DETERMINATION OF ALLOWABLE MOVEMENT RATINGS FOR VARIOUS PROPRIETARY BRIDGE DECK EXPANSION JOINT DEVICES AT VARIOUS SKEW ANGLES

MICHIGAN DEPARTMENT OF TRANSPORTATION

TESTING AND RESEARCH DIVISION
RESEARCH LABORATORY SECTION

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Determination of allowable movement ratings for various proprietary bridge deck expansion joint devices at

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INTRODUCTION

The Problem

Since early 1978, Michigan has been specifying various single-element, continuous length, elastomeric strip seal devices for virtually all new and reconstructed bridge expansion joints.

The movement ratings of expansion joint devices, as provided by the manufacturer, are for an angle of crossing of 90 degrees (zero degree skew). Angle of crossing is defined as the acute angle formed between the expansion joint and the longitudinal centerline of the bridge. However, design and field conditions usually require that the expansion joints be installed at an angle of crossing other than 90 degrees. Therefore, it is essential to the effectiveness and life of the expansion joint device that guidelines be established for each system, relating the maximum movement the system effectively provides as the angle of crossing decreases from 90 degrees. A survey of the companies that manufacture the various expansion joint devices indicated that little or no research has been conducted to determine such guidelines. Any guidelines that were available appeared to be theoretical in nature and extremely general. Because of this problem, the Design Division requested that a research project be initiated to evaluate the expansion joint devices currently approved for use by the Department. It was requested that each device be evaluated at 10-degree intervals from a 90 to 30-degree angle of crossing.

A research proposal was prepared by the Research Laboratory outlining the general procedure to be used, and was approved by the Engineering Operations Committee.

Research Procedure

Each company manufacturing an approved expansion joint device was requested to supply a 4 to 6-ft long section, including all accessories, in the 2, 3, and 4-in. movement categories for laboratory evaluation.

The Research Laboratory's Structural Mechanics Group was requested to design and construct a special testing frame to be used in conjunction with a hydraulic ram operated by an MTS (Material Test System) controller. The testing frame was designed with a moving crosshead which maintained the direction of travel in a straight line, but allowed the angle between the direction of travel and the joint device (angle of crossing) to be changed by 10-degree intervals (Fig. 1).

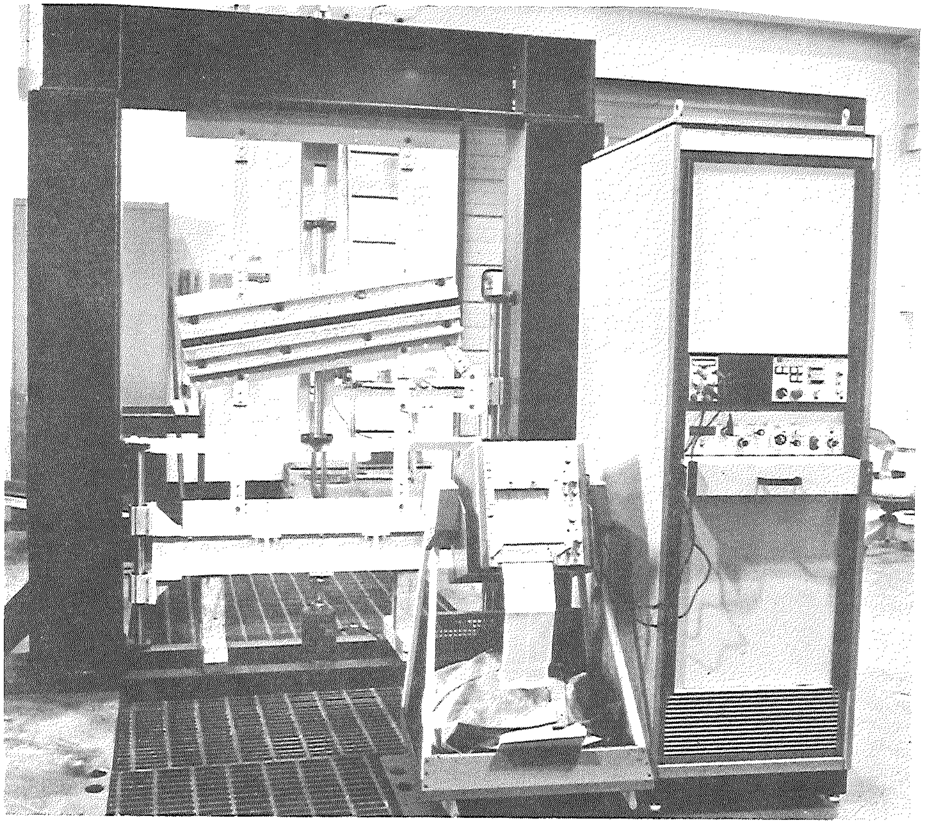

Figure 1. Testing frame, MTS controller, strip recorder, and joint device (installed at an 80-degree angle of crossing).

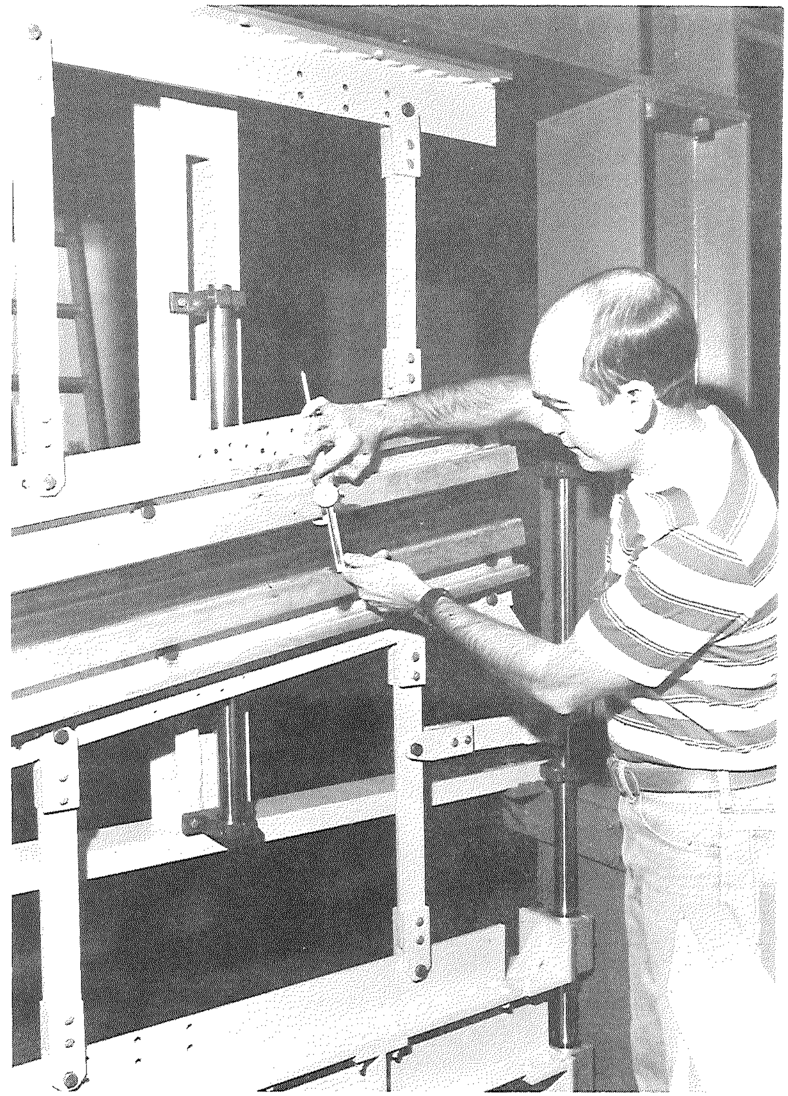

Figure 2. Measuring perpendicular joint width of device at an 80-degree angle of crossing.

Each joint device was assembled and mounted in the testing frame in a manner similar to that which would be used to install the device in the bridge. Each time the angle between the direction of travel and the joint device was changed, the device was repositioned to ensure that the seal was in a relaxed condition when the joint width was at the manufacturer's recommended midpoint. Commencing at the recommended midpoint, the joint width was slowly increased and the seal was observed to see if any physical material distortion, buckling, or excessive shear occurred prior to reaching the maximum recommended perpendicular width. If a limitation was reached prior to the maximum recommended opening, the joint width was decreased until the limitation was no longer present. The perpendicular joint width at this point was measured to the nearest 1/100 of an inch (Fig. 2) and recorded to the nearest 5/100 of an inch as the extension limit. The joint width was returned to the midpoint and then slowly decreased to the recommended minimum or to an obvious limitation. If a point of limitation was reached prior to the recommended minimum opening, the joint width was increased until the limitation was no longer present and the perpendicular width was then measured and recorded as the closure limit. The smaller of the two perpendicular measurements (midpoint to extension limit, or midpoint to closure limit) was considered to be one-half the total perpendicular movement that could be effectively provided by the joint device at a given angle of crossing.

Once the limits for the joint device had been established at the given angle of crossing, the device was cycled five times at a rate of approximately two cycles per minute. The forces applied to the joint device at its limit points were recorded on the fifth cycle.

The process was basically the same for each 10-degree interval except that after the limits had been established for the 30-degree angle of crossing, the joint device was cycled 100 times between the limits, at a rate of approximately 18 cycles per minute. After the completion of the 100 cycles, the device was examined to determine if any visible damage had occurred in the cycling process.

A summary of all data obtained is given in the Appendix.

LABORATORY EVALUATION

Pro-Span System

Fel-Pro Inc. submitted their low-profile Pro-Span system in the 2 and 4-in. movement categories for evaluation.

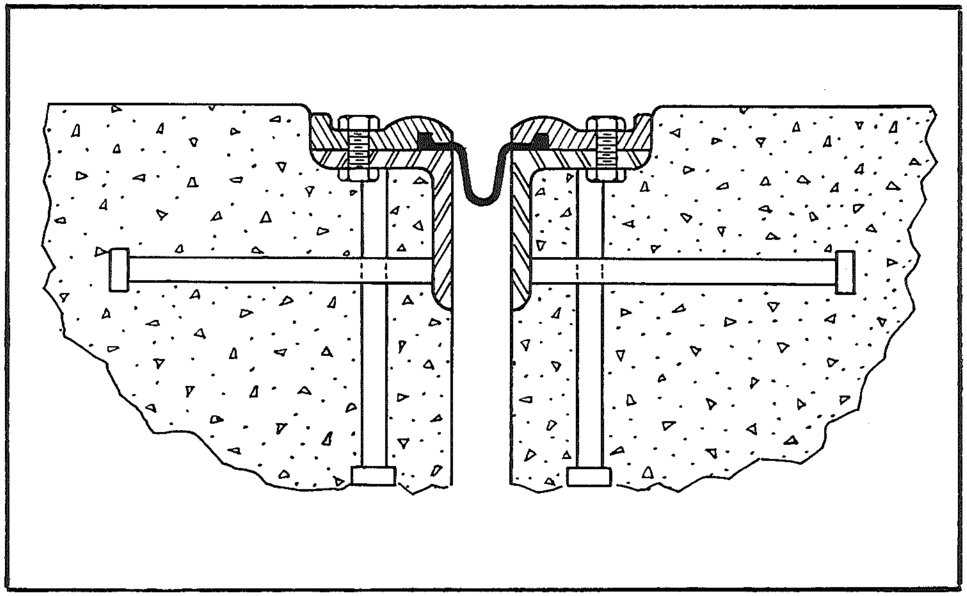

Figure 3. Pro-Span 4-in. low profile system.

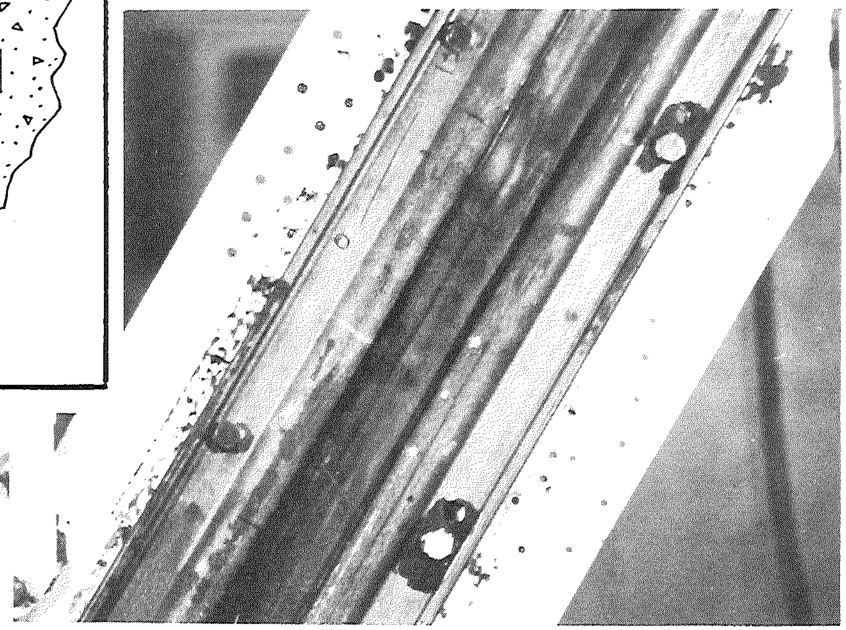

Figure 4. Pro-Span 2-in. system in extension at a 30-degree angle of crossing. Sealing gland is stretched taut.

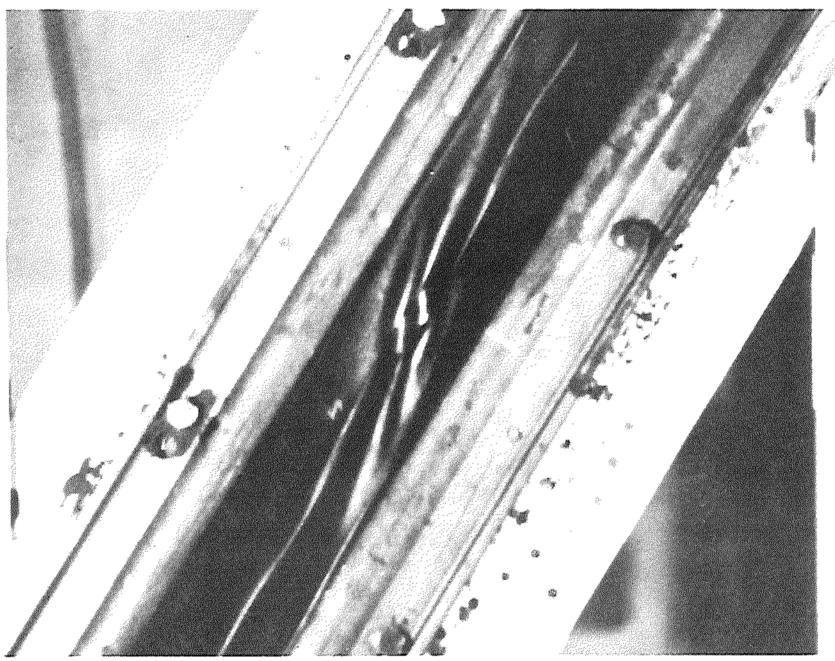

Figure 5. Pro-Span 4-in. system in extension at a 30-degree angle of crossing. Sealing gland is taut and buckled.

This system consists of a continuous length fabric-reinforced elastomeric sealing gland, positioned between a cast-in-place metal seat and a bolt-down metal extrusion (Fig. 3).

The manufacturer's literature recommends that the midpoint joint width be set at 1/4 in. plus one-half the manufacturer's rated joint movement. Therefore, the midpoint openings for the 2 and 4-in. devices are 1-1/4 in. and 2-1/4 in., respectively.

Our evaluation of the 2-in. system indicates that it is capable of providing its rated perpendicular movement at angles of crossing from 90 through 60 degrees. As the angle decreases below 60 degrees, the system can no longer provide its perpendicular movement because the sealing gland becomes stretched taut prior to reaching the 2-1/4-in. perpendicular joint opening (Fig. 4).

The 4-in. system provides its rated perpendicular movement at angles of crossing from 90 through 70 degrees. As the angle decreases below 70 degrees, the sealing gland becomes taut and begins to ripple prior to reaching the 4-1/4-in. perpendicular joint opening (Fig. 5).

Table 1 is a summary of the experimentally determined movement limits for the Pro-Span systems.

TABLE 1
EXPERIMENTALLY DETERMINED PERPENDICULAR MOVEMENT CAPABILITIES (IN INCHES) OF PRO-SPAN LOW-PROFILE SYSTEMS VS. ANGLE OF CROSSING

Joint System	Angle of Crossing						
	90°	80°	70°	60°	50°	40°	30°
Pro-Span 2-in. system	2.0	2.0	2.0	2.0	1.7	1.5	1.4
Pro-Span 4-in. system	4.0	4.0	4.0	3.8	3.2	2.8	2.2

Watson Bowman Strip Seal and Alu-Strip Systems

Watson Bowman Associates, Inc., submitted two systems for our evaluation, the Watson Bowman Strip Seal and the Alu-Strip. Each system was submitted in both the 3 and 4-in. total movement ranges, with the sealing gland preassembled into the hold-down panels by the manufacturer.

The systems consist of a continuous length elastomeric sealing gland with locking lugs which fit into cavities in the vertical face of metal hold-down panels. A high-solids lubricant adhesive (Bon Lastic) aids in the insertion of the lugs into the cavities and then acts as an adhesive when cured. The Alu-Strip system (Fig. 6) uses aluminum hold-down panels while the Strip Seal system uses steel hold-down panels. The sealing glands for both systems are identical, as are the positions of the sealing glands within the cavities of the hold-down panels. Therefore, the following discussion pertains to both the Alu-Strip and Watson Bowman Strip Seal systems.

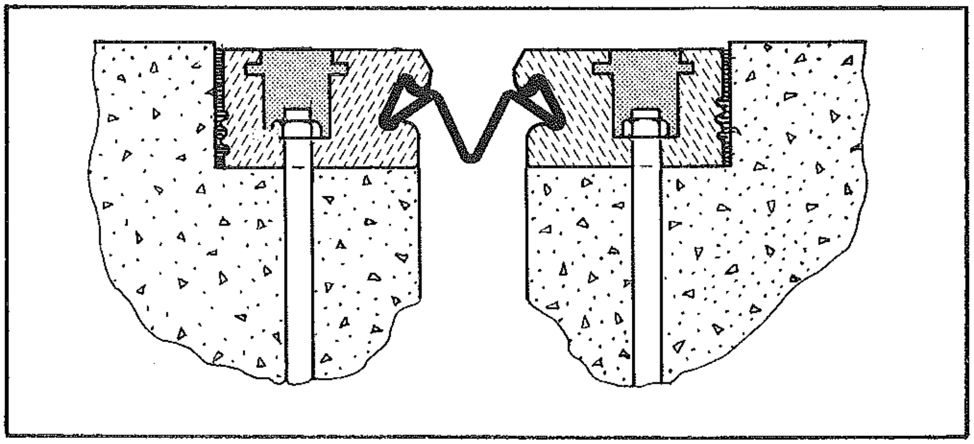

Figure 6. Alu-Strip 4-in. system with a S-400 gland.

Midpoint joint widths as recommended by the manufacturer are equal to one-half the manufacturer's rated movement. Therefore, the midpoint openings for the 3 and 4-in. devices are 1-1/2 and 2 in., respectively.

Our evaluation of the 3-in. system indicates that it is capable of providing the manufacturer's rated perpendicular movement at angles of crossing from 90 through 60 degrees. The 4-in. system provides its rated perpendicular movement at angles of crossing from 90 through 70 degrees. As the angle of crossing decreases from these values, the systems cannot achieve their maximum rated perpendicular joint widths. The sealing gland first ripples (Fig. 7) and then inverts upward (Fig. 8). The inverted gland is then highly susceptible to damage by traffic since it extends above the hold-down panels. Also, once inverted, the gland of the 4-in. system tends to remain inverted upon reclosure of the joint and thus can be pinched between the faces of the hold-down panels and forced further upward into the path of traffic (Fig. 9). The 3-in. system is capable of more movement than the 4-in. system for angles of crossing of 50 degrees or less. This unexpected development is apparently related to the additional width of the sealing gland in the 4-in. system. The larger gland develops more ripples and will invert at a smaller opening than the smaller gland.

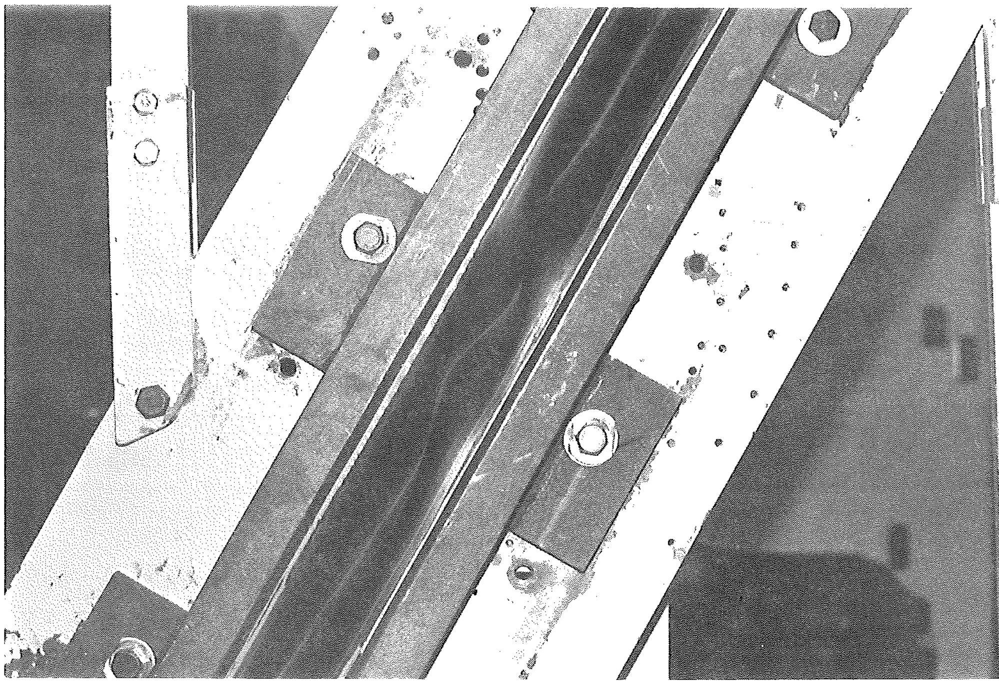

Figure 7. Watson-Bowman 4-in. strip seal in extension at a 30-degree angle of crossing. Sealing gland begins to buckle.

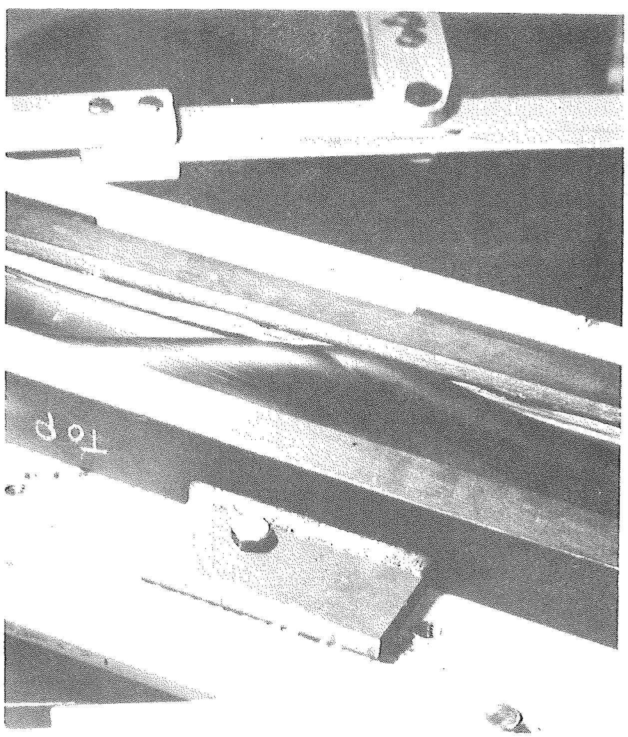

Figure 8. Watson-Bowman 4-in. strip seal. The sealing gland has inverted upward and extends above the metal extrusions.

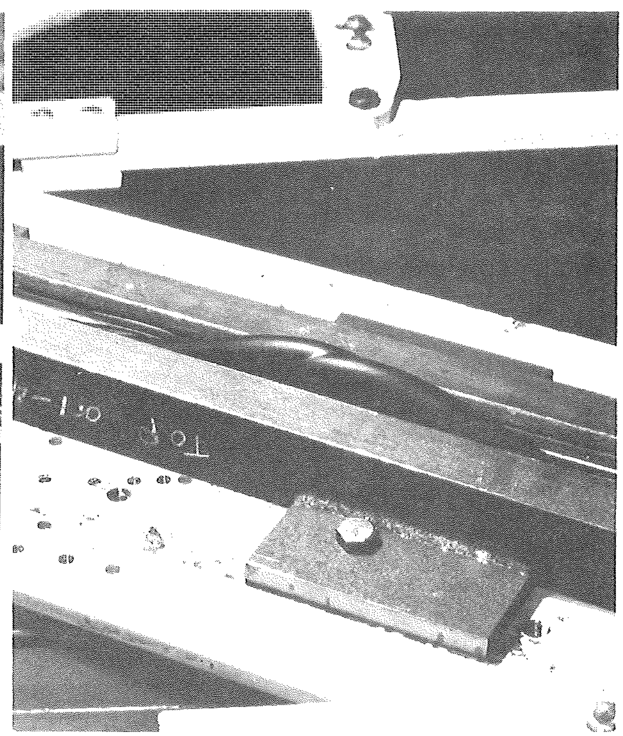

Figure 9. Watson-Bowman 4-in. strip seal. Sealing gland remains inverted and is caught between the hold-down panels when the joint closes.

Table 2 summarizes the experimentally determined movement limits for the Watson Bowman systems.

TABLE 2
EXPERIMENTALLY DETERMINED PERPENDICULAR MOVEMENT CAPABILITIES (IN INCHES) OF THE WATSON BOWMAN SYSTEMS VS. ANGLE OF CROSSING

Joint System	Angle of Crossing						
	90°	80°	70°	60°	50°	40°	30°
Watson Bowman 3-in. system (S 300)	3.0	3.0	3.0	3.0	2.9	2.2	1.4
Watson Bowman 4-in. system (S 400)	4.0	4.0	4.0	3.8	2.8	1.8	1.3

Acme Strip Seal and Trojan Systems

Acme Highway Products Corp. submitted two systems for evaluation, their strip seal system in the 2, 3, and 4-in. movement categories and their Trojan system in the 3 and 4-in. movement categories.

The Strip Seal system consists of a continuous length elastomeric sealing gland with locking lugs which fit into cavities in the vertical faces of the steel hold-down panels. A high-solids lubricant adhesive aids in the insertion of the lugs and then acts as an adhesive when cured (Fig. 10).

The manufacturer's recommended midpoint joint width for the Strip Seal is 1/4 in. plus one-half the manufacturer's rated movement. Therefore, midpoint openings for the 2, 3, and 4-in. systems are 1-1/4, 1-3/4, and 2-1/4 in., respectively.

The Trojan system consists of a continuous length elastomeric sealing gland positioned between a cast-in-place metal seat and a bolted down aluminum reinforced elastomeric pad (Figs. 11 and 12). The manufacturer also produces a system called the Titan which uses the same sealing gland, but the hold-down is an aluminum extrusion instead of the aluminum reinforced elastomeric pads. Since the sealing glands' basic dimensions and midpoint joint widths are the same for both systems, we have considered the Trojan system and the Titan system as one, for the purpose of our evaluations.

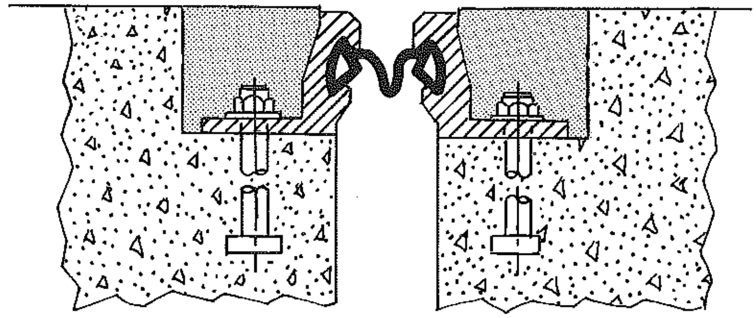

Figure 10. Acme 4-in. strip seal system.

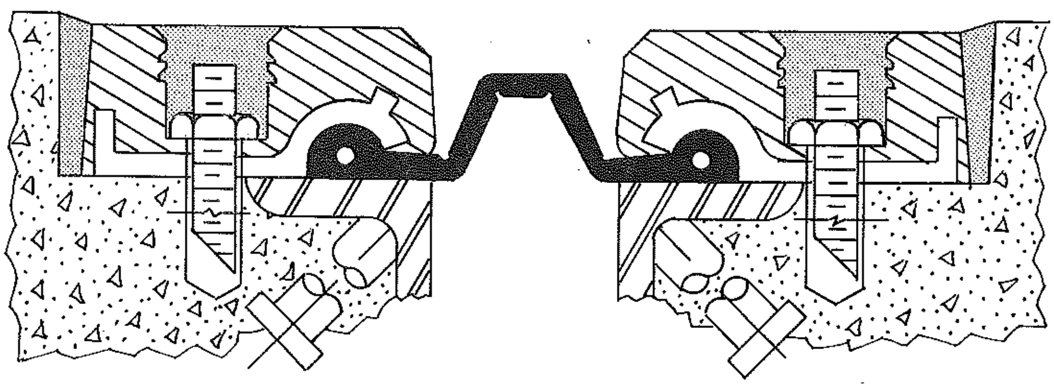

Figure 11. Acme 3-in. Trojan with TR 300 gland.

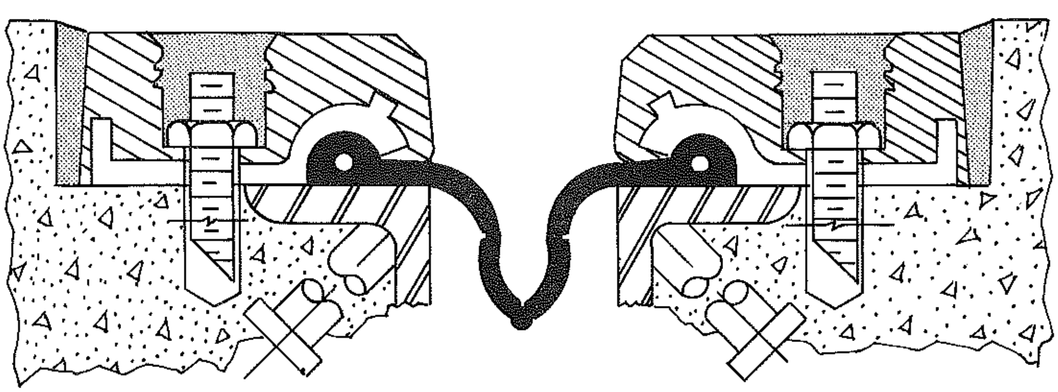

Figure 12. Acme 4-in. Trojan with TR 400 gland.

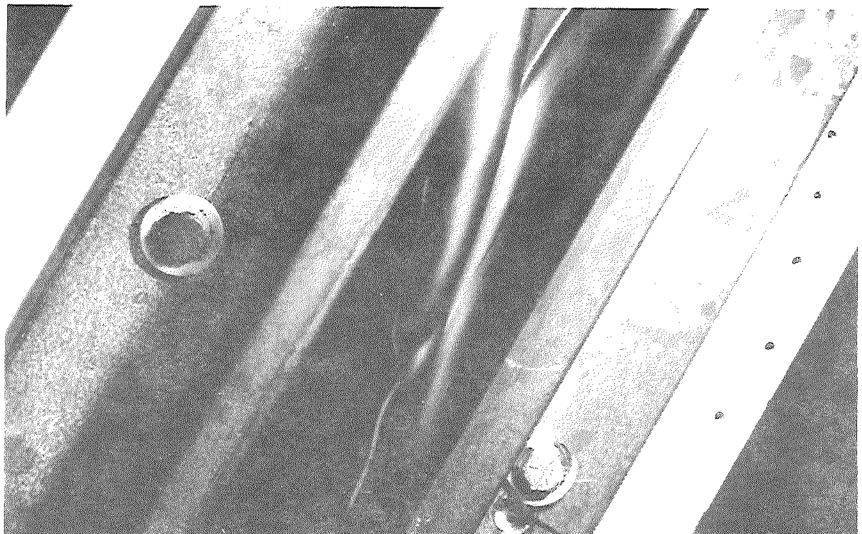

Figure 13. Acme 4-in. strip seal in extension at a 30-degree angle of crossing. The sealing gland has started to buckle.

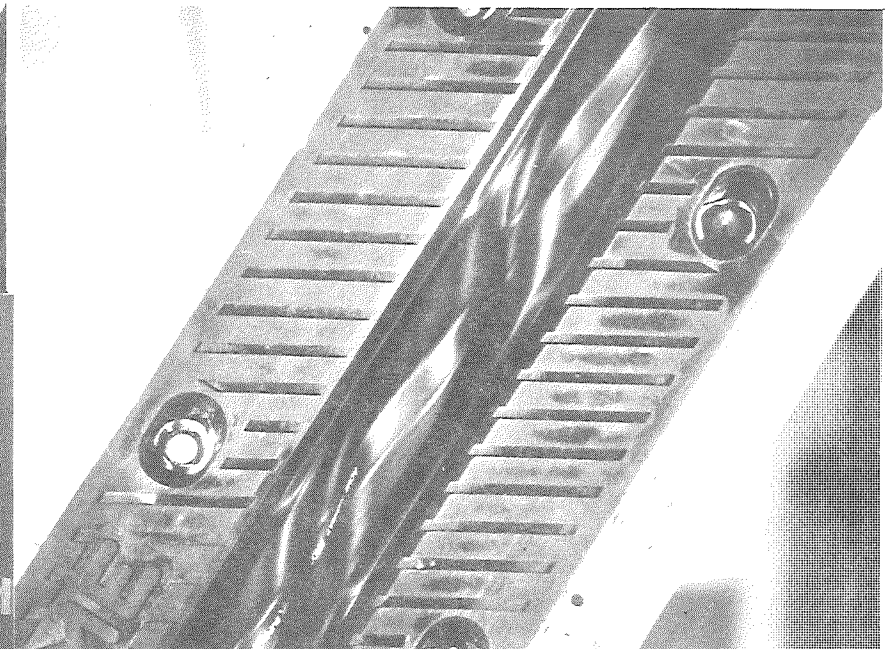

Figure 14. Acme Trojan 3-in. system in extension at a 30-degree angle of crossing. The sealing gland has started to ripple and buckle.

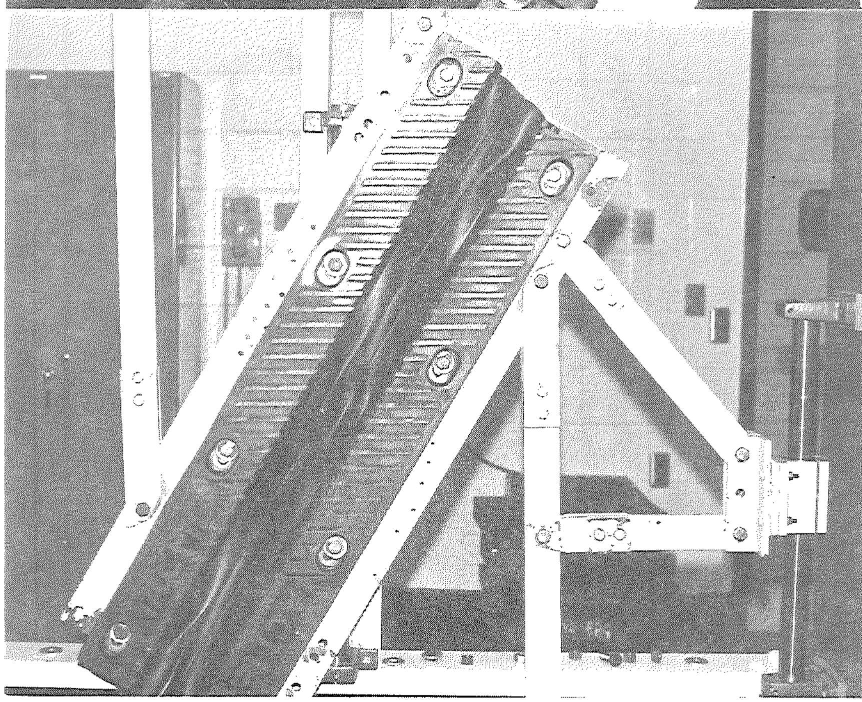

Figure 15. Acme Trojan 4-in. system in extension at a 30-degree angle of crossing. The sealing gland is starting to ripple and buckle.

The manufacturer's recommended midpoint opening for the Trojan is 1/2 in. plus one-half the manufacturer's rated movement. Therefore, the midpoint openings for the 3 and 4-in. systems are 2 and 2-1/2 in., respectively.

Only the 3 and 4-in. Strip Seal systems have been evaluated to date. Both of these devices provide their rated perpendicular movement at angles of crossing from 90 through 70 degrees. As the angle of crossing decreases, both systems become limited in their ability to achieve their maximum rated perpendicular joint opening. The sealing gland first begins to ripple, then, as the width is increased, the sealing gland inverts upward and extends above the top of the metal extrusions and would thus be subjected to possible traffic damage (Fig. 13).

The 3-in. Trojan system evaluated used the standard sealing gland as shown in Figure 11. Our evaluations indicate that it is capable of providing the manufacturer's rated perpendicular movement at angles of crossing from 90 through 60 degrees. As the angle of crossing decreases below 60 degrees, the sealing gland becomes stretched taut prior to achieving its maximum rated joint opening. This caused the sealing gland to ripple and buckle (Fig. 14).

The 4-in. Trojan system uses a low-profile sealing gland as shown in Figure 12. Our evaluation of this system indicates that it is not capable of providing the manufacturer's rated perpendicular movement at a 90-degree angle of crossing. The problem encountered with this system is that the sealing gland has a tendency to invert upward prior to reaching its maximum rated opening and then remains inverted as the joint closes. This problem becomes more severe as the angle of crossing decreases. The sealing gland begins to ripple and buckle (Fig. 15). As the joint opening is increased the gland then inverts upward (Fig. 16) and remains inverted upon closure, thus being caught between the hold-down pads (Fig. 17).

Table 3 is a summary of the experimentally determined movement limits for the Acme systems.

Onflex Systems

Structural Accessories, Inc. submitted their Onflex systems for evaluation. The Onflex systems consist of a continuous length elastomeric sealing gland positioned between the seat and bolt-down aluminum extrusions.

The Onflex 25 and 45 systems (Fig. 18) are rated by the manufacturer at 2-1/2 and 4-1/2 in. of perpendicular movement, respectively. The sealing

TABLE 3
EXPERIMENTALLY DETERMINED PERPENDICULAR MOVEMENT CAPABILITIES (IN INCHES) OF THE ACME SYSTEMS VS. ANGLE OF CROSSING

Joint System	Angle of Crossing						
	90°	80°	70°	60°	50°	40°	30°
Acme 3-in. Strip Seal (AS 300)	3.0	3.0	3.0	2.7	1.9	1.9	1.2
Acme 4-in. Strip Seal (AS 400)	4.0	4.0	4.0	2.0	1.7	1.3	1.0
Acme 3-in. Trojan (TR 300)	3.0	3.0	3.0	3.0	2.7	2.0	1.4
Acme 4-in. Trojan (TR 400)	3.2	3.2	3.0	2.5	1.5	1.0	0.6

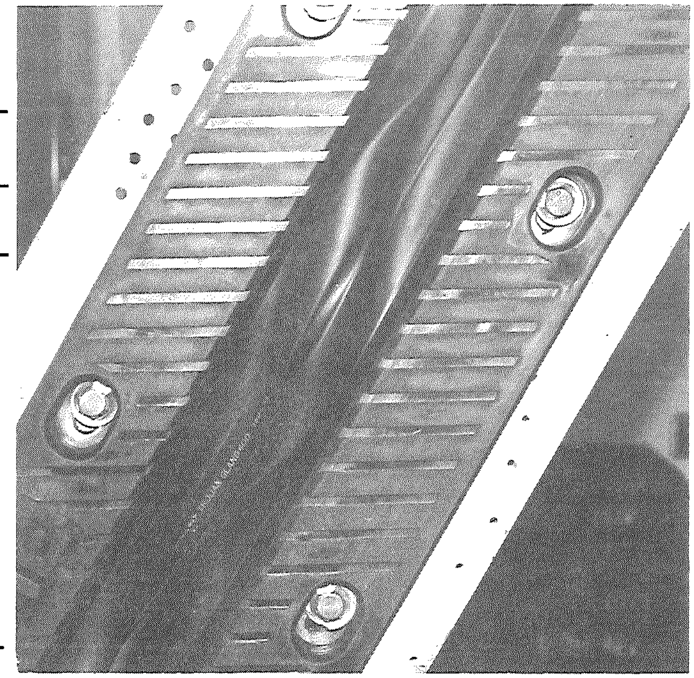

Figure 16. Acme Trojan 4-in. system in extension at a 30-degree angle of crossing. The sealing gland has buckled and inverted.

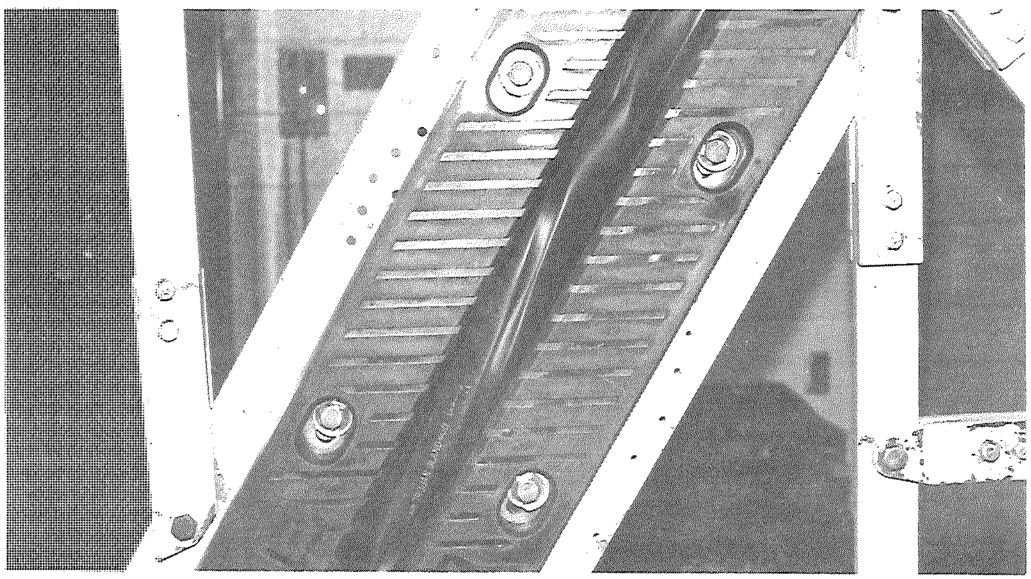

Figure 17. Acme Trojan 4-in. system at a 30-degree angle of crossing. The joint width was increased until the gland partially inverted and then the width was decreased. The gland remained inverted and was caught between the pads.

gland is corrugated and has fabric reinforcement and is reported by the manufacturer to be expressly engineered to accommodate the more severe angles of crossing.

The Onflex 20 and 40 systems (Fig. 19) are rated by the manufacturer at 2 and 4 in. of perpendicular movement, respectively. The sealing gland is not corrugated or reinforced. The Onflex 20 sealing gland has a single arch as opposed to the double arch of the Onflex 40.

The manufacturer's literature contained conflicting data with regard to the recommended midpoint joint width. For our evaluation we used a midpoint of 1/2 in. plus one-half the manufacturer's rated perpendicular movement for the Onflex 20, 25, and 45 systems and a midpoint of 1 in. plus one-half the manufacturer's rated perpendicular movement for the Onflex 40 system.

Testing of the Onflex 20 indicates that it is unable to provide the manufacturer's rated movement at a 90-degree angle of crossing. Excessive force develops upon closure of the joint to the extent that the aluminum hold-down panels start to deflect prior to reaching the manufacturer's recommended minimum joint width. The compressive force at a 0.55-in. joint width at a 90-degree angle of crossing is 1,680 lb/lin ft which is considerably in excess of recommended maximum operating forces. This limitation is consistent throughout all angles of crossing from 90 to 40 degrees. At 30 degrees, the device becomes slightly more limited in closure.

The Onflex 25, a corrugated system designed for more severe angles of crossing, is also limited in closure. Prior to closing to its stated minimum perpendicular joint width, the gland extends upward above the aluminum hold-down panels (Fig. 20). The sealing gland is thus susceptible to possible damage by traffic. Interestingly, the Onflex 25 provides slightly less movement capability (except at a 30-degree angle of crossing) than does the Onflex 20.

The nature of the limiting factors of both the Onflex 40 and 45 are similar and, except for the greater movement capability of the Onflex 45 at 90 degrees through 70 degrees, the two systems are nearly identical in their movement capabilities for angles of crossing of 60 degrees or less. For angles of crossing of 90 through 60 degrees, the limiting factor for these two systems is that of closure. Prior to closing to their recommended minimum joint widths, excessive forces are developed in compression. These forces have a tendency to deflect the aluminum hold-down panels due to excessive forces on the gland. The Onflex 40, prior to reaching its stated maximum perpendicular joint opening, tends to try to pull the gland

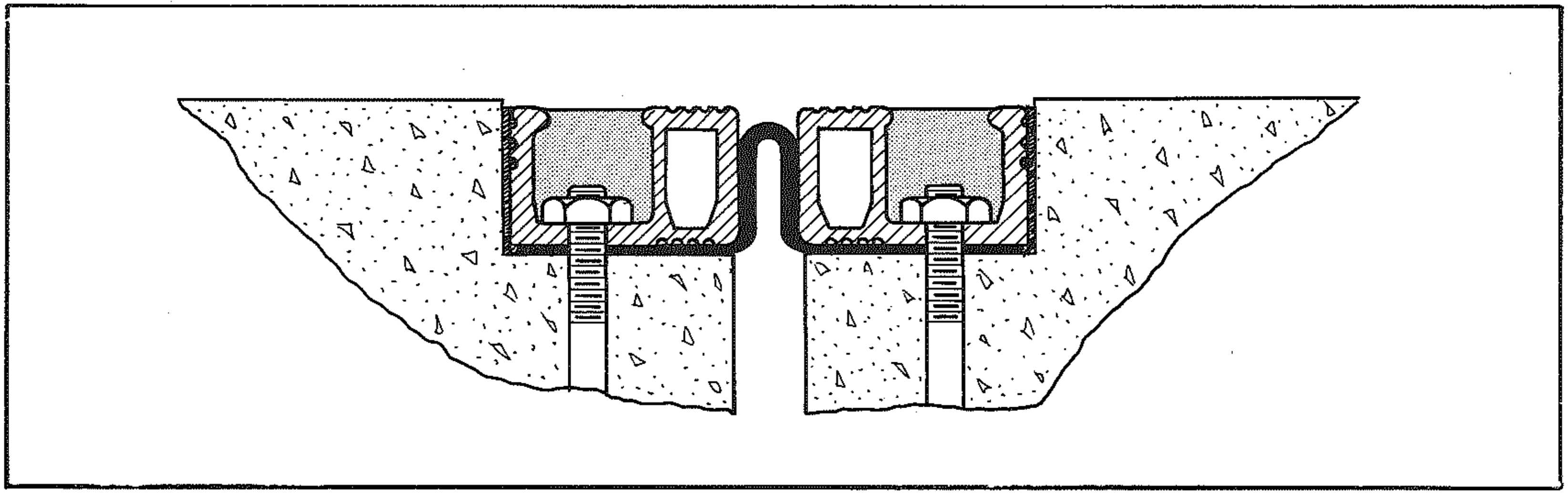

Figure 18. Onflex 45 system.

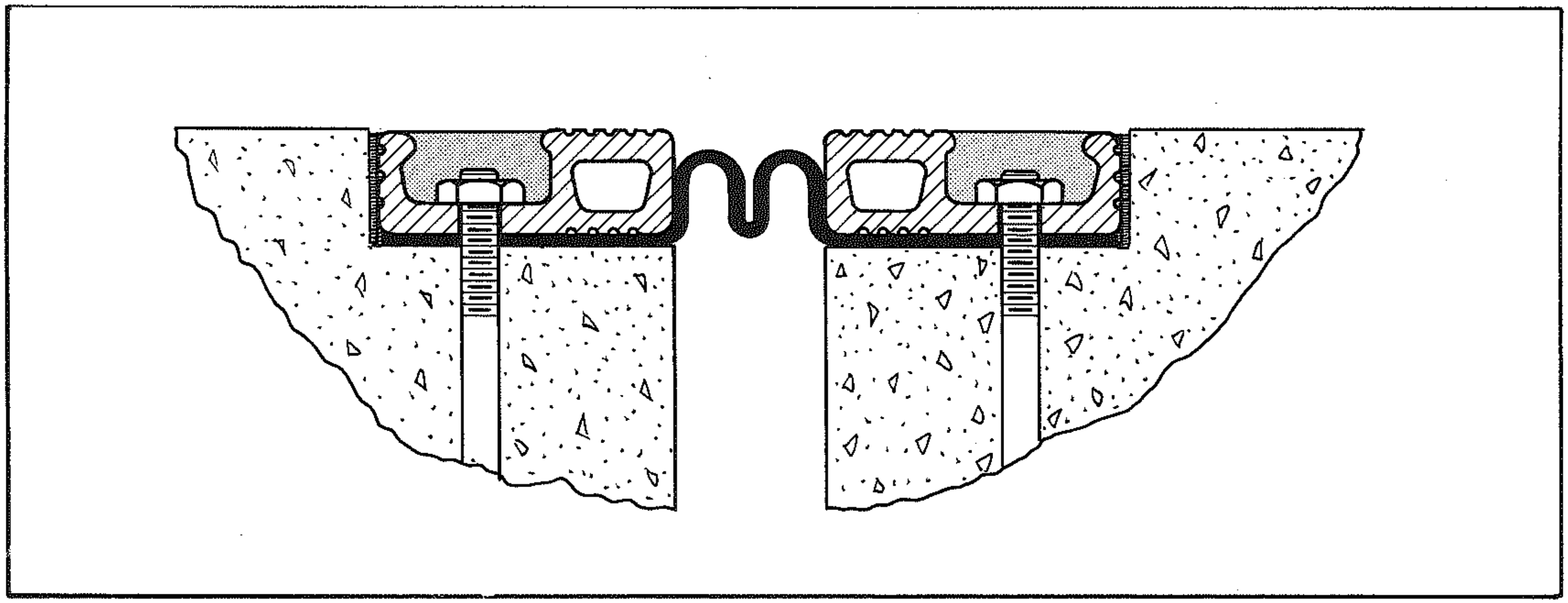

Figure 19. Onflex 40 system.

from under the aluminum hold-downs, especially near the ends (Fig. 21) while the Onflex 45 ripples extensively and develops points of high stress (Fig. 22).

It does not appear that the corrugated systems have any advantage over the noncorrugated systems regarding movement capabilities when installed at the various angles of crossing. However, the corrugated systems do have fabric reinforced glands, a feature which is advantageous in resisting tears.

Table 4 summarizes the experimentally determined movement limits for the Onflex systems.

TABLE 4
EXPERIMENTALLY DETERMINED PERPENDICULAR MOVEMENT CAPABILITIES (IN INCHES) OF THE ONFLEX SYSTEMS VS. ANGLE OF CROSSING

Joint System	Angle of Crossing						
	90°	80°	70°	60°	50°	40°	30°
Onflex 2-in. system (20)	1.8	1.8	1.8	1.8	1.8	1.8	1.6
Onflex 2-1/2-in. system (25)	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Onflex 4-in. system (40)	3.8	3.8	3.8	3.8	3.6	2.8	2.0
Onflex 4-1/2-in. system (45)	4.1	4.1	4.0	3.7	3.6	2.8	2.0

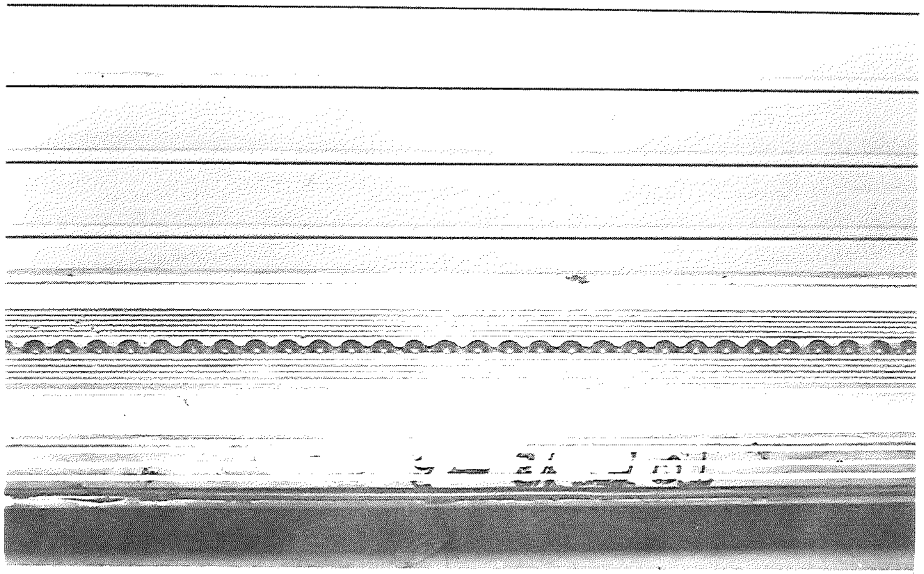

Figure 20. Onflex 25 system in closure at a 90-degree angle of crossing. When closed to the manufacturer's recommended minimum joint width the sealing gland extends above the aluminum extrusions.

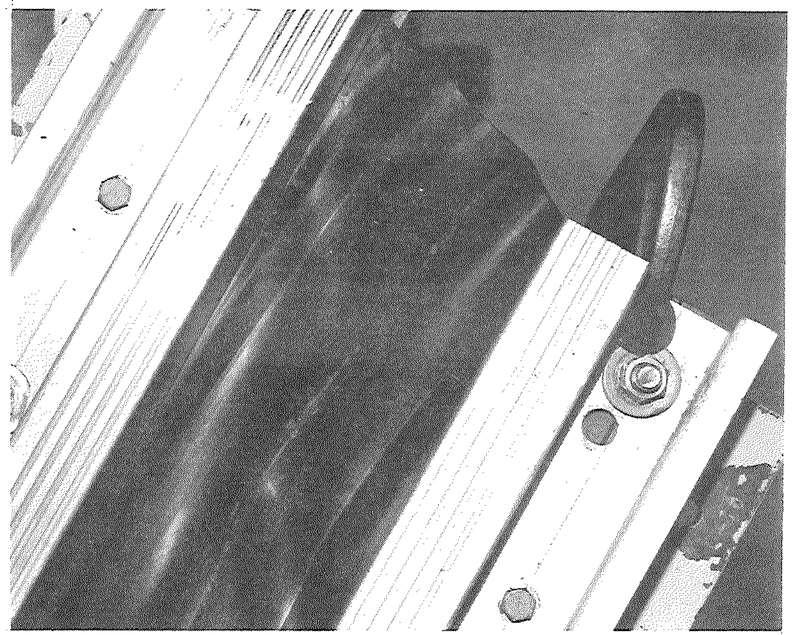

Figure 21. Onflex 40 system in extension at a 30-degree angle of crossing. The sealing gland is stretched to the extent that it is starting to pull out from under the aluminum extrusions.

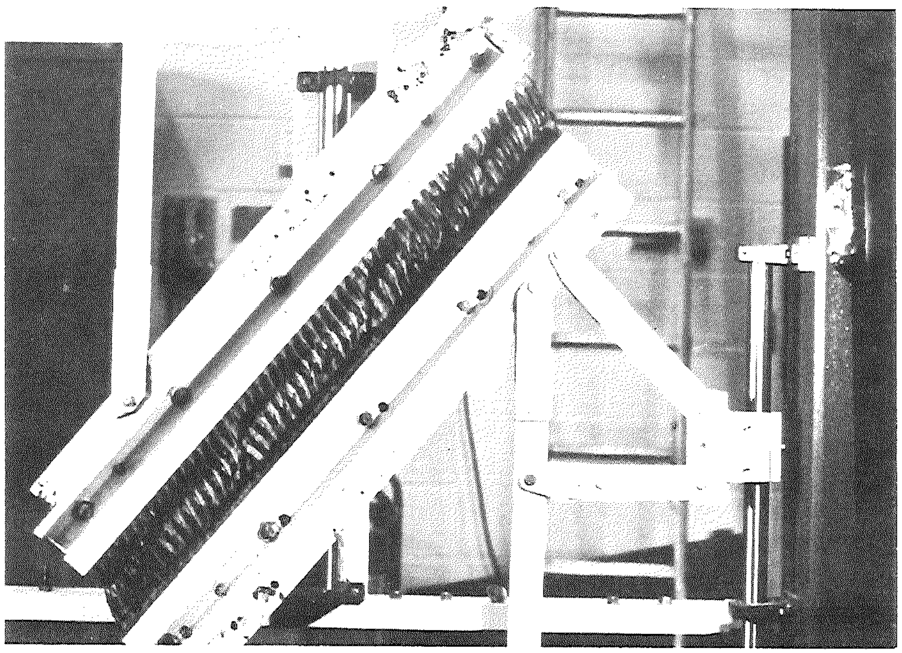

Figure 22. Onflex 45 system in extension at a 40-degree angle of crossing. The sealing gland develops ripples which create points of high stress within the gland.

SUMMARY AND CONCLUSIONS

Summary

The main intent of this project was to develop guidelines relating the maximum movement a given expansion joint system can effectively provide at given angles of crossing. Table 5 is a summary of experimentally determined movement limits for all systems evaluated. It must be noted that due to time constraints, the testing was limited to only one sample of each device; however, since the manufacturers were informed of the intent of our evaluation, it must be assumed that they submitted a sample which was well within their specifications and thus typical of their material. Also, limitations established in the laboratory may vary from those that exist in actual field use when the system is exposed to variable construction techniques during installation, traffic, and environmental conditions.

It should also be noted that many of the manufacturers produce more than one style of sealing gland for the same system. Based on our evaluations, a change in the configuration of the gland can have a great influence on the limitations of the system. Therefore, the guidelines developed under this project may pertain only to the style of gland evaluated.

It was noted in reviewing the manufacturers' literature that in most cases when they state that the system can accommodate 'overtravel', the overtravel is in extension only and not in closure. In fact, it appears that in some cases the overtravel or safety factor was already included in their recommended movement rating for the system.

In reviewing the problems encountered with the various systems, discussion was based on the most severe limiting factor of each particular system. Frequently, the system may have been limited in its movement capability in both directions, that is, in both closure and extension. Usually, however, the determining limitation was significantly greater than any limitation which may have occurred in the opposite direction.

Generally, the past practice of the bridge designer, when specifying the size of an expansion joint device for an installation with a severe angle of crossing would be to simply specify a system which had a rated movement capability greater than would have been required for the same joint movement at a 90-degree angle of crossing. For example, if 3 in. of perpendicular movement was required at a 40-degree angle of crossing, the designer would normally specify a system rated for 4 in. of perpendicular movement. Our evaluations indicate that this method is often invalid since some 3-in. devices can accommodate more movement at severe angles of crossing than a similar 4-in. device (see Figs. 23 and 24 in Appendix).

TABLE 5
EXPERIMENTALLY DETERMINED PERPENDICULAR
MOVEMENT CAPABILITIES (IN INCHES) OF
EVALUATED SYSTEMS VS. ANGLE OF CROSSING

Joint System	Angle of Crossing						
	90°	80°	70°	60°	50°	40°	30°
Onflex 25	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Onflex 20	1.8	1.8	1.8	1.8	1.8	1.8	1.6
Pro-Span 2-in. system (low-profile)	2.0	2.0	2.0	2.0	1.7	1.5	1.4
Acme 3-in. Strip Seal (AS 300)	3.0	3.0	3.0	2.7	1.9	1.9	1.2
Acme 3-in. Trojan (TR 300)	3.0	3.0	3.0	3.0	2.7	2.0	1.4
Watson Bowman 3-in. system (S 300)	3.0	3.0	3.0	3.0	2.9	2.2	1.4
Acme 4-in. Trojan (TR 400)	3.2	3.2	3.0	2.5	1.5	1.0	0.6
Onflex 40	3.8	3.8	3.8	3.8	3.6	2.8	2.0
Acme 4-in. Strip Seal (AS 400)	4.0	4.0	4.0	2.0	1.7	1.3	1.0
Watson Bowman 4-in. system (S 400)	4.0	4.0	4.0	3.8	2.8	1.8	1.3
Pro-Span 4-in. system (low profile)	4.0	4.0	4.0	3.8	3.2	2.8	2.2
Onflex 45	4.1	4.1	4.0	3.7	3.6	2.8	2.0

Conclusions

The majority of the expansion joint systems evaluated will provide their full perpendicular movement range from a 90-degree through a 70-degree angle of crossing. As the angle of crossing becomes more severe, the total perpendicular movement a system can adequately provide decreases due to the inability of the system to fully extend to its maximum recommended perpendicular width or fully close to its minimum recommended perpendicular width, or both.

A few of the expansion joint systems evaluated failed to adequately provide the manufacturers' full movement rating at a 90-degree angle of crossing; therefore, the movement rating has been decreased for our design purposes.

The logical assumption that a system which provides the most movement capability at a 90-degree angle of crossing will also provide the most movement at a more severe angle of crossing is not always valid. Our evaluations indicate that some devices which provide 4 in. of perpendicular movement at a 90-degree angle of crossing will provide less movement at a 30-degree angle of crossing than a similar device which provided only 3 in. of perpendicular movement at a 90-degree angle of crossing.

APPENDIX

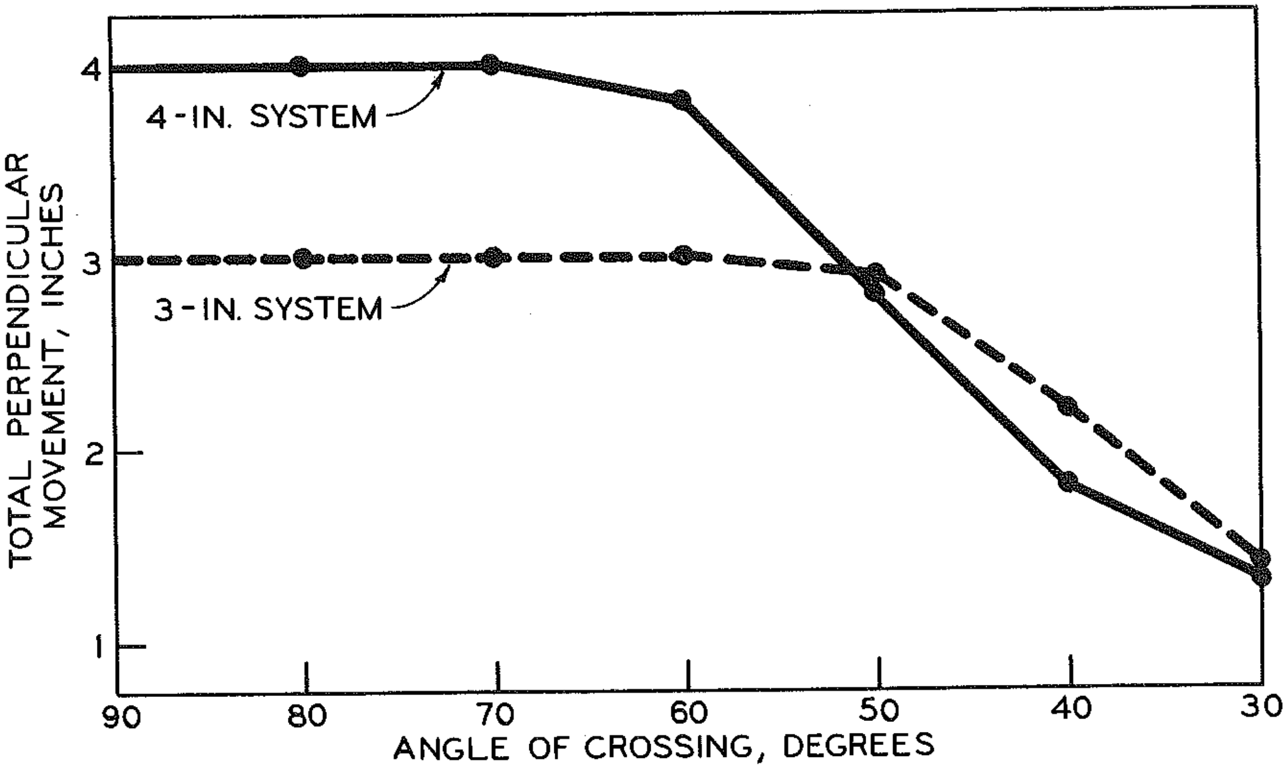

Figure 23. A comparison of the perpendicular movement capabilities of a Watson-Bowman 4-in. system vs. a Watson-Bowman 3-in. system at various angles of crossing.

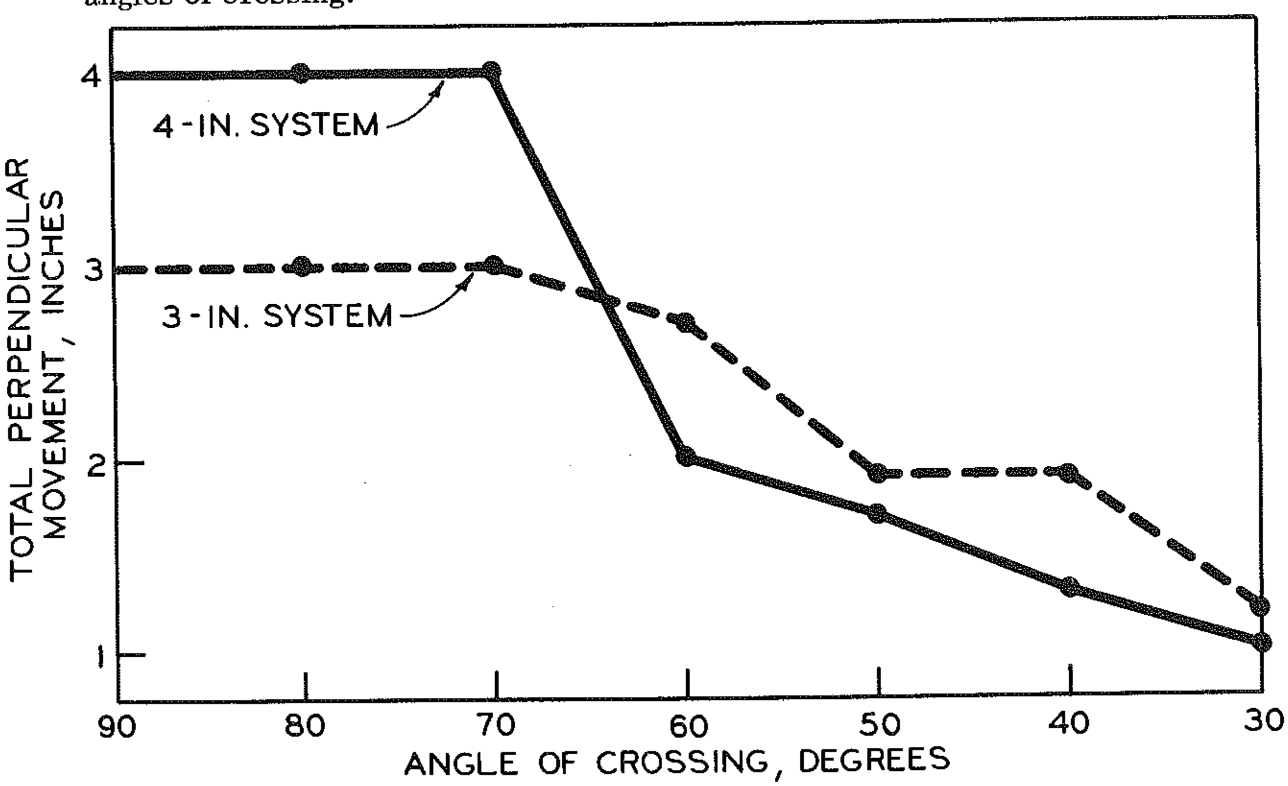

Figure 24. A comparison of the perpendicular movement capabilities of an Acme 4-in. strip seal vs. an Acme 3-in. strip seal at various angles of crossing.

TABLE 6
PRO-SPAN 2 IN. (LOW-PROFILE)

Angle of Crossing	90°	80°	70°	60°	50°	40°	30°
Experimentally determined limit in extension, in., perpendicular (from midpoint)		1.00	1.00	1.00	0.85	0.75	0.70
Experimentally determined limit in closure, in., perpendicular (from midpoint)		1.00	1.00	1.00	1.00	1.00	0.95
Assigned limit, in., perpendicular (from midpoint)		1.00	1.00	1.00	0.85	0.75	0.70
Force in extension at assigned limit, lb/lin ft		80	80	90	120	360	430
Force in closure at assigned limit, lb/lin ft		120	250	330	420	130	210

TABLE 7
PRO-SPAN 4 IN. (LOW-PROFILE)

Angle of Crossing	90°	80°	70°	60°	50°	40°	30°
Experimentally determined limit in extension, in., perpendicular (from midpoint)		2.00	2.00	1.90	1.60	1.40	1.10
Experimentally determined limit in closure, in., perpendicular (from midpoint)		2.00	2.00	2.00	2.00	1.60	1.60
Assigned limit, in., perpendicular (from midpoint)		2.00	2.00	1.90	1.60	1.40	1.10
Force in extension at assigned limit, lb/lin ft		80	140	180	50	110	180
Force in closure at assigned limit, lb/lin ft		280	320	470	190	80	150

TABLE 8

WATSON BOWMAN 3 IN. SYSTEM (S-300)

Angle of Crossing	90°	80°	70°	60°	50°	40°	30°
Experimentally determined limit in extension, in., perpendicular (from midpoint)		1.50	1.50	1.50	1.45	1.10	0.70
Experimentally determined limit in closure, in., perpendicular (from midpoint)		1.50	1.50	1.50	1.50	1.40	1.40
Assigned limit, in., perpendicular (from midpoint)		1.50	1.50	1.50	1.45	1.10	0.70
Force in extension at assigned limit, lb/lin ft		70	50	100	110	130	140
Force in closure at assigned limit, lb/lin ft		150	150	---	150	100	110

TABLE 9

WATSON BOWMAN 4 IN. SYSTEM (S-400)

Angle of Crossing	90°	80°	70°	60°	50°	40°	30°
Experimentally determined limit in extension, in., perpendicular (from midpoint)		2.00	2.00	1.90	1.40	0.90	0.65
Experimentally determined limit in closure, in., perpendicular (from midpoint)		2.00	2.00	2.00	2.00	1.90	1.90
Assigned limit, in., perpendicular (from midpoint)		2.00	2.00	1.90	1.40	0.90	0.65
Force in extension at assigned limit, lb/lin ft		30	60	70	100	110	120
Force in closure at assigned limit, lb/lin ft		570	---	180	190	90	90

TABLE 10
ACME 3 IN. STRIP SEAL (AS 300)

Angle of Crossing	90°	80°	70°	60°	50°	40°	30°
Experimentally determined limit in extension, in., perpendicular (from midpoint)			1.50	1.35	0.95	0.95	0.60
Experimentally determined limit in closure, in., perpendicular (from midpoint)			1.50	1.50	1.50	1.25	1.05
Assigned limit, in., perpendicular (from midpoint)			1.50	1.35	0.95	0.95	0.60
Force in extension at assigned limit, lb/lin ft				40	40	60	70
Force in closure at assigned limit, lb/lin ft				60	60	90	70

TABLE 11
ACME 4 IN. STRIP SEAL (AS 400)

Angle of Crossing	90°	80°	70°	60°	50°	40°	30°
Experimentally determined limit in extension, in., perpendicular (from midpoint)		2.00	2.00	1.00	0.85	0.65	0.50
Experimentally determined limit in closure, in., perpendicular (from midpoint)		2.00	2.00	2.00	1.75	1.65	1.35
Assigned limit, in., perpendicular (from midpoint)		2.00	2.00	1.00	0.85	0.65	0.50
Force in extension at assigned limit, lb/lin ft		50	90	60	70	90	110
Force in closure at assigned limit, lb/lin ft		110	160	50	60	70	50

TABLE 12
ACME TROJAN 3 IN. (TR 300)

Angle of Crossing	90°	80°	70°	60°	50°	40°	30°
Experimentally determined limit in extension, in., perpendicular (from midpoint)				1.50	1.35	1.00	0.70
Experimentally determined limit in closure, in., perpendicular (from midpoint)				1.50	1.50	1.50	1.35
Assigned limit, in., perpendicular (from midpoint)				1.50	1.35	1.00	0.70
Force in extension at assigned limit, lb/lin ft				110	100	80	80
Force in closure at assigned limit, lb/lin ft				90	60	60	70

TABLE 13
ACME TROJAN 4 IN. (TR 400)

Angle of Crossing	90°	80°	70°	60°	50°	40°	30°
Experimentally determined limit in extension, in., perpendicular (from midpoint)	1.60	1.60	1.50	1.25	0.75	0.50	0.30
Experimentally determined limit in closure, in., perpendicular (from midpoint)	2.00	2.00	2.00	2.00	2.00	1.50	1.20
Assigned limit, in., perpendicular (from midpoint)	1.60	1.60	1.50	1.25	0.75	0.50	0.30
Force in extension at assigned limit, lb/lin ft				20	30	30	40
Force in closure at assigned limit, lb/lin ft				30	30	40	20

TABLE 14
ONFLEX 25

Angle of Crossing	90°	80°	70°	60°	50°	40°	30°
Experimentally determined limit in extension, in., perpendicular (from midpoint)	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Experimentally determined limit in closure, in., perpendicular (from midpoint)	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Assigned limit, in., perpendicular (from midpoint)	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Force in extension at assigned limit, lb/lin ft	60	190	170	230	260	300	230
Force in closure at assigned limit, lb/lin ft	130	---	---	---	150	180	250

TABLE 15
ONFLEX 45

Angle of Crossing	90°	80°	70°	60°	50°	40°	30°
Experimentally determined limit in extension, in., perpendicular (from midpoint)	2.25	2.25	2.25	2.25	1.80	1.40	1.00
Experimentally determined limit in closure, in., perpendicular (from midpoint)	2.05	2.05	2.00	1.85	1.85	1.75	1.75
Assigned limit, in., perpendicular (from midpoint)	2.05	2.05	2.00	1.85	1.80	1.40	1.00
Force in extension at assigned limit, lb/lin ft	60	---	300	360	180	140	150
Force in closure at assigned limit, lb/lin ft	420	---	300	300	150	170	140

TABLE 16
ONFLEX 20

Angle of Crossing	90°	80°	70°	60°	50°	40°	30°
Experimentally determined limit in extension, in., perpendicular (from midpoint)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Experimentally determined limit in closure, in., perpendicular (from midpoint)	0.90	0.90	0.90	0.90	0.90	0.90	0.80
Assigned limit, in., perpendicular (from midpoint)	0.90	0.90	0.90	0.90	0.90	0.90	0.80
Force in extension at assigned limit, lb/lin ft				90	100	100	110
Force in closure at assigned limit, lb/lin ft				300	---	350	260

TABLE 17
ONFLEX 40

Angle of Crossing	90°	80°	70°	60°	50°	40°	30°
Experimentally determined limit in extension, in., perpendicular (from midpoint)	2.00	2.00	2.00	2.00	1.80	1.40	1.00
Experimentally determined limit in closure, in., perpendicular (from midpoint)	1.90	1.90	1.90	1.90	1.90	1.80	1.80
Assigned limit, in., perpendicular (from midpoint)	1.90	1.90	1.90	1.90	1.80	1.40	1.00
Force in extension at assigned limit, lb/lin ft				80	100	80	100
Force in closure at assigned limit, lb/lin ft				360	240	120	70