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Earthworks logistics in the high density urban development conditions – case study

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Abstract. Realisation of the construction projects on highly urbanised areas carries many difficulties and logistic problems. Earthworks conducted in such conditions constitute a good example of how important it is to properly plan the works and use the technical means of the logistics infrastructure. The construction processes on the observed construction site, in combination with their external logistics service are a complex system, difficult for mathematical modelling and achievement of appropriate data for planning the works. The paper shows describe and analysis of earthworks during construction of the Centre of Power Engineering of AGH in Krakow for two stages of a construction project. At the planning stage in the preparatory phase (before realization) and in the implementation phase of construction works (foundation). In the first case, an example of the use of queuing theory for prediction of excavation time under random work conditions of the excavator and the associated trucks is provided. In the second case there is a change of foundation works technology resulting as a consequence of changes in logistics earthworks. Observation of the construction has confirmed that the use of appropriate methods of construction works management, and in this case agile management, the time and cost of the project have not been exceeded. The success of a project depends on the ability of the contractor to react quickly when changes occur in the design, technology, environment, etc.

1. Introduction

Dense urban development generates many difficulties during realisation of various types of building structures, particularly within the scope of logistics.

The limited construction site obstructs both spatial organisation of the construction facilities but also, organisation of the works and construction works technology, communication of the construction with the surrounding area: necessity to use urban roads and streets.

In the earthworks analysed in the paper a small construction site means necessity to develop a well thought-out concept for execution of the works and application of appropriate computational models to predict the time and cost of works. The processes constituting the earthworks require synchronisation of action with other processes, realised simultaneously or being subject to them. Mistakes during planning of such processes may substantially extend the time of realisation of the given projects, increase the costs as well as deteriorate the quality, including safety of the conducted works.

Logistics processes are as follows: planning the works concept (making allowance for realisation of the excavation in the logistics concept), designation of the access routes, stopping places (waiting for entrance to a construction site to the excavator), development of the soil from excavation: driving back to the recipients and storage of the soil from excavation intended for reuse. The case of making excavation analysed in the paper is an example illustrating importance of the supplemental processes that the logistics processes constitute during realisation of the construction works, and a perfect example of using the engineering and managers thoughts and knowledge.

In the paper the results of the analysis of the logistics service for execution of excavation for the building of the Centre of Power Engineering (CPE), situated within the precincts of AGH University, in densely built-up are shown. The analysis includes the critical description of a concept of execution of the earthworks by the Contractor of the construction works, results from observation of the realisation of excavation and the proposal of the methods for planning of the logistic model of the earthworks, enabling optimisation of the project from the perspective of the cost and time criteria.

The analysis contains a critical description of the earthwork construction plans for the design of the underground part of the building which was proposed during the project planning phase and which underwent a modification during the building phase. Owing to the application of modern management methods (among others, agile management) the design modification had no impact on project costs or duration.

2. Organisation of the earthworks

2.1. The concept of logistics earthworks logistics in phase concept in the planning and design of the project

The investment project anticipated removal of 27 263 m^3 of soil in order to make the foundations and the underground garage. Plan the implementation of earthworks was dependent on the established technology of foundation works and underground part of the building i.e. the state of "zero". The project provided for execution of the safety slotted wall and next excavation. The planned maximum depth of excavation was approx. 6.5 m. Of foundation of the building, there are five layers of soil, i. e.: (a) asphalt surface of a car park with stone, (b) anthropogenic embankment, (c) sand, (d) interbeddings of alluvial soils, (e) loam soils. The soil from the excavation was to be segregated and delivered to the right recipients (Figure 1A).

a) b)

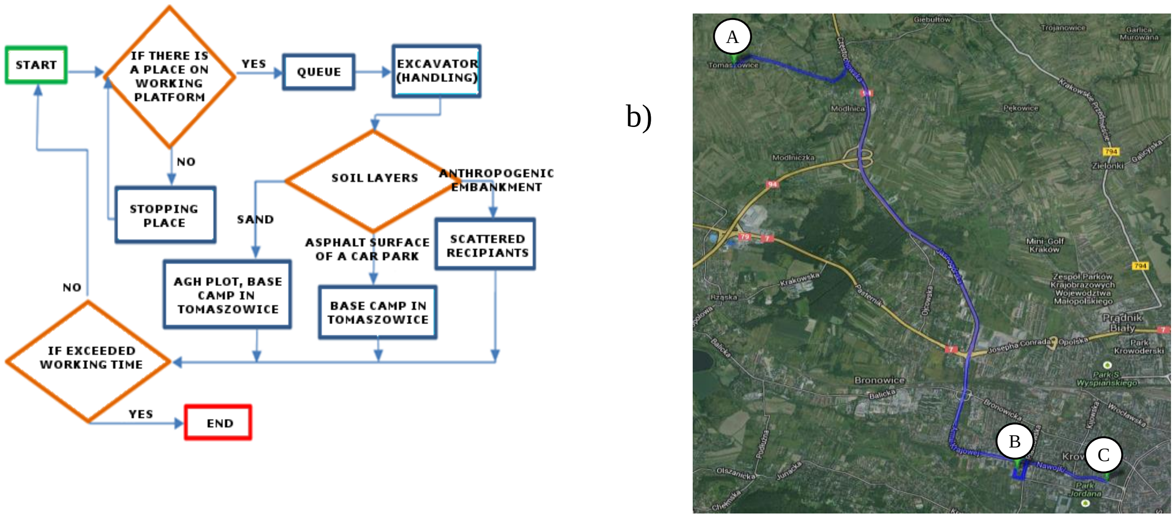

Figure 1. a) Scheme for conducting the earthworks during construction of the CPE; b). Location points set aside land: A) the construction site, B) plot AGH Street. Tokarski, C) base contractor Tomaszowicach [3]**.**

The plan was to make use of the platform to perform the excavation (see Fig. 4 and 5).

As can be seen the limited construction site made, requires the necessity to introduce a stopping place outside it. Complexity of the conducted works results also from the fact of excavating the soil by layers that have been transported in various places.

Two permanent places for removal of the selected soil have been anticipated, they have been as follows: contractor's base camp in Tomaszowice (approx. 12 km) and a plot belonging to AGH located at Tokarskiego street in Krakow (approx. 1.8 km) (Figure 1B). Moreover part of the soil from excavation the subcontractor of the earthworks handed over to the scattered recipients. The soil from the excavation has been picked by layers, which have been later used for various purposes. Asphalt surface stripped by the excavators headed to contractor's base camp in Tomaszowice, where he planned to use it for reinforcement of the unsurfaced road, whereas the anthropogenic embankment substantially found his way to the scattered recipients. The sands have been stored on the AGH plot and at the contractor's base camp in Tomaszowice. They characterised with good quality and therefore there have been a possibility of managing or selling them.

To plan the time of earthworks and their logistics model is adopted queuing theory in order to take into account the particularly difficult the construction, under conditions of high uncertainty and risk. Adopted a simplified model M / M / 1 / FIFO / N / F. This model have been used for description of the earthworks system. In this paper earthworks system is a set of machines: the excavator and the cooperated trucks. The model assumes work of an excavator and N number of trucks removing the soil, of which every one works in a closed cycle. A closed cycle means that immediately after unloading the vehicle returns on the construction site for another loading. It has also been adopted that queuing discipline has a FIFO character (first in – first out), which means that the trucks have been handled based on the sequence of reporting.

With the use of the formulas 1 – 3, with assumption that handling times and the times for reporting the trucks in the queue have an exponential distribution, an analysis of efficiency as well as of unit costs of the reviewed system making allowance for different number of transporting trucks have been conducted. Based on the research an average intensity of arrival of the trucks λ=0,02 has been calculated, and an average intensity of handling the trucks by an excavator μ=0,25 [6,7,8]. It means that the average time for handling amounted to circa 4 min., whereas the time necessary for the transport, unloading of the soil and return to the construction site took around 50 min. It has been confirmed by the information made available by the Internet service Google Maps, which depending on the choice of route between the construction of the Centre of Power Engineering and the contractor's base camp in Tomaszowice provided time for one-way passage within the scope from 14 to 18 minutes. Nevertheless, it should be taken into account that the trucks move slower and additionally certain time should be added for unloading, for which we obtain approx. 14 min. Such data enable to calculate the following parameters, which constitute a basis for calculation of the costs for teamwork and its minimum efficiency [7]:

$$P_k = \frac{m!}{k!(m-k)!}\left(\frac{\lambda}{\mu}\right) P_0, \text{ for } 1 \le k \le n \qquad (1)$$

where: P_k – probability that in the queueing system (excavator and trucks) at the moment of time t there are k of trucks; P_0 – probability of the excavator's downtime (trucks may be on their way or are unloaded); m – number of trucks; λ – average intensity of arrival of the trucks, expressing the number of the trucks arriving at the time unit; μ - average intensity of handling the trucks by an excavator, expressing the number of the trucks handled by an excavator within the time unit.

$$k_{j(m)} = \frac{8(k_z + mk_s)}{W_{(m)}} \qquad (2)$$

where: $k_{j(m)}$ – cost of the production unit with employment of m of trucks (EUR/m^3),
k_z – cost of one machine-hour of the excavator's operation (EUR/m-h); k_s – cost of one machine-hour of operation of the trucks (EUR/m-h); m – number of the trucks; $W_{(m)}$ –system efficiency (machine teams) with employment of m of trucks (m^3/shift).

$$W_{(m)} = (1 - P_0) \cdot \mu \cdot q \cdot T \text{ (m3/T)} \qquad (3)$$

where: P_0, μ - as above, q – average capacity of the handled trucks (m^3), T – reviewed time of operation of the system.

The analysis have been conducted for the scope of 2÷18 trucks. It has been assumed that the cost of one machine-hour of the excavator's operation amounts to 29.15 EUR gross, and of a trucks 11.85 EUR gross, whereas the average capacity of the trucks amounts to 8.6 m^3. The costs that have been adopted for the analysis constitute only an assumption and do not reflect the actual costs that the contractor incurred, whereas the average capacity of the trucks has been calculated based on the conducted research in specific two measuring dates and may have changed depending on compilation of the trucks by the subcontractor.

On the Figure 2 the results of analytic calculations for the system efficiency have been presented. The lowest unit cost $k_{j(m)}$ of earth works (equation 2) is when the excavator and 11 trucks are working. Machine system efficiency (earthworks system) increases with the increase of the number of trucks working with the excavator (equation 3) and the probability P_k (equation 1) of downtime of the entire queueings system is decreasing. However, the cost of performing all earth works is increasing.

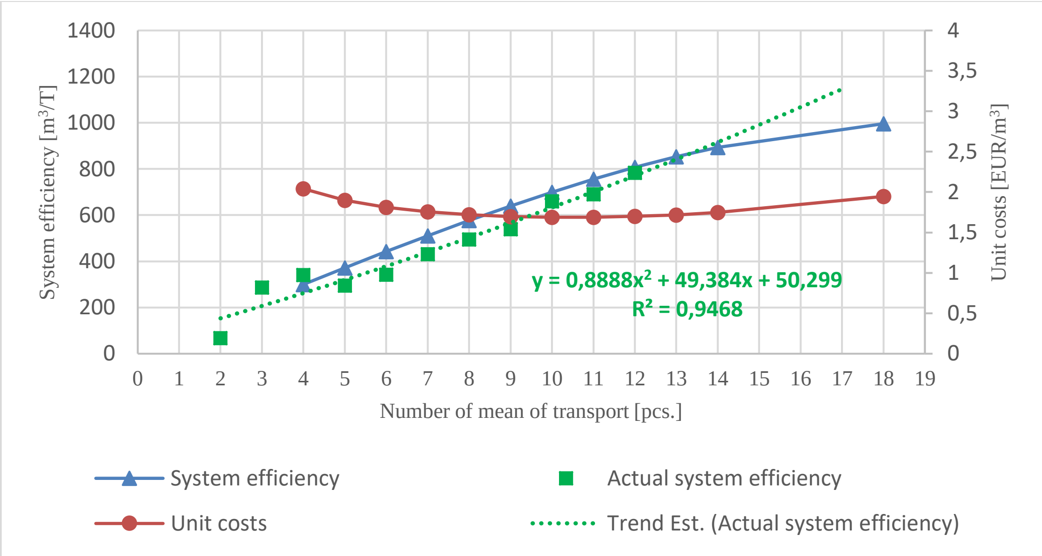

Figure 2. Diagram of the system efficiency and of unit costs depending on the number of the trucks.

Due to the fact that the observation of the actual implementation of the construction possessed relevant data in Figure 3 further shows the actual system performance, which is calculated as the average productivity in the days when there worked established number of trucks. The data were used to calculate the actual productivity was obtained from [9] (Figure 3).

The results of analytic calculations for the system efficiency have been presented, which have been obtained while using the queuing theory, depending on the number of the trucks (cooperating with excavator), and the actual efficiency of the system with a trend line being a quadratic function that has given the best match within the analysed scope. Change of the unit costs has also been taken into account, which aimed at selection of the most reasonable number of the trucks. As can be seen on Figure 2 there are certain differences between the actual system efficiency and the efficiency calculated based on the applied model. The maximum differences amount to approx. 100 m^3/T which is a good result if we take complexity of the real model into account. It may be easily noticed that the minimum unit cost corresponds to 10 trucks of the capacity 8.6 m^3. In contrast, after the analysis of the chart for export of the materials from the construction site, an average number of trucks used by the subcontractor has been calculated, which amounted to 6.82 [number of trucks/day]. Whereas the average daily volume of the exported soil amounted to circa 430 [m^3/day]. It is related to changeable intensity to of the conducted earthworks, which has been presented on the Figure 3.

Based on the results of the conducted research it has been estimated that the cost of the earthworks with the use of 6, 7 and 10 trucks respectively amounts to: 49409.05 EUR, 47856.46 EUR and 46021.37

EUR. The anticipated time for realisation of the task for 6, 7 and 10 trucks amounts to 62 working days, 54 working days and 39 working days.

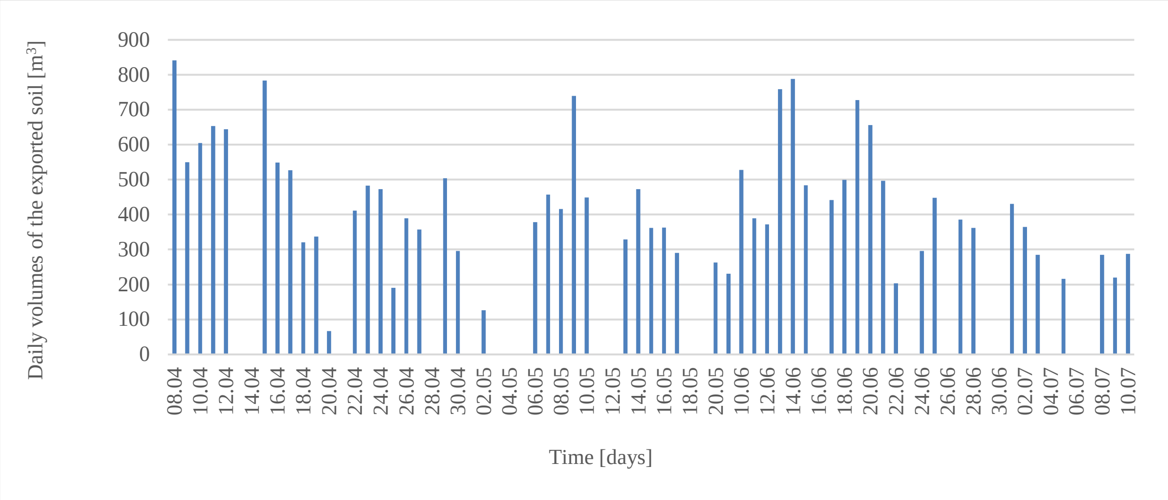

Figure 3. Daily volumes of the exported soil while conducting the earthworks on the construction site of the Centre for Power Engineering of AGH [9].

The adopted model and the method for a solution i.e. queuing theory, would prove well if they were not changes technology foundation work. But, these results can be the basis for making decisions about the sets of co-operating machines, depending on the changing conditions of the construction.

2.2. Execution of earthworks after changing technology foundation works

The design and building conditions for the Energy Centre were difficult and the investor gave the contractor the choice to decide on the foundations technology and the security method for foundation excavation during construction. The contractor suggested to use a bentonite band rather than a diaphragm wall beyond the outline of the foundation walls which are partially protected by earthen buttresses, walls with steel elements reaching a depth of 12 m, and in the corners, by steel pipes. The existing buildings were safeguarded with Jet Grouting piles (Figure 4).

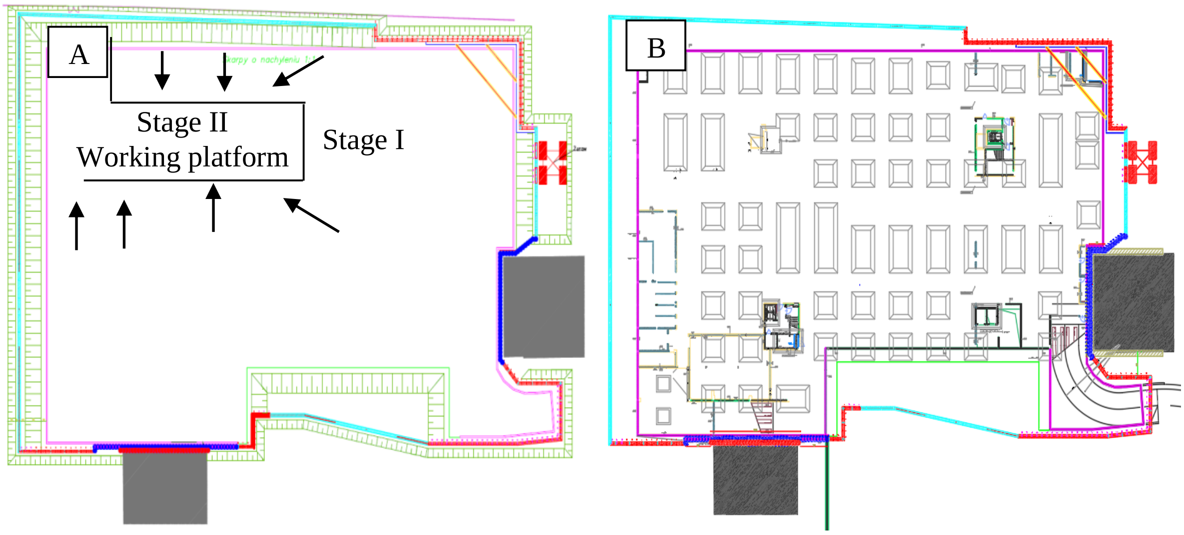

Figure 4. A) Project of sloping the excavations and consecutive stages of soil excavation, B) Project of the foundations and anti- filtration barrier.

bentonite band, earthworks direction, jet grout columns

reinforced bentonite band (IPE 300), mobile offices, existing buildings

The start of the earthworks depended in large measure on the installation of a waterproof bentonite band (Fig. 4) allowing for the effective drainage of the construction site. After the band's installation, the soil removal process was initiated, all the while leaving a working platform for the storage of machines and building materials (Fig. 5). The working platform was removed during the final stage of the earthworks. The casting of bottom slabs was started with a slight delay after the start of earthworks. After adequate preparation, the bottom of the excavated pit was covered with a layer of concrete on which were layed layers of waterproofing and reinforcement. The final stage of the earthworks consisted of pouring concrete on the foundations.

Most of the time, one excavator operating on the site was used for loading the trucks and another one worked on excavating the foundations site. However, there were times when the two excavators worked in series, one passing the soil to the other, which led to the lengthening of the truck loading cycle.

Figure 5. Construction site area with a marked working platform for the machines and for storage of the construction materials (own sources).

The change in the foundation design from the diaphragm wall to a bentonite band lengthened the construction time and required the contractor to reorganize the work. It required a flexible adaptation of all the construction processes and operations including the logistical operations supporting the earthworks which were executed by a subcontractor. The case described here is an example of the application of agile construction (that is the combination of agile production and project management). It allows the contractor to adapt faster to new situations and unexpected events, improve management and keeping in with timetables and costs. Using agile construction techniques requires of managers professional and managerial knowledge and experience.

Due to the technological change in the design of the foundations and the resulting change in the organization of work and random construction-related events, the original plans for earthworks logistics and the optimization of time and costs could not be put into action. However, owing to the application of rational methods of organization and management, like agile construction, the real construction time was 64 days and used 2 to 12 trucks per day. The start of earthworks was delayed but the adoption of the new organization for the interrelated processes largely eliminated the delay in the overall construction schedule and did not increase construction costs.

3. Summary

Constructions sites in high-density urban development, the Centre of Power Engineering of AGH constitutes an example of which, are very interesting projects in terms of logistics. Logistics of the earthworks i.e. assurance of execution of excavation and export of soil from the excavation is a difficult organisational challenge in conditions of extensive urban traffic, limitation of the construction site surface and conducting simultaneous works on the same plot (area). While planning the investment even on the initial stage of preparing the investment for realization the concepts of logistic handling of the construction site and their specific stages has to be made, necessary to estimate feasibility, costs and time for construction.

The proposed model and method for designation of these parameters with the elements of optimisation calculation seems to be a helpful tool at the concept stage. The obtained results may be deemed as approximate. Whereas on the performance stage for operative management, after specification of the works organisation the proposed in chapter 2.1. model (supplemented with adequate data) could be a basis for simulation modelling and searching for decision variables ensuring optimum solution from the point of view of the criteria adopted by the contractor (time, cost, quality, ecology etc.).

However, as practice shows, in the phase of execution of works, there are changes (technology works, construction, materials, etc.), which entail changes in the planned and agreed concepts of work organization. There is a need for rapid and appropriate response managers to avoid default (cost, time, quality), contained in the contract. The preferred method is agile management. Using agile management [4] in construction (agile construction [1, 5]), we can adapt to change, react to the jobsite changes rapidly, complete projects efficiently, and capture more profit.

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