in the event of the river making its way into the workings. The company considered its workings perfectly safe, and objected to comply with the requisition, and in a dispute of this by arbitration, each side appointing an arbitrator, and a Judge umpire. This was the first arbitration case held under the Act. It was heard in September, 1907, before Mr. Justice Denniston, who, together with the arbitrators, visited the workings of the mine before the case began.

In giving evidence, the late Chief Inspector for the Auckland district stated that if anything went wrong with the workings, assuming such a subsidence as would let in water, there would be little chance of the workmen escaping, and therefore there ought to be an outlet shaft on the other side of the river. In January, 1907, the pillars in one part of the mine under the river had "fretted" for about two weeks, this being the first occurrence of the kind in the mine. The fretting was accompanied by crackling noises, and large flakes of coal split off from the sides of the pillars. The pillars had been reduced by this, and the material of which they were composed had perished considerably. Timber had been put in in compliance with his requisition to keep large flakes from falling, but he considered the "bords" should be filled in to half their height by mullock to make them safer.

(N.B.—Under the river the seam is from 30 to 50 feet thick. The bottom 20ft. only is worked, from 9 to 30 feet of coal being left to support the fireclay roof. The bords are thus 20ft. high, and their width is 14ft.

Cross-examined: He had not tested the strength of the coal nor calculated the strength of the pillars, and did not think anyone could, nor the load they could support, and he could not give the safety factor (!). If the pillars got weaker a "crush" might come suddenly, and there would be no chance for anyone, as he believed there was running sand right down to the coal level. The presence of clay strata would make a difference.

The Assistant Inspector agreed with these opinions, and further stated that the pillars might give no warning before they collapsed (!) Neither of these gentlemen were able to give information concerning the important under sea workings at Newcastle, New South Wales, or the special conditions under which they are worked.

The evidence on behalf of the company showed that the seam is from 35 to 55 feet in thickness. The boring contractors results showed that the overburden consisted of 80ft. or so of fireclay, and above this up to 118ft. or more of more recent clays, alternating with gravels and coarse sand.

The mine is worked on the pillar and bord system, and at least 9ft. of roof coal is always left to support the fireclay above. In the workings under the river bore holes were put up into the roof at intervals of five yards to ascertain the thickness left. Where the fretting disturbance occurred there would be about 30ft. of roof coal. The pillars are 82ft. long, 24ft. wide, bords 14ft. wide (a series of measurements showed the bords to be only 13½ft. wide at the place of disturbance). and "cut-throughs" are 8ft. wide.

The mine manager, Mr. E. S. Wight, gave evidence of his experience of undersea workings in England and at Newcastle, New South Wales, and cited subsidences which were not attended by an influx of water, clay strata being chiefly responsible in preventing this. Quotations were made from a paper by Mr. A. A. Atkinson, Chief Inspector of Coal Mines for New South Wales ("North of Eng. Inst. of Mining Engineers," Vol. XXIII.), describing the working of ocean colleries in New South Wales and elsewhere.

Mr. Wight had tested 1in. cubes of coal from the mine, and found them to be unaffected by a weight of 1 ton (2,240lbs.). The weight of overburden per square foot of pillar area at 160ft. depth he estimated at 28,858lbs., or about 200lbs. per square inch, giving a factor of safety of at least 11. The area affected by flaking or fretting was opened out seven years ago, and no robbing of pillars is proceeding there or at any other part of the mine. The proposed new shaft might be of use in the case of an explosion, but the mine is not gassy and naked lights are used. In the case of an inundation of western workings the proposed shaft would be flooded first, as the seam dips slightly westwards.

Mr. F. A. Riche, B.Sc.,* and the author, described tests which they performed conjointly upon samples taken from the worst of the pillars complained of. One-inch cubes were unaffected by a load of 2,240lbs. applied perpendicularly to the bedding plane, and as this was the sum total of the weights available it became necessary to cut smaller specimens in order to ascertain the breaking or crushing load. Cubes with ¾-inch sides were therefore cut, using a fine saw. These were tested in the same way as the 1-inch cubes (for method see p. 25), and bore a weight of 14cwt., or 2,785lbs. per square inch, at which load a slight crackling sound could be detected, and some of the specimens showed slight cracks as the loading was further increased. All the ¾-inch cubes carried the full 20cwt., or 3,980lbs. per square inch, wihout crushing, only slight cracks being visible after five minutes of this load. The specimens were exhibited in Court. There is no testing machine in Auckland, and the crushing strength of the coal was not known until tests had been made in Sydney (after the Court's decision had been announced).

The factor of safety for the pillars varies with the proportion of coal left as pillars, and with the thickness and specific

* Of the Californian State University.

gravity assumed for the overhead strata and the strength of the coal as found. In this case the strata are known approximately by two bores, which were put down one at either side of the river. The mean of the results was used. The method of calculation adopted was as follows:—

Calculation of Load upon the Pillars.

Where the disturbance was greatest (under the river) there is approximately 150ft. of cover.

Strata.	Weight per cubic feet.	Total per sq. ft.
Water, 16ft., @	62.5lbs. ..	1,000lbs.
Mud, say, 20ft., @	110lbs. ..	2,200lbs.
Fireclay and gravels, 84ft., @ ..	130lbs. ..	10,920lbs.
Roof coal, 30ft., @	75lbs. ..	2,250lbs.
Total weight = ...		16,370lbs.
		or 114lbs. per square in.

Proportion of Area Left as Pillars.

The above weight is supported by pillars, which are the following fraction of the original area, viz.—

$$\frac{24 \times 82}{38 \times 90} = 0.576$$

The pressure per unit area of the pillars is therefore—

16,370 ÷ 0.576 = 284,200lbs. per suqare foot.
Or 114 ÷ 0.576 = 198lbs. per square inch.

Factor of Safety.

Taking the load at which slight crackling was detected, viz., 2,785lbs. per square inch, the factor is 2,785 ÷ 198 = 14.5. Taking the higher load at which none of the speicmens crumbled or failed beyond slight cracking, 3,980lbs. per square inch, the factor is 3,980 ÷ 198 = 20.

Method of Testing the Coal.

Test Pieces.—As already stated, these were cut from material which had fretted and fallen from the worst of the pillars. It would seem reasonable to suppose that the results would be lower than those obtainable from "run-of-mine" coal. Time did not permit of this being tested by experiment, as the crucial tests were performed in the early morning before the Court sat, and sittings were prolonged into the evening to expedite business. Subsequent tests (p. 29) showed the true factors at initial failure to be 12.7 and 23.9 for fretted lignite and 17.2 and 27.3 for "run-of-mine" lignite.

Method of Testing.—**The method was that devised by the** mine manager, Mr. E. S. Wight. Vertical guides were fixed on the outside of the office wall. so as to keep a double column of rectangular 56lbs. weights steady and vertical when built upon a base board placed on top of the specimen of coal. The bottom of the guides rested upon one of the large foundation timbers of the building. Two pieces of kauri pine, about 1½in. thick, were cut to fit the space between the guides. The bearing surface of each was planed, and diagonals were drawn across to find the centre. One such board was placed at the bottom of the space between the guides and the specimen put on the centre of it. The top board was then put on top of the specimen in a similar way, and on this the weights were placed in pairs, care being taken to allow both weights to begin to bear at the same time. After 10cwt. had been built up, the weights were put on, one at a time, the slight eccentricity of loading temporarily caused being assumed to be negligable.

Mr. Riche gave the factor of safety as 19, calculating upon the coal sustaining 3,980lbs. per square inch without failing, and the author quoted a factor of 14, as the result obtained by using the lower figure of 2,785lbs. per square inch, at which load slight crackling was always detected.

Where you are concerned merely with the support of the roof. and do not intend to rob the pillars afterwards, the crushing weight would be employed in the calculation; but where it is intended to rob the pillars subsequently, the first indication of failure would be taken. as it is important to keep the coal in the best possible condition, so as to avoid any possibility of crushing prior to extracting the pillars. In the present instance there is no intention to extract the pillars afterwards, as so much of the area is under water; but, in my opinion, this fact also makes it advisable to use the breaking weight when calculating the factor of safety. However, Mr. Riche considered that the nature of the overhead strata was such as to practically nullify the danger from water, and hence his use of the higher figure (which is still *below* the crushing weight) for the strength of the coal.

It is important to remember that alluvial strata are subject to variations. We might find, for instance, a run of gravel extending almost down to the coal, as supposed by the inspector, although bores at various places on the property have not discovered any such run of gravel. In the present instance, in order to show that the work was being carried out under the safest possible conditions, I used the lower figure, 2,785lbs. per square inch, which still gave the high factor of safety. 14.

This is higher than would be the case if the pillars were of the minimum size required by law in the under-sea collieries at Newcastle, New South Wales. With 120ft. minimum cover of sandstone, the pillars must be at least 24 by 72 feet, with bords and cut-throughs not more than 18ft. wide. (See New South Wales Department of Mines Report for 1905, p. 119, Special Regulations for the working of ocean collieries.)

The proportion of pillar area required is, therefore—

$$\frac{24 \times 72}{42 \times 90} = .457 \text{ of the original area.}$$

Against

$$\frac{24 \times 82}{38 \times 90} = .576 \text{ of the original area, as at Ralph's mine.}$$

Newcastle mine managers leave more than the minimum, but we were concerned with the minimum required by the New South Wales regulations.

Nature of the Overburden.

In the Newcastle, New South Wales, collieries trouble has been occasioned in the past by leaks, due in some measure to the presence of small faults and volcanic dykes in the sandstone roof, and in one instance the flow of water was stopped by damming the section off. For an underwater colliery, fireclay is a much better cover than sandstone, being an ideal water barrier. Its effect as a stopping is evident in many small cracks and crevices and a few small hitches in Ralph's mine.

Cause of the Fretting Disturbance.

Much was made of the "fretting" of a few of the pillars as an indication that they were unreliable. The departmental witnesses attributed this fretting to a variety of causes.

1. The rapid weathering of lignite. This was combated by the fact that the coal used in the tests was some of that which had fretted and fallen from the worst of the pillars.
2. The extra loading due to river being in flood. The rise of 10ft. or so could only produce an extra 3 per cent. of loading, which is negligable.
3. The chief cause was held to be changes in temperature, due to fresh ventilation currents after the air had been practically at rest in these workings for some years. No fretting occurs, however, in workings along which steam-pipes run to supply a small pump, though the temperature and moisture variations there are considerable.

The mine manager advanced the theory that an earth tremor was responsible for the disturbance.

It is more probable, however, that slow earth movements were responsible for the disturbance, which came on gradually and passed off gradually. The flaking eventually reduced the size of the pillars by about six inches all round on the average, and less than a dozen pillars were affected to this extent. It has been shown that the pillars are easily capable of supporting the small overburden, and it appears to me that the only way to account for the disturbance is to suppose a local upward movement of the strata below the coal. An upward movement would be resisted by the coherence, inertia, and weight of the overburden, with the result that the coal would be subjected to stresses gradually increasing to a maximum, and then falling off as the superincumbent strata gave way sufficiently to ease the pressure. The amount of bending would be inappreciable. Permanent bench marks had not been placed in the workings, so it was impossible to test this theory by a survey. as the movement would almost certainly be too small to detect without the presence of bench marks..

This was the only theory by which I could account for a strain sufficient to cause flaking. An earth tremor might assist in starting such a movement, but would not of itself account for a purely local disturbance, which slowly worked up to a maximum and gradually subsided—taking several weeks in all.

Possibility of Inundation.

Regarding the possibility of an inundation. a simple calculation shows that if it were possible for the pillars to collapse completely, and spread out so as to fill the bords, the total subsidence would only average six feet. The subsidence would be less above the centre of each pillar and more above the bords and cut-throughs; but with from 9 to 30 feet of roof coal, this inequality would not be great. In any case, the fireclay cover, 80ft. thick, would almost certainly accommodate itself to the movements at once, and prevent an influx of water.

The calculation for subsidence is as follows:—

Cubical contents of a pillar $= 24 \times 82 \times 21$ c. ft.

Add at least 25 per cent. for increased space occupied by the crushed material, and the new volome .. $= 24 \times 82 \times 21 \times 1.25$ cu. ft.

Distribute this over a new base, 90ft. x 38ft., and the height will .. .. .. $= \dfrac{24 \times 82 \times 21 \times 1.25}{90 \times 38}$ ft.

$= 15.1$ ft.

Total fall (average) .. $= 21 - 15 = 6$ft.

The Award.

The arbitrators disagreed upon some of the points raised, and the matter thus became one for the decision of the umpire. About two months after the case, Mr. Justice Denniston filed an award completely in favour of the company.

Commenting upon the evidence, his Honour said:—"The whole of the scientific and expert evidence is to the effect that the mine, though under the river, is one of the safest in the world." (See "N.Z. Mining Record." XI., No. 5, p 231, December 16, 1907).

Further Tests of the Taupiri Lignite.

The safety of Ralph's mine having been satisfactorily settled as far as the Taupiri Coal Mines, Ltd., were concerned, I was still anxious to know the crushing strength of good and fretted lignite, for we had been unable to fracture our specimens.

By the kind permission of Professor Warren. Mr. A. J. Gibson tested four one-inch cubes of good "run-of-mine" lignite and six one-inch cubes of fretted material. Subsequently Mr. Morrison tested five other specimens of special shape. I desire to thank these gentlemen for their kindness, and for the care and trouble which they have taken. The results are summarised in Table I., and the details are given in Appendices A. and B.

TABLE I.

Giving Summary of Tests upon Taupiri Lignite (See Appendix), from Ralph's Mine, Huntly, N.Z.

From	Size.	No. of Tests.	Fretting Load per sq. in.	Crushing Load per sq. in.
Good run of mine material	1 x 1 x 1 in. high	4	3,410 lbs.	5,405 lbs.
Fretted material	1 x 1 x 1 in. high	6	2,520 lbs.	4,738 lbs.
	The above tests are those made by Mr. A. J. Gibson, A.M.I.C.E.			
Good run of mine material.	$1\frac{3}{4}$ x $1\frac{3}{4}$ x 1in high	1	1,862 lbs. and 3,270 lbs.	5,560 lbs.
ditto.	$2\frac{3}{4}$ x $2\frac{3}{4}$ x 1in. high	2	2,192 lbs. and 4,062 lbs.	6,380 lbs.
ditto.	4 x 1·2 x 1in. high	2	1,015 lbs. and 2,595 lbs.	4,145 lbs.
	N.B.—In column 4 (fretting load) the first figures are those at which crackling began. The second figures given are the loads at which small pieces began to flake off the sides or edges of the specimens. The above are tests made by Mr. Morrison.			

The machine employed was rather large for the work, being a 100,000lb. Greenwood and Bathby machine, but the results, as given in Appendices A. and B., do not seem to me to be unduly irregular, especially when the double journey is considered from Huntly to Auckland, and thence to Sydney.

From these tests the "fretting" load for good lignite averages 3,410lbs. per square inch, and the "crushing" strength 5,405lbs. per square inch (as determined from four good one-inch cubes), the corresponding figures for "fretted" material being 2,520lbs. and 4,738lbs. respectively.

Using these figures for the determination of the factor of safety, we get:—

For Good Lignite—

$$\frac{\text{Fretting load} \quad .. \quad 3{,}410}{\text{Overburden} \quad .. \quad 198} = 17.2$$

$$\frac{\text{Crushing load} \quad .. \quad 5{,}405}{\text{Overburden} \quad .. \quad 198} = 27.3$$

For Fretted Lignite—

$$\frac{\text{Fretting load} \quad .. \quad 2{,}520}{\text{Overburden} \quad .. \quad 198} = 12.7$$

$$\frac{\text{Crushing load} \quad .. \quad 4{,}738}{\text{Overburden} \quad .. \quad 198} = 23.9$$

These factors of safety are higher than those from our tests at Huntly, since we had not sufficient weights available to fracture the specimens.

It is remarkable that lignite, which is supposed to be such a weak material, should have a strength so much greater than that of the bituminous coal mentioned on p. 33, and not far short of good anthacite. (See p. 31, Table II.).

Effect of the Shape of the Test Pieces.

The typical pyramidal form of failure noticed by Mr. Gibson, has an angle of 20 to 30 degrees at the base, and this at once suggested to me further tests upon square blocks of such a size that the apexes of the pyramids of failure would coincide.

With an angle of 20deg. at the base, this requires a block 2¾ x 2¾ x 1 inch; with 30deg. as the angle, the block would require to be $1\frac{3}{4}$ x $1\frac{3}{4}$ x 1 inch. Three of the first size and two of the second were obtained, but unfortunately one of each reached Sydney damaged in transit.

At the same time two blocks were cut of the same proportions as the mine pillaars, viz., 4in. x 1.2in. x 1in. high.

When comparing these with previous tests, some slight allowance must be made for the fact that these specimens were cut in March, but could not be tested until July, by which time they may have deteriorated slightly, though the packages were not opened until the machine was available, see Table I.

It is interesting to note that the blocks representing the mine pillars show less strength than the 1in. cubes, though they still give a factor of safety of $4.145 \div 198 = 20.9$, which is more than ample. The 1in. cubes are less strong than the $1\frac{3}{4}$in. square blocks, and these again are less strong than the $2\frac{3}{4}$in. square blocks, as was expected.

From this I conclude that for the same area of base, square pillars are stronger than rectangular ones, and that the larger the base the greater will be the resistance to crushing. Also that the height of the seam is the chief dimension affecting the strength of the pillars.

Strength of Anthracite and Anthracite Pillars.

When the safety of the pillars of Ralph's mine was in question, the only data which I possessed as to the strength of coals was that given in the "Coal and Metal Miners' Pocket-book" (7th Ed., 1902, p. 290). On p. 290 we have the results of tests by Mr. W. Griffiths upon 11 specimens of widely different dimensions. The variation is so great that it is impossible to state what the crushing strength is, but it is noticeable that the crushing weight decreased from 3.4 to 0.8 tons per square inch of base area as the height increased from $1\frac{1}{2}$ to 6 inches, thus confirming the view that height is the most important dimension of a pillar.

In 1900 the Scranton Engineers' Club (Scranton, Pa.) appointed a special committee to investigate the strength of anthracite coal, particularly with reference to the northern Pennsylvania field One hundred and thirty-three samples were tested at Cornell University, 177 at Lehigh University, and 113 at the Pennsylvania State College. The results, together with the committee's deductions, were published in Mines and Minerals for March, 1903. I include a short summary of the figures, which are of great importance. The averages of the results given are in lbs per square inch of base area, as follows:—