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Mine Roof Simulator

Definition and Discussion of Parameters

UNITED STATES DEPARTMENT OF THE INTERIOR

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Definition and Discussion of Parameters

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MINE ROOF SIMULATOR

Definition and Discussion of Parameters

by

Lewis V. Wade[1]

ABSTRACT

This report provides background information concerning a mine roof simulator currently being considered by the Bureau of Mines. The simulator is a mechanical device with the ability to simulate the forces and displacements associated with mine roof over an area 20 by 20 feet. The topics covered in the report include a conceptual description of the system, definition of system capabilities, discussion of how such capabilities were decided upon, description of available control modes, and a comparison between the mine roof simulator facility and similar facilities existing elsewhere.

INTRODUCTION

The mine roof simulator is a mechanical device with the ability to simulate the forces and displacements imposed by mine roof on artificial support. The simulator could provide Bureau researchers with a multipurpose tool to aid in the conduct of roof support research studies.

The simulator is somewhat similar in concept to facilities existing at the Bergbau Forshung, Essen, West Germany; the National Coal Board, Bretby, England; and the Dowty Corp., Tewkesbury, England. A more detailed comparison of these facilities is included in the body of this report.

This report provides the reader with detailed background information on the simulator as it currently exists on paper. It is the author's intent to follow this report with another giving specific details of the simulator design when that design is completed and to aid in the preparation of a third report outlining specifically how the facility could be used during its initial phase of operation.

CONCEPT OF THE MINE ROOF SIMULATOR

An understanding of the concept of the mine roof simulator is best approached by starting with the concept of a press or compression testing

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[1] Supervisory research civil engineer.

machine. Figure 1A is a conceptual view of the loading surfaces (platens) of such a simple press. Note that the lower platen is fixed, but the upper platen is capable of controlled movement in the Z direction. The first instance where the simulator deviates from a simple press is that the upper platen is capable of controlled linear movement in the X direction as well as the Z direction. In addition, the platen is capable of controlled angular movement about the X axis and the Y axis.

The second major deviation of the simulator from the simple press is that the upper platen of the simulator is divided into three sections as shown in figure 1B. Each platen segment is capable of individual control in the displacement modes mentioned previously. In addition to controlled linear motions in the X direction and Z direction of each upper platen segment, the forces in these directions may be individually controlled.

DEFINITION OF SIMULATOR PARAMETERS

The previous section is a conceptual description of the mine roof simulator; the following is a precise listing of system parameters:

Lower platen size	feet	20 by 20
Number of upper platen segments		3
Upper platen segment size	feet	20 by 6-2/3
Vertical load capacity of upper platen segment	tons	1,000
Total vertical capacity	do	3,000
Horizontal load capacity of upper platen segment (125 tons available independent of platen position)	do	265
Total horizontal capacity (375 tons available independent of platen position)	do	795
Vertical stroke	inches	144
Horizontal stroke	do	10
Vertical throat opening	feet	1-13
Allowable tilting motion (Y axis rotation, fig. 1B)	degrees	0-20
Allowable twisting motion (X axis rotation, fig. 1B)	do	0-5

In addition to the aforementioned parameters, the simulator is being designed so that 2-foot layers of rock or a rocklike material could be attached to both the upper and lower platens, should such a feature be required in the future.

DISCUSSION OF SIMULATOR PARAMETERS

The following are brief explanations of the reasons behind the selection of the aforementioned parameters.

Lower Platen Size

Two basic considerations were impacted on the selection of the lower platen size. The first consideration was that the load area be of sufficient size to adequately represent a typical coal mine intersection. It was felt that a 20-foot-square area was acceptable for this purpose.

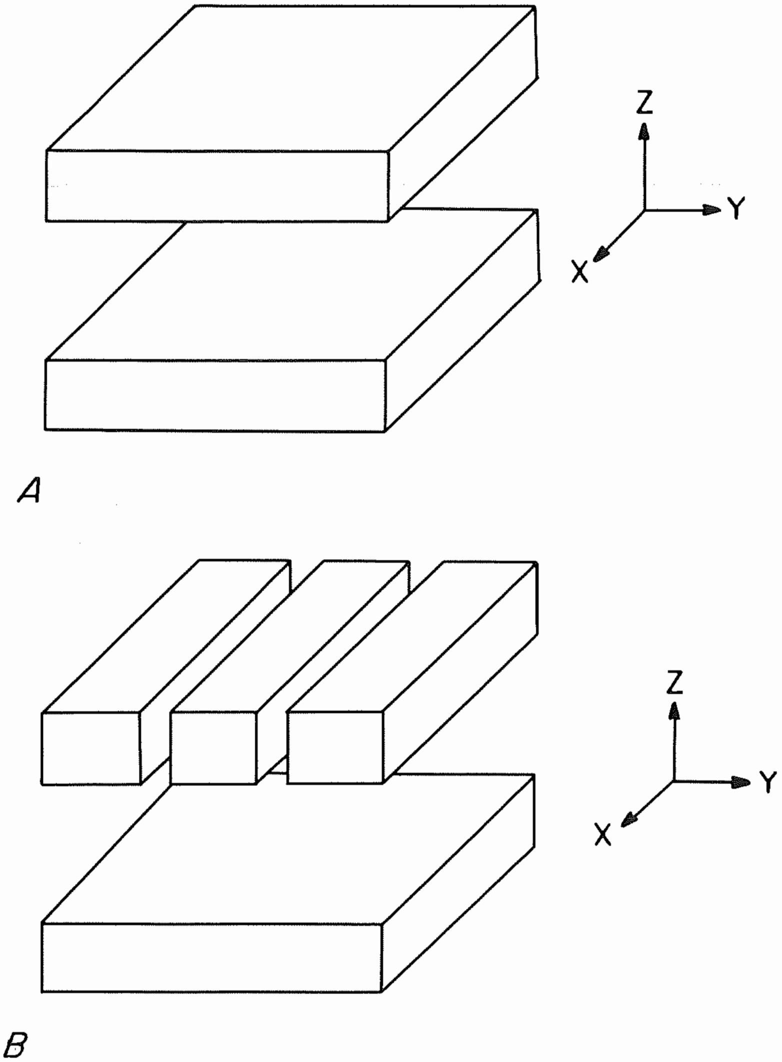

FIGURE 1. - Conceptual view of *(A)* simple press and *(B)* segmented upper platen.

The second consideration was that the load area of the simulator be large enough to allow for investigations into the behavior of longwall- and shortwall-type supports. During the discussions that follow, reference will be made to table 1. The data in table 1 is based upon an in-house survey made of available longwall and shortwall supports. The survey was not intended to be all inclusive but simply was an attempt to gather representative data on longwall/shortwall supports. Thirty-three longwall supports and seven shortwall supports were included representing eight support manufacturers.

Table 1 indicates that the 20-foot dimension arrived at from the consideration of a intersection is an adequate length for the supports considered. Table 1 also indicates that if one support were to be investigated at one time, a lower platen width of 80 inches would be adequate. It is intended, however, that the machine have the capability of investigating more than one such support simultaneously. Of the supports considered, a 20- by 20 foot load area would allow for the simultaneous investigation of three supports in 2.5 pct of cases considered, four supports in 22.5 pct of the cases, and five or more supports in 75 pct of the cases considered. It was felt, therefore, that a 20- by 20-foot load area was adequate in the area of longwall/shortwall support investigations.

TABLE 1. - Dimensional data on representative longwall and shortwall powered roof supports

Parameter	Number of units considered	Value of parameter		
		Minimum	Average	Maximum
Length of longwall unit..........inches..	23	104	136	212
Extended length of shortwall unit..do....	7	192	210	227
Width of units....................do....	31	26	44	79
Yield load of unit................tons..	40	168	479	1,050
Yield load of leg.................do....	40	33	118	200
Hydraulic travel of leg.........inches..	29	14	26	48
Height of unit....................do....	35	-	-	144

There was one additional factor that led to the decision of a square load area; if the load area was not square, a directional bias would be designed into the facility. Consider figure 2--figure 2A shows a plan view of a 20- by 20-foot load area; figure 2B shows two 20- by 10-foot load areas. The broken lines on all three diagrams show the possible segments of the upper platen. In addition, the sides of load area that could be considered the coal face during longwall support investigations are labeled. The interfaces between such segments are lines where a change in load intensity or displacement may be simulated. It is only with the square configuration that such discontinuities can be applied both perpendicular and parallel to the simulated face. Note that in both test configurations shown in figure 2A, the constraint against horizontal motion of upper platen segments in the Y direction remains in effect. With the configurations shown in figure 2B, the line of discontinuity must either be perpendicular or parallel to the simulated face. For this reason it was felt that the utility of the simulator would be greatly increased with a square load area.

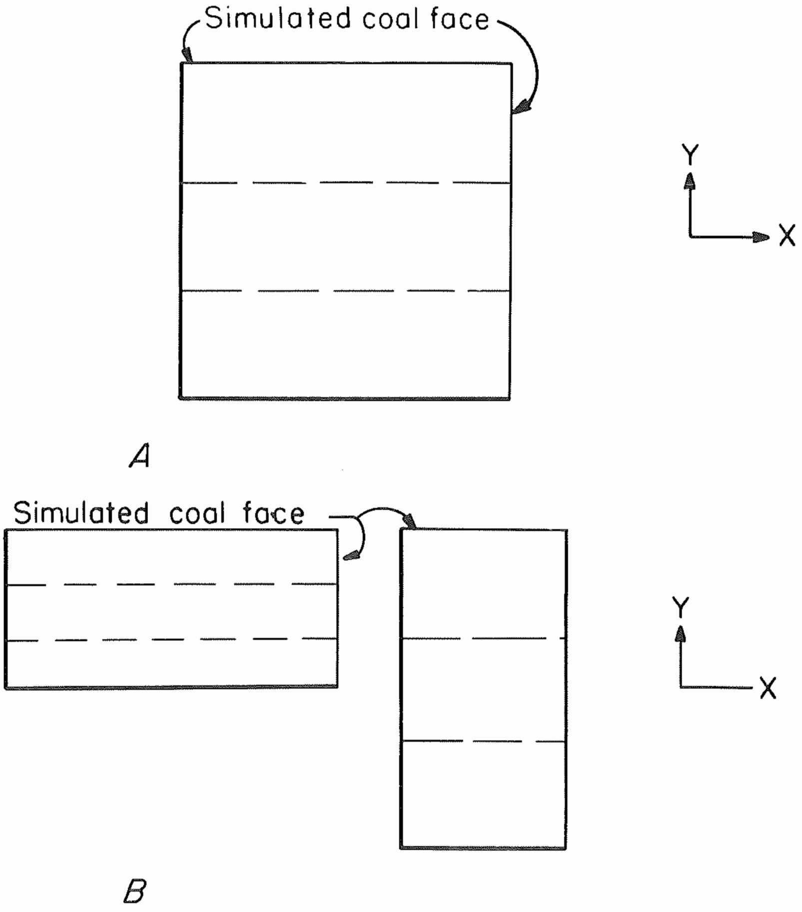

FIGURE 2. - Plan view of *(A)* square simulator load area and *(B)* rectangular simulator load area.

Number of Upper Platen Segments and Upper Platen Segment Size

Given the selection of the lower platen area of 20 by 20 feet, the number of upper platen segments and upper platen segment size may be considered simultaneously. There are three basic considerations that bear on this decision. They are the following:

1. Cost.--As the number of segments increase, the cost of the facility increases. Therefore, the consideration of cost would lead to the selection of the minimum possible number of segments.

2. Independent platen segment operation.--Although it will be possible to conduct investigations on the behavior of a number of longwall supports, investigations centering around an individual support are also essential. One of the advantages of a segmented upper platen is that the facility could be used as N independent facilities, where N is the number of platen segments. The criteria for each of these N facilities would be that it is of sufficient size to independently test a support. Analysis of the data leading to table 1 shows that 5-foot-wide platen segments (that is, four segments) would be of sufficient size to handle all but one of the 40 supports considered. Eighty-inch-wide platen segments (that is, three segments) would allow for the independent testing of any support. Basically this consideration leads to two possible alternatives, a four-platen arrangement or a three-platen arrangement.

3. Number and location of potential discontinuities.--Figure 3 shows a schematic view of a three-platen and four-platen simulator as well as the longest support encountered in the preparation of table 1. The first difference between the three- and four-platen systems is that there are three potential discontinuities in a four-platen simulator and only two in the three-platen system. In addition, the other principle difference is the location (s) along the length of a support where a load or displacement discontinuity could be located. In an attempt to quantify this variable, table 2 was prepared. It should be noted that of the 33 longwall supports considered in table 1 all were less than 160 inches.

Basically, therefore, the selection of upper platen size came down to a decision of cost versus utility and the decision was made to proceed with three 80-inch-wide upper platen segments.

TABLE 2. - Percent coverage of support length with discontinuity

Length of support	Percent coverage[1]	
	Three-platen system	Four-platen system
13 feet, 4 inches or less..........	100	100
15 feet...........................	66-2/3	100
18 feet...........................	22-2/9	11-1/9

[1] Percentage of the length of the support where a discontinuity in load or displacement could be applied with a three-platen system or a four-platen system.

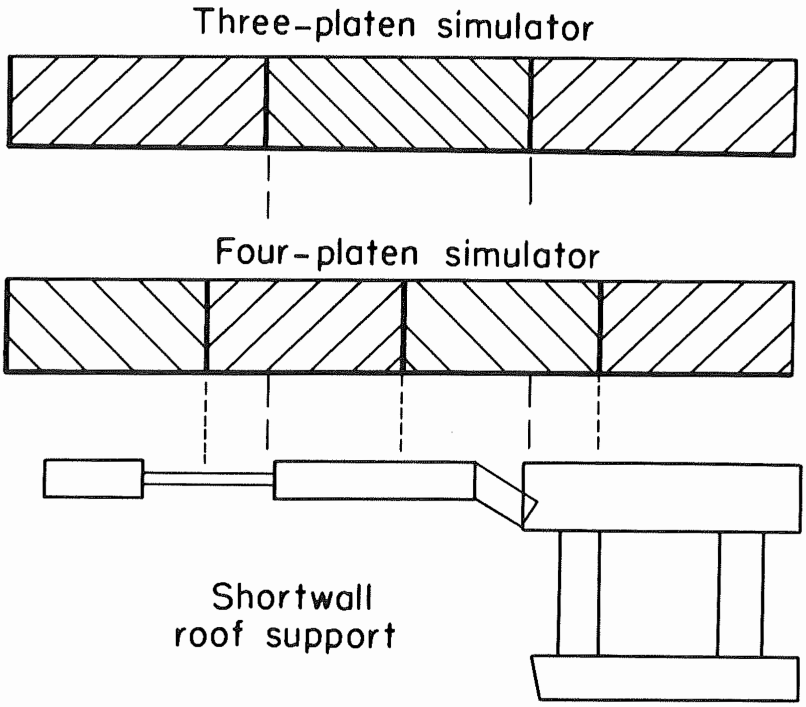

FIGURE 3. - Schematic representation of simulators with three and four upper platen segments.

Vertical Load Capacity of Upper Platen Segment

The decision concerning the vertical load capacity of each upper platen segment was based primarily on the consideration of the ability of each segment to independently load to yield a support unit. It was decided that 1,000 tons would be more than sufficient to handle the majority of cases (that is, 36 of the 40 supports considered in table 1 had unit yield loads of 700 tons or less; three, between 700 and 800 tons; and one, above 1,000 tons). A support with a capacity greater than 1,000 tons could be handled simply by loading the support with two-platen segments.

Total Vertical Capacity

Based upon the decisions discussed previously, the total maximum vertical capacity of the facility is set at 6 million pounds. With this capacity it will be possible to simultaneously yield five 600-ton-capacity units, or four 750-ton-capacity units, or three 1,000-ton-capacity units.

Horizontal Load Capacity of Upper Platen Segment and Total Horizontal Capacity

In the section dealing with the definition of system capabilities, two different values are listed for horizontal load capacity of upper platen segment and total horizontal capacity. The reason this is necessary is shown in figure 4. In this figure is shown a possible test configuration involving a tilted upper platen. Should the intent of the test be to subject the support to a vertical load, it can be seen from the free body diagram that the tilt of the upper platen results in both a horizontal and vertical load through the vertical actuators, and therefore, it is necessary to use the horizontal platen to correct this situation. Let us define P_T as the resultant horizontal load on the support, P_A the horizontal load applied by the horizontal actuator, and P_V as the horizontal component of load induced by the vertical actuator. Therefore,

$$P_T = P_V + P_A.$$

The value of 265 tons listed for horizontal load capacity of upper platen segment is really the maximum value of P_A; the value of 125 tons is the maximum value of P_T with P_V at its maximum positive value.

The decision concerning the horizontal capacity of each upper platen segment was based upon the following two considerations:

1. Each platen segment must have sufficient horizontal load to allow for the simulation of any horizontal motions recorded in service. Unfortunately, this is a difficult capacity to quantify because the force necessary to deform a support in a given way is a function of the stiffness of that support. A conservative approach to this problem would be to design into the system sufficient horizontal load capacity to initiate slip between the support and the roof. Assuming a coefficient of friction between roof rock and support of 0.51 (<u>2</u>),[a] this implies that a horizontal load of 250,000 pounds would be sufficient to initiate slip for support with a yield capacity up to 245 tons. A horizontal load of 530,000 pounds would permit testing of supports up to 520 tons.

If two adjacent platens were used to apply horizontal load, the aforementioned capacities could be doubled; that is, supports with yield capacities of over 1,000 tons could be investigated.

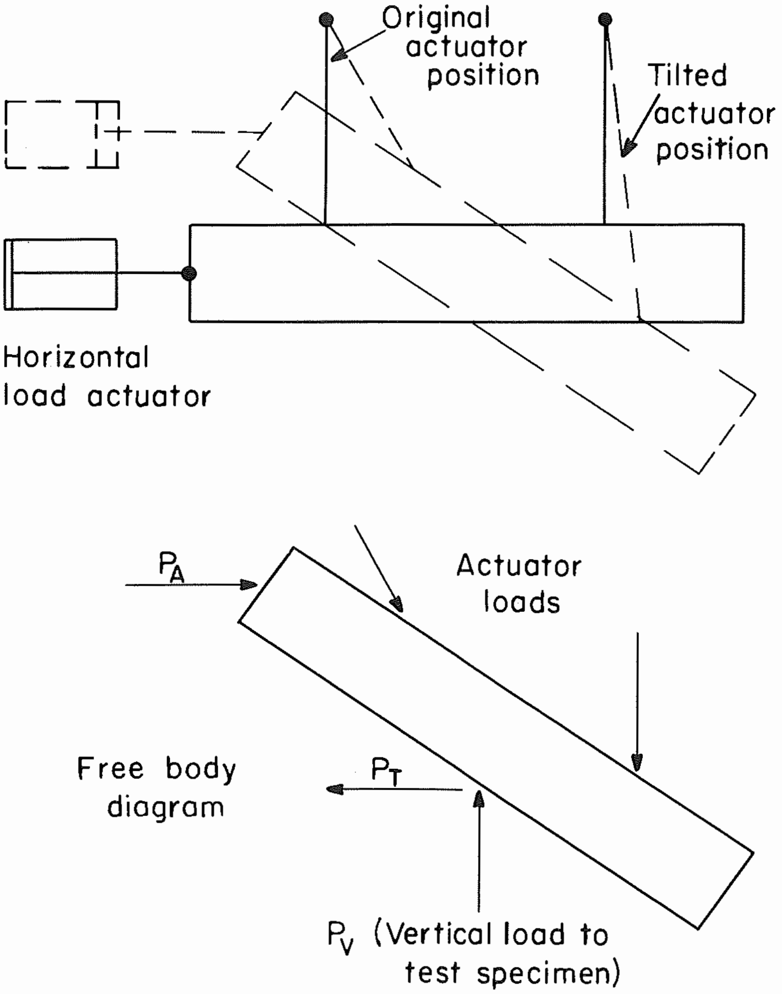

FIGURE 4. - Diagram of actuator positions for tilted upper platen segment.

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[a] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

2. A support unit subjected to a pure gravity load in an inclined seam would be subjected to two force components, one normal to roof/floor contact member and one parallel to that member. To simulate such a loading with a horizontal platen, both vertical and horizontal loads would have to be applied. The ratio of parallel force to normal force is the tangent of the angle of inclination of the seam. The ratios of horizontal to vertical force established previously, that is, 1,000 to 125 tons and 1,000 to 265 tons, would allow for investigations of the type mentioned previously of seams inclined at angles up to 7.125° and 14.842°, respectively, at maximum vertical load. Using two adjacent platen segments at a combined vertical load of 1,000 tons would allow for investigations of seams inclined at angles up to 14.036° and 25.173°, respectively.

Based upon the previous considerations, the horizontal loading capacity of each platen segment was set at 125 tons. Total horizontal capacity is, therefore, fixed at 375 tons.

Vertical Stroke

A reasonable first approach to the section of the vertical stroke for the simulator would be to consider hydraulic travel of leg data presented in table 1. With a maximum hydraulic travel of 48 inches, it was felt that 60 inches of vertical stroke would be more than sufficient. The original specifications of the simulator called for the 60 inches. To understand why this specification is now 144 inches, the section on vertical throat opening must be considered. Figure 5 is an elevation view of the simulator, demonstrating the interaction between vertical stroke and throat opening. Assuming that a vertical throat opening of between 1 and 13 feet is desirable (this will be discussed later), there are two methods for achieving vertical actuation over the range of throat openings. The first method involves the separation of the upper platen actuation mechanism from the crosshead positioning mechanism as shown in figure 5, and the second is to cover the entire throat opening range with platen actuator stroke.

Preliminary design work and cost estimating revealed that the second alternative should result in a significantly less expensive facility. Therefore, the vertical stroke was set at 144 inches.

Horizontal Stroke

A review of the literature (3) indicates that a reasonable upper bound on the magnitude of relative lateral movement (roof to floor) which might be experienced on a longwall would be 1 inch of movement per 1 foot of seam height. It was felt, therefore, that 10 inches of movement corresponding to a 10-foot seam was sufficient capability to design into the simulator.

Vertical Throat Opening

The decision concerning the vertical throat opening that should be designed into the facility was reached by estimating the range of seam heights likely to be encountered. An estimate of 2-1/2 to 10 feet was established.

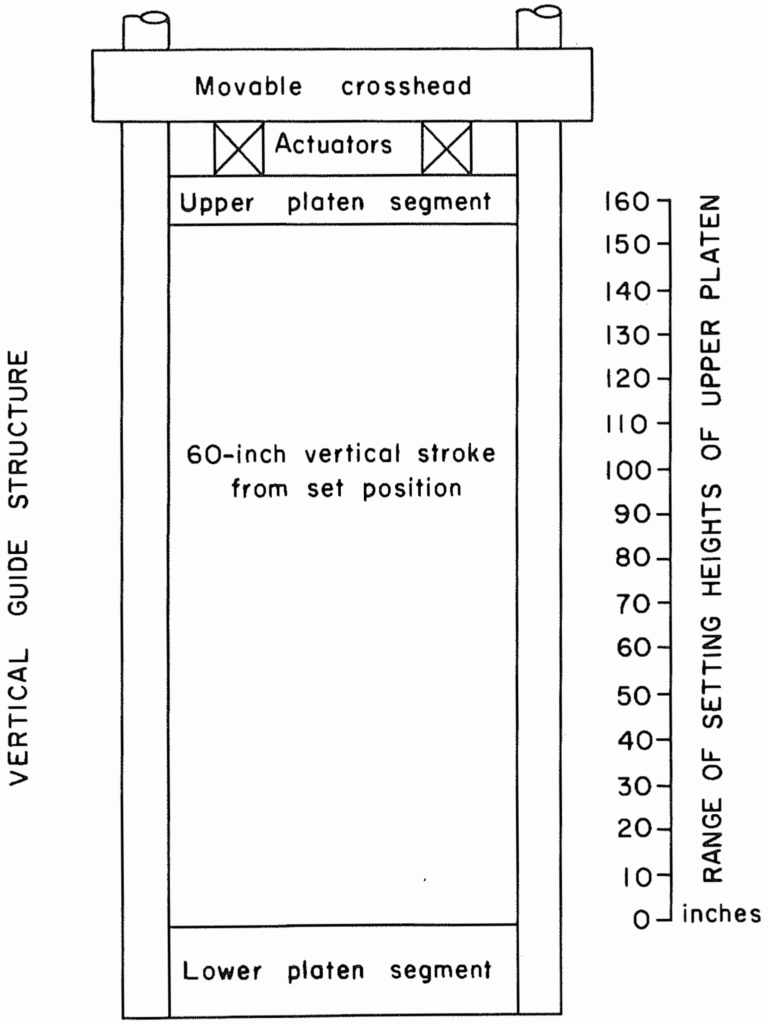

FIGURE 5. - Elevation view of simulator.

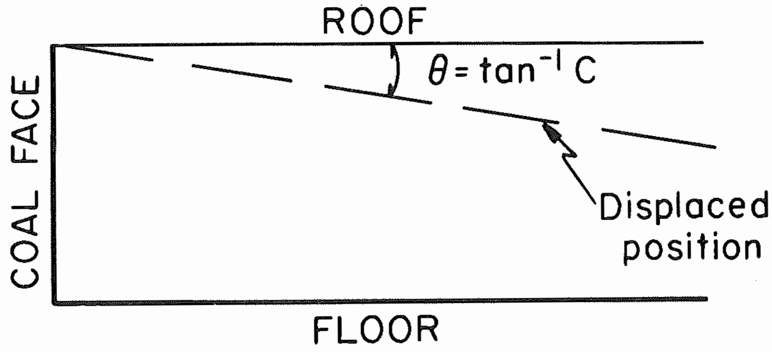

FIGURE 6. - Platen movement simulating differential convergence.

The specified value of 1 to 13 feet was decided upon to leave a margin of error on each side of that estimate.

Allowable Tilting Motion

The determination of the maximum tilting motion was approached in the following way. The approach is based on the variation in convergence of roof and floor as a function of distance from the face. This differential convergence may be modeled as shown in figure 6. Ashwin and others (1) give the formula for normal convergence $C\left(\frac{mm}{m}\right)$ as

$$C = 10.8\,H + 29.2,$$

where H is the height of the seam, and θ (see figure 6) is defined as

$$\theta = \tan^{-1} C.$$

Since the maximum throat opening for the system is 13 feet (3.95 m), let us assume this to be the value of H; a maximum seam height of 13 feet yields a value for θ of 4.11°. As a result of periodic weighing a convergence of 2C might be expected, or a resulting angle θ of 8.18°. It was felt that 20° would provide for more than sufficient capacity for the most severe cases.

Allowable Twisting Motion

The inclusion of a possible twisting motion

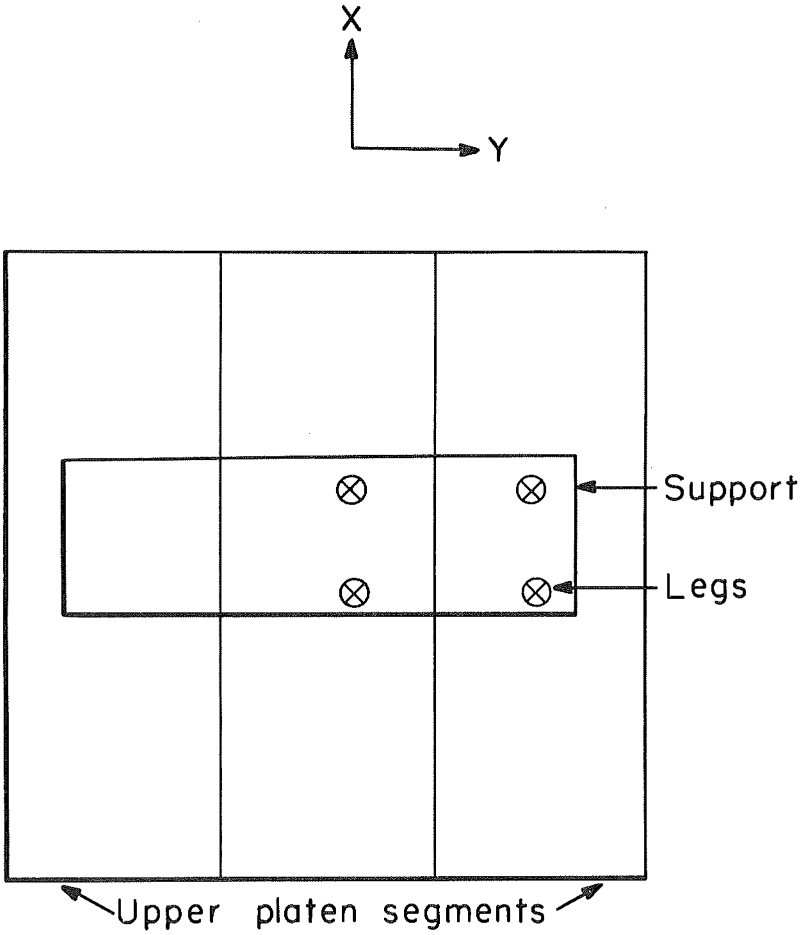

FIGURE 7. - Test configuration for simulation of normal convergence and lateral movement parallel to coal face.

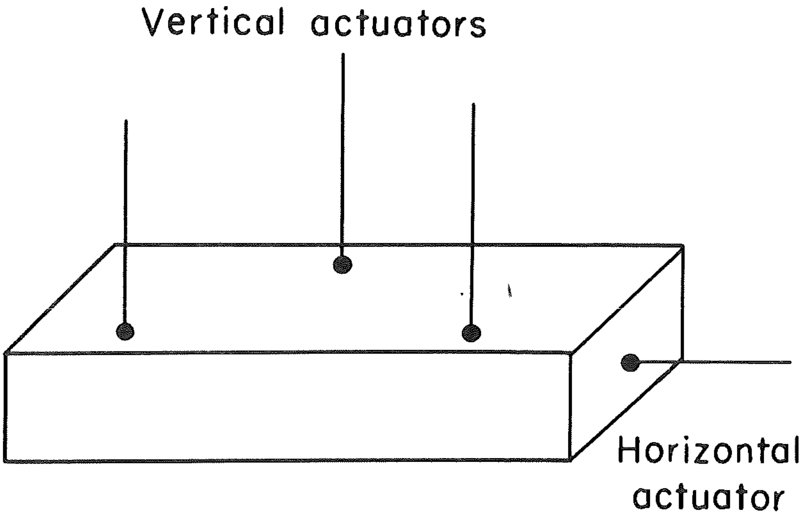

FIGURE 8. - Schematic view of upper platen segment.

greatly increases the range of roof-floor movement that may be simulated in the test facility. A possible application of this twisting motion is a situation which would require both normal convergence as well as lateral roof movement parallel to the face. This combination of actions could be simulated by having the props oriented to the upper platen as shown in figure 7. For such situations it is necessary to simulate normal convergence using the twist motion capability. For this reason the maximum twist angle was set at 5°, large enough to allow for normal convergence of a 13-foot seam.

SIMULATOR CONTROL SYSTEM

It is wise to begin a discussion of the simulator control system with the basic repeating element of the facility, the upper platen segment. Figure 8 is a plan view of the upper platen showing the approximate location of force and displacement producing actuators. Given this actuation scheme and the displacement constraints designed into the facility, that is, no Y displacement and no Z rotation, leads to the following four displacement control functions for each platen segment:

1. Z displacement.
2. X displacement.
3. X rotation.
4. Y rotation.

Corresponding to the four displacement control functions are four force control functions:

1. Z force.
2. X force.
3. X moment.
4. Y moment.

Of the eight control functions only the following six may be used to directly control the simulator:

1. Z displacement.
2. X displacement.
3. X rotation.
4. Y rotation.
5. Z force.
6. X force.

The remaining two functions, X moment and Y moment, were not included as primary control functions because it was felt unlikely that meaningful values of these functions could be determined from underground measurements. It should be noted that should it be desirable in the future, such control functions could be included with the development of the necessary software.

The control system is designed so that the system may be simultaneously controlled by three nonmutually exclusive primary control functions; that is, X force and X displacement cannot be simultaneously controlled for one platen segment. Control by one or two primary control functions is also permissible.

Such control flexibility leads to the definition of 31 different simulation types. Table 3 contains a listing of these simulation types. Note that if a displacement or rotation primary control function is neither a control nor a slave for a given simulation type, its value may be maintained at zero if desired.

The 31 simulation types (table 3) apply to each upper platen segment. The system control logic does not require that the three upper platen segments be controlled in the same way.

TABLE 3. - Listing of simulation types[1]

Simulation type	Displacement		Rotation		Force	
	Z	X	X	Y	Z	X
1	C_1	-	-	-	S_1	-
2	-	C_1	-	-	-	S_1
3	-	-	C_1	-	-	-
4	-	-	-	C_1	-	-
5	S_1	-	-	-	C_1	-
6	-	S_1	-	-	-	C_1
7	C_1	C_2	-	-	S_1	S_2
8	C_1	-	C_2	-	S_1	-
9	C_1	-	-	C_2	S_1	-
10	C_1	S_2	-	-	S_1	C_2
11	-	C_1	C_2	-	-	S_1
12	-	C_1	-	C_2	-	S_1
13	S_2	C_1	-	-	C_2	S_1
14	-	-	C_1	C_2	-	-
15	S_2	-	C_1	-	C_2	-
16	-	S_2	C_1	-	-	C_2
17	S_2	-	-	C_1	C_2	-
18	-	S_2	-	C_1	-	C_2
19	S_1	S_2	-	-	C_1	C_2
20	C_1	C_2	C_3	-	S_1	S_2
21	C_1	C_2	-	C_3	S_1	S_2
22	C_1	-	C_2	C_3	S_1	-
23	C_1	S_3	C_2	-	S_1	C_3
24	C_1	S_3	-	C_2	S_1	C_3
25	-	C_1	C_2	C_3	-	S_1
26	S_3	C_1	C_2	-	C_3	S_1
27	S_3	C_1	-	C_2	C_3	S_1
28	S_3	-	C_1	C_2	C_3	-
29	-	S_3	C_1	C_2	-	C_3
30	S_2	S_3	C_1	-	C_2	C_3
31	S_2	S_3	-	C_1	C_2	C_3

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[1] C_n = The nth control function for a given simulation type.
S_n = Slave to the nth control function for a given simulation type.

COMPARISON OF EXISTING SUPPORT TEST FACILITIES AND THE MINE ROOF SIMULATOR

The purpose of this section is to present brief descriptions of existing support test facilities. The facilities that will be discussed include, in addition to the mine roof simulator, the following installations:

1. The Bergbau Forshung test rig located in Essen, West Germany.

2. The National Coal Board test rig located in Bretby, England.

3. The Dowty Corp. test rig located in Tewkesbury, England.

4. A number of single support test rigs, an example being the rig at Gullick-Dobson Ltd. works in Wigan, England.

Although all the aforementioned facilities, including the mine roof simulator, share a common purpose, that is, the ability to allow for the development of working loads in a support structure, there is a fundamental distinction that divides the five facilities into two distinct categories. This distinction is whether the facility in question actively applies load to the support structure or passively reacts load developed in some other manner in the support structure, that is, pressurizing the legs of a longwall support.

Of the five facilities mentioned, only two, the Bergbau Forshung facility and the mine roof simulator, are "active" in nature. The remaining three are static frames built to react loads but not to apply loads.

Having established this major distinction and prior to comparing specific system capacities, a brief discussion of the method of operation of each facility will be presented.

Mine Roof Simulator

Figure 8 shows a schematic view of an upper platen segment of the facility. The actuators shown in this figure are responsible for the development of the force and displacement capabilities of the facility.

Bergbau Forshung Test Rig

To aid in understanding the operation of the rig, the conceptual views of figures 9 and 10 are shown. The machine is operated by controlling the magnitude of the forces applied to the platen segments through the hydraulic rams, four rams for each of the six segments of the rig. For the moment, assume that control is supplied through the known extension of the hydraulic rams; this assumption is made so that the operation of the rig can more easily be explained. Consider segment 6 shown in figure 10, the support shown could be tested by forcing known elongations of rams A and C. These elongations would cause the lower platen to experience a positive X displacement while the upper platen would undergo both a positive X and a negative Y displacement. The net result to the support would be, assuming no slip takes place between support and platens, a shortening of the vertical distance between points I and II, and possibly a relative X displacement between these points.

In reality it is the ram forces that are controlled. Therefore, a support is subjected to a known force system.

National Coal Board (NCB) Test Rig

The discussion of the NCB rig also applies to the Dowty and Gullick-Dobson rigs. In principle, these rigs are static frames built to react load. Figure 11 shows the manner in which such rigs are used in the testing

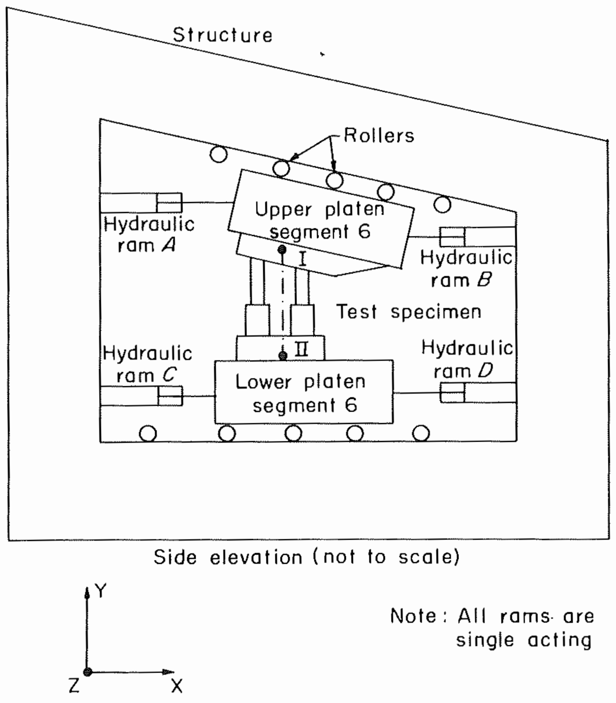

FIGURE 9. - Schematic side view of German test rig.

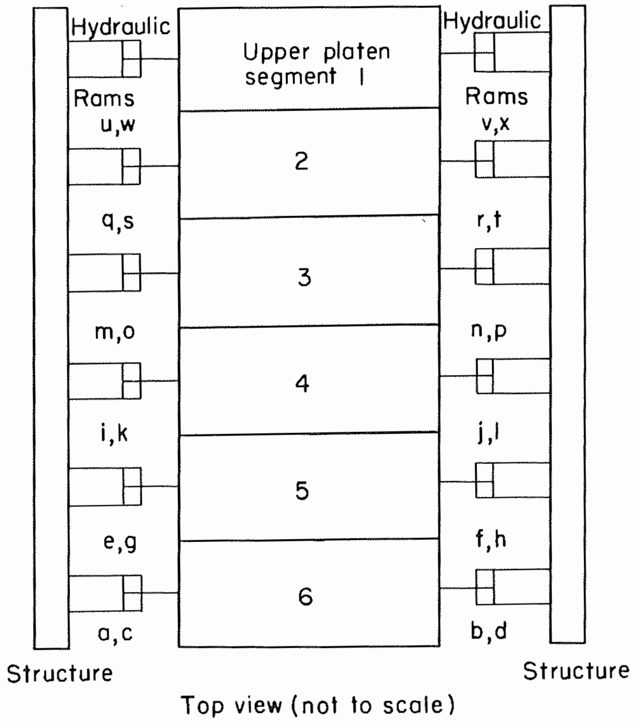

FIGURE 10. - Schematic top view of German test rig.

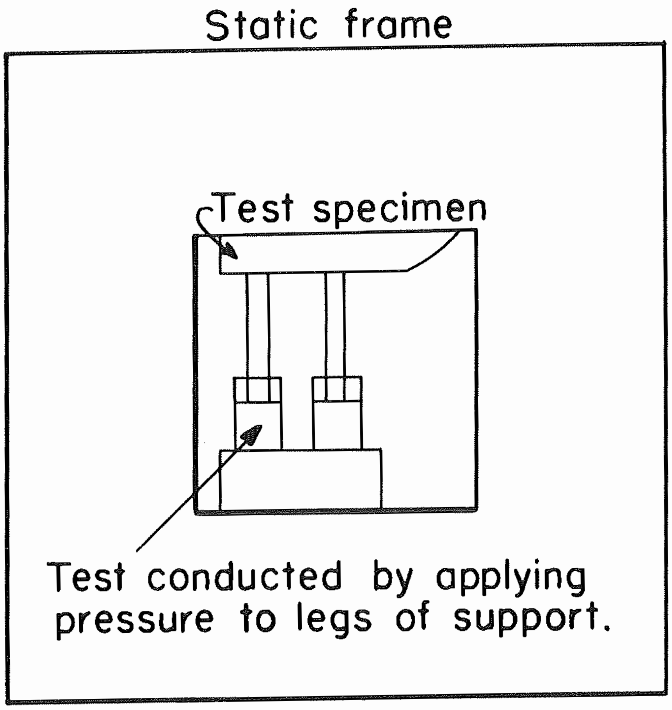

FIGURE 11. - Role of static frame in longwall support testing.

of longwall powered roof supports. To completely describe the utility of such frames, the following two test procedures must be considered.

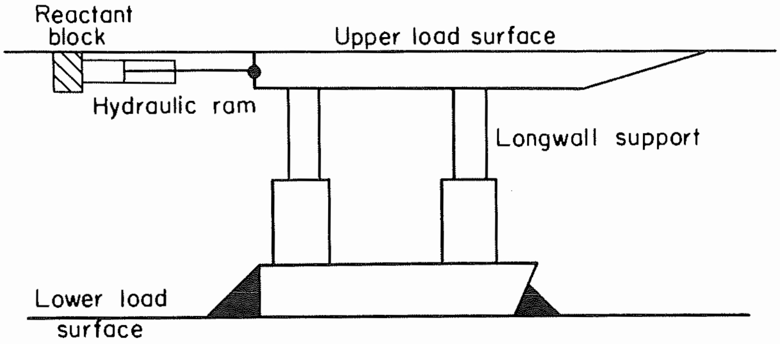

FIGURE 12. - Horizontal loading of longwall support using static frame.

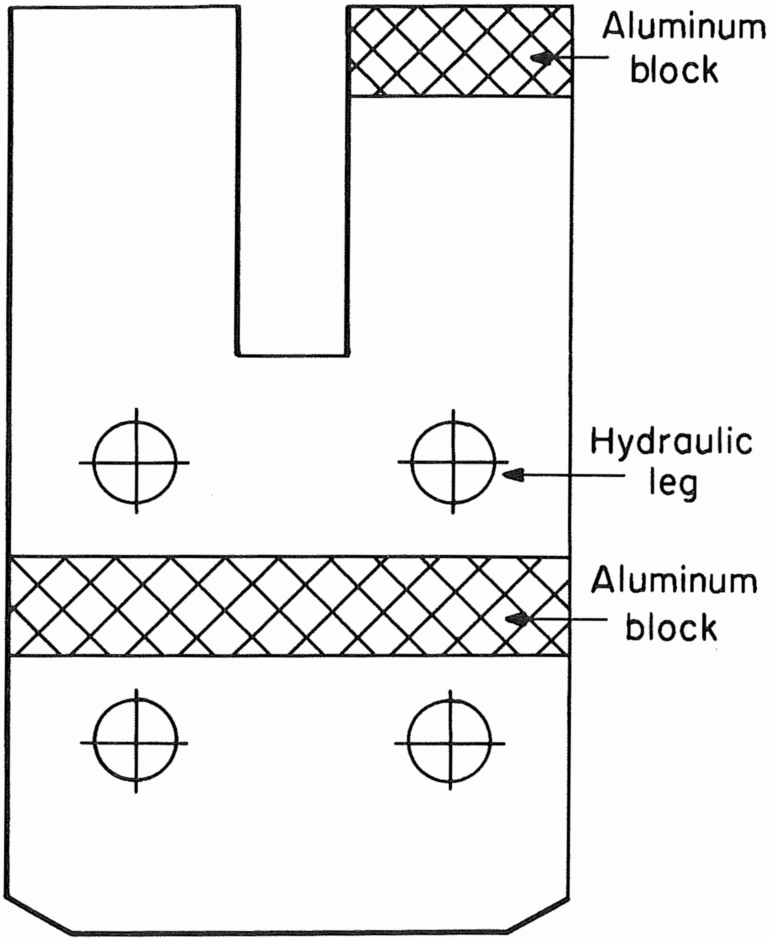

FIGURE 13. - Plan view of powered roof support roof contact member.

1. Horizontal Loading of Support.--Although the frame itself cannot apply load, it can be used to react load developed by hydraulic rams external to the support being tested. Figure 12 shows such a setup with the net result being the application of a horizontal load to the support.

2. Development of Nonuniform Vertical Loading Patterns.--For the test shown in figure 11, the vertical load distribution along the support roof contact member is a function of the stiffnesses of the support and the test rig. It is possible, however, to develop more controllable and discontinuous load distributions. This is done through the use of aluminum blocks as shown in figure 13.

To complete the discussion of the operation of the five test rigs, table 4 contains a listing of selected parameters for these facilities.

It should be noted that the information contained in table 4 represents the author's understanding of published reports and oral communications with the people involved. It was not supplied directly by these individuals.

TABLE 4. - Listing of support test facility parameters

Parameter	Facility				
	Mine roof simulator	Bergbau Forshung	NCB	Dowty	Gullick-Dobson
A. Geometric:					
1. Load area size.........feet..	20 by 20	18 by 23	20 by 16	16 by 17	12 by 5
2. Vertical throat opening.......do...	1 to 13	2 to 9	2 to 8	2-1/2 to 12	2 to 10
B. Load:					
1. Total vertical load application capacity.....tons..	3,000	1,300	-	-	-
2. Total vertical load reactant capacity......do...	3,000	1,300	500	700	1,000
3. Total horizontal application capacity......do...	800	120	(1)	(1)	(1)
4. Total horizontal load reactant capacity......do...	800	120	(2)	12	(2)
C. Permissible control functions:					
1. Vertical load.......	Yes	Yes	[3]Yes	[3]Yes	[3]Yes
2. Horizontal load.....	Yes	Yes	[4]Yes	[4]Yes	[4]Yes
3. Vertical displacement.......	Yes	[5]Yes	No	No	No
4. Horizontal displacement.......	Yes	[5]Yes	[4]Yes	[4]Yes	[4]Yes
5. Angular displacement	Yes	No	No	No	No
D. Permissible combinations of control functions....	See text	C_1 - C_2 C_3 - C_4	None	None	None
E. Additional capabilities:					
1. Can entire rig rotate.............	[6]Yes	Yes	Yes	Yes	No
2. Magnitude of rotation......deg..	20	90	45	90	-
F. Relative cost estimate (normalized to NCB facility)..............	70.0	10.0	1.0	1.2	0.2

[1] Dependent on external actuator size and ability of structure to react load.

[2] Uncertain, assume it is similar to capacity of Dowty facility.

[3] Control achievable through hydraulic of support using external hydraulic power supply.

[4] Control achievable through external hydraulic actuator.

[5] Control achievable through known extension of hydraulic rams.

[6] Rotation possible using tilt or twist of upper platen segments and wedges on lower platen.

SUMMARY

This report is intended to provide the reader with factual information concerning the mine roof simulator and other similar facilities. It was not the purpose of this report to discuss the trade-offs that exist between these facilities.

As of this writing, the mine roof simulator represents another alternative available to the Bureau of Mines in its considerations of roof support test facilities. It is not necessarily the alternative that will eventually be selected for construction should indeed the decision be made to construct any such facility.

REFERENCES

1. Ashwin, D. P., and others. Some Fundamental Aspects of Face Powered Support Design. Min. Eng., August 1970, pp. 659-671.

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3. National Coal Board. Powered Support Test Manual. Min. Res. Develop. Est. Tech. Memo., No. PA/MT(72) 1, 60 pp.