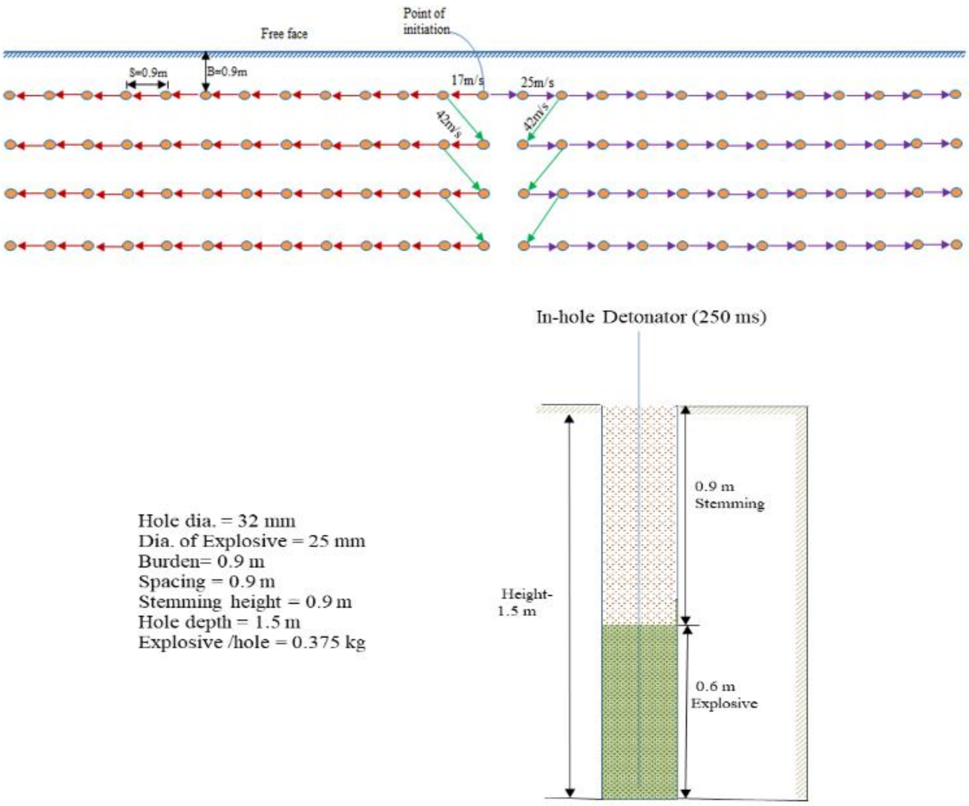

Figure 11. Layout of the suggested controlled blast design patterns

Table 6 Parameters of controlled blast design

Design parameter	value/range
Hole diameter	32 - 34 mm
Burden	0.8 - 0.9 m
Spacing	0.8 - 0.9 m
Depth of hole	1.5 m
No. of holes in a round of blast	50-180 (depending on site conditions and distance from the structures and will change after vibration and other blast results)
Type of explosive	Cartridge-type emulsion explosive (25 mm dia., 200 mm length, ~125 g per cartridge
Charge per hole	0.25 - 0.375 kg
Charge length	0.4 - 0.6 m
Max. charge per delay	1.0 - 2.5 kg (dependent on number of blast holes and distance to the nearest structure)
Total explosive quantity in the blasting round	12.50 - 67.50 kg (depending on site conditions, distance from structures and will change after vibration and other blast results)
Initiation system	Non-electric detonator system (Nonel) with in-hole detonators (DTH) of 250/275/450 ms and trunk-line detonators (TLD) of 17, 25 & 42 ms
Stemming length	0.9 - 1.1 m
Stemming material	Drill cuttings or crushed dust (size < 5 mm)

5.1 Protective arrangements

In order to avoid any flyrock from the blasting face, the entire blasting patch should be covered (muffled) before final firing after making surface connections of the charged holes. For this, heavy duty blasting mat built of rubber in sufficient quantities should be used. The entire blasting area should be covered using the blasting mats in addition to 1.5 m distance in all the sides. A photograph showing the muffling practice of a blasting patch is shown in Figure 12.

Figure 12. Muffling/covering of blasting patch using blasting mats

6 CONCLUSION

The comprehensive evaluation of various rock breakage techniques for timely completion of excavation works indicates that the use of controlled blasting methods with explosives is a feasible and safe option for the GLSR construction site. In contrast, non-explosive methods such as mechanical type hydraulic breakers, chemical expansion agents, plasma blasting, and thermal rock splitting are significantly slower and insufficient to meet the daily production targets within the project timeline.

The safety assessment of the controlled blasting method with explosives was conducted using data derived from a CSIR-CIMFR scientific study at a similar site in India. Based on this, an empirical equation was developed to predict ground vibrations by correlating the maximum explosive charge per delay with the distance of nearby structures from the blast point. Using this model, the safe explosive charge per delay (Qmax) was determined with a threshold Peak Particle Velocity (PPV) of 5 mm/s to ensure the safety of foothill structures.

The corresponding blasting exclusion zones for a 5 mm/s threshold PPV were established as 63 m, 78 m, 90 m, and 100 m for Qmax values of 1.0 kg, 1.5 kg, 2.0 kg, and 2.5 kg respectively. Since the nearest residential structure lies 70 m from the GLSR boundary, limiting Qmax to 1.0 kg ensures vibration levels remain below 5 mm/s. Additionally, because blasting will occur at the hilltop, an elevation difference of more than 55 m between the blast site and foothill residences will further reduce the vibration intensity.

Therefore, the detailed assessment confirms that controlled explosive blasting can be safely employed for hard rock excavation at the GLSR site, enabling timely completion of the project without jeopardizing the safety of nearby residential structures. The findings and methodology adopted in the present research work can be applicable to other similar cases where rock excavation is required in the urban vicinity.

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CONFLICTS OF INTEREST/COMPETING INTERESTS

The authors declare no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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