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Review paper

ROCK EXCAVATION METHODS IN URBAN AREAS

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Abstract: The increased volume of construction works, which includes the construction of new residential and business buildings, hotels, garages, shopping centers, and similar, is increasingly common in urban areas. Such works are increasingly coming into contact with different types of problems during construction, as one of these problems we single out the appearance of solid rock mass during excavation at the construction sites of future buildings foreseen in the construction project. During the construction of facilities or part of the building, which includes the underground premises of a building, it is necessary to excavate the material on site, however, due to its physical and mechanical characteristics, it is not always possible to excavate this material with conventional machinery. The composition of the material that is removed is sometimes in the form of solid rock, and thus its excavation is more complicated, so other methods must be used: controlled blasting, application of expansive mortars, etc. This paper presents some of the possibilities of removing solid rock material for the purpose of smooth construction of buildings.

Keywords: urban areas, excavation, expansive mortars, controlled blasting, construction

1 INTRODUCTION

The technology of excavating rock material can be performed by various methods that require precise execution and a high degree of safety during the execution of the works in order to perform them without unwanted consequences.
Some of the methods that can be applied in order to remove the rock mass are:

- application of explosives (blasting),
- application of expansive mortars,
- possibility of cutting rock material (chain saw machines, diamond wire saw machines),
- application of hydraulic breakers or rippers.

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The mentioned methods can be used and are very effective. However, many factors influence the choice, such as the scope of work and the amount of rock material that needs to be removed, the expected and available time for excavation, the characteristics of the rock material, etc. Generally, smaller amounts of rock material and material with cracks can be easily crushed with the already-mentioned machinery (hydraulic breakers or ripper). Currently, there is a lot of equipment available on the market in the form of heavy hammers (breakers) and rippers, which can be mounted on hydraulic excavators. When the rock is solid and without cracks, a very efficient way of removal can be done with cutter machines, which are normally used in mines of decorative stone. The application of expansive mortars has the advantage that there is no noise, vibration, or other negative effects, which is also a problem with work in an urban environment and needs to be reduced to an appropriate level. The disadvantages of expansive mortars are the high costs and profitability of works when it comes to a large amount of rock material. In the case of a large amount of material (solid rock), the effective method is the use of explosives, but attention should be paid to all negative effects which can appear during the blasting. This method is mostly used in combination with the other mentioned methods. In this paper, we will present each of the mentioned methods in detail and the technology of excavating solid rock mass in urban areas during the construction of buildings.

2 CONDITION ASSESSMENT IN THE CONSTRUCTION AREA

Before the excavation of rock material needs to record the condition of the surrounding area, regardless of the choice of method, especially if it involves the use of explosives. When excavating the rock mass, there are negative effects that can occur, namely:

- noise and vibration,
- the appearance of dust and gases,
- blasting vibration,
- flyrock.

Most often, in the immediate vicinity of such places, where the work is being carried out, there are a large number of residential and business buildings, churches, or some landmarks (cultural monuments) and similar, therefore it is necessary to inspect them and record the current condition (in the form of photographs, documents...). During work, it is necessary to use compliance with the prescribed measures of protection and safety at work. Figure 1. shows an example in urban area.

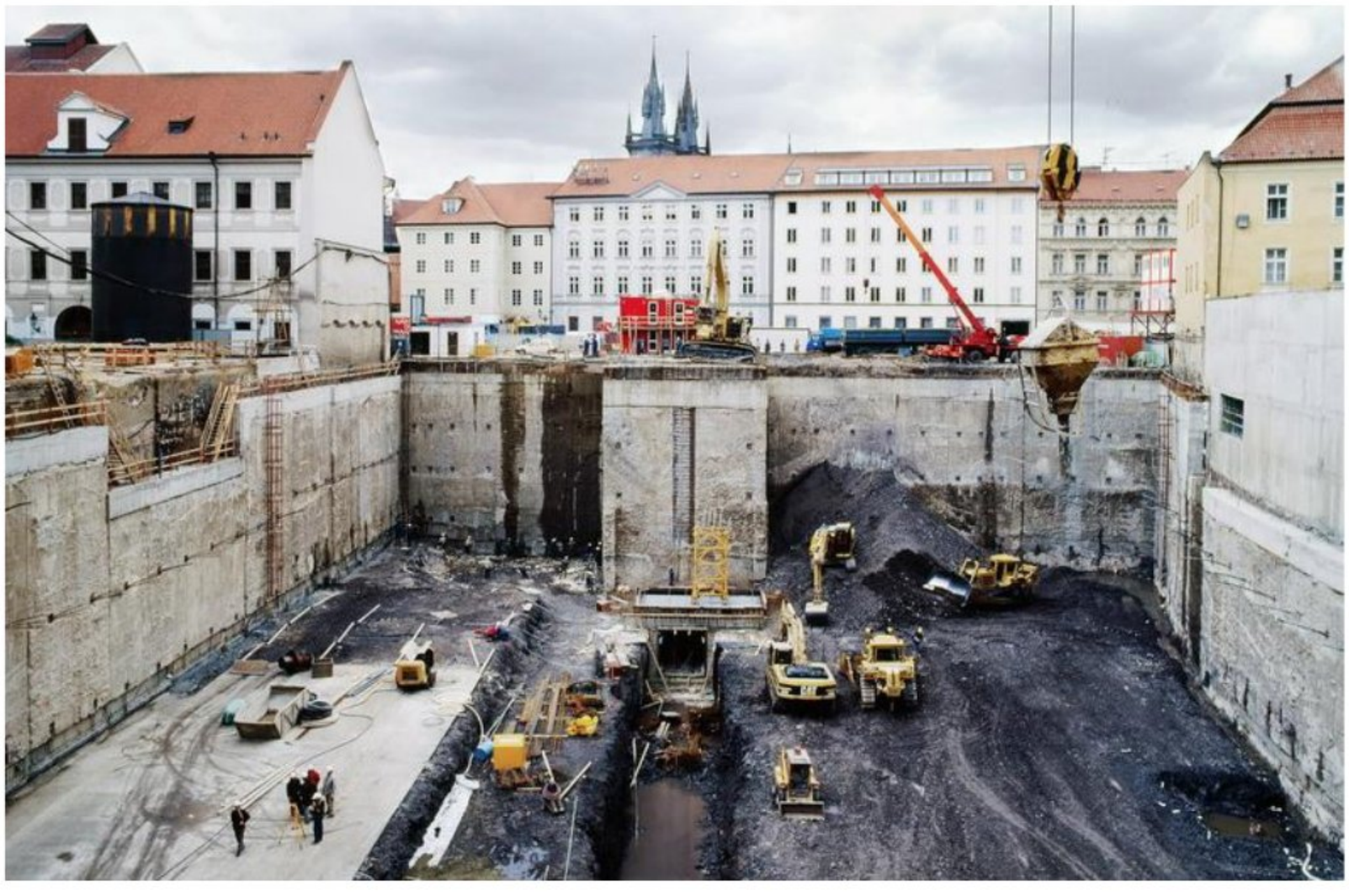

Figure 1 An example of excavation of rock material in an urban area (Zakladani, 2023)

3 TECHNICAL DESCRIPTION AND WORK TECHNOLOGY

The work on the excavation requires attention and precision, the conditions are a challenge for everyone, and it is necessary to follow all prescribed parameters and calculated values. When choosing the appropriate method for excavating rock mass in urban areas, it is important to consider factors such as safety, noise, vibration, limited space, and environmental protection. These techniques are often applied with appropriate precautions and technical experts to ensure the efficiency and safety of work in urban areas.

3.1 Application of explosives (blasting)

Drilling of boreholes, as well as contour boreholes, is carried out with a drilling diameter of 27 mm to 51 mm, therefore the use of explosives is reduced to cartridge explosives of smaller diameter and quantities that must be calculated beforehand. In order to carry out blasting works as safely as possible, it is necessary to follow the prescribed quantities of explosives per delay time during such works. Currently, various models of well-known manufacturers of this type of equipment such as AtlasCopco, Sandvik, etc. can be found on the market. Figure 2 shows one drills that can be used for drilling with small-diameter boreholes.

Figure 2 AtlasCopco drilling machine for small diametar (Epiroc, 2023a)

The application of this type of drilling machine or similar allows the production of small diameter boreholes and thus the use of a smaller amount of explosives in order to reduce the impact of harmful effects of blasting in urban areas such as the impact of seismic effects. This type of drill can also be used for drilling auxiliary boreholes that are used, for example. for threading the diamond wire and later cutting the rock material. Small-diameter wells can be used for the use of expansive mortars if there is a need for their application.

At the location of the works, it is necessary to define in advance the zones of the maximum permitted amount of explosives per delay time in relation to the surrounding objects. During blasting, work safety measures should be observed, during blasting it needs to stop all work, stop traffic if there is any, and give a sound signal before the initiation of the blast field, covering the blast field is also necessary before initiation (with blasting mats, etc.). Each borehole that is filled with the prescribed amount of explosives must properly do the stemming of the borehole in order for the blasting effect to be complete. Figure 3 shows different cartridge diameters of „Maxam“ explosives.

Figure 3 Different cartridge diameters of „Maxam“ explosives (Maxam, 2018)

The initiation of charging in the boreholes is done by the Nonel initiation system. The Nonel system provides adequate safety during initiation, reduction of seismic effects of blasting, a combination of different delay times, use in boreholes filled with water, etc. Initiation of Nonel detonators outside of boreholes can be done with an electric detonator, primer, or machines specialized for initiation of Nonel detonators (Savić, 2000). The detonating cord can be used when charging in the boreholes only inside the borehole, or if there is a danger that there will be a bad transfer of detonation between explosive cartridges, as well as when separating the charge inside the borehole, also it can be used for contour boreholes (Purtić, 1991). Figure 4 shows non-electric initiation system „Nonel“.

Figure 4 Non-electric initiation system „Nonel“ (Trayal, 2023)

Before initiating a blast field, it is necessary to cover the blast field with some protective mats in the form of blasting mats, etc. By covering the blast field, the possibility of flyrock during blasting is prevented (Figure 5).

Figure 5 Covering the blast field with protective mats (Quarry, 2023)

After blasting, it is necessary to load and transport the material to the predicted location and clean the work site for the preparation of the next blast field. The work on preparing the terrain for the drilling of blast fields needs to be coordinated with the construction work so that the dynamic of all works can be performed without problems. It is a very complex type of blasting and excavation of rock material, so all work must be done with attention. The size of the blast fields, that is, the amount of blasted material must also be in accordance with the calculations of the blasting parameters, and the duration of the blast series must not be longer than 1s. The quantities of explosives per delay time must be in accordance with the project to obtain the best blasting results and reduce the negative effects on the environment.

3.2 Application of expansive mortats

Expansive mortars were created from the construction industry's need to destroy various concrete structures in urban areas without explosives and explosions. Very quickly they found application in mining when splitting and separating primary blocks in decorative stone mines. There are a large number of manufacturers of expansive mortars on the market, but mostly they are chemical agents with similar characteristics (Maksimović, 2006).

Table 1 The speed of reaction for expansive mortars depends on the temperature (Maksimović, 2006)

N^0	Ambient temperature (°C)	The speed of reaction, slow (h)	The speed of reaction, fast (h)
1	50	8	3
2	40	12	4
3	30	15	5
4	20	20	10
5	10	30	15

First of all, by expanding in the borehole, they develop a pressure force in the range of 7-8 (kN/cm^2), which is much more than the necessary force for splitting the rock material. The speed of expansion directly depends on the temperature of the rock material, that is, the external air temperature, and it is proportional to the temperature. Fast reaction mixtures are 20% - 30% less powerful and this should be taken into account when determining the distance between the boreholes (Maksimović, 2006).

Expanding mortars have the following advantages:

- the rock mass splitting process is "quiet" without vibrations and explosions,
- by initiating the chemical reaction, or the process of spreading the mortars, the need for the presence of workers is not necessary,
- absolutely clean ecological product and very acceptable from the ecological aspect,
- safe storage,
- the use and preparation of the mortars are very simple and safe for humans, normally with the use of safety gloves and protective glasses (Maksimović, 2006).

The disadvantages are as follows:

- it is more expensive than classic explosives, but the price is slowly approaching the price of classic explosives,
- has limited application in cold and continental climates, because it cannot be used at temperatures below -5 °C,
- application in a tectonically cracked material is limited, it requires a solid rock material (Maksimović, 2006).

As for the method of use, the expansive mortars are mixed with water in an approximate ratio of 3:1. When the mixture is obtained, without blobs, it can be put into the borehole. Considering that the mortars are of alkaline composition, it is necessary to perform all operations with safety gloves and possibly use glasses. Boreholes are protected from contact with water, or rain, by covering them with PVC film (Maksimović, 2006).

Table 2 The required amount of expansion mortars according to the borehole diameter (Maksimović, M., 2006)

1	Borehole diameter (mm)	30	40	50
2	Amount of powder (kg)	1,1	2,0	3,1
3	Amount of mortars (kg)	1,4	2,6	4,0

Expansive mortars have the following advantages over other technologies for the destruction of rock material:

- completely noiseless rock splitting,
- do not generate smoke, dust, and gas,
- no vibrations and negative effects,
- do not cause damage to the rock mass (Maksimović, 2006).

3.2.1 Application of expansive mortars for making protective screen

Blasting works must be carried out mainly with the prior preparation of a free surface around the work site in the direction of the buildings located near it. That free surface represents a type of protective screen that will reduce the impact of blasting vibration on the environment (Kričak, 2006). The rock mass will therefore be interrupted by a crack, artificially created in order to reduce the resulting waves to the appropriate limit during blasting within the work site. This would reduce the problem of blasting vibration after blasting, as well as the impact of blasting in order to remove rock material from under the horizontal concrete pav and around the pillars. Figure 6 shows an example of making vertical contour holes to create a protective screen.

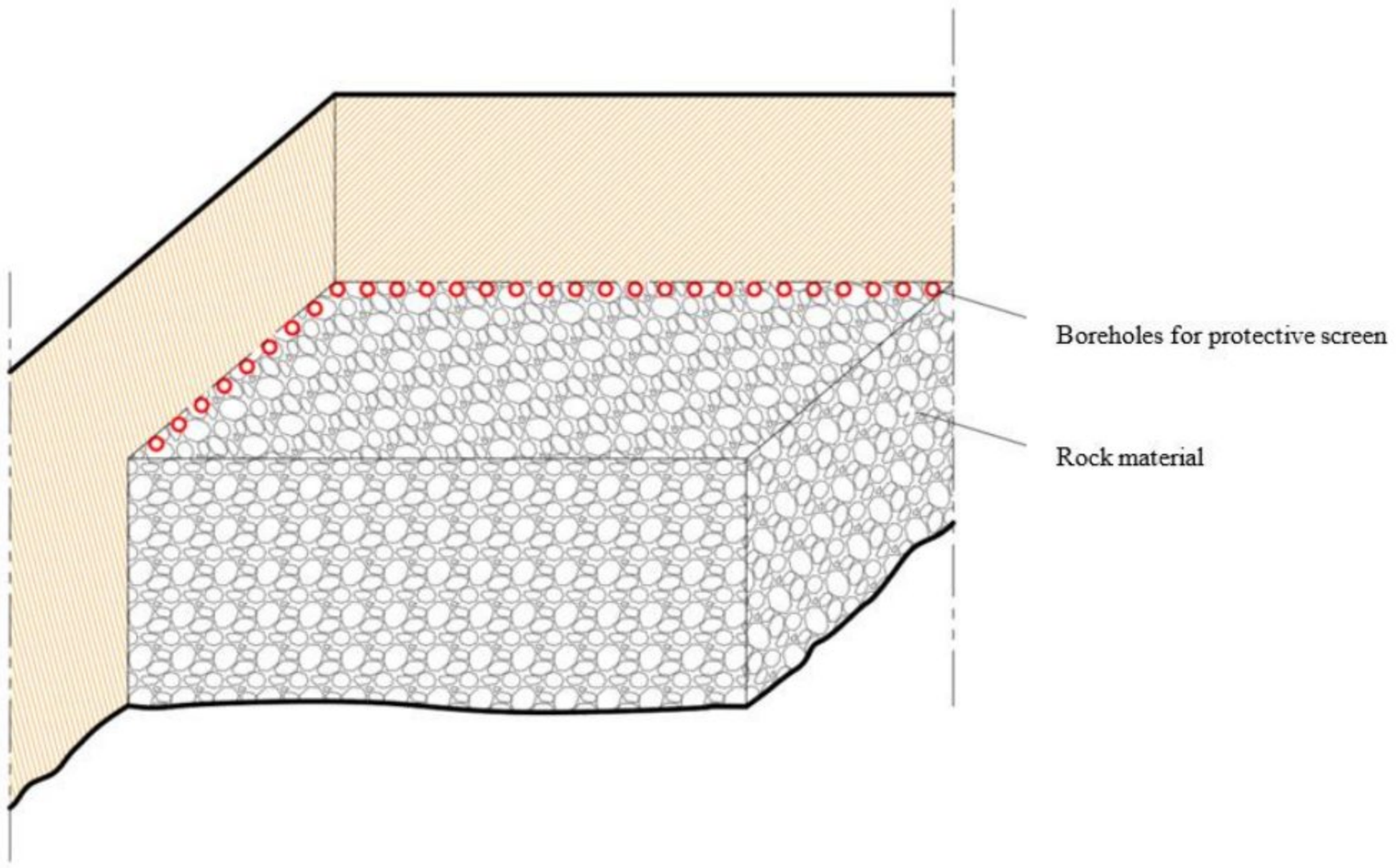

Figure 6 An example of making vertical contour holes to create a protective screen

During construction works, a lot of supporting pillars or piles are installed on the construction site, so blasting around them is risky. It is also necessary to make some kind of crack around the columns with contour boreholes in order to reduce the impact of blasting vibration on the pillars, as shown on figure 7.

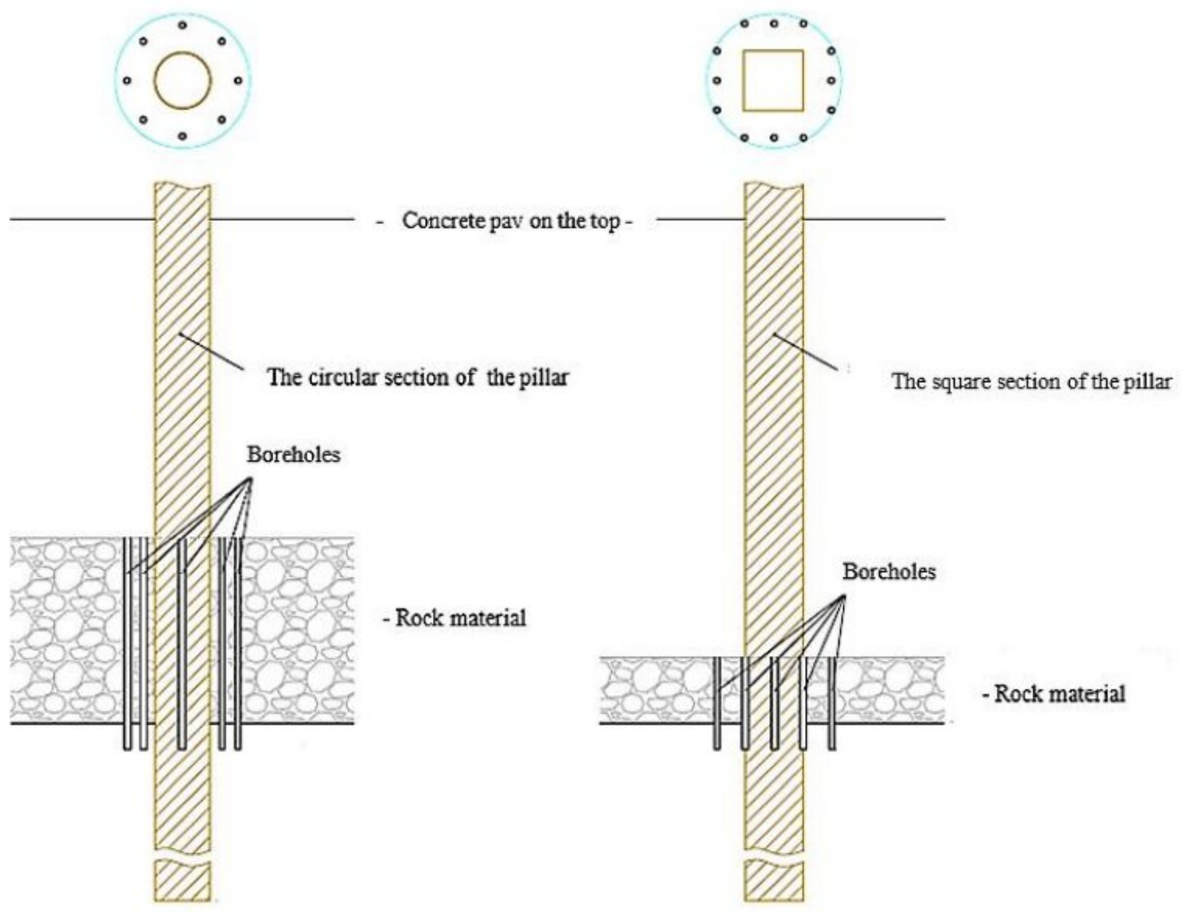

Figure 7 Example of creating contour boreholes around pillars

By creating a protective screen, or free areas around the work site or in locations where the work takes place under the concrete pav, around pillars and piles, and the drilling of boreholes on the blast field, through which we will gradually remove certain amounts of rock material, can be started. The diameters of boreholes that need to be drilled are generally smaller diameters, as well as the use of smaller diameter explosives, due to the limitation of initiating the amount of explosive charge per delay time.

3.3 Possibility of cutting rock material (chain saw machines, diamond wire saw machines)

Cutting machines are good for extracting smaller blocks from the rock mass or forming an ideally flat wall in the rock mass of the foundation pit. They can also be used when creating a protective screen that will reduce negative effects (blasting vibration) on surrounding objects in case of rock material blasting. They are not suitable for large amounts of rock material because the excavation would take a long time due to the very technology of these machines. As a result of the work, stone blocks are obtained, which need to be subsequently crushed and then loaded, which further complicates the process. A diamond wire saw machine is better for the application as it covers larger cutting areas in one go as well as multiple cuts from one spot. Chain saw machines require a flat surface for movement and frequent movement which further slows excavation.

3.3.1 Chain saw machine

Chain saw machines (Figure 8) are used to obtain blocks of decorative stone, but also cut stone. The machine consists of a base (1) on which a motor block (2) is installed, connected to a chain (4). The chain (3) moves along the groove of the chain. The base moves on rails (5). The engine block consists of three hydraulic systems. One is used for driving (turning) the arm (console) of the cutter, and the third - is for moving the base (undercarriage) along the rails. Each hydraulic system can work autonomously, or with a single engine (Popović, 2013).

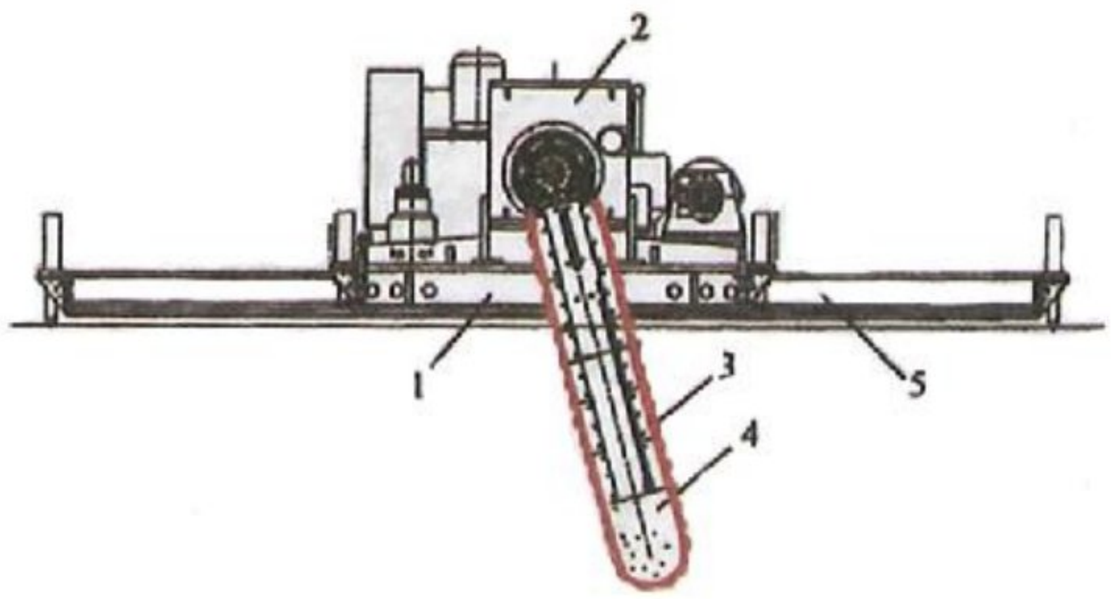

Figure 8 Chain saw machine (Popović, 2013)

The hydraulic system of the machine enables continuous regulation of the cutting speed, pressure, and cutting of the chain, the result of which is the optimization of the working mode of the machine on rock materials with different physical and mechanical properties. For making horizontal (underground) cuts, the cutting assembly is fixed on the additional support, which enables the cut to be made at the floor level (trimming) (Popović, 2013). Chain saw machine developed by FANTINI is shown on figure 9.

Figure 9 Chain saw machine by Italian company FANTINI (Fantini, 2023)

3.3.2 Technology of chain saw machine operation

Cutting with a chain saw machine, the maximum cutting depth is about 2m. A horizontal cut with a chain saw machine is simpler, because the cutting waste flows away with the water, while it is difficult with a vertical cut, so a large part of the chain's energy is spent on removing the cutting waste, instead of cutting. Therefore, compared to the chain saw machine, the diamond wire saw machine has some advantages. In surface mines of decorative stone during excavation, these two machines usually work in combination (Popović, 2013). The technology of making a vertical cut with a chain saw machine machine without making a cut beforehand is shown on figure 10.

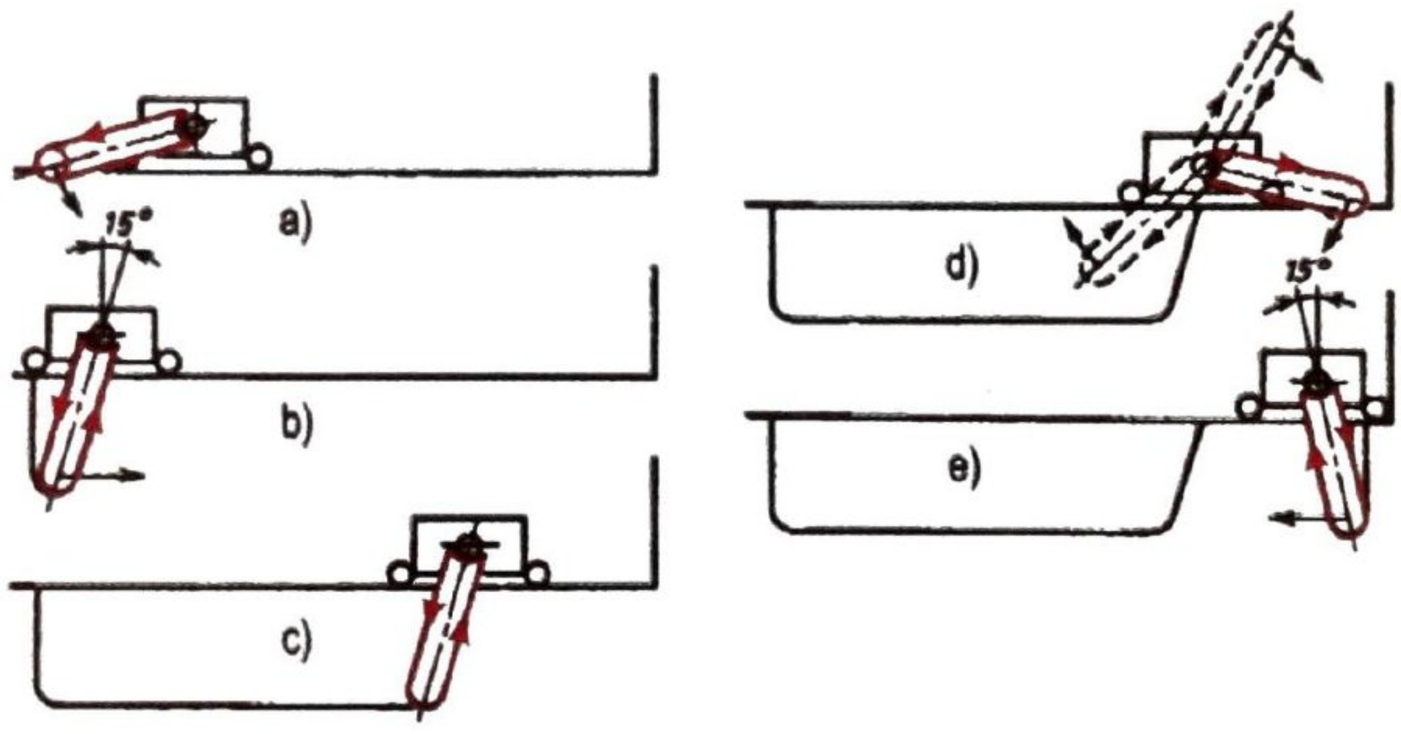

Figure 10 The technology of making a vertical cut with a chain saw machine without making a cut beforehand: a- chain cutting; b- working stroke of the machine in a vertical cut; c- completion of the cut; d- turning the chain (clockwise) and new chain cutting; e- working stroke of the machine in the anticlockwise direction and finishing the vertical cut (Popović, 2013)

3.3.3 Diamond wire saw machine

Cutting with a diamond wire saw machine is a procedure that has become established and has almost become dominant in relation to other machines in the exploitation of decorative stone. When it comes to igneous rocks, there are objectively more factors that make cutters with diamond rope more suitable than other machines (Maksimović, 2006). The advantage of using this machine for the purpose of making a protective screen is that a larger cutting surface can be covered with a rope than with a chain saw machine.

Good performance, good impacts on the working and living environment, flexibility in handling, and a wide range of applicability of the machine, make the diamond wire saw machine best suited to the requirements of a wide range of destruction of rock materials and trends in the protection of the environment. The destruction of the rock material takes place in a closed-cutting system and can be realized in the following ways:

- the convergence of two boreholes,
- by cutting a borehole with one cut plane,
- by the intersection of two cut planes (Maksimović, 2006).

By mechanical structure, most cutting machines consist of the following basic parts:

- undercarriage frame,
- motor part,
- dashboards (Maksimović, 2006).

The undercarriage is a steel construction of the machine that enables safe, secure, and long-lasting operation of the machine. The undercarriage is structurally solved in different ways depending on the manufacturer. Basically, all constructions carry the motor part of the machine with the drive wheel, as the most important part of the machine (Maksimović, 2006).

The cutting mode can be adapted to the physical-mechanical characteristics of all rock materials. The speed regulation is especially important when starting and ending a cut. A good cutting regime can achieve an optimal relationship between the performance and durability of wire (Maksimović, 2006).

The most important features of a diamond wire saw machine are:

- technical performance of the machine,
- construction and type of steel wire rope with diamond wire rope (Maksimović, 2006).

During operation, the machine moves on a frame or rail track, which can have different profiles (square, triangular, and tubular). The frame consists of rails or rail segments of different lengths (usually 3 m). It contains various components and moving devices and serves to support all the connecting installations (such as a derrick with guides, and a guard for the steel rope, which can be unwound for protection during cutting). The statics, as well as the dimensions of the rail track, are different in different models, which is logical because they carry motor construction of different powers (Maksimović, 2006). Diamond wire saw machine is shown on Figure 11.

The exceptional operability of a diamond wire saw machine is achieved by a set of auxiliary devices, guides, and rollers that technologically create the conditions for changing the direction of cutting, achieving a certain geometry, and any technological requirement when it comes to cutting (Maksimović, 2006).

Figure 11 Diamond wire saw machine by Italian company LOCHTMANS (Lochtmans, 2023)

3.3.4 Technology of diamond wire saw machine operation

There are several ways to perform the primary cut. In specific conditions, a technological solution that corresponds to the specific situation will be adopted. In principle, the following methods of performing cuts are applied:

1. horizontal cutting with a "loop",
2. vertical cutting with a downward "loop",
3. vertical cutting of back cuts with a guide,
4. vertical cutting with an upward "loop",
5. vertical cutting of the "blind" cut (Maksimović, 2006).

Working diagram of diamond wire saw machine is shown on figure 12.

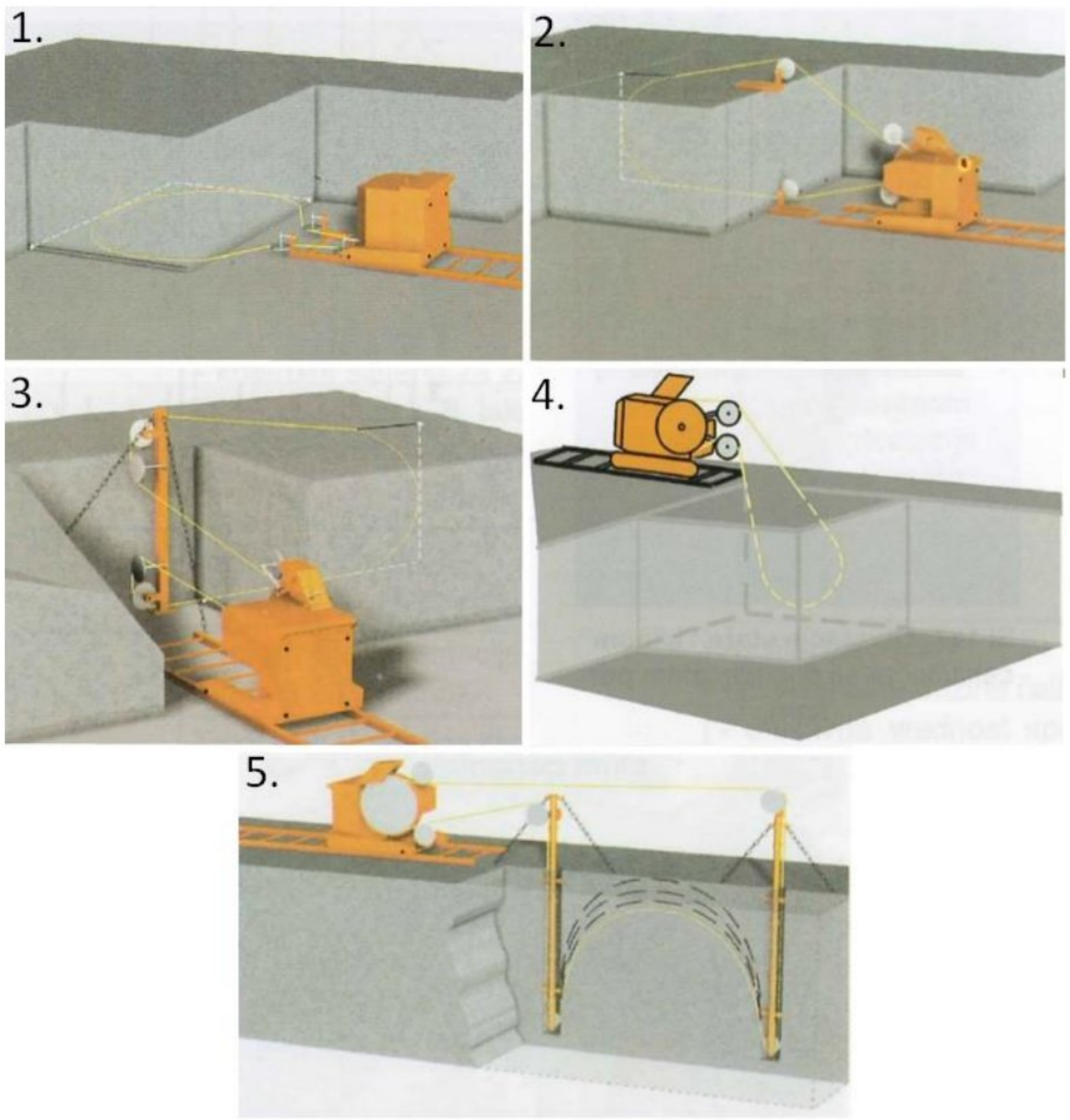

Figure 12 Working diagram of a diamond wire saw machine (Maksimović, 2006)

3.4 Application of hydraulic excavator with breakers or rippers

Fragmentation of the material can be performed by a mechanical process, or with an impact hammer mounted on a hydraulic excavator. An excavator with an installed hydraulic hammer is a machine that is mainly used for auxiliary work on surface mines, such as crushing larger (oversized) pieces of rock. Fragmentation of material with this type of machine or a hydraulic excavator with a ripper is mainly used for auxiliary fragmentation and unapproachable parts related to work around supporting pillars, and under supporting structures where blasting cannot be applied. Of course, these machines require a lot of time to be able to crush compact rock, so they are mainly used for smaller amounts of material in inaccessible locations, auxiliary work, and crushing larger pieces of rock. Figure 13. shows the operation of a hydraulic excavator with a hydraulic hammer.

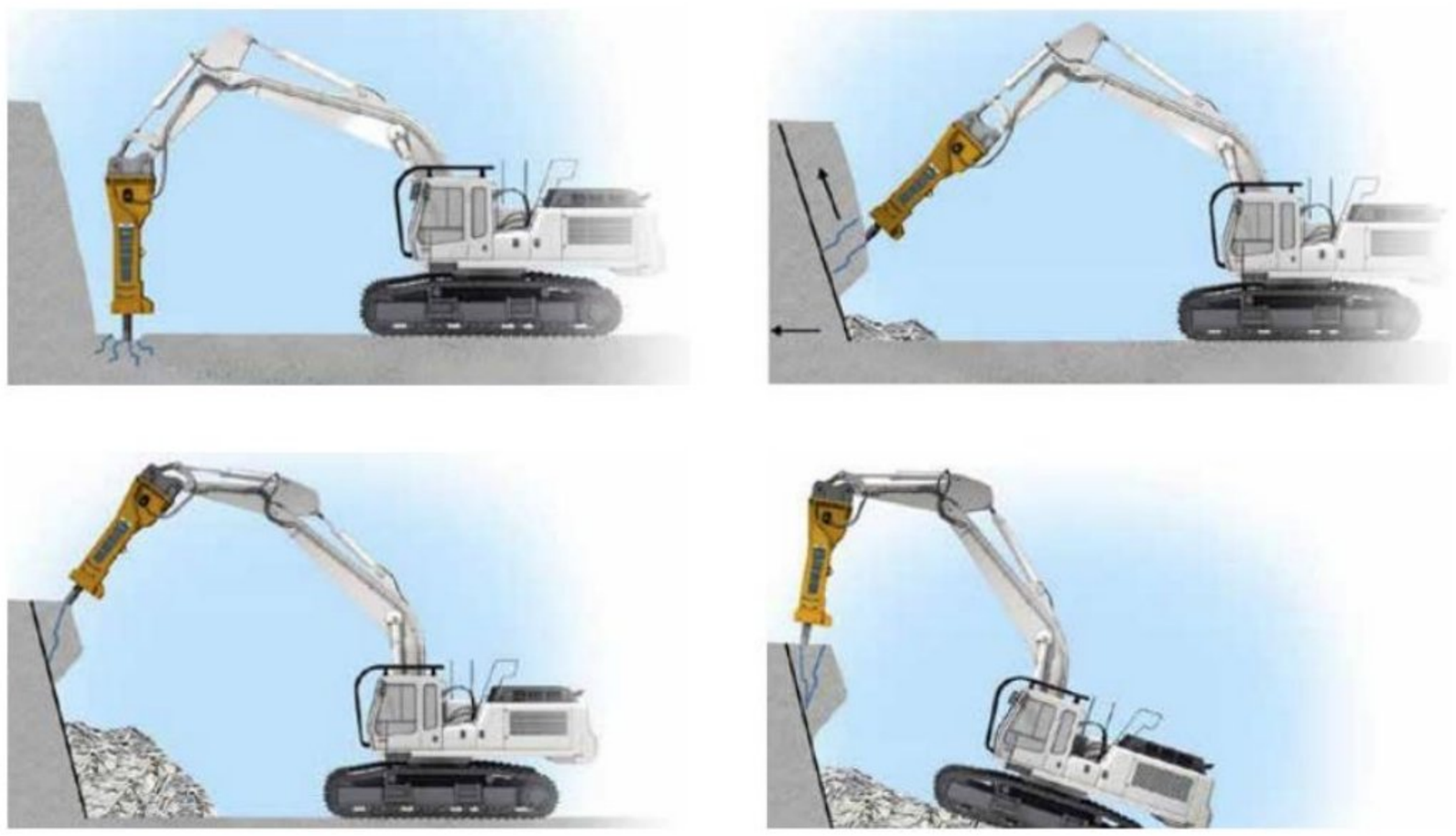

Figure 13 Operation of a hydraulic excavator with a hydraulic hammer (Epiroc, 2023b)

A hydraulic excavator with a ripper (Figure 14) is a machine that is intended for breaking rock material, it is similar to a hydraulic excavator with a hammer, with the difference being that the ripper produces shocks due to vibrations generated in the mechanism itself. The ripper is made of wear-resistant steel, it makes less noise than other machines designed for the same purpose.

Figure 14 Hydraulic excavator with the ripper (Xcentric, 2023)

During work on the removal of the rock mass after its fragmentation by one of the methods, it is necessary to load and transport the material outside the work site to the designated place. For this purpose, trucks are used for transport, and hydraulic excavators are used for loading at smaller locations and in urban environments. In accordance with the scope of work and the quantities that need to be calculated, the required number of trucks and loading machines must be calculated, these works must be in accordance with the dynamics of rock material excavation at the site.

4 CONCLUSION

The excavation of rock material is a complex excavation procedure in an urban environment. The works are taking place in the nearness of existing buildings and safety and health measures at work must be observed in order to reduce negative impacts on people and the environment, as well as the safety of workers at the work site itself.

When there is a large amount of material that needs to remove in order to be able to continue with the construction work on the site, the effective excavation method for the rock mass would be a combination of the mentioned methods, for example, the application of controlled blasting with the use of expansive mortars, where for this purpose to have some drilled boreholes either for explosive or mortars. Also, the application of different types of cutting machines also requires the production of smaller diameter boreholes, for example, in order to pass a diamond rope if that method is used. The above-mentioned mechanization can be used as a secondary method and according to some calculations, the best efficiency would be obtained.

When carrying out blasting, it is necessary to ensure all conditions for the safe initiation of the blast field, such as notification of blasting, stopping of traffic, sound notification before the initiation of the blast field, and others. The method of blasting rock material with explosive means is perhaps the cheapest form of rock mass excavation. However, this method must be combined with some of the presented methods in order to create screens that would protect the surrounding objects, because most of the work sites are in urban areas.

Through this paper, some of the possibilities of excavation rock material in the urban environment are given, where a combination of these methods can be used to obtain an efficient way to carry out the work.

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