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BUREAU OF MINES

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

in	inch	s	second
psi	pound per square inch	st	short ton

TWO-LEG LONGWALL SHIELD MECHANICS

By Thomas M. Barczak,[1] and David E. Schwemmer[2]

ABSTRACT

This Bureau of Mines report investigates shield mechanics by describing the elastic response and interaction of shield components to applied vertical and horizontal displacements for various canopy and base contact configurations. This research provides information on generalized shield mechanics, which is applicable in describing the behavior of all two-leg shield supports. Utilizing mechanics of materials concepts and known kinematic relationships for two-leg shield supports, free-body diagrams are constructed for each shield component illustrating internal axial, shear, and bending moment responses required to maintain equilibrium for each load case evaluated. Predicted shield (component) responses are verified by controlled displacement of instrumented longwall shields in the Bureau's mine roof simulator (MRS). Conclusions drawn from these analyses include shield structural responses are significantly dependent upon canopy and base contact configurations. Applied displacements also significantly affect shield responses. Horizontal displacement produces different responses than those produced by vertical displacements. The direction of horizontal displacement is also significant in evaluating shield response. Applications of shield mechanics to in situ support monitoring are also discussed. An objective of this research program is to establish unique shield responses to identify in situ load conditions.

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INTRODUCTION

A two-dimensional diagram of a two-legged longwall shield is shown in figure 1. As illustrated in the figure, the shield is comprised of the following components: (1) canopy or roof beam, (2) caving shield, (3) front lemniscate link, (4) rear lemniscate link, (5) base or floor beam, and (6) leg cylinders. This Bureau of Mines report describes the structural responses (axial, shear, and bending moment) of each component to various vertical and horizontal shield displacements (loading conditions) under a variety of canopy and base contact configurations believed to be representative of typical and worst case underground environmental conditions. The objective of this analysis is to assess internal shield structural responses and evaluate the dependency of this behavior on loading conditions and contact configurations, specifically, the initial conditions due to setting the support and boundary conditions imposed by relative movement between the roof and floor strata. The structural responses described in this analysis of generalized shield mechanics are generic for two-legged lemniscate longwall shields. While the mechanics of materials and kinematic relationships are generic for all shields, component stiffness and geometries are likely to be shield specific. Therefore, the specific shield design must be considered in evaluating component interactions to determine dominant component behavior and mechanisms, which govern application of these generalized shield mechanics.

This research is part of the Bureau's research program to optimize mine roof support systems. Optimization can be considered in terms of (1) support selection and (2) support design as illustrated in the optimization plan shown in figure 2. The primary contribution of this work towards these optimization goals is to provide a fundamental evaluation of shield mechanics and a foundation for load transfer investigations and critical load studies of specific shield designs. Another goal of the Bureau's research is to develop technology to use supports as monitors of strata activity. To do this one must be able to distinguish strata activity from the response of the support structure and to establish unique shield responses to identify in situ load conditions and contact configurations. An understanding of shield mechanics is essential to achieving these goals and optimizing support selection.

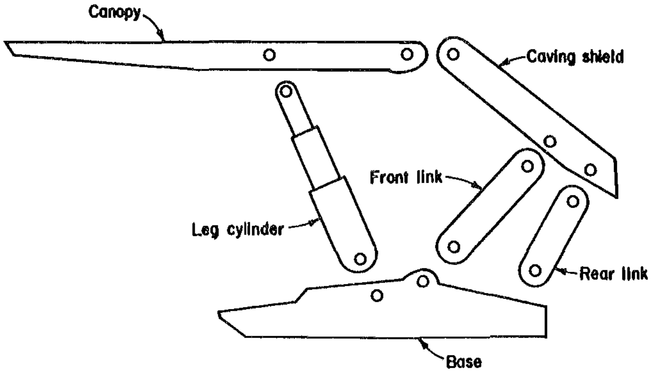

Figure 1.—Two-dimensional diagram of longwall shield.

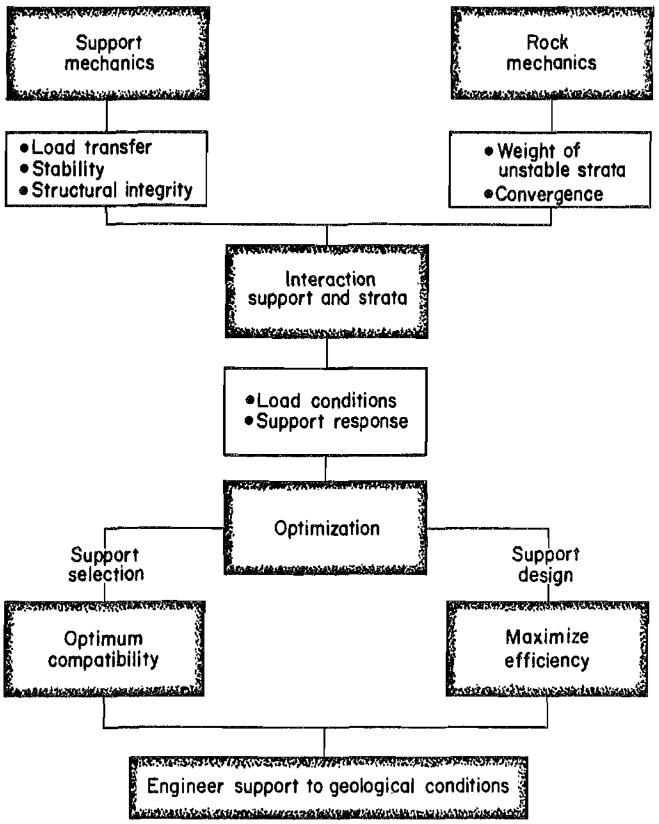

Figure 2.—Optimization of mine roof supports.

Procurement of longwall roof supports requires a large capital investment and coal operators frequently require some form of performance testing by the manufacturer before accepting delivery of the supports. In order for the coal operator to properly interpret these tests or to instruct the manufacturer to conduct tests of their own interest, some understanding of shield mechanics is necessary. This research provides a basic understanding of the mechanics governing shield behavior and will assist both coal operators and researchers in evaluating shield behavior from performance tests.

The shield mechanics described in this report have been verified by full-scale testing of two, typical, two-legged longwall shields of different manufacture in the MRS. Each component was strain gauged and component deformations were monitored under controlled loading conditions. The MRS (fig. 3), is a large hydraulic press capable of providing controlled vertical and horizontal displacements to longwall shields.

Previous research in the area of shield mechanics has generally been limited to assessment of leg, canopy capsule, and front lemniscate link forces to evaluate external resultant shield loading by rigid-body analysis[3] under full-contact loading conditions. A complete study of shield mechanics, involving all shield components under both partial and full-contact configurations for both vertical and horizontal shield displacements (loading conditions) has not been attempted prior to this, at least with verifiable test results.

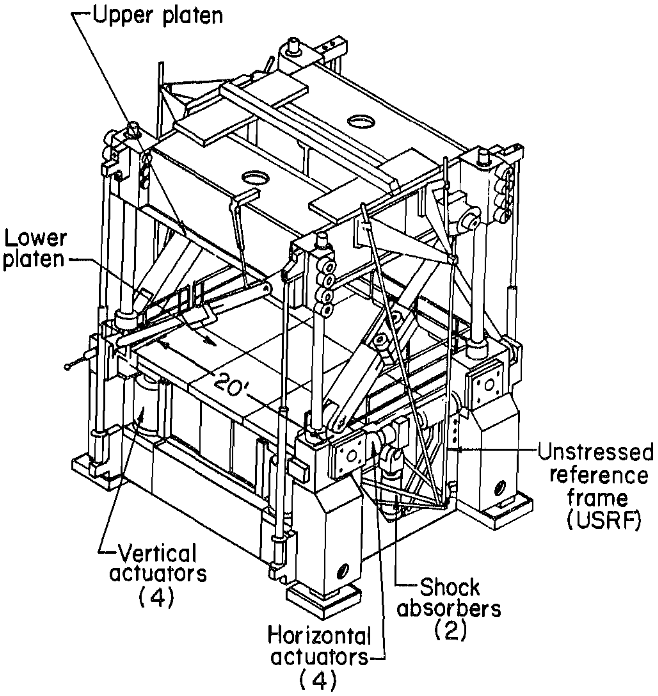

Figure 3.—Mine roof simulator.

ENVIRONMENTAL CONDITIONS

The surrounding strata creates an environment with which the shield support must interact during mining operations to provide effective ground control. The response of the shield is dependent upon the conditions imposed upon it by the environment. Environmental considerations evaluated in this study include contact configurations (vertical and horizontal restraints on the canopy and base) and displacement-controlled loading conditions. In addition, initial shield conditions created by setting the support are evaluated. The motivation for these evaluations is while shields are imposed with setting conditions as well as displacement profiles, the superpositioning of initial conditions with boundary conditions will provide shield behavior for any load condition.

SETTING CONDITIONS

Previous research in shield load transfer mechanics has determined that shield performance is dependent upon how the support is set (initial conditions). Two types of setting conditions are described: horizontally constrained and unconstrained. These conditions (fig. 4) are the extremes in the range of possibilities.

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[3] Barczak, T. M., and R. G. Garson. Shield Mechanics and Resultant Load Vector Studies. RI 9027, 1986, 43 pp.

Barczak, T. M. Technique to Measure Resultant Loading on Shield Supports. Paper in 25th Proceedings of Rock Mechanics, 1985, pp. 667-679.

Barczak, T. M., and S. J. Kravits. Shield-Loading Studies at an Eastern Appalachian Minesite. RI 9098, 1987, 81 pp.

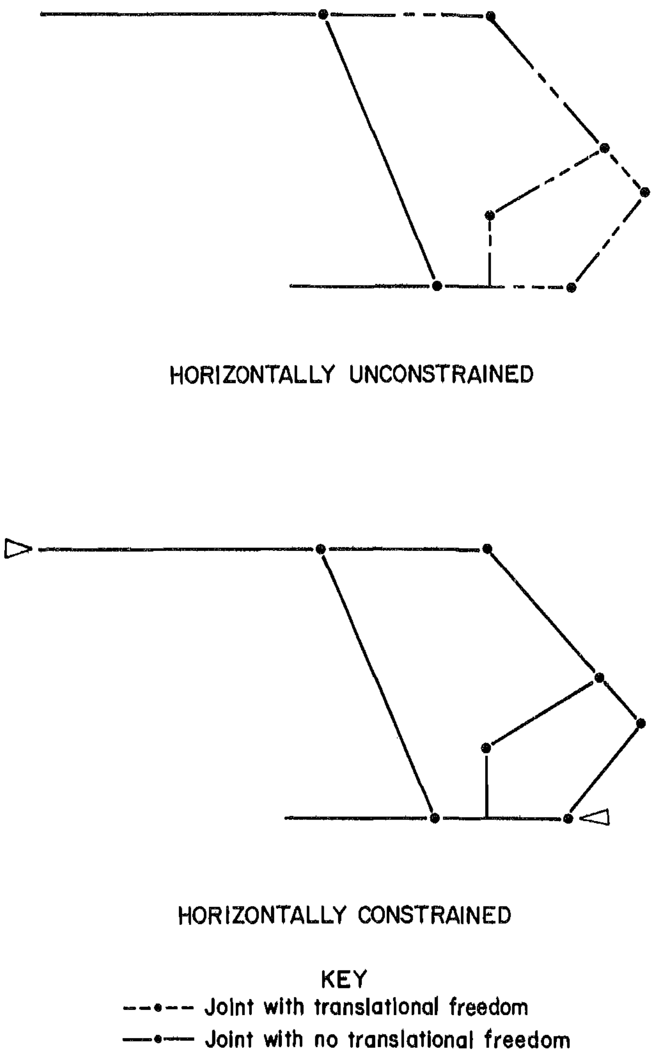

Figure 4.—Types of setting conditions.

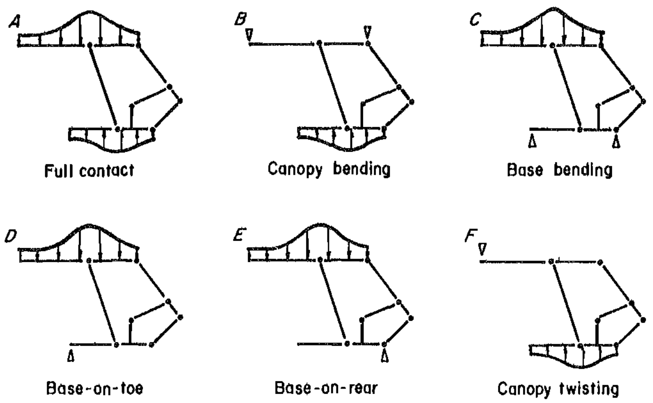

Figure 5.—Description of shield contact configurations.

Horizontally constrained setting is intended to describe setting conditions that remove horizontal translational freedom in the pin joints of the structure. This can be achieved when horizontal resistance is provided during support by advancement of the support under partial contact with the roof strata, or if the canopy is restrained (i.e., striking step in roof strata) during advancement. Horizontally unconstrained setting conditions do not remove pin translational freedom and occur if the support is advanced without horizontal resistance.

CONTACT CONFIGURATIONS

There are many possible contact configurations that may occur underground, ranging from full canopy and base contact to a variety of partial contact configurations. The scope of this investigation includes two-dimensional analysis of symmetric contact configurations involving full, one-point and two-point canopy and base contacts. One unsymmetric canopy and base contact configuration, three-point canopy or base contact, was also investigated. Emphasis is placed on those contact configurations that cause a different response in one or more shield components.

Contact configurations chosen for this investigation are grouped into six primary categories, which were influential in altering shield response: (1) full canopy and base contact, (2) canopy bending, (3) base bending, (4) base-on-toe, (5) base-on-rear, and (6) canopy twisting (unsymmetrical loading). Several combinations of these categories were analyzed in this study. Figure 5 depicts these shield contact configurations for each of the six categories. A brief description of these contact categories and explanations of how they might occur underground follows.

1. Full canopy and base contact (fig. 5*A*) - Full canopy and base contact is probably the most common contact condition. This configuration will occur in all strata conditions where uniform cutting is achieved at the roof and floor interfaces. Full-contact configurations provide minimal canopy and base bending, which is the primary requirement of this contact configuration category. Single-point contact at the canopy and base leg connection theoretically do not produce any bending of the canopy or base. These single-point contacts, while physically possible, are unlikely to occur underground, but this configuration is typically used to analyze full canopy and base contact using resultant loading applied at the leg connection. A more common configuration than single-point contact is partial contact from the leg to the rear of the canopy or base, which is unlikely to produce significant bending because the canopy and base are fairly stiff in these regions, and because there is contact at the leg connection where most of the load is transferred.

2. Canopy bending (fig. 5*B*) - Maximum canopy bending occurs under two-point canopy contact at the ends of the canopy. This condition will occur from protrusions in

the roof interface resulting from inconsistent cutting heights or from natural occurrences such as cavity formation in highly fractured strata above the leg reaction. Some canopy structures are designed with the tip horizon above the plane of the remainder of the canopy to ensure tip loading. Supports with this type of canopy structure can experience canopy bending in all strata conditions.

3. Base bending (fig. 5C) - Likewise, maximum base bending occurs under two-point base contact at the ends of the base, and will occur from protrusions in the floor strata caused by inconsistent cutting heights or from failure of the floor strata.

4. Base-on-toe (fig. 5D) - In this configuration, the base is simply supported and restrained horizontally only at its toe. This configuration can occur from irregularities in the floor, from inconsistent cutting heights, or from natural protrusions. It may also occur when the base is restrained horizontally during advancement (i.e., toe of base strikes a step in the floor and the advancing force is acting to cause a counterclockwise rotation of the support). Another scenario that will cause this configuration is when the support is set with the tip up and the canopy is restrained horizontally, and the canopy capsule is activated to level the canopy to a full-contact condition or the leg force raises the canopy to a full-contact position while lifting the rear of the base off the ground during setting. This scenario does not require roof or floor irregularities, providing sufficient horizontal restraint can be developed at the canopy tip area.

5. Base-on-rear (fig. 5E) - This configuration is similar to the base-on-toe configuration, but is simply supported at its rear. It will also occur from setting the support on irregularities (protrusions at the rear of the base). Likewise, this configuration can occur from setting the support with the rear of the canopy sticking up and using the canopy capsule or leg force to provide a full-contact configuration. However, this is probably less likely to occur than setting the support with the canopy tip in the air, and thus, this configuration is less likely to occur than the base-on-toe configuration.

6. Canopy twisting (unsymmetrical loading) (fig. 5F) - Canopy twisting configurations are used to describe three-point canopy contact configurations where one contact is removed from one of the corners of the canopy. This condition is illustrated in a two-dimensional (side view) diagram as one-point canopy contact at either the canopy tip or rear. This condition can occur whenever the roof interface is uneven. Friable roof is one example of strata conditions, which would promote this type of contact configuration. Similar base-contact configurations were investigated, but since the shields tested had split-base designs, such unsymmetric base configurations do not produce base twisting (torsional loading).

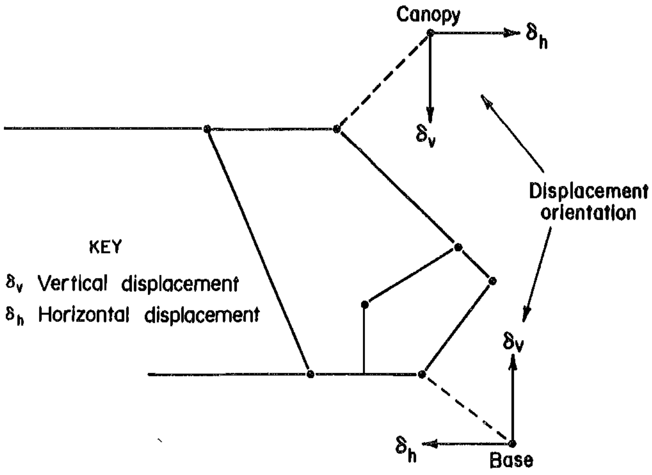

Figure 6.—Shield displacement axis orientation.

LOAD CONDITIONS

The primary function of the shield is to maintain stability against vertical and horizontal displacements resulting from strata activity. As the canopy and base act to interface with the roof and floor strata, shield displacements occur from relative motion between the canopy and base of the support structure. Figure 6 depicts an axis orientation for depicting shield displacement directions. Vertical displacements are in reference to separation between the canopy and base, while horizontal displacements refer to horizontal translation of the canopy relative to the base.

The shield, once set against the roof and in an equilibrium configuration, may be subjected to any combination of vertical and horizontal displacements. Vertical displacements are assumed to always cause convergence of the canopy relative to the base, which is designated as a positive vertical displacement. However, horizontal displacements can have either a positive (face-to-waste) or negative (waste-to-face) direction (of the canopy), resulting in horizontal translation of the canopy relative to the base in either of these two directions. From figure 6 the displacement axis is reversed for the base relative to the canopy. This ensures that a positive vertical displacement of the canopy (roof moving down) produces the same effect as a positive vertical base displacement (floor moving up). Likewise, a positive horizontal displacement is provided by either face-to-waste displacement of the canopy or waste-to-face displacement of the base or both simultaneously.

SHIELD RESPONSES

Longwall shields are pin-jointed structures that are highly indeterminant. To understand shield mechanics, it is necessary to reduce the indeterminancy, determine the degree of pin freedom in the numerous joints, and develop assumptions concerning the development of stresses in specific components. From both full-scale shield testing and analytical-numerical modeling experience, some assumptions (simplifications) can be postulated to aid in evaluation of shield mechanics. These are two-dimensional plane stress member representations provide acceptable shield responses to imposed environmental (in the classical mechanics framework) conditions; front and rear lemniscate links tend to act as axially loaded members; pin rotational restraint may generate a significant bending moment; contact locations typically produce normal and frictional forces; the capsule reactions contribute little to shield capacities; and out-of-plane strains are insignificant in symmetric contact configurations.

Utilizing these concepts and assumptions, a two-dimensional shield model was developed as depicted in figure 1. For an analytical evaluation, this model is sectioned into joints and members (components) (fig. 7). Appropriate locations of strain gauges on these members permit measurement longitudinal and bending strains (deformations), and thus axial and bending moment reactions to be determined. Incorporating these responses into the free-body diagrams for the shield components, shear forces necessary for equilibrium are inferred, and the internal stress state is ascertained.

The analytical procedure devised from this development is utilized to meet the objective of this analysis, namely, to identify the structural response (axial, shear, and bending) for each of the shield components for the load conditions and contact configurations described in the previous sections. In accordance with this objective, an assessment of shield mechanics is developed in the following manner. First, the response of the shield (components) to the two setting conditions is described. Then, three diagrams are depicted for each of the six contact configurations described in the previous section. These three diagrams depict the response of the shield to independent vertical, positive and negative horizontal displacement, respectively. Using the principle of superposition, these diagrams can then be used to describe shield behavior to any combination of vertical and horizontal displacement for a variety of contact configurations.

ANALYSIS OF SETTING CONDITIONS

Shield responses for the two setting (initial) conditions are shown in figure 8 and described as follows.

Unconstrained setting conditions:

Assuming there is translational freedom in the pin joints (unconstrained setting condition), the primary load transferring members between the canopy and base are the leg cylinders. As illustrated in figure 8A, insignificant load is developed in the caving shield-lemniscate assembly because the caving shield-lemniscate assembly has no vertical load capacity and no horizontal displacement occurs to

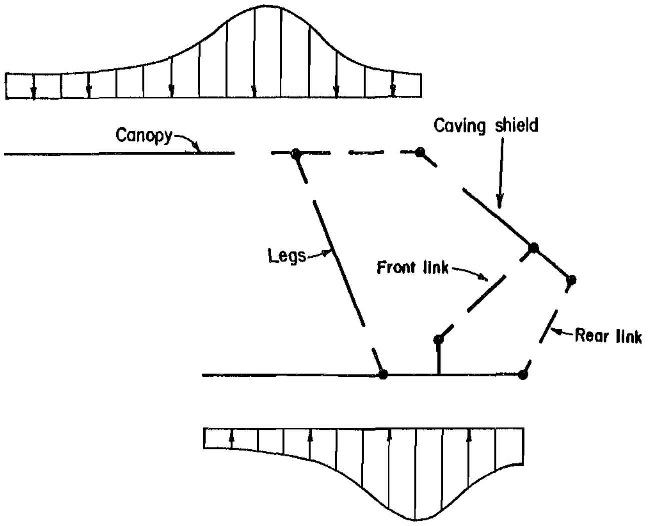

Figure 7.—Free-body representation for shield components.

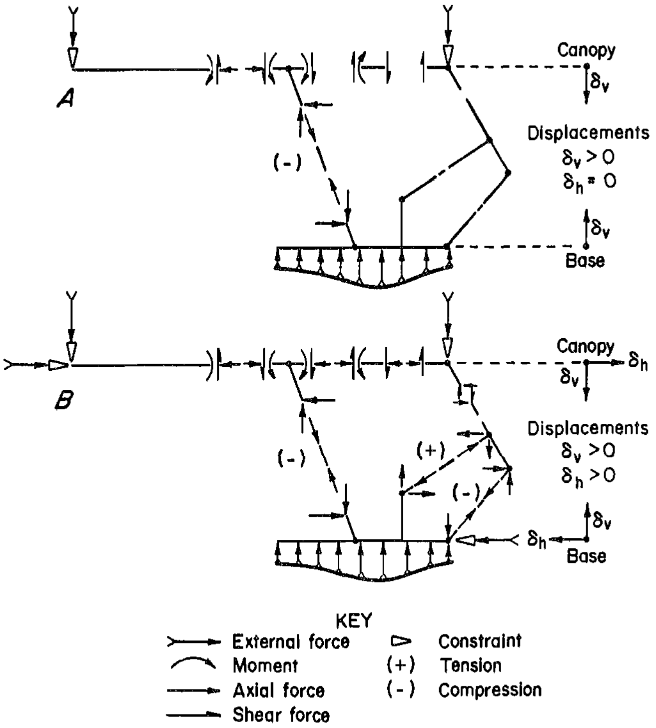

Figure 8.—Analysis of shield setting conditions.

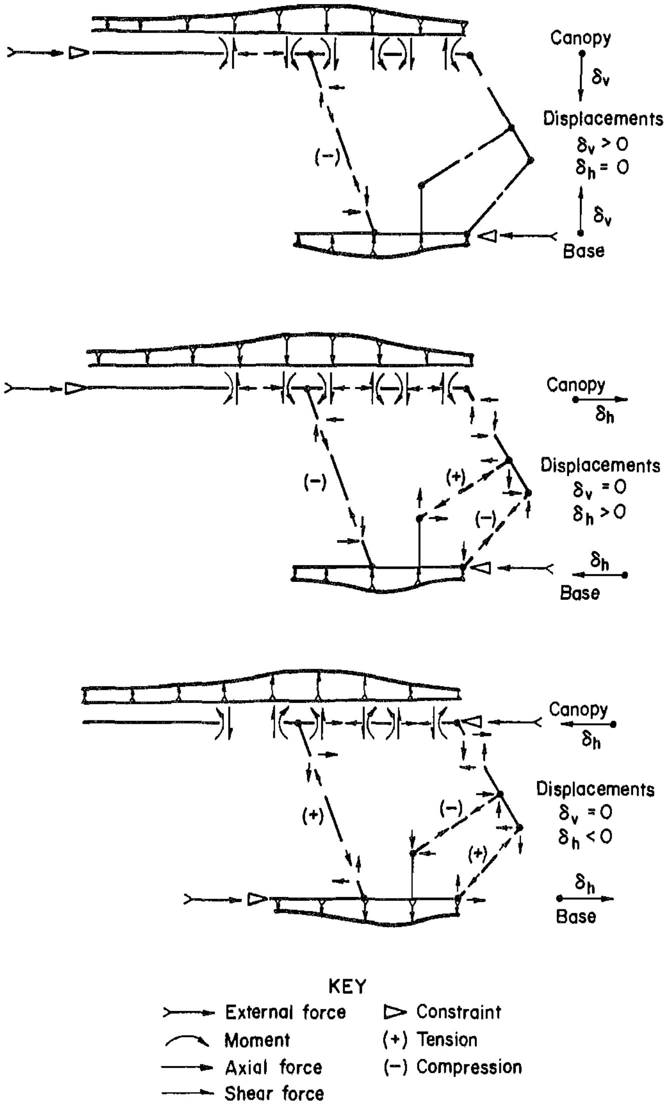

Figure 9.—Analysis of no canopy or base bending shield responses.

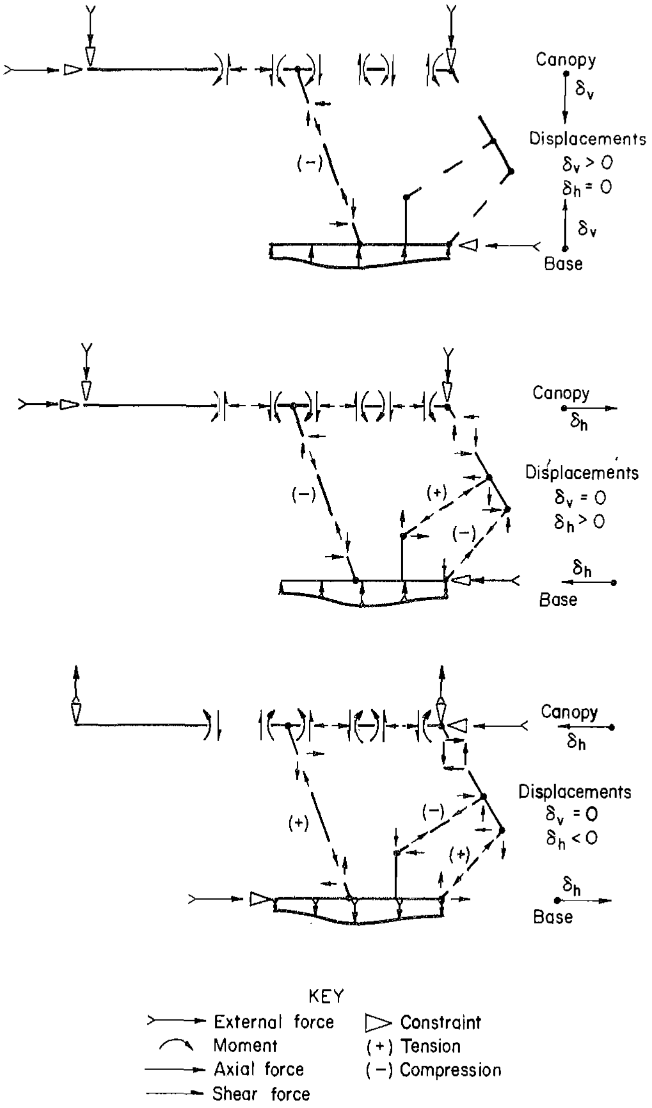

Figure 10.—Analysis of canopy bending shield responses.

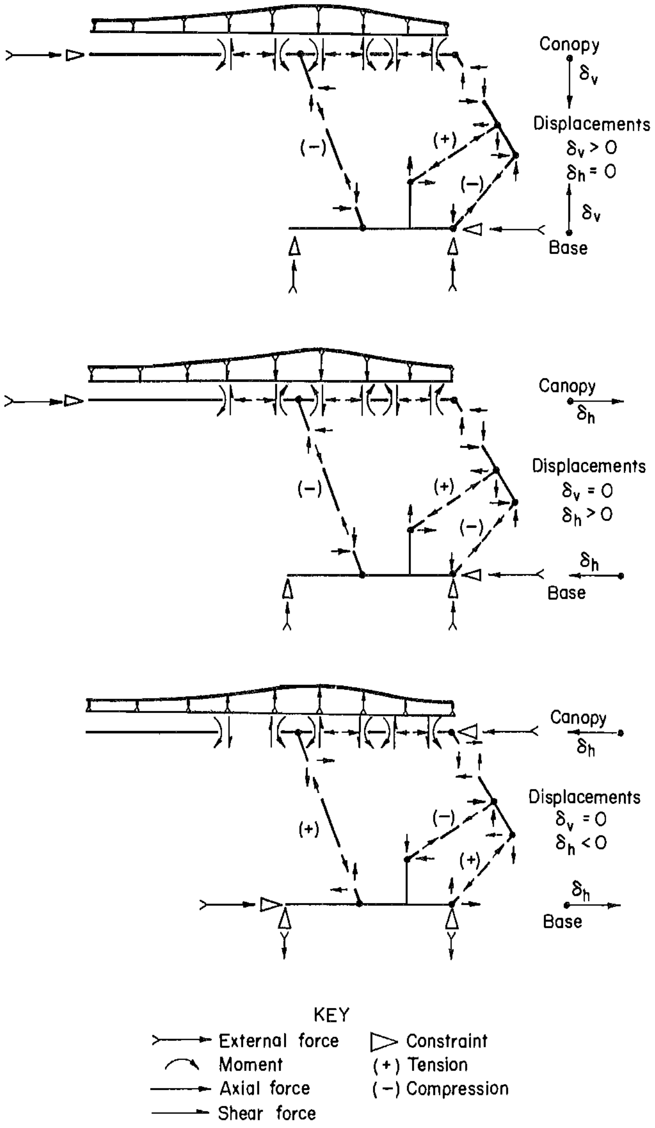

Figure 11.—Analysis of base bending shield responses.

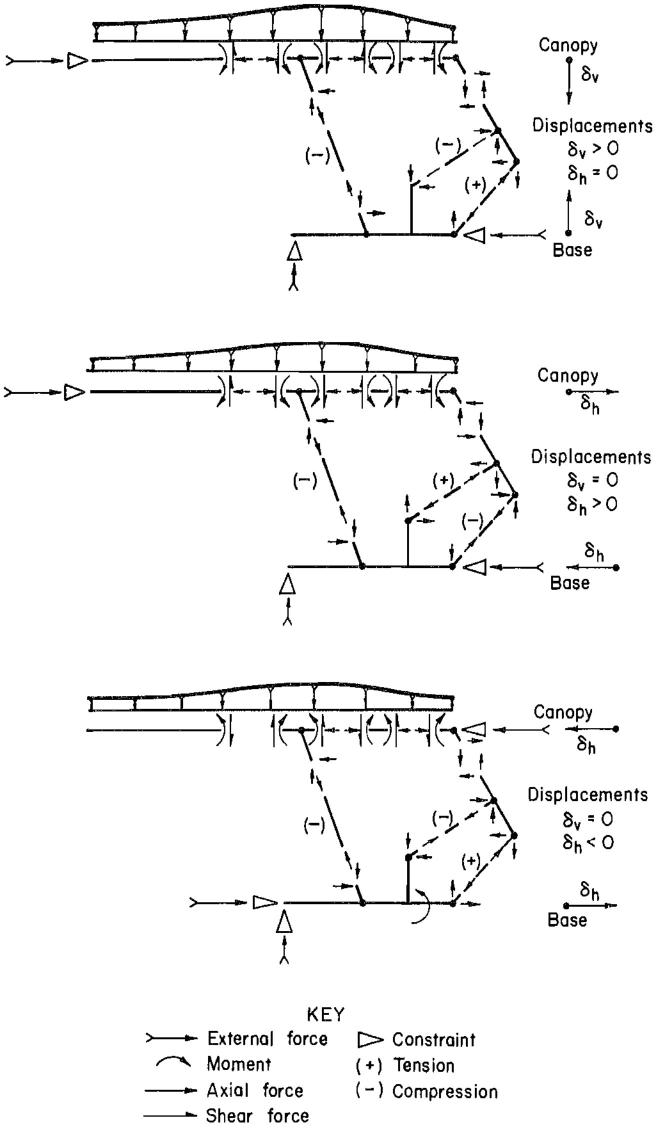

Figure 12.—Analysis of base-on-toe shield responses.

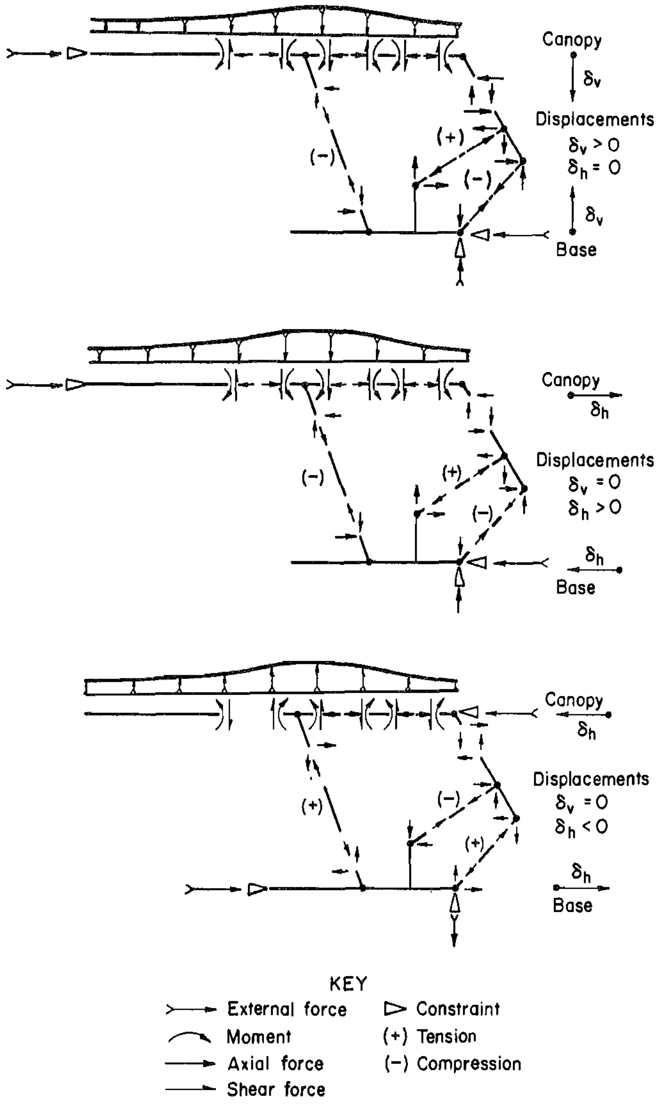

Figure 13.—Analysis of base-on-rear shield responses.

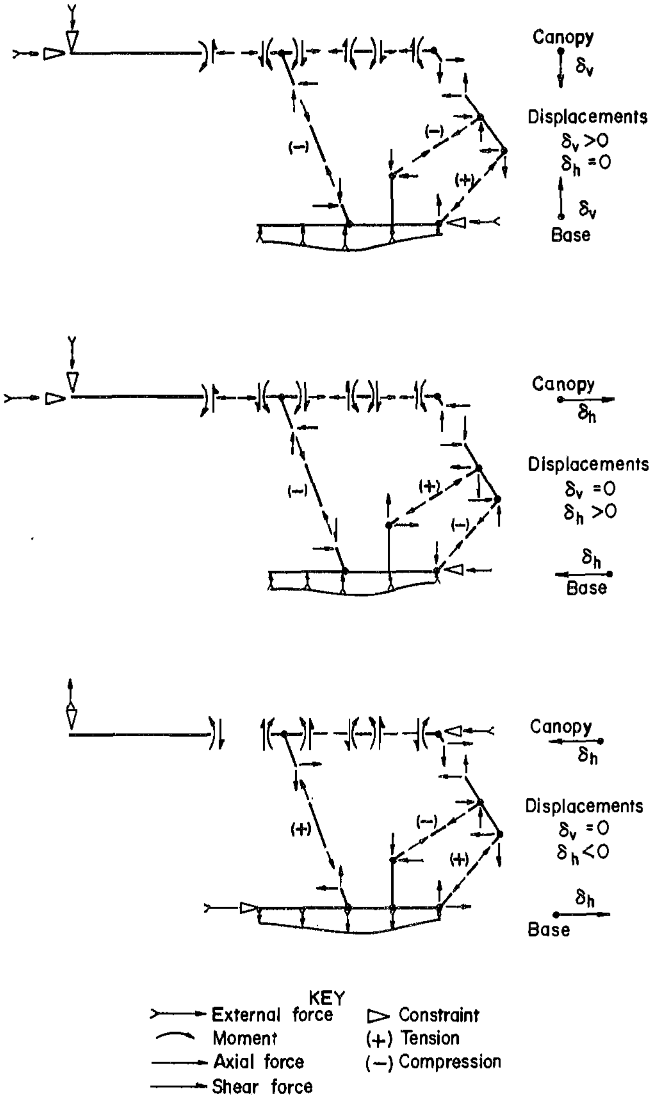

Figure 14.—Analysis of canopy twisting shield responses.

generate force reactions in the caving shield and lemniscate links. Other components respond as follows. The legs act in compression to transfer load from the canopy to the base and the canopy is axially strained in tension between the leg connection and the tip.

Constrained setting condition:

When the shield is set in a constrained configuration such that horizontal pin translation is removed, then the caving shield-lemniscate assembly will respond as illustrated in figure 8*B*. The illustrated caving shield-lemniscate assembly response is caused by face-to-waste displacement of the canopy. A further assessment of the mechanics producing this response in the caving shield-lemniscate assembly is described in the next section under contact configurations. The participation of the caving shield-lemniscate assembly results in the canopy being axially strained in compression between the leg connection and the caving shield joint. Other components respond in the same manner as in the unconstrained setting condition, although not necessarily the same magnitude of strain.

ANALYSIS OF CONTACT CONFIGURATIONS AND DISPLACEMENTS

Shield responses are dominated by canopy and base contact configurations since different contact configurations produce different component responses. Shield responses for each of the six contact configurations shown in figure 5 are illustrated in figures 9 through 14. Component responses are shown for vertical, positive and negative horizontal displacement for each of these six contact configurations. Shield responses for some other contact configurations of interest are shown in appendix A.

A review of figures 9-14 reveals that shield response for horizontal displacements is largely independent of contact configuration (vertical restraint on canopy and base). However, the direction of horizontal displacement changes the response of several shield components, most notably the lemniscate links and leg cylinders. Positive horizontal displacements (i.e., face-to-waste displacement of the canopy) produce tensile strains in the front link and compressive strains in the rear link, while negative horizontal displacements produce compression in the front link and tension in the rear link. Likewise, opposite leg responses are produced from positive horizontal displacement compared with negative horizontal displacement; positive horizontal displacements produce leg compression while negative horizontal displacements relieve load (make less compressive).

Canopy behavior was also found to be dependent upon the location of application of horizontal load (displacement). If horizontal displacements are produced by horizontal restraint at the canopy tip or hinge pin as shown in figures 9 through 14, both positive and negative horizontal displacements are likely to produce axially compressive forces in the canopy structure. However, if the displacements are produced from strata displacements resulting from friction along the canopy surface at the roof interface as illustrated in figure 15, then tensile strains may occur in portions of the canopy for negative horizontal displacements. Tension in the canopy produced by axial deformation resulting from negative horizontal displacement can also occur if the negative horizontal displacement is produced from internal leg forces where the canopy slides on the roof. While horizontal displacements produce axial deformations in the canopy, bending is likely to be the more dominant canopy response and either positive or negative horizontal displacement will exaggerate the bending.

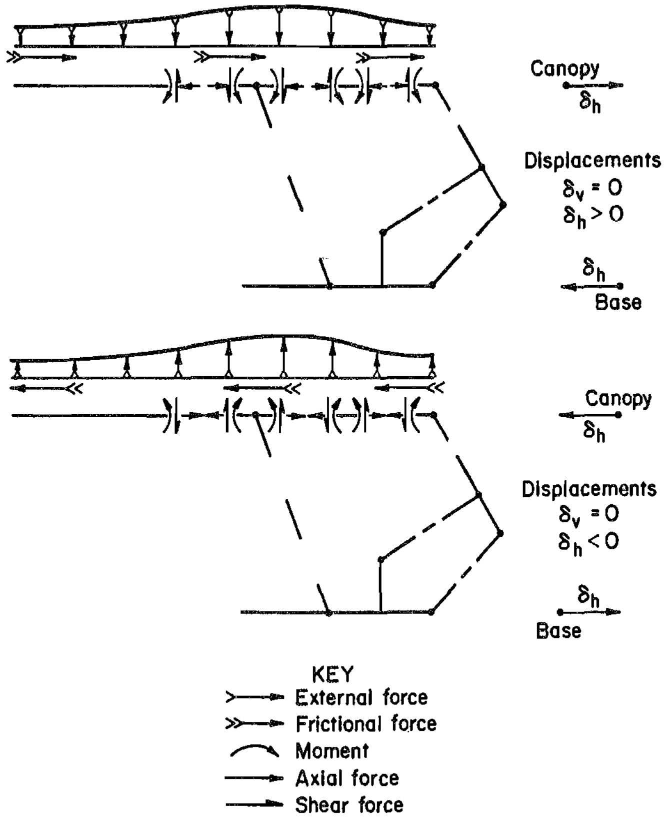

Figure 15.—Frictional force reactions during horizontal strata displacements.

While shield response to horizontal displacement is largely independent of contact configuration, shield response to vertical displacements is much more sensitive to contact configuration. Leg cylinder compression is consistent for vertical displacement for all contact configurations, but the behavior of the caving shield-lemniscate assembly is contact configuration dependent. An assessment of shield response to vertical displacements for specific contact configurations is described below.

1. Full canopy or base contact (fig. 9) - Under full canopy and base contact, the primary load transferring mechanism between the canopy and base is through the leg cylinders as the caving shield-lemniscate assembly has no vertical load capacity. Therefore, the leg cylinders will be in compression and no significant stresses will be developed in the caving shield-lemniscate assembly. Since loads applied to the canopy must be transferred to the leg cylinder for transferral to the base, loads applied anywhere on the canopy must be transferred by shear stresses through the canopy structure to the leg connection. Bending moments are also created in the canopy for full-contact, distributed loading. Hence, both shear strength and bending strength are important design considerations for the canopy structure.

2. Canopy bending (fig. 10) - The majority of bending in the canopy takes place between the tip and the leg connection, since the canopy is stiff between the leg connection and the caving shield hinge. Therefore, canopy bending is not likely to create much stress in the caving shield-lemniscate assembly, since it is not likely to produce significant horizontal displacement at the caving shield joint.

3. Base bending (fig. 11) - For the contact configuration shown in figure 11, base bending produces tension in the front lemniscate link and compression in the rear lemniscate link. As the base bends due to the leg force, the front link tries to resist this deformation, putting this link in tension. The contact at the rear link results in compressive stresses being developed in the rear link to provide equilibrium of the caving shield-lemniscate assembly. Equilibrium also requires the caving shield to exert an upward and forward reaction on the canopy in response to the base bending. This reaction causes an increase in support capacity by acting in the same direction as the leg reactions.

4. Base-on-toe (fig. 12) - With the base simply supported on its toe, the leg force is pushing down on the base, inducing a rotational tendency to establish another contact point to enhance stability. The caving shield-lemniscate assembly resists this motion and provides stability in this configuration. Since the rear link is subjected to the larger rotational force (displacement), a tensile force is developed in this member. A compressive force is then developed in the front link to maintain equilibrium of the caving shield. As illustrated in figure 12, these responses dictate a downward and backward reaction by the caving shield on the canopy, which opposes leg reactions and thereby reduces shield capacity. This effect is opposite that of the base bending configuration (fig. 11).

5. Base-on-rear (fig. 13) - A similar assessment can be applied to the base-on-rear configuration illustrated in figure 13. In this case, the base is supported at the rear link joint and the rotational displacement of the base by the leg force is resisted by the front link. This behavior results in tensile forces in the front link and compressive forces in the rear link, which is opposite of the base-on-toe configuration. Likewise, an opposite effect results for the caving shield reaction. For the base-on-rear configuration, the caving shield reaction enhances shield capacity.

6. Canopy twisting (fig. 14) - Stability in this configuration is qualified in the sense that two-dimensional one-point canopy contact is dependent upon out-of-plane strains to maintain stability. (This configuration is a two-dimensional representation of unsymmetrical three-point canopy contact). With one-point contact at the canopy tip as illustrated in figure 14, the canopy wants to rotate counterclockwise about the leg connection. This motion tries to pull the caving shield towards the face. Resistance to this motion by the caving shield-lemniscate assembly results in compressive forces in the front link and tensile forces in the rear link. In addition, shield capacity is reduced in this configuration by the reaction of the caving shield-lemniscate assembly. With one-point contact at the canopy rear, the opposite reactions will occur. The overall result of unsymmetric canopy loading will be development of torsional stresses in the caving shield, which are evidenced by opposite reactions in the lemniscate links from one side of the shield to the other.

SUMMARY ASSESSMENT AND GENERALIZED BEHAVIOR

A summary assessment of shield responses for the described contact configurations is shown in table 1. As previously indicated, shield response for horizontal displacement is independent of contact configuration, except for axial canopy deformations. For vertical displacement, the response of the caving shield-lemniscate assembly is

TABLE 1. - Summary assessment of shield responses[1]

Configuration	Vert. disp.			Pos. horz. disp.			Neg. horz. disp.		
	Legs	Front link	Rear link	Legs	Front link	Rear link	Legs	Front link	Rear link
Full contact	(–)	0	0	(–)	(+)	(–)	(+)	(–)	(+)
Canopy bending	(–)	0	0	(–)	(+)	(–)	(+)	(–)	(+)
Base bending	(–)	(+)	(–)	(–)	(+)	(–)	(+)	(–)	(+)
Base-on-toe	(–)	(–)	(+)	(–)	(+)	(–)	(–)	(–)	(+)
Base-on-rear	(–)	(+)	(–)	(–)	(+)	(–)	(+)	(–)	(+)

[1](+) designates tension; (–) designates compression.

dependent upon the contact configuration. This is significant since the participation of the caving shield-lemniscate assembly can influence overall shield capacity. Generally, if the front link is in compression, shield capacity is reduced, and if it is tension, shield capacity is increased. It is also concluded that the front and rear link must always be opposite to maintain equilibrium of the caving shield. Finally, it must be remembered that this analysis pertains to changes in strain (stress) profiles because of various environmental conditions, and as such, does not provide for absolute strain magnitudes.

SUPERPOSITION OF DISPLACEMENTS

Separate free-body diagrams were presented in the previous section (figures 9-14) for vertical, positive and negative horizontal displacements. Assuming the superposition of various displacements (load conditions), it is possible to evaluate shield response to a variety of displacement combinations. Without knowledge of the magnitudes of the internal forces, controlling factors are not definitely known. Therefore, analyses to determine the final stress state of the various components from combined displacements is limited.

However, knowledge of the shield mechanics from generalized analyses is useful in assessing which displacement is dominant if the final stress state is known. For example, let's consider the superposition of a vertical displacement with a negative horizontal displacement for a base bending contact configuration (fig. 11). Since the stress state for the lemniscate links are opposite for these two displacements, an assessment of the dominating displacement can be determined from analysis of link behavior.

Appendix B contains final stress states for some positive and negative displacement combinations applied to a longwall shield in the MRS. A brief discussion of shield mechanics pertaining to these load conditions is also included in appendix B.

In principal, the concept of superposition can also be applied to contact configurations. Again, since the magnitudes of the stress must be known to evaluate controlling factors, this is considered beyond the scope of this study of generalized shield mechanics. However, this study provides a foundation for research to evaluate displacement and contact superposition in greater detail in future studies.

LABORATORY TEST VERIFICATION

A 500-st longwall shield, representative of the generic configuration described in figure 1, was instrumented and tested under controlled vertical and horizontal displacements in the MRS for the contact configurations described in the previous section. The leg cylinders were instrumented with pressure transducers and other structural components were instrumented with strain gauges as shown in figure 16 to measure component responses.

The support was set at 4,000 psi leg pressure (under either constrained or unconstrained conditions) and then subjected to controlled displacement by the simulator. Vertical displacement was applied first, followed by either a positive or negative horizontal displacement. Therefore, when comparing test results with the free-body diagrams presented in the previous section, it is necessary to interpret the test data by examining changes in strain behavior and not the actual stress (strain) value. This is necessary because the test results show final strain states after initial (set) conditions and both vertical and horizontal boundary displacement conditions.

Test results showing strain responses for the canopy and caving shield are depicted in appendix C for the various contact configurations. Figures 17 through 22 depict strain responses for the leg cylinders and front and rear lemniscate links. These components best illustrate the changes in shield response for different displacements and contact configurations. Monitored shield responses (component strains) are illustrated in separate graphs for vertical, positive and negative horizontal displacement, to facilitate comparison to the free-body diagrams presented in figures 9 through 14. Again, remember it is necessary to assess changes in strain and not absolute strain values.

The simulator test results are consistent with the shield responses illustrated in the free-body diagrams presented in figures 9 through 14. For example, figure 17 shows the change in link behavior for change in horizontal displacement from a positive to a negative direction for full canopy and base contact, which is consistent with shield responses illustrated in figure 9. Comparison of figure 17 with figure 19 shows the influence of base bending deformation on link behavior. Examination of component responses for a base bending configuration reveals for significant link activity in response to vertical displacement, while the links remain largely inactive for vertical displacement in the absence of base bending. The mechanics describing this behavior are discussed in the free-body analysis referenced in figures 9 and 11. Comparison of figure 19 with figure 20 shows change in link behavior for vertical displacement when the support is set on its toe compared with partial contact base support (base bending). These results are consistent with the free-body analysis presented in figures 11 and 12, respectively.

Another interesting discovery from the laboratory tests was that some unsymmetrical contact configurations could be divided into a symmetric and an unsymmetric, two-dimensional evaluation. For example, an unsymmetric three-dimensional, three-point base contact could be divided into a one-point and a two-point two-dimensional load case. Test results showed left and right link behavior to be consistent with corresponding base contact; one side of the shield responds to a single-point base contact while the side responds to a two-point base contact.

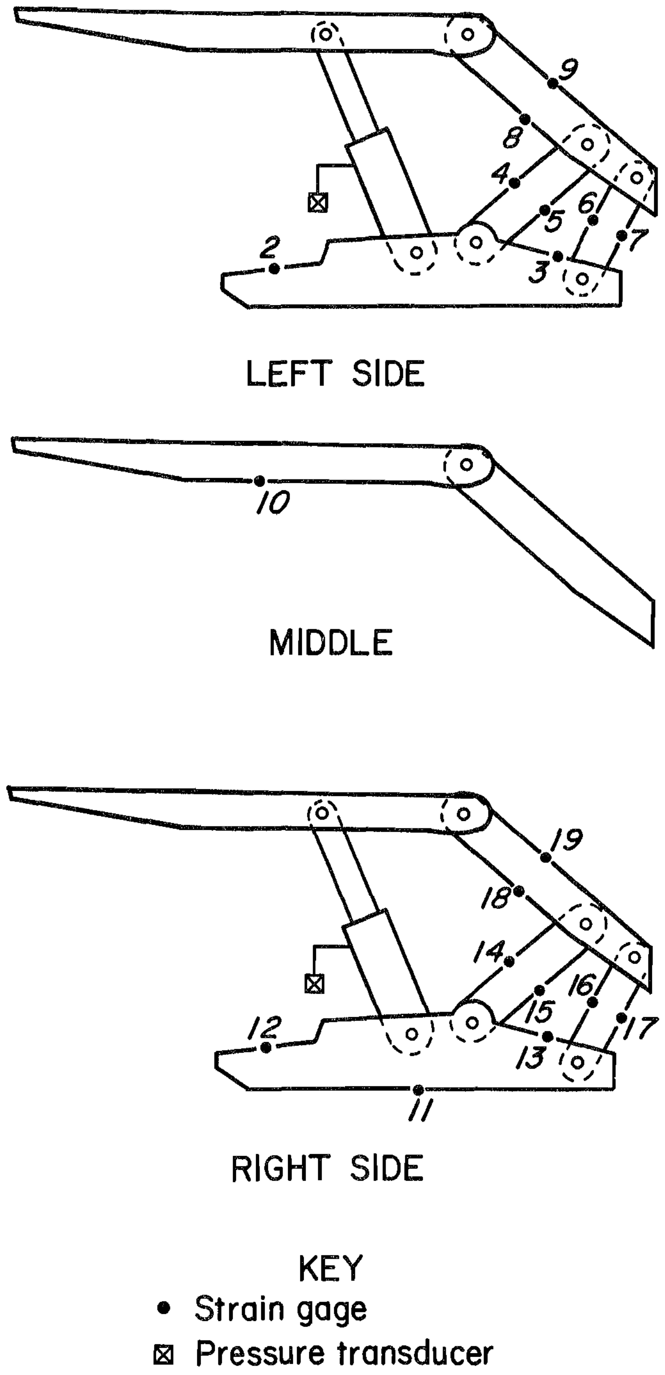

Figure 16.—Strain gage instrumentation for analysis of shield responses.

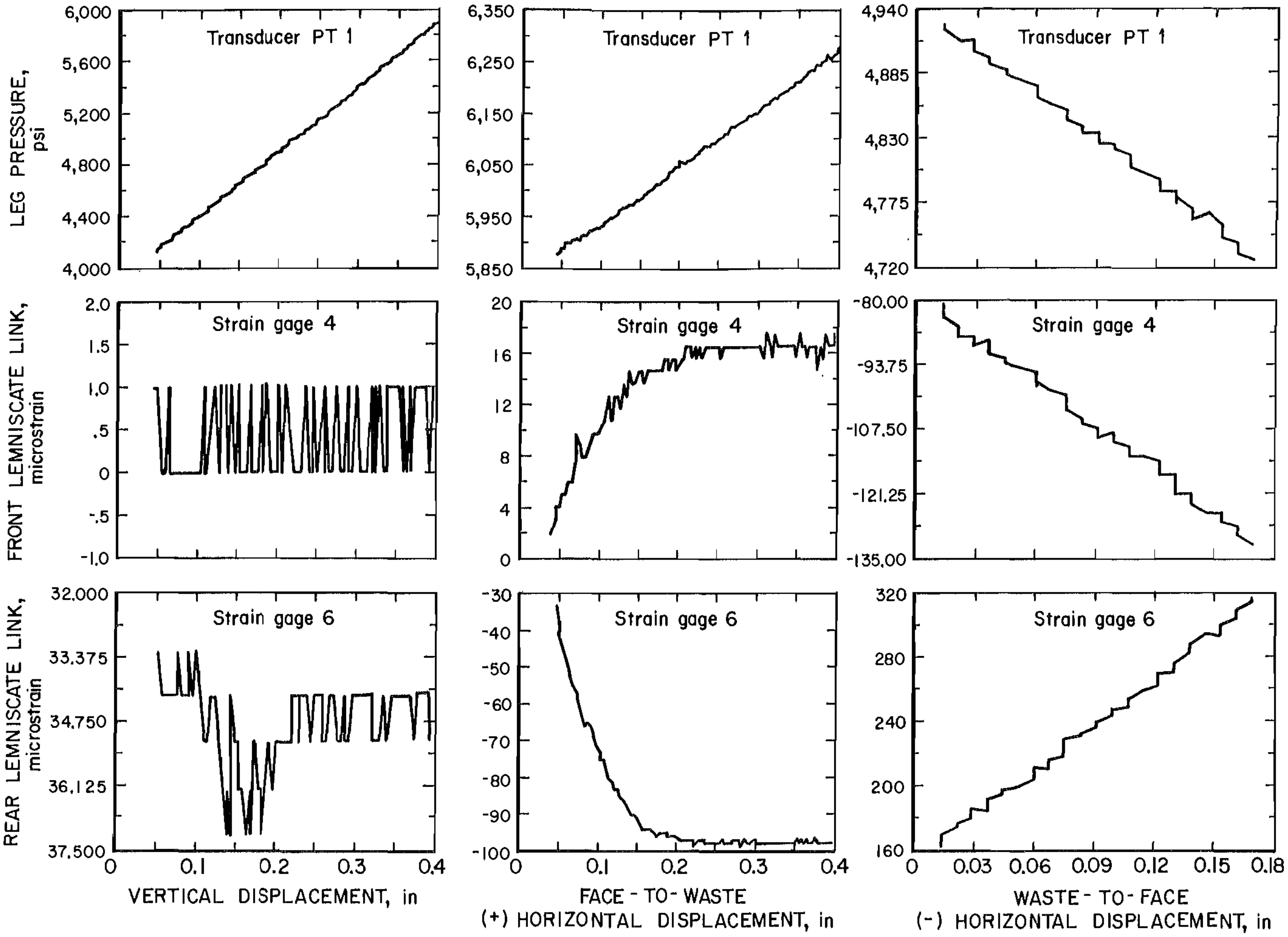

Figure 17.—Full-contact canopy and base test results.

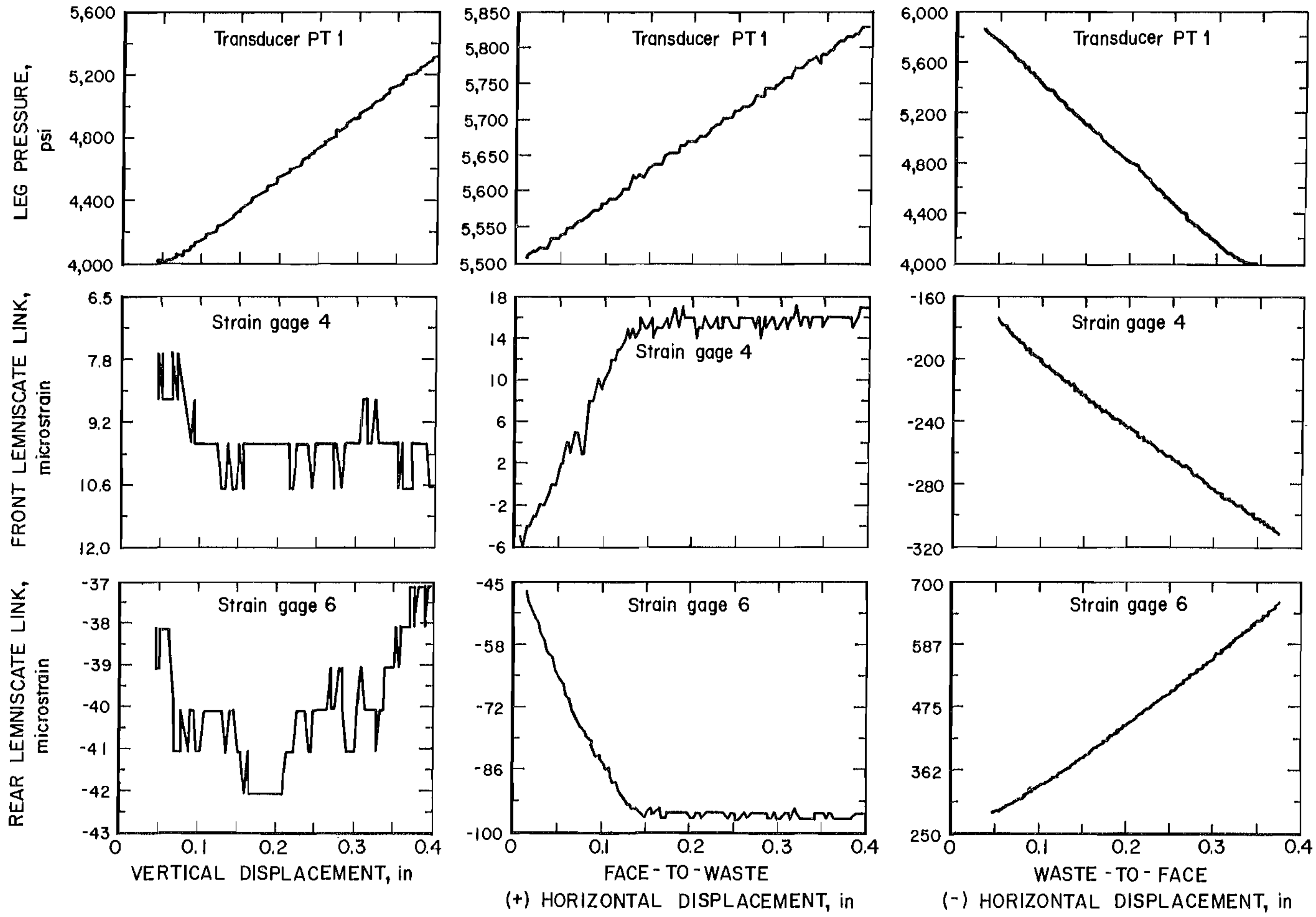

Figure 18.—Canopy bending test results.

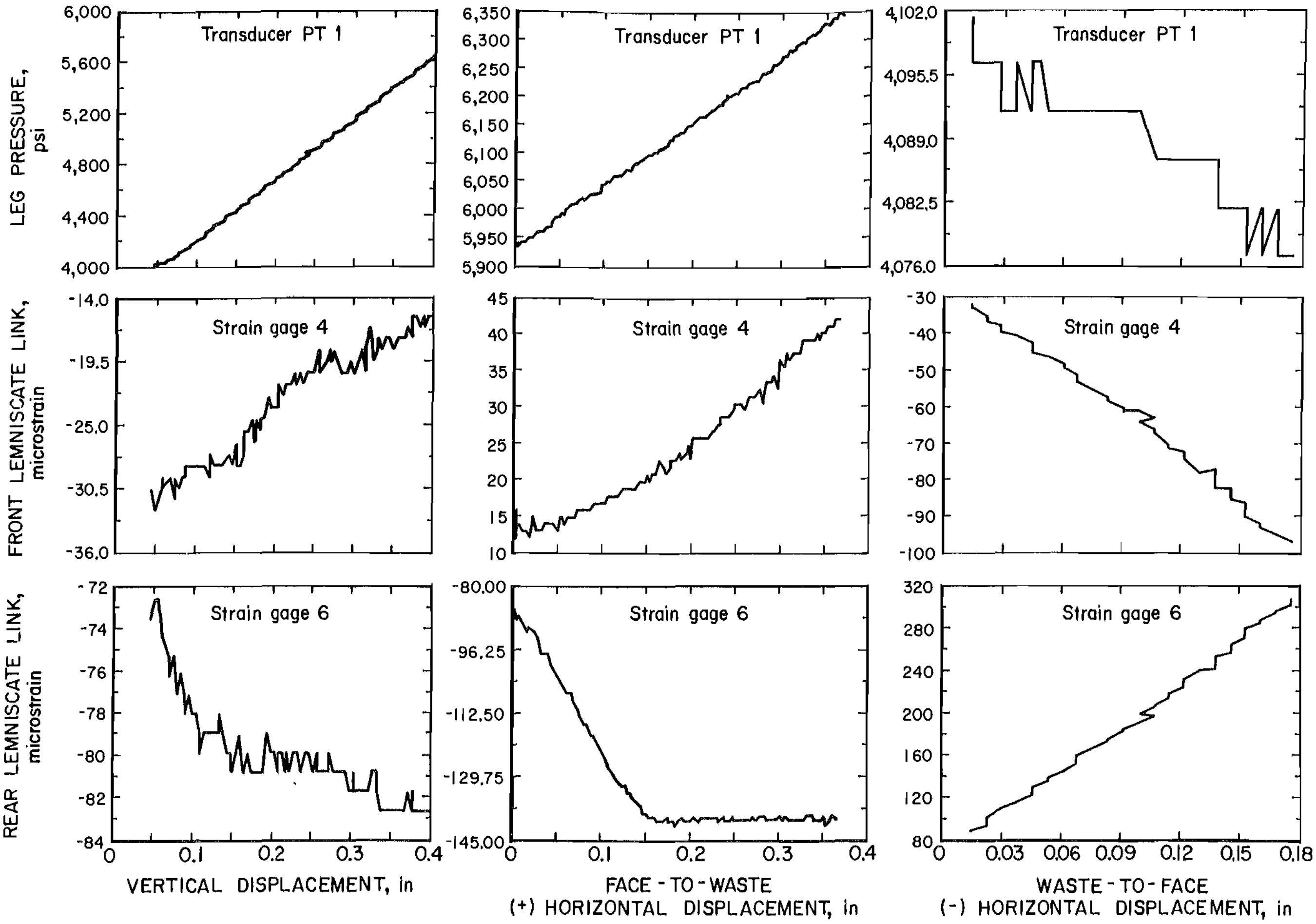

Figure 19.—Base bending test results.

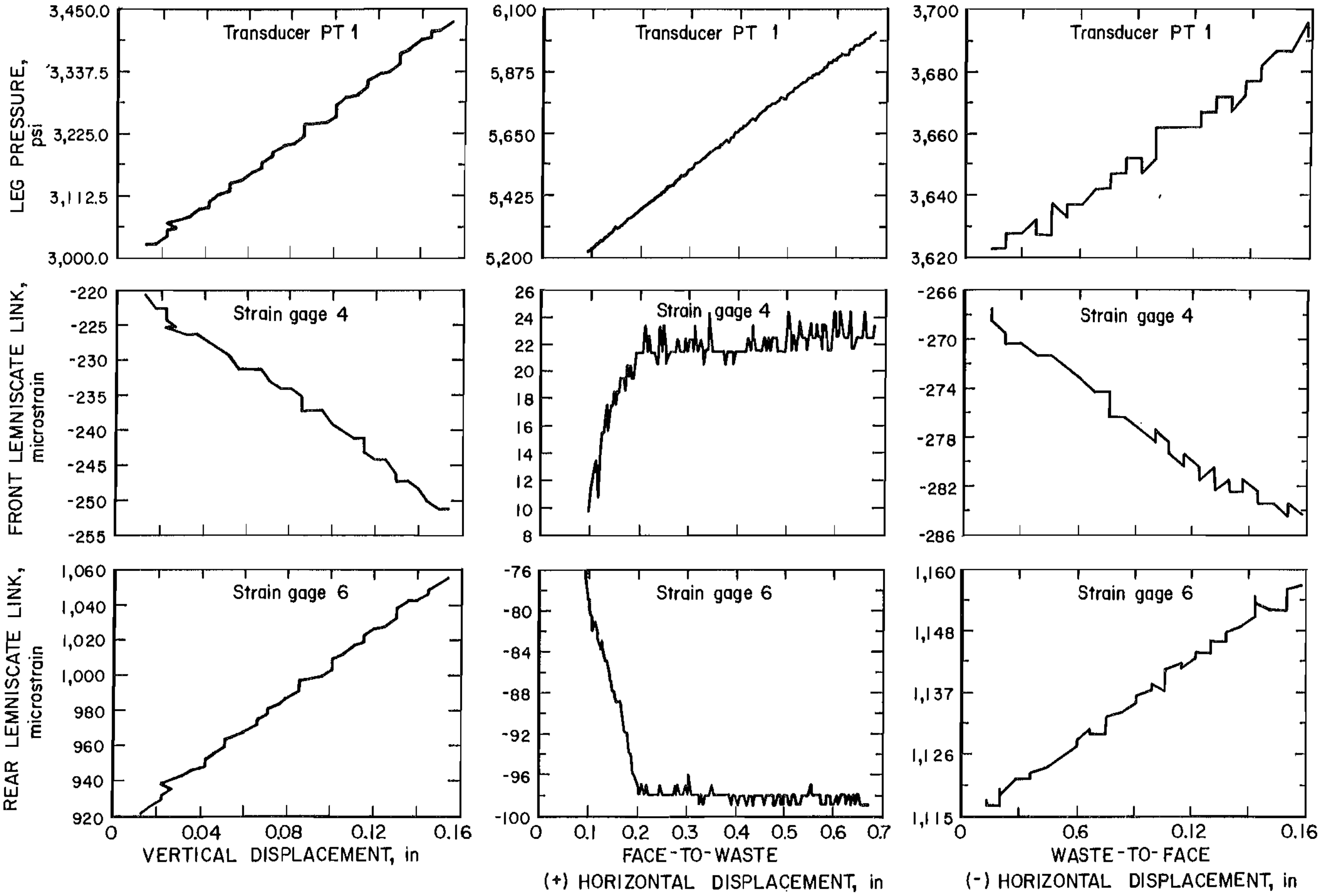

Figure 20.—Base-on-toe test results.

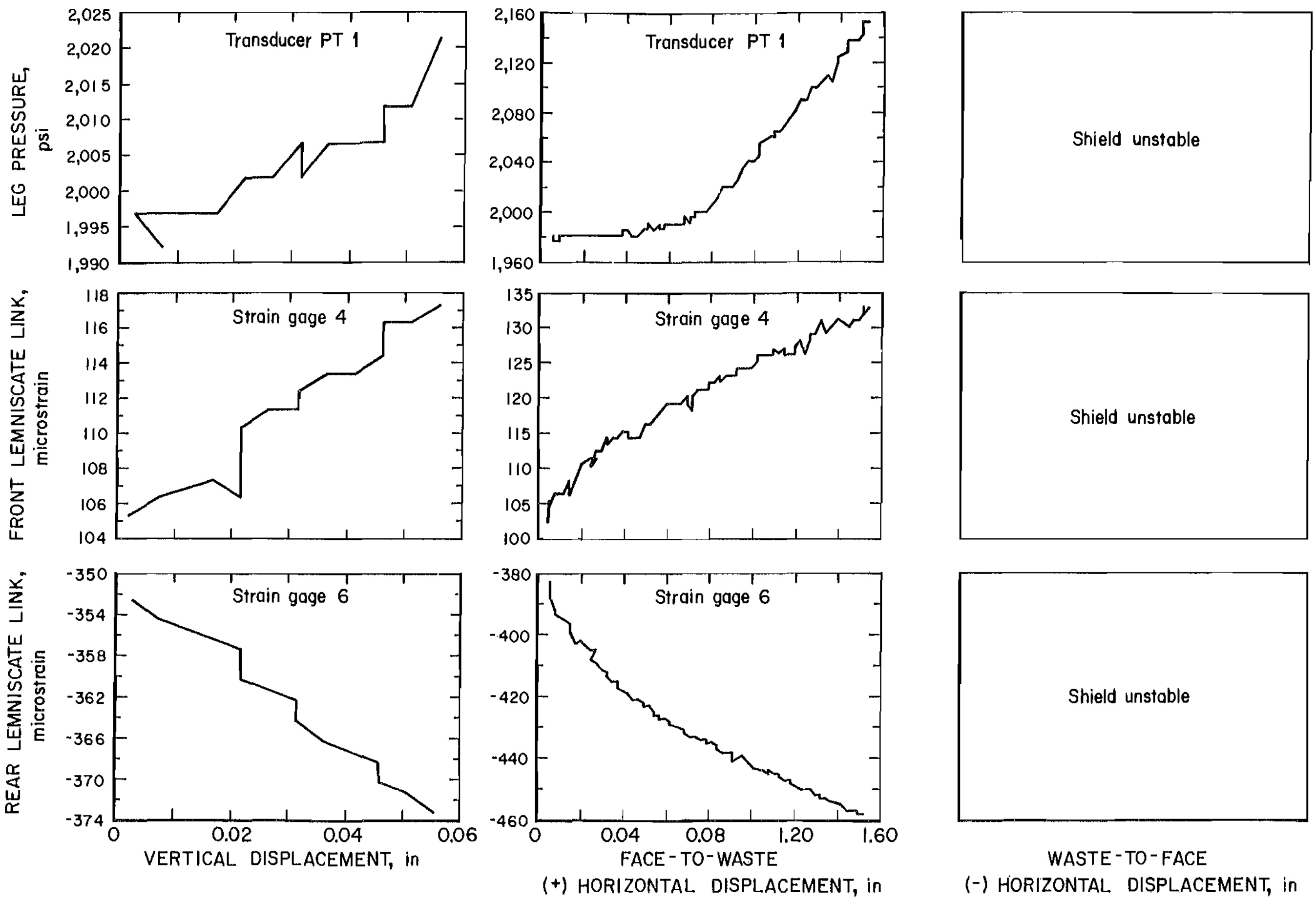

Figure 21.—Base-on-rear test results.

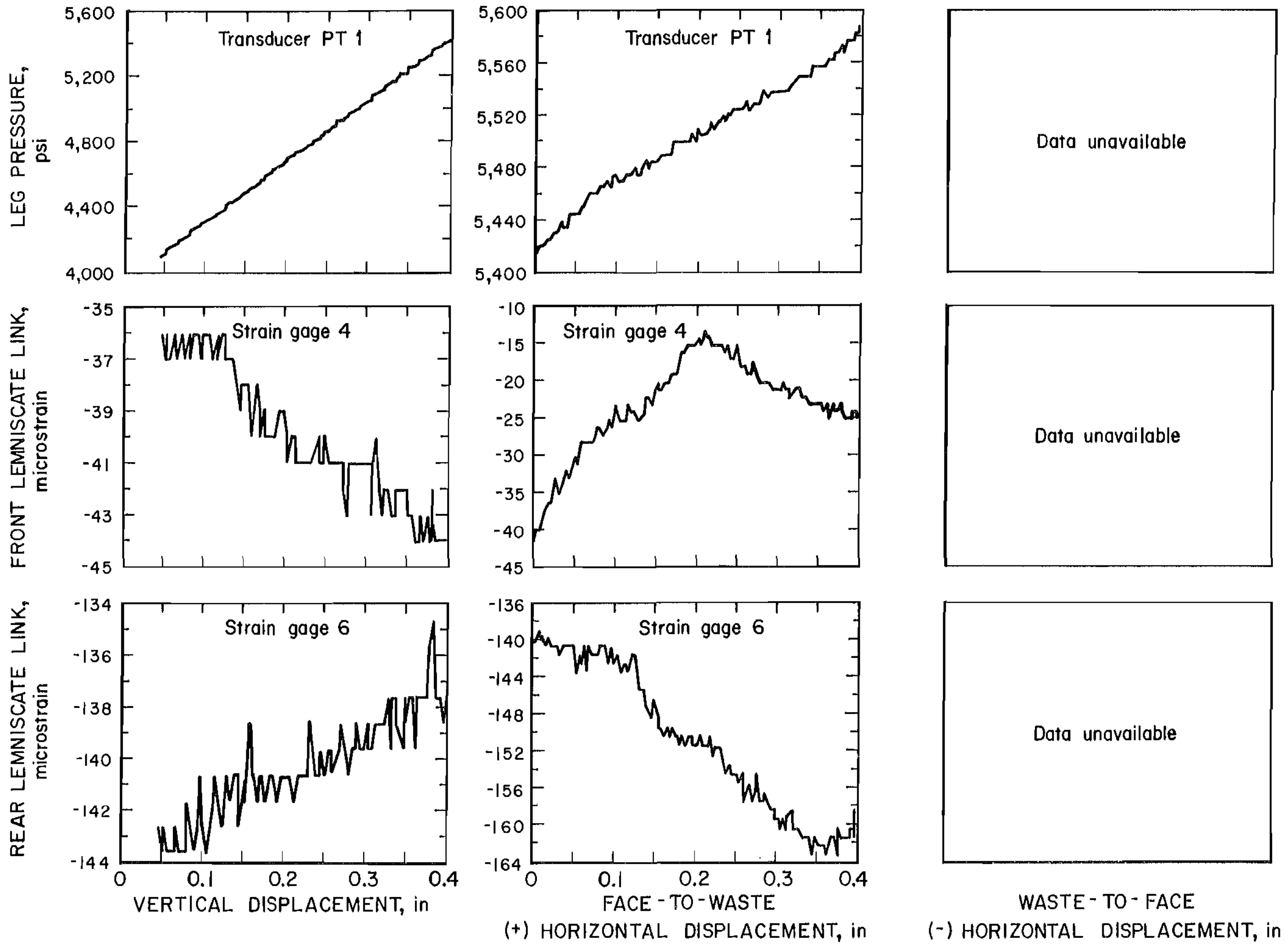

Figure 22.—Canopy twisting test results.

APPLICATION TOWARDS IN SITU SUPPORT MONITORING

One of the formidable tasks facing researchers and coal operators is to be able to assess in situ support loading to optimize support selection and design. Some of the ways in which shield mechanics can benefit these efforts are described as follows.

Assessment of strata activity - A fundamental question facing longwall support designers is the source of horizontal shield loading. The Bureau is developing techniques to assess horizontal shield loading[4] and this study of shield mechanics contributes to these efforts. The natural tendency of the shield support is to generate horizontal load by waste-to-face displacement of the canopy from the horizontal component of the leg force. Friction developed between the strata and the canopy resists this motion creating an external horizontal force acting on the support in response to internal shield mechanics. Once the friction capability of the strata is exceeded, the caving shield-lemniscate assembly must equilibrate the unbalanced leg force to maintain support stability. Another way to generate horizontal shield loading is by face-to-waste strata movement, which is translated to the shield by frictional force at the canopy interface. Therefore, horizontal shield loading can be generated by strata behavior or from internal shield mechanics. Isolation of the source of horizontal shield loading has significant impacts in shield design; since, if properly designed, the support needs only to respond to loads generated in response to strata activity.

A review of the shield responses previously presented indicates that the direction of the horizontal displacement can be determined from an assessment of internal shield (component) responses. Namely, the behavior of the lemniscate links is opposite for opposite directions of horizontal displacement. However, further analysis necessitates the identification of base bending boundary conditions to establish a unique shield response to properly distinguish positive and negative horizontal displacements.

Critical load conditions - While it is not feasible to sufficiently instrument an active shield underground to identify critically stressed areas, it is feasible to instrument a shield sufficiently to determine dominant basic responses of several components. Using this information and knowledge of shield mechanics, better judgments can be made in designing laboratory tests which are more realistic of actual underground conditions, to evaluate critical shield loading.

CONCLUSIONS

Optimization of longwall roof support selection and design requires an understanding of support mechanics. This report describes general mechanics for two-legged, lemniscate shield supports. This analysis is a prerequisite to the quantification of load transfer of specific shield designs.

Salient points and conclusions drawn from this research are summarized as follows.

1. A shield, once set in an equilibrium configuration, can be subjected to vertical (roof-to-floor), positive horizontal (face-to-waste), and/or negative (waste-to-face) horizontal displacements of the canopy relative to the base from activity of the strata or internal shield forces.
2. The six major components of a shield (canopy, caving shield, front lemniscate link, rear lemniscate link, base, and leg cylinders) interact and distribute load to equilibrate forces resulting from applied displacements to the canopy and base structure.
3. Shield response is dependent upon canopy and base contact configuration. Six types of canopy and base contact configurations have been identified, which are believed to be representative of typical and worst-case underground load conditions. Shield responses vary significantly for these six contact configurations.
4. Shield (component) responses are dependent upon the displacement direction (vertical or horizontal) for a specific contact configuration. Component responses are also dependent upon whether the horizontal displacement is in a face-to-waste or waste-to-face direction.
5. Shield (component) responses are independent of contact configuration for horizontal displacements, except for axial canopy deformations.
6. For vertical displacement, the response of the caving shield-lemniscate assembly is dependent upon the contact configuration.
7. The front and rear lemniscate links must always act opposite (tension or compression) to one another to maintain equilibrium of the caving shield.
8. Superposition of displacement load conditions and contact configurations is possible if controlling factors are known for specific shield designs.
9. An assessment of strata activity (loading conditions) can be deduced from shield response if component responses are sufficiently monitored to establish unique responses.

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[4] Barczak, T. M., and W. S. Burton. Assessment of Longwall Roof Behavior and Support Loading by Linear Elastic Modeling of the Support Structure. RI 9081, 1987, 7 pp.

APPENDIX A.–MISCELLANEOUS LOAD CASES

The contact configurations described in the text are thought to be representative of typical and worst case underground conditions. While many other contact configurations are possible, it is believed that most other contact configurations will not result in a behavior that cannot be described by the six basic configurations analyzed in the text. Some other contact configurations and component responses are illustrated in figures A-1 through A-3.

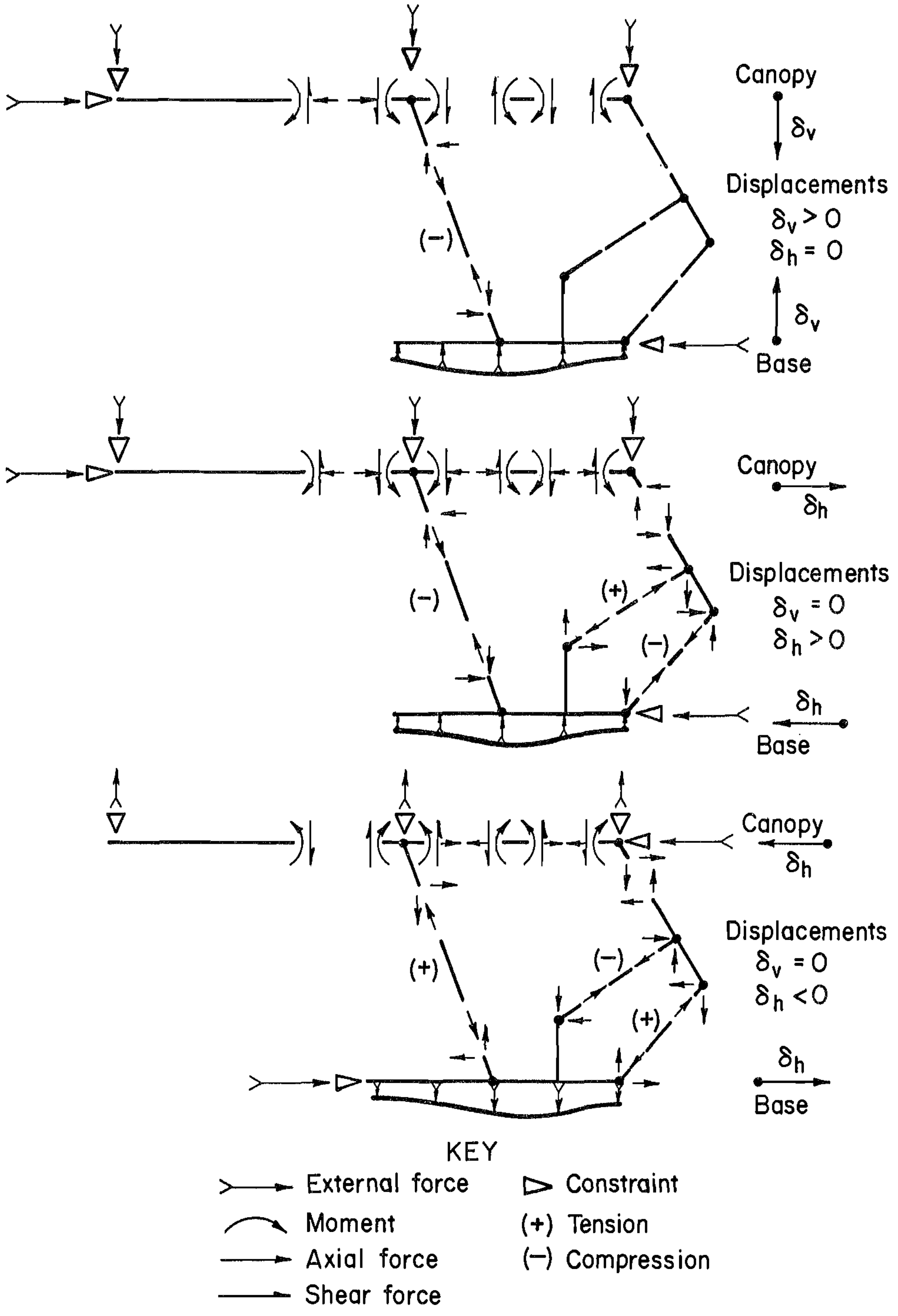

Figure A-1.–Analysis of three-point canopy contact configuration.

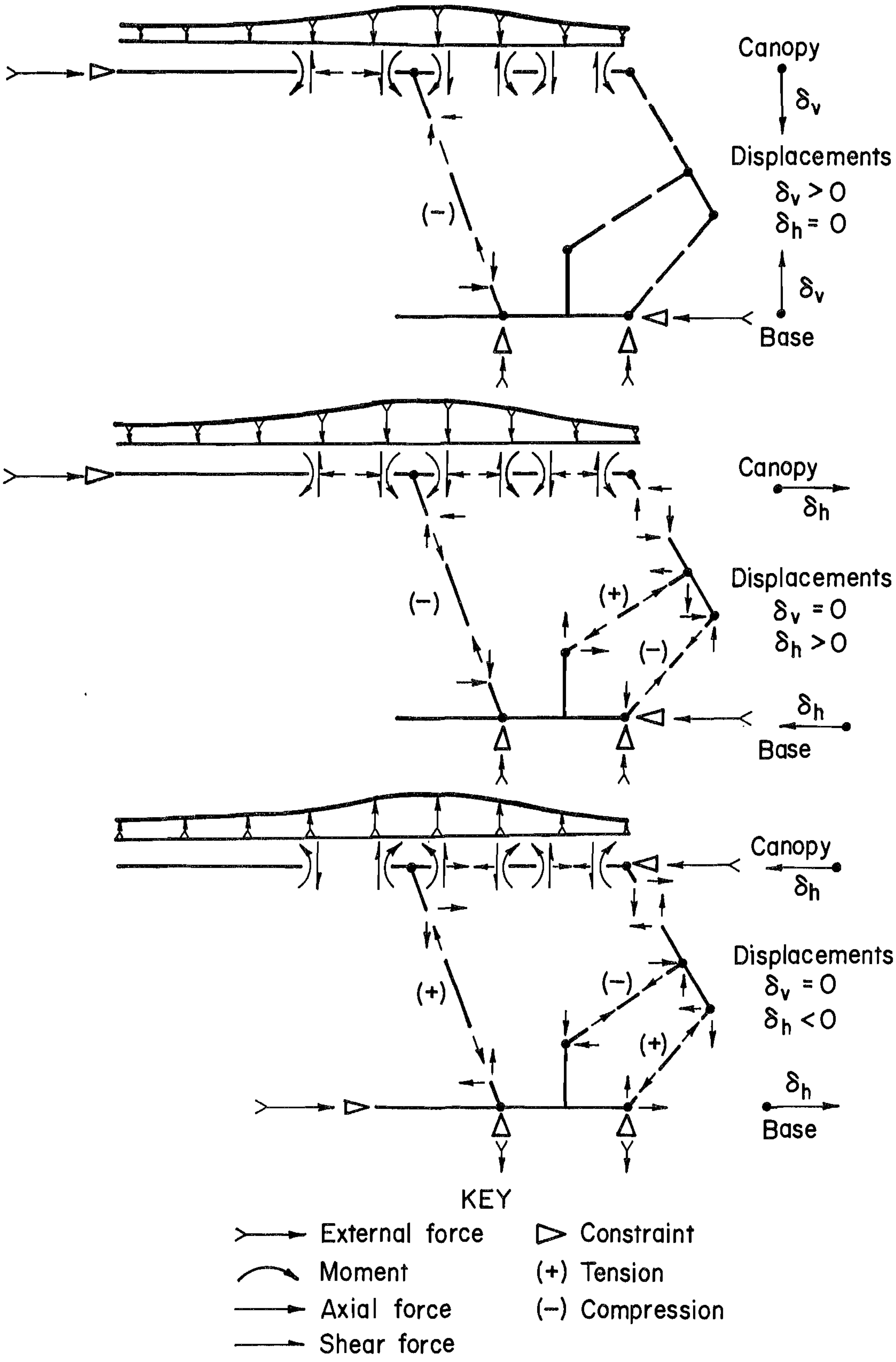

Figure A-2.—Analysis of base contact at leg and rear link.

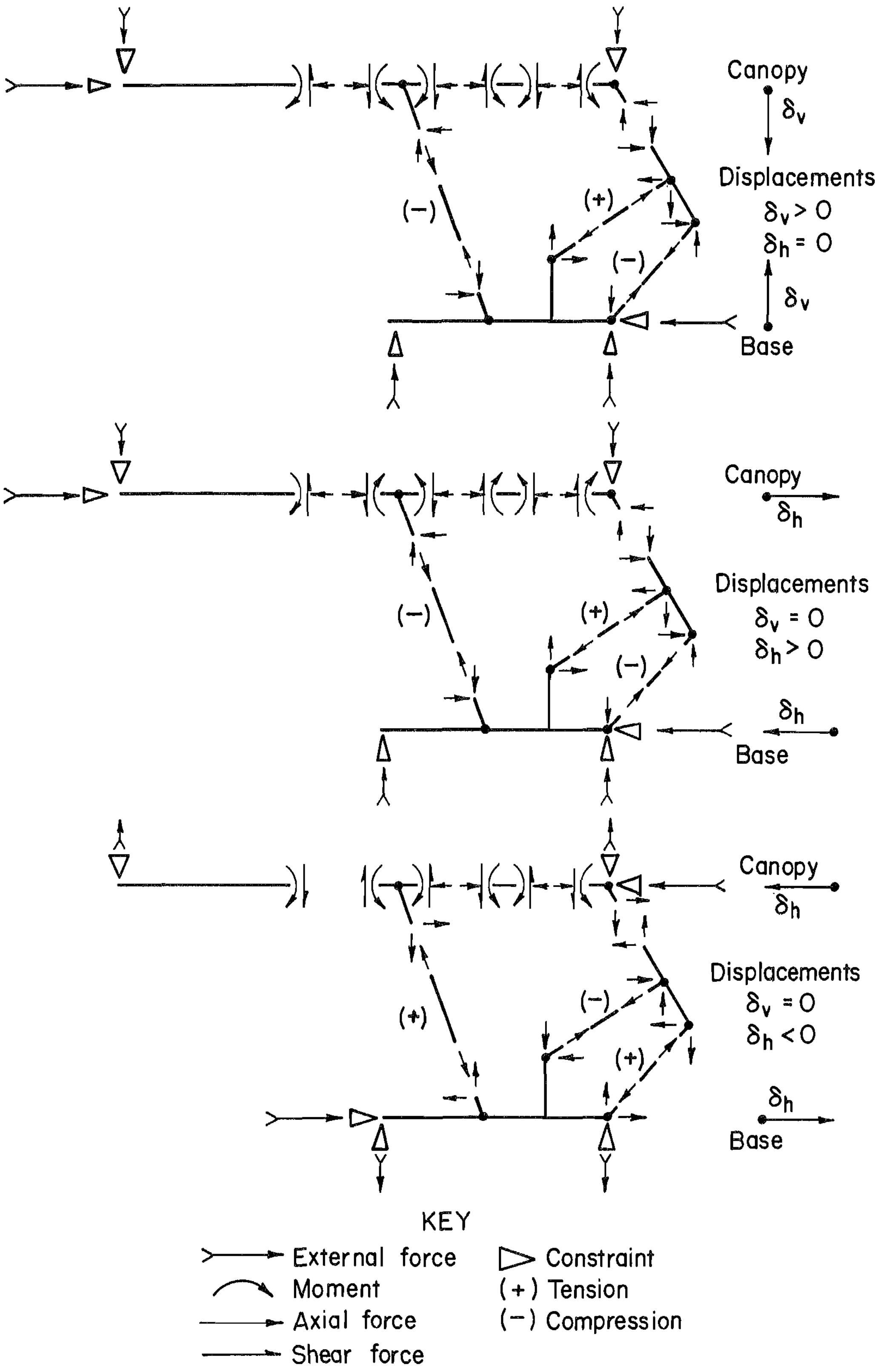

Figure A-3.—Analysis of the combination of canopy and base bending.

APPENDIX B.–EXAMPLES OF SUPERPOSITION OF VERTICAL AND HORIZONTAL DISPLACEMENT

The analysis provided in the text segregated shield component responses for vertical, positive, and negative horizontal displacements. As indicated in the text, these behaviors could then be superimposed with one another and with initial shield conditions to provide assessment of behavior for any combination of displacements. The superposition of initial shield conditions with vertical and horizontal displacements can be seen from tests conducted in the simulator as illustrated in figures B-1 through B-5.

These two cases were selected because of the significant change in component response illustrated for this shield for these boundary and loading conditions. These illustrations show measured shield responses for the leg cylinders, front and rear lemniscate links. Remember that these trends in responses are expected to be the same for all shields of this basic configuration, but the strain magnitudes shown are specific to this shield.

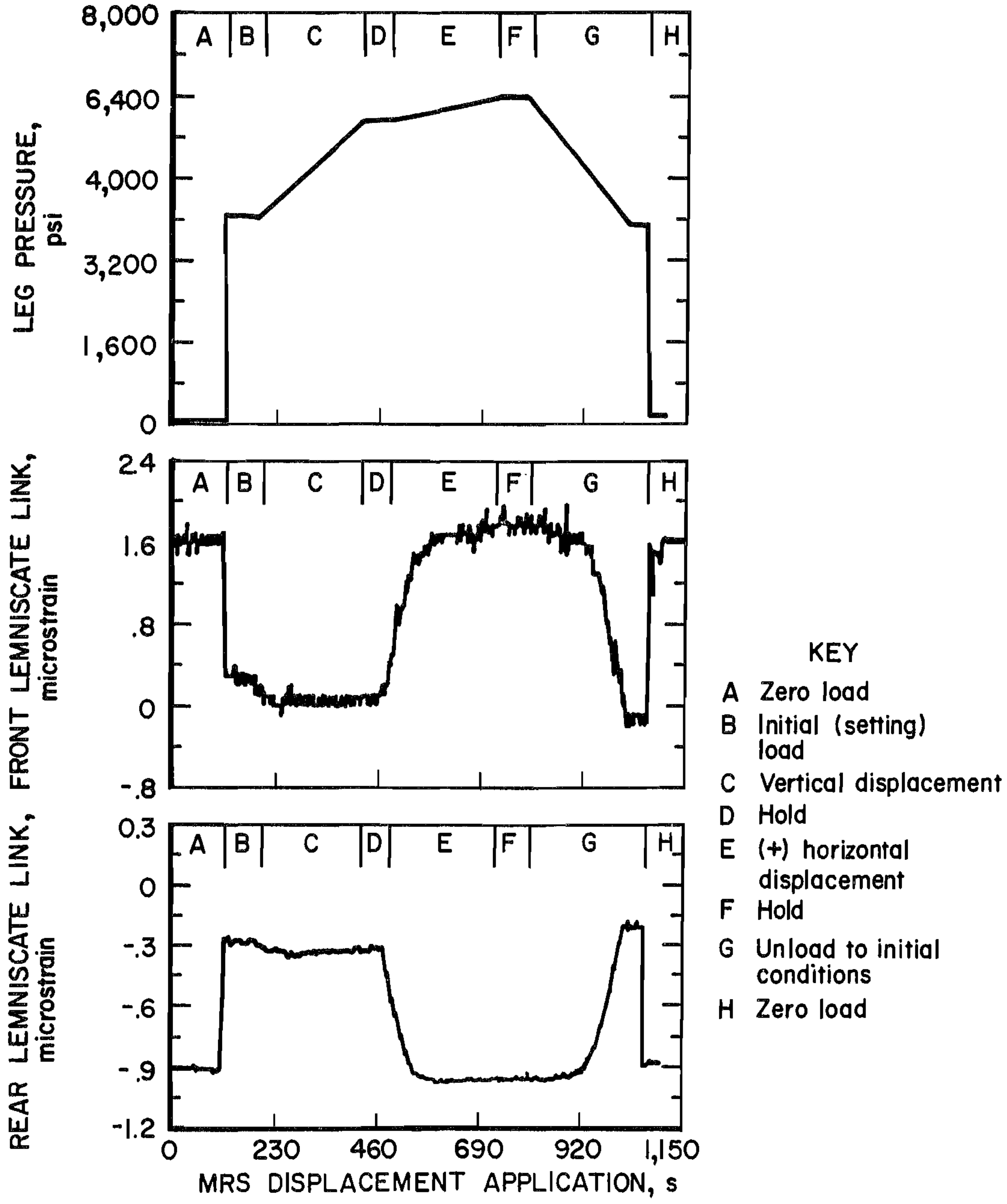

Figure B-1.—Combined vertical and face-to-waste (+ horizontal) displacement for full canopy and base contact.

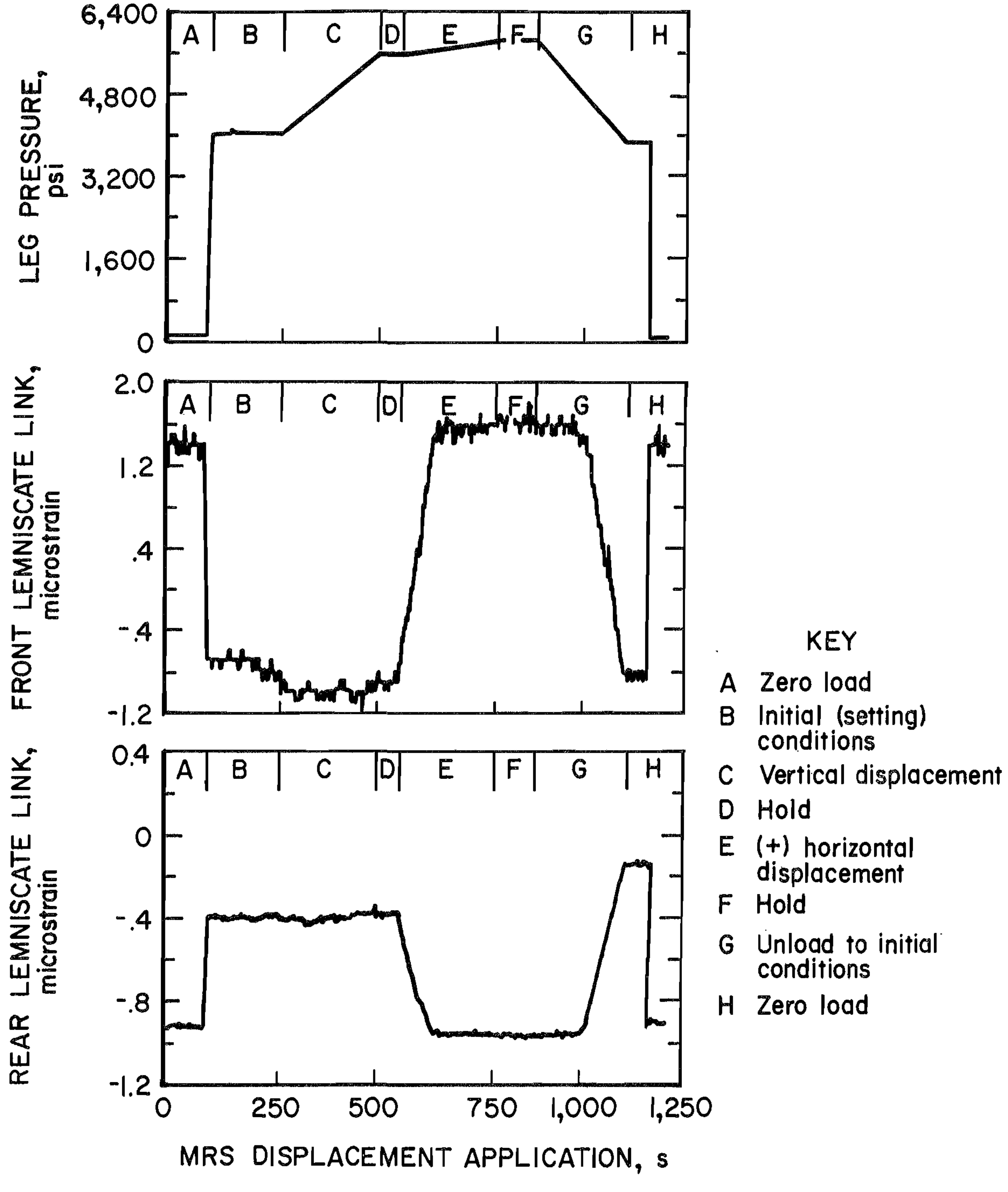

Figure B-2.—Combined vertical and face-to-waste (+ horizontal) displacement for canopy bending contact configuration.

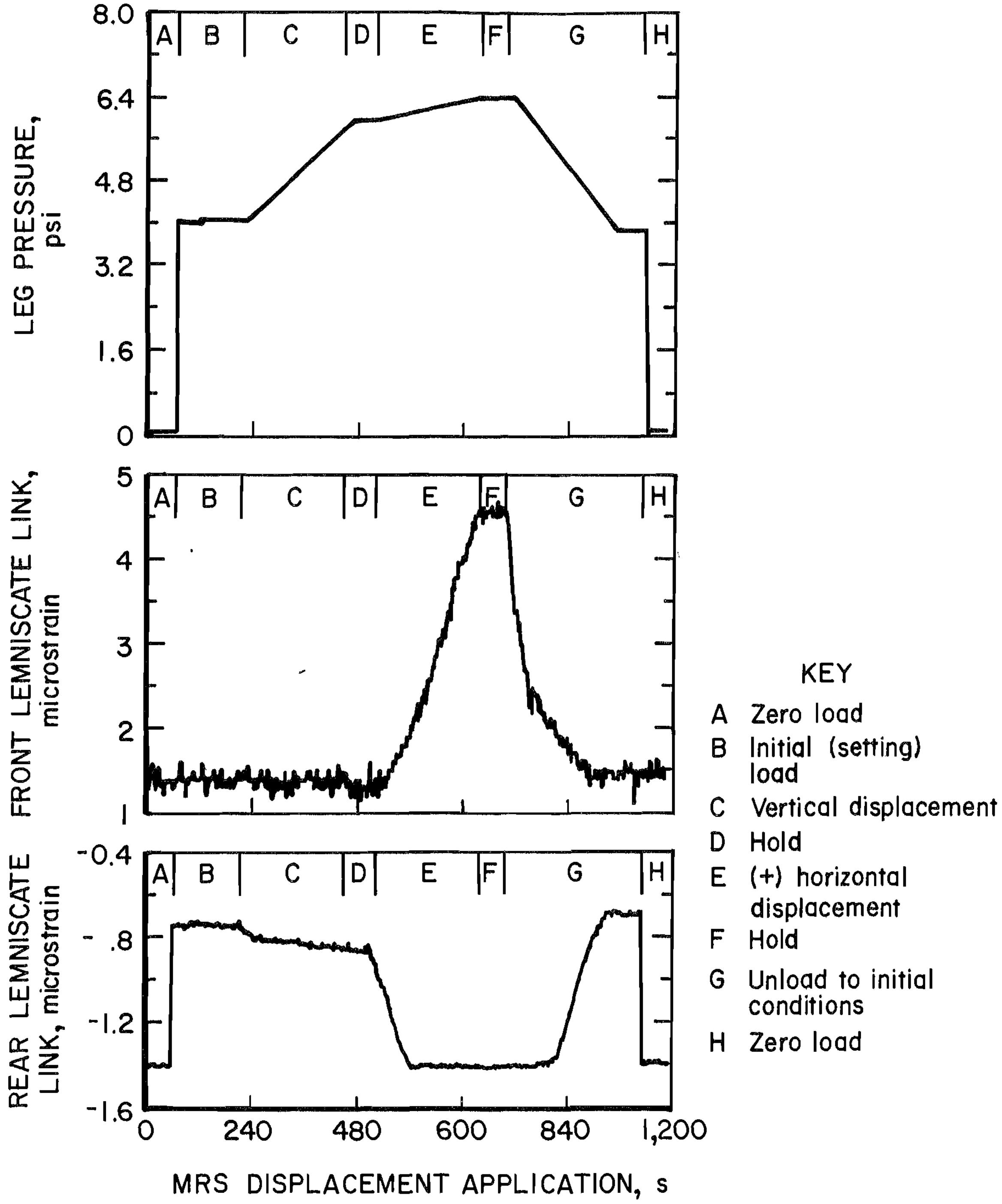

Figure B-3.—Combined vertical and face-to-waste (+ horizontal) displacement for base bending contact configuration.

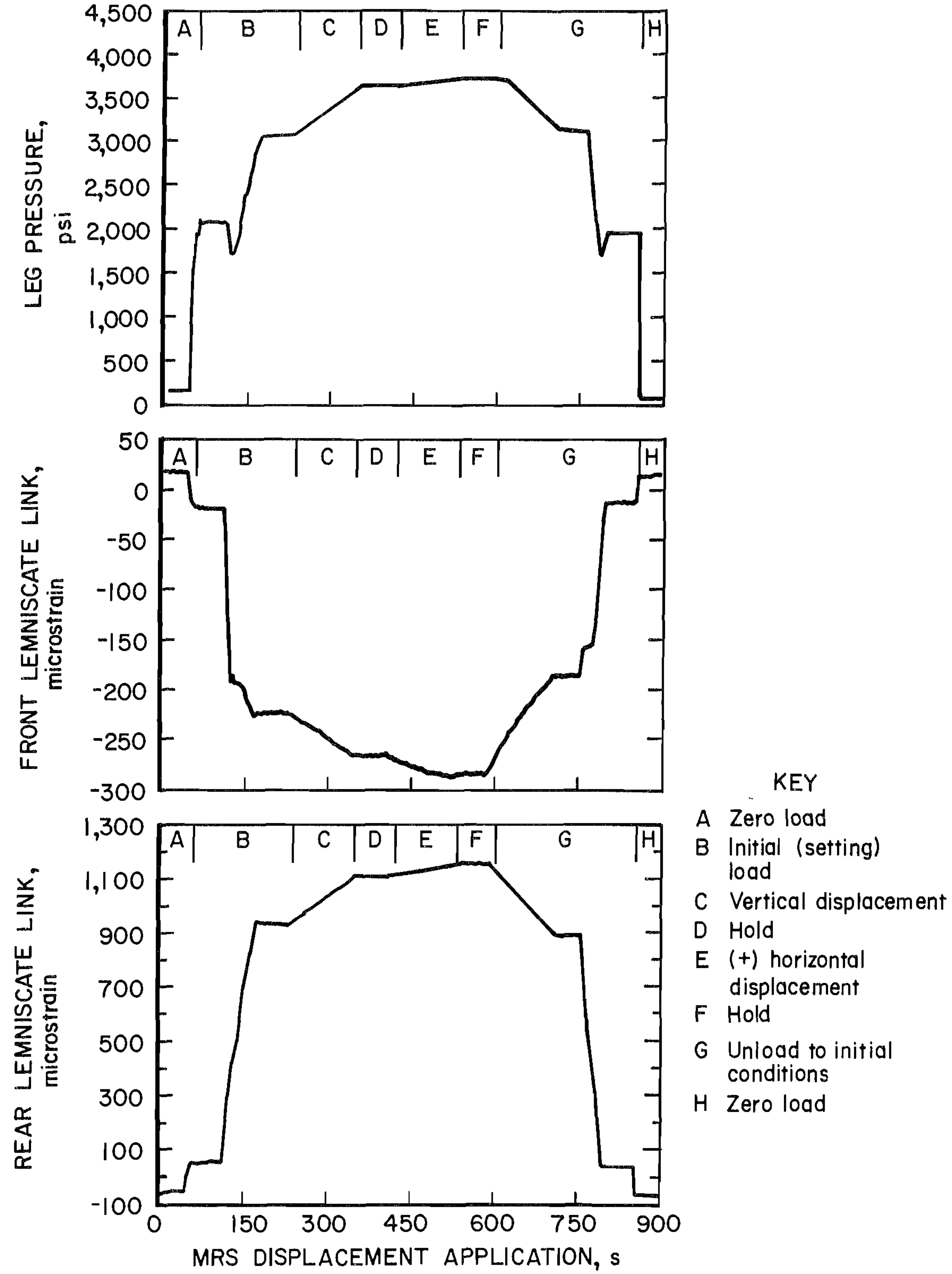

Figure B-4.—Combined vertical and waste-to-face (- horizontal) displacement for base-to-toe contact configuration.

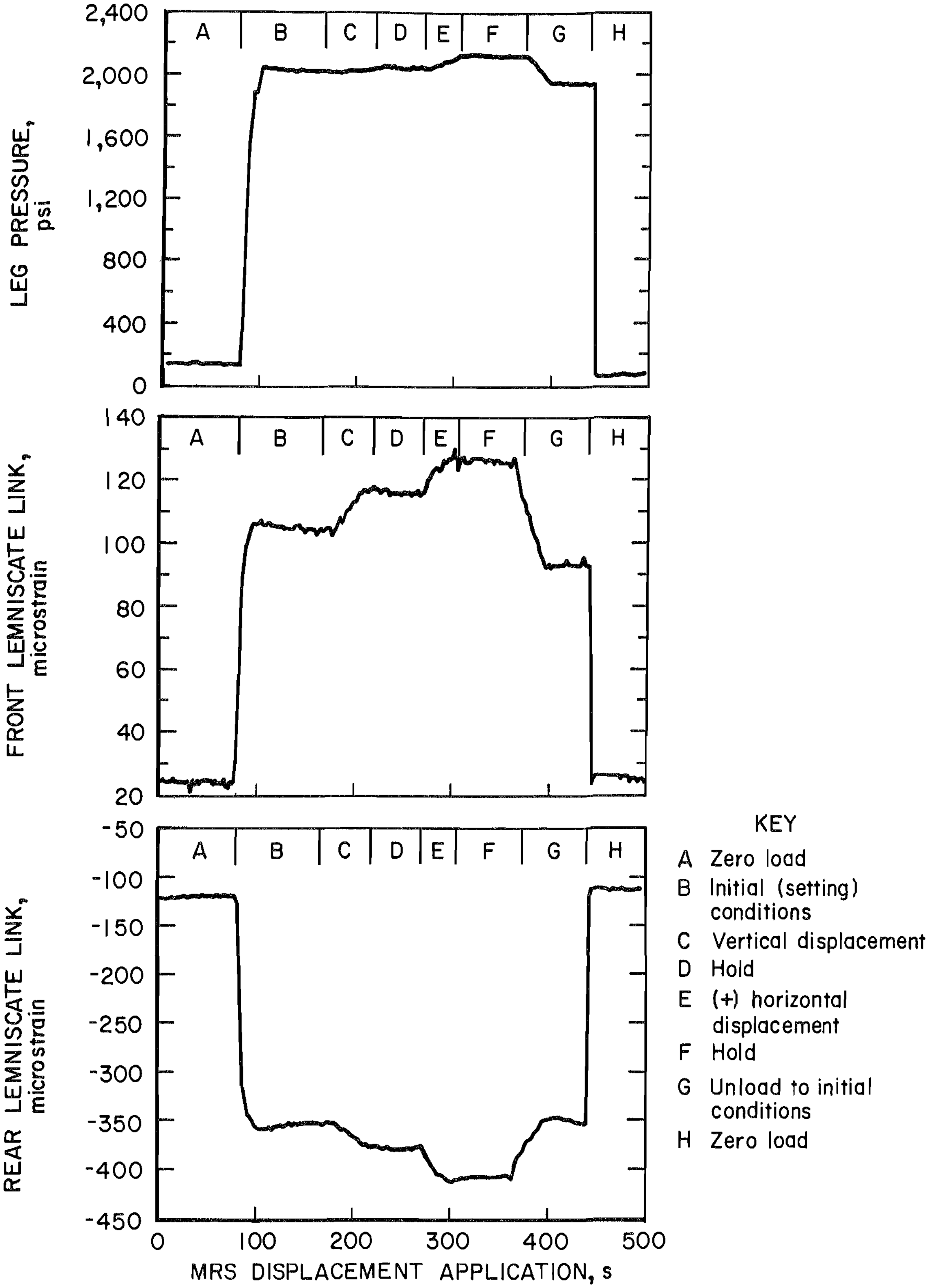

Figure B-5.—Combined vertical and face-to-waste (+ horizontal) displacement for base-on-rear configuration.

APPENDIX C.–MRS VERIFICATION TESTS

Test results describing the response of the leg cylinders, front and rear lemniscate links were documented in the text. The response of the canopy and caving shield for these tests are shown in figures C-1 through C-6 to provide a complete profile of shield component responses.

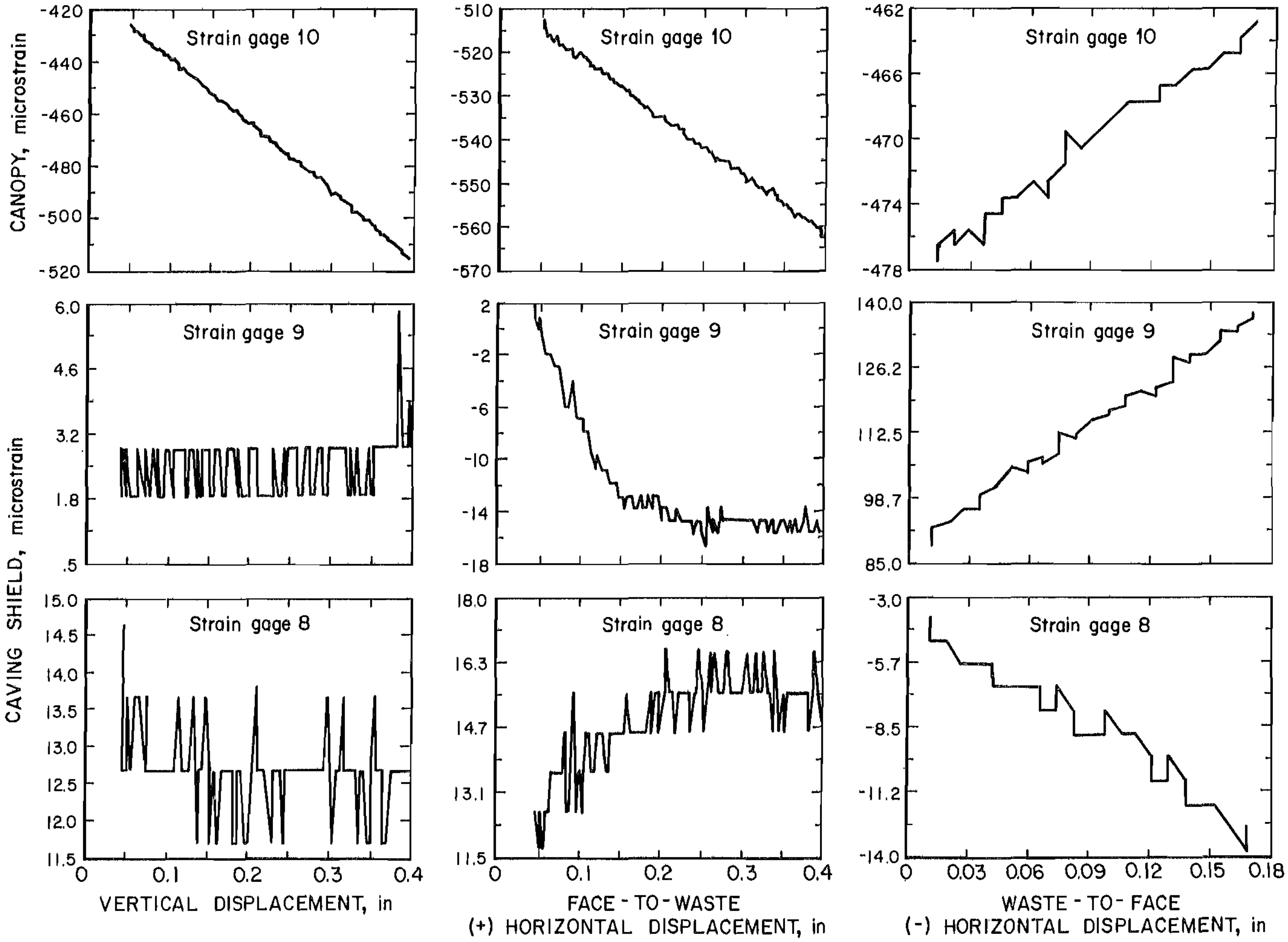

Figure C-1.—Canopy and caving shield responses for full canopy and base contact configuration.

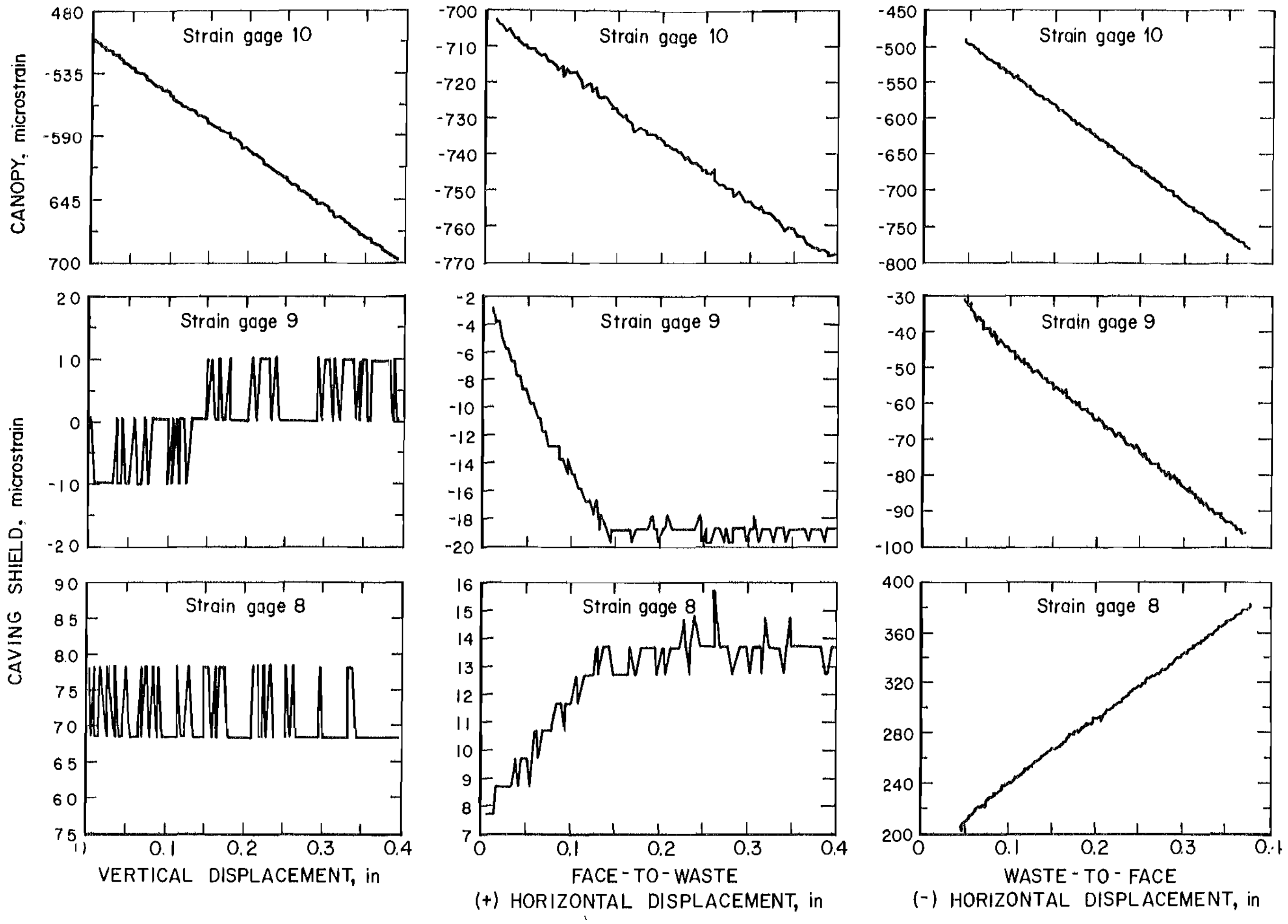

Figure C-2.—Canopy and caving shield responses for canopy bending contact configuration.

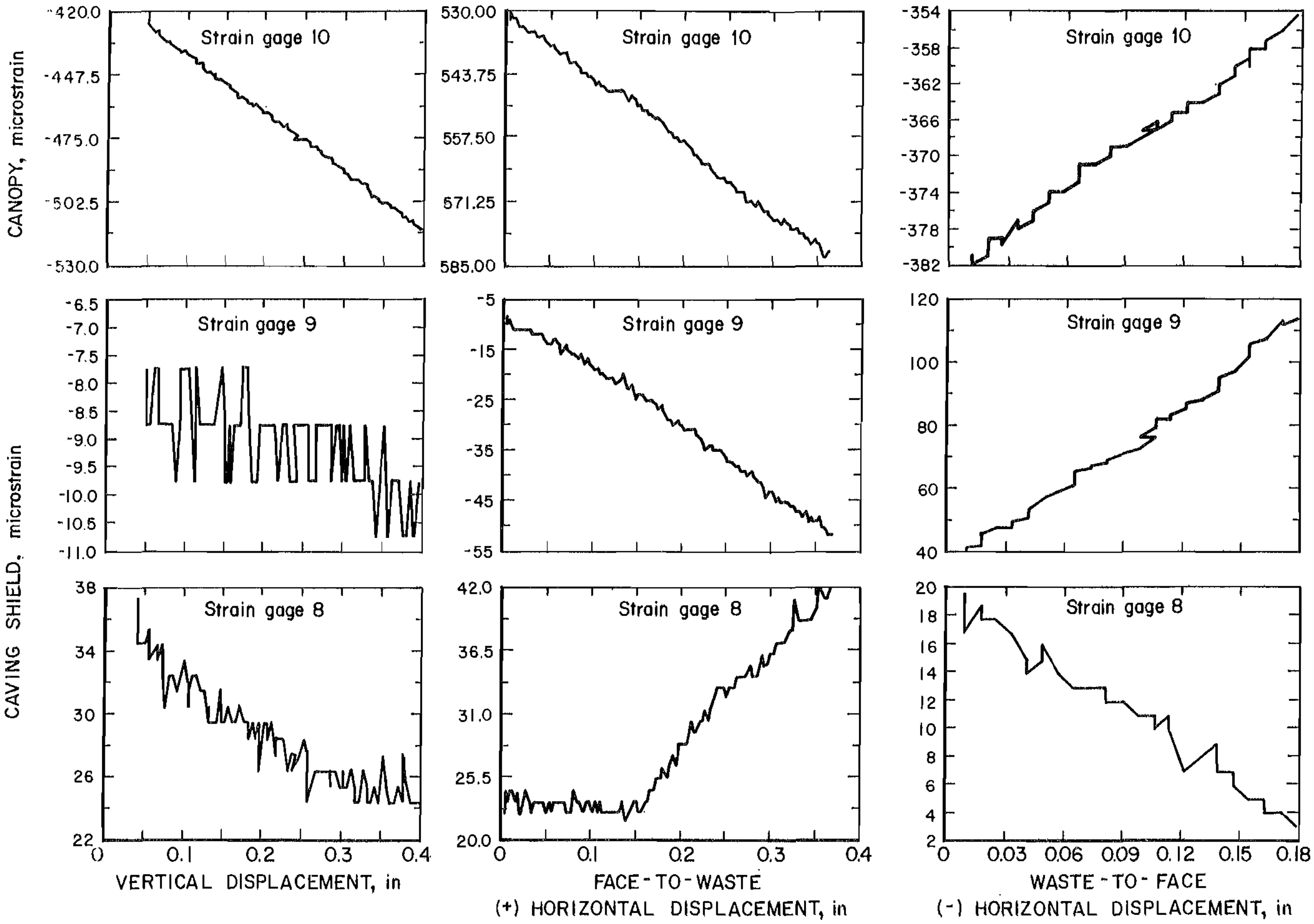

Figure C-3.—Canopy and caving shield responses for base bending contact configuration.

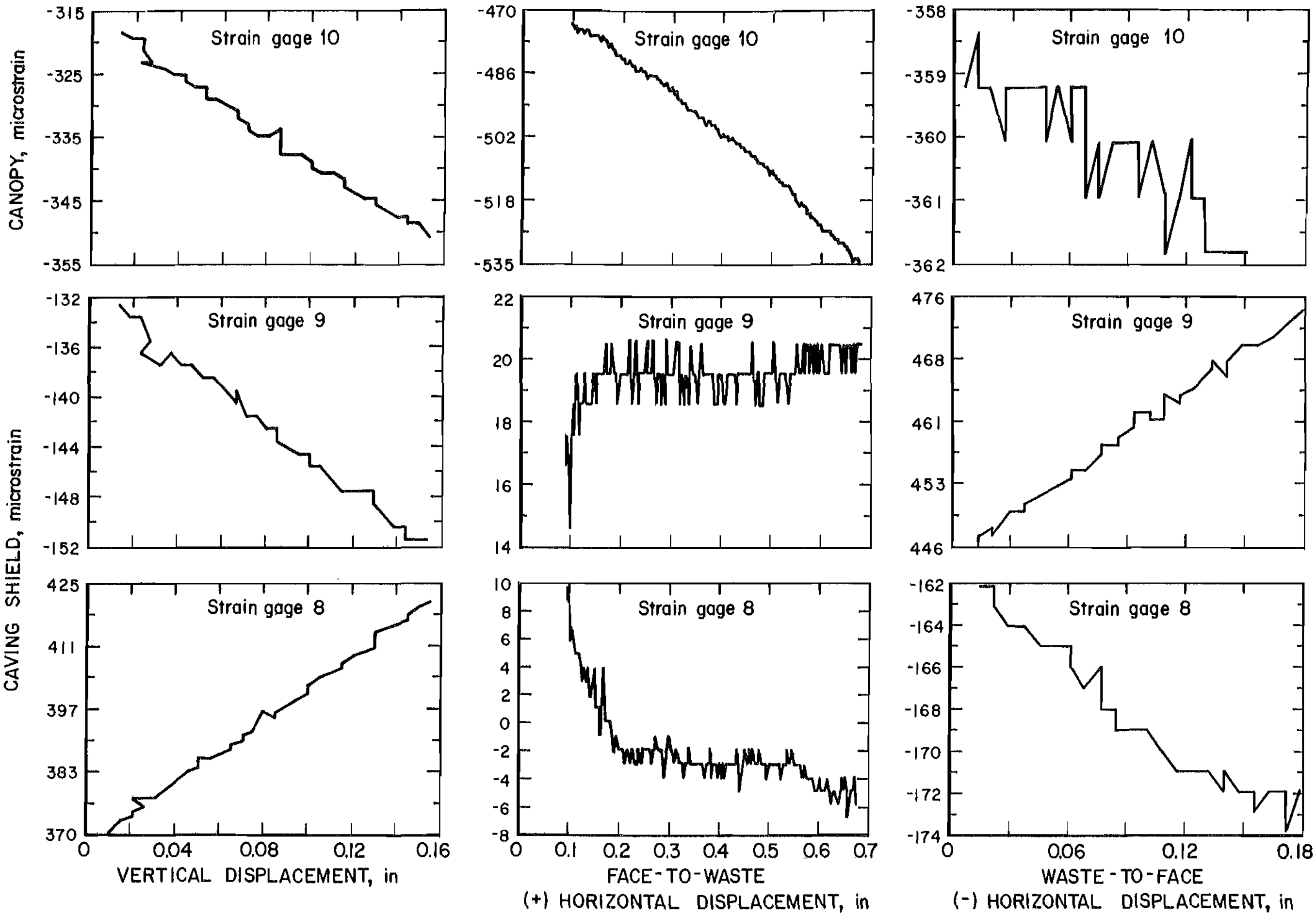

Figure C-4.—Canopy and caving shield responses for base-on-toe contact configuration.

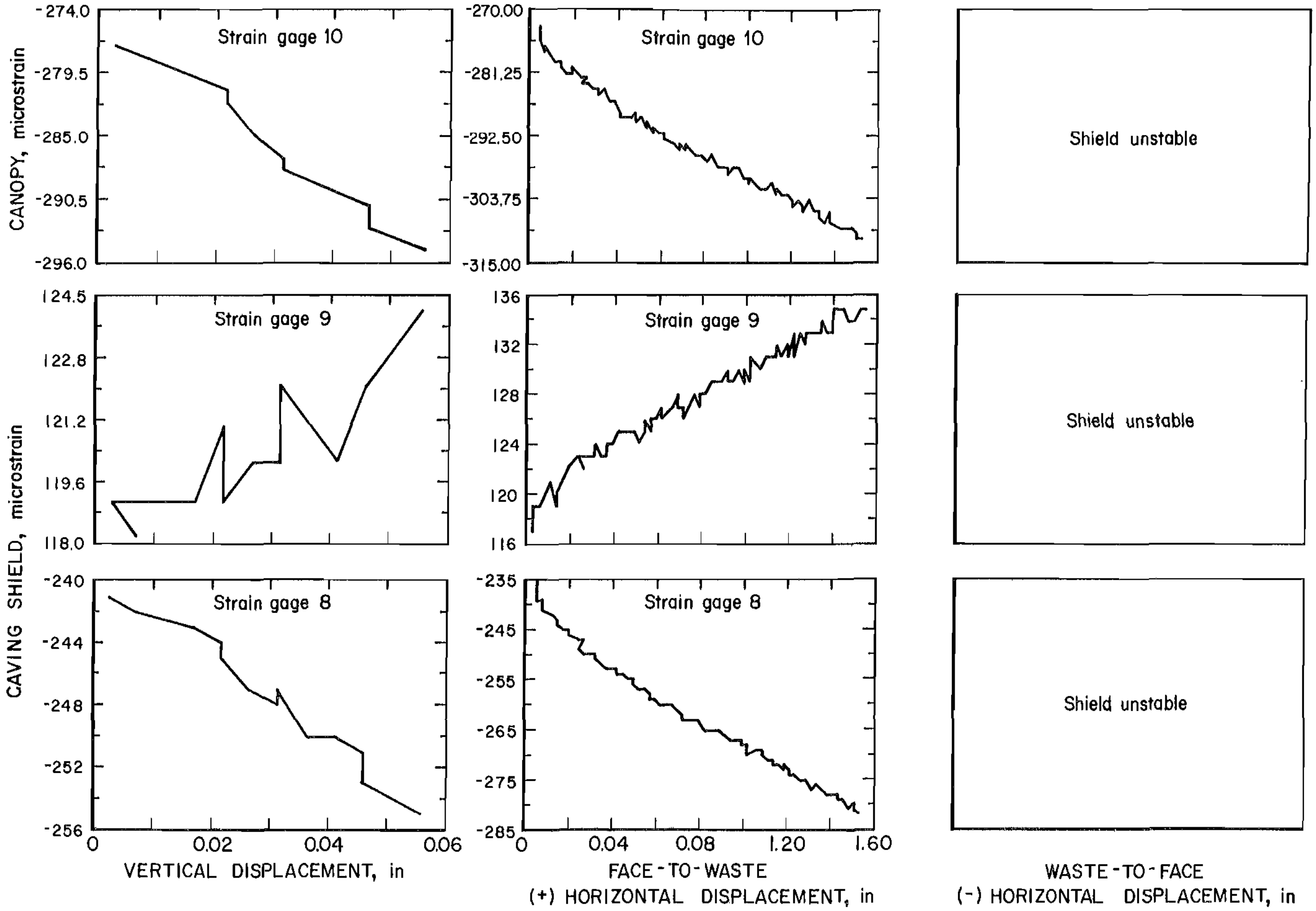

Figure C-5.—Canopy and caving shield responses for base-on-rear contact configuration.

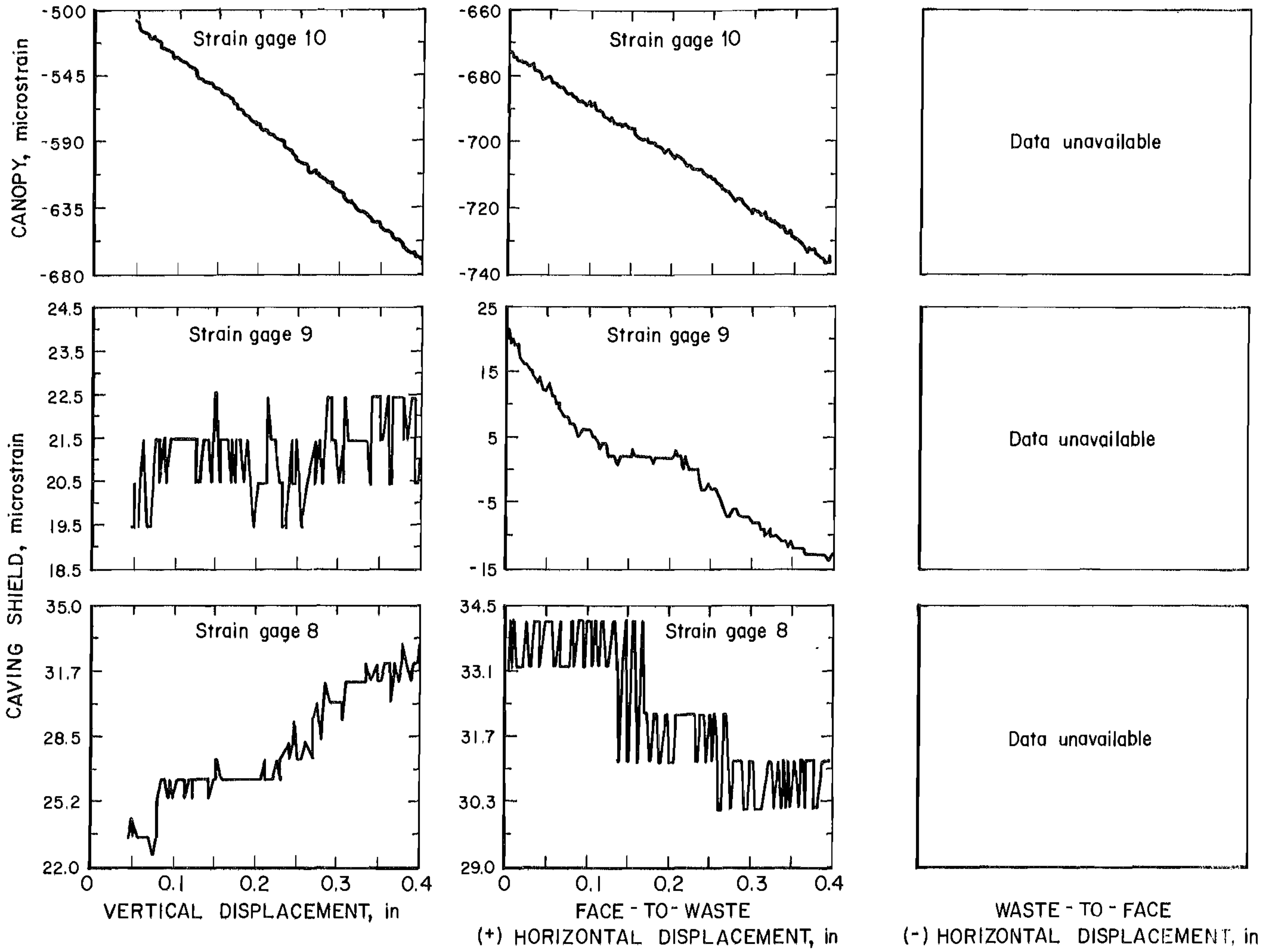

Figure C-6.—Canopy and caving shield responses for canopy twisting configuration.

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