PRESSURE DISTRIBUTION OF 2–LEG SHIELD SUPPORTS

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and

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ABSTRACT

Measurement of pressure distribution under the base plate of the Henschel's 2–leg 800–ton shield was performed underground for two shifts using 12 pressure cells installed in two rows, one each under each split base plate. Pressure distribution was uneven depending on contact condition. In general the highest base pressure occurred at 1/3 of the base plate contact length from the rear edge. The resultant was near vertical, and the pressure under the tail side split base plate was always higher than the head side.

For comparison, pressure distribution on the canopy and under the base plate was also measured under controlled conditions at the USBM's Mine Simulator Testing Facilities in Pittsburgh, PA. A total of 45 tests were conducted under several simulated contact conditions. The results showed that the actual contact area is highly dependent on the compliance of the immediate roof and floor due to the sloped canopy tip and a base lifting device under the base tip. The loading distribution tends to change in magnitude and profile as the leg pressure increases. The base lifting device exaggerates the high toe loading on the base plate characteristics of this type of shield support.

This paper describes in detail the testing methods, data analysis results obtained, and recommended changes.

INTRODUCTION

In order to improve the performance of the longwall shield supports, a better understanding of the pressure distribution between shields and contacting strata is required. Underground measurements of pressure distribution under the base plate of a 2–leg shield (Fig. 1) employed at Laurel Run Mine, Island Creek Coal Co. were conducted. Pressure distribution under the base plate was uneven due to non–uniform contact conditions between the base plate and the mine floor. In particular there was no contact in the area from 56 to 107 cm (22 to 42 in) from the tip of the base plate, due to the existence of a base lifting device at the tip of the base plate. Therefore, it is obvious that the structure of the base lifting device produces a two–point contact, i.e. one at the tip and the other at the rear of the base plate. Due to higher bending stiffness, the base plate is highly resistant to deform under loading. Thus it is most likely that the floor has to deform in order to establish a more uniform pressure distribution. In hard floor condition, the lifting device usually causes a stress concentration under the base plate at the tip. Fortunately, quite often a soft floor exists or there are plenty of debris between the base plate and the floor that are compressed to conform to the base geometry.

Fig. 1. Henschel's 2–leg shield.

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In addition, the 2-leg shield is designed with the canopy tip deflecting upwards approximately 5 cm or 2 in (Fig. 1), in order to increase tip loading. This design produces a two-point contact, i.e. one at the tip and the other at the rear of the canopy. The canopy is so stiff that it will not produce full contact along the length of the canopy even when the leg pressure is increased to yield load. Therefore, under this type of canopy design the immediate roof strata must deform to alter the contact configuration in order to produce a more uniform distribution. In order to confirm the underground measurements and to evaluate the design and performance of the 2-leg shields, a study of load distribution on the canopy and under the base plate under laboratory controlled conditions was conducted at the Mine Simulator Testing Facilities at Pittsburgh Research Center, U. S. Bureau of Mines in Bruceton, PA. The results showed that the actual contact area is highly dependent on the compliance of the immediate roof and floor due to the slope canopy tip and a base lifting device under the base tip. The loading distribution tends to change in magnitude and profile as the leg pressure increases. The base lifting device exaggerates the high toe loading of the base plate characteristics of this type of shield.

METHODOLOGY

Underground Measurements:

Twelve pressure cells were arranged in two clusters of 6 per cluster in two rows. Each row was set underneath the center line of the split base. In this method, the pressure cells can only measure the vertical component of the load under the base plate. Two methods of underground measurements were performed:

1. Measurement with steel plate. Two full-sized steel plates were laid underneath each split base and 6 pieces of pressure cells in each row were placed between the steel plate and the split base plate. This test was performed at the middle portion of the face. Pressure variations of the pressure cells as well as the legs in a mining cycle were recorded every 5 minutes. The measurement continued for six complete mining cycles.

2. Measurement without steel plate. Two parallel rows of pressure cells were placed directly between the split base plates and the floor. This test was performed at the same location but during non-production period. In this method, pressure cells were monitored only during support setting and the measured data were only for reference in this study.

Laboratory Measurements:

A total of 45 tests were conducted in the Mine Roof Simulator (Fig. 2). The simulator is capable of providing controlled forces or displacements in both vertical and horizontal direction to a full-sized longwall shield. The load frame has a force capacity of 1362 metric tons (3 million pounds) vertically and 726 metric tons (1.6 million pounds) horizontally. 24 hydraulic pressure cells were used to measure the pressure/load distribution on the canopy and under the base plate. The cells are constructed of two parallel stainless steel plates, 15.24 cm by 15.24 cm (6-in by 6-in), that were welded on the sides and filled with oil. Each cell was filled with a tube which was connected to a pressure transducer for measurement of hydraulic pressure developed in the cell.

![USBM Mine Roof Simulator](image)

Each pressure cell was calibrated to a force of 136 metric tons (300,000 pounds). Calibration was made in a stiff 454 metric tons (1 million pounds) load frame. The measured force from each cell is distributed over the entire area of the canopy or base plate as an approximation of contact pressure for
full-contact load condition. Pressure equilibrium is preserved in the distribution process by distributing the measured cell pressures in proportion to the area of the cells relative to the area of the canopy or base plate such that the total pressure remains a constant. Accordingly, the measured pressure from each cell, \( P_c \), is converted to average pressure, \( P_r \), for analysis of pressure distribution (assuming all pressure cells are in contact throughout the loading):

\[
P_r = \frac{P_c \times 36 \times n}{W \times L}
\]

where \( n \) is number of pressure cells on the canopy or under the base plate, and \( W \) and \( L \) are width and length of the canopy or base plate, respectively.

Based on the calibration characteristics of each cell, the pressure readings of each cell was converted to the measured pressure, \( P_r \).

Different roof and floor conditions were simulated as follows:

1. Very stiff strata was simulated by the rigid steel plates of the load frame and 15.24x15.24 cm (6x6 in) steel plates. The steel plates were inserted between the steel plate and each pressure cell in order to maintain some distance between the plates and the canopy or the base plate.

2. The immediate roof or floor strata which deform under contact pressure were simulated in the load frame by placing one or more layers of plywood, 10x10x2 cm (4x4x1/4 in), on each pressure cell, while hard rubber pads (10 pieces) were used to simulate more compliant strata conditions.

Three sets of measurements were performed, i.e. combined canopy and base test, canopy test, and base plate test. Two types of machine control were used alternatively for all tests. In the horizontal displacement control, the lower plates of the simulator is fixed to a certain position, so that the simulator will react to the force generated by the shield while in the horizontal force control the horizontal axis of the lower plate of the simulator maintains zero force, allowing the plates to freely displace in the horizontal direction.

RESULTS

Underground Measurements:

Although load distribution was uneven due to non-uniform contact between the base plate and floor, the following major trends of the pressure distribution under the base plate were identified:

1. The highest pressure under the base plate occurred mostly near the legs connection point at one-third of the base plate contact length from the rear edge, instead of near the tip contact line of the base plate as usually expected for a 2-leg shield (Fig. 3). However, the tip pressure of the base plate can not be ignored because sometimes the highest base pressure, although in much smaller magnitude, was found in this portion (Fig. 4).

Fig. 3. Pressure distribution base plate highest pressure near legs connection point.

Fig. 4. Pressure distribution under base plate highest pressure near tip area of base plate.
2. The point of action of the resultant load under the base plate was always located around two--third of the contact length of the base plate from the rear edge. Assuming that the resultant load on the canopy was applied at the connection point between the leg and canopy, and there was no load on the caving shield, the direction of the resultant load can be determined as shown in Figs. 3. The angle of application of the resultant load from the horizontal was approximately 90 degrees, sometimes approaching 90 degrees. As shown in Fig. 4, since the highest pressure was near the tip of the base plate, the point of action of the resultant load on the base plate moved toward the tip and its angle of application was close to 90 degrees.

3. The resultant force was always non--centrally located. The tail--side split base plate was usually more severely loaded than the head--side one.

4. The maximum pressure under the base plate during the testing was 4.48 MPa (650 psi) and located under the tail--side split base about 61 cm (24 in) from the rear edge. Therefore, the bearing capacity of the floor should be higher than 4.48 MPa (650 psi), otherwise a new shield design is required so that the pressure distribution of the base plate can be tolerated under soft floor conditions.

5. There was near no contact under the base plate between 56 and 107 cm (22 and 42 in) from the tip of the base plate, due to the existence of a base lifting device at the tip of the base plate. The structure of the base lifting device reduces the contact area between the tip of the base plate and the floor and usually causes stress concentration under the base plate and underneath the legs.

Laboratory Tests

Combined Canopy and Base Tests:

13 combined tests of canopy and base plate were conducted. As shown in Fig. 5, five contact configurations for the combined tests were evaluated. Fig. 5A simulates stiff roof and hard floor conditions with two--point contact. The contact configuration in Fig. 5B was used to simulate full base contact and full canopy contact except for the sloped tip portion. While Fig. 5C, D and E show different canopy contact configurations with full base contact.

Fig. 5. Contact configurations of canopy and base plate.

Fig. 6 shows the average load at 41.34 MPa (6000 psi) of leg pressure for two--point contact on the canopy and base plate with lifting device. As the leg pressure increased from 8.89 MPa (1000 psi) to 41.34 MPa (6000 psi), the maximum load was always developed at the rear of the canopy and at the toe of the base plate. Total loading of the rear five pressure cells on the canopy was 432 metric tons (475 tons) at 34.45 MPa (5000 psi) of leg pressure. This was approximately 36.52 MPa (5300 psi) distributed evenly over the five pressure cells. Total load at the tip of the canopy was 106 metric tons (117 tons) or 9.06 MPa (1300 psi). Total load on the toe of the base plate was 214 metric tons (235 tons) on right side and 182 metric tons (200 tons) on left side or approximately 44.76 and 38.56 MPa (6500 and 5600 psi), respectively for a contact area 464 sq. cm (72 sq. in). Load at the rear of the base plate was 75 and 105 metric tons or 15.85 and 22.05 MPa (33 and 115 tons or 2300 and 3200 psi) for right and left sides, respectively.

Fig. 6. Average load on canopy and base plate.
Test 01 — Leg pressure 5000 psi
Under weak roof and compliant floor condition as usually occurred at mine sites, canopy contact occurs in an area more than 30 in from the rear edge and approximately 50% of the canopy in the tip area have no contact (Fig. 7). This contact condition produces a pressure/load concentration near the leg connection point. Maximum load on the base plate is located about 25.4 cm (10 in) from the toe, upon which the ram cylinder of the lifting device acts.

![Image](Fig 7. Pressure distribution on the canopy and base plate. Combined test 03 – Leg Pressure 5977 psi.)

In order to evaluate the interaction of the canopy and base contact conditions, pressure distribution under the base plate was measured under three different canopy contact conditions as shown in Fig. 8 (Tests 08, 10 and 12). Seven pressure cells were evenly spaced under each base plate to simulate a full base contact condition. As seen in Fig. 8, with contact at canopy tip (Test 08), the canopy resultant load was much closer to the rear of the canopy at lower leg pressure than the other two contact configurations where there was no contact at the tip of the canopy (Tests 10 and 12). This difference in canopy resultant load location shifted the base resultant load slightly towards the rear at low leg pressure. However, as the leg pressure increases, the difference reduces. When the leg pressure is increased to near or over 34.45 MPa (5000 psi), i.e. larger than the setting pressure, the resultant load on the canopy is confined to near the leg–canopy connection point, regardless of the changes in canopy contact configurations. For the base plate, the resultant load is located toward the toe of the base plate as the leg pressure increases regardless of the canopy contact condition (Fig. 9).

![Image](Fig. 8. Comparison of canopy resultant location. Tests 08, 10, and 12.)

![Image](Fig. 9. Comparison of base resultant location. Tests 08, 10, and 12.)

Load distribution under the base plate for these three canopy contact configurations is similar (Fig. 10), except a higher toe loading is produced at high leg pressure when there is canopy tip contact.

Load distribution on canopy for these three canopy contact configurations is slightly different (Fig. 10). The maximum contact loading occurs when the contact line is near the leg connection point, because it requires very little force at the rear of the canopy to maintain equilibrium. The most uniform canopy loading occurs when the canopy contact is evenly distributed on both sides of the leg connection point.
Canopy Tests

In order to obtain more data for detailed analysis, a series of individual tests for canopy and base plate were conducted.

A total of 10 tests (Test 14–23) were conducted to measure the pressure distribution on the canopy. As shown in Fig. 11, three different canopy contact configurations were investigated. Full base contact (i.e., without lifting device) was employed for all canopy tests. Steel/wood and hard rubber pads were utilized to simulate the compliance of the immediate roof and assess the impact of strata deformation on the pressure distribution.

Tests 14 and 21 were arranged such that shield was reacted against the rigid steel platens of the simulator to simulate a strong flat roof structure that did not deform under the shield contact pressure. These tests indicated that contact was established over about 20% to 40% of the canopy for leg pressure up to 29.63 MPa or 4300 psi (Fig. 12). At this magnitude of loading, there was no contact directly above the legs, which was 1.07 m (3.5 ft) from the rear edge of the canopy, and no contact at 0.6 m (2 ft) from the tip of the canopy. Hence, there existed a span of about 2.13 – 2.44 m (7 – 8 ft) in the middle portion of the canopy where contact was never established under this loading condition. While loadings larger than 31 MPa (4500 psi) were not attempted for these tests, the data suggested that a full canopy contact could not be attained when shield was reacting against a flat stiff surface even at yield leg pressure.

In order to simulate the immediate roof condition where the strata deform under contact
pressure, wood and hard rubber pads were placed between pressure cells and the platen. The contact area on the canopy was increased from 40% for the rigid roof simulation discussed above to about 90% for wood (Fig. 13) and 100% for the hard rubber contact materials (Fig. 14) at leg pressures of about 41.34 MPa (6000 psi).

The contact pressure at the canopy tip was very small as compared to that at the rear area of the canopy regardless of the contact configuration. This was attributed to the following two factors: (1) since the tip of the canopy is 2.25 times as far from the leg as the rear edge of the canopy, only 44% of the force applied at the rear of the canopy is required at the tip of the canopy to maintain equilibrium; and (2) due to the geometry of the canopy with the tip inclined upward, more contact is developed at the rear of the canopy than near the canopy tip as the leg pressure increases, which further reduces the forces required forward of the legs for maintaining moment equilibrium. In addition, the pressure is more uniformly distributed and the resultant load on the canopy is closer to the legs when soft contact materials are utilized than those under stiff contact conditions.

Tests were also conducted for the case in which the sloped portion of the canopy was not in contact with the load frame (Fig. 15). This contact configuration may be caused by a layer of debris on the flat portion of the canopy or where cavities form in the immediate roof that prevents tip contact. The pressure profile for this configuration was more uniformly distributed in the front portion but with higher loads near and behind the legs.

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Base Plate Tests

A total of 22 tests were conducted to evaluate the contact pressure on the base plate of the shield (Test 25 – Test 45). A full base contact was simulated by using 24 pressure cells (12 cells on each split base) for all tests. All tests employed wood or hard rubber pads under the pressure cells to simulate floor deformation. Rigid floor conditions were not simulated.

Horizontal loading is typically generated from the internal leg force and the restraining frictional force imposed by the immediate roof and floor. When the canopy is permitted to displace toward the face without external resistance, no horizontal loading is generated. Without horizontal loading, the resultant vertical force acting on the base must be coincident with the resultant vertical force acting on the canopy. Since the canopy resultant force is located near the leg—canopy joint, the resultant vertical force acting on the base is at about 100 cm (75 in) from the rear or 53 cm (21 in) from the toe of the base. If the immediate roof and floor are capable of restraining the natural tendency of the canopy and base plate to displace horizontally from the action of the leg forces, horizontal loading will be developed that will reduce the toe loading. On the other hand, if there is loose debris on the canopy or under the base plate, the canopy and base plate may not be restrained and toe loading will be greater. Fig. 16 (Tests 25 and 26 where the base lifting device was removed) shows that toe loading was higher when the horizontal force was eliminated. Another comparison of base load was made with and without horizontal force when the base lifting device was installed. As shown in Fig. 17 (Tests 33 and 34), when the horizontal force was completely eliminated the base loading increased rapidly at the toe area to 59 metric tons (65 tons) when the leg pressure was 16.24 MPa (2357 psi).

Tests were conducted to determine the effect of the base lifting device on the base loading distribution. The lifting device of the 2–leg shield is designed such that it promotes two–point contact at the toe and rear of the base plate and causes concentrated loading in these areas. From tests 28 and 35, a comparison of the base loading developed with and without the lifting device under horizontal force control (i.e. no horizontal force) is shown in Fig. 18. In these tests, the maximum toe loading is increased by 170% from 38 to 106 metric tons (42 to 117 tons) at about 25.02 MPa (3628 psi) of leg pressure, while the load at the rear of

Fig. 16. Comparison of base loading with vs without horizontal force.

Fig. 17. Comparison of base loading with vs without horizontal force.

Fig. 18. Comparison of base loading with vs without lifting device.

11th International Conference on Ground Control in Mining, The University of Wollongong, N.S.W., July 1992.
the base is increased by an order of magnitude from about 1.8 to 22.7 metric tons (2 to 25 tons). Notice that when the base lifting device was installed, there was no or very little loading in the area between 56 to 127 cm (22 to 50 in.) from the toe of the base plate (Fig. 17).

In order to determine the effect of canopy contact configuration on the base loading distribution, an effort was made to control the location of the resultant load on the canopy by placing contact blocks at certain locations. However, as previously indicated, the resultant load on the canopy was confined to the vicinity of the leg—canopy connection in order to maintain equilibrium. Hence, the base pressure distribution was not significantly affected by the changes in the canopy contact configuration.

In summary, when the base lifting device was removed and horizontal loading was present, the base pressure profile was fairly linear between the rear and the toe of the base plate. Peak toe pressure was typically in the range of 2.76 MPa to 3.45 MPa (400 to 500 psi) when the leg pressure was approaching 41.34 MPa (6000 psi), while pressure at the rear of the base plate was typically in the neighborhood of 0.35 to 0.7 MPa (50 to 100 psi). On the other hand, the existence of the lifting device and the absence of horizontal loading can produce more nonlinear pressure profile with higher toe loading.

**CONCLUSIONS**

1. Since the pressure cells typically covered a small percentage of the total area of the canopy and/or base plate, an accurate assessment of the magnitude of the contact pressure of the shield was difficult to obtain. However, the objectives of this study were accomplished, assuming the contact configuration established between shield and the simulator adequately simulated the underground conditions. The approach taken in this study was to distribute the pressure/loads measured by 24 pressure cells over the entire area of the canopy and/or base plate using a stress contour software program. Therefore, it is necessary to scale the measured pressures/loads in proportion to the percentage of the measured contact area in order to preserve force equilibrium when extrapolating to the full contact load condition.

2. Since the canopy tip is sloped upwards and a base lifting device installed underneath the toe of the base plate, the actual contact area achieved underground with this particular shield design is highly dependent upon the compliance of the immediate roof and floor. It is concluded that a full contact with the canopy and base plate will not be achieved without deformation of the strata, and a high contact pressure will be developed at both ends of the canopy and base plate under very stiff immediate roof and floor conditions.

3. The loading distribution tends to change in both magnitude and profile as the leg pressure increases. The general tendency is that initially the load concentrates at both ends of the canopy and the base plate, and then migrates to other area as the leg pressure increases and causes additional contact areas. When the leg pressure exceeds the setting pressure, the general load distribution is of the type continually increasing from canopy tip to the rear of the canopy, and decreasing from the toe to the rear of the base plate. A linear approximation can be achieved, but a nonlinear approximation is more accurate when the horizontal force is removed.

4. The sloped tip of the canopy promotes initial contact of the tip and discourages contact between the tip and the leg connection point. Even with this design, the amount of tip loading is rather small, about 10% of the total shield capacity for stiff roof condition and less than 5% for more compliant roof and floor strata.

5. The base lifting device exaggerates the high toe loading on the base plate. A more effective design from the perspective of reducing base loading is that the lifting device does not prevent the base plate from making a full contact with the floor.

6. Under uneven floor condition, however, the highest base pressure occurs mostly at one-third of the base plate contact length from the rear edge, while the point of action of the resultant load under the base plate is always located around one-third of the base contact length from the tip end. Sometimes, the highest base pressure is located near the tip end of the base plate. The maximum base pressure of 4.48 MPa (650 psi) was measured near the point underneath the tail—side leg. The direction of the resultant load was
nearly vertical to the base plate. The pressure was always higher under the tail–side split base plate than under the head–side. It was found that there was nearly no contact under the base plate in the area about 56 – 127 cm (22 – 50 in) from the tip end of the base plate.

RECOMMENDATION

The lifting device creates a point contact at the toe of the base plate. It should be recessed into the base plate such that its bottom is flushed with the remainder of the base plate or an alternative design be considered.

The canopy tip which is raised 2-in above the rear portion is too stiff and consequently creates two-point contact with the roof. In order to produce more uniform contact between the canopy and the roof, the canopy structure should be made softer so that under the yield load it becomes flat.

If possible the shield may be redesigned with a wider base plate and a longer toe.

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