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AN EVALUATION OF TECHNOLOGICAL OVERBURDEN THICKNESS LIMIT OF OIL SHALE OPEN CASTS BY USING DRAGLINES

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This paper discusses an actual problem of Estonian oil shale open casts: the technological limit of overburden thickness. The allowable principle stripping operation schemes for walking draglines at Estonian oil shale open casts are presented. Computer modelled methodology is worked out for evaluation technological limit of overburden thickness in Estonian oil shale open casts and in similar conditions. As the result of the study it is possible to declare: the technological overburden thickness is 16-27 m for dragline ES15/90 and 20-37 m for dragline ES30/120 depending on geological and mining conditions.

The methodology allows mining engineers to calculate and evaluate open cast mining conditions and cutting parameters for Estonian oil shale open casts or similar conditions and leads to solving one of the key problems in long range planning, the limit of surface mining. It helps to prepare the documentation and diagrams of stripping operations.

Introduction

Almost half of oil shale mined in Estonia comes from surface mines with open cast technology. Surface mining has always been more economical then underground one. Therefore the current paper is aimed at evaluation of open cast mining conditions. Since there are neither new perspective oil shale deposit, nor oil shale field available for opening completely new oil shale mine in Estonia, we have to evaluate actual possibilities for continuing surface mining. There exists an actual problem of open casts concerned to economical and technological limit of overburden thickness. When mining front reaches the supposed thickness

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limit it has to be decided either to finish the mining or continue with the underground method.

Methodology for evaluating and calculating the overburden thickness limit has been worked out for Estonian surface mining conditions where walking draglines are the main stripping excavators. The output of the computer-generated calculations is the graphs describing overburden thickness limits for draglines with different geometry. Additionally principles for calculating draglines productivity for Estonian oil shale open casts are presented. As a problem of stripping machinery, relations between productivity of old stripping excavators and suitable overburden thickness are given.

The increase in hard overburden thickness increases the cost of blasting. The cost of blasting is also affected by current economic situation where the price of blasting materials increases relatively faster. The increase of expenses is also affected by the use of old stripping excavators what generates higher maintenance and lower productivity of the draglines. Questions of overburden thickness and productivity decrease are discussed.

Background

The increase in overburden thickness in Estonian oil shale open casts is mainly caused by the deepening of the oil shale seam in a southerly direction. The surface is flat without any notable hills. Therefore, the expenses of surface mining increase when moving the mining front southward due to the increasing thickness of the overburden.

There are currently three large oil shale open casts operating in the Estonian oil shale deposit (rock characteristics and mining conditions shown in Table 1). The total overburden thickness in working fronts is

Table 1. **Characteristics of Estonian Oil Shale and Open Cast Mining [3]**

Characteristics	Overburden		
	Soft overburden	Hard overburden	
	Bench		
	Upper bench	Upper part of intermediate bench	Lower part of intermediate bench
Rock characteristics	Moraine, sand and sandy aleurolite Peat	Clayey dolomite and mergel Layered dolomitized clay	Clayey, bituminous limestone and dolomite
Swell factor	1.24 m^3/m^3	1.43 m^3/m^3	
Bench slope angle, deg	50°	75°	
Spoil slope angle, deg	35°; 15°(clay, peat)	40°	

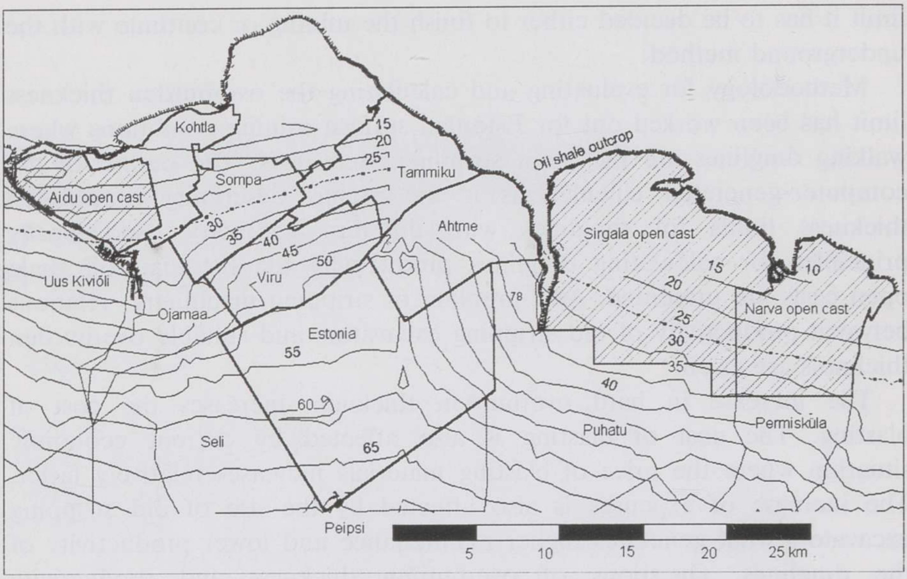

Fig. 1. Map of the area with oil shale open cast mining fields and isolines of overburden thickness, m

13-20 m in *Sirgala,* 16-18 m in *Aidu* and 21-27 m in *Narva* open cast. The map of the area with oil shale mining fields and isolines of overburden thickness are shown in Fig. 1. Current mining fields have been placed in order to follow geographical possibilities and not to go deeper than 30 m. The depth of 30 m was taken as the maximum for overburden thickness for available draglines.

Economic Limit of Overburden Thickness

The economic limit of overburden thickness is the point at which it is not profitable to continue with surface mining operation due to the high cost of stripping and blasting operations. The limit of overburden thickness is calculated based on the economic stripping ratio. The economic stripping ratio is equal to [{(income from oil shale/tonne) - (oil shale mining cost, incl. mining operations, haulage, preparation, etc., excluded stripping cost/tonne) - (minimum required profit/tonne)}/(stripping cost per cubic meter of overburden)] [1]. The economic stripping ratio has to be multiplied by the productivity of the oil shale layer (tonnes/m^2) to get the thickness limit. After economic calculations one has to decide at which point to either finish, to continue surface mining or to start underground mining. When reaching technological limit, necessary investments for bigger or additional draglines rapidly increase. Investments are needed also for underground mining with the difference that this method enables to mine greater amount of reserves.

Fettweis [2] shows (see Fig. 2) that both surface and underground mining costs increase with increasing overburden thickness. In the case of underground mining, the stable zone is much greater and the cost increases with greater depths. A certain price of oil shale is needed to cover the costs for surface or underground mining at various depths.

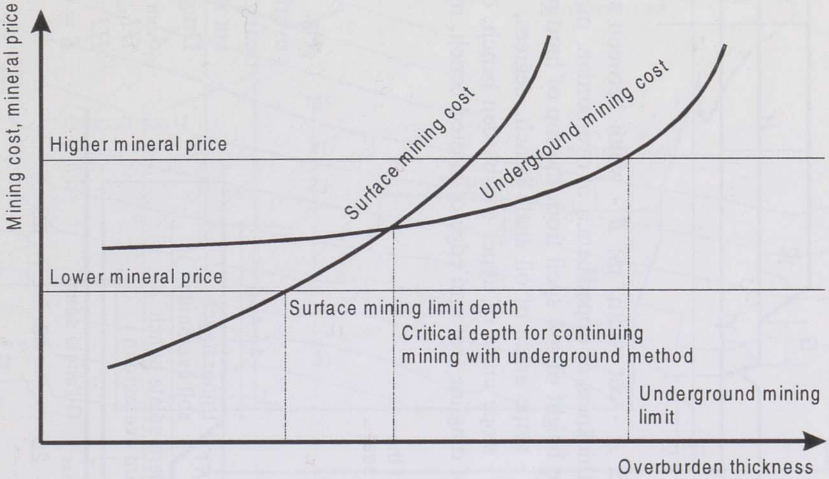

Fig. 2. Mining limits depending on mining cost, mineral price and mining depth [2]

The economic calculations of surface and underground mining have shown that the use of underground method would bring about higher price of oil shale. Since the overall price of oil shale now covers also the costs of operating underground mines, the increase of the price in the future will be not very rapid. On the other hand, the current price does not cover all necessary investments in current mining fields, so the price could be underestimated.

Strip Mining Cut Diagrams

Figure 3 shows the basic parameters for calculation of suitable overburden thickness.

According to dragline productivity and overall operations efficiency it could be more effective when the dragline is situated on the top of the overburden bench. If the ground bearing strength of the surface is too low to support the dragline, on the overburden a competent bed is selected as the horizon for the working bench. Since the overburden in Estonian oil shale deposit requires partial destruction, the upper bench is excavated without and intermediate bench after blasting.

All angles in Fig. 3 depend on rock characteristics. The cut width and the spoil size depend on dragline geometry.

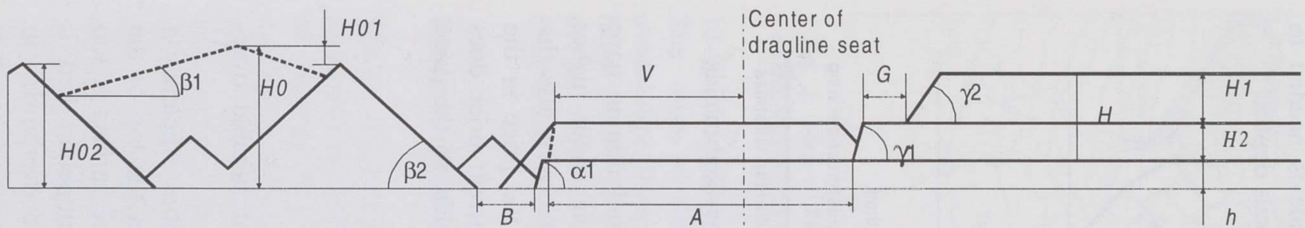

Fig. 3. Basic parameters for calculating suitable overburden thickness. Legend: *A* - cut width, m; *B* - width between spoil and oil shale bench, m; *h* - oil shale seam thickness, m; *H* - overburden thickness, m; *H1* - thickness of upper bench of overburden, m; *H2* - thickness of intermediate bench of overburden, m; *H0* - total spoil height, m; *H01* - relative height of soft spoil from the top of hard rock spoil, m; *H02* - height of limestone spoil, m; *G* - width of intermediate bench berm, m; α - slope angle of oil shale bench, degrees; β1 - angle of soft overburden repose, degrees; β2 - angle of hard overburden repose, degrees; γ1 - slope angle of upper overburden bench, degrees; γ2 - slope angle of intermediate overburden bench, degrees; *V* - distance between centre of dragline seat and edge of blasted bench, m

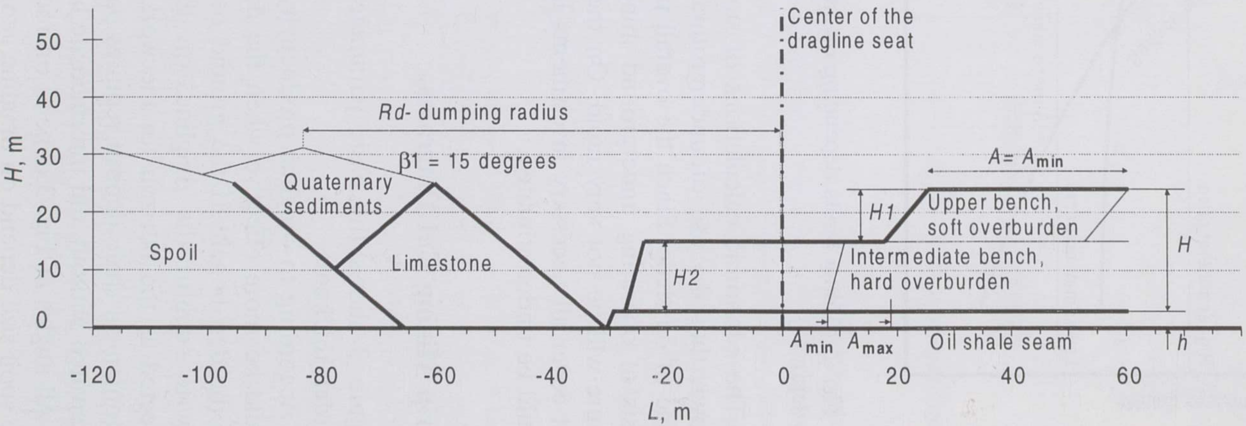

Fig. 6. Results of the overburden thickness calculations as mining cut diagram. Dragline ES15/90, A_{min} = 35 m, $H1_{max}$ = 9 m, $H2$ = 12 m, B = 0 m

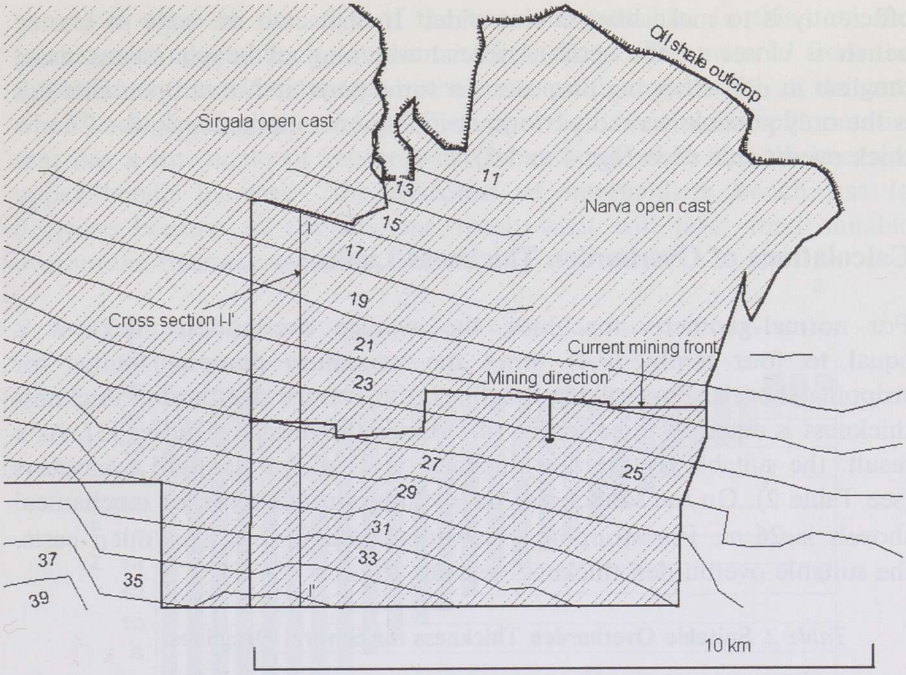

Fig. 4. Location of the mining front at the *Narva* open cast and overburden thickness

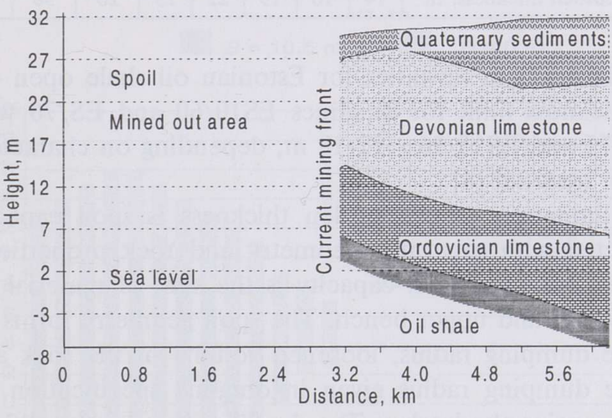

Fig. 5. Narva open cast cross-section *I-I′*

Apart from the reduction of the boom length required, and, hence of the capital cost, a narrow cut width provides more efficient use of the spoil space since it reduces the valleys between spoil peaks. The minimum width of a pit must be sufficient to allow the dragline boom to swing on a 90° scale when operating in the nearest position to the edge of the high-wall. Another possibility to use the dragline reach more efficiently is to make blasted seat wider. In that case the edge of blasted bench is closer to the spoil. Artificial widening of bench means using dragline in non-stripping purposes. In some parts at *Narva* open cast this is the only possible way to perform stripping operations due to the 27 m - thick overburden (See Figs 4 and 5).

Calculations of Overburden Thickness Limits

For normal-geometry machines, the average overburden thickness is equal to four tenths (0.4) times the maximum dumping radius for stripping shovels. For walking draglines, the average overburden thickness thickness is equal to three tenths (0.3) times the dumping radius [3]. As a result, the suitable overburden thickness is 33 m for standard excavators (see Table 2). On the same bases the overburden thickness for mechanical shovels is 26 m. For stripping excavators, used in Estonian open casts, the suitable overburden thickness reaches 25 m.

Table 2. **Suitable Overburden Thickness for Several Draglines**

Parameter	Boom length, m							
	50	60	70	80	90	100	110	120
Total overburden thickness, m	14	16	19	22	25	26	30	33

In proposals made in seventies for Estonian oil shale open casts, the overburden thickness limit for draglines ES10/60 and ES/70 was 12 m, and for ES20/75 and ES15/90 - 12-18 m, depending on characteristics of the overburden material [4].

The main limitation of overburden thickness is spoil capacity. It is closely connected with excavator geometry and rock properties. In the case of two benches, the spoil capacity is the sum of material from the intermediate bench and upper bench. The spoil geometry forms from cut width, dragline dumping radius, loosened volume of the rock and angle of repose. The dumping radius given in dragline specification could be increased with casting the bucket. The dragline rope inclines 12-15° from vertical and R_{max} could increase from 2.5 to 15 m depending on boom length [5].

The purpose of overburden thickness calculation is to analyse critical mining situations where cut geometry counts. Due to this the calculation does not include the making of smooth spoil shapes. Levelling of spoils has to be done with additional equipment such as bulldozers.

The spoil capacity is maximum if the top of the spoil situates in the maximum distance from the overburden bench. The dragline could situate as close to the edge of the bench as possible. In this case the thickness of upper bench could create limitations. The material from the upper bench has to be dug out in the same width as cut width in the case when a single dragline is used. The upper bench contains soft material that has a low angle of repose what means that when the thickness of upper bench increases, the thickness of intermediate bench has to decrease because of the dragline reach what will limit total suitable overburden thickness (see Fig. 6).

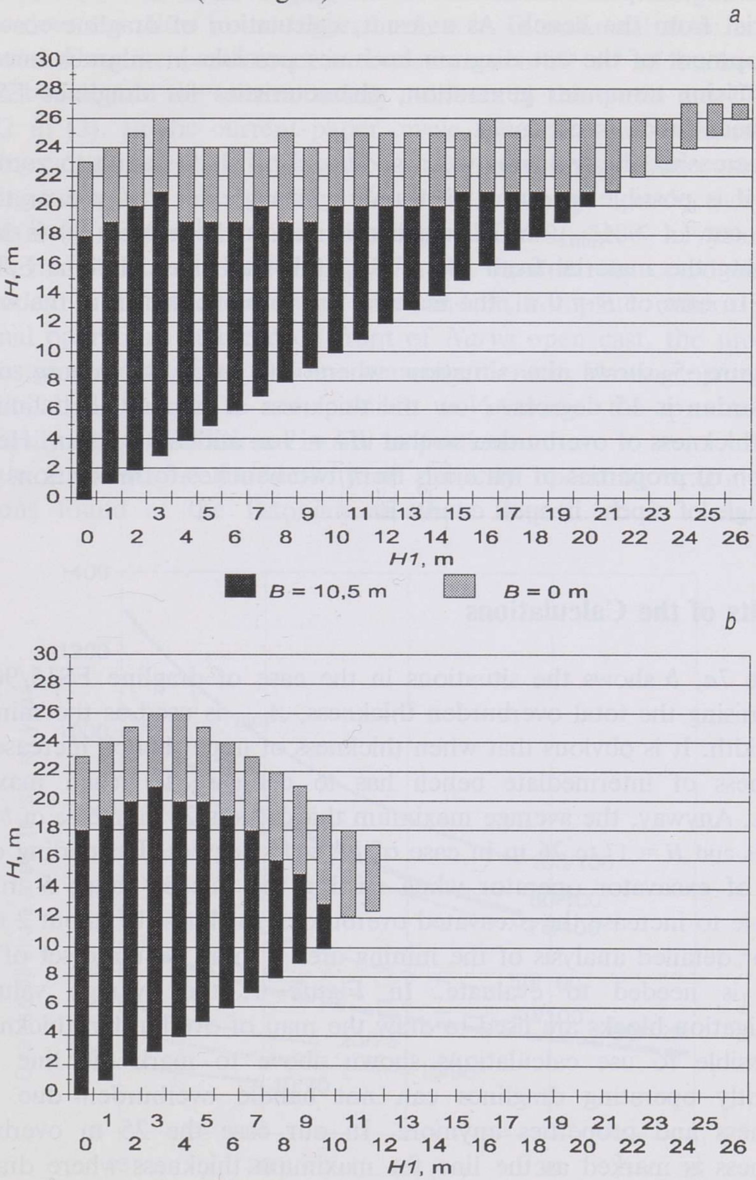

Fig. 7. Suitable overburden thicknesses H for dragline ES15/90, $A_{min} = 35$ m: a - $b_1 = 35$ degrees; b - $b_1 = 15$ degrees

Using the conventional graphic method, every mining situation needs to be calculated separately and several interrelated parameters have to be taken into account. This method is time-consuming for getting a satisfactory result and often simplifications are made. For the case of computer calculations, one can see the relationships between different parameters and decision making is much faster. The main difference between the conventional method and computer calculations is the calculation of spoil volumes and their comparison to the volume of loose material from the bench. As a result, calculation of dragline reach and development of the cut diagram becomes possible in minutes instead of days. Using computer generation, characteristics for draglines ES15/90 have been made (see Fig. 7).

Decreasing the width between spoil and oil shale bench to zero (B = 0 m) it is possible to dump overburden in a greater distance or to strip wider cut ($A > A_{min}$). In oil shale open casts the value (B) is left for dumping the material from layers F_{upper}, D and intercalations E/D and C/D. In case of B = 0 m, the material has to be hauled from the working front.

Figure 5 shows the situation where the angle of repose of soft overburden is 15 degrees. Now the thickness of upper bench limits the total thickness of overburden so that $H1$ = 9 m and $H2$ = 12 m. Here the relation of properties of materials from two benches form relations where the angle of repose in spoil counts in.

Results of the Calculations

Figure 7*a, b* shows the situations in the case of dragline ES15/90. For maximising the total overburden thickness, A_{min} is used as the minimum cut width. It is obvious that when thickness of upper bench increases, the thickness of intermediate bench has to decrease to reach maximum values. Anyway, the average maximum thickness is 25 m in case of $b1$ = 35 degrees and H = 17 to 26 m in case of $b1$ = 15 degrees. Depending on the skills of excavator operator when casting the bucket about 5 m, it is possible to increase the excavated overburden thickness by about 2 m.

For detailed analysis of the mining area a more accurate set of boreholes is needed to evaluate. In Figure 1, the average values of investigation blocks are used to draw the map of overburden thickness. It is possible to use calculations shown above to mark the line where currently operating draglines can not handle overburden due to its thickness and properties anymore. In our case the 25 m overburden thickness is marked as the line for maximum thickness where draglines work properly. Due to the lack of boreholes data, a more precise analysis has not been performed yet.

Productivity of Draglines

Dragline productivity is a function of its geometric parameters, mining conditions and technological and organisational conditions. The main parameters are the size of the bucket and the cycle time. Usually it is possible to change the bucket in the range ± 5 m^3 [6]. At *Aidu* open cast the bucket of a dragline ES15/90 has been changed to 20 m^3. Since it has not been done with any other draglines, it seems that the strength of the dragline does not allow to use bigger buckets in Estonian oil shale mining conditions. Dragline parameters in Estonia reach 20 m^3 of bucket and 90 m of boom, and the corresponding numbers in the world are 170 m^3 and 122 m [3]. In the current paper, cycle times that are presented in technological schemes for Estonian oil shale open casts [4] are used for displaying draglines productivity. In 1974, average productivity of draglines was 2300 m^3/year for dragline ES10/70, 3200 m^3/year for ES15/90 and 4650 m^3/year for ES20/70 [4]. Productivity could be the same today if the draglines were new and in complete order. From additional operations at the deep front of *Narva* open cast, the productivity has gone down. Due to some rearrangement in blasting operations and critical depth, it is not possible to evaluate the productivity theoretically without additional in situ inspection.

Figure 8 shows the productivity of properly operating draglines in conditions found at the Estonian oil shale deposit. It is clear that

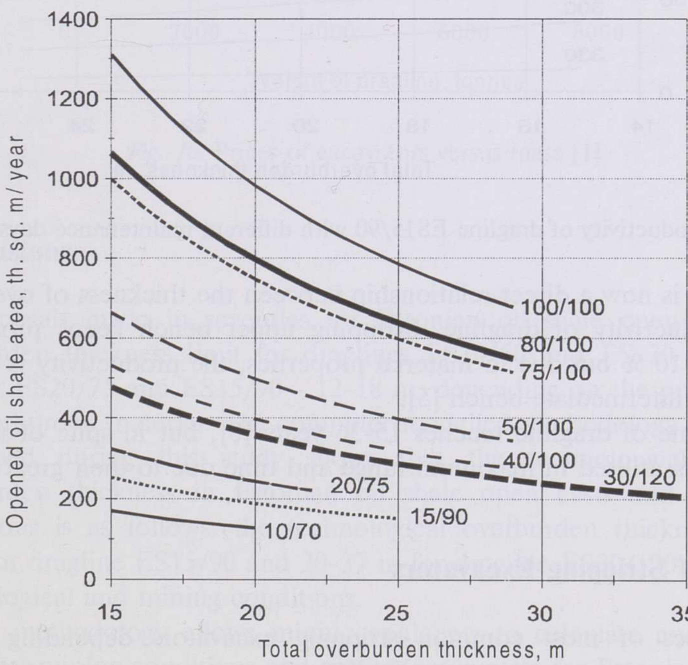

Fig. 8. Productivity of draglines and overburden thickness limits

increasing bucket size increases the productivity remarkably and longer boom allows stripping a greater volume of overburden.

The best way for evaluating productivity of old draglines, is to do it through showing the number of days in a year when a dragline needs to be maintained or repaired. The average number of required maintenance days in a year is 45-58 [7]. Figure 9 shows the decrease in the dragline ES15/90 productivity in an open oil shale area ready for mining in overburden from 15 to 25 m, when the minimum number of maintenance days in a year is 30 and the maximum - 330.

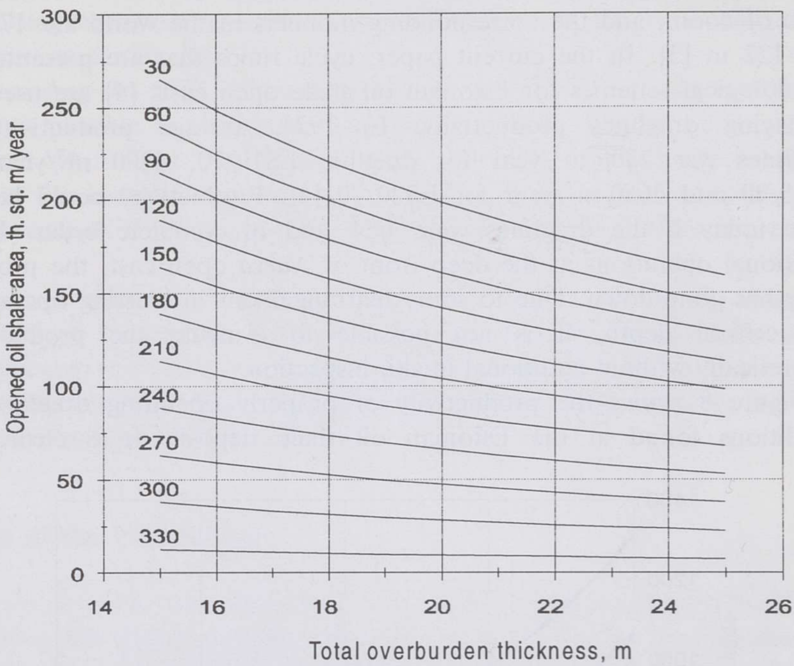

Fig. 9. Productivity of dragline ES15/90 with different maintenance days per year

There is now a direct relationship between the thickness of overburden and productivity of dragline. Stripping upper bench keeps productivity down by 10 % but due to material properties, the productivity is equal to stripping intermediate bench [5].

Lifetime of dragline reaches 15-36 years [8], but in spite of that they are always utilised in maximum range and time due to their great cost.

Prices of Stripping Excavators

The prices of most common stripping excavators depending on the excavators mass are shown in Fig. 10. One can see that a 1620-tonne dragline ES15/90 costs approximately 110 mill kroons and a 4000-tonne

ES30/120 about 300 mill kroons. In case of purchasing a new 30-cubic-meter and 120-meter boom dragline, by preliminary evaluation, the cost of stripping operations could increase about 30 %. Despite expenses, the lifetime of draglines currently in use will soon be over, and decisions for continuing have to be made.

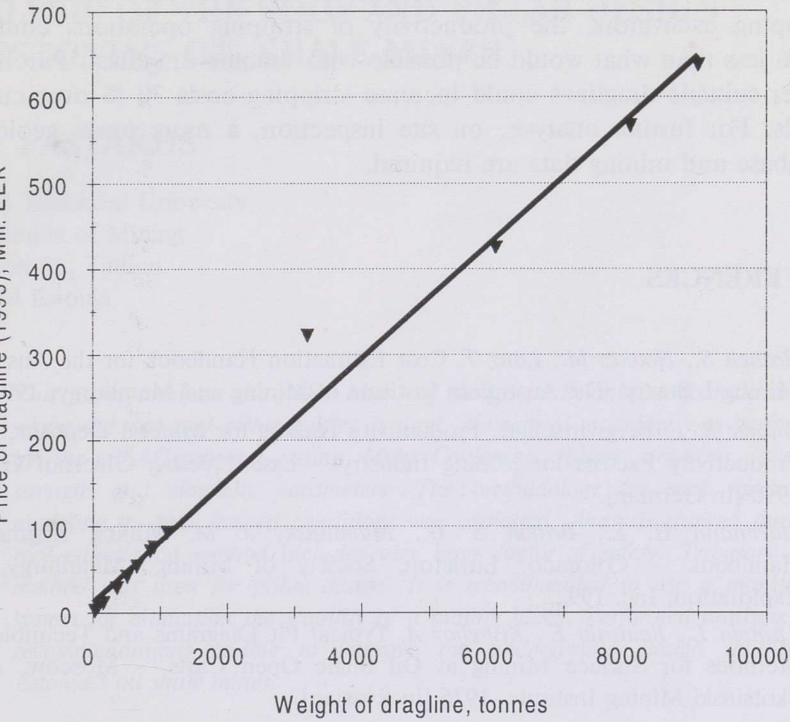

Fig. 10. Prices of excavators versus mass [1]

Conclusions

In proposals made in seventies for Estonian oil shale open casts, the overburden thickness limit for draglines ES10/60 and ES/70 was 12 m and for ES20/75 and ES15/90 - 12-18 m, depending on the properties of the overburden material. The computer modelled methodology which was developed during this study shows that the technological limit of overburden thickness in Estonian oil shale open casts and in similar conditions is as follows: the technological overburden thickness is 16-27 m for dragline ES15/90 and 20-37 m for dragline ES30/120 depending on geological and mining conditions.

The methodology allows mining engineers to calculate and evaluate open cast mining conditions and cutting parameters for Estonian oil shale open casts (or similar conditions) and leads to a solution of a key problem in long range planning: the limit of surface mining. Since there are currently three large oil shale open casts operating in the Estonian oil shale deposit, at *Narva* the working front has already reached its maximum value. The total overburden thickness at the working fronts is 13-20 m in the *Sirgala*, 16-18 m in the *Aidu* and 21-27 m in the *Narva* open cast. Due to the critical overburden thickness and the use of old stripping excavators, the productivity of stripping operations could be 60 % less than what would be possible with suitable draglines. Purchasing larger suitable draglines could increase stripping costs 30 % over current levels. For further analysis, on site inspection, a more exact geological database and mining data are required.

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