THE CRUSHING STRENGTH OF COAL,

AND THE

STRENGTH OF MINE PILLARS.

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Shaft Pillars.

In any system of coal mining it is necessary to leave an area of unworked coal immediately round the shaft, in order to prevent subsidence at the surface or damage to the workings at the shaft bottom.

The area to be left as a "shaft pillar" depends upon the space occupied by the mine buildings at the surface, the thickness, strength, and inclination of the seam, the depth, weight, and strength of the overburden, and the presence in it of faults, dykes, or other irregularities.

All these factors vary considerably, and it is impossible to embody them in a formula giving a solution for general use. Each case should be considered upon its own merits, and due regard should be paid to uncertainty caused by difficulty in ascertaining reliable information upon any of these points.

Formulæ which are given in textbooks or pocket-books do not agree with one another within very wide limits, and they either assume an *average* or *good* strength of coal and overburden or ignore these points. Most of them also ignore the effect of the thickness of the seam. Such formulæ are, therefore, unscientific, misleading, and apt to be dangerous.

Of those which take into account the thickness of the seam we have—

R. J. Foster's

$$\text{Radius} = 3\sqrt{\text{Depth of overburden} \times \text{thickness of seam}}.$$

(See Coal and Metal Miner's Pocket Book, p. 286.

*R. S. Kay's

$$\text{Radius} = \frac{\sqrt{3 \times \text{depth of overburden} \times \sqrt[3]{\text{thickness of seam.}}}}{0{\cdot}8}$$

Hughes (Textbook of Coal Mining, 3rd Ed., p. 149) says:—"It is impossible to give any general rule by which the size of shaft pillars for given depths may be determined. Everything depends upon the nature of the beds overlying the seam, the inclination of the strata, the nature of the floor and roof, and the question of stowing the excavation."

Mine Pillars.

The remarks just made apply with equal force to rules for the determination of the size and shape of mine pillars when working coal by any system in which the coal is first divided into square or rectangular blocks termed "pillars," which may or may not be removed subsequently by "robbing" or "working in the broken."

In the early days coal was chiefly obtained at or near the outcrop of the seam, where the weight of overburden was usually small. Thin pillars or "ribs" of coal of the minimum size deemed sufficient were left as permanent roof supports, without any idea of extracting them later on. When outcrop coal became scarce and deeper coal had to be worked, insufficient attention was given to the additional weight of overburden, and the pillar area left was frequently inadequate, in consequence of which many workings collapsed, or closed entirely by "creep" or "crush," causing loss of unworked coal and sometimes of life. Later, these pillars were made very large, and when formed were extracted or robbed as far as possible consistent with safety to life and property.

The minimum size of mine pillars for various depths of overburden is now regulated by the Government in all civilised countries. Such regulations are usually formulated after a careful revision of the practice found to be fairly safe in older countries or districts, but they are open to the same objections as have been urged against formulæ for shaft pillars, their chief defect being that they ignore the effect of the thickness and strength of the seam. Such regulations should err, if anything, upon the side of safety. But in the case of pillars which are not to be extracted, there is need for careful consideration of each problem on its own merits, to avoid needless sacrifice of valuable mineral or danger to life and property, and it is time that engineering consideration should be allowed to have due weight, and that such questions be considered from a more scientific standpoint than is customary.

* See Brough's Mine Surveying, p. 284.

In Appendix A, Report of the Royal Commission on Earth Subsidences at Newcastle (N.S.W. Government Printer, 1908, price 1s. 6d.), Mr. John Sulman refers to this matter as follows:—

" . . . . The suggestion that the strength of pillars might be ascertained by test and calculatoin in the same manner as supports are worked out in other branches of engineering evidently came as a new idea to the practical mine managers interested."

"It is admitted on all hands that the fixing of pillar sizes has been purely empirical."

"The subject appears to me to be worthy of investigation, and, if my ideas are sound, to be quite possible of solution. I do not wish to give the idea that scientific calculation can supercede practical knowledge, but I do maintain that it would be a most valuable accessory, and give mine managers and inspectors a method of checking the size of pillars and laying out of collieries, which they do not at present possess."

Mr. Sulman suggests that a special Board should be appointed to make the necessary preliminary inquiries, tests, and experiments, as this work would be long and somewhat expensive.

Crushing Strength of Coal.

When determining the dimensions of the simplest supports in engineering practice, it is necessary to know the strengths of the materials concerned and the stresses to which they may be subjected, as well as the manner in which those stresses will be applied. Until quite recently, however, coal miners have been content to work without knowledge of the crushing strength of coal, which is surely the most important of all data required for determining the most suitable size of mine pillar.

Data Available.

Some crude tests of anthracite coal were made by Mr. W. Griffiths, of Scranton, Pa., and are quoted in the Coal and Metal Miners' Pocket-book (1902 Ed., p. 290), which states that these are (in 1902) "the only data available as to the crushing strength of anthracite coal."

In 1903 the Scranton Engineers Club published the results of some 400 tests of coal from various parts of the Pennsylvanian anthracite coalfield, with a view to determining the strength of anthracite pillars. (See "Mines and Minerals," p. 368, March, 1903).

Recently Messrs. Daniels and Mocre ("Eng. and Mining Journal," August 10th, 1907, p. 263) have published the results of some 45 tests upon anthracite samples and 12 tests of bituminous coal.

These tests are considered fuller further on (see pp. 31 and 32), in conjunction with those upon lignite from the Taupiri collieries, New Zealand.

General Review of the Position with Regard to Coal Mining.

It is evidently an exceptional occurrence for a colliery manager to trouble to ascertain the strength of his coal, and probably few have figured out the weight of overburden which the pillars may have to support when fully loaded.

In early methods of pillar mining, the pillars were left standing until such time as the drivages had been advanced to the boundaries of the colliery, after which the miners "robbed" the pillars as they worked back from the boundary to the shaft. In this way falls of roof did not endanger the travelling roads and haulage ways.

Fretting.

If such pillars be too small, then, with hard strata above and below the seam, the weight of overburen cracks the pillars, and the free faces give evidence of this by the phenomenon known as "fretting," *i.e.*, pieces of coal break off the sides with a cracking and rending noise, and cracks appear in various directions in the pillar.

Fretting seriously diminishes the quantity of "round" or lump coal derived from the pillars when they are "robbed," and is also proof that the breaking load for the coal has been passed.

Crushes.

If the pillar area be more inadequate still, the pillars crush and crumble to pieces, and the workings collapse, and even if it were possible to extract the crushed coal it would be an unprofitable product. Much coal has been lost by "crushes," and in order to avoid this, many collieries are worked upon systems in which the pillars are attaacked soon after they have been formed. In the case of deep workings, the great weight of overburden renders it absolutely necessary to adopt some system of this sort, unless longwall working is applicable.

Where the roof is not quite strong enough for the width of excavation made (bords and walls), timbering becomes expensive, and it is then advisable to decrease the width of the workings and increase the size of the pillars in order to reduce the timber bill. This narrow work is more expensive as regards the actual mining or cutting of the excavations, but a net reduction per ton of coal mined is effected.

Mr. F. Danvers Power ("Aus. Mining Standard," August 5th, 1908, p. 160), in describing the methods of working at the Metropolitan Colliery, Helensburgh, New South Wales, calls attention to this. The cover is from 1,100 to 1,500 feet thick, and where the roof is bad two narrow (4yd.) bords, separated by a 24yd. pillar, are driven, instead of one wide bord of 10 yards. The main pillar is also increased from 50 to 100 yards in width. Calculating from the dimensions given, the pillar area in the old method works out at 80.6 per cent., and in the newer method 88.8 per cent. of the whole.

"Squeeze," "Thrust," and "Creep."

When the stratum above or below the seam is softer than the coal, the pressure due to the overburden pushes the pillars bodily into the soft stratum, and the roof appears to squeeze down ("thrust") or the floor to swell up ("creep") into the workings, and in this way a "squeeze" may completely close up the principal workings, in which case the coal in the area concerned is usually lost, since any fresh openings made would close up more rapidly than the first, owing to the further reduction of pillar support. F. W. Parsons ("Eng. and Mining Jour.," 23rd March, 1907, p. 557) describes a recent squeeze, which resulted in the loss of 320 acres of a 5½ft. seam, which rested upon a soft clay. Hughes (p. 149), instances a case where a shaft pillar 260 yards by 800 yards was insufficient, and great difficulty was experienced in securing the pit arch at the shaft bottom.

Effect of Size of Area Opened Up.

When the area opened up by pillaring is small, and the overhead strata are strong, the overburden tends to arch, and so relieves the pillars from a great portion of the weight. But where the area opened up is large, the pillars eventually have to support the whole weight. In the case of inclined strata, the pressure would be less, being equal to the weight of overburden multiplied by the cosine of the angle of dip of the seam.

As the pillared area increases, the relief due to arching or dome action diminishes, until we finally obtain a central area in which there is no such relief, the pillars having to support the whole weight of overburden. Round the sides of this central area the roof gives some relief by cantilever action, which diminishes as the pillared area increases.

Hence it is unsafe to infer that pillars which stand well in the early years of a mine's life will suffice later on, when the maximum loading is reached owing to the absence of relief by arching or cantilever action.

In outcrop workings the relief is only by cantilever action; and in the case of an isolated hill there would be little or no relief, and the pillars would have to bear their maximum load at an early period of their history, as is pointed out in the Report of the Royal Commission already referred to. (Par. 87, p. 22).

Faults, dykes, and other interruptions to the continuity of the strata would seriously diminish relief action, and as we cannot foretell their positions or effect it would be best to ignore relief action altogether when deciding upon the size of pillars which are to stand for some considerable time.

In the hurry to obtain dividends, however, managers have every inducement to make openings of the maximum dimensions, so as to obtain a large output in the early stages, without proper forethought of the possible loss due to squeezes, fretting, and crushes as the weight settles down with the development of the colliery. As has already been stated, loss of coal in this way has already led to the adoption of methods in which pillars are never left standing for long, but are attacked soon after they have been formed.

Necessity for Early Extraction of Pillars in Deep Mining.

When we consider how unreliable arching or cantilever action may be, it is evident that pillars should be quickly extracted when working at great depths (and if possible longwall working should be adopted instead), for, if we assume the convenient average of 144lbs. weight per cubic foot for the rocks forming the overburden (N.B.—Weight of one cubic foot of sandstone=151lbs.; shale=162lbs.; limestone (compact, hard)=168lbs.; clay=120-130; gravel=100-120; earth (packed) =90-100—see Trautwine), then every 1ft. depth of overburden causes a pressure of 1lb. per square inch of surface beneath it. Bituminous coal, with a crushing strength of 1,100lbs. per square inch, could not be left as pillars for long if the depth of overburden were 1,000ft., because if we left upwards of 90 per cent. of the coal as pillar area the loading would still exceed the crushing strength of the coal.

Stress = 1,000 ÷ 90 x 100 = 1,111lbs. per square inch.

In "Practical Coal Mining" (Gresham Pub. Co.), Vol. II., p. 303, this is expressed as follows:—"At a depth of 1,500ft. and over, the limit of tension of the coal is passed, and any pillars left in are crushed." What is meant, however, is that the limit of *compression* is passed.

Strength of Mine Pillars.

In the case of the subsidence at Newcastle, it appears to have been impossible to obtain samples of the coal from the faulty workings in order to test them, such workings being inaccessible; but, in the Commissioner's Report, p. 22, par. 86, a strength of 1,000lbs. is assumed for the top band of coal, which was the weakest. With 60 per cent. left as pillar area and 350ft. of cover, the load per square inch of pillar area would be

$$\frac{350 \times 100}{60} = 583\text{lbs.}$$

which gives a factor of safety less than 2, if the strength of the coal be 1,000lbs., as assumed.

The Report states this in a slightly different way, viz.: "If the crushing strength be taken at 1,000lbs., less 40 per cent. excavated, there would be left, say, 600lbs. pillar resistance to a static load of 350 to 450lbs."

There is no doubt that, as the top coal is tender, the value assumed for it is high, since good bituminous coal is only 1,106lbs. (see p. 32), so that the factor of safety is too low for mining under a town.

When one considers that in the early days the workings were probably not laid out with the same regularity as at present, that the 18-foot seam contains a tender 3ft. 7in. band (see sketch in Appendix to the Report), which was probably unequal to a pressure of 1,000lbs. to the square inch, and that there were other old workings in seams above, a factor of safety below two seems ridiculously low for working under an important city.

Subsidence.

In addition to loss of coal through crushes and squeezes, the question of subsidence at the surface must also be considered, for in many cases this entails compensation to the owners of property.

If subsidence be slow and regular, no serious damage will result as a rule. It is therefore important that the robbing of pillars should be conducted in such a way as to advance the line of the working faces systematically and regularly, in which case it is comparable with longwall methods. With regular working, it is often possible for the overburden to accommodate itself to its new position by bending and settling gradually with little or no fracture. (See Brough's "Mine Surveying, 10th Ed., p. 280).

Regularity of output is important, and cessation of work for any lengthy period is most serious, as it interrupts the slow wave of subsidence, and may cause fracture extending to the surface.

Similarly, gradual subsidence is caused by the mining of some metalliferous deposits. Precise levelling by the U.S. Geological Survey has shown that a gradual subsidence is taking place over the undermined area at Butte, Montana. During 1904-6 three important bench marks subsided at the rate of 0.218, 0.368, and 0.444ft. per annum, the amount increasing as the underground workings were approached. (See "Mining and Scientific Press," April 11, 1908, p. 493).

Caving or Doming.

When a fall of roof takes place, the strata above, if fairly strong, like sandstone, compact limestone or shale, tend to fall in such a way as to leave a dome-shaped cavity, which is nearly filled with the fragments. Speaking of the copper mines of Butte, Montana, C. T. Rice says ("Eng. and Mining Jour.," April 6th, 1907, p. 676):—"I haave been in several caved stopes, and have in all of them been able to worm my way to the top of the pile of caving, where in every case a dome-like cavity remained."

"It will probably be found that the crushing and transverse strengths of the rock are the main factors in determining the shape of the arch, and possibly it may be well to have crushing tests made on the rock."

In some of the Butte mines "the stopes cave without any warning, and kill many men," and this he attributes to the roof having approached an unsuspected fault, and advises that the important faultings about a mine should be studied, with a view to preparing for possible caving.

The recent disaster at Mt. Morgan, about October, 1908, by which seven men lost their lives, owing to the fall of a large mass of ore, appears to have been due to an unsuspected head or joint running through the ore body horizontally, and extending to a large vertical dyke, on both sides of which the working chambers extend.

The chamber method of mining this portion of the deposit is described by J. Bowie Wilson, B.E., "Aus. Mining Standard," August 26, 1908, p. 233, and again in greater detail by Gerard W. Williams, "Eng. and Min. Journal," March 27th, 1909, p. 635.

The nature and shape of caving domes has been studied by M. Fayol, whose conclusions are given in Hughes' Coal Mining (p. 150).

Alex. Richardson ("Jour. Chem., Met., and Min. Soc. of South Africa," March, 1907; also abstract in "Eng. and Mining Jour.," August 3rd, 1907, p. 196) discusses the direction of the possible fracture due to subsidence in the Rand mines, and the proper location of pillars to prevent surface damage.

He states that, according to M. Fayol, when sandstone (and presumably also when other strong material) predominates in the strata, and for excavations of large area, subsidence should not extend to a height exceeding 200 times the height of the excavation. But Richardson proceeds to instance cases of subsidence of from 6 to 10 feet caused by colliery workings at a depth of from 1,800 to 2,400 feet. Also workings at 2,500ft. in the Midlands and South Yorkshire which cause appreciable subsidences at the surface. On the other hand, Newstead

Abbey is instanced as having been undermined by longwall workings in a 3ft. 8in. seam at a depth of 1,680ft., no damage resulting from the regular subsidence of 23in. Also, at Sunderland, where the cover contains 50 per cent. of hard rock (limestone, shale, etc.), workings at 1,400 to 1,800 feet are prosecuted without reference to the surface.

Clearly then, in the matter of subsidence, the chief factor is the character of the overburden and the presence in it of faults, dykes, or other interruptions to its continuity.

Richardson (loc. cit.) calculates the proportion of the area to be left as pillars supporting the overburden. The Johannesburg Municipality tested the strength of local quartzite ore from various mines, the mean result being 7,521lbs. per square inch, though this was certainly low, because of the difficulty in chiselling flat surfaces on the blocks upon which to apply the pressure. In some experiments sand was used to distribute the pressure, but in others steel surfaces were used. 16,000lbs. per square inch was assumed as the probable true value. It would have been preferable to have cut surfaces by means of lapidary wheels, using carborundum powder. The results obtained would then have been approximately true, whereas no one pretends that the figures employed (viz., 16,000lbs. per sq. in.) are other than an assumed value.

The Case of Ralph's Mine, Huntly, New Zealand.

The case of Ralph's mine is interesting in that, so far as I am aware, it is the first case on record in which the safety of the mine has been decided by judicial procedure, which hinged upon the strength of the coal in the pillars and the weight and nature of the overburden. There were other points of interest, but the chief one was the strength of the pillars, and this drew my attention to the remarkable scarcity of information upon the subject.

Ralph's mine is situated at Huntly, on the Waikato River, about 60 miles south of Auckland. The greater part of the workings are on the western side of the river, but the two shafts required by law are upon the eastern side, along which runs the Government railway, by which the coal is shipped to Auckland. It is a lignite of excellent quality, and is preferred to other local coals for household purposes, selling at 30s. per ton. The river is only a few chains from the shafts, and is about 11 chains wide, so that the main workings, which extend 90 chains westwards from the shafts, are mostly on the other side.

The Chief Inspector for the Auckland district alleged that the workings were unsafe, by reason of the river which flows overhead, and the Mines Department, on his recommendation, required the company to put down a third shaft on the western side of the river as an additional means of escape for the men