

THESIS FOR THE DEGREE OF PH.D.

MINING SUBSIDENCE.

An Investigation of: (at the surface)

Draw.

The Relation between Draw and the Direction of Advance.
 The Relation between Draw and the Direction of Cleavage.
 The Relation between Draw and the Thickness of Deposit
 extracted.

Amplitude of Subsidence.

The Horizontal, Tensile, and Compressive Stresses caused by
 Subsidence.

Lateral and Longitudinal Movement.

An Investigation of: (underground)

'Underdraw'

Coal Compression.

Lateral Extension of the Coal Stratum towards the Waste.

The Horizontal, Tensile and Compressive Stresses Induced
 in the bed overlying the Coal Seam by the General
 Subsidence of the superincumbent strata.

Pack Compression.

by

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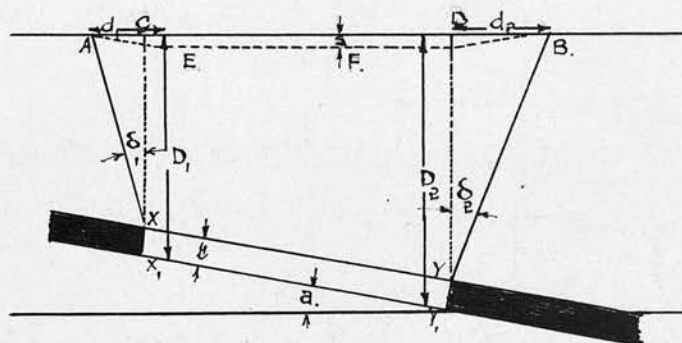
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TERMINOLOGY AND NOTATION.



-Idealized Vertical Section illustrating-
 Subsidence - Fig. N°1-

Figure No. 1. is an idealized section illustrating subsidence due to mining a bed or seam of minerals. The effect on the strata overlying the seam is not shown. The inclination of the bed is called the dip and is indicated by α .

The thickness of the bed, t , is the distance from its roof and its floor, measured at right angles to the plane of stratification.

The portion XYX_1 has been removed, and the settlement of the superincumbent beds has caused the surface to subside over the distance AB .

$ACBD$ is the original surface, and $A'EFB$ the surface after subsidence.

The subsiding strata are superjacent with reference to the seam, and subjacent with reference to the surface.

The edges of the unworked parts, namely XX_1 and YY_1 are called faces, and sometimes ribsides. A face advancing from $Y_1 - X_1$ is a rise face; a face advancing from $X_1 - Y_1$ is a dip face.

D_1 is the depth of a rise face, and D_2 that of a dip face.

If F is a point on the surface where settlement is complete - the ground there having again reached stability - the extent of vertical displacement, S , is spoken of as the amplitude of subsidence.

A line, such as AX , joining the face XX_1 and the surface point at the edge of the subsided area is termed a limiting line.

XC being a vertical, the horizontal distance at the surface between AC is the DRAW.

If A should lie between C and D , the draw is regarded as negative.

The/

The angle AXC (δ_1) is the angle of draw to the rise.

The angle BYD (δ_2) is the angle of draw to the dip,

$$\text{whence } d_1 = D_1 \tan \delta_1$$

$$\text{and } d_2 = D_2 \tan \delta_2$$

The area of mineral removed, of which X_1Y_1 is a diameter, is the mined area, and is sometimes referred to as the excavated area.

The surface area affected by subsidence is the area of settlement.

When the surface over the mined area moves in a horizontal direction, and parallel to the line of face, the movement is spoken of as lateral movement.

When the surface over the mined area moves in a horizontal direction and parallel to the direction of advance of the face, the movement is spoken of as longitudinal movement.

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INTRODUCTION.

I N T R O D U C T I O N.

Subsidence and its effects are matters of concern to Local Authorities, Public Utility Companies, Property Owners, Civil Engineers, Builders and Architects.

To the mining industry it is a matter of extreme importance. Financial compensation for damage caused by mining subsidence is a heavy burden on the mining industry, while the Authorities mentioned in the first paragraph annually spend large sums of money repairing the damage caused by the process.

Ignorance of the effects of mining subsidence has prevented the systematic exploitation of many areas of coal; and it is gratifying to learn that property owners and mining engineers are now allowing the complete extraction of coal seams (by the longwall method) under property where formerly they stipulated in their leases that protective pillars had to be left.

From the economic side, further research with a view to reducing the compensation for damage caused by subsidence is justified, while from the academic point of view mining scientists and engineers will find many intricate problems which must be solved before the subject can be put on a rational basis. Indeed, the remarks made by Professor J.J. Rutledge¹ are worthy of serious consideration by mining scientists, engineers and research authorities:-

"When demonstration mines are provided and research work is carried on, the 'angle of break' will be as important to the mining engineer, as the 'angle of repose' is to the civil engineer, and the laws governing subsidence will be known to some extent, and coal mining will take rank as a profession".

This branch is one of the most controversial in mining science, and it is somewhat remarkable that a subject of/

1. Trans. Amer. Inst. Min. & Met. Engrs., 1919-1920, Vol. LXIII, page 763.

of such great importance to the mining industry as mining subsidence should have received such scant recognition in our literature. The fact that no generally accepted theory of subsidence exists has had a most unfortunate result for the mining industry. Particularly is this so when an action for surface damage is brought against a colliery company when, almost invariably, the company is put in the difficult position of demonstrating that it did not do the damage. In legal theory the onus of proving that the damage complained of has been caused by the company in question should rest on the plaintiff. The expense and irritation caused by multitudinous legal actions and disputes, and the ever increasing number of claims lodged for compensation for damage done, has caused many colliery concerns to acquire the surface and underground rights of the estates in which they propose to exploit the coal.

Draw is the most controversial branch of mining subsidence. A list of British observations on draw is included in this work, and a perusal thereof will illustrate the extreme variability which characterises this and many of the other phases of the phenomena. If we had a rational explanation of the causes of draw we would have well in hand what is admittedly a very difficult problem. As an aid to the solution of this problem many more investigations are called for. Professor Briggs has recently suggested a new direction of attack, one from which we are sure valuable information will be obtained:-

"At a last analysis, Mining Subsidence
 "is a branch of the Science of Strength of Materials,
 "and such systematisation as is possible with so
 "diverse and capricious a subject is more likely to
 "proceed from a patient inquiry into the reactions
 "of the rocks involved (whether shearing, bending or
 "flowing) than from any other direction of attack".

Of the recent British contributions to the theories/

theories of subsidence, the most important are those of
 Professors Louis¹ and Briggs², and T.A. O'Donahue³, and we
 think it must be conceded that:

"An imperfect theory, possibly even an
 "erroneous one is better than none at all as a basis
 "for the systematic study of the subject",

quoting the statement made by Professor H. Louis.

In a discussion of Professor Louis' paper, W.
 Wallace Thornycroft suggested the following heads for
 inquiry:

"(1) To trace the characteristic curves
 of waves of subsidence travelling with advancing
 longwall faces, having regard to:

- (a) Depth, character and inclination
 of strata;
- (b) The method of working outside the
 pillar;
- (c) The direction of such workings;
- (d) The thickness of the seam and
 method of packing.

(2) To study and compare the subsidence
 caused within the area of a stoop or pillar of coal,
 having regard to:

- (a) Depth, character and inclination
 of strata;
- (b) The method of working outside the
 pillar;
- (c) The direction of such workings;
- (d) The thickness of the seam and the
 method of packing.

(3) To study and compare the effects of
 subsidence due to the extraction of coal by stoop and
 room working, having regard to:

(a)/

-
1. H. Louis, "A Contribution to the Theory of Subsidences",
Trans. Inst. Min. Engs., Vol. LXIV, 1922-1923, page
 261-262.
 2. H. Briggs, "An Attempt at the Rationale of Faulting and
 Subsidence", Trans. Inst. Min. Engs., Vol. LXXIII, 1926-27
 "An Outline of Research", Colliery Engineering, Vols. V,
 VI and VII, 1930.
 3. T.A. O'Donahue, "Subsidence Caused by Coal Mining", Trans.
Inst. Min. Engs., Vol. LXXVIII, 1929-30.

- (a) Depth, character, and inclination of strata;
 - (b) The thickness of the seam and method of packing, if any.
- (4) To study the effects of subsidence caused by the working of a second or third or more seams following upon the extraction of the first.
- (5) To study the effects of faults large and small on subsidence".

To the above list we might add:

(6) To observe and measure the magnitude and direction of lateral and longitudinal movement of the surface.

(7) To measure the magnitude of the horizontal, tensile and compressive stresses caused by subsidence.

(8) To conduct experiments in advance of the coal face underground (the distance in advance explored to be not less than 100').

(9)* To conduct experiments on coal measure strata to study the manner of fracture and general behaviour of those rocks under

(a) Transverse loading;

(b) In shear;

(c) In tension

(d) In compression;

(e) To determine their elastic limits.

With/

* An inquiry of this nature is at present being carried out by D.W. Philips¹, who has contributed two papers on the subject to our literature:

1. D.W. Philips, "The Nature and Physical Properties of Some Coal Measure Strata", Trans. Inst. Min. Engs., Vol. LXXX, 1929-1930; and "Further Investigation of the Physical Properties of Coal Measure Strata and Experimental Work on the Development of Fractures", Manchester Geological and Mining Society, December 8, 1931.

With regard to any subsidence investigation we cannot emphasise too strongly that, no matter how carefully the surface observations and measurements have been made, they will never attain full utility unless they are combined and synchronised with an equally exact description of underground operations, i.e., the method of working, packing, support, rate of advance of the face, general subsidence of the roof, etc. In our investigation we attempted to synchronise our surface and underground observations.

OBJECT OF THE INVESTIGATION.-

The object of this investigation was to observe and measure at the surface (Part I of this work):

- (1)(a) The Extent of Draw.
 - (b) The Extent of Draw with reference to The direction of advance of the line of face;
 - (c) The Extent of Draw with reference to The cleavage of the coal;
 - (d) The Extent of Draw with reference to The thickness of deposit extracted.
- (2) The Amplitude of Subsidence.
- (3) The Horizontal, Tensile and Compressive Stresses (caused by the general process of subsidence) in and beyond the excavated area.
- (4) Lateral Movement.

To observe and measure underground (Part II of this work):

- (1) In Advance of the Coal Face
 - (a) Under Draw;
 - (b) Coal Compression;
 - (c) Lateral Extension of the Coal Stratum towards the Waste or Goaf;
 - (d) The horizontal, tensile and compressive stresses induced in the bed overlying the coal stratum by the subsidence of the superincumbent strata.
- (2) Pack Compression along a line underground, the exact surface subsidence of which was ascertained.

With/

With regard to Section No. 4, Part I, this is a new line of investigation, and one which is of great importance in view of the destructive effects of this form of movement, and further there is no doubt whatever as to the truth of the statement made by Professor Briggs:

"Apart from material considerations, a better knowledge of the incidence of such (lateral) movements is likely to assist in the elucidation of the mechanics of subsidence perhaps to a greater degree than anything else".

With regard to Section 1, Part II, we claim that we are the first to make such observations in conjunction with a subsidence investigation.

The writer's investigations were carried out at Barbauchlaw Mine, Armadale, Linlithgowshire, which was under his supervision, and the surveys, levellings, measurements and observations hereafter described were made for the purposes of this inquiry only.

Part I contains the records of the surface observations, and the results and conclusions arising therefrom, together with a description of the surveying and levelling methods employed in the investigation.

Part II contains the records of the underground observations, and the results and conclusions arising therefrom, together with a description of the general layout of the workings of the mine and the method of work practised.

In Part III we have attempted a summary review of recent researches relating to our subject, and under appendices we have described the method of mining coal under a farm steading at Niddrie, Midlothian. Appendix No.2 is devoted to the visible damage to a house, cemetery and walls, caused by the workings of Bridgend Colliery, Linlithgowshire.

At the outset I wish to record my indebtedness to Professor Briggs under whose direction and supervision the/

the work herein described was carried out. He afforded me every facility in the performance of the work, and was ever ready to discuss my difficulties. His personal interest, keen criticism, and considered advice have been invaluable.

PART I

SECTION 1.

METHODS OF SURVEYING AND
LEVELLING AND GENERAL
LAYOUT OF SURFACE
STATIONS.

We include in this section a brief description of the methods of surveying and levelling practised in this investigation to correlate accurately the surface and underground survey and levellings. The measurement of draw and lateral movement demand as a preliminary the precise determination of the relative position of a large number of stations at the surface distributed over the area about to be affected by subsidence, while synchronisation of the surface and underground observations and measurement necessitates the precise determination of the position of the coal face with relation to the point of observation and measurement at the surface. If satisfactory results are to be obtained only the most accurate methods of surveying and levelling should be employed. The method of surveying practised at the surface was that of Triangulation, while underground the main roads were surveyed by means of a transit theodolite.

The surface triangulation system can be seen on the large plan, and, although the triangles are not 'ideal', they embrace as triangulation stations, the main stations, from which levellings and linings were made to measure amplitude, lateral movement, etc. In the actual triangulation of the surface, the angles were measured by means of a 6" Transit Theodolite manufactured by Messrs W.F. Stanley & Co. Ltd., London, the horizontal plate of which was graduated to 20", and the instrument was fitted with a fine adjustment centering apparatus. The angles in the triangulation were measured six times, three face right and three face left observations per angle. The errors were distributed in the usual way, and the whole survey checked by the measurement of a check base line. Four sun observations were made to determine the True North bearing of one of the lines in the triangulation system. Using this line/

line as a reference or base line, the surface survey was continued to the coal face underground by means of a theodolite traverse. This survey was over specially prepared stations, and the angles between the stations were measured. The surveys were checked to ensure accuracy.

We hereby wish to record our indebtedness to Messrs McAdam and Andrews who gave us material assistance in making the surface and underground surveys.

LEVELLING.-

Levelling is one of the most important operations in an investigation into mining subsidence, and it was necessary in this inquiry to determine:

- (i) The exact difference in level of stations at the surface and station underground;
- (ii) The amplitude of subsidence;
- (iii) The extent of Draw.

To determine (i) it is best to refer the surface and underground levels to a common datum, preferably the ordnance datum. The levels of the surface and underground stations in this inquiry are referred to that datum, and levellings were run from three separate ordnance bench marks to ensure accuracy. The operation of levelling was carefully performed, and the levellings were always checked back to stations situated outside the area likely to be affected by subsidence. They were always run in closed circuits.

The levelling instrument used in this investigation was a precise level manufactured by Messrs W.F. Stanley & Co. Ltd., London.

CONSTRUCTION OF SURVEYING AND LEVELLING STATIONS.*

Small vertical and horizontal movements must be detected in an inquiry such as this, and, if the stations are not of a sound, solid construction, movements due to other causes/

causes than subsidence may be recorded. The stations used for the purposes of this inquiry were constructed as follows:- A hole 18" x 18" x 18" was made in the ground; into the centre of this hole was driven a 2'6" length of $\frac{1}{2}$ " gas tubing, the upper end of which projected $\frac{1}{2}$ " beyond the level of the surface of the ground. The hole was then filled up to the level of the surface with concrete. This formed an admirable surveying and levelling station, while observations and measurements of the horizontal, tensile and compressive stresses caused by subsidence could be made fairly accurately by measuring to the centres of the projecting tubes.

PART I

SECTION 1.

SUB-SECTION (a).

OBSERVATIONS AND MEASUREMENTS

TO DETERMINE THE EXTENT

OF DRAW.

INTRODUCTORY.-

Draw is one of the most controversial branches of Mining Subsidence. The measurement of the extent of draw is relatively simple, and an explanation of the causes probably one of the most difficult problems facing the investigator. As already stated in the general introduction, the direction of attack, from which sound practical results are most likely to proceed, is that outlined by Professor Briggs¹, while Professor Louis'² contribution is worthy of further study. We have included in this section of our work a section of the strata overlying the Colinburn coal seam, and we regret (realising the importance of such information) that we are unable to furnish information as to the general character, behaviour and manner of fracture of the rocks included therein. The multitudinous formulæ, rules etc. compiled for the determination of the extent of draw (the bulk of which are useless in practice), and the urgent necessity for further information as to the causes of draw, are ample justification for further investigation.

METHOD OF MEASUREMENT.-

Two lines were set out in areas 1 and 2, one parallel to the direction of advance of the coal face, the other at right angles to that direction (see diagrams No.3 and No.25.). Pegs were driven into the ground at intervals of 10 feet along the entire length of the lines in area No. 1, while in area No. 2 this procedure was only carried out/

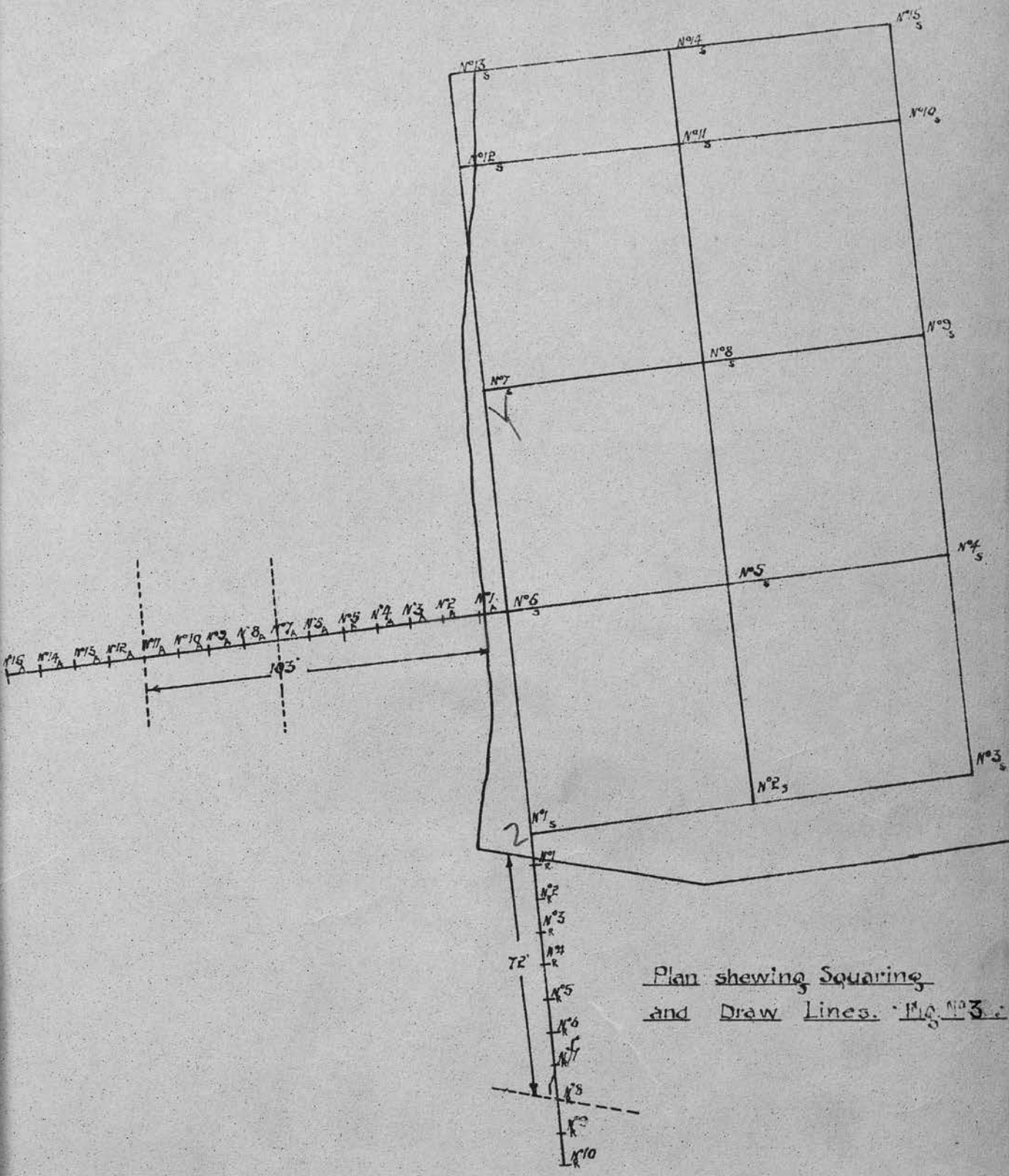
1. H. Briggs, Colliery Engineering, 1930, Vol. VII, p. 23.

2. H. Louis, Contribution to the Theory of Subsidence, Trans. Inst. Min. Engs., Vol. LXIV, 1922-1923.

Surface clay.		14-0
Sandstone.		1-3
Bally Fireclay.		11-9
Coal.		0-6
Fireclay.		5-0
Coaly Blae.		1-6
Flakey Sandstone.		9-2
Coal.		2-8
Fireclay.		1-5
Sandstone.		15-3
Fireclay.		2-9
Coal.		4-2
Flakey Fireclay.		4-0
Sandstone.		9-4
Fireclay.		3-2
Blae.		4-0
Fireclay.		3-6
Coal.		0-6
Fireclay Sand. Ribs.		6-3
Coal.		0-8
Fireclay Sand. Ribs.		19-4
Coal.		0-9
Sandstone.		14-0
Coal.		2-0
Fireclay.		9-5

Section of Strata
over
Colinburn Coal.

Fig. No. 2.



Plan shewing Squaring
and Draw Lines. Fig. 103.

Table N°2.

LEVELLINGS ON LINE IN ADVANCE OF FACE.

102

No.15	No.14	No.13	No.12	No.11	No.10	No.9	No.8	No.7	No.6	No.5	No.4	No.3	No.2	No.1	Deduct Const.	'7
493.16493.	58493.17493.	43493.43493.	68494.50494.	81495.29495.	67495.67495.	88496.37496.	22496.22496.	98497.01497.	49497.88497.	497.88497.	497.88497.	497.88497.	497.88497.	497.88497.	497.88497.	7th July '28
			0.03	0.04	0.04	0.07	0.10	0.11	0.18	0.21	0.25	0.30	0.30	0.30	0.30	17th Aug. '28
			0.02	0.09	0.13	0.18	0.25	0.31	0.39	0.44	0.50	0.56	0.56	0.56	0.56	17th Sept. '28
			0.07	0.12	0.17	0.23	0.31	0.36	0.46	0.51	0.57	0.62	0.62	0.62	0.62	14th Oct. '28
			0.08	0.15	0.21	0.28	0.35	0.42	0.51	0.56	0.62	0.68	0.68	0.68	0.68	18th Nov. '28
			0.20	0.21	0.29	0.37	0.44	0.51	0.60	0.63	0.69	0.75	0.75	0.75	0.75	22nd Dec. '28
			0.03	0.41	0.42	0.50	0.60	0.65	0.74	0.79	0.85	0.90	0.90	0.90	0.90	31st Mar. '29
			0.03	0.41	0.42	0.50	0.60	0.65	0.74	0.79	0.85	0.90	0.90	0.90	0.90	25th Apr. '29
			0.03	0.41	0.42	0.50	0.60	0.65	0.74	0.79	0.85	0.90	0.90	0.90	0.90	8th June '29
Final Draw 103 ft.																
Advancing Draw 73 ft.																
1st Area investigated.																

Table N°3.

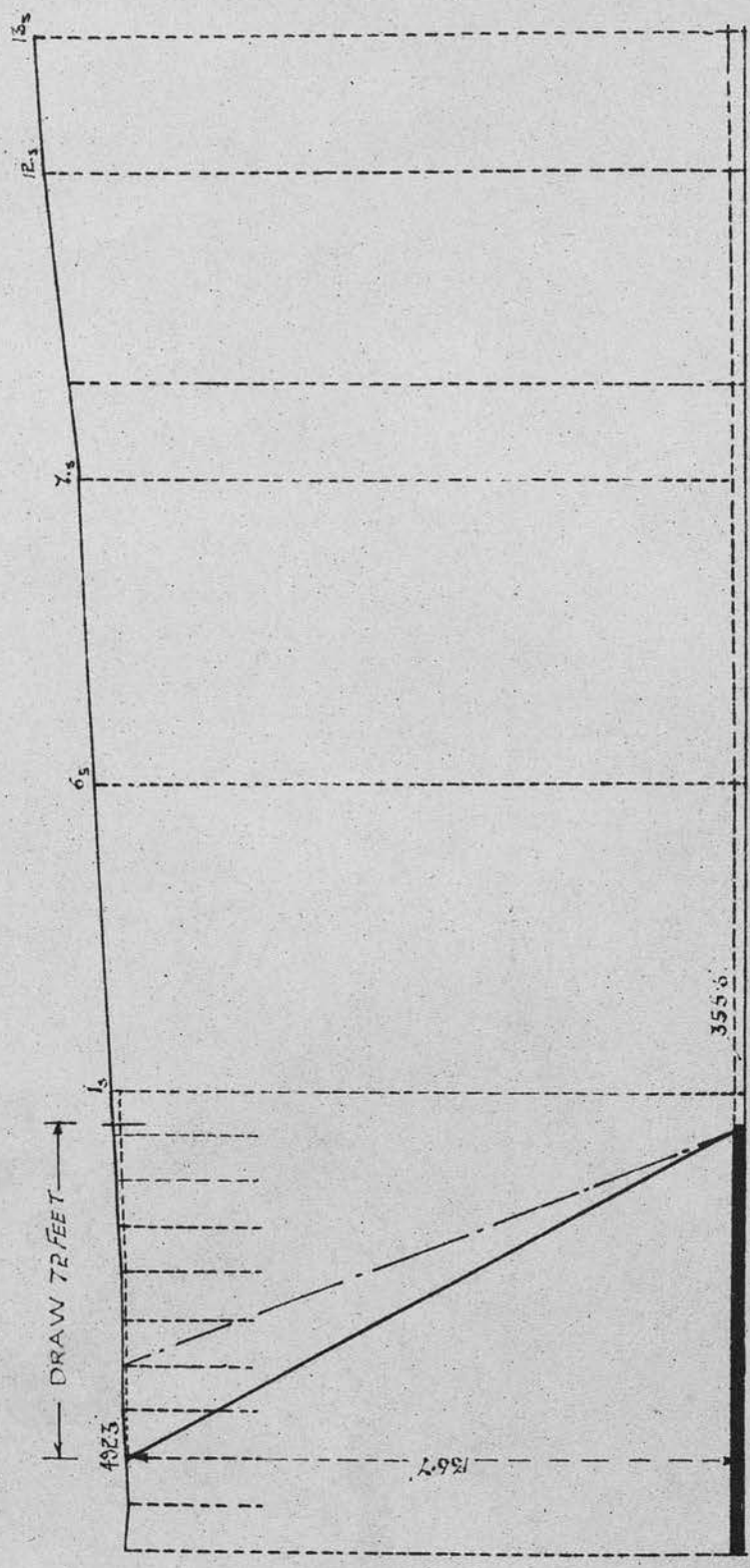
MONTHLY LEVELLING ON LINE 1 - 7

MONTHLY LEVELLING ON LINE 1 - 7

No.1 _B No.1 _L	No.2 _B	No.3 _B	No.4 _B	No.5 _B	INCLUDING DRAW PEGGS.										INCLUDING DRAW PEGGS.														
					No.6 _B	No.7 _B	No.8 _B No.2 _L	No.9 _B	No.10 _B	No.3 _L	No.4 _L	No.5 _L	No.6 _L	No.7 _L	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9	No.10	No.11				
495.73	495.99	495.90	494.56	494.84	495.30	495.39	495.50	495.26	495.39	499.34	503.05	505.35	505.99	508.63	508.69	508.90	509.45	510.06	510.09	510.27	510.02	510.06	509.70	509.64	509.46				
					Const. + 6 feet from No. 2 _L													Const. + 23 feet from No. 7											14th Oct. 1928
												0.02	0.02													18th Nov. 1928			
											0.02	0.02	0.02													22nd Dec. 1928			
										0.03	0.02	0.02	0.02													29th Feb. 1929			
										0.04	0.08	0.11	0.09	0.05												31st Mar. 1929			
										0.05	0.14	0.26	0.21	0.05												25th Apr. 1929			
										0.07	0.15	0.30	0.25	0.05												8th June 1929			
							0.06		0.06	0.14	0.22	0.51	0.50	0.16												4th Aug. 1929			
							0.10		0.10	0.33	0.41	0.88	0.87	0.35												4th Sept. 1929			
					0.01	0.04	0.15	0.06	0.09	0.53	0.68	1.23	1.13	0.44	0.03	0.02	0.02	0.02	0.02	0.02	0.02					1st Oct. 1929			
					0.03	0.05	0.17	0.10	0.13	0.69	0.90	1.38	1.27	0.47	0.03	0.02	0.01	0.02	-	-						1st Nov. 1929			
			0.03	0.08	0.08	0.11	0.25	0.22	0.31	0.89	1.07	1.45	1.30	0.47	0.03	0.02	0.02	0.02	-	-						1st Dec. 1929			
		0.02	0.04	0.08	0.11	0.17	0.32	0.29	0.39	1.04	1.21	1.57	1.40	0.52	0.03	0.04	0.03	0.04	0.02	0.02						2nd Jan. 1930			
	0.02	0.03	0.06	0.08	0.13	0.19	0.35	0.35	0.46	1.10	1.26	1.61	1.42	0.54	0.03	0.03	0.02	0.03	0.01	0.01						1st Feb. 1930			
0.03	0.03	0.03	0.06	0.08	0.17	0.20	0.37	0.35	0.46	1.13	1.27	1.61	1.44	0.54	0.03	0.03	0.02	0.03	0.01	0.01						5th June 1930.			
0.03	0.04	0.05	0.06	0.11	0.16	0.19	0.39	-	-	1.14	1.33	1.68	1.48	0.56	0.04	0.03	0.02	0.03	0.01	0.01									

37 >

out along the length of the lines at right angles to the direction of advance of the face. Measurements were made of the distance between the pegs to determine the stretch or otherwise of the ground, and levellings were run from temporary bench marks (hereafter referred to as investigation bench marks) situated outside the area likely to be affected by subsidence to those pegs to determine the subsidence or rise to which they were subjected. The levels were repeatedly checked and were run in closed circuits. With reference to the measurement of 'advancing draw' the position of the face with relation to the subsiding pegs was ascertained on the date on which settlement was first detected. The tabulated results of the levellings and observations are shown on page No. , Table No. 1, 2, & 3. The position of the coal face underground with relation to the surface stations is shown on diagrams No. 3 & 4.



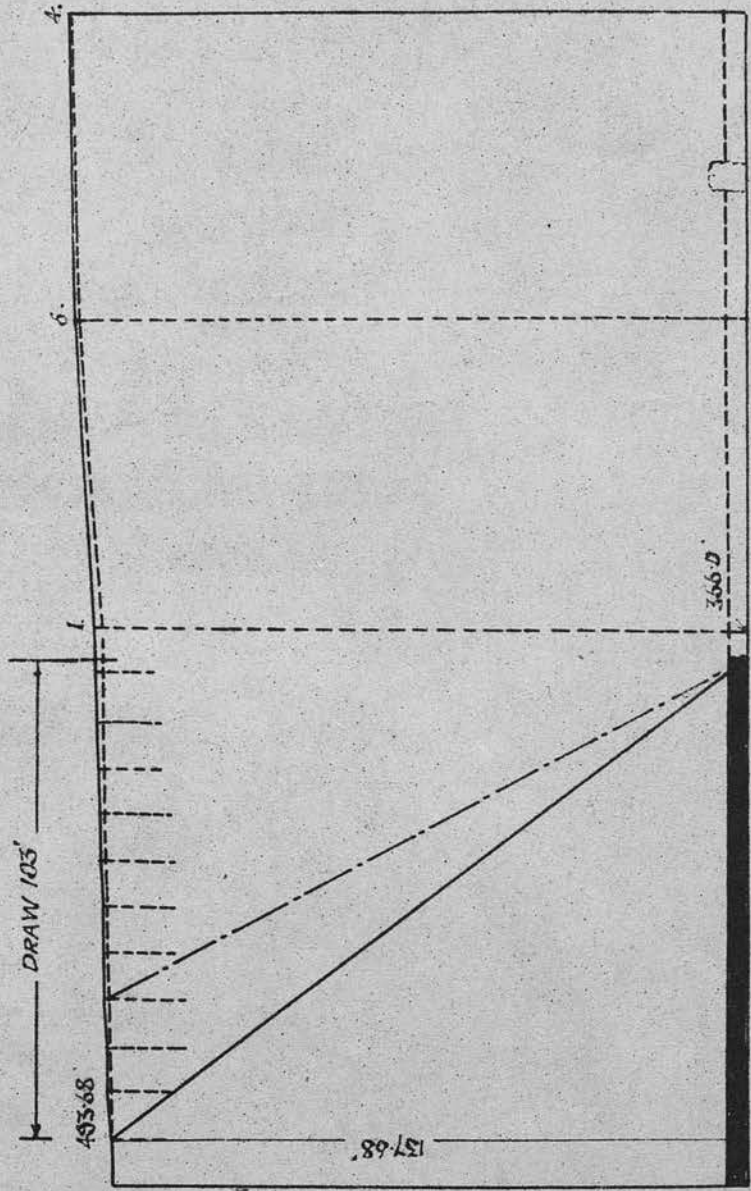
Section on line 1, 6, 7, 12, & 15.
 Scale Horizontal & Vertical = 1/500. - Fig. No. 4.

Section on Line J-6 & 4

Horizontal Scale 1/500

Vertical Scale 1/500

Fig. No. 5



PART I

SECTION 1.

SUB-SECTION (a)

OBSERVATIONS AND MEASUREMENTS

TO DETERMINE THE EXTENT

OF DRAW.

RESULTS AND CONCLUSIONS.

RESULTS AND CONCLUSIONS.

- (1) The final draw in the directions investigated was positive.

Indeed, we are of the opinion that many of the negative draws recorded in our literature are negative because of the crude methods of measurement employed in their determination. In many instances the extent of draw has been ascertained from the position of cracks only.

- (2) The advancing draw was always less than the final draw.

The advancing draw in Area No. 1 unfortunately was not ascertained. The face had been stopped for one month on the date of the first observation when a positive draw of 72' was indicated. Thereafter the draw gradually increased until

- (3) The final draw measured on a line parallel to the direction of advance of the face situated towards the centre of the excavated area (area No. 1) was 103'.

This line, however, ran over an area from which the coal had been extracted by a longwall face travelling in the opposite direction 20 years ago.

- (4) The final draw measured in a direction at right angles to the direction of advance of the face was 72' (area No. 1).

The first observations, made a month after the face had stopped advancing, indicate a positive draw of 52 feet; thereafter subsidence gradually extended/

extended outwards until the final distance of 72 feet was reached.

The above conclusions are inferred from the observations made in Area No. 1.

Area No. 2.

- (5) The advancing draw was ascertained on two separate lines (1_L - 7_L and 14_L - 8_L) and was 52' (positive).

Unfortunately the final draw was not measured; the face did not stop advancing during the period of this investigation.

- (6) The draw measured in a direction at right angles to that of the advance of face was finally 72' (positive) area (A - 1_L).

- (7) The extent of draw measured at the top end of the face line area (7_L - B) (see diagram No. 27.) was only 53'.

The ironstone seam situated 10 - 14 feet below the workings of the Colinburn coal seam had been extracted by the longwall method, 20 - 30 years years ago, and as a consequence

- (8) Draw was less (53' against 72') and subsidence erratic (see Table No. 3).

- (9) There was a marked difference in the incidence of draw on a line parallel to the direction of advance of the face, and that observed in a direction parallel to the line of face. The stations towards the centre of the line 1_L - 7_L were the first to subside; as the process evolved the zone of subsidence enlarged until the area over the 'rib-sides' was affected, subsidence finally extending 72' beyond the ribside. In the other direction, that parallel to/

to the direction of advance of the face, settlement started 52 feet in advance of, and travelled with, the face.

- (D) A rising of the surface round the fringes of the area of settlement did not take place.

Observers have referred to, and recent investigators (Herbert and Rutledge, Auchmuty and Thorneycroft, to mention a few) have recorded "a slight uplift of the surface as a prelude to subsidence".

In this regard we can only state that this uplift is not general.

A PLEA FOR THE STANDARDISATION OF THE METHODS OF DETERMINING
DRAW. -

Perhaps in no other operation involved in an investigation into the subject of Mining Subsidence is there such urgent necessity for standardisation. The causes of draw are admittedly difficult to delineate, but the methods of determining the extent of draw signified in many of the recorded observations do not by any means tend towards a simplification of this intricate problem. In many instances draw is ascertained by the position of cracks in the surface, or by the position of damaged structures; in others by levelling, but only in rare instances is precise levelling utilised to the full advantage and to the degree desirable.

The only rational method of determining the extent of draw is by levelling, and before the measurement of draw can be put on a proper scientific basis a definite standard of levelling must be adopted. Levels have been taken to various standards. In the past some workers have considered $\pm .1'$ as a reasonable standard. This standard, however, is far too low and should be considered extremely unsatisfactory.

By way of illustrating the result of adopting the above standard in place of our own standard of $\pm .02'$, we find that the advancing and final draw which was 52' and 72' respectively would be 10' and 22' if the levels less than $\pm .1$ are disregarded. Indeed, we have no hesitation in suggesting that many of the small values of negative draws recorded in our subsidence literature are attributable to the crude methods of measurement employed in their determination.

In view of the scientific and accurate instruments now available, and of the high degree of precision easily obtainable, we suggest that levels run for the purpose of determining/

determining the extent of draw should be taken to $\pm .02'$, and that at least three determinations should be made before a station is considered to start or stop moving.

PART I

SECTION 1.

SUB-SECTION (b)

RELATIONSHIP BETWEEN DRAW AND
THE DIRECTION OF ADVANCE
OF THE LINE OF FACE.

RESULTS AND CONCLUSIONS.

RESULTS AND CONCLUSIONS.

The direction of advance of the coal face in Area No. 1 was at right angles to the direction of advance of the coal face in Area No. 2.

- (1) Since the extent of draw in each area was (where conditions were normal) 72' positive, we are therefore in a position to state definitely that the direction of advance of the coal face does not influence the extent of draw.

PART I

SECTION 1.

SUB-SECTION (c)

RELATIONSHIP BETWEEN THE EXTENT
OF DRAW AND THE DIRECTION
OF THE CLEAVAGE OF
COAL.

RESULTS AND CONCLUSIONS.

RESULTS AND CONCLUSIONS.

In Area No. 1 the extent of draw, measured on a line parallel to the direction of the main cleavage was equal to the extent of draw measured on a line at right angles to that direction in Area No. 2. It is therefore reasonable to suggest that:

- (1) The extent of draw is not influenced by the direction of cleavage.

PART ISECTION 1.SUB-SECTION (d)

RELATIONSHIP BETWEEN THE EXTENT
OF DRAW AND THE THICKNESS
OF DEPOSIT EXTRACTED.

RESULTS AND CONCLUSIONS.

RESULTS AND CONCLUSIONS.

In the areas investigated, Areas No. 1 and No. 2, there was a considerable difference in the thickness of deposit extracted. The thickness of the 'working' in Area No. 1 was 45", and in area No. 2, 22". Since the extent of draw was the same in those areas we can definitely state that under the circumstances and conditions prevailing at this mine:

- (1) The extent of draw is not influenced by the thickness of deposit extracted.

It is difficult to see how the thickness of deposit extracted should influence draw. The extraction of a thick deposit (other conditions being equal) must materially increase the amplitude of subsidence, but amplitude is influenced by (among other factors) the amount of packing material introduced into the place of the excavated deposit, and the resistance offered to compression by that material. Indeed, the amplitude of subsidence over an area from which a thick deposit has been extracted, and the waste completely packed, may not be as high as that over an area from which a thinner seam has been extracted, and the waste improperly and scantily packed.

Indeed, we tentatively suggest that little or no information of any practical or theoretical value can proceed from an investigation of this relationship, and that more valuable information would emanate from an inquiry into the relationship between Amplitude and Draw.

PART I

SECTION 2.

AMPLITUDE OF SUBSIDENCE.

- (1) The nature of the soil, its composition, its moisture, and its water content.
- (2) The rate of subsidence.
- (3) The amount of subsidence.
- (4) The nature of the surface.
- (5) The nature of the water.
- (6) The nature of the water.
- (7) The nature of the water.

INTRODUCTORY.-

The amplitude of subsidence is characterised by its extreme variability; generally amplitude is diminished as depth increases, however the area of settlement generally increases with the depth, therefore a reduction in amplitude is what one would expect. The rate of diminution however is not rapid, except for shallow depths, it being retarded by the increased pressure (therefore compression) suffered by the fractured beds. The following factors exercise an influence over the amplitude of subsidence:

- (1) The method of working;
- (2) The method of packing, e.g. Hydraulic, pneumatic, hand, partial, complete, or not at all;
- (3) Rate of advance of the face;
- (4) Presence of old workings at a higher or lower level, stoop-and-room working, have an enormous effect, particularly if the stoops are small;
- (5) Nature of packing material used for stowing the wastes;
- (6) Nature of super and subjacent strata;
- (7) Nature of the surface deposits.

We do not propose to enter into a discussion of the methods of reducing the Amplitude of Subsidence, although this is a very important consideration in some districts where the lowering of the level of the surface beyond a certain point may cause the inundation of large areas of land. We merely state that the solution of this problem lies in the complete stowing of the 'wastes' by either of two systems: hydraulic (sand stowing preferably) or pneumatic stowing. In this investigation the amplitude of subsidence was measured in Areas No. 1 and No. 2. Unfortunately the surface in Area No. 1 had subsided a considerable amount before the observation and measurements were initiated. In Area No. 2, however, the results are more/

LEVELLINGS OF PEGS IN SQUARING.

Peg No.	1s	2s	3s	4s	5s	6s	7s	8s	9s	12s	11s	10s	13s	14s	15s	Date
Reduced Level	493.26	494.93	500.84	497.58	501.20	503.11	500.38	504.51	508.44	508.40	508.44	513.88	510.57	511.04	515.56	18:8:28
	0.13	0.08	0.05	0.27	0.12	0.05	0.35	0.14	0.06	0.25	0.16	0.05	0.13	0.11	0.03	17:9:28
	0.22	0.10	0.06	0.40	0.16	0.07	0.50	0.19	0.07	0.35	0.21	0.07	0.19	0.15	0.04	13:10:28
	0.27	0.12	0.06	0.46	0.17	0.07	0.61	0.22	0.07	0.41	0.23	0.07	0.21	0.15	0.04	18:11:28
	0.32	0.17	0.10	0.56	0.23	0.09	0.70	0.27	0.10	0.48	0.28	0.11	0.27	0.22	0.07	22:12:28
	0.34	0.27	0.15	0.68	0.35	0.19	0.71	0.27	0.11	0.48	0.28	0.11	0.27	0.21	0.07	31: 3:28
	0.34	0.27	0.15	0.68	0.35	0.19	0.71	0.27	0.11	0.48	0.28	0.11	0.27	0.22	0.07	25: 4:28
	0.34	0.27	0.15	0.68	0.35	0.19	0.71	0.27	0.11	0.48	0.28	0.11	0.27	0.22	0.07	8:6: 28

Table. №5.

more satisfactory, and the figures recorded in Table No. indicate the 'amplitude' at the various surface stations. We attempted to correlate amplitude of subsidence and pack compression (See Part II, Section 2 of this work); this correlation, we must admit, however, was not very successful.

OBSERVATIONS AND MEASUREMENTS.-

Area No. 1 was divided into a series of perfect squares, see diagram No. 3, the stations forming the corners of which were used for the purpose of measuring amplitude. In Area No. 2, see diagram No. 25, stations were set out at intervals of 66' along the length of two lines, which ran approximately parallel to the opposite sides of a road at the surface. Levellings were run at intervals of one month from the investigation bench marks to those stations, and the results recorded. Careful observations and levellings were made to detect an uplift in advance of the face, and a re-elevation towards the centre of the excavated area. Despite careful observation, neither uplift or re-elevation were detected. The results of the observations and levellings are recorded in table No. 5.

We do not propose to discuss the results obtained in Area No. 1 for the reasons given in the introduction to this section of our work. In Area No. 2, however, the results obtained were very satisfactory, and we describe them fully.

RESULTS OF OBSERVATIONS IN AREA NO. 2. -

A perusal will show that the first evidence of settlement was furnished when stations No. 5_L and No. 6_L subsided 0.02'. Those stations then remained stationary for two months. Thereafter the rate of subsidence rapidly increased and the increased rate of settlement continued for several months, when the characteristic slow rate of subsidence of the 1st phase reappeared. The final values of /

of amplitude for the stations Nos. 4_L, 5_L and 6_L are high, 1.33', 1.68' and 1.48' respectively. The same procedure was carried out on the line, 8_L9_L-14_L, and again the amplitude of settlement is a maximum in the same area, i.e., in the vicinity of stations Nos. 8_L9_L and 10_L. The results of the levellings run along the line 1_L-7_L are interesting since they illustrate the incidence of settlement over a restricted area on a line at right angles to the direction of advance of the face. Indeed, we suggest that the results are similar to those one would expect over an area from which the coal has been extracted by the stoop-and-room method of mining.

The pegs towards the centre of this line were the first to subside, and as the process of settlement continued the pegs all in their turn were affected in rotation from the centre out towards the edges of the excavated area, Settlement finally extending beyond to ribsides to produce draw. The amplitude of subsidence was a maximum about the centre of the line, and decreased progressively towards the edges of the area. Diagram No.30 illustrates the process.

PART I
SECTION 2.

AMPLITUDE OF SUBSIDENCE.

RESULTS AND CONCLUSIONS.

RESULTS AND CONCLUSIONS.

We intended at the outset of this investigation to compare amplitude of subsidence on the line 1_L-7_L at the surface, and pack compression along a line of exactly the same plan position under: ground. Measurements and observations were made for this purpose, see diagram No.30 and table No.14. . The analyses of the observations and results, however, were rendered valueless by the presence of old workings underground situated 10 - 14 below the position of the Colinburn coal workings. Subsidence occurred in these workings, and, as a result, the amplitude of subsidence at the surface was out of proportion to the thickness of the seam extracted, and the compression suffered by the packs.

- (1) The amplitude of subsidence varies with the position at which it is measured.
- (2) Amplitude is a maximum towards the centre of the excavated area.
- (3) Levellings indicate that the surface of the ground above an excavated area assumes practically its original contour, but at a lower level, in a direction parallel to the direction of advance of the face.
- (4) The final contour of the surface on a line parallel to the line of face has but little resemblance to the original contour.

The above conclusion refers to observations where the length of face is comparatively short, say, 150 yards long.

- (5) That in view of the alteration of the surface contour/

contour, referred to above, and the stresses induced on the surface as a consequence of the alteration, the length of a coal face proceeding to advance under surface property should be a maximum to ensure that damage caused by subsidence will be a minimum.

This question is discussed fully in Appendix No. 1 and No. 2.

(6) Areas of high amplitude coincide with areas of high pack compression.

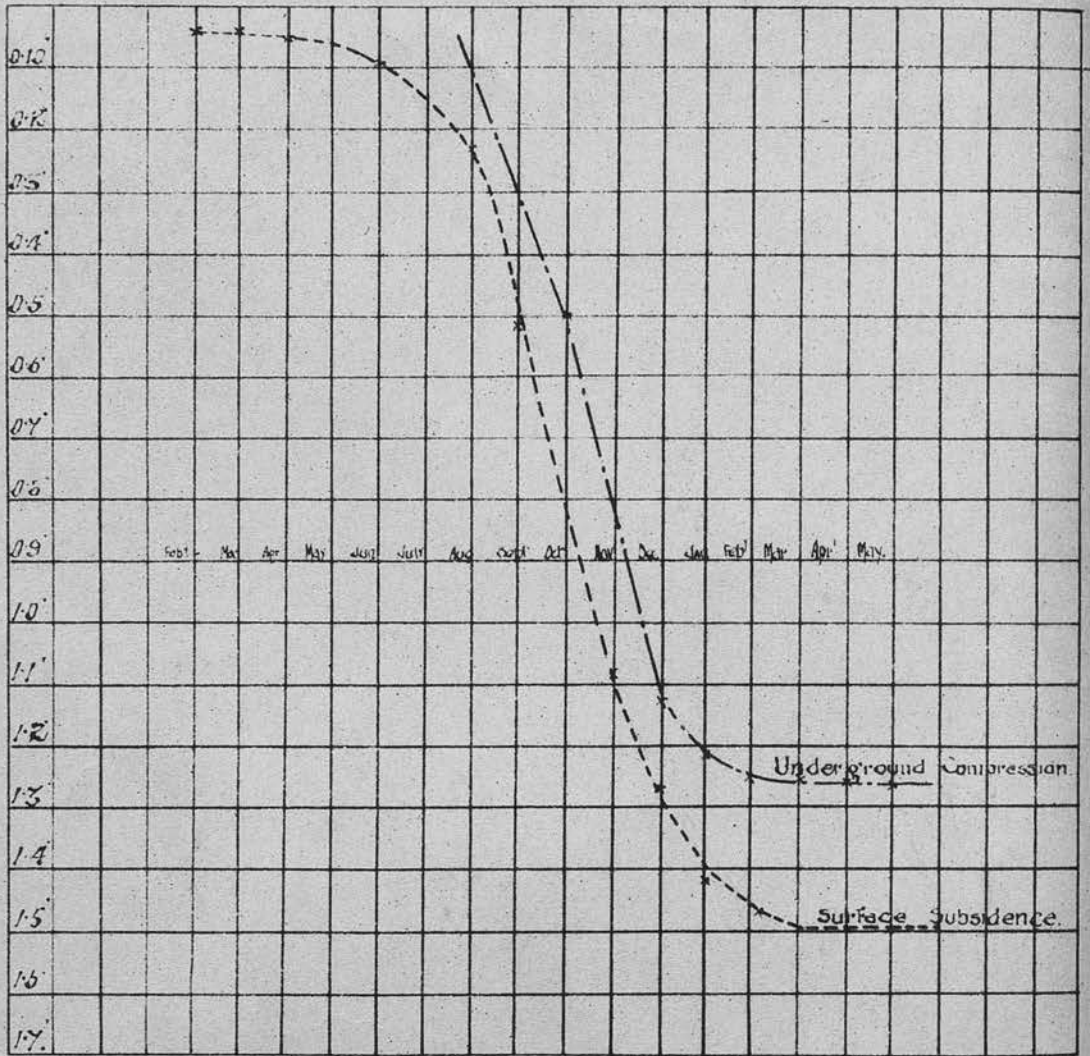
This illustrates the necessity of building packs in such a manner, and of such material, as will offer a high resistance to compression if amplitude is to be reduced to a minimum.

Conclusions Nos. 3 and 4 are important from the surface damage point of view; indeed, they will become more important if the pernicious practice of mining coal by the short (longwall method) method extends, and the tendency is in that direction. This method is the worst possible to practice, and seriously damages the surface and dislocates drainage if the deposit is thick.

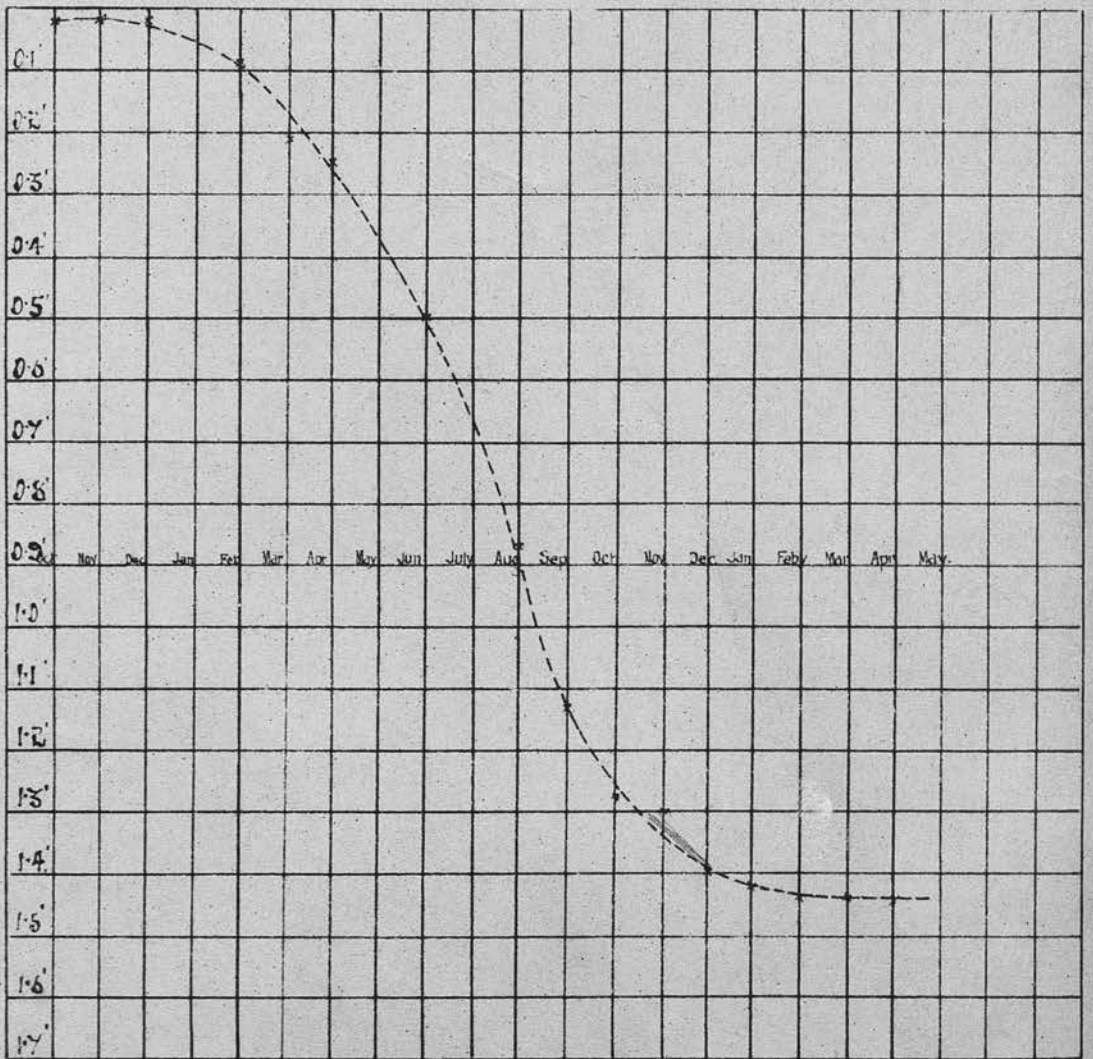
TIME ELEMENT IN SUBSIDENCE.-
INTRODUCTORY.-

The duration of subsidence is a matter upon which experience and opinion varies enormously. The principal factor controlling the rate of settlement is the depth of the workings. In this regard, generally, the greater the depth the longer the interval before moves become apparent at the surface, which is only natural when we consider that the subsidence movements have to be propagated from the face where they start upwards through the superjacent strata - the more even the settlement and the more protracted the subsidence process as a whole. There are certain factors which modify the time element in subsidence, such as method of working, rate of advance of the face, thickness of the seam, nature of super and subjacent strata, and the presence or absence of workings above or below the seam being removed.

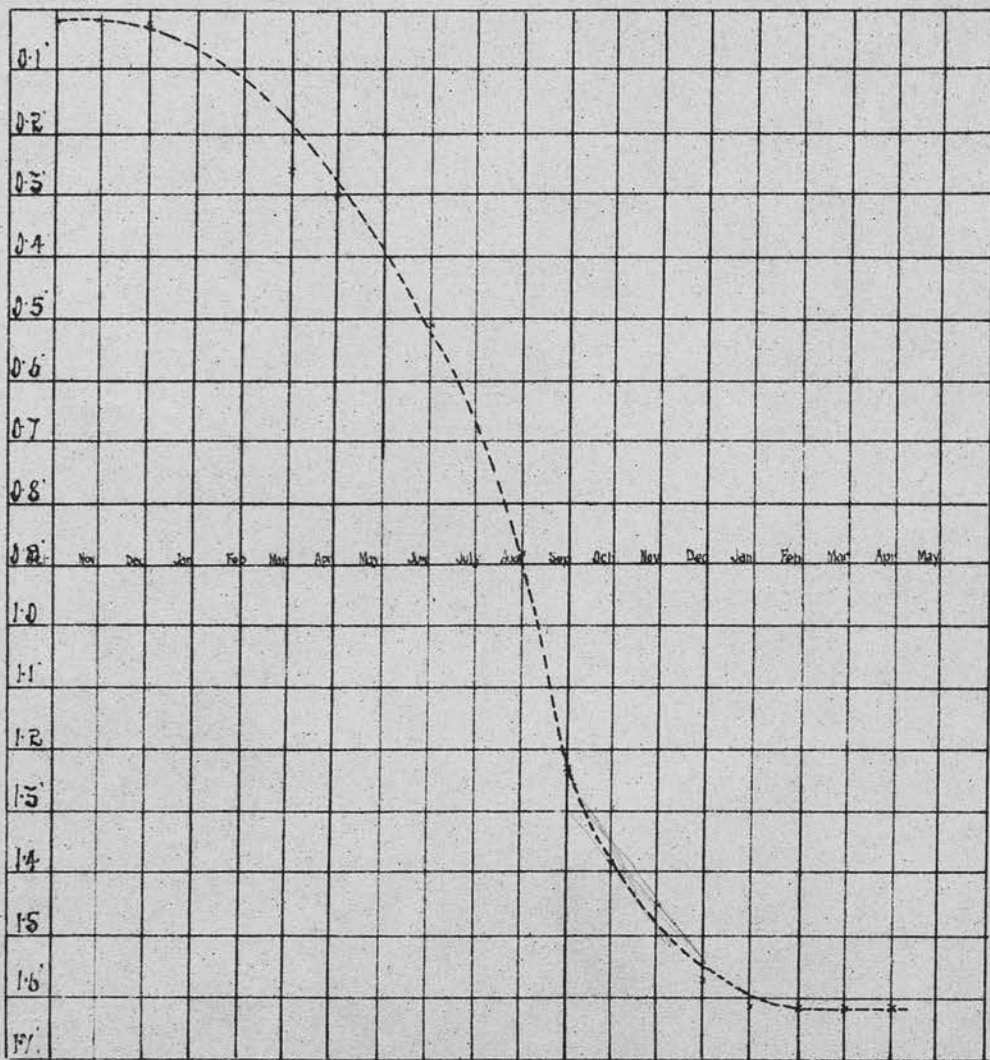
A reference to the records relating to the duration of subsidence reveals the exasperating vagueness of many of the observations. For example, it is often uncertain when timing starts; sometimes it is from the first sign of damage to a structure and sometimes from the first indications of movement; while, on other occasions, information regarding this essential point is hazy or absent. Information as to when the process is considered to end is also equally unsatisfactory. Only in rare instances, when time subsidence graphs are given, are we tolerably certain of the sequence of events. To a scientific study of the time element in subsidence time subsidence graphs are absolutely essential, and although, as already stated, only in rare instances are they included in British records, a commendably complete series were included in the records of Messrs Herbert & Rutledge's investigation (Bulletin No. 238, U.S. Department of Commerce and Bureau of Mines, 1927), which relates to the subsidence resulting/



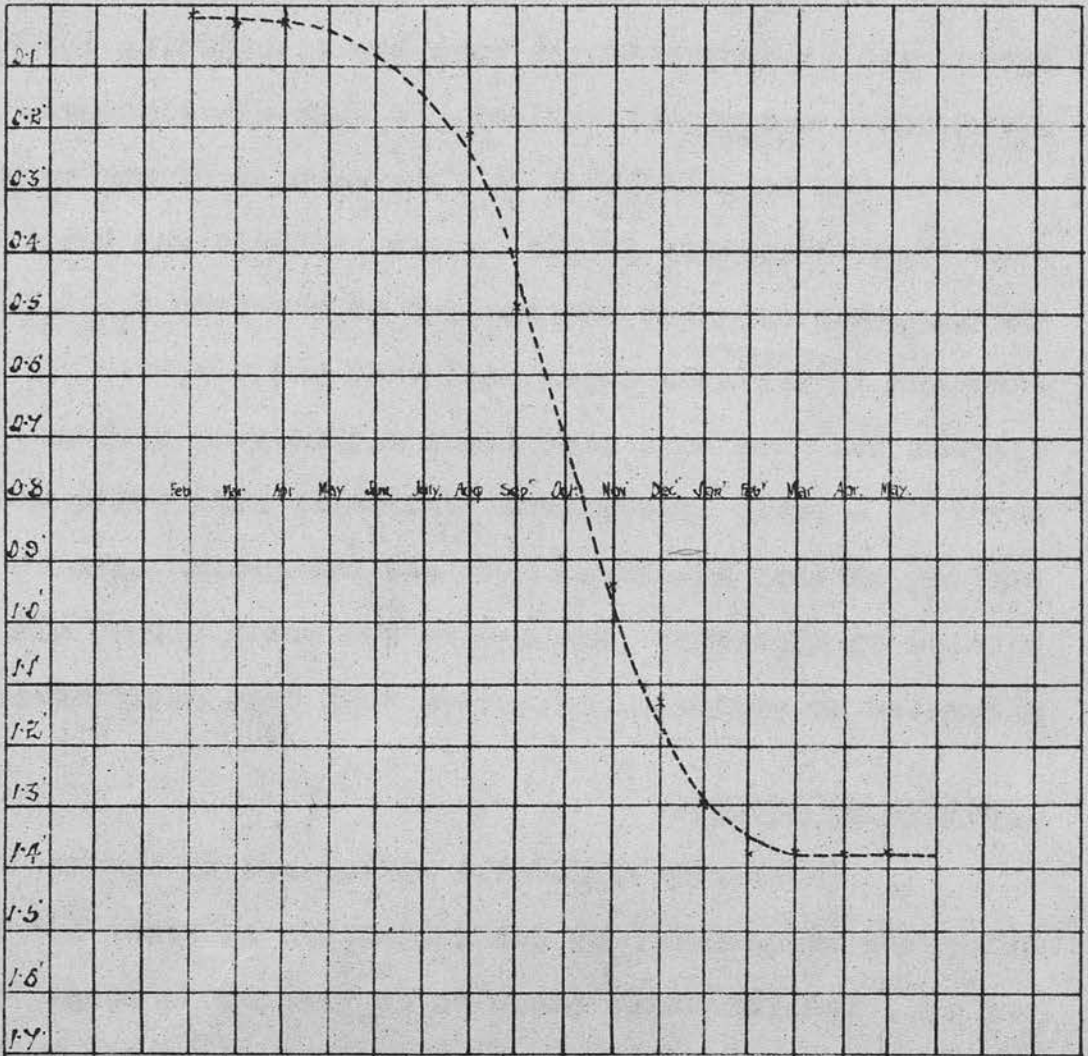
-Time Subsidence Curve: - Peg No 10- Mg. No 6 -



Time Subsidence Curve. Peg N° 61. Fig. N° 7



Time Subsidence Curve - Peg N° 5 - Fig. N° 8



-Time Subsidence Curve- - Peg. N° 9. - Fig. N° 9

resulting from longwall mining at two mines in Northern Illinois. Time subsidence graphs not only indicate the start and finish of the settlement process; they also furnish valuable information regarding the rate of settlement which varies enormously throughout the settlement cycle, and demonstrate such rare but interesting occurrences as 'uplift' and 're-elevation', if such are recorded.

We have included in this section of our work four time subsidence graphs, which indicate the nature of the vertical movement ascertained at stations $5_L, 6_L, 9_L, 10_L$ situated in the area where amplitude was a maximum. On diagram No. 6 we have also drawn a time pack compression curve of a point underground vertically underneath the surface station No. 10_L . On all our graphs time is plotted as abscissa; one square = 1 month (time) and elevation as ordinate one square = .1 foot settlement.

SEQUENCE OF EVENTS.-

There was but little difference in the sequence of events as observed at the respective stations Nos $5_L, 6_L, 9_L$ and 10_L , and for that reason we do ^{not} propose to describe the movement at all those stations, but to limit our observations to station No. 5_L , diagram No. 8 .

Movement of station No. 5_L was first detected on the 19th December, 1928, when that station was 52 feet in advance of the coal face line, and settlement was .02". During January, February and March, when station No. 5 was one foot in advance of the coal face line, the rate of settlement was very slow. Thereafter the rate of settlement increased rapidly, and this rapid rate of settlement continued for eight months until November, when, the characteristic slow rate of settlement of December, January and February began to re-appear. The face at this date was 86 feet in advance of station No. 5_L .

During/

During the period November - March, when settlement virtually ceased, settlement was very slow indeed. The settlement process had lasted 17 months, and the face had advanced 134 feet beyond Station No. 5_L before its virtual cessation.

Briefly, the salient features of the settlement process were as follows:

Surface subsidence varied widely;

The maximum settlement was 1.68 feet or about 80% of the thickness of the seam;

The rate of settlement increased gradually as the coal face approached a station;

When the rate was practically uniform, the surface sank about 0.16' per month for about eight months. The interval from the commencement of movement of a station to its virtual cessation was 17 months.

The face was 52 feet behind a station when movement started, and had advanced 134' beyond it when movement stopped.

The distance advanced beyond the station when movement virtually ceased was 134', which is the approximate depth of the seam from the surface.

TIME - PACK COMPRESSION.-

On diagram No. 6 we described two graphs, one time-subsidence, the other time pack compression, the profiles of which bear a marked resemblance to each other in all parts except that which relates to the first part of the settlement process. This is due to the fact that time compression measurements were not made in advance of the coal face, and, as a consequence, the curve/

curve is somewhat incomplete. Had such observations been made the resemblance would undoubtedly have been more pronounced. It should be observed that pack compression is decidedly less than surface subsidence, and that this is undoubtedly due to the subsidences which took place over and in the roadways in the old ironstone workings situated 10 - 14 feet below the Colinburn Coal workings.

PART I

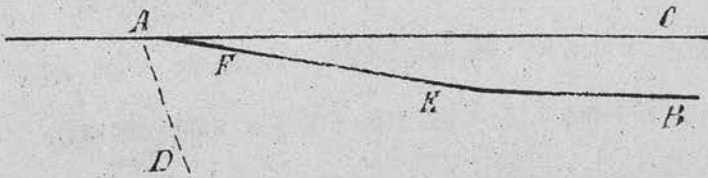
SECTION 3.

HORIZONTAL, TENSILE AND

COMPRESSIVE STRESSES

CAUSED BY

SUBSIDENCE.



Illustrating the incidence of Horizontal, Tensile and Compressive
Stresses. After M. B. S. No. 10.

INTRODUCTORY.-

The fact that the surface in a subsiding area is subjected to tensile and compressive stresses is well known. Stretching takes place over the zone of draw, and may extend some distance beyond this zone, although it is generally confined to it. The presence of tension is indicated by the formation of gaping cracks in the ground at the surface, and in buildings, walls, and other structures. Walls, pipes, and cables are very susceptible to damage by this force. To determine the stretch at the surface measurements should always be made. The surface may not show the slightest sign of the presence of the various stresses to which it is subjected. The surface road in this investigation, although subjected to several tensile and compressive stresses, did not exhibit any sign of their existence.

The generally accepted cause of the tensile and compressive stresses in an area over an advancing longwall face is the bending of the surface, Fig. 10. (from Dr. Briggs' book "Mining Subsidence") shows in vertical section a side of an area of settlement. AC is the original line of the surface; AFEB the contour during and after subsidence. The curve AFEB being longer than the straight line AC, the surface along the curve is thrown in tension, and cracks are liable to open in the zone AF and close again in the vicinity of EB. Many instances can be cited in which, as the subsidence wave approaches, a building leans towards the advancing face, and then develops cracks which widen and finally close up after the face has passed beyond. Numerous examples are recorded in our subsidence literature from which important information can be gleaned as to the nature and effects of the stresses which are a consequence of the process of subsidence. We briefly outline a few from Dr. Briggs' admirable book "Mining Subsidence"¹

1. Mining Subsidence, Chapter V, page 117.



Shirebrook Colliery, Nottinghamshire.-

As the workings of this colliery approached Stuffynwood Hall, fractures appeared nearly parallel to the advancing face. The conservatory walls were fractured and some cast-iron pipes, which gave the first warning of the fracture, were cracked at the cement joints. Other breaks developed at intervals, there being eventually six. When fully opened the first crack was $\frac{3}{4}$ " , the second and third $\frac{1}{4}$ " and the others about $\frac{1}{2}$ " wide. They attained their maximum width when the working face was almost vertically underneath. Thereafter they began to close, and when the workings had advanced about 300 feet further, the walls had practically resumed their normal position. Between the third and fifth fracture there was evidence after they had closed of considerable crush.¹

Skegby Churchyard.-

In 1893 cracks formed in the walls of this churchyard as the result of working coal from the Teversal Pit, Nottinghamshire. A wall parallel to the face was observed to be leaning towards it, but ^{was} not fractured or out of line. The cracks gradually opened, being widest at the top. The greatest gap of 8" was attained when the face was almost vertically below them. Then compression supervened, being eventually sufficient to throw up the stonework in the form of a segment of a circle. A portion of the wall had to be rebuilt.²

Damage and cracks are not confined to shallow workings, although generally damage is harsher over them. J. Dickinson mentioned cracks wide enough to put his foot into/

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1. W. Hay, "Damage to Surface Buildings caused by Underground Workings", Trans. Inst. Min. Engrs., XXXVI, 1908, p. 427.
 2. J. Piggford, "Notes on Subsidence caused by Coal Workings at Teversal and Pleasley Collieries", Trans. Inst. Min. Engrs., XXXVIII, 1909, page 122.

into over workings 1,800' deep.¹ He also observed that cracks 3'4" wide when the 10 yd. seam of South Staffordshire was being extracted at a depth exceeding 600 feet².

K. Stewart,³ in his observations, recorded a pull or draw (really a lateral shift of 2'6½"), and revealed the fact that this form of movement may extend beyond the zone of settlement. He estimated the elongation of the surface at the sides of the area of settlement in question at 3 - 4 ins. He also observed considerable compression over the centre of the area.

G.H. Ashwin⁴ tested the extention of the surface on the fringe of an area of settlement by measuring between pegs in that area. He found the elongation to be quite 10' over a distance of rather more than 1000 ft. - or about 1%.

In a recent investigation⁵ Thorneycroft observed as a longwall face approached Plean House, that the house tilted away from the advancing face. Thereafter it assumed a vertical position and then began to tilt toward the advancing face, finally assuming a vertical position after the face had advanced beyond it.

The foregoing illustrate the effects of the horizontal, tensile and compressive stresses, which are inseparable from the general process of subsidence, and although/

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1. Dickinson, Discussion of Goodwin's paper.
 2. Dickinson, Trans. Manchester Geol. Society, Vol. II, 1859, p. 13.
 3. K. Stewart, Discussion of "Some Notes on Subsidence and Draw", Trans. Min. Inst. Scot., Vol. VII, 1885-6, p. 224.
 4. G.H. Ashwin, Trans. Inst. Min. Engrs., Vol. IX, 1894-5, p. 107.
 5. W. Thorneycroft, "Effects on Buildings of Ground Movement and Subsidence caused by Longwall Mining", Trans. Amer. Inst. Min. & Met. Engineers, 1931.

although knowledge in this regard is now widespread, information as to the magnitude of those stresses is very scanty indeed. Yet such information is extremely important from the protection and design of property point of view. Indeed, when our knowledge of the magnitude and nature of these stresses has been increased our position with regard to the design and protection of property to withstand them will be materially strengthened, and incidentally, the compensation for damage caused by them may be materially reduced. In this investigation we synchronised the observations on the horizontal, tensile and compressive stresses, lateral movement and amplitude of subsidence, and in our results and conclusions we have attempted to show the relation between these branches of the subject.

OBSERVATIONS AND METHODS OF MEASUREMENTS.-

The observations and measurements were confined to Area No. 2, the stations $A_L-1_L-7_L$ to B_L and 8_L-14_L being utilised for this purpose. The measurements were made by means of a steel band, graduated to .01'. The observations on the line $A_L-1_L-7_L-B_L$ indicate the state of the surface with regard to stress on a line

Parallel to the line of face
and at right angles to the
direction of advance.

Those made between the stations $1_L-14_L-13_L$ indicate the state of the surface with regard to stress

On a line parallel to the direction
of advance of the face,

and also by measuring the distance between the draw stations
 A to 1_L and 7_L to B ,

The stretch of the ground on the
fringes of the area of settlement
was ascertained.

The following is a brief description of the results of the observations and measurements:

The observations and measurements made in June indicated/

Table No. 5.

Year	1950	1951	1952	1953
A	1000000	1000000	1000000	1000000
B	1000000	1000000	1000000	1000000
C	1000000	1000000	1000000	1000000
D	1000000	1000000	1000000	1000000
E	1000000	1000000	1000000	1000000
F	1000000	1000000	1000000	1000000
G	1000000	1000000	1000000	1000000
H	1000000	1000000	1000000	1000000
I	1000000	1000000	1000000	1000000
J	1000000	1000000	1000000	1000000

HORIZONTAL TAPE MEASUREMENTS

BETWEEN SURFACE LEVELLING STATION.

39.89 p. 57
 out-
 mar. 0.04

1	2	3	4	5	6	7	a
66 66 66 66.05 66.08 66.14 66.22 66.24 66.27 66.26	66.00 65.95 65.94 65.93 65.88 65.87 65.81 65.82 65.80	66.10 66.05 66.06 65.05 66.00 65.97 65.97 65.91 65.93	66.10 66.10 66.10 66.00 65.93 65.93 65.94 65.91 65.92 65.91	65.83 65.78 65.78 65.78 65.79 65.82 65.82 65.82 65.81 65.80	66.32 66.23 65.96 65.92 65.88 65.88 65.85 65.84 65.82 65.82	39.98 39.98 39.98 40.00 40.05 40.06 40.08 40.08 40.10 40.12	21st April, 1929. 2nd June, 1929. 8th August, 1929. 1st September, 1929. 1st October, 1929. 2nd November, 1929. 1st December, 1929. 2nd January, 1930. 2nd February, 1930. 1st March, 1930.
↑ .26	↑ .20	↑ .18	↑ .19	↑ .03	↑ .50	↑ .14	
	16) 26.4 (1.40%		1.10	330		40/14 .35%	
			330) 1100 990 1100	(.33%			

11.12.29

19.57
 2.0

HORIZONTAL MEASUREMENTS

BETWEEN STATIONS.

14	13	12	11	10	9	8	7	6	5	4	3	2	1
66.07 66.08 66.10 66.10 66.12 66.20 66.27 66.32 66.35 66.39 66.39 -32	66.12 66.12 66.11 66.08 66.10 66.09 66.02 65.00 65.97 65.93 65.92 -.20	66.20 66.19 66.23 66.22 66.24 66.19 66.18 66.14 66.11 66.10 66.09 -.11	66.28 66.30 60.25 66.23 66.15 66.15 66.19 66.22 66.21 66.21 66.21 -.07	66.10 66.04 66.06 65.95 65.94 65.99 65.97 65.94 65.90 65.89 65.88 -.22	66.23 66.17 66.15 66.07 66.00 66.05 65.95 65.94 65.93 65.92 65.90 3.3	66.23 66.17 66.15 66.07 66.00 66.05 65.95 65.94 65.93 65.92 65.90 3.3							
14	13	12	11	10	9	8	7	6	5	4	3	2	1

-33

+32

93 in 330

(.28%)

330) 930
 260

 2700
 2640

 600

Table N°8.

indicated a reduction in the distances between the stations 2_L to 7_L . The greatest reductions occurred between stations 5-6, 6 - 7, the area where settlement was first detected, and where 'amplitude' was a maximum. During June, July and August the distances between these stations were further reduced; the other stations, however, had not yet been affected.

During September, however, compression increased slightly from 2_L - 7_L , and the surface between 1_L and 2_L suffered a slight elongation (indicating tension in this zone). In the areas embracing stations 7_L to 13_L and A_L - 1_L the distances were normal; the surface, therefore, was free of stress. An interesting observation here was that although the distance between 1_L - 2_L had been increased, the station No. 1 had not subsided.

October: Stations 2 - 7 were still subsiding on that date, and compression, as a consequence, had increased between all the stations except 5 - 6, where it was slightly reduced. The surface between 1_L and 2_L has been subjected to a further tension, and the distances between the station 7_L to B_L and A_L to 1_L increased for the first time, indicating the onset of tension.

October to March: The measurements and observations then indicated increased compression towards the centre of the line, and increased tension over and beyond the edges of the mined area.

The difference between the original and final distance between the stations was as under:

<u>Stations</u>	<u>Difference (in feet)</u>	<u>State of Ground with regard to Stress.</u>
1 - 2	+ .26	Tension
2 - 3	- .20	Compression
3 - 4	- .18	"
4 - 5	- .19	"
5 - 6	- .03	"
6 - 7	- .50	"
7 - B	+ .14	Tension

The/

The results of the observations and measurements were confirmed, by a similar series of observations and measurements on the line $8_L - 14_L$.

The difference between the original and final distance between the stations and the final state of the surface with regard to stress on the line $8_L - 14_L$ is indicated below:

<u>Station</u>	<u>Difference (in feet)</u>	<u>State of Surface with regard to stress.</u>
14 - 13	+ .32	Tension
13 - 12	- .20	Compression
12 - 11	- .11	"
11 - 10	- .07	"
10 - 9	- .22	"
9 - 8	- .33	"

This concludes the work on a line parallel to the line of face.

OBSERVATIONS AND MEASUREMENTS (MADE BETWEEN STATIONS $1_L - 14_L$, $2_L - 13_L$ AND SO ON) IN A DIRECTION PARALLEL TO THE DIRECTION OF ADVANCE OF THE FACE.-

The results of the above observations and measurements are set out in Table No. 8. The dates indicated therein coincide with the dates of the amplitude and lateral movement observations. The successive positions of the face with reference to the point of observation, on the date on which the observations were made, are shown on Diagram No. 27.

Four distinct relative phases of the process were observed, and they can be illustrated by considering the variation in the measured distance between stations 6_L and 9_L .

The original distance between those stations was 33.60'. By June this distance had increased to 33.88'. Thereafter the distance increased until August, when it reached a maximum of 33.93'.

The First Tension Phase:

During September and October there was a reduction/

Table № 10.

№	Имя	Возраст	Пол	Профессия	Образование	Семейное положение	Состояние здоровья	Примечания
1	Иванов Иван Иванович	45	Мужчина	Инженер	Высшее	Женат	Хорошо	
2	Петров Петр Петрович	32	Мужчина	Учитель	Среднее	Неженат	Удовлетворительно	
3	Сидоров Сергей Сергеевич	28	Мужчина	Рабочий	Среднее	Женат	Хорошо	
4	Климов Алексей Алексеевич	55	Мужчина	Пенсионер	Высшее	Вдовец	Удовлетворительно	
5	Васильев Владимир Владимирович	22	Мужчина	Студент	Среднее	Неженат	Хорошо	
6	Михайлов Михаил Михайлович	40	Мужчина	Рабочий	Среднее	Женат	Удовлетворительно	
7	Попов Павел Павлович	38	Мужчина	Инженер	Высшее	Женат	Хорошо	
8	Смирнов Николай Николаевич	50	Мужчина	Рабочий	Среднее	Женат	Удовлетворительно	
9	Зайцев Александр Александрович	30	Мужчина	Учитель	Среднее	Неженат	Хорошо	
10	Кузнецов Константин Константинович	42	Мужчина	Рабочий	Среднее	Женат	Удовлетворительно	

This page contains a table with 10 rows and 9 columns. The columns are labeled: №, Имя, Возраст, Пол, Профессия, Образование, Семейное положение, Состояние здоровья, and Примечания. The rows contain data for individuals with names like Иванов, Петров, Сидоров, etc.

The text on the right side of the page is very faint and mostly illegible. It appears to be a continuation of the document or a separate section of text.

EXTENSION OF STRETCH OF GROUND OVER AND

BEYOND THE AREA OF EXCAVATION.

Pegs spaced at intervals of approximately 10 feet were installed over and beyond the excavated area. Their direction can be observed on plan; it is approximately at right angles to the direction of advance and parallel to the line of face. The primary object of the pegs was to determine the extent of the Draw. Measurements were taken from to No. 1 Peg. The original distances are given on the first line; the others are as found at the different lines and intervals.

	8/8/29	1/9/29	1/10/29	1/11/29	1/12/29	2/1/30	1/2/30	1/3/30	31/3/30	After this date Pegs are constant	Stretch and Compression
Orig.											
74.53	74.53	74.53	74.53	74.53	74.53	74.53	74.53	74.53	74.53	74.53	nil
84.53	84.53	84.53	84.53	84.53	84.53	84.53	84.53	84.53	84.53	84.53	.01 +
88.50	88.50	88.50	88.50	88.50	88.50	88.50	88.50	88.50	88.50	88.50	.04 +
6.07	6.07	6.07	6.07	6.07	6.07	6.07	6.07	6.07	6.07	6.07	.09 +
16.02	16.02	16.02	16.03	16.03	16.03	16.03	16.03	16.03	16.03	16.03	.12 +
26.12	26.12	26.12	26.15	26.15	26.15	26.15	26.15	26.15	26.15	26.15	.16 +
36.10	36.10	36.13	36.14	36.16	36.16	36.17	36.19	36.19	36.19	36.19	.22 +
46.13	46.13	46.13	46.17	46.20	46.20	46.23	46.23	46.23	46.23	46.23	.16 +
56.12	56.12	56.14	56.16	56.23	56.23	56.25	56.27	56.27	56.27	56.27	.06 +
66.05	66.05	66.08	66.18	66.22	66.22	66.24	66.26	66.27	66.27	66.27	.16 +
76.15	76.15	76.17	76.22	76.26	76.26	76.28	76.31	76.31	76.31	76.31	.16 +
86.26	86.27	86.27	86.34	86.36	86.36	86.37	86.39	86.39	86.39	86.39	.13 +

Compression

reduction in the above distance and on the date of the October observation the distance was back to normal, i.e., 33.60'.

The Second Phase (Stress in Surface nil):

From October to January there was a progressive reduction in the above distance until the minimum distance of 33.46' was recorded.

The Third Phase (Compression):

Thereafter the distance between the stations progressively increased until March, when the final value of 33.60' was observed and recorded. The distance between the stations was back to normal.

The Fourth Phase (Stress in Surface nil).

STRETCH OF GROUND ON THE FRINGES OF THE AREA OF SETTLEMENT.-

This was demonstrated by linear measurements between the draw pegs 1 to 2 and 7_L to B set out at intervals of approximately 10 feet. Their positions, with reference to the 'ribsides' underground, can be seen on the large plan. The results of the observations and measurements are shown on Tables No. 9+10. The original distances between the pegs are those under the date 8/8/29. A perusal of Tables No. 9+10 reveals that 'the stretch' increased progressively (from the position where settlement virtually starts) towards the ribside.

PART I

SECTION 3

HORIZONTAL, TENSILE AND

COMPRESSIVE STRESSES

CAUSED BY

SUBSIDENCE.

RESULTS AND CONCLUSIONS.

RESULTS AND CONCLUSIONS.

(1) This inquiry has proved that the surface on the fringes of an area of settlement is under tension.

(2) When coal is removed by the longwall method of mining there are four relative phases in stress processes caused by subsidence, when observed in the direction of advance of the face.

The First Phase is characterised by tension which gradually increases to a maximum.

Second Phase: The intensity of tension gradually decreases to zero; the surface is then free of stress.

Third Phase: The surface during this phase of the process is subjected to compression, which gradually increases to a maximum.

Fourth Phase: The intensity of compression gradually decreases to zero, and the surface is again free of stress.

(3) There is a decided difference in the incidence of the horizontal, tensile and compressive stresses caused by subsidence when observed
 (i) in a direction parallel to the direction of advance of the face;
 (ii) in a direction parallel to the line of face.

(4) The stresses set up in a direction parallel to the line of face are compressive towards the centre and tensile towards and over the edges of the mined area.

(a) At the centre compression is a minimum and may be absent;

(b) As we travel towards the edges of the area of settlement, compression increases to a maximum and then decreases to zero, being finally replaced by tension.

(5)/

- (5) The nature and intensity of stress varies in different areas.
- (6) The surface in and beyond an area of settlement can be subjected to severe horizontal, tensile and compressive stresses without exhibiting any indications of their presence.

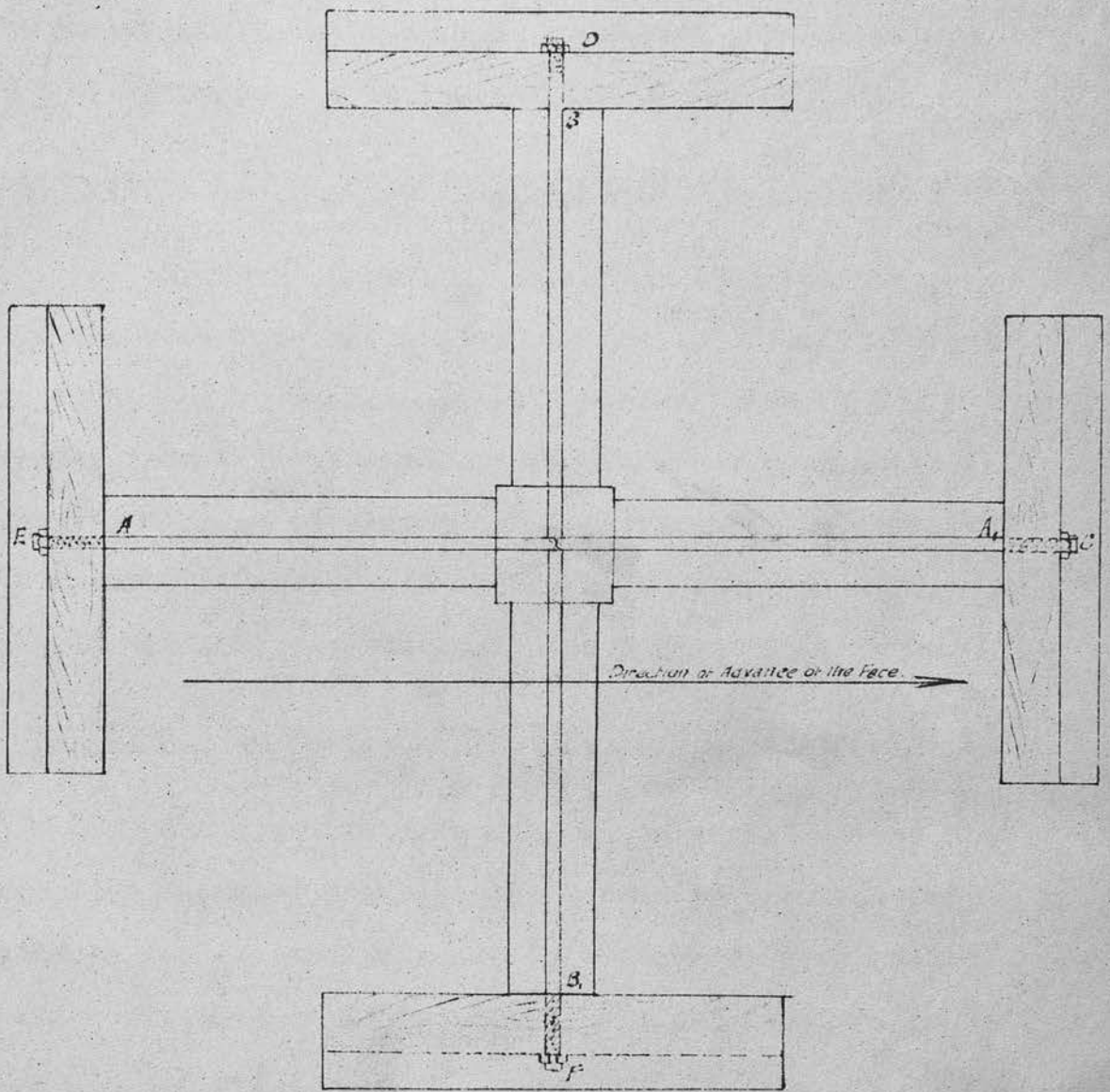
Contrast the surface road in this investigation with the cemetery, house and walls in Appendix No. 2.

- (7) Our observations and measurements indicate that at the surface tension never extends beyond the point where settlement starts.
- (8) From our observations we can reasonably infer that the worst possible position for surface structures, from the surface damage point of view, is the fringes of an area of settlement. Here the surface never assumes its original contour, and, as a consequence, structures are permanently deflected from the vertical. Further, the stresses in this zone are tensile (permanently) and, as a result, structures may be rent asunder.

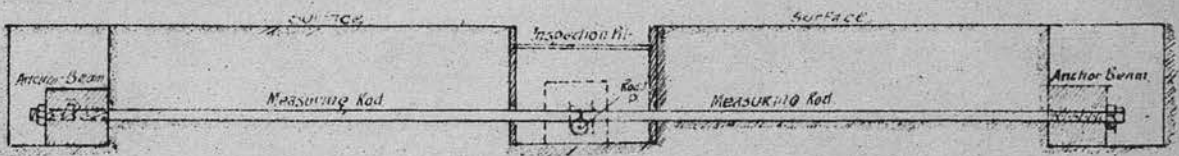
INTRODUCTORY.-

Many and diverse are the methods by which the incidence of the horizontal, tensile and compressive stresses in the surface over a mined area can be demonstrated. Perhaps the most commonly used and satisfactory method is that of linear (tape) measurement. A wall running parallel to or at right angles to the direction of advance of a face, as diagram No. clearly illustrates, is an excellent, if somewhat crude automatic indicator. There is another method, that of installing measuring rods a few feet below the surface, which, although not so commonly employed, is very satisfactory and can be applied in situations where circumstances may make the installation of concrete monuments and direct linear measurements undesirable, and perhaps impossible. For example, in the centre of a field, which is being cultivated and ploughed. It is this latter method we are chiefly concerned with and propose to describe.

For the purpose of measuring and observing the horizontal, tensile and compressive stresses caused by subsidence, ^{and} of demonstrating the method of measurement, the apparatus shown on diagram No. II. was installed in the field in advance of, but adjacent to, the surface roadway. The installation involved the setting out and excavation to a depth of 3' of an inspection pit 4' x 4' in which the observations and measurements were made, of two main trenches AA₁ and BB₁ each 33 feet long and four others, CDEF on the diagram, each 16 feet long. Anchor beams were placed in the trenches CDEF, and extension rods, (of which there were four sets, each approximately half the length of the main trenches, AA₁-BB₁) were securely attached to them and set out along the bottom of the trenches A and A₁ and B and B₁. An inspection pit 4' x 4' x 3' was excavated and lined at the place where the trenches A A₁ and B B₁ intersected/



- PLAN -



- SECTION A.A. - Fig. No. 11.

Diagram illustrating Surface (Rod) Arrangement
 For Measuring Horizontal Tension and Compression.

- Scale of feet -



intersected. The trenches were then filled up. Thus we had in the centre of the inspection pit the ends of the four sets of measuring rod which just touched and could be utilized in the determination of the stretch or otherwise to which the surface was subjected; and observations and measurements could be made no matter what operations were being performed at the surface of the ground.

OBSERVATIONS AND MEASUREMENTS IN DIRECTION OF ADVANCE OF THE FACE.-

Observations were started on 25th February, 1930, when the coal face was almost vertically under the short trench C, and an overlap of .25" was recorded. The overlap gradually increased as the face advanced until July when the maximum overlap of 3' was observed. Thereafter the overlap decreased and on the 16th December, 1930, the date of the last observations, was 2'2".

OBSERVATIONS AND MEASUREMENTS IN A DIRECTION PARALLEL TO THE LINE OF FACE.-

Observations were made at intervals of one month from 25th February onwards. The results are recorded on Table No. (overleaf) and indicate that the rods were pulled apart a distance of $\frac{1}{2}$ " on the 26/3/31 and remained in that position thereafter.

RESULTS AND CONCLUSIONS.-

We do not propose to discuss the results of the experiments just described, for although the observations have been somewhat late in being started, and, as a result, the later part of the stress processes only has been recorded, we have already dealt very fully in Part No. 1. Section III of this work with the Horizontal, Tensile and Compressive stresses caused by subsidence. Our chief purpose was to demonstrate this method of measurement and this we have done/

done.

<u>Date</u>	<u>Overlap</u>	
	<u>A - A₁</u>	<u>B - B₁</u>
25/2/30	.25"	1/10"
18/3/30	.56"	
26/3/30	1.58"	1/4"
4/5/30	2.50"	
5/6/30	2.75"	1/2"
2/7/30	3.00"	
5/8/30	3.00"	1/2"
8/9/30	2.5 "	1/2"
9/10/30	2.5 "	1/2"
10/11/30	2.5"	1/2"
10/12/30	2.5"	1/2"

A A₁ in a direction parallel to the direction
of advance of face.

B B₁ in a direction parallel to the line of
face.

PART I

SECTION 4.

LATERAL AND LONGITUDINAL

MOVEMENT.

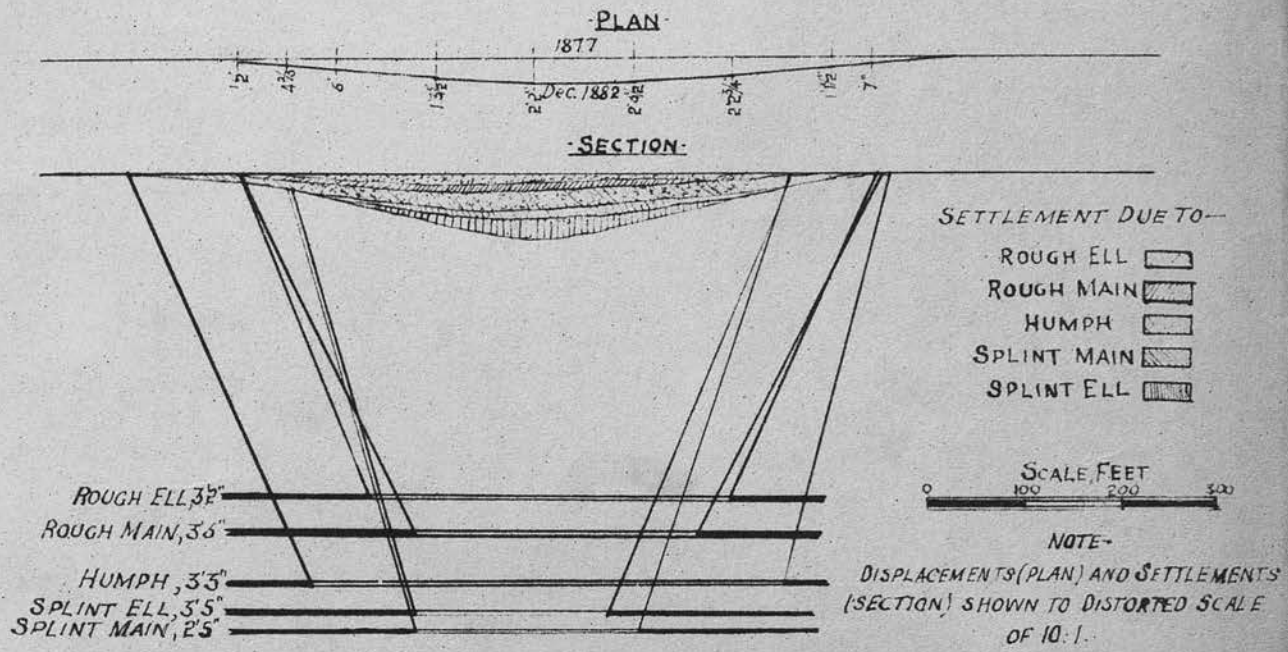
INTRODUCTORY.-

Lateral movement of the surface during the onset of subsidence is of great importance in view of its destructive effects. It is now generally recognised that the general process of subsidence involves a lateral and longitudinal displacement of the surface, and that its presence is most obvious on the fringes of an area of settlement. That lateral movement may amount to several feet is not so generally recognised however; yet in one recorded instance in North Staffordshire, a surface point was shown to have moved transversely 5.9' during the period 1870 to 1923, and a further 1.5' since then. At the point in question the vertical settlement was only 15", but it increased to 11 feet at a point $1\frac{1}{2}$ miles away.¹ Mention of the importance of this form of movement, from the damage point of view, was first made by Dr. R.T. Moore, who, when contributing to the discussion of Dr. J.S. Dixon's paper,² gave particulars of levellings carried out over a period of $4\frac{1}{2}$ years during and subsequent to the removal of the Ell Coal (7 feet) at Allanshaw Colliery, the bord-and-pillar method being used. The depth was about 720 feet. Here the maximum settlement was 4.13 feet, or 59%. Unfortunately the sections did not extend beyond the mined area and therefore draw was not measured; but a farm house 195' in advance of the face was cracked so that the angle of draw was at least 15° . A matter of much interest arises in connection with this house. Despite the considerable damage done, it had only subsided 1 inch. Referring to this house, Dr. Moore made the important observation:

"That in his opinion the injury was due to lateral movement preceding vertical sinking".

K. Stewart furnished particulars of an admirably detailed/

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1. Hutchieson, Trans. Inst. Min. Engs., LXXVI, 1929, page 307.
 2. Dixon, "Some Notes on Subsidence and Draw", Trans. Min. Inst. Scot., VII, 1885-6, page 224.



- Plan and Section of Subsidence at Govan Colliery (after R. Stewart) - *Fig. No. 12.*

detailed example of subsidence in stages. The subjoined figure, after Dr. Briggs, has been constructed from his charts. He not only measured vertical movement, but also ascertained the lateral displacement caused by the advancing faces on a line roughly parallel to them. The coal was removed in each of five seams in succession, a sixth and uppermost seam having been worked long before. The pillar had waste on each side. The seams were removed in the order in which they appear in Tables No. II., where particulars of amplitude and draw are recorded. He observed that draw, if anything, was increased by the wastes at the sides of the mined area. The important part of K. Stewart's contribution from the point of view of the section is that which refers to lateral movement, and is briefly as follows: The line parallel to the faces, see diagram No. set out straight in 1877 was considerably bent by 1882, when the fourth, but not the fifth, seam had been extracted. The lateral displacement was $2'6\frac{1}{2}"$ in a direction towards the advancing faces; and continued beyond the area of settlement on the right hand side. Tension and compression was also indicated in the area affected by subsidence. The surface beds were sand and strong brick clay, the latter being 40' thick.

Table. No. II.	Thickness		Depth ft.	Greatest Amplitude			Draw on Left Side		Draw on Right Side	
	ft.	ins.		ft.	ft.	in.	per cent	ft.	Degrees	ft.
Rough Ell	3	2	330	1	2	37	130	$21\frac{1}{2}$	140	23
Rough Main	3	6	366	1	2	33	180	26	180	26
Hump	3	2	420	2	3	71	about 200	about $25\frac{1}{2}$	110	15
Splint Main or Virgin	2	5	468	0	10	34	160	19	150	$17\frac{1}{2}$
Splint Ell	3	5	453	2	3	66	-	-	180	$21\frac{1}{2}$
Greatest total depression at any point 7 feet 3 ins. or 49 per cent. Average angle of draw, $21\frac{1}{2}$ degrees.										

Recently Auchmuty and Thorneycroft have furnished
important/

information on ground movement, the method of measurement employed by Thorneycroft being somewhat novel. (See Resume of Recent Researches).

The importance of the form of movement is now being more generally recognised - and rightly so - for, as Dr. Briggs recently stated:¹

"Apart from material considerations a better knowledge of the incidence of such movements is likely to assist in the elucidation of the mechanics of subsidence perhaps to a greater degree than anything else!"

In this enquiry we were chiefly concerned with longitudinal movement, although lateral movement was also observed in Area No. 1. Unfortunately, the observations were a little late in being commenced in this area, and, as a consequence, the later part of the process only was observed. We have synchronised the observation on lateral movement, amplitude and the horizontal, tensile and compressive stresses caused by subsidence. (This synchronisation has not hitherto been attempted) and we have attempted in our conclusions to show the relationship between these different branches of the subject.

OBSERVATIONS AND MEASUREMENTS.-

For the purposes of this inquiry stations A₁, 2_E, 3_L to 7_LB were set out in a perfectly straight line along one side of the road at the surface. Stations 8_L and 14_L were set out by measurements, and the intervening stations (9_E, 10_L, 11_E, 12_L, 13_L) ranged in line by means of the theodolite. This work was performed before the ground was affected by subsidence. Since AB were never affected by subsidence the movement of any station could be ascertained by planting a theodolite at A, sighting at pole at B and ranging poles in the line opposite each station.

The/

1. Briggs, "Subsidence Problems", Colliery Engineering, Jan. 1930, vol. VII, page 22.

The measured distance between the centre of a pole and the centre of a station gave the direction and magnitude of the lateral movement of the station. By measuring the distance between the poles and the stations 1_L-14_L , 2_L-13_L and so on; the lateral movement of the stations 8_L-14_L was also ascertained. Observations were made at intervals of approximately one month on lateral movement, vertical settlement and the horizontal and tensile and compressive stresses caused by subsidence. The observations were synchronised with those made underground.

The results of the observations and measurements on lateral movements, together with their positions with relation to the coal face underground, are illustrated graphically on diagrams Nos. 13 to 24.

RECORD OF OBSERVATION ON AREA NO. 1.-

The stations in this area were finally deflected towards the solid coal, i.e., in a direction parallel to the direction of advance of the face.

In Area No. 2, the sequence of events was as follows: The first observations were those made on the 22nd April, 1929, when the face was a few feet in advance of the line of the stations and indicated a deflection at stations 3_L , 4_L , 5_L , 6_L and 7_L towards the mined area, i.e., in a direction opposite to the direction of advance of the face. The values of the deflections were:

<u>No. 1</u>	<u>No. 2</u>	<u>No. 3</u>	<u>No. 4</u>	<u>No. 5</u>	<u>No. 6</u>	<u>No. 7</u>
0	0	.10'	.15'	.22'	.25'	.26'.

June: Observations were made in June; the deflection values then were

0	0	.10	.10	.22	.25	.33
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During July and August the stations 6_L and 7_L began to move in the opposite direction. They were now moving in the direction of advance of the face; the other stations still continued to move in the opposite direction. The values of the deflection measured on 8th August, 1929 were:

No./

<u>No. 1</u>	<u>No. 2</u>	<u>No. 3</u>	<u>No. 4</u>	<u>No. 5</u>	<u>No. 6</u>	<u>No. 7</u>
		.03	15	21	11	14

September: This month brought forth the interesting observation that the pegs 7, 6, 5 were back in their original positions.

Deflection values measured on 1st September, 1929:

<u>No. 1</u>	<u>No. 2</u>	<u>No. 3</u>	<u>No. 4</u>	<u>No. 5</u>	<u>No. 6</u>	<u>No. 7</u>
	0.03	.08	.11	-	-	-

October: Station No. 6 had actually moved beyond its original location, and took up a position indicating a deflection of .03' in the direction of advance of the face. Station No. 5 remained stationary, while the other stations, although still deflected towards the mined area, were moving in the same direction as the face, and towards their original position.

November: Stations Nos. 7, 6, 5 had then moved into positions which were .16', .13' and .19' beyond their original locations in the direction of advance of the face. Station No. 4 was in its original position; No. 3 was .03' beyond its original position, and Station No. 2 was just moving back into the line AB. Station No. 10 on the line $8_L - 14_L$ furnished the first evidence of movement on this line and it is important to note that

The face had advanced beyond the station
and that vertical movement had preceded
lateral displacement.

December: Stations Nos. 7, 6, 5, 4, 3 and 2 were all deflected in the direction of advance of the face, their respective deflection values being .32', .38', .30', .14', .20', .08'.

January: The stations were deflected in the same direction, the deflection values being .40', .37', .31', .32', .22', 0.

February/

February: Although there were small increases in some of the deflections the stations were now assuming their final positions. Deflection, .37', .39', .39', .32', .31', .24', 0. After February the movement ceased.

OBSERVATIONS ON THE LINE 8 - 14.-

This line was approximately 33.3' in advance of the line $1_L - 7_L$. The face had therefore to advance that distance beyond the position where horizontal movement started on line $1_L - 7_L$, before movement was recorded. It was observed that the face had advanced 3' beyond station No. 10 before that station began to move in a direction opposite to that of the advance of the face, and vertical subsidence preceded lateral displacement. Movement started on 1st September, 1929, the deflection observed at station No. 10 being .04' towards the mined area. In October all the pegs, except No. 14, were now moving towards the mined area; the distances moved were as under:

<u>No. 8</u>	<u>No. 9</u>	<u>No. 10</u>	<u>No. 11</u>	<u>No. 12</u>	<u>No. 13</u>	<u>No. 14</u>
0.00	0.10	0.17	0.20	0.14	0.5	0.00

November: The pegs continued to move in the same direction; the distances moved from the original positions of the station then were:

<u>No. 8</u>	<u>No. 9</u>	<u>No. 10</u>	<u>No. 11</u>	<u>No. 12</u>	<u>No. 13</u>	<u>No. 14</u>
0.00	0.01	0.08	0.13	0.16	0.14	0.00

December: The direction of movement of some of the stations was now reversed. Stations $8_L, 9_L, 10_L$ were now moving in the direction of advance of the face. The deflections were:

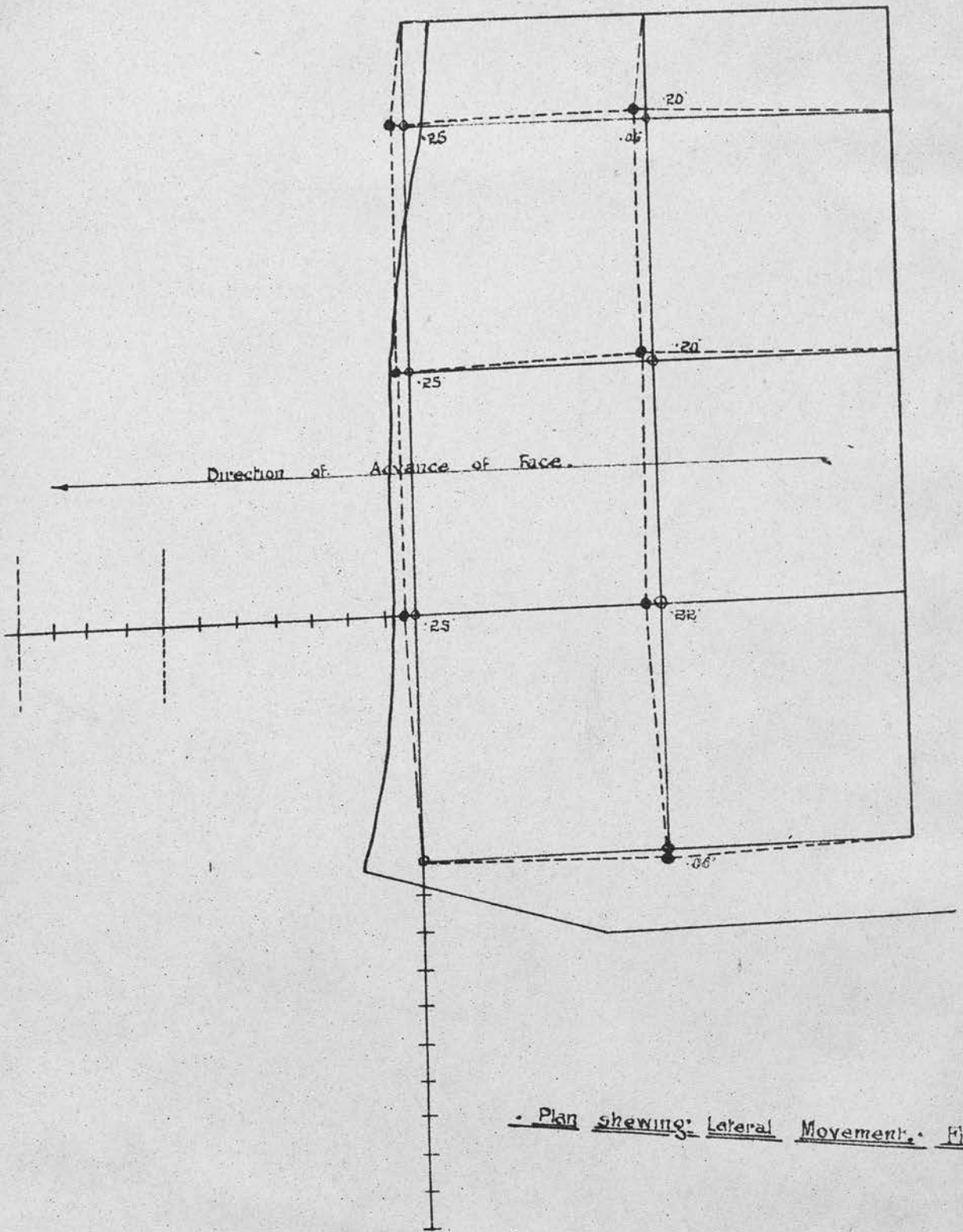
<u>No. 8</u>	<u>No. 9</u>	<u>No. 10</u>	<u>No. 11</u>	<u>No. 12</u>	<u>No. 13</u>	<u>No. 14</u>
0.18	0.29	0.07	0.04	0.09	0.03	0.00

In the direction of advance of the face.

In the opposite direction to the direction of advance of the face.

January: The stations on that date had all moved through their original positions, and were deflected to the locations indicated below:

<u>No. 8</u>	<u>No. 9</u>	<u>No. 10</u>	<u>No. 11</u>	<u>No. 12</u>	<u>No. 13</u>	<u>No. 14</u>
0.33'	0.39'	0.18'	0.14'	0.02'	0.12'	0.00'



Plan showing Lateral Movement. Fig. N°13

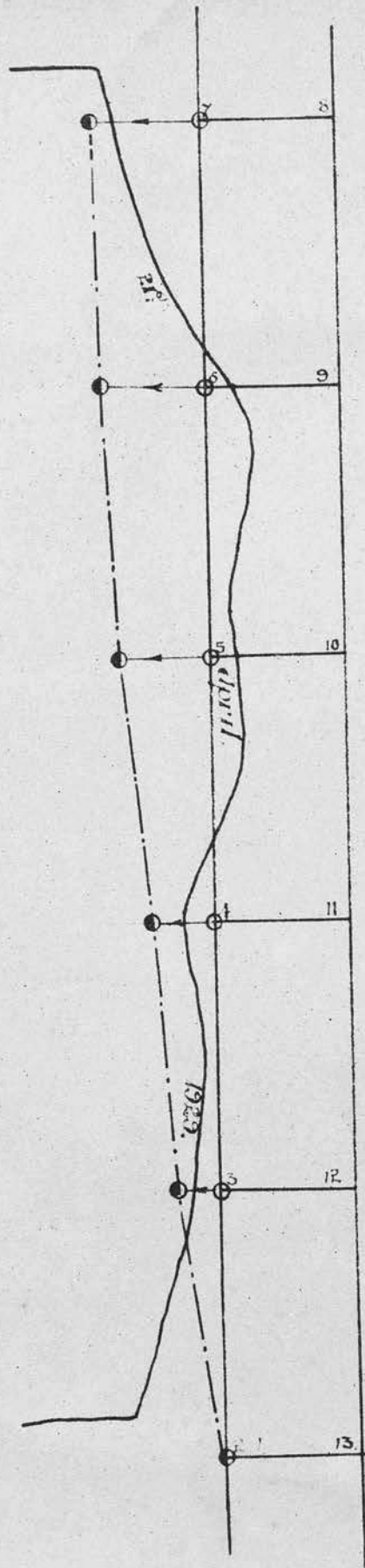
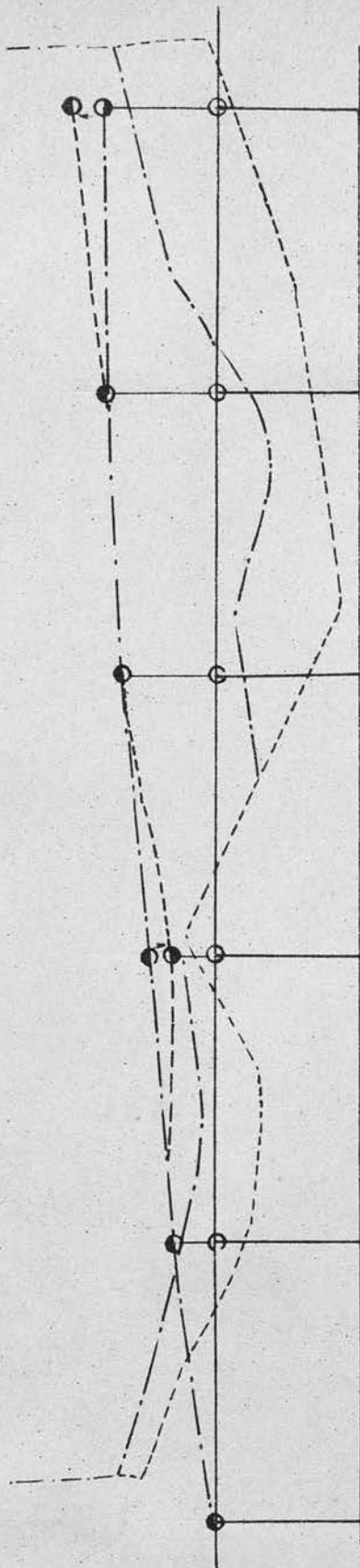


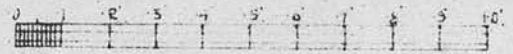
Fig. N^o 4.

21st April 1929.



Lateral Movement

Scale of Feet



Reference:

Face line on June shown thus -----

April -----

Lateral Movement profile on June shown thus -----

profile on April -----

Fig. No. 15.

5th June 1929.

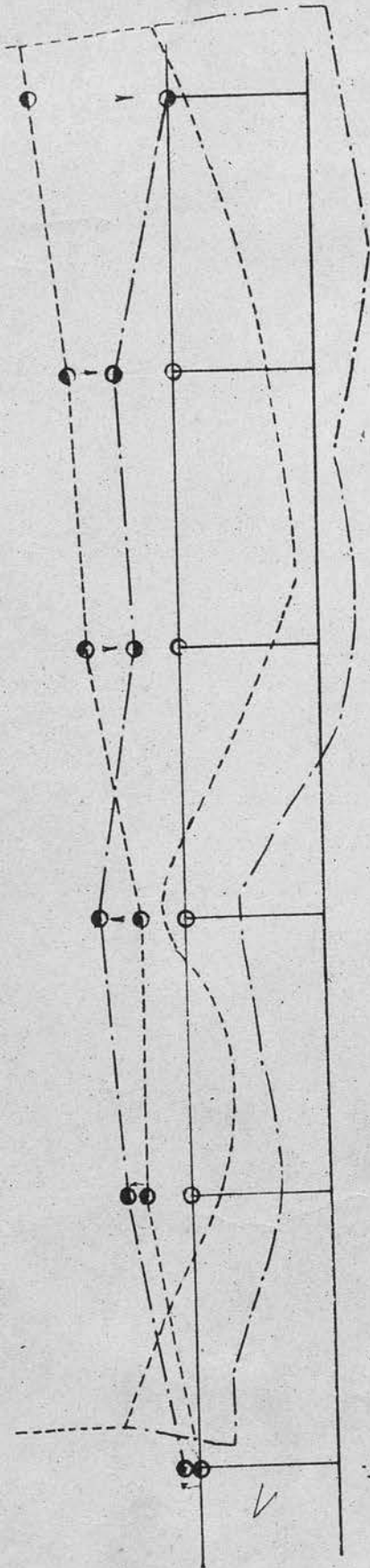
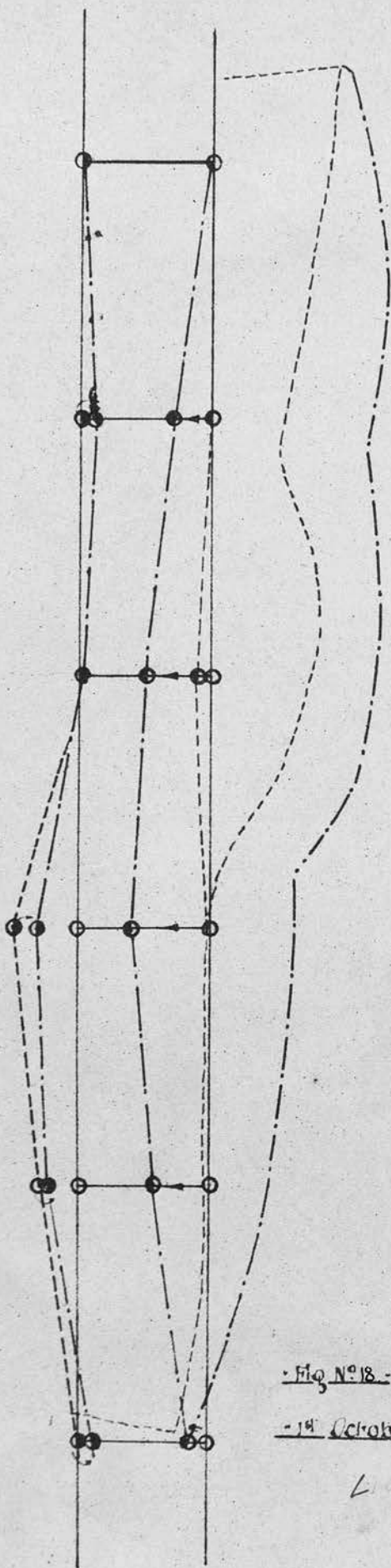


Fig. N° 16.

8th August 1923.

✓ 16



- Fig. N° 18 -

- 14 October 1929 -

✓

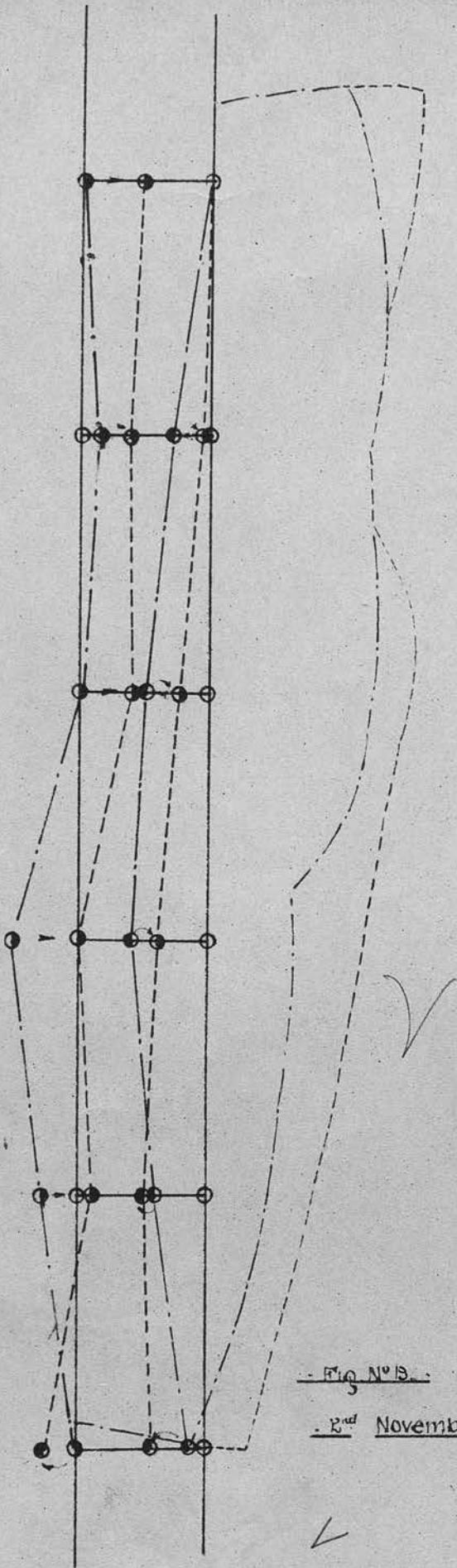


Fig N° 13.

3rd November 1929.



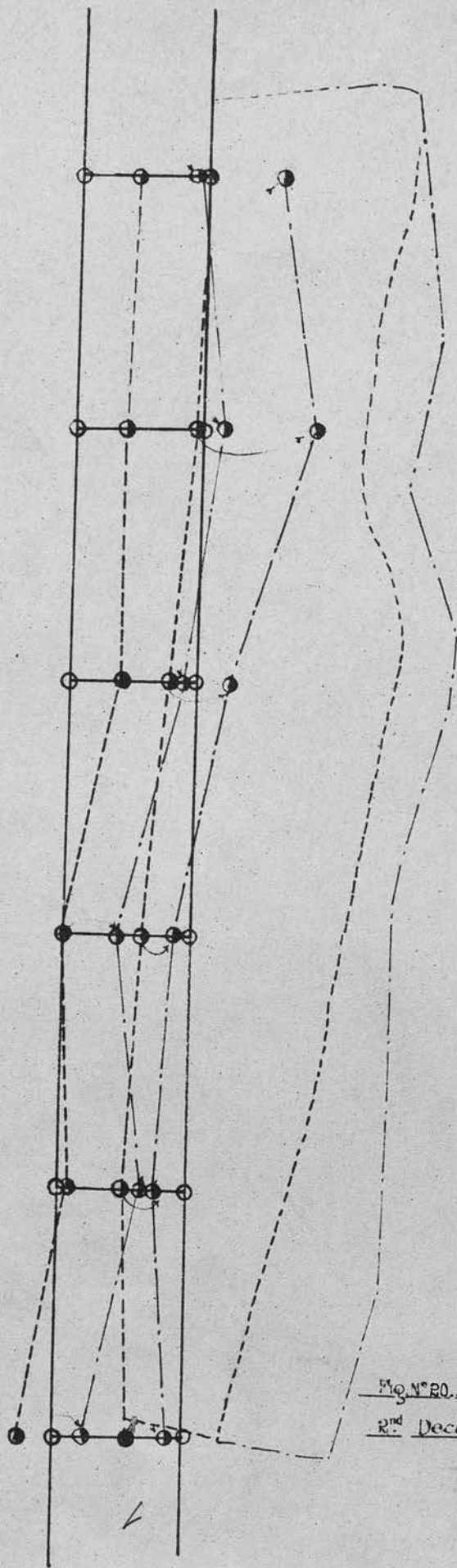
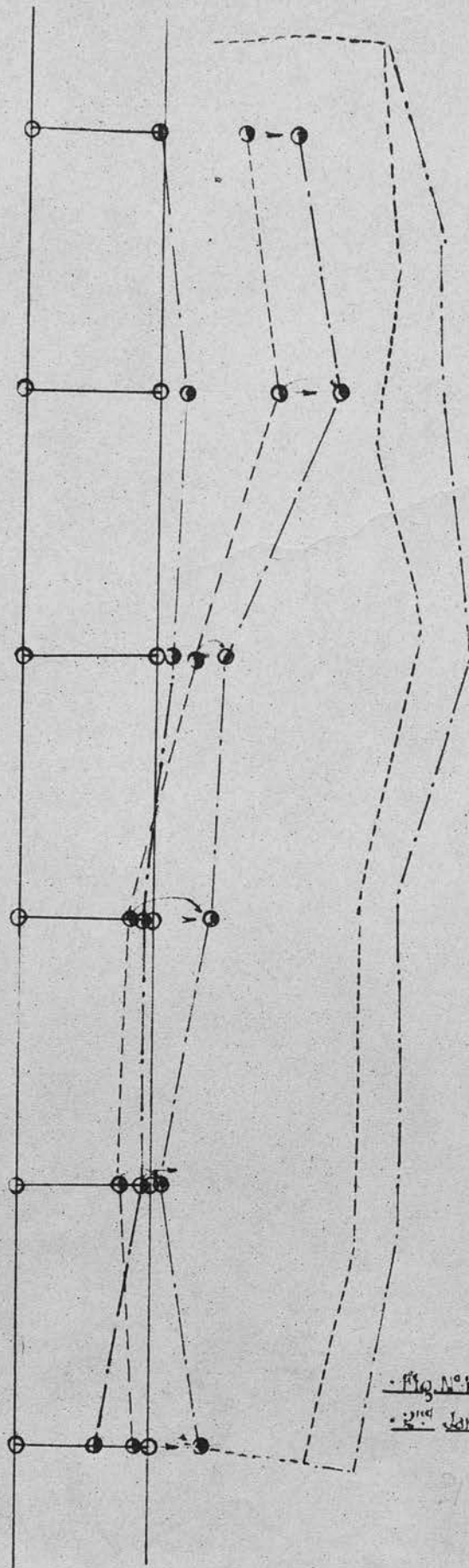
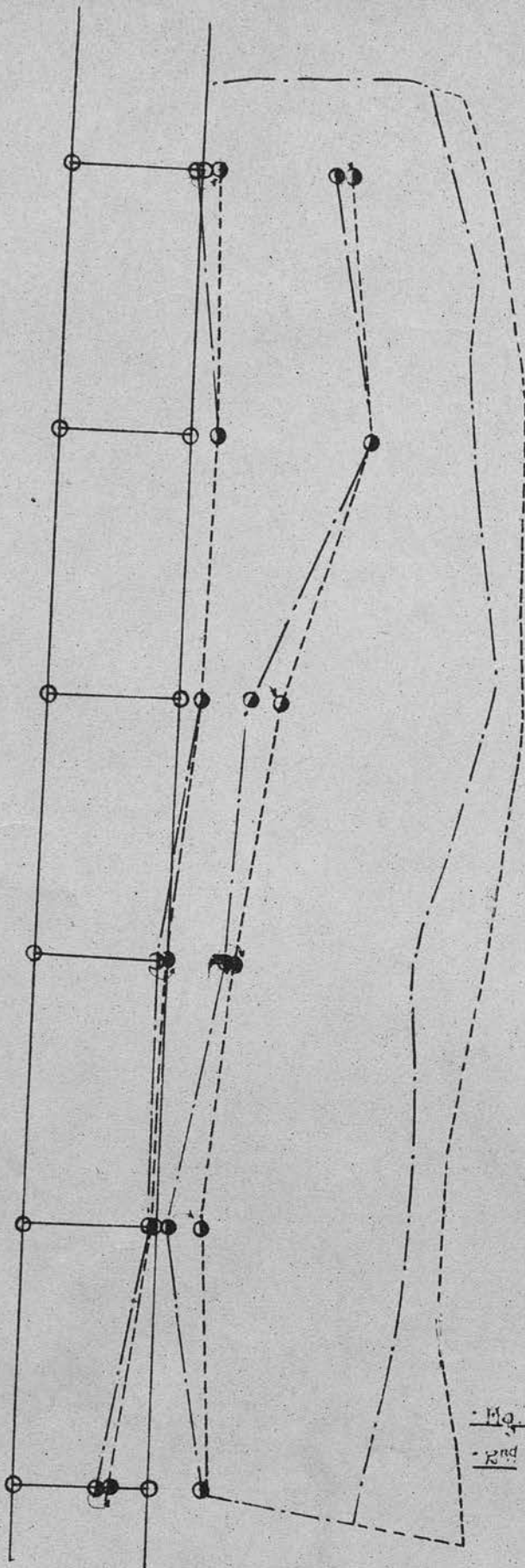


Fig. N° 20.

2nd December 1929.

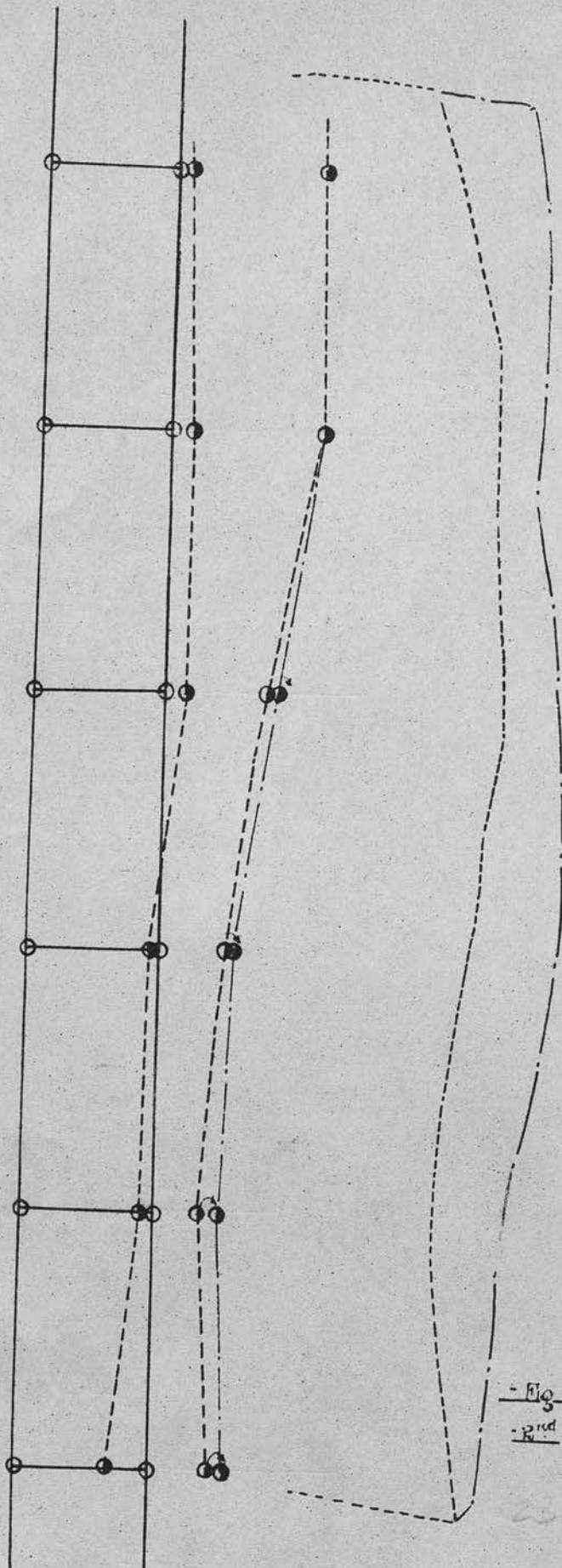


• Fig. N° 61. •
 • 2nd January, 1930 •

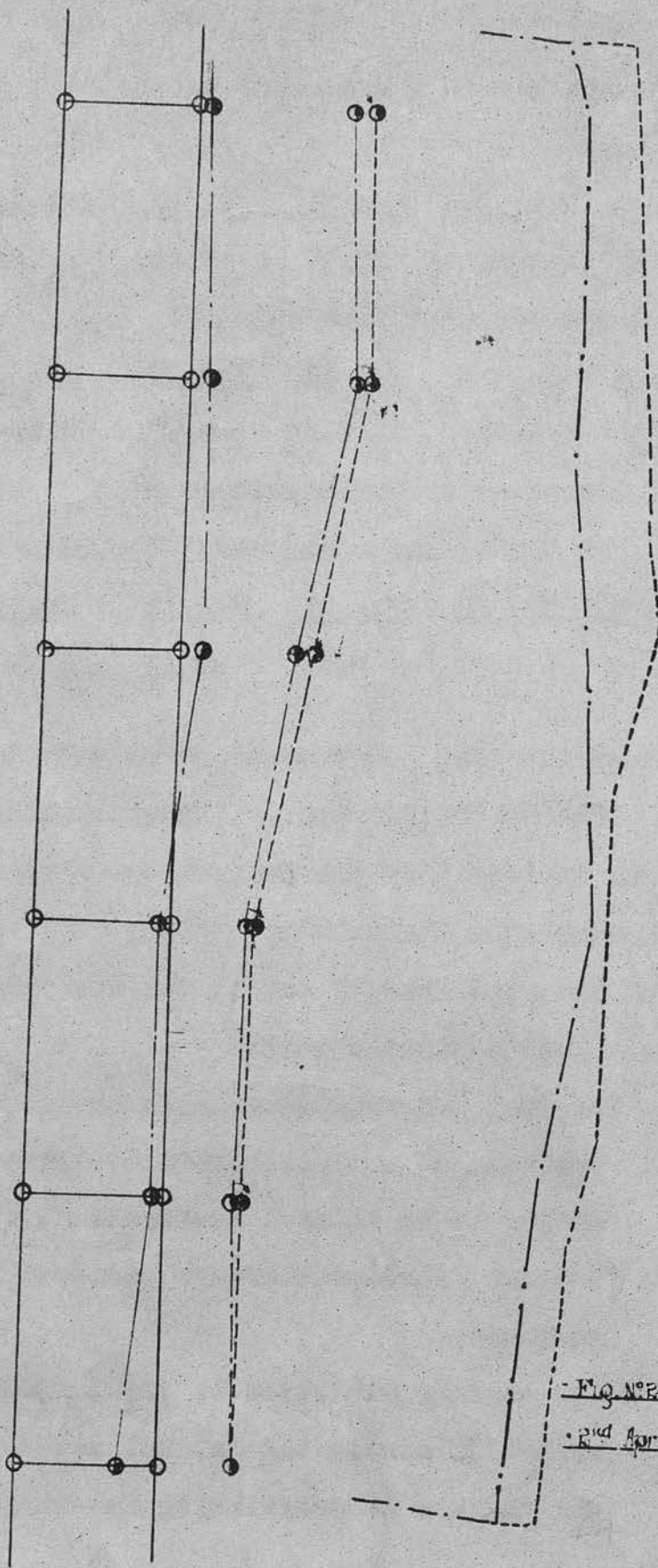


• Ho. No. 22.

• 2nd February, 1930.



- Fig. N° 25 -
- 2nd March 1950. -



- Fig. №24 -
- 2nd April 1930 -

The movement was now in the direction of advance of the face.

February: Movement was in the same direction, and the deflections as under:

<u>No. 8</u>	<u>No. 9</u>	<u>No. 10</u>	<u>No. 11</u>	<u>No. 12</u>	<u>No. 13</u>	<u>No. 14</u>
0.37	0.39	0.26	0.17	0.12	0.16	0.00

March: The figures recorded then were:

<u>No. 8</u>	<u>No. 9</u>	<u>No. 10</u>	<u>No. 11</u>	<u>No. 12</u>	<u>No. 13</u>	<u>No. 14</u>
0.39	0.41	0.28	0.19	0.17	0.19	0.10

April: Small increases in the magnitude of the movement were observed, but the movement was now 'slowing up':

<u>No. 8</u>	<u>No. 9</u>	<u>No. 10</u>	<u>No. 11</u>	<u>No. 12</u>	<u>No. 13</u>	<u>No. 14</u>
0.43	0.44	0.32	0.20	0.19	0.19	0.00

Observations and measurements were made during May and June. The stations, however, remained stationary at the positions indicated by the deflections above.

This completes the work on Longitudinal Movement. The chief points of interest brought out by the observations and measurements just described were:

- (1) The face had always advanced beyond the position of a station before it was subjected to lateral movement.
- (2) Vertical subsidence always preceded lateral movement.
- (3) When coal is extracted by the longwall method of mining the lateral movement of the surface is oscillating in character.

PART I

SECTION 4.

LATERAL AND LONGITUDINAL
MOVEMENT.

RESULTS AND CONCLUSIONS.

RESULTS AND CONCLUSIONS.

- (1) The movement diagrams demonstrate that where coal is extracted by the longwall method of mining, as the face advances towards, under, and beyond a station at the surface, the movement of that station is of an oscillating character when observed in the direction of advance of the face.
- (2) Although observations and measurements were not made to determine the direction and magnitude of the movement in a direction parallel to the line of face, we can infer from the tension and compression measurements that the movement, hereinafter referred to as lateral movement, (to differentiate between the movement occurring in a direction parallel to the direction of advance of the face, which is really longitudinal movement) is also of an oscillating character.
- (3) The movement on the fringes of an area of settlement is a combination of lateral and longitudinal movement, but we suggest that the final displacement will be greatest in a direction towards the centre of the mined area.
- (4) There are two relative phases in the incidence of longitudinal movement (phases (a) and (b)):
 - (a) During the onset of the first phase the surface moves in the opposite direction to the direction of advance of the face;
 - (b) The second phase is characterised by a movement in the same direction as the direction of advance of the face.
- (5) The face had always passed beyond a point at the surface before movement of that point commenced.
- (6)/

- (6) Vertical subsidence precedes lateral or longitudinal movement.

This is an important observation, and is in opposition to that made by Dr. R.T. Moore that "lateral movement precedes vertical settlement".

- (7) The movement starts towards the centre of the line of the advancing face, in the zone, therefore, which is first subjected to the horizontal, tensile and compressive stresses caused by subsidence and where vertical settlement commences.

- (8) Zones of maximum amplitude of subsidence coincide with zones of maximum longitudinal movement. This would suggest that longitudinal movement and amplitude are closely related.

- (9) The magnitude and direction of movement varies in different areas.

- (10) The line of movement follows the line of face.

This observation is important from the point of view of damage to property. In view of this fact, we suggest that where it is proposed to remove the coal under any important surface structure the line of face should be kept straight and should be parallel to the greatest length of the structure.

THE RELATION BETWEEN THE RATE OF SUBSIDENCE OF TWO STATIONS,
AND THE HORIZONTAL, TENSILE AND COMPRESSIVE STRESSES TO
WHICH THE SURFACE BETWEEN THEM IS SUBJECTED, AND THEIR
LATERAL AND LONGITUDINAL MOVEMENTS.-

To demonstrate this relationship let us consider the stations No. 5_L and No. 10_L. The surface levellings run during June and August indicate that the station No. 5_L was subsiding at the rate of .37' per month, and No. 10 at .14' per month. The horizontal, tensile and compressive observations indicate tension during that period. Through: out the months of September and October, Station No. 10_L and 5_L were subsiding at the rate of .49' and .22' per month respectively. The locus of the high rate of subsidence has been reversed and it was observed that the surface between those stations was now under compression, a reversal of stress.

We shall now consider the relationship between longitudinal movement and the horizontal stresses caused by subsidence. For this purpose let us consider the same stations No. 5 and No. 10. The original distance between them was 33.55'. When measured in June this distance was 33.80', the maximum distance recorded. Tension between the stations was therefore a maximum, and longitudinal movement was a maximum in a direction opposite to the advance of the face. Observations and measurements made during September indicated a reduction in this tension and a corresponding reduction in longitudinal displacement. During the period of September and October the surface between the stations was free of stress; the distance was back to the original 33.55', and station No. 5 was back in its original position. Then followed the compression phase, and compression was ^{at} a maximum when the distance between No. 5_L and No. 10_L was ^{at} a minimum, 33.00', and longitudinal movement in the direction of advance of the face had also reached its highest value. During the months of/

of January and April the intensity of compression was gradually reduced to zero, while longitudinal displacement remained constant.

CAUSE OF LATERAL AND LONGITUDINAL MOVEMENT OF THE SURFACE IN AN AREA OF SETTLEMENT.-

We hesitate to advance a cause for this movement, but tentatively suggest the following:

Lateral and longitudinal movement is caused by the difference in the rate of subsidence of points at the surface. Thus the difference of the rates of subsidence of a point situated towards the edge of the mined area, and that of a point situated just beyond the edge of that area, induces the pull or displacement of that point towards the mined area. Further, back in the zone where settlement is nearly complete, the rate of subsidence of a point is slower than that of a point in advance which has still to undergo considerable vertical settlement before it comes to rest. This difference causes a pull in the opposite direction and the point moves back towards the edge of the mined area.

In the paragraphs devoted to a description of the connection between horizontal movement and the horizontal stresses caused by subsidence, we have demonstrated that the stress and movement processes are concurrent processes in every phase except phase (d), during which compression of the surface decreases from a maximum to zero, and longitudinal displacement remains constant and a maximum in the direction of advance of the face. In view of the absence of confirmatory evidence, we do not propose to advance a reason for the cessation of horizontal movement during this phase. We, however, advance (tentatively) that the final displacement in the direction of advance of/

of the face may be due to the fact that this was the final direction of movement, and that the bias was therefore in favour of displacement in that direction. From the foregoing pages we suggest that the most important considerations - from the point of view of surface damage - are

- (1) The rate of advance, which should be as rapid as possible;
- (2) Regularity of rate of advance, which should be kept constant.

PART II

INTRODUCTION.

I N T R O D U C T I O N .

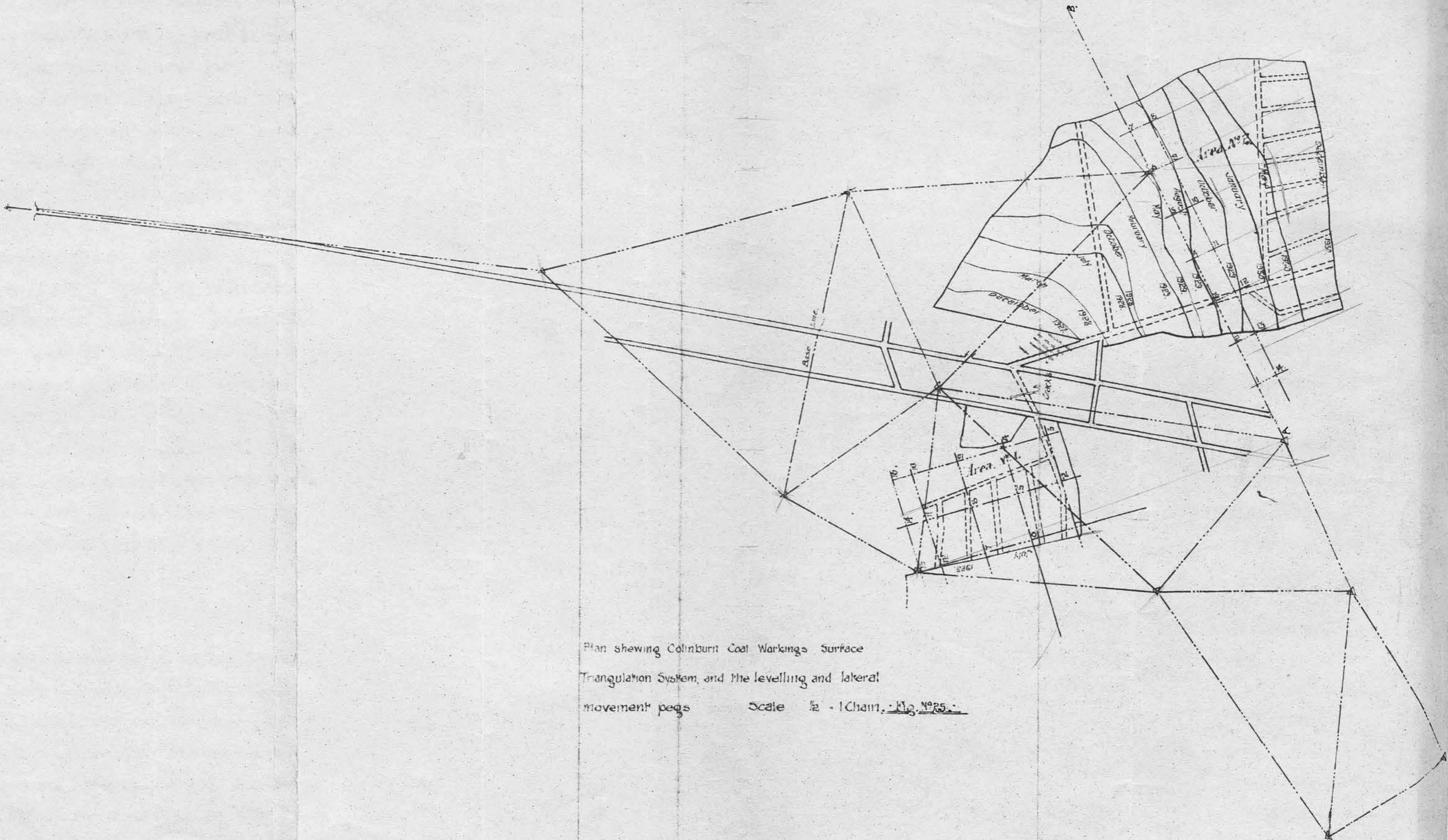
No matter how carefully surface measurements are made they can never attain full utility unless they are combined and synchronised with an equally exact description of underground operations. The immediate roof of the mine is the starting point of the process, and this is the common sense starting point of any scientific inquiry into the phenomena. Yet, in many of the recorded investigations information as to the method of working, packing, support, rate of advance of the face, presence or absence of old workings above or below the seam working is singularly scanty, and in most instances absent, although it is generally recognised that those factors, individually and collectively, have a profound influence on the general process of subsidence. In certain directions the investigation of subsidence has been woefully neglected, and in this regard one is struck by the absence of information on the effects of subsidence as revealed in the workings in seams situated at higher levels, although observations in workings situated above the working seam should furnish reliable information as to the processes of shearing and bending, and the causes of draw. Indeed, valuable as laboratory tests and experiments on the behaviour of rocks when subjected to stresses in a testing machine undoubtedly are, they can never replace nor furnish such reliable information as ^{will} Δ observations on the behaviour of different strata ^{as} Δ revealed when extracting coal at different levels.

In this investigation we synchronised the surface and underground observations in advance, at, and behind the coal face. The methods of measurement (used in the underground observations) are perhaps a little crude and the value of the work would have been enhanced if roof pressures had been recorded (by means of dynamometer props/

props) and continuous convergence records made by means of autographic recorders. Nevertheless, incomplete and crude as the observations undoubtedly are, they add to our knowledge of a branch of the subject where very little information is available.

858
 97
 841
 87
 17

858
 97
 841
 87
 17



Plan shewing Colburn Coal Workings Surface
 Triangulation System, and the levelling and lateral
 movement pegs Scale $\frac{1}{2}$ - 1 Chain. - 110. No 25.

SITUATION OF THE MINE, METHOD OF WORKING, AND GENERAL
LAY-OUT OF WORKINGS.-

The mine is situated near Armadale, Linlithgow:shire. The seams worked are the Colinburn Coal and Colinburn Fireclay. They belong to the upper coal measurement and at this mine lie at depths varying between 0 - 140'. The seams outcrop on the western boundary of the leasehold and dip gently towards the N.E. Zones of no inclination are common. The coal is inferior in quality and not generally worked. The clay, however, is a high grade refractory clay, and is interspersed with bands of good and inferior gas coal. The clay forms the pavement of the Colinburn Coal Seam. Faults are few and far between. The seam is approached by means of a cross-cut mine driven from the surface which dips towards the North and strikes the fireclay bed, (in which the road then continues) a short distance from the surface. Roads are driven to right and left from this main road (in the approximate direction of level course) with a slight rise until they strike the coal, then they are continued in the seam.

METHOD OF WORKING.-

The longwall method of mining is practised at this colliery. In area No. 1 the working seam was the Colinburn Coal and 18 - 20' of the Colinburn Fireclay. The general layout is shown on the large plan. A heading was set out to the rise and coal places were branched off at intervals of 38'. The branch roads and heading were brushed 8 feet wide, and the full thickness of the blaes band overlying the coal which varied between 3' and 4'. The ripped material was divided evenly and built along the road sides to form the roadside packs which were well built and tapped out tightly to the roof. Props were set in straight lines and at regular intervals of 3'6". They were/

were withdrawn regularly by means of a sylvester, and the roof between the waste allowed to collapse to within three rows of props from the face. The row nearest the waste was reinforced by some of the props extracted. The blaes band, collapsed, is the first stage of the settlement process up to the sandstone band (see section) of overlying strata. The overlying strata subsided gradually on the packs which almost invariably were pushed into the soft fireclay floor. The coal was difficult to get and was undercut by hand to a depth of 2 - 3 ft. It was then blasted down and filled into tubs, and hand drawn to main dock. The face advanced slowly, but regularly.

METHOD OF MINING THE COAL UNDER STATION 1_L- 7_L 8_L and 14_L.-

The working seam in this area was the Colinburn Coal only, which varied in thickness from 21 - 28'. The clay underlying the coal was of inferior quality and for that reason was left in tact. The face was worked on a line approximately parallel to the road at the surface. A heading was set out to the rise and branch roads ^{were} set off at regular intervals of 38'. The heading and branch roads were ripped 7 - 8 feet wide and the ripping, the thickness of the blaes band which varied in thickness from 3'6" to 4'6" was divided evenly and built along each side of the roadways to form the roadside packs. Props were set in line and at regular intervals of 3'6" and in rows behind the face. They were regularly withdrawn and re-set at the face. Diagram No. 26 shows the position ~~of~~ roads and packs with reference to face line, and demonstrates the arrangement one would find any day throughout the course of this investigation. The coal was undercut by hand to a depth of 2'6" to 2'9", and was filled into tubs and transported by hand to the main haulage. The face advanced very slowly, 4 ins. per day over a period of one year, and the overlying beds subsided very gradually on the/

the packs, which, as in the other area, were invariably forced into the pavement. In both areas the sequence of events was very straightforward, and the results from the mining point of view very satisfactory - no fall and no sudden weights, just a gradual subsidence of the beds on the packs. The sinking of the packs into the pavement caused the floor in the roadways to heave badly, and, as a consequence, a reasonable height of roadway was difficult to maintain. When it was necessary to increase the height of width of any roadway, the roof was ripped and the material transported to the surface where it was utilized in the manufacture of composition bricks.

WEIGHT BREAKS OR FRACTURES.-

These were generally badly defined and were somewhat difficult to discern; nevertheless, they invariably sloped or haded towards the waste. The 'line of break' followed the line of face, and it was observed some distance back in the waste area that although the sandstone overlying the blaes band was fractured in a direction parallel to the line of face fracturing had also occurred in that bed in a direction parallel to the direction of advance of the face.

INCIDENCE.-

The distance between the fractures which were only discernible at the face, (they could not be detected in advance of the face,) was very irregular, and did not seem to be connected to either the rate of advance or depth of undercut.

ROOF CONTROL.-
INTRODUCTORY.-

In any subsidence investigation the proper place to start observations is at the coal face; indeed, in view of the results obtained in this investigation, observations in advance of the coal face are also essential to the problem. Subsidence starts here and eventually extends to the surface. Since observations were made on the coal and on the blaes band immediately overlying it, a careful study of roof control was necessary if any of the many intricate problems involved were to be elucidated. The following is a brief review of the problem in general.

The beds above the seam and, indeed, the beds under the seam may be considered as slabs or likened unto thin plates gripped or fixed at the ends since they extend to the solid on the faces of an area of excavation. As a general consequence of extracting the coal, we have a lowering of the roof (the superjacent strata), a heaving of the pavement (the subjacent strata) and coal compression some short distance in advance of the face line, and perhaps lateral extension of the coal stratum, and the over and underlying beds, i.e., towards the waste area. This lateral movement, it should be noted, does not affect the beds collectively; some beds may, and others may not, move horizontally. Indeed, the movement between the beds is differential and is influenced by the physical characteristics and strength properties of the individual beds. It has recently been asserted that all the beds as they move outwards towards the waste area thin somewhat. After a certain area of coal has been extracted the superjacent beds acquire kinetic energy. Roof control in all essentials means control of this energy; and the ideal to aim at is gradual absorption. The magnitude of this kinetic/

kinetic energy is unknown, and so far has not been successfully measured. It is, however, reflected on the supports and on the beds themselves. These reflections are our chief guides in roof control. The kinetic energy is not constant, (and this fact calls for careful surveillance at the face), but varies from day to day and from hour to hour. This is inferred from the variations in the rate of subsidence. The cycle of operations at the coal face (cutting, stripping, brushing, packing, prop extracting) all exert an influence on the forces in action. The superjacent beds once in motion retain that motion for a considerable period. The motion is generally a maximum at the coal face, fading out some short distance in advance of the face, and extending back into the excavated area. Since motion is zero at the edge of the underdraw, a maximum at the coal face and some little distance behind it, decreasing to zero in the area of waste consolidation, it is obvious that the greater the resistance offered to motion at the coal face the greater will be the control over the roof, and the less the final subsidence providing the support is of a permanent character. In roof control, which embraces the roof and floor at, in advance, and in the waste area behind the face, the primary support should be as permanent as possible. The only rational method of offering such support is by a series of well-conditioned and constructed packs, and in this regard width can be safely sacrificed if attention is directed towards tightness and stability. Props, although important in roof control, are essentially a secondary consideration in the problem, and are essentially temporary in nature and position. Nevertheless, they should be as rigid as possible; their rigidity, however, must be governed by the amount of subsidence recorded as the roof passes from the coal face to the waste, or to the position where they are/

should
 are withdrawn and allow however of some little subsidence without destruction. Props should check the initial deflection, reduce it to a minimum, and should only be in position for as short a period as possible. Packs should be built of the strongest material available, and for effective control should be built forward as close to the coal as circumstances will permit as soon as the roof has been exposed. Delay in supporting the roof allows of rapid subsidence and generally fracturing of the beds. By maintaining a maximum height at the coal face it is possible to introduce a maximum height of pack. This reduces (other things being equal) the amplitude of subsidence at the surface. Again, packs effectively distributed and built at the proper place and at the proper time (this applies equally to all face supports) reduces the deflection of the roof over and in advance of the face to a minimum. Beds are fractured generally at the zones of maximum rate of change of deflection or subsidence, and it should be the aim to prevent fracturing in advance and over the face. In the area behind the face fracturing is not of much consequence. It should not be forgotten that bad roof control in one seam may make things particularly difficult in other seams above and even in seams below. Indeed it is generally under such circumstances that roof control is very difficult, if at all successful. The general process of subsidence over the lower seam fractures the beds over and under the higher seam. In reviewing roof control we are forced to the conclusion that the all important consideration is the preservation of the strength properties of the different beds. Whole or unfractured beds by virtue of their strength properties are capable, as Phillips¹ has shown, of performing actual work, therefore of assisting in/

1. Phillips, D.W., Trans. Inst. Min. Engs., Vol. LXXX, 1929-1930.

in the support of the overlying beds. Fractured beds, on the other hand, are dead weights or loads on the supports and reinforcements.

BREAKS.-

These are generally termed waste breaks and usually made or slope towards the waste. They are generally formed at the face, but may be, and often are, formed in advance of it. To prevent their formation, as already stated, is of primary importance; and this can best be done by reducing the deflection of the beds over, and in advance of the face, to a minimum.

INCIDENCE OF FRACTURES.-

This is believed by many observers to be controlled by the depth of undercut; recent investigations, however, do not support this view. Dr. Winstanley demonstrated in his investigations¹ that those breaks are formed at zones of concentration of forces where the general subsidence starts some few feet in advance of the face. He also demonstrated that depth of undercut had little or no influence on the distance between them. He postulated "that a plane about which any bed begins to "subside independently of the bed below may be regarded as "a fixing plane for that bed". Since the bed below offers support to the bed above, the fixing plane should progressively pass further towards the waste. However true this may be for the first few beds, obviously a stage is soon reached where the opposite is the case since draw soon becomes positive. Indeed, Eckardt states² that bending and gripping causes increases in the horizontal zone affected, that/

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1. Winstanley, "Longwall Roof Control", Trans. Inst. Min. Engrs., 1930-31, Vol. LXXXI, p. 373.
 2. Eckardt, Gluckauf, Vol. L, 1914, pp. 449 and 485.

that the line progressively advances over the solid.

INFLUENCE OF DEPTH ON CONDITIONS UNDERGROUND.-

Depth does not influence the conditions at the coal face. Prop pressures equal to those observed in deep workings have been recorded in shallow workings. Since prop pressures are independent of depth it is reasonable to suggest that the superjacent strata subside individually, and not collectively, as some authorities suggest. In the waste area behind the face, depth is the dominating factor, and exerts a decided influence on the pressures recorded.

FRACTURES.-

There are two kinds of fracture or breaks, those due to bending and those due to shear. Shear fractures are by far the most important variety developed by subsidence, and give rise to the phenomena of positive draw. They are characterised by the following features:

- (1) They incline forward (over the unwrought deposit);
- (2) The fracture is smooth on the surface and its sides tend to press together.

BENDING MOMENT FRACTURES.-

These are produced when a stratum comes under the influence of a bending moment sufficient in magnitude to cause the bed to fracture. This kind of fracture is characterised by (1) a backward hade; (2) a sagged irregular profile and (3) a tendency for the cleft to open. The second and third characteristics tend (during and after the subsidence process has ceased) to produce a permanent elongation of a fractured bed. Contrasted with shear fractures, which are generally, although not always, confined to the higher strata ^{and} tend to produce positive draw; bending moment fractures (although they do occur at higher levels) are the kind which appear in the nether roof at, behind and sometimes in advance of the coal face, and tend to diminish draw.

PART II

SECTION 1

SUB- SECTION (a).

UNDER DRAW.

INTRODUCTORY. -

The observations conducted in advance of the coal face underground are perhaps the most interesting of all those made underground. We claim that this is a new line of investigation from the point of view of a subsidence enquiry. At the present time, however, the zone in advance of the line of face is being explored very thoroughly by a roof control investigator working under the supervision of the Safety in Mines Research Board. Prior to these investigations it was generally assumed that subsidence started at the coal face. We are now in a position, however, to state definitely that vertical movement starts in advance of the coal face. The distance in advance must be variable, but distances as high as 75' have been recorded, and as a result, in the future, any consideration of the causes of draw will have to take into account this fact.

Halbaum was one of the first to refer to the thinning of the coal stratum in advance of the face, and in this regard he made the following statement:¹

"It is a matter of common observation (where observation is possible), that the coal bed adjacent to the face line (or goaf line) is less than its normal thickness. The descent of the roof on the unworked coal stratum is a maximum at the face line and runs out to nothing some little distance beyond that line, i.e., into the solid coal. The measured distance of this zero point from the line of face may be called the 'Underdraw'. This thinning or compression cannot be easily demonstrated in a system of longwall advancing, but it may be readily observed in a system of longwall retreating and in the second working of a bord or pillar system".

E. Watson supported Halbaum in regard to under draw, at longwall faces. He gave measurements made in a heading driven in advance of a longwall face in the Cannock/

1. Halbaum, "Great Planes of Strain in the Absolute Roofs of Mines", Trans. Inst. Min. Engrs., XXX, 1905, page 175.

Cannock Chase district. The section of the seam at the point of observation in the heading was:

Top Coal.....	2'5"
Soft Fireclay.....	7"
Bottom Coal.....	2'1".

When the face reached the point of measurement the section had become:

Top Coal.....	2'4"
Soft Fireclay.....	5"
Bottom Coal.....	2'0".

A point of importance here is that the coal was not so easily compressed as the fireclay. The coal was only reduced in height 2 ins. in 54, while the fireclay suffered the same reduction in 7".

Many more observations on under draw are called for so that its relation to the following may be ascertained:

- (1) Depth of seam from the surface;
- (2) The thickness of the seam and method of mining;
- (3) The inclination of the seam.

'Draw' over an advancing face is always less than that over a stationary face. It would be interesting to know if a similar increase in the extent of under draw occurs when a face stops advancing.

Our observations hereinafter described are somewhat incomplete, and the methods of measurement on the crude side; nevertheless, they add to our knowledge of a branch of the subject where our knowledge is very scanty indeed.

METHOD OF MEASURING UNDER DRAW.-

For the purpose of measuring under draw, coal compression, lateral extension of the coal stratum towards the waste, and the horizontal, tensile and compressive stresses/

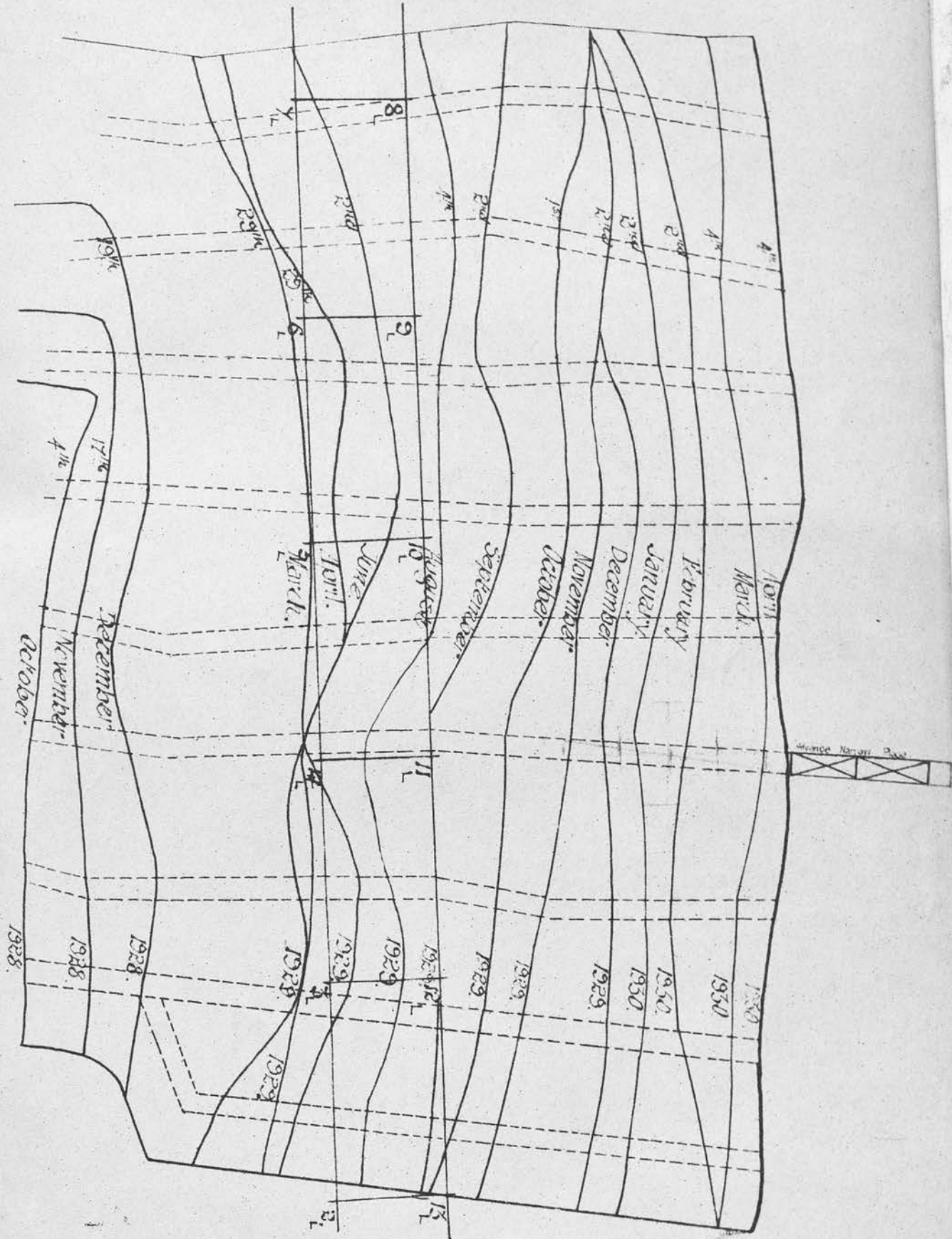


Fig. No. 87.

Table. №12.

UNDERGROUND EXPERIMENTS IN ADVANCE OF COAL FACE LINE.

Reduction in Height in Inches					Horizontal			Distance of Coal from Pin.	
1	2	3	4	5	A	B	C		
4.618	4.697	5.476	5.022	5.634	28/7/30	4.951	5.140	5.323	8' from No. 1.
0.025	0.003	0.000	0.000	0.000	4/8/30	0.006	0.003	0.003	3'
0.035	0.008	0.000	0.000	0.000	8/8/30	0.107	0.011	0.007	5' 6"
0.078	0.022	0.000	0.000	0.000	14/8/30	0.107	0.011	0.008	7' 6" from No. 1. Back
	0.028	0.000	0.000	0.000	16/8/30	0.130	0.011	0.008	6' from No. 2.
	.067	0.003	0.000	0.000	29/8/30	0.141	0.011	0.008	2' from No. 2.
	.277	0.022	0.000	0.000	23/8/30	0.181	0.011	0.003	Position is No. 2 Pin
	-	0.031	0.000	0.000	26/8/30	0.224	0.005	0.003	5' "
		0.105	0.000	0.000	29/8/30	0.294	0.002	0.002	3' "
		0.171	0.000	0.000	3/9/30	-	-	-	0.12" "
			0.015	0.006	6/9/30	0.319	0.012	0.077	0.2" "
			0.037	0.011	9/9/30	0.360	0.011	0.142	7' 3" "
			0.092	0.032	11/9/30				1' 0" "
				0.034					0.9" "
				0.036	2 79/30	.449	0.000	.263	No. R
				0.139	7/10/30	.475	0.000	.354	No. 5
					24/10/30	.400	0.000	.516	56' in advance
					15/11/30	.312	0.000	.477	60' beyond
					27/11/30	.312		.469	
					30/12/30	.309		.416	

Table No. 13. Coal Compression Measurements.

Distance from Point of Measurement to Coal Face	Point of Measurement	
	S	R
6 feet (seam 24" thick)	0.000"	-
4'3"	0.005"	-
1'6"	0.053"	-
0'1"	0.116"	-
6'0"	-	0.000
4'0"	-	0.006
1'6"	-	0.114

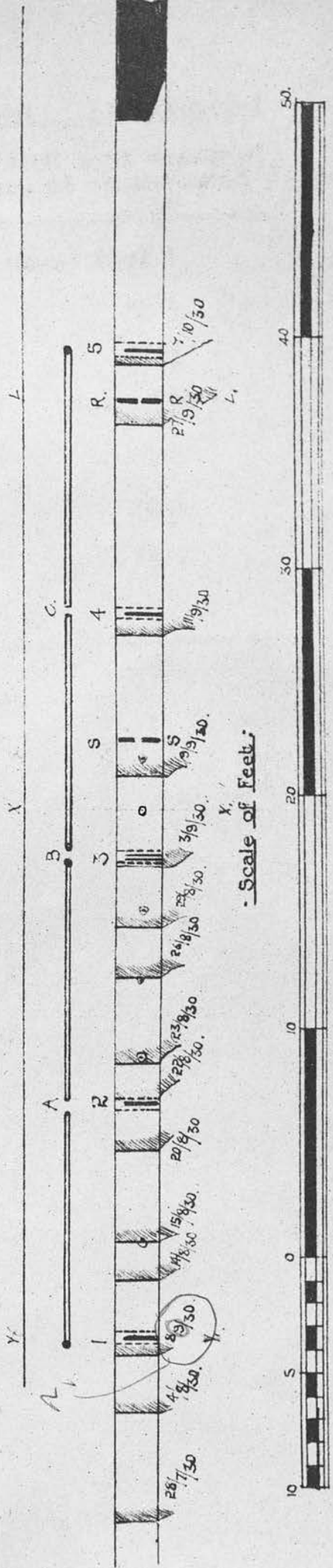
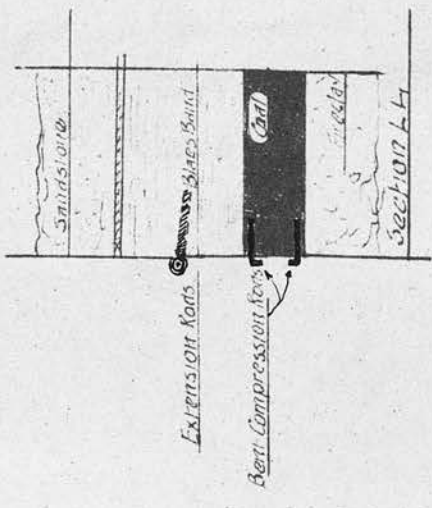
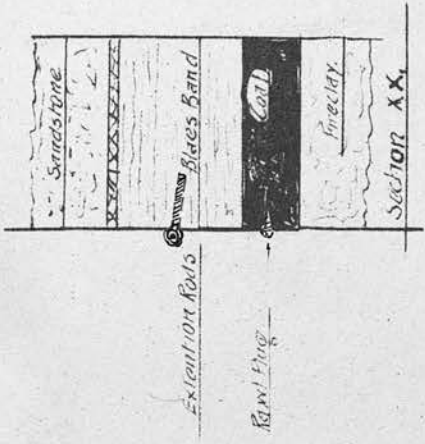
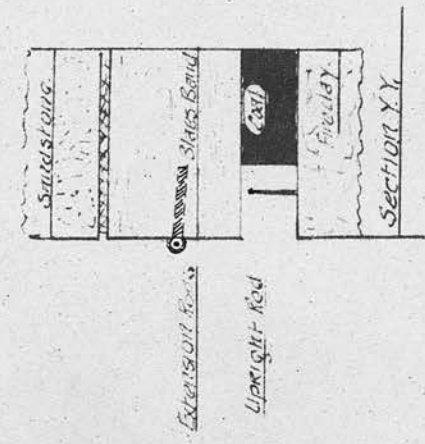


Fig. No. 88.

stresses caused by the subsidence of the superincumbent beds, the face was stopped and a narrow road, 6 feet wide and 6 feet high, ^{was} driven 60 feet in advance of the face line. The position of the road is shown on diagram No. 27. Along the length of this road five recesses were cut to the full height of the seam and two feet into the side of the roadway. In these recesses rods 1" in diameter (extending to within 3" of the bottom of the Blaes band overlying the coal seam, see diagram No. 28.) were permanently fixed in position by means of concrete. A series of preliminary measurements were then made to ensure that all movement had ceased before the face started to advance again. When all movement had ceased, the face was started and measurements were made (by means of a micrometer caliper graduated to 1/1000 of an inch) of the distance between the top of the vertical column and the bottom of the blaes band, and the position of the face with relation to the point of measurement recorded.

The results of the observations and measurements are recorded on table No. 2, and the position of the face with relation to the point of measurement on the date of the successive observations is shown on diagram No. 28.

A perusal of the table, and an examination of the diagram, reveals that when the face had advanced to within 3' of column No. 1 the convergence of the roof and floor of the seam was 0.025" at No. 1, and .003" at No. 2. When the face had advanced still further to within .5' of column No. 1, the convergence recorded at No. 1 and No. 2 was .035" and .008" respectively. When the face was just in line with No. 1 column the final convergence observed was .078". This procedure was carried out as the face advanced to, and passed beyond the other three vertical columns, and, as a result of the observations and measurements, we can / ~

can state definitely that:

- (1) Underdraw was 17' ;
- (2) The maximum convergence of roof and floor was .277" .

PART II

SECTION 1

SUB-SECTION (b).

COAL COMPRESSION.

The convergence of the roof and floor (observed and measured in the preceding section) could be accounted for by any of the following:

- (1) Pure compression of the coal;
- (2) Lateral extension of the coal stratum towards the waste;
- (3) A combination of (1) and (2).

To determine the amount of convergence due to coal compression the following observations and measurements were made along the length of the road described in the preceding section (a). Four holes 3 feet long were bored in the coal seam, two 3" from the top of the seam and two 3" from the bottom. Bent steel rods 1" in diameter were permanently fixed in position in these holes by means of concrete. Diagram No.28. shows the arrangement. Measurements were made of the distance between the ends of these rods by means of a micrometer caliper graduated to 1/1000". The position of the face with relation to the point of observation was also noted.

The results of the observations are recorded on table No.3. , and indicate that when the face was 4'3" from s the coal was compressed .005"; as the face advanced compression increased, and was .053" when the face was 1.5' from s, and .116" when the face had advanced to within 1".

The results of the observations and measurements at s were confirmed at k.

- (1) So far we are in a position to state definitely that part of the convergence of the roof and floor of the seam recorded in section (a) was due to pure compression of the coal;
- (2) The maximum compression recorded was .116".

PART II

SECTION 1

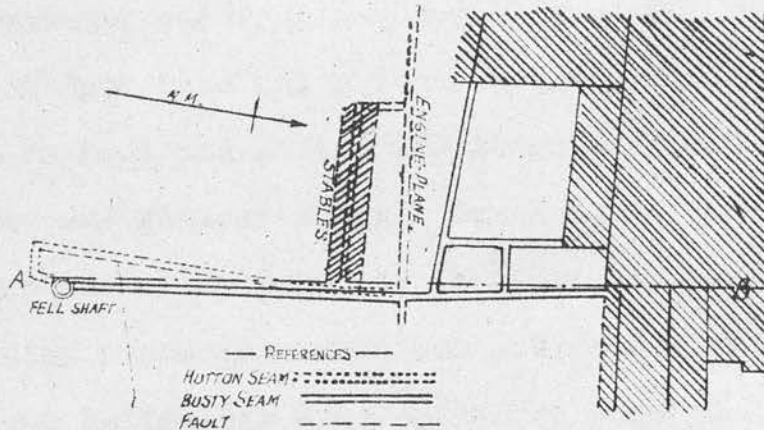
SUB-SECTION (c).

LATERAL EXTENSION OF THE COAL
STRATUM TOWARDS THE WASTE.

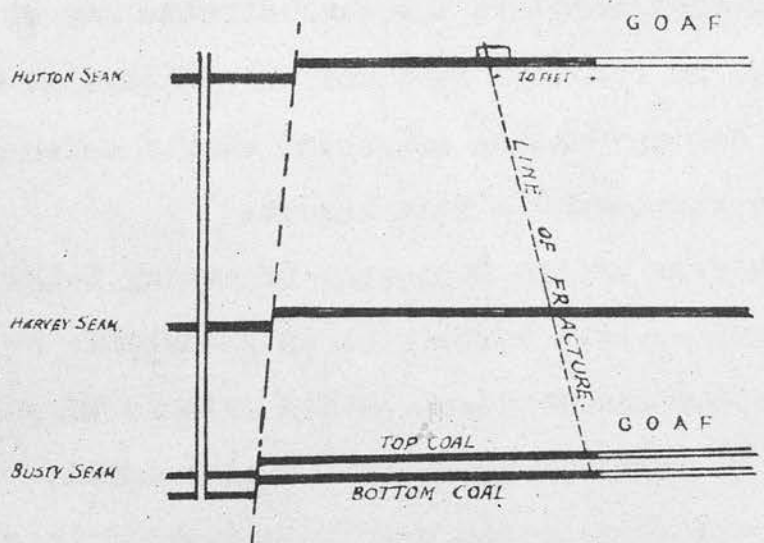
Holes 3 feet long were bored in the coal at intervals along the length of the advance roadway. Into these holes rawl plugs were driven and a brass screw nail was screwed into the centre of the plugs. Measurements were made of the distance between the centres of grooves in the screw nail heads to determine the magnitude of this movement. Despite careful observation and measurement no movement was detected.

PART IISECTION 1.SUB-SECTION (d).

THE HORIZONTAL, TENSILE AND
COMPRESSIVE STRESSES INDUCED
IN THE BED OVERLYING THE
COAL STRATUM BY THE
SUBSIDENCE OF THE
SUPERINCUMBENT
STRATA.



- Subsidence affecting the Hutton Seam, Burnhope Colliery. -
 Plan of Workings. -
 (Kirkup)



- Cross-section on line AB. -
 -M.C. N° 29.

INTRODUCTORY.-

The movement of the immediate roof in a mine is the starting point of the subsidence process. Subsidence begins here and extends upwards, and an investigation should follow suit. It is widely known that the fractures induced in the beds immediately overlying the coal seam are generally inclined backwards towards the waste, and that at higher levels they may be inclined forward towards the unworked coal. We are, however, in the dark as to the cause of this change in direction, and precisely where this change occurs. Many more investigations are called for in order that our knowledge of the processes involved in the subsidence of the beds superjacent to the coal stratum may be increased.

Observations in roadways situated in workings at higher levels than the seam being extracted should materially increase our knowledge in this regard.

In view of the frequency of mining below a seam which has already been worked, it is remarkable how few are the recorded observations on the effects of subsidence as revealed in workings lying at a higher level. In this regard the most interesting and instructive British Observation on record is that of J.P. Kirkup¹. It relates to the extraction of the top and bottom Busty seam from below the Harvey and Hutton Seams at the Burnhope Colliery, Durham. It was while working the top Busty (22" thick) that Mr. Kirkup noticed that the roads in the Hutton Seam, 279 feet above, were considerably affected beyond the edge of the wrought-out area in the top Busty Seam. The movement was most evident in the Hutton stables where the brick walls were fractured in a direction inclining towards the Busty coal. On the haulage plane running parallel to the stables the/

1. Trans. Inst. Min. Engrs., XXXI, 1905-06, page 180.

the effects were marked, while, on the opposite side, towards the Fell shaft stretching was indicated by the opening of cement joints on an earthenware pipe line, as far as 150 feet beyond the stables and 30 feet from the shaft. Mr. Kirkup stated that the presence of a fault may have prevented the disturbance reaching the shaft.

In a commendably complete recent American investigation, which relates to the extraction of coal by the longwall method under the working of a cement mine situated 465 feet above the coal workings and 125 feet from the surface, R. Laird Auchmuty¹ observed that the action in the cement mine is similar to that observed on the surface. In the cement mine, however, instead of settlement there was a decided upthrust in advance of the coal face, and apparently settlement did not start until the coal face had advanced 75' beyond the point observed. The action referred to at the surface is ground movement.

ARRANGEMENT OF APPARATUS.-

For the purposes of this section horizontal steel rods were installed in the advance roadway described in the preceding sections. At intervals of 20 feet holes were bored towards the centre of the blaes bed. The holes dipped slightly (to facilitate the 'grouting in' of anchor rods) and were 2'6" long. Short anchor rods were placed in these holes and permanently 'grouted' by means of cement in their position. Horizontal extension rods 10 feet long were then connected by means of a screwed coupling to the anchor rods. The general arrangement of the rods is shown on diagram No. 28.

METHOD OF MEASUREMENT.-

Variations in the distance between the ends of the rods/

1. R. Laird Auchmuty, "Subsidence and Ground Movement in a Limestone Mine caused by Longwall Mining in a Coal Bed below", Technical Publication No. 396, Amer. Inst. Min. & Met. Engrs., 1931.

rods and between the sets of rods (points A, B and C, on the diagram) were measured by means of a micrometer caliper graduated to 1/1000 of an inch, and the position of the face with relation to the point of measurement recorded. The measurements indicated the horizontal, tensile and compressive stresses induced in the blaes bed by the subsidence of the superjacent strata.

RESULTS OF THE OBSERVATIONS AND MEASUREMENTS.-

These are recorded on table No. 12., and the sequence of events was as follows: When the face was 6' from column No. 1, and 10'6" from the point A, the measurements indicated a horizontal extension of .006' in the distance between the ends of the rods at A. When the face had advanced to point 7'6" from A, the extensions observed at A, B and C were 0.107", 0.003" and 0.003" respectively. The point of observation, C, was then 22'6" in advance of the line of face. The observations and measurements were continued as the face proceeded to advance toward and beyond the points A, B and C., and it was observed that the distance between the ends of the rods at A and B progressively increased until the maximum increases of .475" and .516" respectively were recorded when the face was 30 feet in advance of the point A. Thereafter the distance between the ends of the rods gradually decreased until the minimum extension 0.309" was recorded. Although the face still continued to advance the distance between the rods remained constant.

PART II

SECTION 1

SUB-SECTIONS (a), (b), (c) and (d).

RESULTS AND CONCLUSIONS.

RESULTS AND CONCLUSIONS.

- (1) Vertical Movement of the superjacent strata commences not at the coalface, but well in advance of it - over the solid coal.
- (2) The distance in advance of the under draw, varies. In this investigation it was 17', but distances up to 75' have been recorded elsewhere.

In view of the variable under draws recently recorded, we suggest that the following factors may influence under draw:

- (i) Depth, inclination and thickness of seam;
 - (ii) Nature of coal;
 - (iii) Nature of parting between the seam and the roof and between the seam and the pavement;
 - (iv) Nature of super and subjacent strata;
 - (v) The general method of mining (supports and reinforcements);
 - (vi) Presence or absence of water, and the discharge of gas.
- (3) The coal stratum in advance of the coal face line is reduced in height. The reduction in height is zero at the edge of the underdraw and increases progressively towards the coal face line, where it is a maximum.

The maximum reduction in height recorded in this investigation was .277"; the thickness of the seam 23".

Although it is usual to refer to this 'thinning' of the coal stratum as a reduction in height, in view of the fact that the pavement rises and the roof descends, a more appropriate term would be convergence of the beds.

Dr. Winstanley¹ observed this converging movement

75/

75' in advance of the coal face, that is, over the solid coal.

- (4) Convergence of the roof and pavement may be due to:
- (i) Pure coal compression assisted perhaps by the loss of moisture and the discharge of gas;
 - (ii) Lateral extension of the coal stratum towards the waste;
- Or a combination of (i) and (ii).

- (5) The convergence recorded in this investigation was due entirely to pure compression of the coal, for, despite careful observation and measurement, lateral extension of the coal stratum towards the waste was not detected. The absence of this movement may be due to the excessive convergence of the roof and pavement of the seam at the coal face (a consequence of the slow rate of advance of the face) which would materially increase the resistance offered to movement of the coal stratum in a horizontal direction. Further, the pavement, and the upper 12" of the coal seam are soft, and, as a consequence, movement in a vertical plane would be in the direction of least resistance.

Although horizontal movement was not detected in this investigation, the possibility of its existence should not be overlooked in any subsequent inquiry into the subject. Indeed, the existence of this form of movement is now firmly established by the general practice of mining. Side pressure in deep workings is due to flow stresses produced by gravity stresses.

In/

In this regard Professor G. Knox¹, contributing to the discussion on J.S. Carson's² paper, made the following statement:

"In the South Wales coalfield they were "subject to these (flow stresses) before they "got out any coal at all, because the "stresses were so great that immediately "they took away and part of the support "the material began to flow".

Again, Muller³, as the result of a series of laboratory tests and experiments on carboniferous strata, claims to have confirmed Langecker's theory of the "latent working capacity of rocks" (which Langecker states manifests practically in forward push and fissuring at the coal face); and his observations on the forward push and fissuring of the coal face. He states definitely, however, that these phenomena will only persist so long as there are no appreciable resistances to be overcome.

- (6) The beds immediately overlying the coal stratum are in tension in advance of the coal face line. The distance recorded in this investigation was 22'6" (underdraw 17').
- (7) Tension extends beyond the point where vertical movement of the superjacent strata commences.
- (8) Two distinct stress phases were observed as the face advanced towards, under, and beyond the point of observation. The first phase is characterised by tension, which extends beyond the coal face line, and increases progressively as/

1. Knox, Colliery Guardian, June 12, 1931, page 2062.
 2. Carson, Trans. Inst. Min. Engrs.
 3. Muller, Glückauf / 47048, 1930.

as the face advances towards and 30 ft. beyond the point of observation to a maximum. Thereafter follows the second phase, during which the tension is gradually reduced and is finally superceded by compression.

- (9) As a consequence of fracturing, the beds overlying the coal stratum are permanently elongated. This must result in considerable horizontal compression which may cause side pressure in the roadways (situated in lower beds or beds just over the seam) in the waste area behind the face. In the upper beds (the beds immediately subjacent to the surface) it will produce re-elevation towards the centre of the mined area.
- (10) As a result of the observations on the horizontal, tensile and compressive stresses induced in the bed overlying the coal seam, we suggest that bending produces positive draw.
- (11) Tension in advance of the coal face line is due to the bending and gravity stresses on the beds, and to the relief afforded by the loose side at the face.

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PART II

SECTION 2.

PACK COMPRESSION.

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INTRODUCTORY.-

The control of the roof is the foundation of mining, and the pack the foundation of roof control. Its importance, however, is not limited to roof control for, as we have demonstrated in the foregoing pages, it is of prime importance in the control and limitation of surface subsidence. Indeed, if the observation made as a result of the subsidence investigation at Dalziel Colliery has a general application, (when hydraulic stowing almost entirely eliminated draw, where it was generally extensive) the pack has a decided bearing on the extent of draw also. In this section of our work we have attempted to correlate the surface and underground subsidence, and for that purpose we observed and measured pack compression in two directions, viz: parallel and at right angles to the face line. Our attempt at correlation, however, has not been very satisfactory. The presence of old workings in the vicinity of roads 789, into the roadways of which subsidences occurred, made an accurate correlation impossible. Nevertheless, information of some little value with regard to the relation between pack compression and amplitude of subsidence was obtained and recorded.

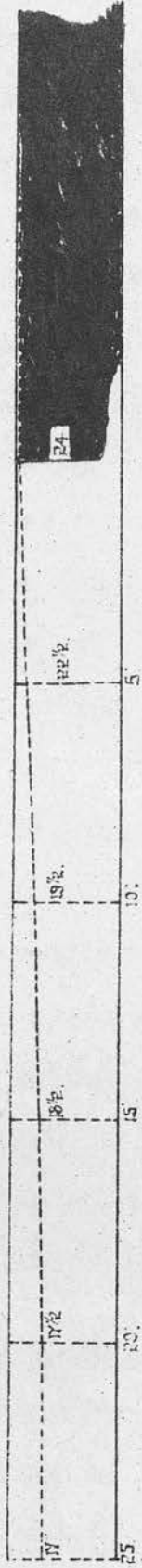
PACK COMPRESSION OBSERVATIONS.-

The heights of the roadside packs were measured on a line vertically underneath the surface line $1_{\text{I}} - 7_{\text{II}}$; the object was to correlate the surface and underground subsidences. The figures are recorded on Table No. 14. The rise or heave in the roadways was not taken into consideration, nevertheless, it should not be forgotten that heave in the roadways and cundies may contribute appreciably, particularly if the roadways and cundies are wide, and the pavement soft, to the amplitude of surface subsidence. Measurements and observations were also made/

Table. №14.

COMPRESSION MEASUREMENTS.

Cundies		No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	Cundies			
25	25	25	25	24 1/2	24	24	25	24	24	24	24	24	24	24
25	24 1/2	19 1/2	15 1/2	13	13 1/2	18	17	17	22	24	22	22	23	24
25	23 1/2	18 1/2	15 1/4	11 1/2	11 1/2	16	14 1/2	15	16 1/2	19	19	19	19	24
25	22 1/4	18	14 1/4	10 1/4	11	15	13 1/2	13 1/4	14	17 1/2	18 1/2	18 1/2	19	24
24 1/2	22	17 1/2	14	9 1/2	10 1/2	16 1/2	13 1/4	13	13	16 1/4	16 1/4	18	19	23
24 1/2	21 1/2	16 1/2	13	9 1/2	9 1/2	16 1/4	12 1/4	12 1/4	12 1/2	16	15 1/2	17 1/2	19	23
24 1/2	21 1/2	16 1/2	12 1/2	9 1/4	9	16 1/4	12	12 1/4	12 1/2	15 1/2	15	17 1/2	18 1/2	23
24 1/2	21 1/2	16 1/2	12 1/2	9	9	16 1/4	12	12 1/4	12	15 1/2	15	17 1/4	18 1/4	23
24 1/2	21 1/2	16	12 1/2	8 5/6	8 1/2	15 5/6	11 1/4	12	12	15 1/2	15	17 1/4	18	23
24 1/2	21 1/4	16	12 1/2	8 5/6	8 1/2	15 5/6	11 1/4	12	12	15 1/2	15	17 1/4	18	23

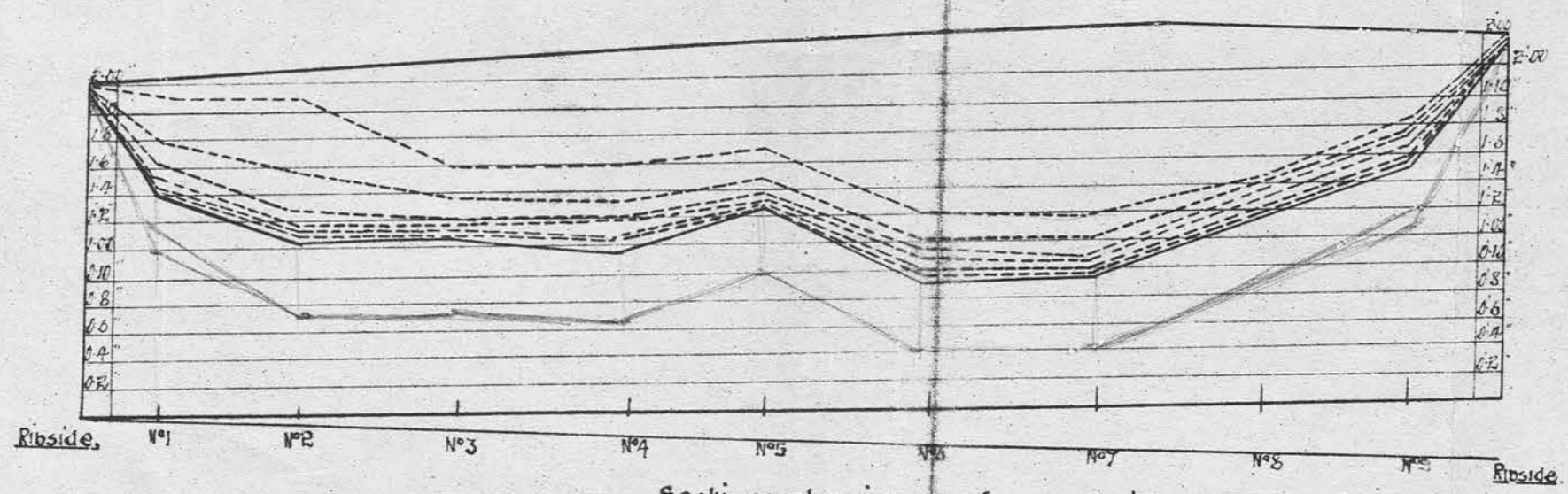
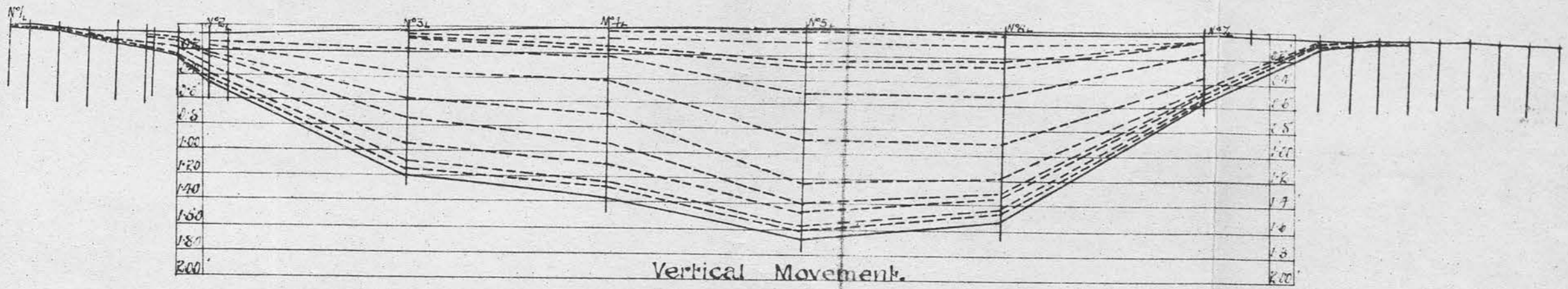


Sagging of Roof in the Waste. - Fig. No. 20.

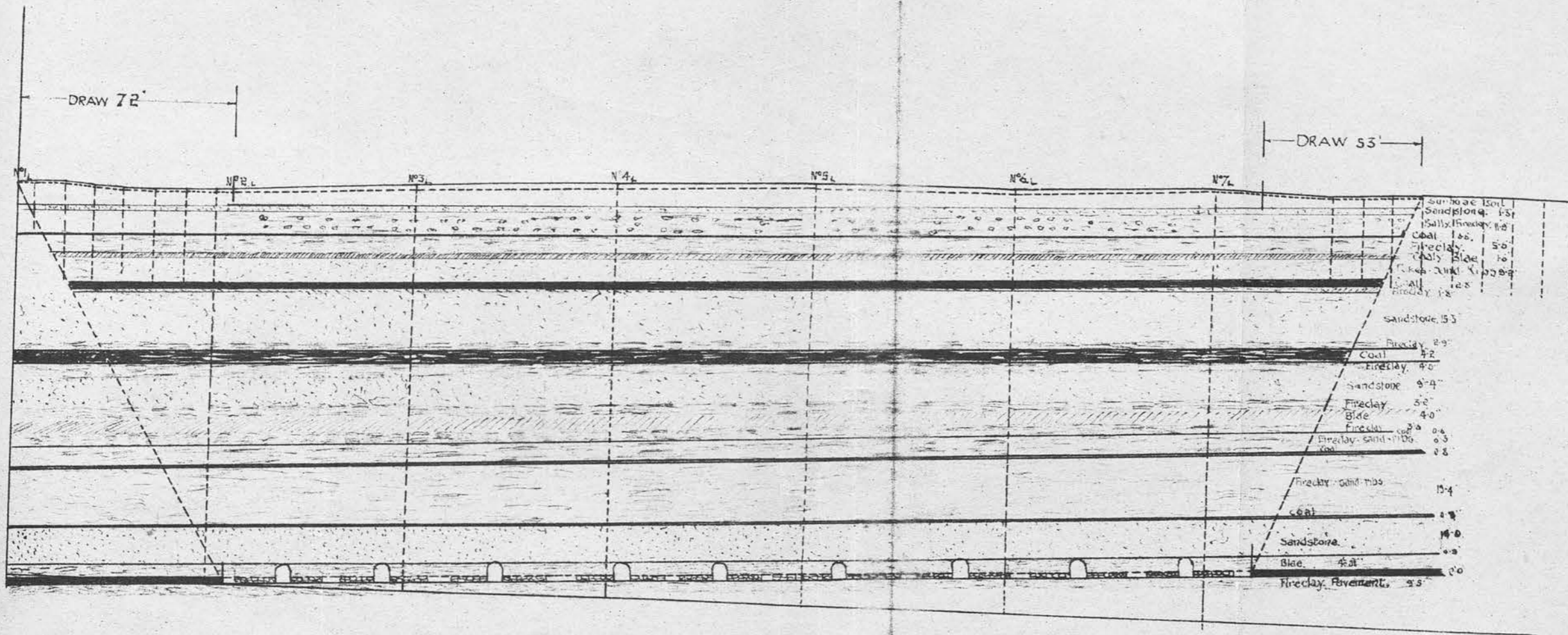
made along the length of the roadway, No. 4 (see diagram No.), that is in a direction parallel to the direction of advance of the coal face. We have plotted two profiles, one indicating pack compression in the direction of advance of the face, and the other pack compression at right angles to that direction, diagrams No.30 and No.31 respectively. Diagram No.30 is a typical longwall profile, the characteristic features of which are small subsidence in advance of the coal face, which is zero at the edge of the underdraw, and increases progressively to the coal face line where subsidence over the solid coal is a maximum. From the coal face to a few yards behind it there is a rapid increase in the rate of subsidence of the roof and rise of the floor, which is due to the small initial resistance offered by the packs and supports to the subsidence of the beds over this area. This is indicated by a steepening of the profile gradient at that point. As we travel still further away from the face line, the packs begin to consolidate with a resultant increase in their resisting capacity, and a consequent flattening of our profile. Eventually we reach the area of pack consolidation in which vertical movement of the beds virtually ceases, and where our profile is practically flat.

PACK COMPRESSION ON A LINE PARALLEL TO THE LINE OF FACE.-

That there is a marked difference in the profile of a section plotted to measurements made in this direction is clearly shown on diagram No.31. The profile is typical of that obtaining in a restricted area from which the coal has been extracted by the longwall method of mining. A study of the profile reveals that pack compression is a maximum towards the centre of the line and decreases progressively to a point beyond the ribside - over the solid coal - the edge of the underdraw, where it is zero. It should be observed that the ratio of the flattened centre to the entire length of the profile is small. If the/



Sections shewing surface subsidence and Underground pack Compression. Fig. N°212



Section on line 1 7 indicating Draw Amplitude and a Section of Strata.

Size and Position of Paces and Candles to scale.

Horizontal Scale 1 in 500' Vertical Scale - 1 in 500' - Fig. No 32.

the line had been longer the ratio would have been increased, and the ratio of the end portion, where compression is relatively small, to the total length would have been reduced. These ratios have an important bearing on surface damage, see Part N^o 1, Section N^o 3. of this work. Another important point, which diagram No. 31. clearly demonstrates, is the marked resemblance of the surface and underground contours plotted on a line of exactly the same plan position.

PART II

SECTION 2.

PACK COMPRESSION.

RESULTS AND CONCLUSIONS.

RESULTS AND CONCLUSIONS.

- (1) We purposed at the outset of this work to correlate the surface and underground subsidences, and, indeed, observations and measurements were made for that purpose. Unfortunately, however, subsidences occurred in roadways situated in a seam 14' below the Colinburn Coal Seam, and, as a result, the amplitude of the surface subsidences was out of all proportion to the pack compression observed underground. Nevertheless, robbed as we are of the first fruits of our labours, a few interesting facts were observed.
- (2) Zones of maximum pack compression coincide with zones of maximum amplitude of surface subsidence. It therefore follows that the amplitude of surface subsidence can be reduced by increasing the resistance of the packs to compression.
- (3) Roadways in workings situated below the seam being worked may collapse and fill up after the workings at the higher level have advanced beyond them and thereby increase the amplitude of surface subsidence.
- (4) The resistance offered by the packs to compression depends on (among other factors) the condition of the material of which they are built.

In the vicinity of the roads 7 8 9 (see diagram No. 31) the beds overlying the Colinburn Coal Seam had been severely fractured by the working of the ironstone seam/

seam below. As a result, the packing material was small and weak, and pack compression high in this area, see Diagram No. 31.

- (5) Pack heights indicate the effectiveness or otherwise of most of the operations involved in roof control. Thus (if we consider pack heights as measured in the direction of advance of the face) if the initial height recorded at the face is much less than the height of the seam, the props and supports are not rigid enough, have been late in being introduced, or the interval of time elapsing between the extraction of the coal and the introduction of the pack is too great. Again, if there is a rapid reduction in the pack height just behind the face, the pack has not been properly built and tightened to the roof; and if the rapid reduction persists for a day or two the material, method of building, and size of pack are not satisfactory.

PART IIIA RESUME OF THE RECENT
RESEARCHES RELATING
TO MINING SUBSIDENCE.

INTRODUCTORY.-

In the following brief survey of recent work bearing upon Mining Subsidence, our chief purpose will be to summarily review the main conclusions arrived at by the foremost workers, and a few of the recent investigations. While little or not advance has been made in placing the subject on a rational basis, some useful investigations have been carried out, and many valuable contributions added to our subsidence literature.

The outlook towards subsidence research has decidedly changed within recent years. Observations prior to the last 20 years were almost invariably limited to levellings run across the surface under which mining was proceeding; little or no information was furnished as to the underground operations and nature of sub and superjacent strata, although such data are essential to the problem. Indeed, a study of the records gives the impression that the only data essential to the study of the problem are the depth and inclination of the seam.

The most recent investigations, e.g., those of Rutledge, Auchmuty and Thorneycroft, however, are characterised by their completeness and co-ordination. Nevertheless, even in those investigations there is still room for improvement, and further synchronisation of surface and underground observations would have materially increased their value. There still remains a large and fruitful field for research, and we set out below a few directions of attack from which valuable information, which may be helpful in the elucidation of the many intricate problems which characterise the phenomena, may proceed:

- (1) Lateral and longitudinal movement of rock masses in workings in a seam situated at higher levels than the one being wrought.
- (2) Lateral tension and compression induced above, behind and in advance of longwall faces, and in workings situated above the seam being worked.

(3)/

Observer	District	Depth of Seam D ft.	Thickness of Seam t ft.	Dip a	Maximum Amplitude, s.		Remarks.
					ft.	$\frac{s}{t}$ per cent.	
Dickinson, J....	Lancashire	600	4	-	3	75	Maximum; bord-and-pillar.
Dixon, J.S.....	Bent Colliery, Lanarkshire	648	5.5	1 in 20	-	68	Bord-and-pillar.
Dron, R.W.....	Lanarkshire	500	2.75	1 in 12	2.16	78	Longwall with coal-cutting machines. Three higher seams had been worked 20 years before.
Eltringham, J....	Northumberland	324	3.88	Almost level	1.83	47	Bord-and-pillar.
Barside, E.....	Wigan	1,335	11 (2 seams)	-	8.92	81	-
Goodwin, J.....	Lancashire	< 540	4	-	3	75	Maximum; bord-and-pillar.
Grimshaw, W.J..		198	4	1 in 3	2	50	Working to the rise.
Hamilton, J....	Scotland	600	-	-	-	50 - 60	75 per cent. in extreme cases.
		< 50	-	-	-	75	
Hassam, A.....	N. Staffs.	1,470	5.5)	-	-	-	-
		1,545	4)17.5	-	8.5	46	-
		2,010	8)	-	-	-	-
Hay, W.....	Shirebrook, Notts.	1,595	5	1 in 24	-	30	Longwall.
Hedley, A.M.....	Cleveland	> 50	-	-	-	40	-
Hewlett, A.....	Wigan	540	7.5	-	6	80	-
Hughes, H.W.....	S. Staffs.	432	30	-	13.3	44	-
Kay, S.R.....		360	5	Nearly level	-	70	-
		990	3.5	Do.	-	64	Average Coal Measure Strata, free from massive rock.
Lees, T.G.....		750	6 to 7 (2 seams)	-	3.5	About 54	-
Lloyd, W.D.....	Yorks.	1,066	3.8	1 in 37	-	58.7 43.4	Ordinary packing; longwall. Tight packing; longwall.
Moore, R.T.....	Lanarkshire	240 to 960	-	-	-	75 (nearly)	-
Noss, K.W.....	S. Staffs.	1,626	5	-	1.54 (average)	31	-
O'Donohue, T.A..	Lancs.	850	3.3	16.5°	1.75	53	Coal Measures, 80 per cent. shales; 20 per cent. sandstones; overlain by 40 - 60 feet of drift.
		1,900	2.8	18°	1.5	53	
		3,000	4	12°	1.42	37	
Paterson, M....	Castleford, Yorks.	603	4.25	-	3.3	78	-
Peace, W.....	Wigan	450	4.5	-	3.5	78	-
Piggford, J....	Notts.	1,650	5.5	Undulating	2	36	Longwall
Spencer, W.....		240	5	-	3	60	-
Stewart, R.....	Lanarkshire	330	3.2	-	1.2	37	Longwall. Removing wide strips of coal; waste on each side.
		366	3.5	-	1.2	37	
		420	3.2	-	2.25	71	
		468	2.4	-	0.83	34	
Unsworth.....	Lancs.	453	3.4	-	2.25	66	Strata friable, except for one 30-ft. bed of rock.
		525	3.5	-	2.75	78	
Whitelock, G.C.H.	Castleford, Yorks.	1,650	4.38	-	-	56.3	-
		240	(average)	-	-	70	-
		378	4	-	0.083	2.1	Small amplitude attributed to Batley Sandstone (40 yds.) close to surface.
Wilmot.....	Staffs.	960	5.5	-	1	18	-
Wilson, A.....	Lanarkshire	420	about 4.25	-	1.92	45	Longwall.
Wright, T.....	Newstead Abbey, Notts.	1,680	3	-	1.9	63	Longwall.

- (3) The processes of shearing and bending in the workings of a seam situated above the seam being worked.
- (4) Behaviour and manner of fracture of carboniferous rocks when subjected to horizontal, vertical and oblique stresses.

The lines of attack set out above are all directed to the field between the coal face and the surface, a field of research which has been woefully neglected in the past and from which reliable information as to causes of draw, perhaps the most pressing necessity of the problem, will undoubtedly be obtained.

AMPLITUDE OF SUBSIDENCE.-

The amplitude of subsidence is characterised by its extreme variability. But generally, amplitude diminishes as depth increases. This diminution is quite natural when one considers that the area of settlement is generally increased with depth. The rate of diminution, however, is not rapid except for shallow depths, it being retarded by the increased pressure (therefore compression) suffered by the fractured rocks in the mined area.

RELATIONSHIP BETWEEN AMPLITUDE OF SUBSIDENCE AND THICKNESS OF DEPOSIT EXTRACTED.-

In a consideration of this relationship the ratio

$$\frac{\text{amplitude of subsidence}}{\text{thickness of seam}}$$

is useful. That it is extremely variable is demonstrated on the appended chart (Table No. 15. after Briggs). The cause of the variation, however, is difficult to decide, but among a host of variables we have the following of first moment:

- (a) The method of mining;
- (b) The method of packing; complete partial or not at all;
- (c) The presence of old workings over and under the seam being extracted. Stoop and room workings have an enormous effect, especially if the stoops left are small;
- (d) Nature of packing material;
- (e) Nature of roof and pavement of the seam and superjacent/

- superjacent rocks;
 (f) Nature of surface.

The importance of the nature of the material and the method of packing cannot be over estimated. In this regard instances are on record where, when the hydraulic process of packing was used, the ratio s/t was only $1/20$, and Hudspeth cites a number of instances in which the amplitude varies from 5% to 32%, while in the Liege coalfield this method of packing reduced the amplitude of subsidence from 50% to 20%. A British example, that of Dalziel Colliery, is very striking: a 4-foot seam was extracted with an s/t ratio of 1 : 6, while draw (which generally was very extensive) was almost entirely eliminated. The best results are obtained by this process when complete sand stowing is applied in virgin areas.

Summing up with regard to the influence of hydraulic stowing over amplitude of subsidence, Hudspeth¹ made the following significant statement:

"Hydraulic stowing does for shallow workings what depth does for deep workings. It causes a more regular and equal settlement of the surface; it tends to avoid these irregularities in the settlement of the surface, which cause surface damage. Its advantages in avoiding surface damage are necessarily relative, in so far as in thin seams practically unstowed at large depths causes less damage than a shallow thick seam stowed hydraulically".

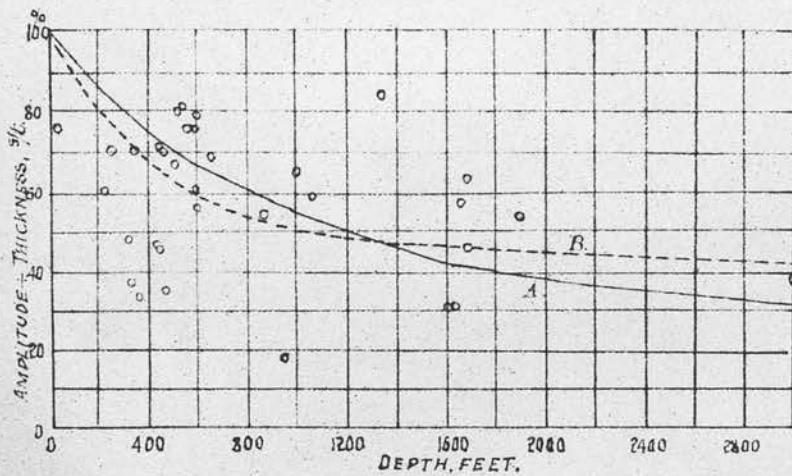
RELATION BETWEEN AMPLITUDE AND DIP.-

The Dortmund Board found that generally amplitude decreases with increases of dip. Their findings, based on a considerable amount of field work, are as under:-

<u>Dip of Bed</u>	<u>s/t.</u>
0°	0.14
10°	0.39
20°	0.28
30°	0.26
40°	0.19
50°	0.16
60°	0.12

The figures above refer to Westphalian mines where stowage is more complete than in British mines; the figures are

therefore/

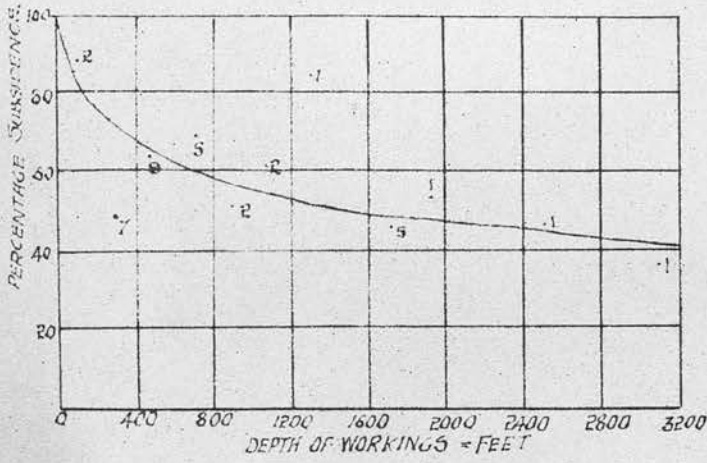


Relation between Amplitude of Subsidence and Depth of the Workings. -- M. No. 33.

The line A Fig represents Menzel's relations :

$$\frac{s}{t} = \frac{350}{D + 350} \text{ for depths, } D, \text{ up to 350 or 400 metres and}$$

$$\frac{s}{t} = \frac{400}{D + 400} \text{ for greater depths.}$$



Curve showing Variation in Percentage Subsidence with Depth of Workings. Fig. No 34.

therefore low. Above 65° the result is reversed; the area of settlement diminishes and, as a consequence, the ratio s/t increases. At 90° , the maximum, the beds may slip between the roof and pavement, and in general the area of settlement is V-shaped and deep.

RELATION BETWEEN AMPLITUDE AND DEPTH.-

In this regard Dr. Briggs supplied some very useful graphs and information in a recent contribution¹ to the subject. He also discussed the various factors influencing the relationship. The graphs are very useful and indicate that the amplitude of subsidence decreases as the depth increases. Dr. Briggs plotted percentage subsidence against the depth of the working in feet on one, and amplitude of subsidence against the depth of the working on the other (see diagrams No.35. and No.34.). To smother out the aberrances as much as possible he graphed the mean values relating to each successive 200 feet up to a depth of 3200, and indicated the relative weight of the means by writing the number of observations averaged. Thus the first point expressing the subsidence for depths from 0 - 200 feet (percentage subsidence 88) plotted against the depth 100 feet, is the mean of two results, and the second point, which refers to depth from 200-400 feet is the mean of seven observations and so on.

The curve is the graph of

$$\% \text{ Subsidence} = \frac{400}{400} + \sqrt{d}$$

where d = the depth of the seam stated in hundreds of feet.

DRAW.-

This is one of the most controversial branches of mining subsidence. Measurement of the extent of draw is one of the simplest, and an explanation of the causes one/

1. Briggs, "Subsidence Problems", Colliery Engineering, Jan. 1930, pages 21 - 23.

Table. №16.

one of the most difficult problems facing the investigator. Little or no advance had been made towards the solution of this problem; nevertheless the last quarter of a century has not been entirely unfruitful in this regard; we have already referred to the contributions of Professors Louis and Briggs. The problem is being attacked from new directions, and we are confident that, as a result of the investigations into the behaviour and manner of fracture of coal measure strata when subjected to forces acting in various directions, much valuable light will be thrown into the obscurities of this important and baffling branch of mining subsidence. Draw, like amplitude, and many of the other phases of the phenomena, is characterised by its extreme variability. A list of British observations on draw is appended hereto, Table No. 16. The list is taken from Dr. Briggs' admirable book "Mining Subsidence".

On perusal, the true significance of variability becomes apparent. Since the variables are almost innumerable, the subject is not amenable to mathematical analysis and still less to mathematical synthesis. Empirical formulæ, however, are sometimes useful and will probably become more so as experience extends and becomes more available.

DRAW OVER DIP WORKINGS.-

It is generally conceded that draw over a face proceeding to the dip will be greater than that over a face proceeding to the rise. This, however, is not general. An examination of the many rules and formulæ compiled for the determination of the size and position of supporting pillars in an inclined seam shows the paucity of our information. The angle of draw over dip faces is generally assumed to increase as the inclination of the beds increases until, at a certain dip, the angle reaches a limiting or critical value beyond which there is no corresponding increase/

Observer.	District	Depth of Seam D ft.	Thickness of Seam t ft.	Dip $\frac{t}{a}$	Angle of Draw (from Vertical)	Remarks.
Baker, J.P.....	W. Bromwich	-	-	-	45°	Church standing on a thick sand bed
Binney, -		150	4	-	9½ - 26½°	30 ft. brick clay at surface.
Dixon, J.S.....	Lanarkshire	648	5½	1 in 20	(a) 8¾° (b) 7¾°	Bord-and-pillar, broken-working. Strata contains 219 ft. sandstone and 48 ft. boulder clay. Retreat, 34 ft. a month.
Dron, R.W.....	Ditto	500	2¾	1 in 12	40°	Longwall, with machines. Three higher seams wrought 20 years before.
Eltringham, J..	Northumberland	288	4	1 in 12	26°	Bord-and-pillar.
		306	4	1 in 16	21°	Do.
Goodwin, J.....	Lancashire	720		10°	17°	Dip faces. (Draw over strike faces, 5 - 7°.)
		588		15°	19.1°	
		648		20°	19.4°	
		720	4 to	24°	19.75°	
		528	6	27°	21.75°	
		612		31°	24°	
		750		34°	22.6°	
		594		40°	26°	
Greenwell, G.C.S.	S. Staffs.	-	-	Slight	26½°	-
Hassam, A.....	N. Staffs.	1,470				
		1,545	17½	-	20°	Three seams worked longwall.
		2,010				
Hay, W.....	Shirebrook, Derbyshire	1,595	5	1 in 24	11°9'	Draw measured when face moving. Section includes 80 ft. Magnesian Limestone.
Hedley, A.M....	Cleveland, Yorks.	< 50	-	-	Insignifi: cant	Longwall.
		> 50	-	-	26½°	Maximum for normal strata overlain by level bed of clay or soil. Longwall.
		> 50	-	-	22°	Maximum where sandstone extends to surface; not overlain by clay. Longwall.
		> 50	-	-	45°	Maximum when boulder clay has, to a substantial extent, replaced solid measures. Longwall.
Kirkup, J.P.....	Co. Durham	244	-	-	15°24'	
		600			16°40'	
					18°20'	
Knowles, J.....	Near Manchester	1,590	-	1 in 3½	17½°	Dip face.
Lloyd, W.D.....	Yorkshire	1,066	3.8	1 in 37	6°	Longwall; face parallel to dip; rate of advance, 150-270 ft. a year. No faults. Roof, 2½ ft. bind; then 45 ft. sandstone.
					(maximum)	Rise face.
Mitton, A.D....	Yorkshire	527	3	1 in 4½	Normal to seam	Dip face.
		672	7	"	"	Maximum on rise face.
O'Donahue, T.A.	Lancashire	580	3	16½°	5°	Rise face.
		660	3	20°	Almost zero	Dip face.
		1,940	3	18°	23°	Maximum, rise face.
		2,300	4	12°	8°	Dip face.
		3,000	4	12°	20°	Dip face.
Peace, W.....	Near Ashton, Lancs.	450	4	26°	40°42'	180 ft. of drift over Coal Measures. Dip face.
		450	4	26°	> 15°	Rise face.
Piggford, J....	Teversal and Pleasley, Notts.	1,650	5½	Undulat: ing	16°	Longwall. Rate of advance about 150 ft. a year. Measurement made when face was moving.
Smallman, R....	Warwickshire	1,020	17½	1 in 3 to 1 in 5	18°	Longwall. Dip face.
		1,020	17½	"	< 40°	Longwall. Rise face.
		600	6	1 in 3	about 26°	Longwall. Dip face.
Steavenson, A.L.	Cleveland, Yorks	240	10	-	72°	Exceptional case. Subsidence caused landslide.
	Co. Durham	600	4½	-	< 60°	House standing on freestone.
Stewart, R.....	Lanarkshire	430	4½	-	4°	No draw when face actually moving.
	Ditto	330	15.7	-	21¾°	Average value; 5 seams removed.
		to 453				
Whitelock, G.C.	H.S. Yorks.	1,200	-	-	5¾ - 9½°	When longwall faces moving.
		to 2,100				
Wright, T.....	Newstead Abbey Notts.	1,680	3	-	9½ - 14° 9°	When faces stationary. Longwall. Measurement made when face was moving.

one of the most difficult problems facing the investigator. Little or no advance had been made towards the solution of this problem; nevertheless the last quarter of a century has not been entirely unfruitful in this regard; we have already referred to the contributions of Professors Louis and Briggs. The problem is being attacked from new directions, and we are confident that, as a result of the investigations into the behaviour and manner of fracture of coal measure strata when subjected to forces acting in various directions, much valuable light will be thrown into the obscurities of this important and baffling branch of mining subsidence. Draw, like amplitude, and many of the other phases of the phenomena, is characterised by its extreme variability. A list of British observations on draw is appended hereto, Table No. 16. The list is taken from Dr. Briggs' admirable book "Mining Subsidence".

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increase in the angle of draw.

Within recent years the suggested value of this limiting angle of dip has been altered, and in this regard T.A. O'Donahue (a well-known exponent of the critical angle) has altered his original rule, and now tentatively advances the rule below:

Draw to the Dip Side = $16 + 0.3$ of the
inclination - an increase of 11° .

Indeed, the general trend (as is shown in the table below) is towards higher values.

<u>Observer</u>	<u>Date</u>	<u>Critical Angle of Draw.</u>
Dickinson	1898	18°
O'Donahue	1907	24°
Dortmund Board	1907	35°
O'Donahue	1929	70° (tentatively)

DRAW OVER RISE WORKINGS.-

Reliable information of draw over rise workings is scanty, even more so than that of draw over dip workings; but despite the inevitable exceptions the general relationship between draw and inclination is clear and unmistakable. Increases of inclination generally diminish the draw over faces proceeding to the rise. We record below some recent observations, five of which confirm the general consensus of opinion, while that furnished by C.T. Jackson is an example of the "inevitable exceptions".

O'Donahue observed that draw was nil over a face proceeding to the rise when the inclination was 20° , and negative when the inclination had increased to 45° .

Lea found the following small values of draw occurring over workings in South Wales:

- (a) Draw over a seam 6' thick, using 1 in 14, was negative over a rise face.
- (b) Draw over a seam at a depth of 1751' was 10° over the dip face and $-0^{\circ}.29'$ over the rise face.

(c)/

- (c) Draw over a seam at a depth of 2100' was +11' over the dip face and -6°30' over the rise face,

while Mr. C.T. Jackson furnished information which revealed that the angle of draw over the workings of an 18'8" seam lying at a depth of 200', where the superjacent carboniferous rocks were capped by Mesozic marls and sandstones, was 20°17' over a dip face, and 25°31' over a rise face. The gradient towards the dip was 1 in 18, and towards the rise 1 in 11.

With regard to the determination of the extent of draw over highly inclined workings, due regard should be given to the possibility of the beds 'slipping' or moving ^{along} the planes of stratification, since such a movement has the tendency to enormously increase the extent of draw.

Summing up, we may state that generally

"over dip faces an increase of dip involves
 "an increase of draw, until in the vicinity of 65 to
 "70° an inclination is reached beyond which the angle
 "of draw will diminish. On the rise a steepening of
 "the gradient will in the majority of the cases cause
 "a decrease in the angle of draw, which may eventually
 "become zero and even negative, but an inclination
 "will eventually be reached beyond which the angle
 "of draw will increase again. This critical angle
 "will be comparatively low (35°), if dip slipping
 "takes place, and comparatively high (65°), perhaps, if
 "dip slipping is absent. When the inclination is
 "90° the draw over workings proceeding to the rise
 "will be positive" 1

DRAW AND THICKNESS OF SEAM.-

There is no direct evidence to prove that the thickness of the deposit extracted influences the extent of draw.

DEPTH AND DRAW.-

It is best to assume once bedrock is reached that draw is unaffected by depth.

SURFACE DEPOSITS AND DRAW.-

The beds immediately under the surface have an important/

important bearing on the extent of draw. Running sands and peat moss deposits have been responsible for many exceedingly long draws. Their influence on the extent of draw is controlled by the amount of fluid they contain.

R.L. AUCEMUTY'S INVESTIGATION.-

Technical Publication No. 396, American
Institute of Mining and Metallurgical
Engineers.

"Subsidence and Ground Movement in a
Limestone Mine Caused by Longwall Mining
in a Coal Seam Below!"

The records of this investigation are perhaps the most complete of any records to be found in this or any other country. These records covered a period of more than three years, and were compiled and used as evidence during the suit of the Marquette Cement Manufacturing Company versus The Oglesby Coal Company Ltd., La Salle County, Ill., in which the cement company successfully endeavoured to stop the coal company from mining under their property.

In this investigation a series of bench marks were established at the surface, and in the workings of the cement mine, and observations as to vertical and both lateral and longitudinal movement were made from time to time. In all there were 145 surface monuments and over 300 pillar plugs, and several base lines in the limestone mine workings. The movements were detected by re-location surveys and levellings at definite intervals. The surveys were made by 3 independent parties, and the results checked against each other. We append hereto diagrams showing lateral, longitudinal and vertical movements, and draw over the solid coal.

Results of Observations on Vertical Movement at the Surface.-

Settlement started 100 - 300' in advance of the coal face line, and the surface subsided a year before the coal/

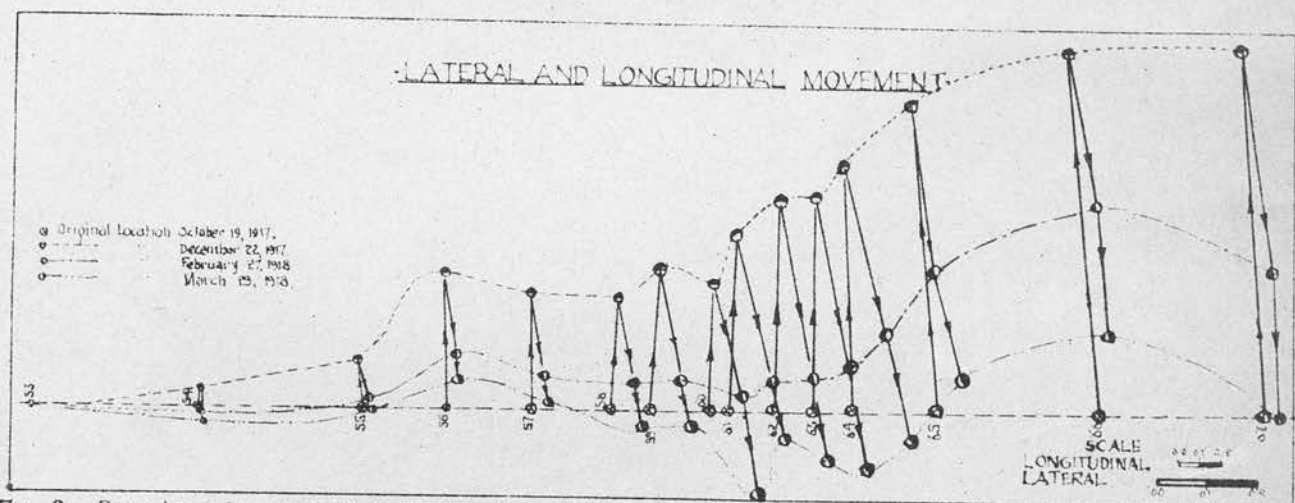
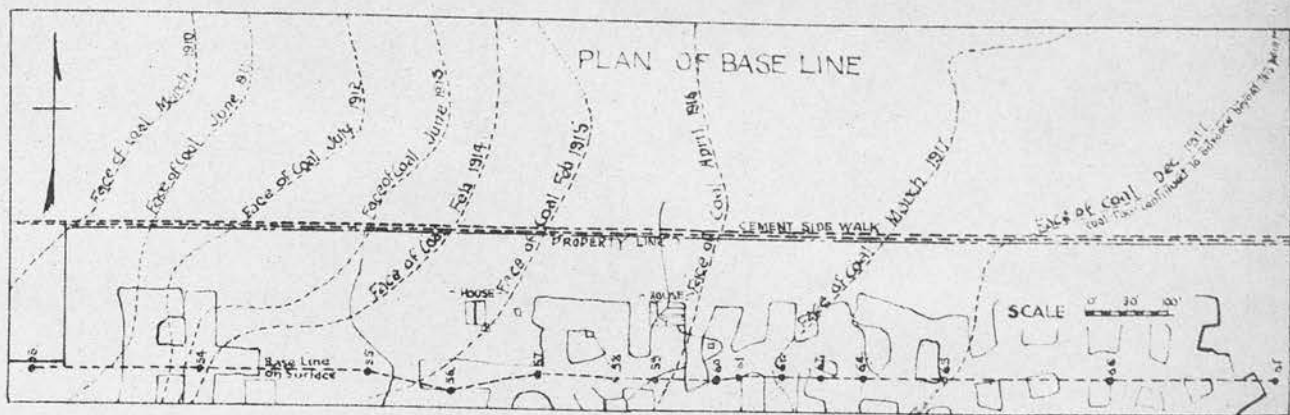
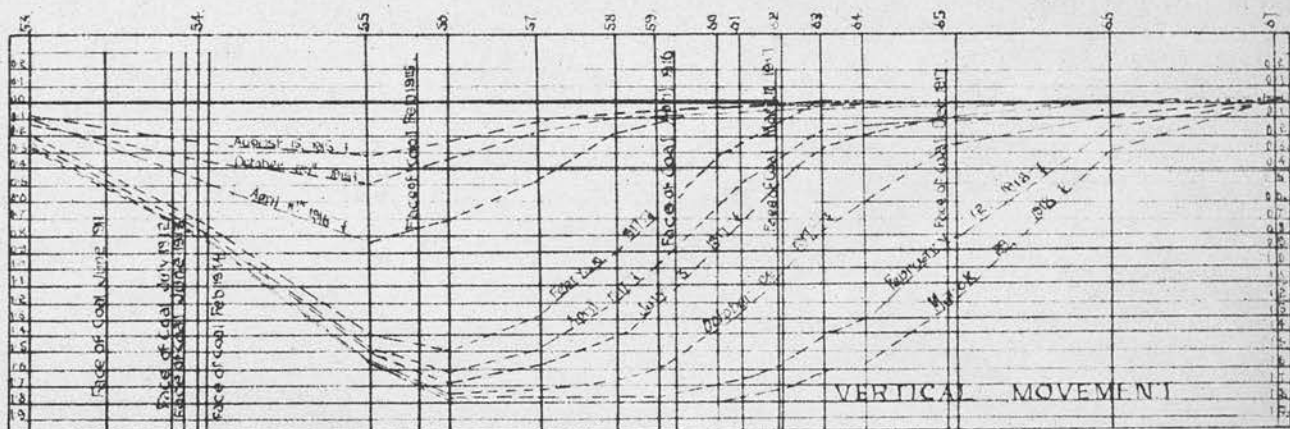


FIG. 2—Base Line, Stations 53 to 67, which parallels property line of Olesby Coal Company and Marquette Cement Manufacturing Company.

Fig. No 55.



• VERTICAL MOVEMENT •

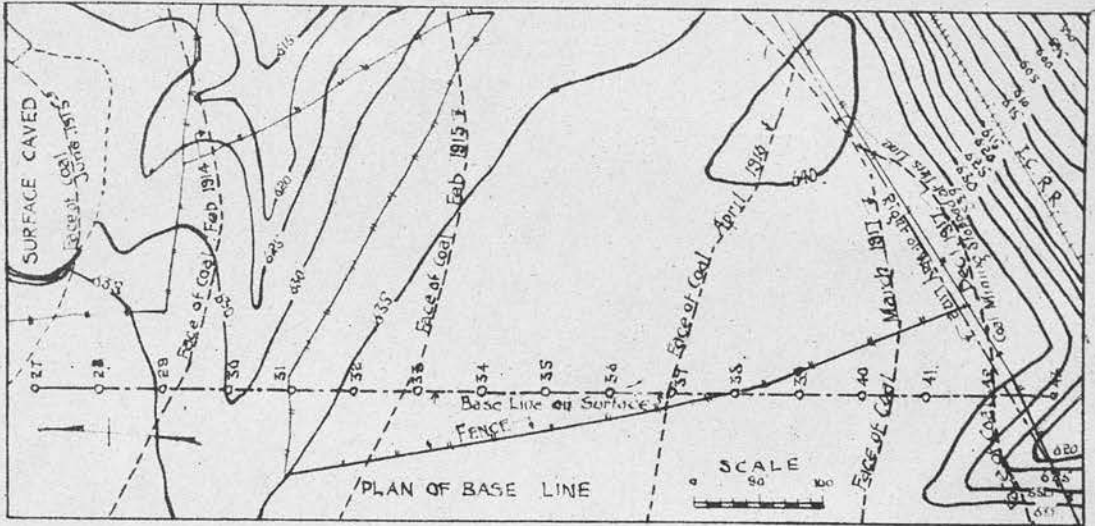


FIG. 3. Base line, stations 27 to 43.

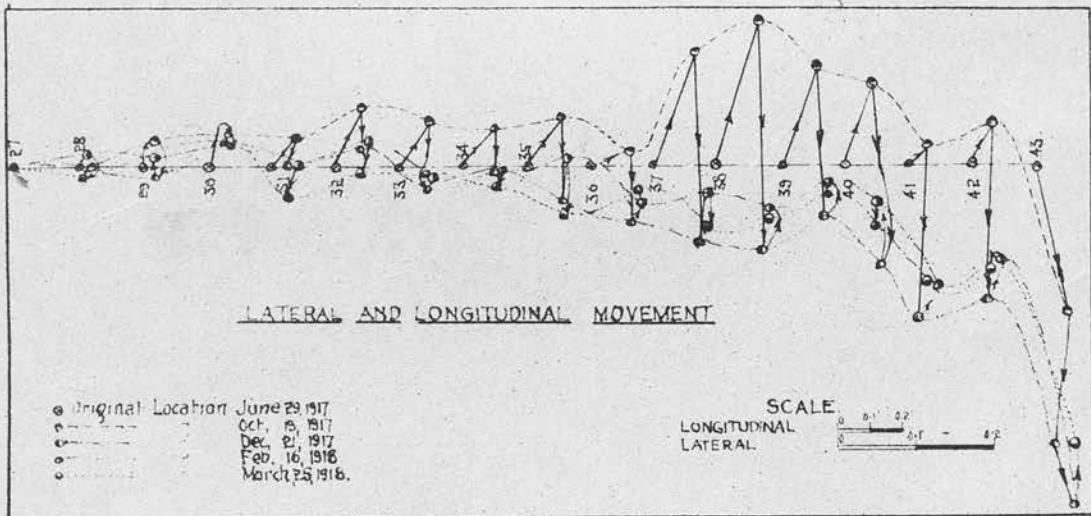


FIG. 3. BASE LINE STATIONS 27 TO 43.

U.S.G. No. 36

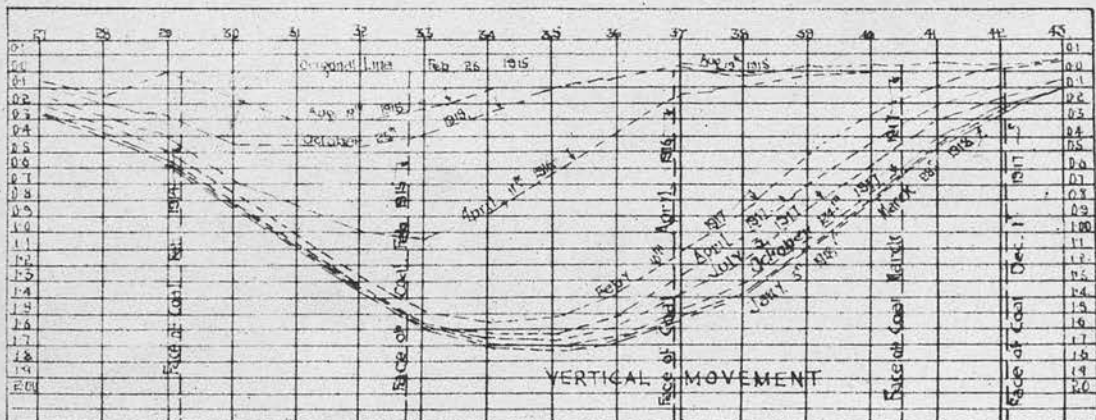
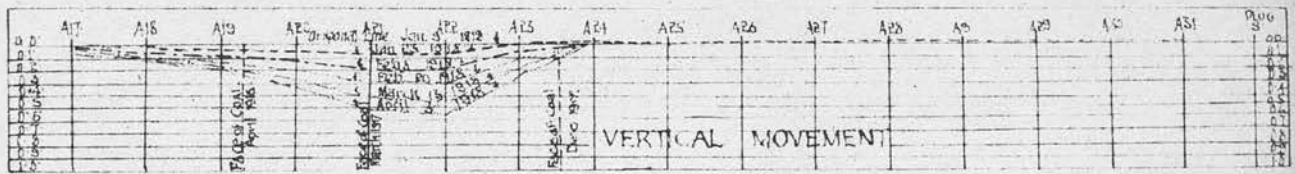
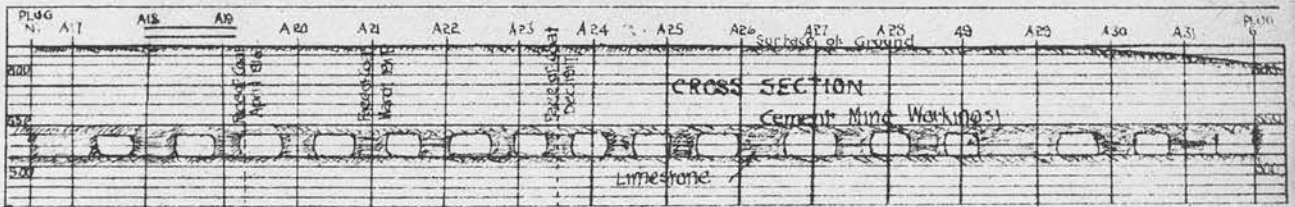
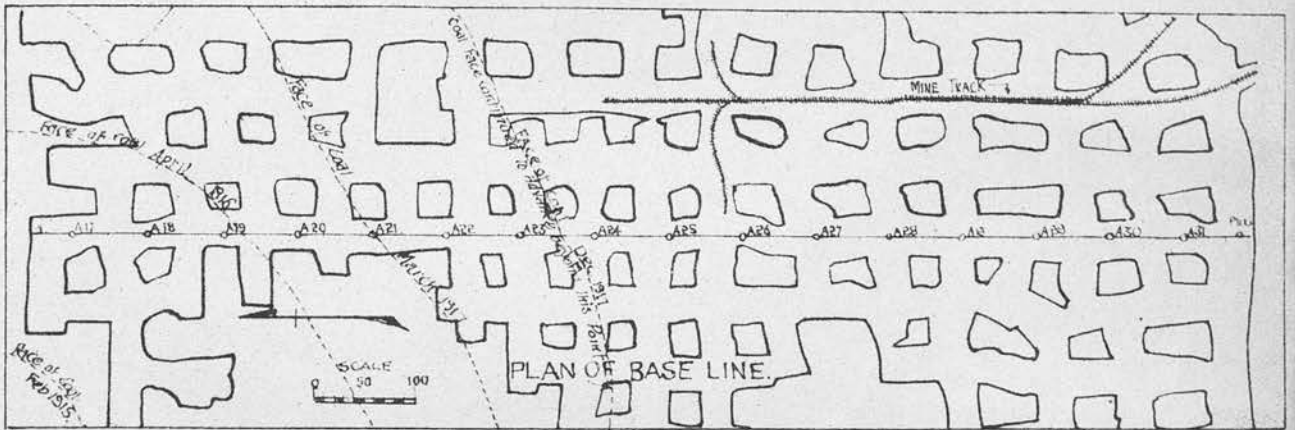


FIG. 3. BASE LINE STATIONS 27 TO 43.



- Fig. 4. - Base Line, stations A17 to A31, in cement workings. -

- Fig. N° 37. -

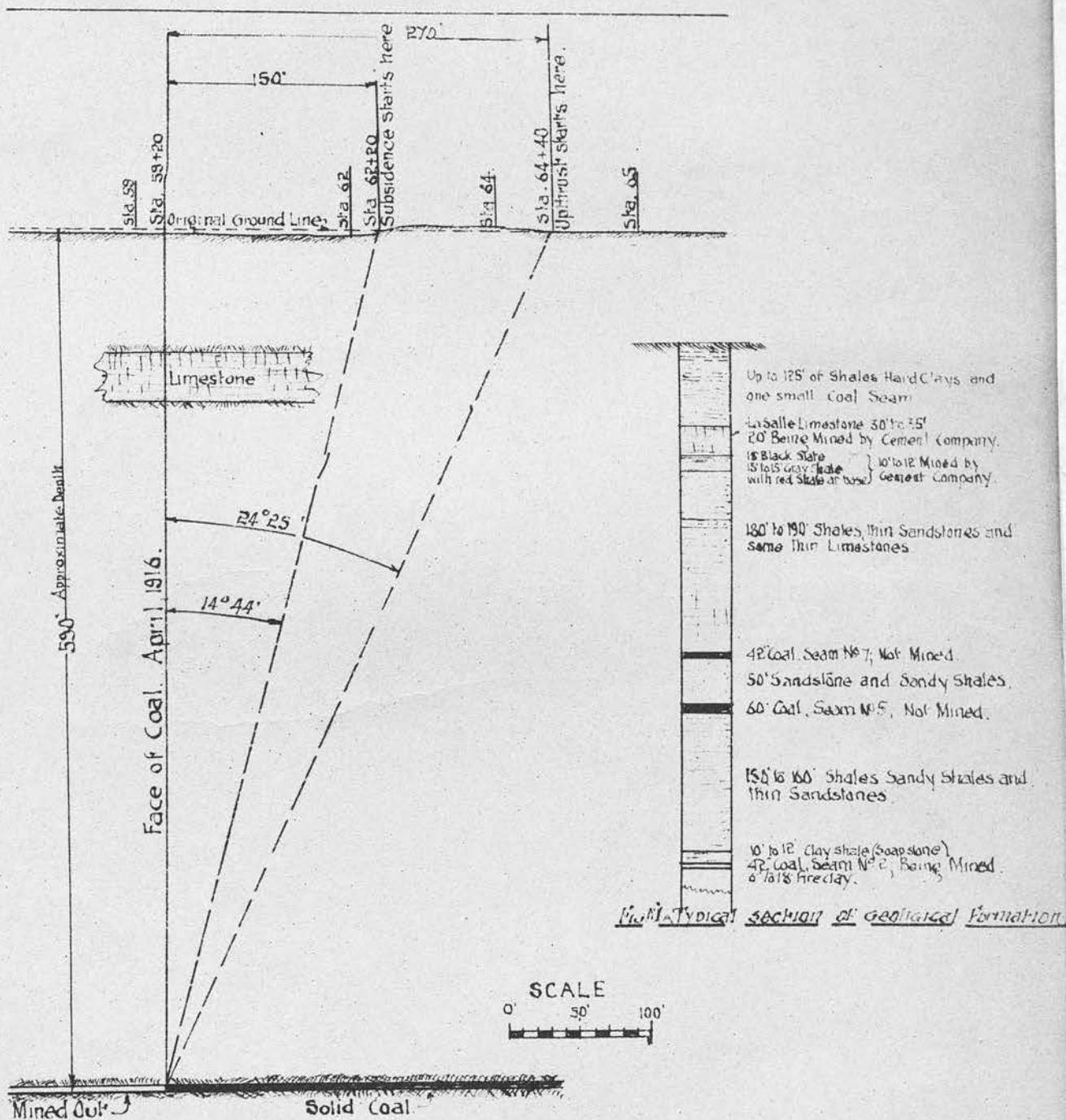


Fig. 5. Δ Angles of draw in advance of coal face. Surface observations made April 11th, 1916. Sketch made from data of Fig. 2.

- Fig. No. 38.

coal directly underneath was mined. Preceding settlement a slight uplift or upthrust action amounting to 0.041' was recorded, and settlement of the surface took place three years after the coal directly underneath had been removed.

Results of observations in the cement workings situated 125 ft. below the surface, and 435-470 feet above the coal workings.-

The ground movement in the cement workings was similar to the ground movement at the surface, but it was observed that, instead of settlement, there was a decided upthrust in advance of the face, and settlement did not start until the face had advanced 75 feet beyond the point observed.

Results of the observations on Lateral and Longitudinal Movement.-

We have appended hereto diagrams (after Auchmuty) illustrating this form of movement. They prove conclusively that this form of movement is of an oscillating character rather than in one direction, and that the direction of movement is influenced by the line, and direction of advance, of the face. Thus, when the line of the coal face was swung round from approximately the North and South direction at station No. 60 (see diagram No.35.) to N.N.E., as the line of face crossed station No. 65 and approached stations Nos. 66 and 67, the alteration in direction was accompanied by a corresponding alteration in the direction of horizontal movement. This observation is very clearly confirmed when we contrast the movement of station No. 60 with the direction and magnitude of that of stations Nos. 66 and 67.

In reviewing Auchmuty's work we are struck by its completeness and co-ordination, and by the commendable way in which it has been presented; but in the section devoted/

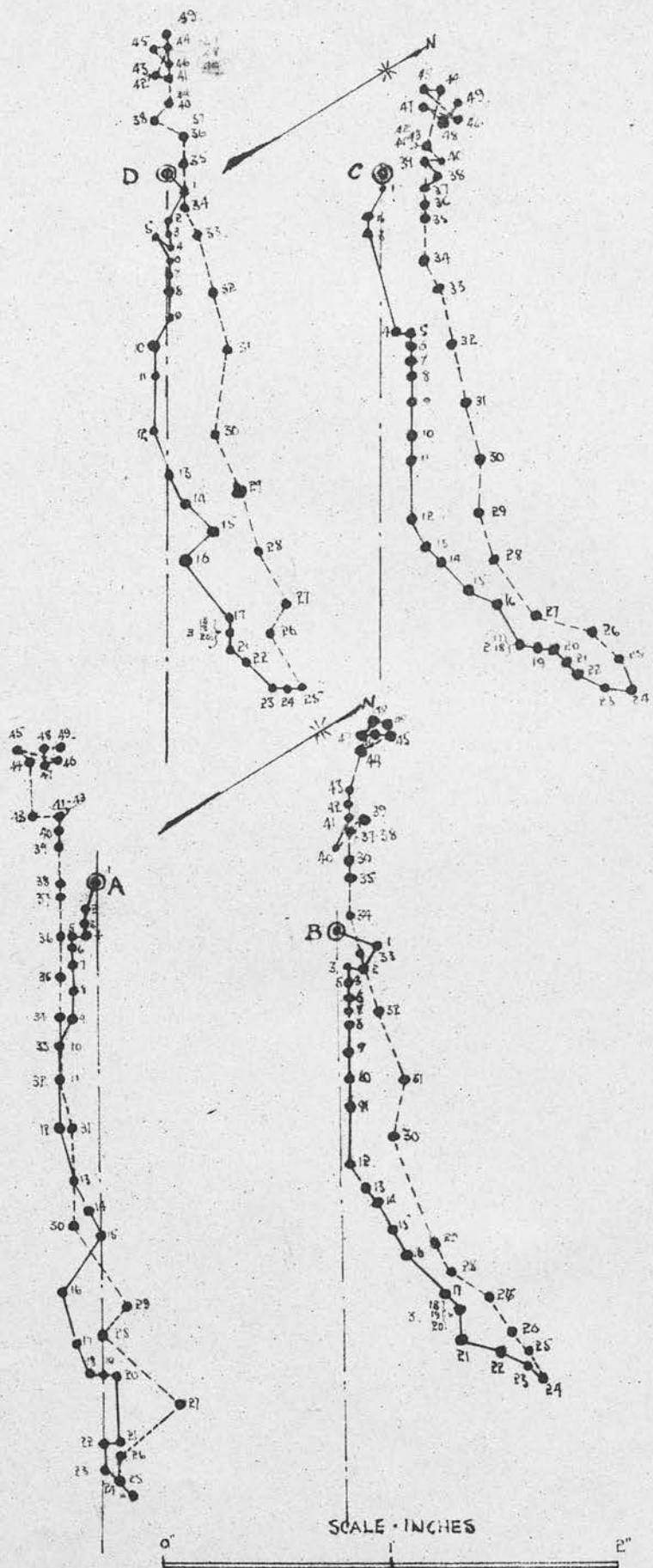
devoted to lateral and longitudinal movement there are a few glaring weaknesses. His observations and relocation surveys have always been too late in being initiated and, as a consequence, his movement diagrams are somewhat misleading unless the fact that they do not demonstrate the entire cycle of movement is kept in mind. The movement of stations No. 53 to 65, recorded on the 22nd December, 1917, when it should be observed the face had advanced beyond all these stations, is characteristic of the second phase of the movement processes (see our observations and movement diagrams) in which the movement and final displacement is in the direction of advance of the face. Further, the face is a considerable distance behind stations No. 66 and 67 on the date of the first two observations made in this area, and, as a result, the movement recorded is that of the first and second phases of the process which are characterised by movement in the opposite direction to that of advance of the face (phase No. 1) and in the same direction (phase No. 2). Although his movement diagrams are very valuable, they would have been more instructive if the observations had been made at shorter intervals, for undoubtedly parts of the general cycle of movement are missed when periods of three months are allowed to elapse between the successive observations.

W. THORNEYCROFT'S INVESTIGATION.-

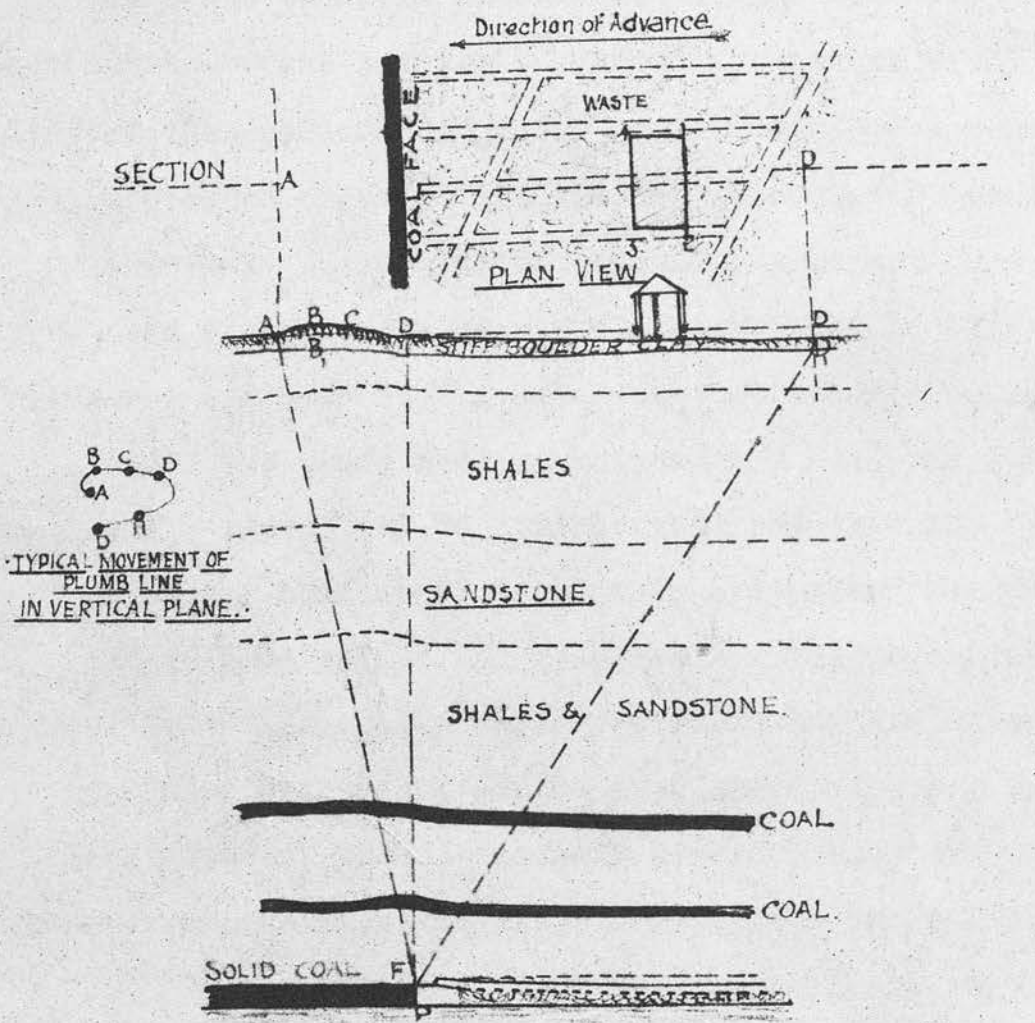
Technical Publication No. 398, American
Institute of Mining and Metallurgical
Engineers, 1931.

"The Effects on Buildings of Ground Movement,
and Subsidence Caused by Longwall Mining".

In the general introduction to this work we enumerated the 'heads' for inquiry suggested by Mr. Thorneycroft, who has recently followed up his suggestion by an investigation (on the lines which he suggested) into the characteristic/



MOVEMENT OF PLUMB BOBS AS CAPD WITH REFERENCE TO BOTTOM OF SEVERAL WALLS OF HOUSE LENGTH OF PLUMB LINES. 50 FEET. SEE HONEYCOMB, FIG. No. 59.



VERTICAL SECTION - AFTER THREE YEARS.
 - DIAGRAMATIC STUDY OF MECHANICS OF SUBSIDENCE - Fig. No 40.

characteristic curves of the waves of subsidence. We do not propose to review the whole publication, but to limit our observations to the first part, which relates to the extraction of the 20" coal bed situated about 490 feet below the surface and 90 feet above a mined out area in a 5 foot seam, which had been mined 12 years earlier.

The workings of both seams advanced under and beyond Plean House, a building of massive stone construction built over a century ago, in which Mr. Thorneycroft resided through the undermining period, and to which no perceptible damage was done by the removal of the coal. The most instructive of his observations were made on this house, those on subsidence curves. The method used was somewhat novel and involved the hanging of long plumb bob lines from the eaves at the four corners of the house. The paths of the respective plumb bob lines were traced on level surfaces, and incidentally the angles made by the house walls and the plumb bob lines gave measures of the slope of the subsidence wave at the respective points.

We append hereto diagrams (after Thorneycroft) illustrating the mechanics of subsidence and the movements of the four plumb bob lines.

Summarizing Thorneycroft's data, we observe that, when the house with relation to the face was in the position AB, the house was tilted away from the advancing face by the slight uplift indicated at B, and, neglecting side movement, the house returned to the vertical about B; then tilted backwards as the face advanced until the curve of the wave of subsidence was reversed, the house eventually assuming a vertical position at D. The typical movement of the plumb lines on a horizontal and vertical plane is shown on diagrams No. 39, 40. .

He states that tension is coincident with the forward and compression with the backward tilting of the house/

house.

The observations worthy of note in this contribution are:

- (1) The uplift of 2" in advance of the face.
- (2) The forward tilting of the house.
(This has never hitherto been detected)
- (3) The positive draw indicated in every example quoted.
- (4) The absence of damage to Plean House.

PHILLIPS' INVESTIGATION.¹

Phillips has recently carried out a series of experiments on coal measure strata, which were concerned chiefly with the nature and physical properties and manner of fracture of these rocks. He demonstrated that beds are capable of doing actual work, thus a bed deflects under a certain load, and rises, or the deflection is reduced on a reduction of the load. His chief conclusions were as under:

- (1) The terms given to the different members of the coal measure strata are vague; each term includes varieties having different mechanical constitution and texture. The variation is reflected in their behaviour under load.
- (2) The modulus of rupture of the rocks indicates that they are strong enough to hold their own loads under wide spans.
- (3) Within certain limits of stress the rocks behave like an elastic substance.
- (4) A rough relation exists between the mechanical constitution and the modulus of elasticity of the rocks tested.
- (5) The modulus of elasticity will not account for large roof deflections.
- (6)/

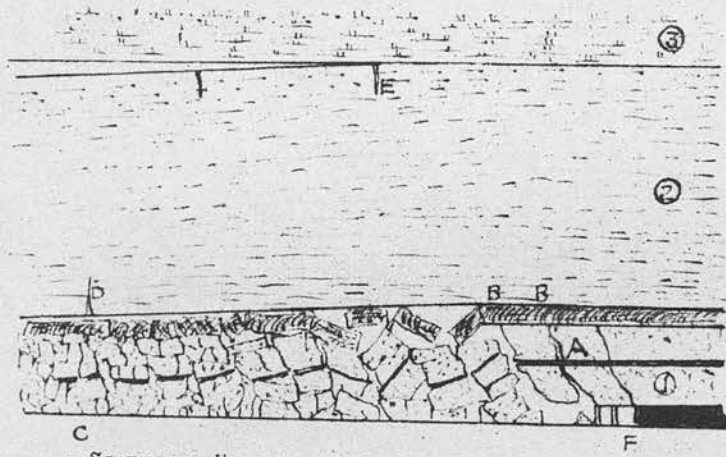
1. Trans. Inst. Min. Engrs., Vol. LXXX, 1929-1930.

- (6) When some rocks deflect under a transverse load there are two movements to consider:
- (a) an immediate deflection on application of load, and
 - (b) a further yield with time.

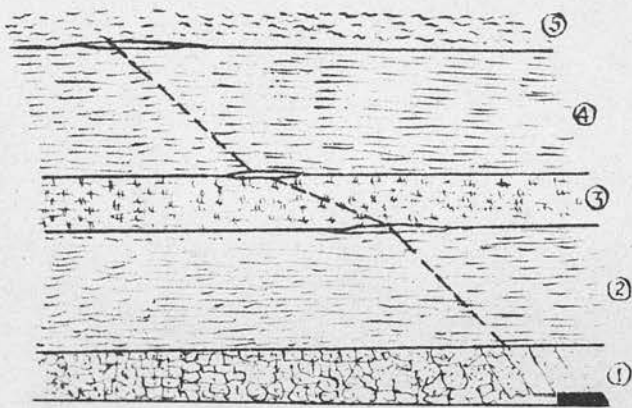
The immediate deflection is not affected by the time yield, but is directly proportional to the stress. The time yield for 24 hours increases with equal increments up to a certain stress. With further stresses it increases progressively until the rock finally breaks.

- (7) The time yield may persist and may account for some of the large deflections that have been recorded.
- (8) An important observation is that within certain limits of stress both deflections are recoverable.
- (9) On relief of stress within the elastic limit rock beams are able to perform work.
- (10) Moisture has a pronounced effect on the time yield; if acting for sufficient time it will cause the rock to fracture. The treatment in this case was very drastic after the first hour the rock beam covered by the (wetting) week was thoroughly wet.

The most important of Phillips' conclusions are Nos. (8) and (9), which point to the advisability of keeping the beds intact and in contact during subsidence at the coal face; in other words, if the beds are not excessively stressed, or deflected, they retain their strength property and materially assist in the control and absorption of kinetic energy by limiting the disturbance of equilibrium and in the prevention of excessive concentration of forces at and in advance of the face line. If a bed is fractured it acts as a dead load on the other beds and supports, and thus may contribute to the fracturing of others by producing excessive deflection or stress.



SECTION OF FACE MOVING REGULARLY TOWARDS THE RIGHT HAND. Fig. N°41.



- Illustrating Consequence of Bending involving -
- A Negative or Back Draw. - Fig. N° 42 -

PROFESSOR BRIGGS "ATTEMPT AT THE RATIONALE OF SUBSIDENCE".-

This important contribution appears in 1927. The following is a summary. He states that when a seam of coal is removed the rocks adjust themselves to the new conditions in any or all of the four ways, namely:

By fracturing under shear
 " " " tension
 " bending without fracture
 " flowing.

When coal breaks under compression it shears along a plane inclined at an angle to the direction of maximum pressure, the angle being determined by the strength characteristics of the rocks. A tension fracture on the other hand takes place at right angles to the tensile stress. The rocks lying over a seam should be considered as individuals each possessing and exercising special characteristics of strength and flexibility under the same stress one bed bends another breaks. He advances the following as the mechanism of subsidence over a flat seam worked on the longwall system, cleavage of other natural planes of weakness being disregarded. The diagram, No.41, illustrates a coal face working regularly to the right hand. The immediate roof (1) is sandstone which fractures. Above is a band of shale which bends. Weight breaks are developing in the sandstone and masses are falling away; under this action the bed loses coherence and continuity. The overhanging position, A, is a cantilever loaded on its top surface and bearing its own weight. The upper bands of A are in tension; this induces cracks which are more or less vertical and extend downwards. If the face had been stationary a freshly forming weight break would have had only slightly from the vertical. The face is however advancing and the actual break is induced to follow it. It therefore takes an irregular line with a considerable average hade. The angle of the weight break/

break seems to depend upon the rate of advance, with slow rates of advance the line is nearly vertical. The distance between these weight breaks seems to be a function of the depth of undercut and rate of advance.

Adjustment of the roof to the new conditions is a slow process, bending is particular in this regard. Bed No. 2 in the diagram is in tension at E and may be in tension at the point of inflexion, D; at these places vertical cracks appear; if these cracks extend far enough, the bed may break and a sudden set occurs in the waste.

The figure No.42. illustrates bending and distinctly shows the possibility of a negative draw only on an advancing face. Should the face stop, then the superjacent strata is left in the form of an overhung cantilever (which is essentially unstable) and which must eventually give positive draw.

Shear planes hading over the unworked part of the seam and causing the positive and more orthodox type of draw are indicated at CB, ED, HG, etc. in Fig. No.43. , where a flat seam 5 feet thick is being wrought under 700' of strata of different kinds. The diagram illustrates what Dr. Briggs suggests as being the actual state of affairs obtaining in coal measures, some of the beds shearing and some bending. The more flexible shales bringing about a negative draw, and the more brittle beds a positive draw, and the extent at the surface of the surface disturbance (the position of the point A) is in effect an algebraic summation of many movements, some towards the unworked portion of the seam and some in the other direction. The general line AF in the section hades at 7°; it however bears only a remote connection with the irregular boundary of the subsided ground.

Dr. Briggs sums up as follows:- Subsidence is due to a combination of shearing, bending and some lines of/

of flowage of the several strata involved. Tension breaks have a minor influence. The beds behave as individuals and not as a compact whole. The behaviour differs so much and so many factors (method of mining and of packing, thickness of seam, manner of collapse of the immediate roof, etc.) have an influence that no attempt to group together an extensive series under a single rule can be anything but unsatisfactory.

Shearing causes positive draw, bending causes negative draw. Subsidence due to shearing has a larger horizontal extent and a smaller vertical displacement than subsidence due to bending.

A bed may bend under one set of conditions or at one stage of subsidence and shear under other conditions.

The greater the superincumbent load the more flexible is a bed. A bed which shears at moderate depth would be more inclined to bend at greater depth. Hence draw is not directly proportional to depth, but relatively less for greater depths.

The time factor is important. Bending and flowage are slow processes.

Lines of levels run across the surface may supply information of immediate use to the mining company concerned, but unless supplemented by a great deal of other information are of little or no service in investigating the general problem of subsidence and are more likely to confuse than elucidate the issue. Organised observations on the strength and physical characteristics of the various strata and on their behaviour as seen in shafts and drifts passing through subsided ground and in seams subsequently extracted over the workings causing subsidence are more likely to furnish reliable data. Owing to the presence of beds which bend the draw in fairly flat coal measure strata is less than that indicated by normal faults in that district.

The/

The hade of such (omitting from consideration transcurrent faults or wrench planes) should be helpful in deciding the size of supporting pillars, inasmuch as their hade gives results on the safe side, unless running ground is involved.

APPENDIX NO. 1.

INTRODUCTION.

Mining Engineers and property owners have been somewhat reluctant in the past to allow the complete extraction of coal by the longwall method of mining under valuable surface property and structures. Indeed, many of them have stipulated in their leases that the coal within a certain area under such property had to be left intact. The size and position of this reserved area (as it is commonly called) with relation to the structure to be protected varies with the depth, inclination, strength and thickness of the seam, nature of the sub and superjacent strata, and the position of faults, if any.

A common practice, however, is to leave a circular area, the diameter of which is equal to the depth of the seam from the surface, under the property to be protected, if a number of structures have to be protected, and they are in close proximity to each other; a series of such circular areas are described on the plan (with as centre the centres of the respective properties to be protected), and the bounding lines of the circles are joined by straight lines. When one considers the amount of coal in these reserved areas (particularly if the seam lies at a great depth and a fair number of seams are involved) one is struck by the fact that the value of the coal left in is out of all proportion to the value (in the great majority of cases) of the property protected. From the practical mining side, these reserved areas are a source of trouble and expense, and, in general, the system of protecting surface structures by means of pillars (other than shaft pillars) entails the following drawbacks:

- (1) A pillar of insufficient size is apt to cause considerably more damage to a structure than the complete extraction of the mineral.
- (2) Leaving pillars of adequate dimensions on any but shallow seams results in the loss of large amounts of mineral.

(3)/

- (3) In deep mines the pressure brought to bear on a pillar may exceed the strength of the coal. Under such conditions no pillar, even of solid coal, can remain intact indefinitely.
- (4) Pillars interfere with the regular development of the mine, and therefore increase 'working costs'.
- (5) To leave coal behind in the waste is highly undesirable in any seam liable to spontaneous ignition.
- (6) By causing irregularities in the settlement of the surface pillars disorganise the drainage of land, and increase the chance of damage to sewers, pipes, and cables passing over them.
- (7)¹ A pillar left in a shallow seam causes uneven subsidence when a seam below is totally extracted. In these circumstances its presence is apt to augment instead of to diminish injury to the structure it was intended to protect.

For the reasons enumerated above, it would obviously be to the advantage of all concerned if the practice of leaving pillars under any but the most important surface structures was discontinued. Before this takes place, however, the difficult task of breaking down the centuries-old barrier of tradition must be accomplished. Perhaps this can be done in no better way than by making available all the information relating to the various operations involved, and the damage done, if any, in cases where coal has been successfully extracted under valuable surface structures. With this object in view, we set out to describe the precautionary measures and underground method of mining practised at Newcraighall Colliery, where coal was successfully removed under a valuable farm steading. Our observations are limited to the underground operations, for, although surface levellings were made prior and subsequent to the removal of the coal, the records are not available from publication. At the outset we wish to record our indebtedness to Mr. Gilbert/

1. (1) - (7) after Briggs, Mining Subsidence, pages 69 - 70.

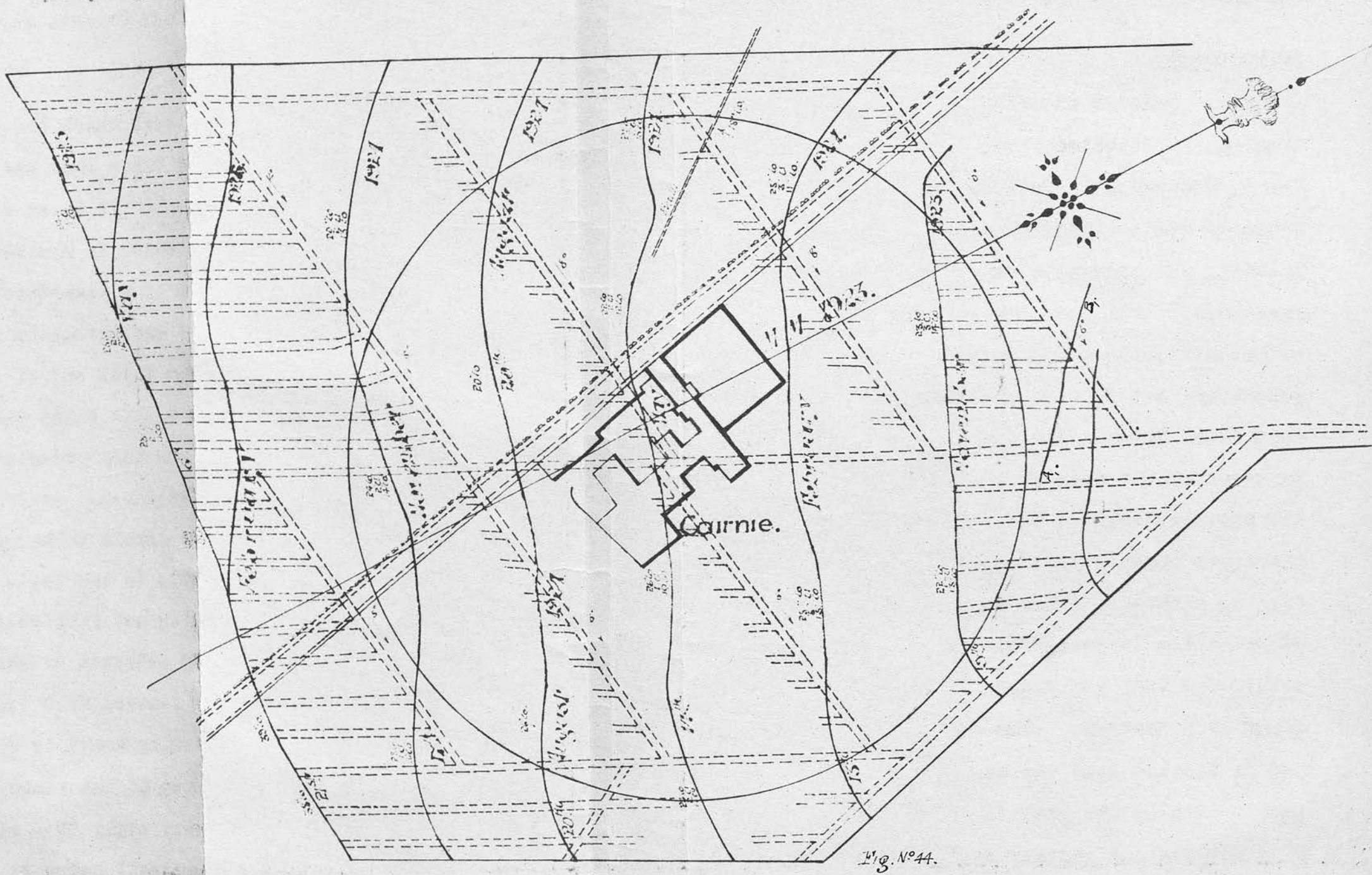
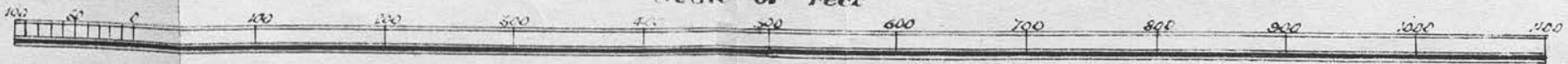


Fig. No 44.

Scale of Imperial chains



Scale of feet



Gilbert Morrison, General Mining Manager, The Niddrie and Benhar Coal Co. Ltd., who kindly granted the writer permission to include in this work the information and data he collected while supervising the operations involved in the extraction of the coal under Cairnie Steading.

INTRODUCTORY.-

Cairnie Steading, under which the coal was removed, is situated about $1\frac{1}{2}$ miles from the winding shaft No. 3, Newcraighall Colliery. It is an ordinary farm steading and dwelling house, which is a massive stone building two storeys high, built a considerable number of years ago. The seam removed was the Salters seam, a valuable deposit overlain by a thick bed of sandstone generally, but in some areas a thin blaes band makes its appearance between the coal and this sandstone. The pavement of the seam is a fireclay bed of variable thickness; the fireclay is soft and very liable to heave, indeed it heaves so readily that roadways in the waste area soon fill up with it. The coal is not difficult to 'get'; nevertheless it is invariably undercut by machines, and within the last few years is removed from the face by means of conveyors. The winding shaft is 810 ft. deep, and is located near the outcrop of the seams, where the inclination of the beds is very high, 60 - 65 degrees. This inclination rapidly decreases, however, as the seams extend outwards, and in the areas now being worked varies from 4 - 10°. The depth of the Salters seam at the farm steading is approximately 970 feet.

METHOD OF MINING AND LAYOUT OF WORKINGS.-

The coal on the line, AB, see diagram No. 44, had been extracted a considerable number of years before permission to extract the coal in the reserved area was granted. The old heading (B) and the side roads thereof leading/

leading to the face were open, but in a bad state of repair. As a preliminary, therefore, these roads had to be ripped and made serviceable. After the necessary repairs had been performed the face was opened out and straightened. The road C was then set out to extract the coal in the dip half of the area, and to work the coal in the dip section of the area forward into line with the old face to the rise. When the faces were in line, two longwall undercutting machines were introduced and the major operation of extracting the coal commenced. As mining proceeded, the length of face gradually increased until the face extended about 30 ft. beyond the rise and dip edges of the circular reserved areas, where the direction of the roads B and C was altered to a direction parallel to the roadway A. Thus the face, as it advanced, extracted the coal within and slightly beyond the reserved area.

METHOD OF PACKING.-

Packing is generally considered to be an important operation from the point of view of limitation of surface damage. In this example, no special precautions were practised. Indeed, the ordinary methods practised throughout the colliery were employed. Nevertheless, it must be admitted that the seam was not unduly thick nor the distance between the branch roads unduly long and that, as a consequence, the packs were fairly broad and the cundies short. As was the usual practice throughout the colliery, the side roads were 8 feet wide, and the ripping thickness 4', and main roads 10 feet wide and the ripping thickness 5'. The ripped material was distributed evenly, and built along the road sides to form the road side packs, which were the only packs used to control and support the roof. The side or branch roads were set out at regular intervals of 38', and were cut off by/

by the main roads or headings regularly at intervals of 200 ft. when possible. It should be observed that only four main roads were set out in the reserved area.

When it was found necessary to increase the height or width of any roadway, the ripped material was transported to the coal face and stowed in the waste. The thin fireclay band occurring towards the centre seam, which collapsed with the coal, was collected and shovelled carelessly into the cundies.

METHOD OF TIMBERING.-

The roof was supported by wood props which were set in line and at regular intervals. The props were not systematically extracted, and only a few were recovered.

METHOD OF UNDERCUTTING.-

The coal was undercut by means of two Anderson & Boyes chain machines (AC, 500 volt, 5 cycle) to a depth of from 4' to 4'6". They worked 'to and fro', and were exceedingly satisfactory; breakdowns were unknown, and the cost of upkeep and repair very low. Indeed, they never 'missed a cut' during the entire period of extraction.

STRIPPING.-

The coal was removed on two shifts; it was filled into tubs and hand drawn to the nearest auxiliary haulage, from which it was transported by endless rope haulages to the pit bottom. In the actual operation of stripping the coal nearest the machine was removed first, and stripping proceeded in the direction of the next cut of the machine - a very satisfactory method where the face is long.

RATE OF ADVANCE OF THE LINE OF FACE.-

To cut and strip a face of this length every day is a very difficult matter indeed. Moreover, men absenting/

absenting themselves from work, where the entire face is undercut by machines, dislocates operations, and tends to make cutting irregular. For those reasons it was decided to aim at the clearing of a definite length of face, rather than a definite rate of advance, that is, number of cuts forward every week. Although this method is apt to cause irregular subsidence of the roof at the face, it is perhaps the best to adopt when the length of face is great.

PRECAUTIONARY MEASURES PRACTISED WITH A VIEW TO REDUCING SURFACE DAMAGE.--

From the foregoing pages it is obvious that, so far as the methods of mining (cutting, stripping and packing) are concerned, no special precautions were taken; indeed, as already stated, the methods were similar to those practised throughout the colliery. It was considered important, however:

- (1) To maintain a regular and high rate of advance of the face; indeed, regularity of rate was considered to be more important than high rate of advance.
- (2) To keep the face straight, and in a constant direction.

APPENDIX NO. 1

RESULTS AND CONCLUSIONS.

RESULTS AND CONCLUSIONS.

- (1) The coal was removed under the farm steading without any appreciable damage to the farm house and adjoining property. Indeed, the Niddrie & Benhar Coal Company Ltd., who were under obligation to repair any damage, have not spent any money on repairs to this day. The only perceptible damage was that to a ceiling of a room on the second storey, which was cracked.
- (2) In view of the successful extraction just described, the colliery company are now removing the coal under all surface buildings by the methods described in the preceding pages, and consequently a large amount of valuable coal is now available for exploitation to the advantage of everyone concerned.
- (3) In view of the successful extraction of the coal under Cairnie Steading, and of the fact that the ordinary methods of longwall mining were practised without any precautionary measures worthy of the name, the removal of the coal in most of the reserved areas distributed throughout the coal field of Great Britain should be seriously considered, and the practice of leaving reserved areas discontinued.

I N T R O D U C T I O N .

In the preceding chapters we emphasized the disadvantages from the point of view of surface damage entailed by the practice of mining coal by the short longwall system. The case we are about to describe demonstrates practically the points we emphasized, and is unique for two reasons:

- (1) The amount of damage done.
- (2) The fact that a legal dispute between the mining company and the cemetery owner resulted in a temporary cessation of mining operations - which materially increased the damage - and that the mining company eventually went into liquidation. The result was that the temporary stoppage became permanent, and, in consequence, the face was stopped at the worst position possible from the point of view of surface damage.

Although our observations are confined to the surface damage, we intended at the outset to measure the extent of draw in two directions, i.e., at right angles and parallel to the direction of advance of the face, and levellings were made for this purpose. Unfortunately, however, all movement had ceased before our observations were started, for, despite the fact that careful levellings and measurements were made during five consecutive months, no movement of any description was detected. This was unfortunate, but the mining company's surveyor was able to supply some information as to the extent of the advancing draw. He stated that damage to the house was first detected when the coal face underground was 50' - 60' from the point of observation. The method of measurement signified, that of determining draw by the presence of damage, is very unsatisfactory, and almost invariably gives a small value; precise levelling would certainly have indicated a longer draw. Although the method of determination is unsatisfactory, the value of draw furnished by the surveyor is valuable, and allows of a comparison between draw/

draw and rate of advance of the face as observed at Craigrigg and Barbauchlaw Mine. Since the seams worked, and the method practised (except inasmuch as the coal was undercut by longwall undercutting machines at Craigrigg Colliery, and rate of advance of the face was consequently much higher) was the same in both cases, and advancing draw was, if anything, greater over the workings at Craigrigg Colliery, we are forced to conclude against the general concensus of opinion - which is that advancing draw decreases as the rate of advance increases - that the rate of advance of the face does not apparently influence the extent of the advancing draw. Indeed, if the rate of advance has an influence, our information seems to point to an increase in rate of advance augmenting the extent of draw. At the outset we wish to record our indebtedness to Mr. Izatt, the caretaker of Gowan Bank Cemetery, who kindly granted us permission to install draw pegs in the paths therein, and to the Mount Vernon Coal Company Ltd., who kindly supplied diagram No.45. .

SITUATION OF MINE AND GENERAL METHOD OF MINING.-

Craigrigg Colliery, the property of the Mount Vernon Coal Company Ltd., is located about 3 miles N.N.W. of Barbauchlaw Mine. The coal removed under a section of Gowan Bank Cemetery was the Colinburn, which, in this area, varies in thickness from 22 - 24" and lies at a depth of 132 feet from the surface. A section of the superjacent strata is similar to the section included in the fore part of this work.

METHOD OF MINING.-

The short longwall machine method of mining is practised at this colliery. The coal is undercut by machines, and is filled into tubs and hand drawn to the nearest auxiliary haulage. The branch roads are set out at/

at intervals of approximately 40 feet and are brushed 8 feet wide and 6 feet high. The ripped material or brushing is built along the road sides to form the road side packs, and is generally distributed evenly on each side of the roadway. These road side packs are the only packs used in the support of the roof.

METHOD OF SUPPORT.-

The roof is supported by the road side packs, and wood props ($3\frac{1}{2}$ " to 4" in diameter) which are set in lines and at regular intervals. Occasionally wood pillars are used to support the roof between the packs and face - if the ripping lags behind - they are withdrawn, however, before brushing commences.

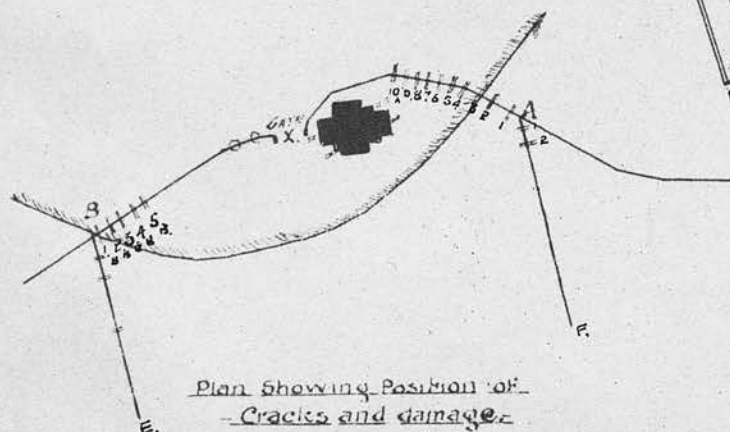
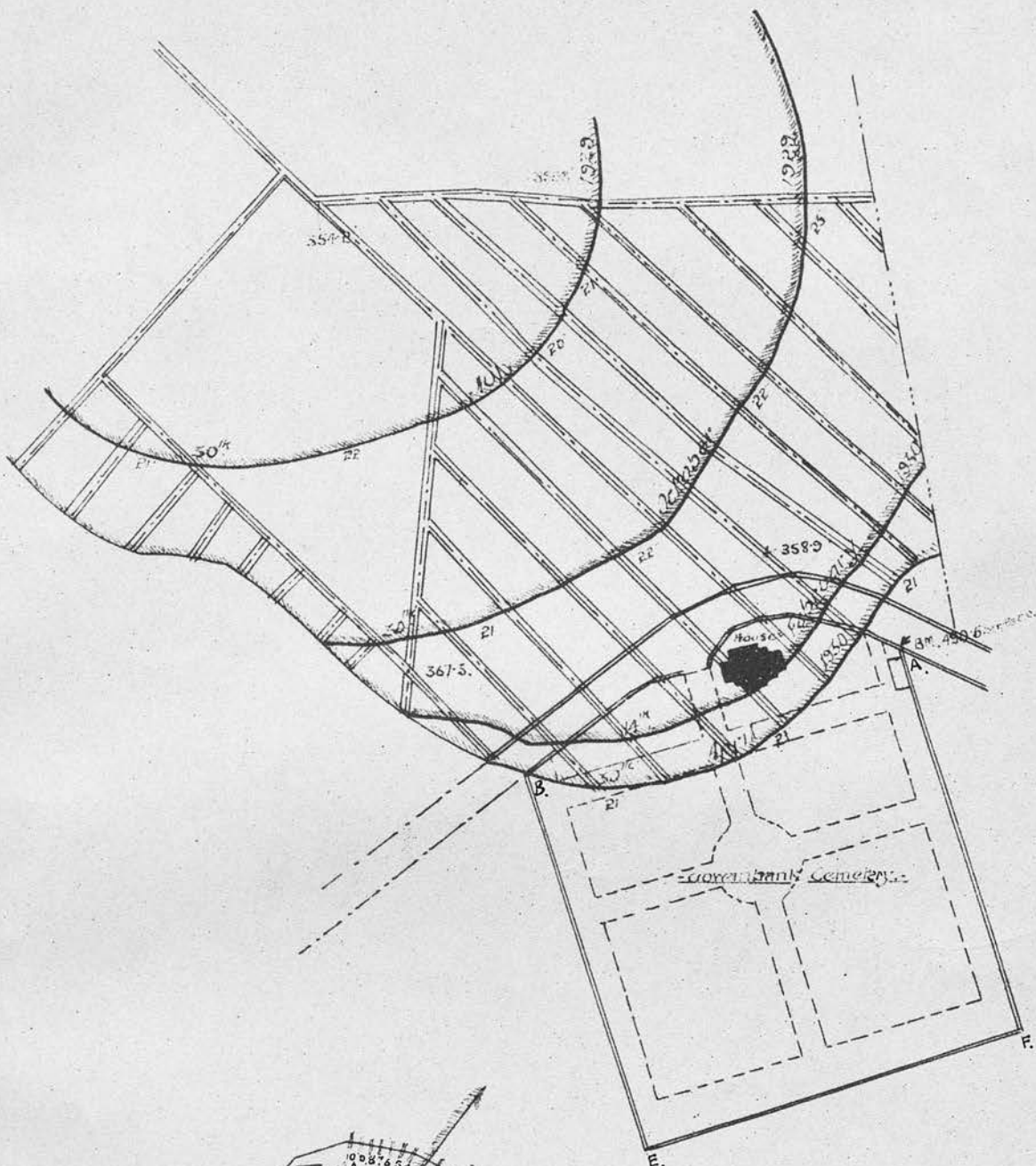
DAMAGE DONE TO THE BOUNDING WALLS OF THE CEMETERY.-

Diagram No.45. illustrates that the coal face underground on 30th April, 1930 - when the face was finally stopped - had advanced slightly beyond the front wall, gate and house of the cemetery, and that the face line at A and B was vertically underneath the 3rd and 1st gape in these walls. There were in all 15 tension cracks in the wall A B, 10 of which occurred between A and the main gateway X and 5 between X and the corner B. The cracks varied in width and hade or slope; some haded forward away from the excavated area and others backwards towards it. The width in inches, and the direction of hade of the respective cracks, are recorded below.

No.1 _A	No. 2 _A	No.3 _A	No.4 _A	No.5 _A	No.6 _A	No.7 _A	No.8 _A	No.9 _A	No.10 _A
1/4	1/8	1/8	1/2	1/2	5/8	5/8	3/8	1/8	1/8
B	B	F	F	F	F	B	B	B	B

Note: B denotes backward hade, i.e., towards the centre of the mined area.
F denotes forward hade, i.e., away from the centre of the mined area.

In the section of the wall between X and B, there were five cracks, the respective widths and hades of which were/



Plan showing position of
- Cracks and damage -

Plans showing workings of Craigigg Colliery
with relation Gowanbank Cemetery and damage
done to a house and walls by these workings.

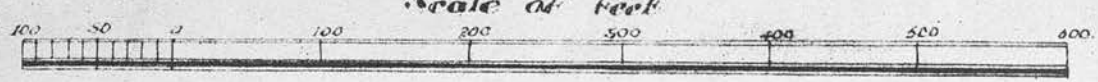
1845

45

a Scale of Imperial chains



Scale of feet



were as under:

No. 1 _B	No. 2 _B	No. 3 _B	No. 4 _B	No. 5 _B
1/8	1/8	3/4	1/2	5/8
F	F	F	F	B

Along the walls BE and AF, 5 cracks occurred - 3 in the wall BE and 2 in the wall AF - all of which had or sloped backwards towards the excavated area. Their respective widths were as under:

	<u>BE</u>		<u>AF</u>	
No. 1 _E	No. 2 _E	No. 3 _E	No. 1 _F	No. 2 _F
3/4	1/2	1/8	1/8	1/8
B	B	B	B	B

A point of interest arises in connection with the wall BE. The edge of the gape No. 2 nearest the mine workings indicated lateral displacement to the extent of 1" of the wall towards the centre of the coal face line. Between the gapes 10_A and 5_B there was evidence of considerable compression, which seemed to increase progressively towards the gate X, where it was a maximum. The wall between 10_A and the gate X did not exhibit any marked signs of compression, but the gateway X was reduced in width, and, as a consequence, the gate jammed between the gate pillars and had to be adjusted to suit the altered width of the gateway. In the section of the wall between the gate X and 5_B, there was pronounced evidence of the severity of compression. The wall, which is built of massive freestone blocks, was severely buckled at two places with the result that the freestone blocks below the coping stone bulged out on both side of the wall to the extent of 4". Another point, and illustrating an observation made in the preceding chapters, was that the wall, although perpendicular between A and 10_A and 5_B and B in the remaining section leaned in an unmistakable fashion towards the centre of the excavated area.

DAMAGE TO CARETAKER'S HOUSE.-

This house was cracked in two places, and in a direction parallel to its length and to the line of face underground. It was also tilted towards the excavated area.

DAMAGE TO HEAD STONES.-

A few headstones distributed over the area between the first pathway and the wall, AB, were tilted towards the centre of the excavated area; indeed, some were periodically adjusted in order to prevent their virtual collapse.

APPENDIX No. 2.

CONCLUSIONS.

CONCLUSIONS.

From the point of view of surface damage, the observations at Gowan Bank Cemetery clearly demonstrate:

- (1) The serious effects of a protracted stoppage of mining operations.
- (2) The mischievous consequences of extracting coal by the short longwall method of mining.
- (3) The nature of the damage caused by tensile stresses, which is difficult to repair, and is much more severe than that caused by compressive stresses.
- (4) The advisability of advancing the face a considerable distance beyond the structure to be protected, and of extracting the coal under a large area on either side of it.
- (5) That a wall over a mined area is an excellent indicator of the stresses to which the surface over such an area is subjected.

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