Selection of Excavators for Earth Work on the Basis of their Performance

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Abstract. For the specific construction of the reconstruction of the railway section Ostrov nad Oslavou and Žďár nad Sázavou will be done removed the railway superstructure and the partial adjustment of the substructure including drainage. For the earthwork will be used excavators of the company Komatsu, with the possibility of adjustment of parameters of the working tool – the length of the bracket and the volume of the shovel. The determined value will be purely indicative, as it does not affect how the operator of the excavator handles the discharge of cargo means.

1. Introduction
Excavators belong to the group of machines designed for earth-moving operations with a cycle-based character of work where operations (phases) within the work cycle are interrupted and repeated. The sequence of the work operations is basically the same only with different times of operations. Time differences are caused by mechanical properties of extracted rocks or materials.

Excavators can exert a high digging thrust and therefore they are used for the disintegration of harder rocks in various types of grounds. The digging thrust is limited only by the conditions for the stability of the machine as a whole. In particular shovel excavators offer a wide range of implements accommodating to various requirements imposed by specific applications. The operating ranges of excavators are really wide and cover not only construction work but also all types of engineering work, surface-stripping work in open-cast mines, extraction of construction materials or land-improvement and agricultural work, etc. [1]

Excavators can be equipped with either rubber-tyred or caterpillar undercarriages. Rubber-tyred undercarriages are used in particular in excavators with the shovel volume not exceeding 1.3 m³, for light-weighted materials up to 1.5 m³. Compared to caterpillar undercarriages, rubber-tyred undercarriages of excavators have the following advantages:

- their weight account for about 20% of the total weight of the excavator, while in excavators with caterpillar undercarriages the figure is (30 ÷ 40)%,
- they have fewer friction surfaces resulting in a longer service life,
- when travelling they are exposed to a lower dynamic stress, in particular on hard surfaces, which results in lower wear and tear of the components,
- they have a higher travel speed (up to 35 km/h),
- travel costs are lower due to the fact that no multi-wheel trailer is needed,
- they do not cause damage to communications surface.

With the undercarriages of caterpillar shovel excavators, the weight is distributed over a relatively large area, which makes it possible to transfer much greater travel forces on the ground compared to
excavators with rubber-tyred undercarriages. This results in a relatively low pressure exerted on the ground regardless of the great weight of the machine, along with better stability, easy passage and ability of movement on impassable terrain with high climbing performance [1].

The implements for excavators with a hinged connection on the slew able superstructure include the following items:
- a slewable beam, which is a load-carrying part of the implement with the respective hydraulic means,
- a dipper stick as the connecting link between the beam and the working machine,
- implements (shovels, grabs, crane implements, etc.).

2. Performance of earth-moving machines
The work cycle of the machine working in a cycle includes a sequence of operations that the machine must perform before returning to the initial position. The cycle time can be determined by a theory-based calculation and depends on the speed of the machine or its implement and the time necessary for reaching the respective phase of the cycle. In addition, it is possible to determine the cycle time by measurements carried out on the respective construction machine. Performance refers to the quantity of work expressed by the physical quantities of output per unit of time \([\text{m}^3 \cdot \text{h}^{-1}]\).[2]

2.1 Theoretical performance
Theoretical performance is based on the technical parameters of the machine and is used for earth-moving machines benchmarking.

For earth-moving machines, the theoretical performance is determined as follows:

\[
Q_{\text{theor}} = \frac{V_0}{t_{\text{cycle}}} \quad \text{[m}^3 \cdot \text{h}^{-1}] \quad (1)
\]

\(V_0\) – volume of the work container [m³]
\(t_{\text{cycle}}\) – work cycle time [h]

2.2 Actual (operating) performance
Actual performance corresponds to the actual utilization of the machine in operation. Specific conditions are integrated in the formula by means of the following coefficients:

\[
Q_{\text{tech}} = \frac{V_0}{t_{\text{cycle}} \cdot k_k \cdot k_p \cdot k_c \cdot k_{tu}} \quad \text{[m}^3 \cdot \text{h}^{-1}] \quad (2)
\]

\(k_k\)– a ground disintegration coefficient, which means the ratio of the volume of disintegrated material in the implement to its volume in the natural (unmade) condition,
\(k_c\) – a coefficient expressing the ratio between the theoretical work cycle time and its actual duration under the respective working conditions,
\(k_p\) – a coefficient expressing the implement filling,
\(k_{tu}\) – a coefficient expressing the time utilization of the machine.

The values necessary for the performance determination are provided in Table 1.

3. A realistic construction project
The construction project opted for is the reconstruction of the station yard in the railway line segment between Ostrov nad Oslavou and Žďár nad Sázavou. The line segment is 100 metres long, the excavation is 15.5 metres wide and the average height of the excavation is 1.75 metres. It will be necessary to extract 2,712.5 m³ of soil. After disintegration 3,309.25 m³ of the extracted soil will be removed, [3].
Table 1. The values necessary for the performance determination

| - | Coefficients | - | Values |  |
|---|---|---|---|---|
| $V_0$ | volume of the shovel | $[\text{m}^3]$ | according to the excavators |  |
| $t_{\text{cycle}}$ | cycle time | $[\text{h}]$ | according to the excavators |  |
| $k_k$ | disintegration coefficient | $[-]$ | 1.22 |  |
| $k_p$ | coefficient of filling of the bucket | $[-]$ | 1.00 |  |
| $k_c$ | coefficient for the given working conditions | $[-]$ | 0.9 |  |
| $k_{tu}$ | coefficient of machine time utilization | $[-]$ | 0.6 |  |

Determination of the time of work of the machine:

$$T = \frac{K}{Q_{\text{tech}}} [\text{h}]$$  \hspace{1cm} (3)

$K$ – quantity of cubic contents $[\text{m}^3]$

$Q_{\text{tech}}$ – actual performance of the excavator $[\text{m}^3 \cdot \text{h}^{-1}]$

For the purpose of the comparison, eight KOMATSU caterpillar excavators with different performance and implements were chosen. The machines are equipped with a one-piece (and in some cases a double-piece) hydraulically operated beam – see Table 2.

Table 2. Compared machines

| Excavators | Boom type | Engine performance $[\text{kW}]$ |
|---|---|---|
| PC160LC | one-piece | 90 |
| PC210LC | one-piece | 123 |
| PC240LC | one-piece | 141 |
| PC240LC | double-piece | 141 |
| PC290LC | one-piece | 159 |
| PC290LC | double-piece | 159 |
| PC360LC | one-piece | 202 |
| PC490LC | one-piece | 270 |

4. Results and discussions

Based on the aforementioned formulas, performance and time of work were determined for the realistic construction project and for various lengths of beams, both one-piece, and double-piece, and for various shapes and volumes of shovels. An example for the PC160LC excavator is provided in Table 3.
Table 3. Excavator PC160LC.

| Boom length [m] | Shovel capacity [m³] | Cycle time [s] | Machine performance [m³. h⁻¹] | Hours of work [h] |
|----------------|----------------------|----------------|-------------------------------|------------------|
| 2.25           | 0.94                 | 15.00          | 99.86                         | 33.14            |
| 2.25           | 0.75                 | 14.00          | 85.36                         | 38.77            |
| 2.25           | 0.60                 | 13.00          | 73.54                         | 45.00            |
| 2.60           | 0.94                 | 15.50          | 96.63                         | 34.24            |
| 2.60           | 0.75                 | 14.50          | 82.42                         | 40.15            |
| 2.60           | 0.60                 | 13.50          | 70.82                         | 46.73            |
| 2.90           | 0.94                 | 16.00          | 93.61                         | 35.35            |
| 2.90           | 0.75                 | 15.00          | 79.67                         | 41.54            |
| 2.90           | 0.60                 | 14.00          | 68.29                         | 48.46            |

In addition, the maximum performance and shortest times necessary to perform the respective work were compared – see Table 4.

Table 4. The results.

| Excavators type | Boom length [m] | Shovel capacity [m³] | Machine performance [m³. h⁻¹] | Hours of work [h] |
|-----------------|-----------------|----------------------|-------------------------------|------------------|
| PC160LC         | 2.25            | 0.94                 | 99.86                         | 33.14            |
| PC210LC         | 2.4             | 1.68                 | 167.31                        | 19.78            |
| PC240LC         | 2.0             | 1.89                 | 188.23                        | 17.58            |
| PC240LC         | 2.0             | 2.28                 | 186.31                        | 17.76            |
| PC290LC         | 2.0             | 2.02                 | 173.99                        | 19.02            |
| PC290LC         | 2.65            | 2.02                 | 157.01                        | 21.08            |
| PC360LC         | 2.20            | 2.66                 | 188.38                        | 17.57            |
| PC490LC         | 2.4             | 3.50                 | 232.38                        | 14.24            |

From Table 4 for individual excavators it can be seen that the PC490LC (figure 1) excavator has the highest performance. Its performance is given by its large shovel thanks to which the excavator is able to shovel large quantities of extracted materials. Considering the fact that the best performing machine among the tested machines is concerned, the result is not surprising as the volume of the shovel sufficiently compensates the time cycle of the machine. On the other hand, the PC160LC excavator had the lowest performance. [4]

However, according to the attained results, the excavators PC240LC and PC360LC have nearly the same performance. According to parameters provided by the manufacturer, the PC360LC excavator has an unambiguously higher engine output. The engine output can be utilized in a higher class of workability where the weaker excavator would not be useful, but as this example of a construction project illustrates, the excavator with a weaker engine can easily reach the same performance thanks to its shorter work cycle.
Based on the times of individual excavators, also the PC490LC excavator fulfils the excavation work at the shortest time thanks to the highest achieved performance. On the other hand, the PC160LC excavator will need the longest time. These values could be expected with respect to the parameters provided by the manufacturer. The high speed of work of the PC490LC excavator is achieved by using a large-volume shovel, which is able to scoop large quantities of extracted material, and also by the high engine output providing the excavator with a high digging thrust. This exemplary construction project illustrates the importance of the work cycle speed, specifically in the case of the PC240LC excavator which is able to compete with much heavier and better-performing excavators which often use shovels with a larger volume.

5. Conclusion
This calculation is for information only and allows the excavator with the highest attained performance and the shortest time necessary for the performance of the respective work to be employed.

On the other hand, the excavator performance depends on filling the shovel to the full, which is not always achieved in practice, and so it is up to the operator whether they extend the work cycle and repeats shovelling, or surface-stripping where applicable, followed by filling the implement, or completes the cycle with the half-empty shovel. And again, human factors cannot be eliminated and must be taken into account when specifying the calculation. The information on time acquired on the basis of our calculation is decisive for the duration of the machine work within the respective construction project. However, it does not take into account the factors which must be considered within the framework of the machine designing and which cannot be even estimated in advance. The formula allows for the unsuitability of the implement where the volume of the implement is either insufficient or excessive. To acquire a more accurate time estimate, unexploded ammunition, etc. All such circumstances extend the time necessary for the work completion.

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