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Construction Time Analysis For Different Steps In Drill-And-Blast Method Of Hydro Power Tunnel Excavation

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ABSTRACT
One of the most important factors influencing the decision whether and how a tunnel is to be built are the estimated time and costs of construction. This study is based on construction time analysis for different steps in drill-and-blast method of hydro power tunnel excavation in working phase of 6.256,00 meters of tunnels which have different diameters varying from 4,20 to 7,60. There are made 737 field measurements and it is seen that many of the machinery and workmanship productions rates per unit time are significantly lower, varying from 35% to 50%, of that defined in their technical specifications, measurements indicate that highest performance is reached in 7,60m diameter tunnel excavation. It is believed that these data will be helpful for planning and management process of tunnel construction projects, especially those planned to be built in Albania where labor market carries similar features.
***Keywords* –**Albania, drill and blast, construction time, tunnel excavation

I. INTRODUCTION

Technological developments of XX and XXI century have set tunnels as an integral part of roads, hydropower works, mines etc. They are among the most complicated structures that require in-depth engineering studies and updated data. Although preliminary analysis of tunnel opening methods are based on geological studies, geological maps and survey of the tunnel axis terrain, decisions are strongly based on previous experiences. In hydropower works energy tunnels are structural elements, which are constructed to divert the natural flow of water. They are built to utilize the water potential energy; hence the hardness of the rock, through which the energy tunnel passes, is not the main selection criteria. The rock hardness effects directly the tunnel excavation time therefore uncertainties of the soil structure and inability to pass the tunnel through hard rock makes time prediction difficult, this difficulty is mostly solved by previous experiences.

Albanian tunnel engineers and tunnel labor market had a valuable experience in design, construction and strengthening of the energy tunnels, which reached its peak around the year 1985 [1]. After this period, as many sectors of Albanian industry, there was a stagnation of more than 25 years in construction of energy tunnels which made it difficult the use of gained experience and updating of energy tunnel construction data, especially time and cost ones. Therefore this study attempts to provide an overview of tunnel construction time necessary for any particular excavation process based on the construction of tunnels on the Fan river hydropower projects, which can be helpful for the Albanian tunnel managers and engineers to reduce uncertainties and estimate more realistic time and cost of construction.

Results of this study are based on analysis of 6.256,00 meters of tunnel excavation which have different diameters varying from 4,20 to 7,60 meters. The data were selected such as to present in the best way all excavation phases of drill-and-blast method. In this study it was concluded that the time required to complete an excavation processes is almost two times higher than that provided in technical specifications.

II. PREVIOUS WORKS

One of the most important factors influencing the decision whether and how a tunnel is to be built are the estimated time and costs of construction [2]. The construction time significantly influences the tunnel construction costs, because substantial part of the costs comprises of the labor and machinery costs, which are time dependent [3]. As the labor and machinery costs are time dependent researchers have worked to collect statistical data for the consumption of time during various different working steps within a drill-and-blast method, such as excavation, mucking out and the installation of rock bolts and steel arches support [4]. Several reports states that cost and time, estimated by the early design phases, overruns commonly in infrastructure projects that include tunnels [5]. Statistical and updated data for Albanian labor and machinery time consumption in tunnel construction projects could not be found [1] therefore this study tend to contribute in creation of a realistic database which can be successfully implanted in existing tunnel construction time and cost models.

III. DRILL AND BLAST METHOD

Tunnel excavation can be seen as a cyclic process with the main activities executed in series [6]. The unit of each cycle in drill and blast method is named round and consists of four successive operations, namely: drill, blast, muck and installation of primary support [7]. Drill is the first operation of a single round and consists of rock quality decision done by geological engineer, application of holes and tunnel face done by survey engineer, drilling the holes in the tunnel face done by drilling jumbo. Blasting consist of charging the holes with explosive, blasting them and provide fresh air via ventilation. Pieces of loosened rock remaining on the tunnel roof and walls during blasting process have to be removed after mucking machines and materials handling equipment are mobilized, and the muck is hauled out of the tunnel face. The primary support is directly related with quality of rock and it is in reverse proportion of it, as the hardness of rock increases the amounts of primary support decreases, types of primary support and round length of tunnels on the Fan river hydropower projects are shown in Table 1.

Table 1. Primary Support of Tunnels on the Fan River Hydropower Projects [1]

Project Value	Rock Quality [8] RQD(%)	Rock Quality [8] Description	Round Length (m)	Primary Support
5	0-20	Very Poor	1,00-1,50	5+15 cm shotcrete, wire mesh, systematic rock bolts, I steel arch profile
4	21-40	Poor	2,00-2,50	5+5 cm shotcrete, wire mesh, systematic rock bolts
3	41-60	Fair	2,50-3,00	5+5 cm shotcrete, wire mesh, systematic rock bolts
2	61-80	Good	3,50-4,00	5 cm shotcrete, local rock bolts
1	81-100	Very Good	3,50-4,00	no primary support

Rock quality in this project is presented in five main classes and based on this there is given the support system shown in Table 1, although there can be different rates that include more than five rock quality types which recommends different support systems [8]. Shotcrete is the element that is used in every tunnel where prime support is needed, wire mesh is an element mainly used where the tension stresses occur in order to reinforce the concrete, now days it is mostly replaced with steel or plastic fibers. Rock bolt is an anchor used for stabilizing rock excavations and transfers load from the unstable exterior, to the confined interior rock mas, mainly used in fair, poor and very poor rocks. Steel arch supports are used in poor or very poor rocks and for this project it is chosen to be I section rib but it can be wide flange rib, TH section rib, 3 bar lattice girder or 4 bar lattice girder.

Installation of primary support is the last operation done within a single round. Depending upon project types it is determined either making the primary support within the round or not [1]. Technical specification of Fan river hydropower projects has determined it as follows: for very poor rocks the next round can start only when primary support is completed, for poor and fair rocks there can be at most one round without primary support before the next round starts and for good rocks there can be at most two rounds without primary support before ne next round starts.

IV. PROCESS TIME ASSESSMENT

Four successive operations drill, blast, muck and installation of primary support are analyzed separately, like shown in Table 2. For these operations there is analyzed velocity of operating vehicles, time of engineering decisions and workmanship in tunnel construction phase.

The vehicles are; jumbo, which is used to drill the holes in tunnel face as well as to drill the holes for rock bolt and forepolings; excavator, which is used to remove pieces of loosened rock remaining on the tunnel roof and walls during blasting, loader is used to load the muck in trucks which haul it out of the tunnel face, shotcrete pump is used to spray the shotcrete, sent there by mixer, into tunnel walls, pick-up trucks which is used for technical staff transport within the tunnel, cement injection pump, which is used to inject cement into rock bolt holes, is moved in tunnel fixed over pick-up truck.

Table 2. Time effecting work processes

Process	Work Done	Time effecting
Drill	- Rock quality decision - Application of holes - Drilling the holes	1. Pick-up track forward and backward velocity. 2. Geological engineer time to sketch the tunnel face. 3. Survey engineer time to apply the holes and tunnel face. 4. Jumbo forward and backward velocity. 5. Workmanship time to drill the holes.
Blast	- Charge the holes - Blats - Ventilation	1. Pick-up track forward and backward velocity. 2. Workmanship time to charge the holes with explosive. 3. Blasting time 4. Ventilation time
Muck	- Remove pieces of loosened rock - Load the muck in trucks - Haul the muck out of tunnel	1. Excavator forward and backward velocity. 2. Workmanship time to remove pieces of loosened rock 3. Loader forward and backward velocity. 4. Workmanship time to load the muck in trucks 5. Truck forward and backward velocity.
Primary Support	- Application of shotcrete - Installation of wire mesh - Topographic measurements - Installation of steel arch profile - Installation of rock bolts	1. Shotcrete pump forward and backward velocity. 2. Mixer forward and backward velocity. 3. Workmanship time to spray shotcrete 4. Pick-up track forward and backward velocity. 5. Workmanship time to install wire mesh 6. Survey engineer time to set steel arch profile 7. Loader forward and backward velocity. 8. Workmanship time to install steel arch profile 9. Jumbo forward and backward velocity 10. Workmanship time to drill rock bolt holes 11. Workmanship to install rock bolts

Time effecting processes are defined in detail in Table 2, for all them there are done measurements in the faces of the tunnel which have different distances from the entrance of it. The measurement are done in time interval of about five months in the excavation process of 6.256,00 m tunnel with diameter varying from 4,20 m to 7,60 m. The geological formation of the analyzed tunnel segments is mainly composed of basalt, serpentine, kaolin, diabase, dunite and there are 0% very good rock (class 1), 24% good rock (class 2), 36% fair rock (class 3), 23% poor rock (class 4), 17% very poor rock (class 5).

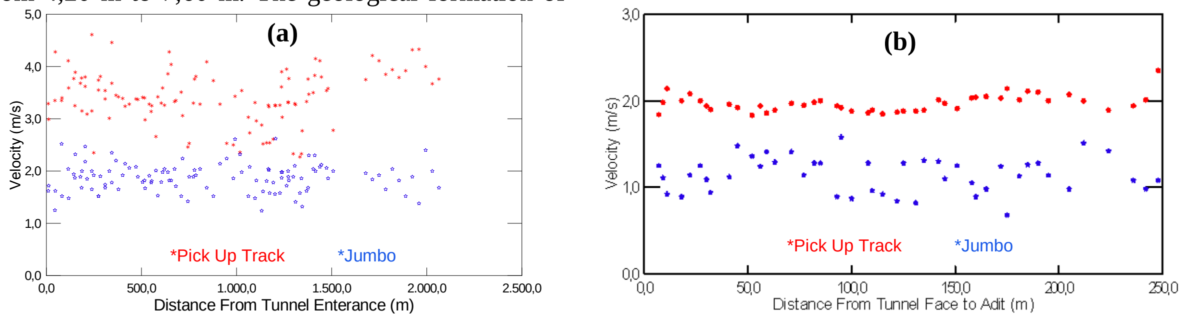

Fig. 1, Pick-up track and jumbo velocity measurements; (a) Pick-up track and jumbo forward velocity, (b) Pick-up track and jumbo backward velocity.

For drilling process there are done 163 measurements in tunnel faces which have different distance from tunnel entrance. From these measurements 117 are done to calculate the forward velocity and 46 are done to calculate the backward velocity of pick up tracks and jumbo. All the work machines used in tunnel construction run backward till the nearest tunnel adit, which in this project are designed to be every 250 meters. In the same way there are measured geological and survey engineers time needed for their work described in Table 2 in 105 different points. Workmanship time to drill the holes is calculated in 56 tunnel faces which consist of four different rock qualities (class). The average forward velocity of the pick-up track is measured to be 3,41 m/s or 12,28 km/h as shown in Fig. 1 (a), and its backward velocity is measured to be 1,97 m/s or 7,10 km/h as shown in Fig. 1 (b),. Similarly the forward velocity of the jumbo is measured to be 1,87 m/s or 6,74 km/h and its backward velocity is measured to be 1,15 m/s or 4,12 km/h. As it is seen from Fig. 1 the velocity of pick up track and jumbo are not related with the distance of tunnel face from its entrance. The average time needed from geological engineer to make rock quality decision and sketch the tunnel face is 16,34 minutes as shown in Fig. 2, and that of survey engineer to apply the holes and tunnel face is 25,44 minutes, as shown in Fig. 2, Similarly to the vehicles velocity, geological and survey engineer times are not related to the distance of tunnel face from its entrance. It is important to emphasize that these engineering teams can work simultaneously in the same tunnel face.

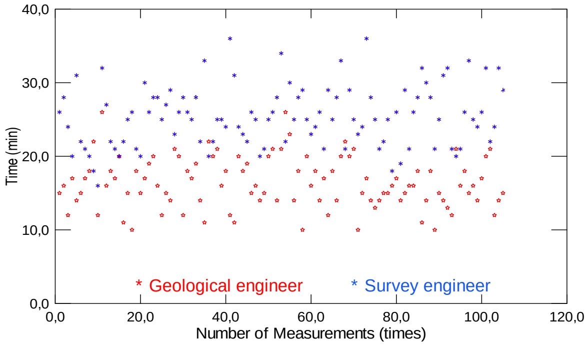

Fig. 2, Time needed by, geological engineer to make rock quality decision and sketch the tunnel face and survey engineer to apply the holes and tunnel face.

Workmanship to drill the holes is directly related to the quality of rock. For every rock quality (class) there exists a pattern which specifies the number of holes per each tunnel face as well as their depth. For this reason the best way to measure the drilling process is time per unit length. In Fig. 3 the drilling process of different rock quality is drown, the data are collected from 100 measurements in 4 different rock quality, and the average time to drill 1 meter rock is 28,52 sec. Time in minutes to drill holes in different tunnel faces can be calculated as (28,52/60) x (number of holes per tunnel face) x (round length).

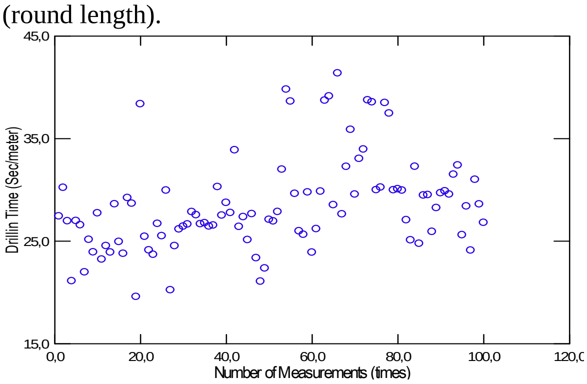

Fig. 3, Drilling time that is needed to drill 1 meter rock measured in four different rock quality.

Blasting is measured similarly to drilling process, as there exists five rock qualities there would be five different times. The measurements could be done based either on time needed to charge 1 meter hole, or the time needed to charge 1 mete cube rock to be blasted, for this study it was chosen to make the measurements per one meter cube rock that would be blasted. There are done 97 measurements as shown in Fig. 4 and the average time to charge the holes of 1 meter cube blasted rock is 0,63 minutes, and the time in minutes to charge a different tunnel face can be calculated as (0,63) x (tunnel face area) x (round length). The velocity of the pick-up track that carries the explosive material to the tunnel face is same with that measured in drilling process. The blasting time is in the range of some seconds and it does not have any effect in the entire time. Ventilation system of this project is face concentration, air supply system. The time needed to supply air to tunnel face after blasting is in the range of 40 to 50 minutes.

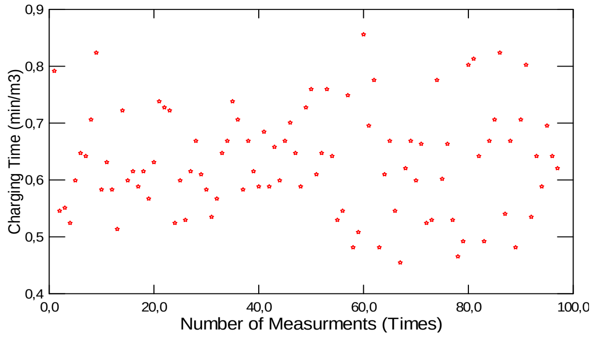

Fig. 4, Charging time that is needed to blast 1 cubic meter rock measured in four different rock quality.

Mucking process is described in detailed in Table 2. There are done 50 measurements for the excavator velocity and 95 measurements for workmanship time to remove pieces of loosened rock as shown in Fig 5. It is measured that the forward and backward velocity of the excavators is approximately the same for this reason it is defined only as excavator velocity. The average velocity of the excavator is measured to be 1,25 m/s or 4,32 km/h as shown in Fig 5 (a). Workmanship time to remove pieces of loosened rock is measured in 4 different rock quality and it has an average time of 24,56 minutes for very poor (Class V) rock, 18,77 minutes for poor (Class IV) rock, 15,59 minutes for fair (Class III) rock and 14,71 minutes for good (Class II) rock, data of this measurements are presented in Fig 5 (b).

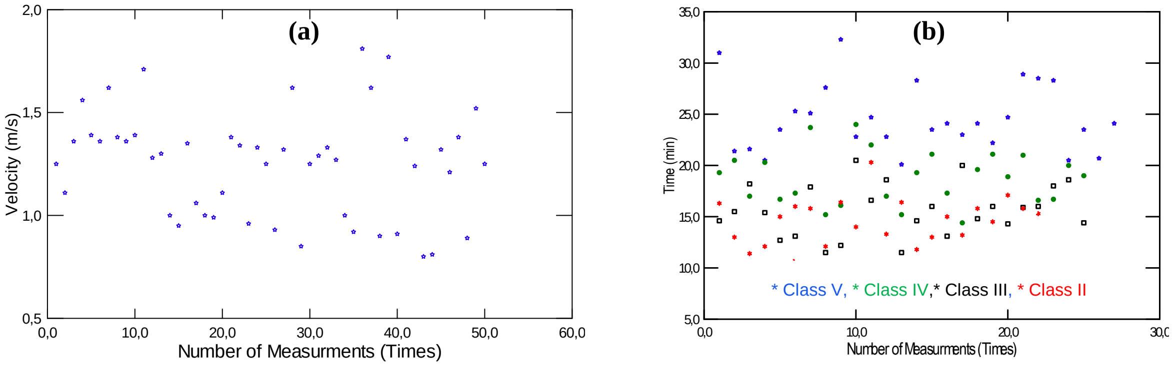

Fig. 5, Excavator velocity and workmanship time to remove pieces of loosened rock measurements; (a) Forward and backward velocity of excavator, (b) Workmanship time to remove pieces of loosened rock in four different rock quality (Class II to Class V).

It is measured that loader and material transporting trucks have very closed average velocity, for these reason the data are put in the same graph. There are done 77 measurements as shown in Fig. 6 and the average forward velocity of the loader and track is measured to be 3,34 m/s or 12,03 km/h and the backward speed of them is 1,62 m/s or 5,83 km/h.

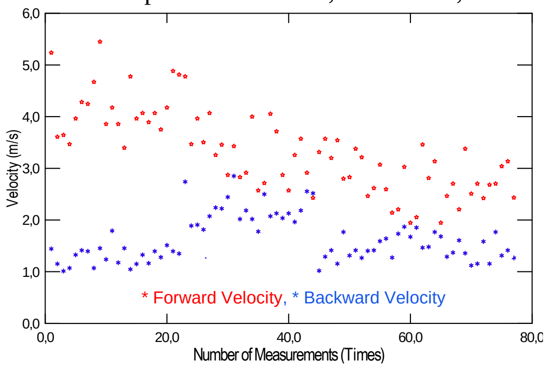

Fig. 6, Loader and track forward and backward velocity measurements.

Time needed to load the muck in truck is measured in 65 tunnel faces which have different distance from tunnel adit. The truck that hauls the material out of tunnel stays on tunnel adit and the material is transported from tunnel face to nearest tunnel adit by loader. Results are shown in Fig. 7 and have a parabolic shape, the time needed to load the material increases exponentially with distance and it best fits with Equation 1, where L is the unit time in minutes needed to load 1 meter cube muck and D is the distance in meters of tunnel face from nearest tunnel adit. As it is shown in Fig. 7 as the distance changes from 150 meters to 250 meters the time needed to load one cubic meter material increases twice.

$$L = 0{,}50 \; e^{(0{,}005 \times D)} \qquad (Eq.\ 1)$$

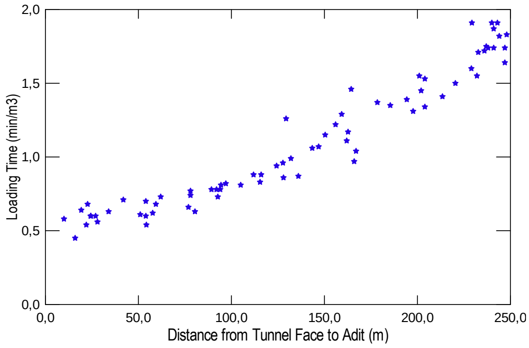

Fig. 7, Time needed to load one cubic meter material in track.

Shotcrete pump and mixer have the same velocity as loader which is shown in Fig. 7, there are done 71 measurements on shotcrete pump velocity and 64 on mixer velocity ant it is noted that the average velocity of them is almost the same and very closed to that of loader. There are different shotcrete thicknesses as shown in Table 1 for these reason the measurements are done per meter cube of sprayed material. The data are collected in 117 tunnel faces and the average time needed to spray a meter cube shotcrete is 11,40 minutes as shown in Fig. 8. The time needed to spray the shotcrete increases slightly as the tunnel face goes deeper, although there is measured only the time that shotcrete pump sprays the material.

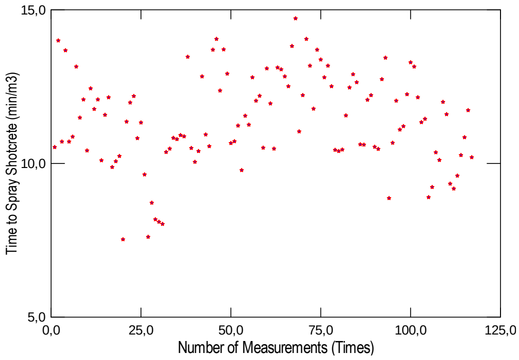

Fig. 8, Time needed to spray one cubic meter shotcrete in tunnel.

Installation of steel wire mesh changes from significantly from Class V to other rock qualities. In the Class V rock the steel profile is installed and after that the wire mesh, so steel arches are used as support in other cases there must be anchored some steel ribs, generally 12mm in diameter, which works as steel wire mash support. Time needed to anchor those steel ribs is some times greater than that of wire mesh installation its self. There are done 46 measurements in Class V rock and 46 measurements in other rock qualities. Time needed to install one square meter steel wire mesh in Class V is approximately 0,68 minutes, and time needed to install one square meter steel wire mesh in other rock qualities is 1,29 minutes as shown in Fig. 9.

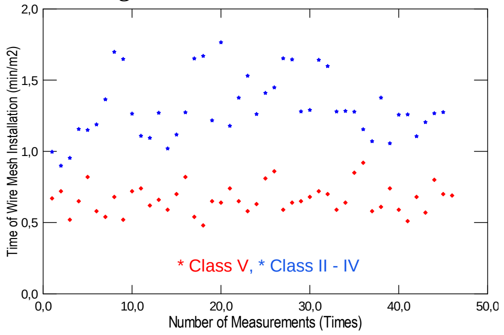

Fig. 9, Time needed to install one square meter wire mesh in tunnel.

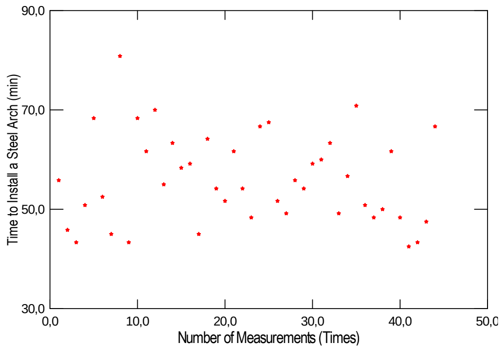

Fig. 10, Time needed to spray one cubic meter shotcrete in tunnel

Steel arches are installed only in Class V rocks as shown in Table 2. There are done 44 measurements of steel arch installation, and the average time to install a single arch is 56,01 minutes as shown in Fig. 10. Steel arch installation consumes a large amount of time at tunnel excavation process. The rock bolt installation mainly consists of three steps, drilling rock bolt holes, injecting cement paste, inserting rock bolt. Drilling process is done by jumbo and has the same velocity of that showing in Fig. 2, so for bolt installation only cement injection ant rock bolt inserting time are measured. There are done 84 measurements on three different rock bolt length 3, 4 and 6 meters. Both cement injection time and rock bolt inserting time is measured in term of rock bolt length. The average time needed to inject cement in 1 meter hole is 1,12 minutes and that of inserting the rock bolt and threading the nut is 0,62 minutes as shown in Fig. 11. The total time needed to inject cement paste and install rock bolt in minutes is 1,74 x L, where L is length of rock bolt in meters.

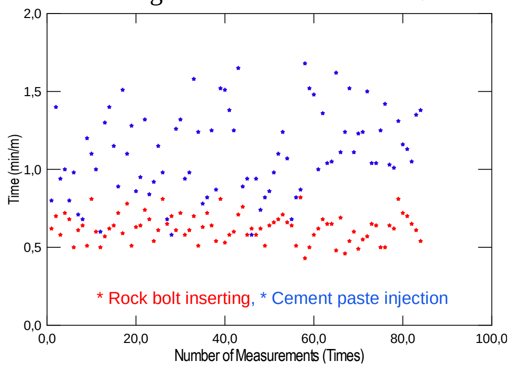

Fig. 11, Time needed to spray one cubic meter shotcrete in tunnel

V. Conclusions

In this study 737 field measurements were made to define the time needed for any particular process in drill and blast tunnel excavation method. Generally it is seen that many of the machinery and workmanship productions rates per unit time are significantly lower than them defined in their technical specifications. Measured velocity of heavy machineries is almost 35%, and their production rates are nearly 50% of that defined and programed by project developers, similar observation are done in workmanship processes. The results obtained in different tunnel diameters, from 4,20m to 7,60m, indicate that highest performance is reached in 7,60m diameter tunnel excavation although the differences are not significant and for this study there is not a good correlation between tunnel diameter and construction time. It is measured that best construction performance is reached when distance from tunnel adit and tunnel face is smaller than 200 meters.

These measurements are very important in practical use and it is also believed that they will be helpful for planning and management process of tunnel construction projects, especially those planned to be built in Albania where labor market carries similar features.

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