

DETERMINATION OF COAL REMAINING IN GOB AT GLI THICK COAL SEAM USING PHYSICAL MODELLING

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ABSTRACT: Longwall top coal caving method (LTCC) is preferred to slicing methods for thick coal seams of 6 m width or more. This method is used at TKİ-GLİ Ömerler mechanized colliery in Kütahya, where 3 m of the seam is produced by longwall and the remaining 5,5 m is won by caving and drawing through the support frame. Although production organization of the method is quite easy, coal losses occur during caving of top coal, whereby it is assumed that no coal loss occurs in the face operation. Due to the hard working conditions in the mine, investigation of coal recovery is studied by the help of a physical model. Through studies carried out in the mine, coal loss of the complete seam (including the face) is found to be 16,64 %. When coal loss amount is compared only to top coal, it turned out to be 24,73 %. To find the coal loss by the physical model, the amount of material behind the face is collected after operating the model, and weighted. Then, this amount is divided by the total amount of material used in the model. By this method, coal loss is found to be 26,3 %. Loss out of the whole seam is 17,43 %. The procedure followed includes firstly to determine the material used in the model which will simulate Ömerler mine coal best. Then, model frame is built and the model is operated. Finally, coal loss measurements and calculations are carried out.

FİZİKSEL MODELLEME KULLANARAK GLİ KALIN KÖMÜR DAMARINDA GÖÇÜKTE KALAN KÖMÜRÜ BELİRLEME

ÖZET : Kalın kömür damarlarında kalınlığın 6 m'yi aşması durumunda dilimli yöntemle göre taban ayak (çekme) yöntemi daha fazla tercih edilmektedir. Bu yöntem Kütahya bölgesinde TKİ-GLİ'ye bağlı Ömerler yeraltı mekanize kömür madeninde uygulanmaktadır. İşletme 8,5 m kalınlığında bir kalın kömür damarına sahiptir ve bunun 3 m'lik kısmı damarın tabanında çalışan ayak ile üretilmekte, geriye kalan 5,5 m'lik kısım ise göçertilerek yürüyen tahkimatın penceresinden kazanılmaktadır. Yöntemin üretim organizasyonunun kolay olmasına karşın, tavan kömürünün göçertilerek tahkimat penceresinden çekilmesi sırasında kayıpların oluşması olumsuz taraftır. Damarın taban kısmındaki ayakta kayıpsız üretim yapılırken, ayak üzerindeki kömürün üretimi sırasında kayıp oluşmaktadır. Madende şartların zor olmasından dolayı kayıpların hesapları, madende yapılan kayıp hesaplarının dışında fiziksel model ile yapılmıştır. Madende yapılan ayak arkası kayıp hesaplarında kayıp tüm damar için % 16,64 bulunmuştur. Kayıp miktarı sadece tavan kömürü rezervine oranlandığında % 24,73 olmaktadır. Fiziksel model çalıştırıldıktan sonra ayak arkası kaybı bulmak için ayak arkasındaki malzeme toplanmış ve modeldeki tüm malzeme ağırlığına oranlanmıştır. Modelde kayıp, tavan kömürü rezervine göre % 26,3 olarak bulunmuştur. Tüm damar için kayıp ise % 17,43'tür. Bu araştırmada model malzemesinde gözönüne alınan faktörler, model kalıplarının oluşturulması ve modelin çalıştırılması ile kayıp değerinin belirlenmesi anlatılmıştır.

1. INTRODUCTION

In Turkey, caving methods are mostly employed in mining of thick coal seams as long as the roof strata is suitable for their use. Longwall with caving is always preferred to stowing faces because of its simplicity, favorable economics, and high productivity. It is assumed that the upper bound of applying single pass longwall (SPL) method as a mechanized system in thick coal seams is about 6 m (Köse and Tatar, 1997). If the thick coal seam cannot be mined by SPL, then multi-slice longwall (MSL) can be employed. However, for thick seams, MSL is less convenient, less economic, and requires more labor compared to LTCC method. When choosing which method to employ, the features of the seam are needed to be considered.

The coal seam being mined at Ömerler underground mine is a thick coal seam. The location of the study field is given in Figure 1.



Figure 1. Location of Ömerler colliery

Tunçbilek coal basin is made up of old Palaeozoic, metamorphic schist and crystallized limestone on the base layer and discordant Mesozoic old serpentinized ultrabasic rock layer over it. The coal seam under production contains generally black and bright lignite. The lower and top part of the seam is more pure, whereas the middle part of the seam is more mixed.

The clay stone over the seam shows weak character and is therefore called ‘soft clay’ stone. This dark grey formation lying on the main coal seam, which has a

thickness between 30 and 80 cm, is shown in Figure 2.

The ‘marl’ formation on top of ‘soft claystone’ is stronger and involves less humidity in terms of natural humidity content. This formation is called ‘roof claystone’. It is colored dark grey and shown in Figure 2. The base clay stone lying under the coal seam is even stronger than these layers of claystone. It has light grey color and is denoted in Figure 2. Finally, the main coal seam is denoted in Figure 2.

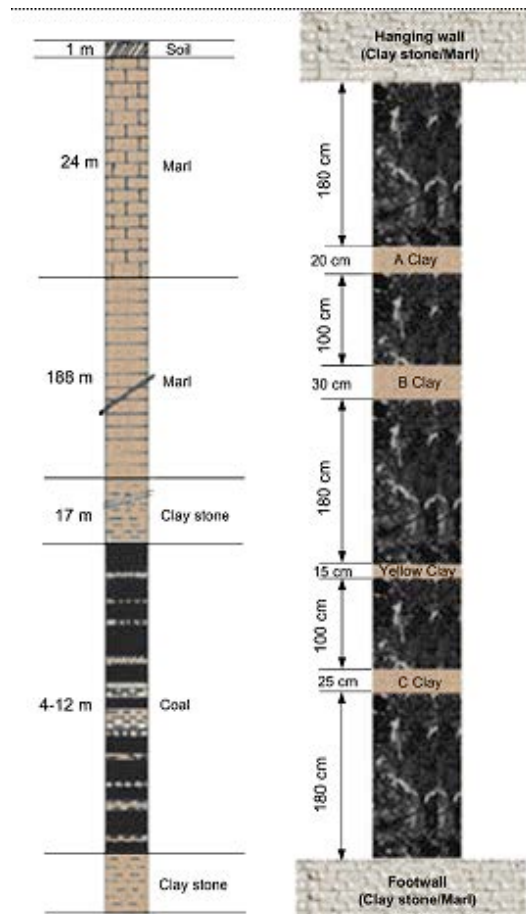


Figure 2. Geology of Ömerler colliery (Çelik, 2005)

Here, the longwall, app. 86 m long, is set up on the floor part of the seam, and, coal left on top is drawn through the roof support (CMEC ZYD 4000/18/32, Chinese manufacture) window onto the face conveyor (SGZ - 730/264, Chinese manufacture). The thickness of the seam is variable due to

layer formation, but it is 8.5 m on average. Of this 8.5 m, 3 m is mined from the longwall, the rest 5.5 m caves in. In case the top coal does not cave in, drawing of coal is carried out with the aid of drilling and blasting. According to the system applied in the mine, the shearer-loader (Eickhoff EDW-150-2L) performs two cuts, 60 cm each, along the face and moves so 1.2 m forward. After roof supports move towards the face, top coal is drawn through the window of each support unit (Destanoğlu et al., 2000). Figure 3 gives the plan (a) and the cross-sectional views (b) of the longwall.

The most negative side of caving method compared to multi-slice method is the coal loss occurring during production of top coal. Coal recovery in top coal turns out to be around 70 % when a thick slice is caved. The recovery of the whole seam (top coal and face coal) is around 80 %. In multi-slice mining, recovery is around 95-97 %. Therefore, if coal loss can be decreased in LTCC, this method would become more advantageous (Özfirat and Şimşir, 2005).

In some of the studies in China and Australia, it is stated that coal recovery in LTCC is around 80-85 %. The results from these studies emphasize that roof support operators should have practical experience during the caving of top coal. (Hebblewhite, 2000; Xu, 2001; Hebblewhite & Cai, 2004).

The LTCC method offers a viable means of extracting up to 75 % to 80 % of seams in the 5-9 m thickness range. The LTCC method is increasing to be used in thick seam mining, for example, there are over 70 LTCC faces operating in China (Hebblewhite, 2000). In addition, in Australia, several Chinese companies have successfully used the LTCC method. The initial thickness - typically 3 m - is cut and loaded conventionally with a shearer and front AFC. The remaining top thickness of coal, typically an additional 3-9 m, is allowed to cave into the rear AFC. By this way, coal recovery is

increased to 85 % from a 9 m seam (Kelly et al., 2001).

In 1988, Şenkal et al. found the coal loss as 24.3 % in the same colliery. However, at that time, longwall equipment was consisted of hydraulic props, AFC, and drilling-blasting as winning method. The most important disadvantage of the LTCC method is that significant coal losses may appear when drawing the coal through the support window.

In previous studies carried out in the field, five different experiments were performed at the mine to find the coal loss. As a result of these experiments, coal loss in the whole seam is found to be 16,64 % (Table 1). When coal loss is compared to top coal, the loss value turns out to be 26,3 % (Özfirat and Şimşir, 2007).

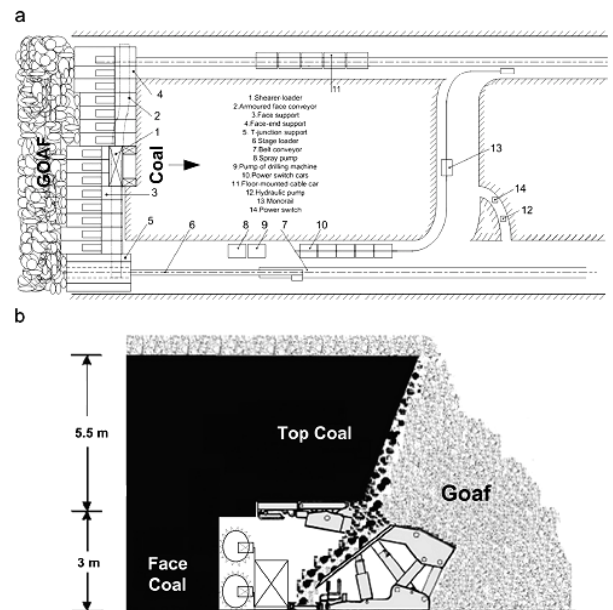


Figure 3. Plan(a), cross-sectional(b) view of the longwall (Destanoğlu et al, 2000)

The purpose of this study is to simulate the mine by a physical model. Since it is impossible to see the coal behind the face, physical modeling is done to observe the caving of coal into the face and rear face.

Table 1. Coal loss and dilution values

| Exp. # | Coal Production | Dilution (%) | Coal Loss (%) |
|---------|-----------------|--------------|---------------|
| 1 | Whole Seam | 25,58 | 23,64 |
| | Top Coal | 38,59 | 34,75 |
| 2 | Whole Seam | 20,70 | 10,83 |
| | Top Coal | 35,44 | 16,48 |
| 3 | Whole Seam | 24,87 | 15,73 |
| | Top Coal | 41,67 | 23,49 |
| 4 | Whole Seam | 23,76 | 15,84 |
| | Top Coal | 38,24 | 23,09 |
| 5 | Whole Seam | 29,6 | 17,16 |
| | Top Coal | 52,42 | 25,83 |
| Average | Whole Seam | 24,90 | 16,64 |
| | Top Coal | 41,27 | 24,73 |

2. LITERATURE SURVEY

Everling (1964) has set both the geometric scale and the strength scale factor as 1/10. He set these two parameters equal without thinking of any theory. In 1965, Everling and Hobbs has used the “ π theorem” to find the strength scale factor. Hobbs (1965) arranged an intensive research programme on the stability of single roadways using the physical modeling method. Whittaker and Hodgkinson (1971) examined the size effects of arch shaped gate roadways with extraction by longwall advancing coal faces. They arranged models made of sand-plaster mixes and reported that models showed no similarity with field observation.

Jeremic (1985) has calculated failure strength of layers in a coal mine by the help of basic friction model.

In India, a physical model is built for a 7,5 m thick coal seam mine and 210 m long face at 147 m depth. Due to the lack of observations in the mine, current operation of the mine is modeled physically and the failure forms of layers are investigated through the model. The overall dimension of the frame on which the model was constructed was 1,47 m \times 2,10 m \times 0,15 m. The model was constructed on a 1:100 geometric scale in

which the coal measure formation of the mine was simulated.

The model of the panel can be seen in Figure 4a. The points measuring stress and convergence are marked on the figure. Within the first 90 meters, a 2,5 m face adjacent to the head gate is produced. Then, from the beginning of the panel, a 2,5 m face adjacent to the base of the seam is produced. The 2,5 m slice in the middle is produced by caving it. In Figure 4b, the caving layers during the production at the top of the seam can be seen. Here, when face has advanced 35 meters, an immediate roof of 2 to 4 m caves in. The remaining 8-10 m high roof has caved under control in a planar form (d).

When the face has advanced 55 meters, the caving height has become 33 m from the operation level. At the end of 90 m advance, the total subsidence to the surface has been 0,79 m. In Figure 4c, the caving layers during the caving process of the middle slice can be seen. Since the operation level has increased during this process, caving height has also increased and changed between 20-24 meters (Singh and Singh, 1998).

Physical models in literature are mostly concerned with stress modeling in mines. There are not many physical models dealing with the caving of coal as presented in this study. Therefore, the studies, which are close in concept to this study, are handled in literature review.

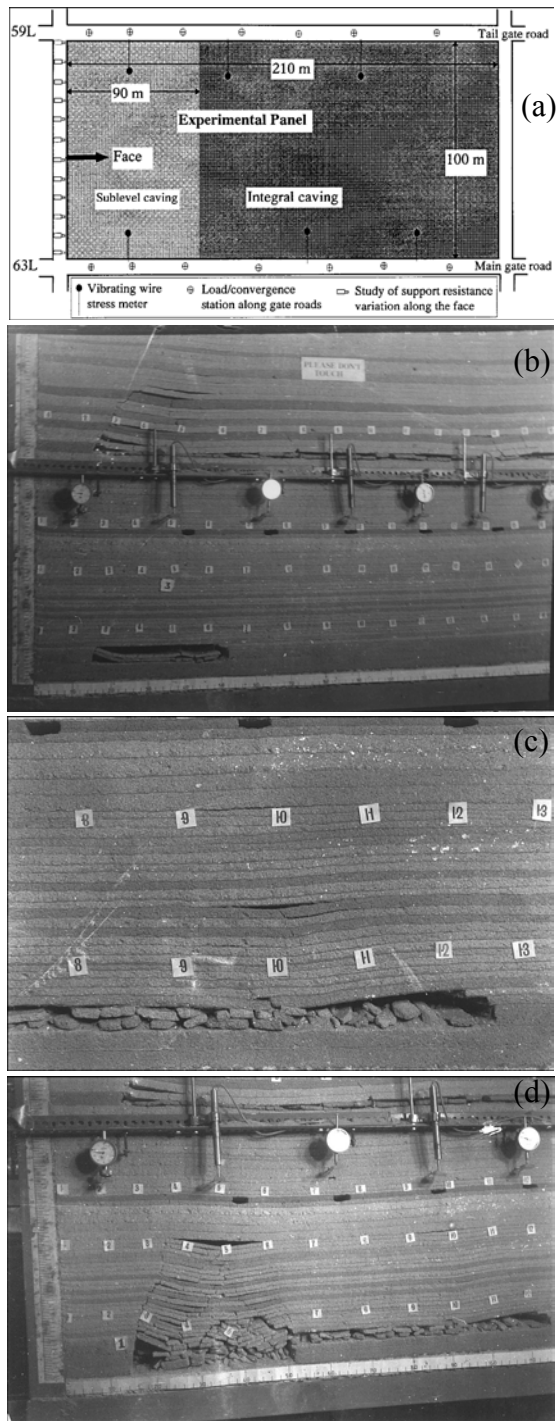


Figure 4. Panel model (a) and models form by production (b,c,d) (Singh and Singh, 1998)

Another modeling study is carried out by Yavuz and Fowell (2003). In this research, it is proved that the roof bolts attached into the roof of roadway between adjacent panels are not effective. The pillar dimensions are not big enough. Authors have examined the layer movements both on a physical model and

a FLAC computer model. Below are the figures of physical models.

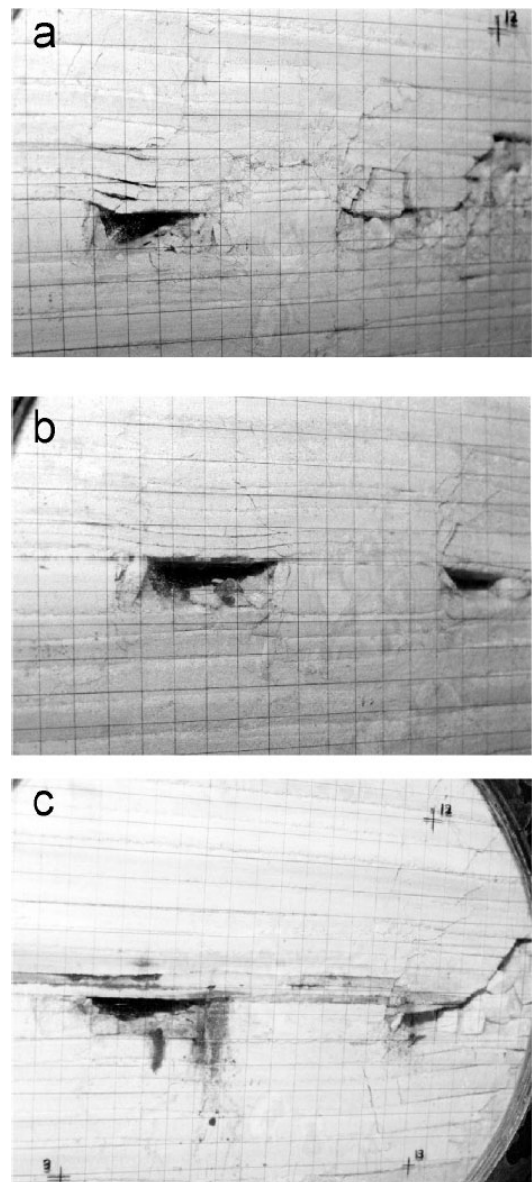


Figure 5. Failure zones in 5 m pillar (a), 7.5 m pillar (b), 10 m pillar (c) models (Yavuz and Fowell, 2003)

As a result of the models, it is found that 1 m pillar is not enough to keep stable and at least 7,5 or 10 m pillar is necessary. By this way, roof bolts would be more effective. The physical model shows that as the pillar width increases, the stress around the gallery decreases and the gallery becomes more stable (Yavuz and Fowell, 2003).

3. PHYSICAL MODEL STUDIES

In a coal mine, it is very hard to observe coal losses and the factors affecting coal losses during production in the mine. Therefore, a physical model is prepared by decreasing the dimensions (according to a certain scale) of the production system of an underground coal mine. Firstly, the scale is determined to be 1/10, so that caving could be observed better. Coal loss is computed by using a single roof support.

The flow diagram of the work for physical modeling is given in Figure 6. This algorithm is applied for the model with 1/10 scale.

When preparing the physical model, uniaxial compressive strength (UCS) values of the coal seam and roof strata are tried to be simulated. In order to do so, roof strata and coal samples taken from the field are brought to rock mechanics laboratory of Dokuz Eylul University Mining Engineering Department. Cores are taken from roof strata samples. Since core cannot be taken from coal, according to TS2028 standard, 7×7×7 cm cubes are prepared from coal samples. Uniaxial compressive strength values of the coal and roof strata are found by experiments carried on the cores and cubes (Figure 7).

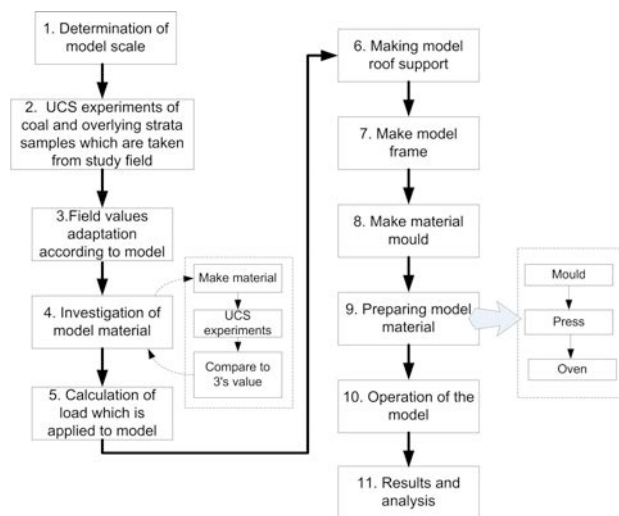


Figure 6. Flow Chart Studies



Figure 7. UCS experiments of coal sample (7×7×7 cm)

3.1. Determination of the Model Scale

In order to build a small-size physical model, scaling the geometry and strength of prototype is necessary. The model can only be designed when the effective parameters of the model and the prototype field is related to each other with a function. If the ratio of the functions of the prototype and the model is found, the following relation can be built in equation 1 (m in the equations defines the model).

$$\frac{\pi_1}{\pi_{1m}} = \frac{f(\pi_2, \pi_3, \dots, \pi_i, \dots, \pi_p)}{f(\pi_{2m}, \pi_{3m}, \dots, \pi_{im}, \dots, \pi_{pm})} \quad (1)$$

When model design is tested, it should satisfy equation 2.

$$\pi_2 = \pi_{2m}, \pi_3 = \pi_{3m}, \dots, \pi_i = \pi_{im}, \dots, \pi_p = \pi_{pm} \quad (2)$$

When the above conditions hold for all variables in the original dimension analysis, the model can provide a correct behavior of the prototype.

3.1.1. Geometric Scale Factor

The ratio of the distance between two points in the model (L_m) to the distance between two points in the prototype (L_p) should be constant. This is stated by equation 3. Geometric scale factor (I) is set to 1/10 thinking of

laboratory conditions and for visual reasons.

$$\frac{L_m}{L_p} = l \quad (3)$$

3.1.2 Strength Scale Factor

According to π theorem, $\pi_m = \pi_p$. Therefore, the following equalities can be expressed:

$$\frac{E_m}{E_p} = \frac{\sigma_m}{\sigma_p} = \frac{\gamma_m L_m}{\gamma_p L_p} \Rightarrow S = \gamma l \quad (4)$$

As equation 4 states, if we take the field material, decrease the granular size and use it in the model frame, density would be same and hence, geometric scale factor would be equal to strength scale factor. Since geometric scale factor is 1/10 in this study, strength scale factor would also be 1/10. But, if another material is used in the model, for example, calcite, which has a grain size between 100 and 500 microns (density 2,6 gr/cm³), then strength scale factors for the layers in the model would be;

For the coal layer on top of the roof support with density 1,36 gr/cm³:

$$S = \frac{2,6}{1,36} \times \frac{1}{10} = 0,191$$

For the claystone layer on top of the coal layer with density 2,5 gr/cm³:

$$S = \frac{2,6}{2,5} \times \frac{1}{10} = 0,104$$

Table 2. Strength of the layers in the model and the field

| Layer | UCS (In the field) (MPa) | Strength Scale Factor | (UCS) (In the model) (MPa) |
|----------------|--------------------------|-----------------------|----------------------------|
| Coal | 12,21 | 0,191 | 2,33 |
| Claystone (3a) | 20,84 | 0,104 | 2,17 |

3.2. Experiments to Determine Suitable Model Material

| | |
|----------------------------------|--------------------------|
| Material used | : Calcite |
| Grain size | : -100 micron |
| Calcite density | : 2,6 g/cm ³ |
| Na ₂ SiO ₃ | : 1,41 g/cm ³ |
| M _{mixture} | : 500 gr |
| Load | : 200 - 300 kg |
| Mould diameter | : 54 mm |

The proportion of binding material is determined to be 5%, 10%, 20% and 30%, respectively. The amount of binding in 5% mixture is computed as:

$$M_{\text{binding}} = 0,05 \times 500 = 25 \text{ g}$$

$$V_{\text{binding}} = 25 \text{ g} / 1,41 \text{ g/cm}^3 = 17,73 \text{ cm}^3$$

Material load pressure is computed as:

$$\text{Material Load Pressure} = 200 / 22,89 = 0,87 \text{ MPa}$$

Mould and material pictures are given in Figure 8.



Figure 8. Material mould

According to the results of experiments, the closest values to the field material are obtained by recipe 2. This mixture will be used in the physical model to represent the material in the field (Table 3).

Table3. Materials and strength parameters

| # | Binding % | Grain size μ | Material load, MPa | Time in the oven, h | Average UCS values MPa |
|---|-----------|------------------|--------------------|---------------------|------------------------|
| 1 | 10 | -100 | 0,87 | 12 | 3,28 |
| 2 | 5 | -100 | 0,87 | 2 | 2,59 |
| 3 | 5 | -100+500 | 1,31 | 12 | 4,27 |
| 4 | 20 | -100 | 1,31 | 24 | 7,56 |
| 5 | 20 | -100 | 0,87 | 24 | 5,48 |
| 6 | 30 | mixed | 0,87 | 4 | no value |
| 7 | 20 | mixed | 0,87 | 12 | 6,05 |
| 8 | 30 | -100 | 0,87 | 24 | no value |
| 9 | 10 | -100 | 0,87 | 2 | 3,29 |

3.3. Modeling Roof Support Studies

The first step in developing the model of the roof support is making the technical drawing of roof support in 1/25 scale. The roof support model out of carton is made in 1/10 scale (Figure 9). Then the roof support modeled with iron sheet, which has enough thickness resisting the model loads, is made using a lathing machine. All measurements on the roof support model is equal to 1/10th of real values. Dimensions of the roof support frame is 175×80cm in real, so it is 17,5×8cm in the model (Figure 9).

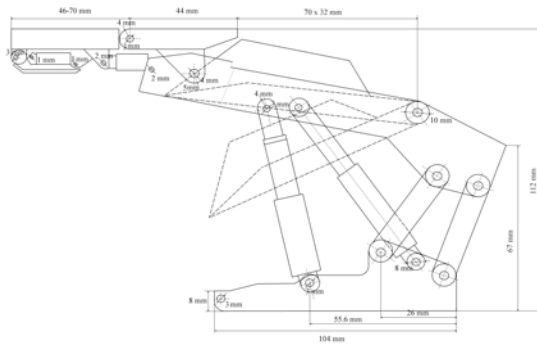


Figure 9. Model views roof support

3.4. Operation of the Model

In order to simulate the mine, model frame is built. Also, in order to represent the coal seam, a material mould of 55cm in height is built. Model material is made up according to recipe 2.



Figure 10. Mould is pressed and dried in the oven

The material mould given in Figure 10 is filled with the material prepared according to recipe 2. When preparing mixture 2, force of 200 kg is applied to 22,89 cm² of cross-sectional area. Therefore, material mould which has a cross-sectional area of 900 cm² is pressed by 7,8 t of force. Then it is left in the oven for 2 hours as recipe 2 states. As binding material used in the model mixture is 5%, the change in the density of the mixture is negligible. Therefore, the density is accepted to be 2,6 gr/cm³.

Material and binding amounts in the mould:

Volume of model material=60×60×15=54000 cm³
 Weight of model material=54000 cm³×2,6g/cm³=
 140,4 kg
 Weight of binding (%5) = 140,4 × 0,05 = 7,02 kg
 Volume of binding= 7,02 / 1,41 = 4,98 l.

After that, the mould is taken out from the oven, and put into the model frame. Model dimensions are 60×60×15 cm. Distance of 12 cm, which corresponds to two cuts in the mine, is marked on the base of the model frame. The roof support is pulled 12 cm in the direction of face advance. The material on top of the roof support was expected to cave in. However, at first trial caving did not occur. In fact, first trial turned out to be unsuccessful as the model frame and the loads flipped over. But, at least to see the next step of the experiment, the materials are collected and refilled to the model mould. The mould is placed on top of the roof supports. Then material is caved in from the mould. The materials coming from the frame of the roof support are collected and weighted (Figure 11, Figure 12).

The results achieved in the first trial are analyzed. According to the findings, model frame is revised and a second trial is made. Model material is remixed according to the second recipe. Then, the material is placed in the model frame and the roof support is pulled 12 cm. This time, the material caved in as expected.

The roof supports are pulled 12 cm at each cut and the material coming from the model frame is calculated at each cut.

As the time spent in the oven and the percentage of the binding material increases, the strength of model material increases. In addition, when the percentage of binding material is above 20%, the model material could not be removed out of the mould (Table 3). Therefore, the mould is left in the oven for 2 hours. Also, in order to represent the discontinuities in the coal, some holes are bored into the model material before putting it into the oven.

At the beginning of longwall production, a certain distance is required for the first breaking of the roof and the first caving. In order to represent this situation in the model, a free surface is formed at the back of the mould. After letting the free surface and 12 cm (first cut) out of the mould, the model material caved into the model frame (Figure 11, Figure 12).



Figure 11. Model frame

After the experiment, it is assumed that face coal production is 100% in the model frame. Coal efficiency is calculated according to the whole seam (Figure 13).



Figure 12. Operation of the physical model

Table 4. Coal Recoveries

| | Amount of Material (kg) | Amount coming from the window (kg) | Recovery according to top coal (%) | Over-all Recovery (%) |
|---------------------|-------------------------|------------------------------------|------------------------------------|-----------------------|
| 1 st Cut | 25,74 | 24,70 | 95,96 | 97,32 |
| 2 nd Cut | 25,74 | 16,17 | 62,83 | 75,36 |
| 3 rd Cut | 25,74 | 17,94 | 69,70 | 79,92 |
| 4 th Cut | 25,74 | 13,78 | 53,54 | 69,21 |
| 5 th Cut | 25,74 | 22,26 | 86,46 | 91,04 |
| Σ | 128,7 | 94,85 | 73,70 | 82,57 |

Production loss according to the whole seam (2nd experiment);

1st Cut: $24,70 + 13,10 \text{ kg} / (25,74 + 13,10) \text{ kg} = \% 97,32$

2nd Cut: $16,17 + 13,10 \text{ kg} / (25,74 + 13,10) \text{ kg} = \% 75,36$

3rd Cut: $17,94 + 13,10 \text{ kg} / (25,74 + 13,10) \text{ kg} = \% 79,92$

4th Cut: $13,78 + 13,10 \text{ kg} / (25,74 + 13,10) \text{ kg} = \% 69,21$

5th Cut: $22,26 + 13,10 \text{ kg} / (25,74 + 13,10) \text{ kg} = \% 91,04$

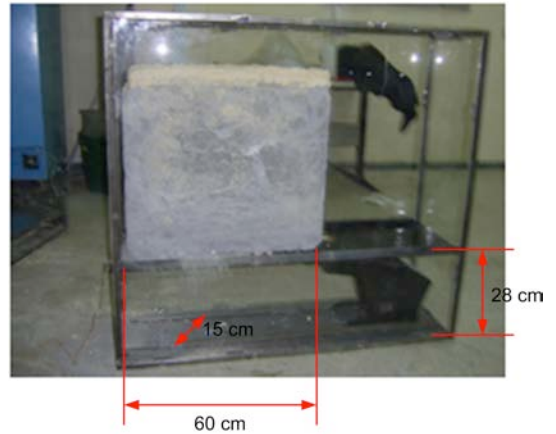


Figure 13. Calculations of material produced in the face

4. CONCLUSIONS

The results obtained from the second experiment are given in Table 4. According to top coal, average coal efficiency is found to be 73,70%. On the other hand, the efficiency is found to be 82,57% when face coal is also included in the calculations.

By field studies, the coal production efficiency is found to be 75,27% in top coal and 83,36% in total coal (Table 1).

Five experiments are done with the 1/10 scale model. In the first four of these experiments, the flow of experiment is not interfered at all. Model material caved in but not as much as desired. In the other experiments, discontinuities are formed in the model material and then, caving is observed. The values given in Table 4 belong to the last experiment. The values obtained from the previous experiments also support the results of the study.

After the experiments with 1/10 scale, another physical model with 1/20 scale and 4 roof supports is determined to be used. The time spent in the oven and the percentage of binding material is determined to be same as 1/10 scale model. In the first physical model, discontinuities are formed in the model material. In the second one, model material and the recipes will be similar to the first one. Since the behavior of top

coal is very important in this study, field conditions will be tried to be simulated even better. In the future studies, geometric scale factor can be 1/100 or 1/200. By this way, layers up to the surface can be simulated through physical modeling.

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