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

SECOND TESTING SERIES

MICHIGAN
DEPARTMENT OF TRANSPORTATION

MATERIALS and TECHNOLOGY DIVISION

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SECOND TESTING SERIES

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Michigan Transportation Commission
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INTRODUCTION

The Problem

Michigan has been specifying single-element, continuous length, elastomeric sealing devices for nearly all new and reconstructed bridge expansion joints since early 1978.

The manufacturers of these expansion joint devices provide stated movement ratings 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 bridge longitudinal centerline. Since field conditions frequently require that expansion joints be installed at angles of crossing other than 90 degrees, it is necessary to determine the ability of the expansion device to perform at various angles of crossing. Guidelines can then be established for each system, relating a system's maximum movement capability as the angle of crossing decreases from 90 degrees. This problem, coupled with the inadequacy of existing guidelines, caused the Design Division to request that a research project be initiated to evaluate expansion joint devices currently approved for use by the Department. The Engineering Operations Committee approved the research proposal subsequently prepared by the Research Laboratory.

The first series of tests were conducted in early 1980 and reported in Research Report No. R-1144 (May 1980). Table 1A in the Appendix summarizes the experimentally determined movement capabilities at various angles of crossing for the expansion joint devices tested in that first series.

After examining the results of the first testing series, some manufacturers redesigned portions of their expansion joint systems in an attempt to increase movement capabilities. Also, new expansion joint devices were developed and submitted to the Department for evaluation. As a result, a series of tests were scheduled and conducted in 1982 and 1983. The results of those tests are contained in this report.

Research Procedure

Each manufacturer of an approved expansion joint device was requested to submit a 40-in. long section, including all accessories, and in all movement categories they intended to supply in Michigan, for laboratory evaluation.

The special testing frame used in the earlier test series was again used. This testing frame, which is used in conjunction with a hydraulic ram operated by a Material Test System (MTS) controller, was designed and constructed by the Research Laboratory's Structural Mechanics Group. A moving cross-head maintains the direction of travel in a straight line.

The angle between the direction of travel and the expansion joint device (angle of crossing) can be changed by 10-degree intervals (Fig. 1). Each device was evaluated at 10-degree intervals from a 90 to 30 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 a bridge. Some devices were submitted pre-assembled by the manufacturers. 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 set at the manufacturer's recommended midpoint. Starting at this recommended midpoint, the joint width was slowly increased and the seal was observed to see if any physical distortion, buckling, or excessive force occurred prior to reaching the maximum recommended perpendicular width. If a limitation occurred prior to reaching 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 and recorded to the nearest 5/100 of an inch as the extension limit (Fig. 2). The joint width was returned to the midpoint and then slowly decreased to the recommended minimum or to an obvious limitation, such as excessive compressive force or buckling of the seal above the riding surface. 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. This 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.

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

The testing procedure was basically the same at each 10 degree interval except that at the limits established for a 30-degree angle of crossing, the joint device was cycled 100 times at a rate of approximately 18 cycles per minute. At the completion of the 100 cycles, the device was examined for any visible damage or problems.

A summary of all data obtained is given in the Appendix (Tables 2A through 12A).

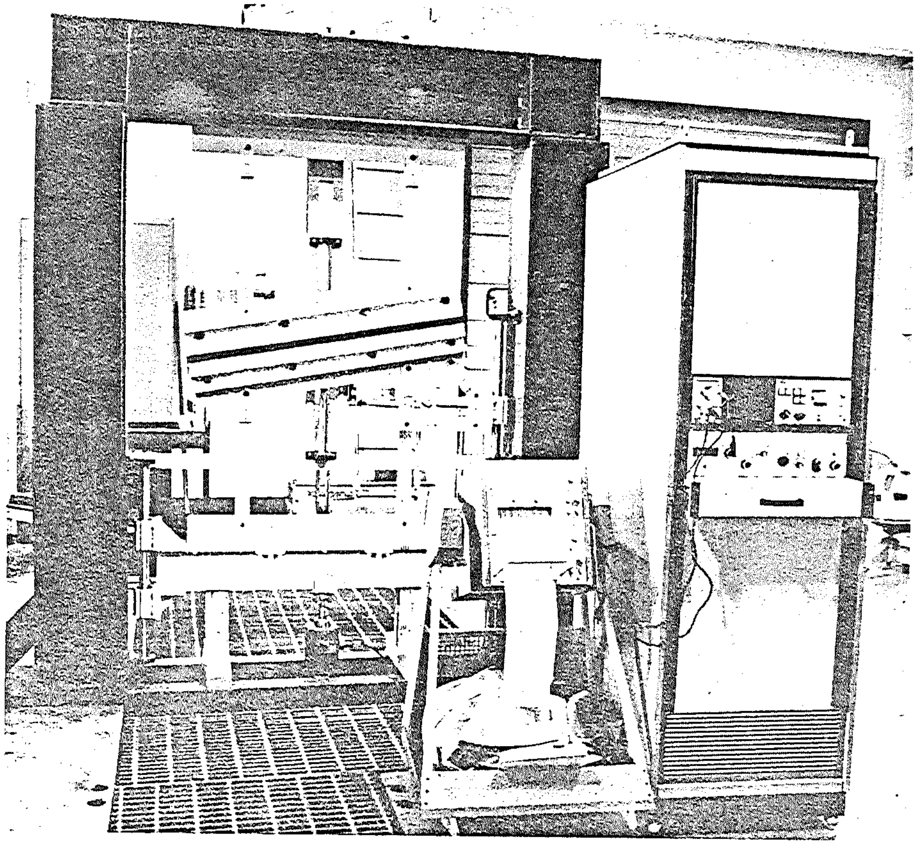
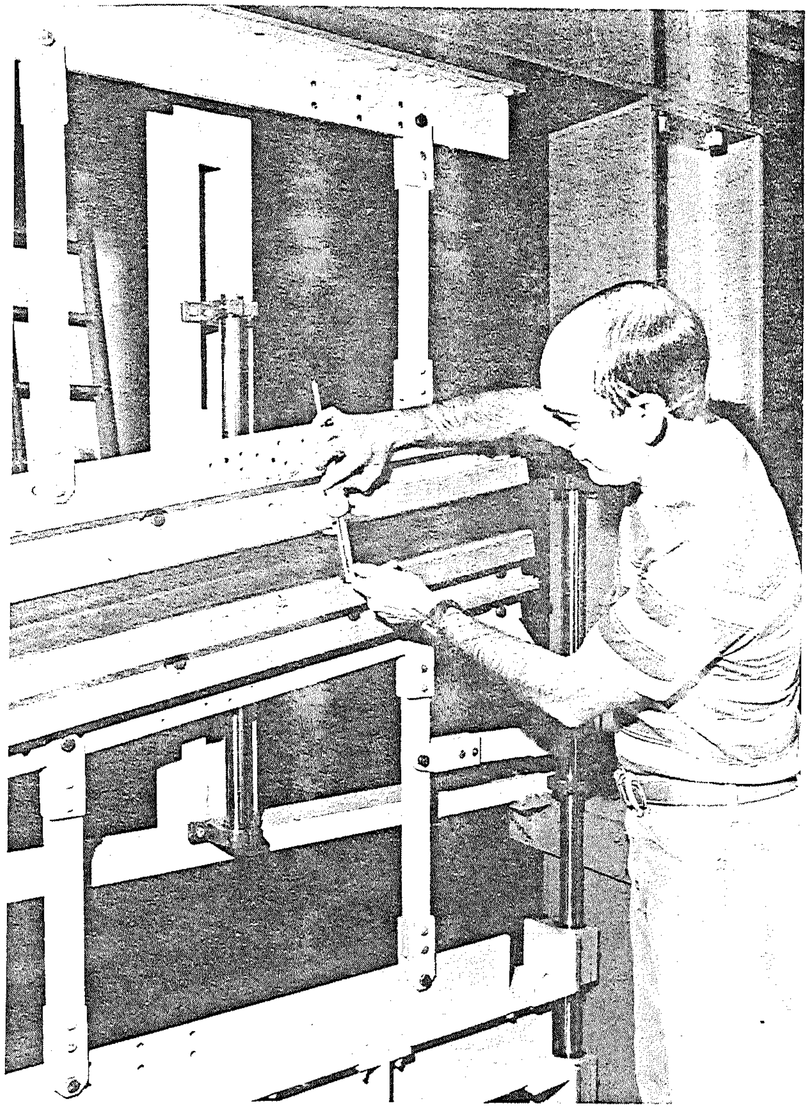


Figure 1. Testing frame, MTS controller, strip recorder, and joint device (installed at an 80-degree angle of crossing).

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



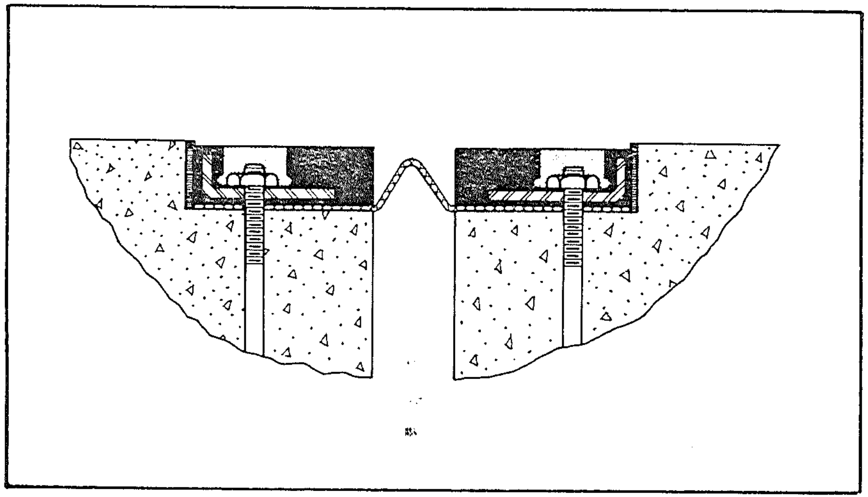


Figure 3. Fel-Span CS T-30A system.

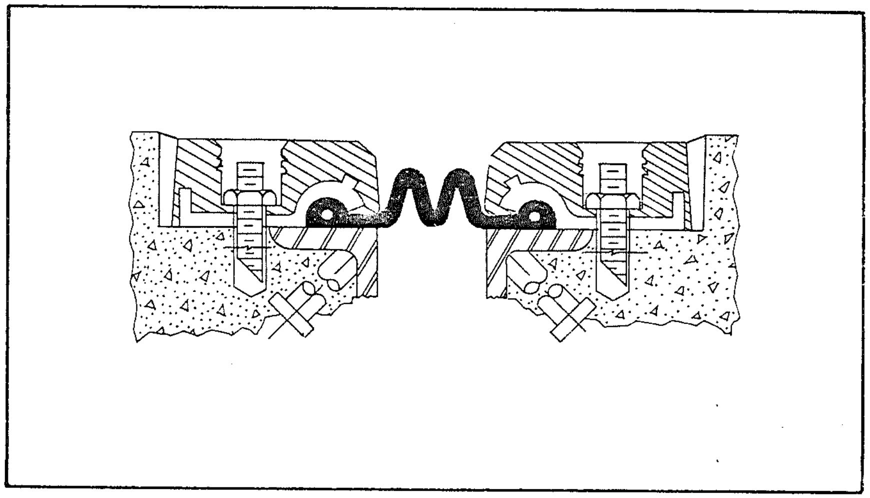


Figure 5. Acme 4-in. Trojan with TR-400 gland.

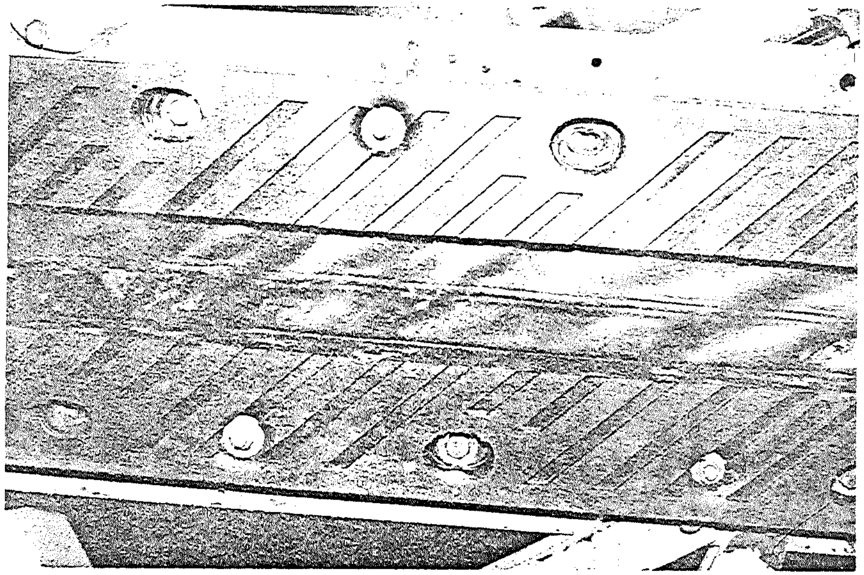


Figure 4. Fel-Span CS 3-in. system in extension at a 60-degree angle of crossing. Sealing gland is stretched taut.

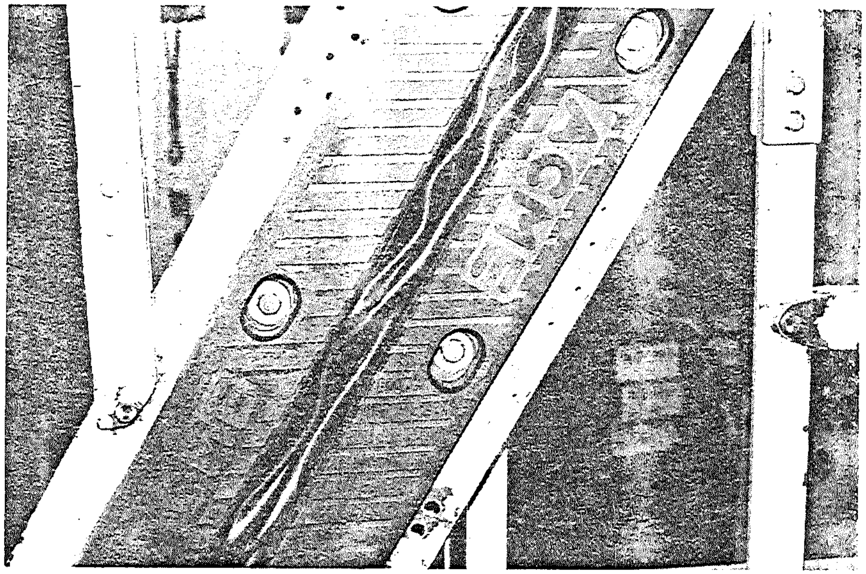


Figure 6. Acme Trojan with TR-400 gland at a 30-degree angle of crossing. The sealing gland has buckled upon closing and extends above the surface of the pads.

LABORATORY EVALUATION

Fel-Span CS System

Fel-Pro Inc. submitted their Fel-Span CS system in the 2, 3, and 4-in. movement categories. The 3 and 4 in. sealing glands had been redesigned and then resubmitted for evaluation.

This system is comprised of a continuous length fabric-reinforced elastomeric sealing gland positioned between a concrete seat and bolt-down, steel reinforced, elastomeric hold-down pads (Fig. 3).

The manufacturer's data recommends a midpoint joint width setting of 1/4 in. plus one-half the manufacturer's rated joint movement. This causes the midpoint openings for the 2, 3, and 4-in. devices to be 1-1/4, 1-3/4, and 2-1/4 inches, respectively.

Evaluation of the 2-in. system shows that it is not capable of providing its rated perpendicular movement at a 90-degree angle of crossing. Upon closure of the joint, and prior to reaching minimum stated closure, the sealing gland becomes compressed between the hold-down pads and excessive force develops.

The 3-in. system provides its rated perpendicular movement from a 90 through 60 degree angle of crossing. At angles of crossing below 60 degrees, the sealing gland becomes stretched taut prior to reaching the 3-1/4 in. perpendicular joint opening (Fig. 4).

The 4-in. system becomes limited in movement capability for the same reason as does the 3-in. system. However, the limitation develops at angles of crossing below 70 degrees.

Table 1 summarizes the experimentally determined movement limits for the Fel-Span CS system.

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

Joint System	Angle of Crossing						
	90°	80°	70°	60°	50°	40°	30°
Fel-Span CS T-20 (2 in.)	1.9	1.9	1.9	1.8	1.8	1.6	1.3
Fel-Span CS T-30A (3 in.)	3.0	3.0	3.0	3.0	2.7	2.5	2.2
Fel-Span CS T-40A (4 in.)	4.0	4.0	4.0	3.9	3.8	3.5	3.2

Acme Trojan System

Acme Highway Products Corp. had included their 4-in. movement, low profile Trojan TR system among their systems submitted for our original testing. In view of the original test results (see Appendix, Table 1A), the manufacturer has completely redesigned the 4-in. Trojan sealing gland and resubmitted this system for evaluation in this testing program.

The Trojan system consists of a continuous length elastomeric sealing gland positioned between a cast-in-place metal seat and bolt-down aluminum reinforced elastomeric pads (Fig. 5). The manufacturer also produces a Titan system which uses the same sealing gland, but the hold-down is an aluminum extrusion instead of an aluminum reinforced elastomeric pad. Since the glands and midpoint settings for both systems are the same, the Trojan system and Titan system have been considered as one system.

The manufacturer's recommended midpoint opening is 3/4 in. plus one-half the manufacturer's rated movement. This yields a midpoint opening of 2-3/4 in. for the Trojan 4 in. system.

This system is capable of providing the full 4 in. of perpendicular movement for angles of crossing from 90 through 40 degrees. At a 30 degree angle of crossing, the sealing gland buckles severely and extends above the surface of the hold-down pads, prior to reaching the minimum closure (Fig. 6).

Table 2 is a summary of the experimentally determined movement limits for the Acme 4-in. systems.

TABLE 2
EXPERIMENTALLY DETERMINED PERPENDICULAR
MOVEMENT CAPABILITIES (IN INCHES) OF
ACME TR 400 SYSTEM VS. ANGLE OF CROSSING

Joint System	Angle of Crossing						
	90°	80°	70°	60°	50°	40°	30°
Trojan TR 400 (4 in.)	4.0	4.0	4.0	4.0	4.0	4.0	2.5

Steelflex RS and Delastiflex MT/CP Systems

The D. S. Brown Co. submitted two systems for evaluation, a strip seal system called the Steelflex RS in the 3 and 4-in. movement categories, and their Delastiflex MT/CP system in the 3-in. movement category.

Steelflex RS systems consist of continuous length elastomeric sealing glands with locking lugs (arrows) which fit into cavities in the vertical faces of rolled steel frame rails which are cast-in-place in the deck. The lugs are inserted with the aid of a lubricant adhesive (Fig. 7).

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

Delastiflex MT/CP systems consist of continuous length elastomeric, double layered, sealing belts with edge seals and bottom locking lugs which fit into cavities in aluminum frames. The sealing belt tested was a snow plow resistant (SPRR) design with added thickness at the riding surface and recessed sealing layers (Fig. 8).

The manufacturer's recommended midpoint joint opening for the Delastiflex MT/CP system is 1/2 in. plus one-half the manufacturer's rated movement. The midpoint opening for the 3-in. system would, therefore, be 2-in.

At angles of crossing of 90 through 60 degrees, the 3-in. Steelflex RS system provides the rated perpendicular movement. At 50 degrees or less the sealing gland inverts (prior to reaching maximum opening) and extends above the top surface of the steel frame rails (Fig. 9). The inverted gland is then susceptible to damage by traffic.

Evaluation of the 4-in. Steelflex RS system indicates it can provide the manufacturer's rated perpendicular movement for angles of crossing of 90 through 70 degrees; for lesser angles this gland develops the same problem as the 3-in. gland.

Our evaluation of the Delastiflex MT/CP 3-in. system indicates that it is not capable of providing the manufacturer's rated perpendicular movement. At angles of crossing of 90 through 50 degrees, the sealing belt becomes tight between the aluminum frames at closure. Excessive force develops which starts to buckle the aluminum. At angles of crossing less than 50 degrees, a problem develops in extension which further limits movement capability. As the joint opening is increased, the gland inverts upward (prior to reaching maximum opening), becoming susceptible to possible damage by traffic (Fig. 10).

Table 3 is a summary of the experimentally determined movement limits for D. S. Brown systems evaluated.

TABLE 3
EXPERIMENTALLY DETERMINED PERPENDICULAR MOVEMENT CAPABILITIES (IN INCHES) OF D. S. BROWN SYSTEMS VS. ANGLE OF CROSSING

Joint System	Angle of Crossing						
	90°	80°	70°	60°	50°	40°	30°
Steelflex RS-300 (3 in.)	3.0	3.0	3.0	3.0	2.2	2.0	1.0
Steelflex RS-400 (4 in.)	4.0	4.0	4.0	2.7	1.5	1.2	0.8
Delastiflex MT/CP 300 (3 in.)	2.8	2.8	2.8	2.8	2.8	2.2	1.6

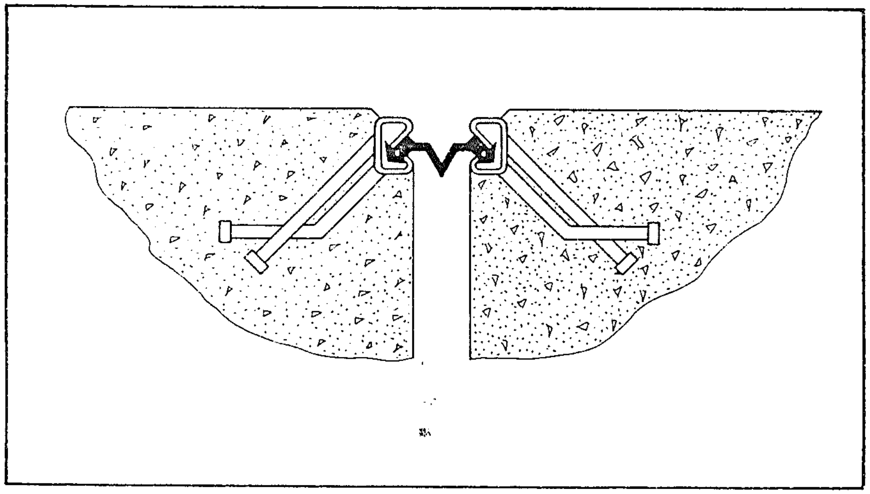


Figure 7. D. S. Brown Steelflex-RS system.

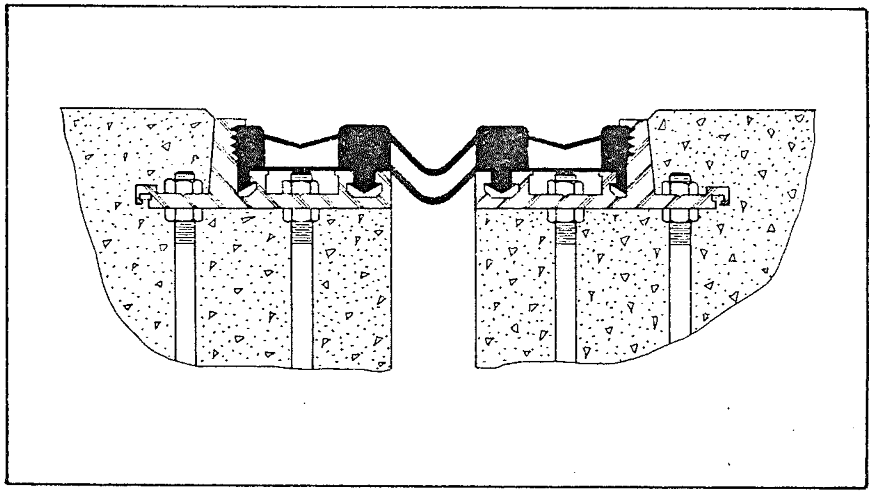


Figure 8. Delastiflex MT/CP system with SPRR sealing belt.

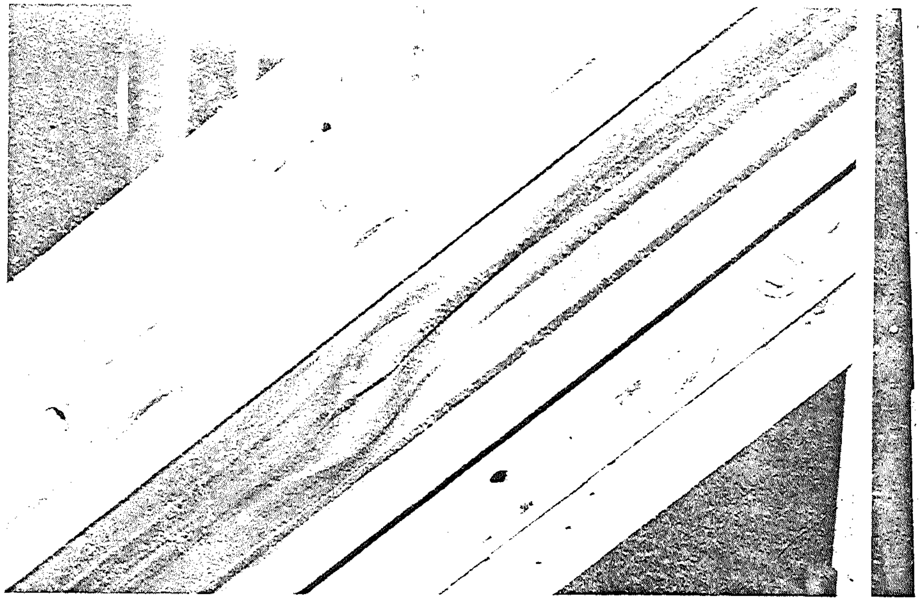


Figure 9. Steelflex RS 3-in. system in extension at a 50-degree angle of crossisng. The sealing gland has buckled and inverted above the top surface of the steel frame rails.

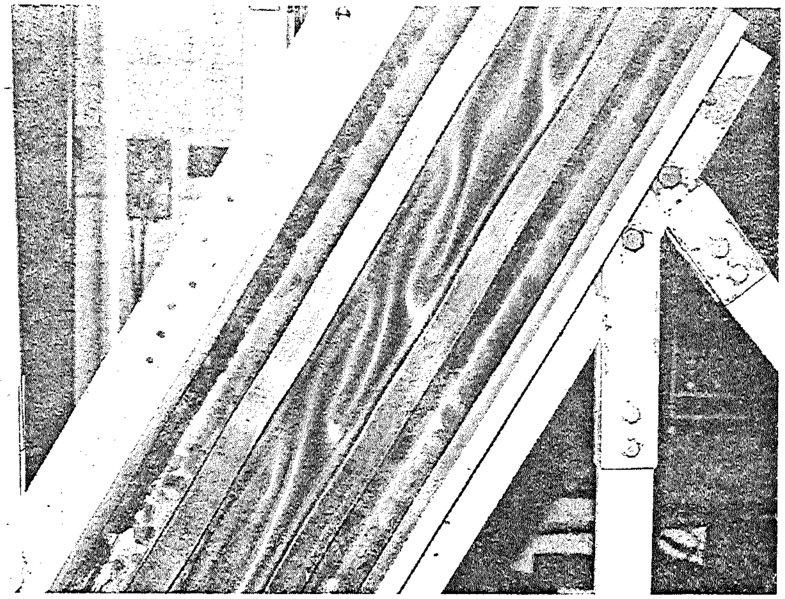


Figure 10. Delastiflex MT/CP system with 3-in. SPRR sealing gland at a 30-degree angle of crossing. The gland has rippled and extends above the top of the riding surface.

Wabo Bendoflex Systems

Watson Bowman Associates, Inc. submitted their Wabo Bendoflex system in the 2-1/2 and 4-1/2 in. total movement ranges.

The fiber reinforced elastomeric sealing membrane is corrugated and is reported by the manufacturer to be engineered to accomodate the more severe angles of crossing. The membrane is positioned between a concrete seat and bolt-down aluminum hold-down panels (Fig. 11).

The manufacturer's literature recommends that the midpoint joint width be set at 3/4 in. plus one-half the manufacturer's rated joint movement for the 2-1/2-in. system, and 1/2 in. plus one-half the rated joint movement for the 4-1/2-in. system. Thus the midpoint openings are 2 and 2-3/4 in., respectively.

The 2-1/2-in. Wabo Bendoflex system can provide its rated perpendicular movement throughout the testing range of 90 through 30-degree angles of crossing.

However, the 4-1/2-in. system is not capable of providing its rated perpendicular movement at a 90-degree angle of crossing. The sealing membrane develops excessive forces in closure which start to deflect the aluminum hold down panels.

Table 4 summarizes the experimentally determined movement limits for the Wabo Bendoflex systems.

TABLE 4
EXPERIMENTALLY DETERMINED PERPENDICULAR
MOVEMENT CAPABILITIES (IN INCHES) OF
WATSON-BOWMAN SYSTEMS VS. ANGLE OF CROSSING

Joint System	Angle of Crossing						
	90°	80°	70°	60°	50°	40°	30°
Wabo Bendoflex 250 (2.5 in.)	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Wabo Bendoflex 450 (4.5 in.)	4.1	4.1	4.1	4.1	4.1	4.1	4.0

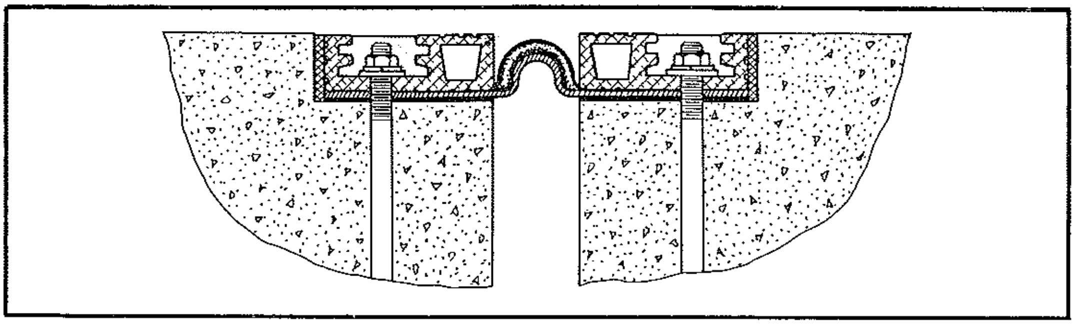


Figure 11. Wabo Bendoflex 250 system.

Gen-Strip CCL System

GT Industrial Rubber Products Co. (General Tire) submitted their Gen-Strip CCL system with the alternate wing-design diaphragm. This system is in the 4-in. movement category.

The Gen-Strip CCL system consists of a continuous length elastomeric diaphragm positioned between a concrete seat and bolt-down metal reinforced elastomeric pads (Fig. 12).

The manufacturer's recommended midpoint opening is 1 in. plus one-half the manufacturer's rated joint movement. This creates a midpoint opening of 3 in. for the 4-in. system.

Our evaluation indicates that the system is capable of providing its rated perpendicular movement at angles of crossing from 90 through 50 degrees. At angles of crossing less than 50 degrees a problem develops in closure--the diaphragm extends up above the riding surfaces of the elastomeric pads (Fig. 13). In this position the diaphragm becomes susceptible to damage by traffic.

Table 5 is a summary of the experimentally determined movement limits for the Gen-Strip CCL system.

TABLE 5
EXPERIMENTALLY DETERMINED PERPENDICULAR
MOVEMENT CAPABILITIES (IN INCHES) OF
GENERAL TIRE SYSTEM VS. ANGLE OF CROSSING

Joint System	Angle of Crossing						
	90°	80°	70°	60°	50°	40°	30°
Gen-Strip CCL (4 in.)	4.0	4.0	4.0	4.0	4.0	2.4	1.1

Onflex Strip Seal System

Structural Accessories, Inc. submitted their Onflex Model 40SF Strip Seal, which is a 4-in. movement category device.

The Strip Seal system consists of a continuous length, fiber reinforced elastomeric sealing gland with locking lugs which fit into cavities in the vertical faces of steel hold-down extrusions. The lugs are inserted with the aid of a high-solids lubricant adhesive (Fig. 14).

Midpoint joint width, as recommended by the manufacturer, is one-half the manufacturer's rated movement. This would mean that the Strip Seal could close to 0-in. However, excessive forces developed when the Strip Seal closed below 0.15 in. In extension, the sealing gland was found to

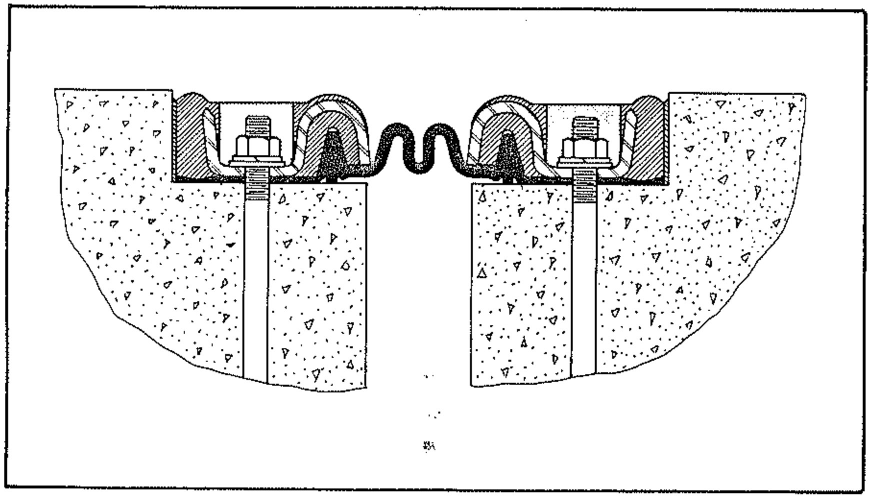


Figure 12. Gen-Strip CCL system.

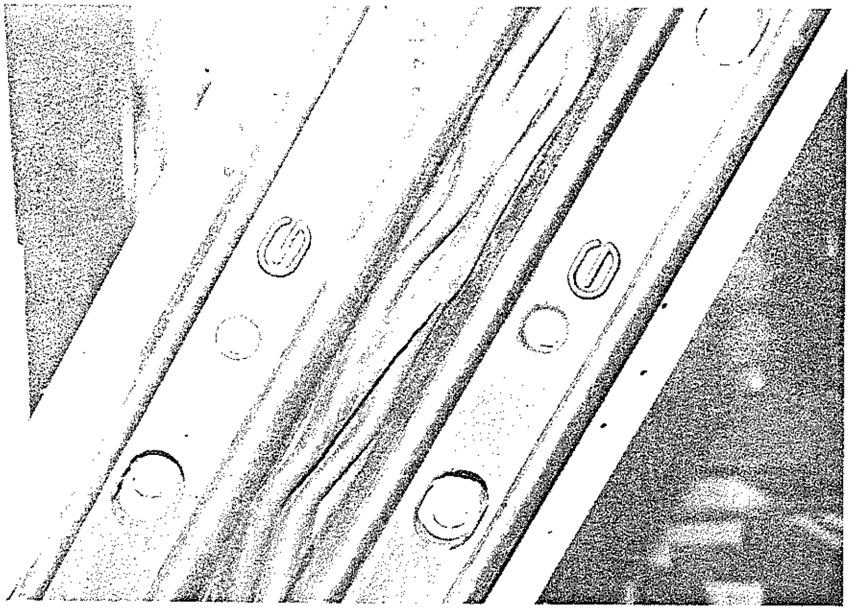


Figure 13. Gen-Strip CCL 4-in. system in closure at a 30-degree angle of crossing. The diaphragm buckles, becomes compressed between the hold-down pads, then extends above the top of the pads.

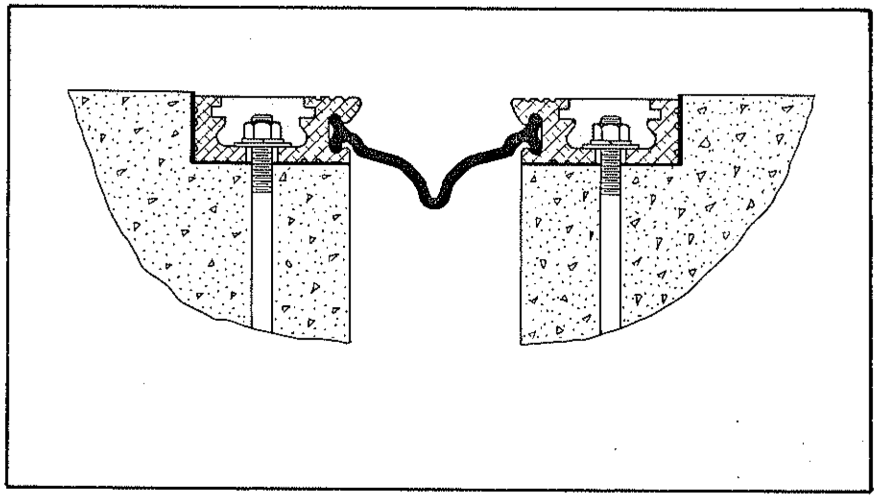


Figure 14. Onflex 40 SF Strip Seal system.

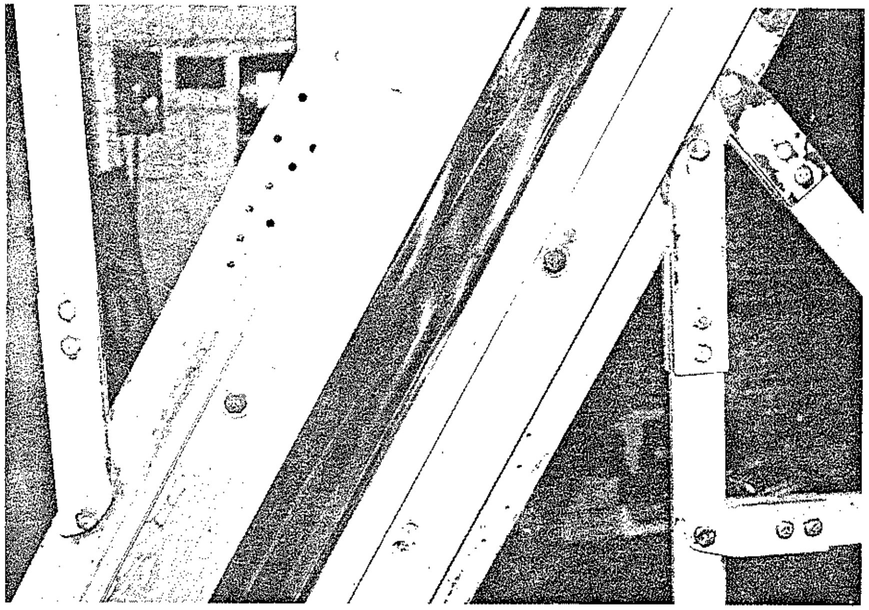


Figure 15. Onflex Strip Seal 4-in. system in extension at a 30-degree angle of crossing. At this experimentally determined limit, the gland has started to buckle. Further extension would cause the gland to invert upward.

be overdesigned at the maximum stated opening. Therefore, a midpoint joint width of 0.15 in. plus one-half the manufacturer's rated movement, or 2.15 in. was used for the 4-in. device.

Testing of the Onflex 40SF indicates that it is able to provide the manufacturer's rated movement at 90 through 60 degree angles of crossing. At angles of crossing less than 60 degrees, the sealing gland inverts upward prior to reaching its maximum rated opening (Fig. 15), becoming susceptible to damage by traffic.

Table 6 summarizes the experimentally determined movement limits for the Onflex 40 SF Strip Seal system.

TABLE 6
EXPERIMENTALLY DETERMINED PERPENDICULAR
MOVEMENT CAPABILITIES (IN INCHES) OF THE
ONFLEX STRIP SEAL SYSTEM VS. ANGLE OF CROSSING

Joint System	Angle of Crossing						
	90°	80°	70°	60°	50°	40°	30°
Onflex Strip Seal 40-SF	4.0	4.0	4.0	4.0	3.4	2.3	1.9

SUMMARY AND CONCLUSIONS

Summary

The main purpose of this project was to determine guidelines relating an expansion joint system's maximum movement capability at given angles of crossing. These experimentally determined movement limits for all systems evaluated are summarized in Table 7. Testing was limited to only one sample for each device. It must be assumed, however, that each sample submitted was well within the manufacturers' specifications and thus typical of their material, since the manufacturers were informed of the intent of our evaluation. Also, limitations established in the laboratory may vary from those that exist in actual field use due to variable construction techniques, installation procedures (especially when the device is installed at other than the midpoint setting), traffic, and environmental conditions.

TABLE 7
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°
Fel-Span CS T-20	1.9	1.9	1.9	1.8	1.8	1.6	1.3
Wabo Bendoflex 250	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Delastiflex MT/CP 300	2.8	2.8	2.8	2.8	2.8	2.2	1.6
Steelflex RS-300	3.0	3.0	3.0	3.0	2.2	2.0	1.0
Fel-Span CS T-30A	3.0	3.0	3.0	3.0	2.7	2.5	2.2
Acme Trojan TR 400	4.0	4.0	4.0	4.0	4.0	4.0	2.5
Steelflex RS-400	4.0	4.0	4.0	2.7	1.5	1.2	0.8
Fel-Span CS T-40A	4.0	4.0	4.0	3.9	3.8	3.5	3.2
Onflex Strip Seal 40-SF	4.0	4.0	4.0	4.0	3.4	2.3	1.9
Gen-Strip CCL 4 in.	4.0	4.0	4.0	4.0	4.0	2.4	1.1
Wabo Bendoflex 450	4.1	4.1	4.1	4.1	4.1	4.1	4.0

These guidelines represent physical limitations of the expansion devices from the manufacturer's recommended midpoint setting. They do not take into account the width of the joint opening at the riding surface. The maximum perpendicular opening would be the manufacturer's midpoint width plus one-half the experimentally determined movement rating.

It is important to note that many manufacturers produce more than one style of sealing gland for the same expansion joint system. Our testing indicates that relatively minor changes in the configuration of the gland can have a major influence on the limitations of the system. Therefore, the guidelines established under this project may pertain only to the particular style of gland evaluated.

Some manufacturer's literature states that their system can accommodate 'overtravel'. Our testing has found that the overtravel is in extension only and not in closure. In fact, it appears that in some cases the overtravel (safety factor) was already included in their recommended movement rating for the system.

When discussing the problems encountered with the various systems, the most severe limiting factor for each system was stated. Frequently movement limitations occurred in both directions, that is, in both closure and extension. Usually the determining limitation was significantly more severe than any limitation occurring in the opposite direction. Occasionally, however, the determining limitation occurred in one direction through the less severe angles of crossing, as well as in the opposite direction through the more severe angles of crossing.

Before the data from our first testing series were available for use (Table 1A in Appendix), the bridge designer would simply specify an expansion joint device for installations with severe angles of crossing that had a movement rating greater than would have been required for the same joint at a 90-degree angle of crossing. As an example, if 3 in. of perpendicular movement were required at a 40-degree angle of crossing, the designer would arbitrarily specify a system rated at 4 in. of perpendicular movement. Our earlier evaluations had shown that this method was often invalid, since some 3-in. devices can accomodate more movement than a similar 4-in. device at severe angles of crossing (Figs. 1A and 2A in Appendix). Evaluations resulting from this second testing series have confirmed our earlier findings (Fig. 3A in Appendix).

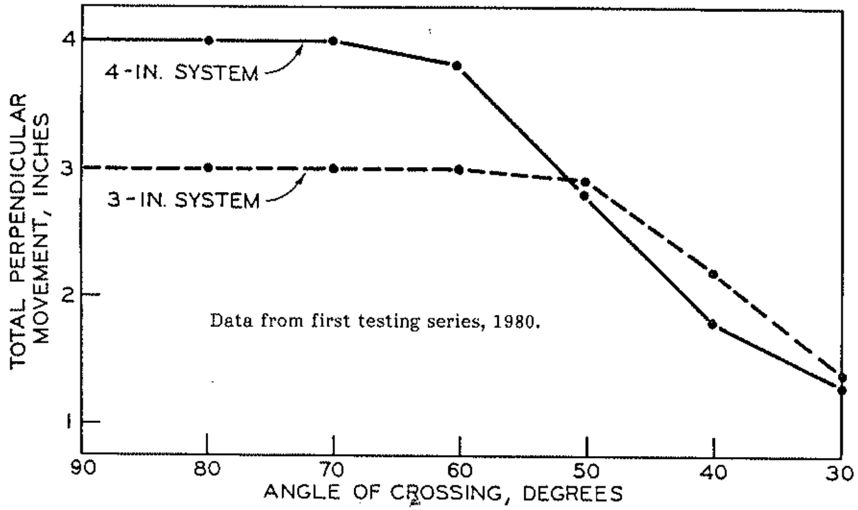
Conclusions

The majority of the expansion joint systems evaluated can provide their full perpendicular movement range (as rated by the manufacturer) 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.

Several of the expansion joint systems failed to provide the manufacturer's full movement rating at a 90-degree angle of crossing. The movement ratings have, therefore, been decreased for our design purposes.

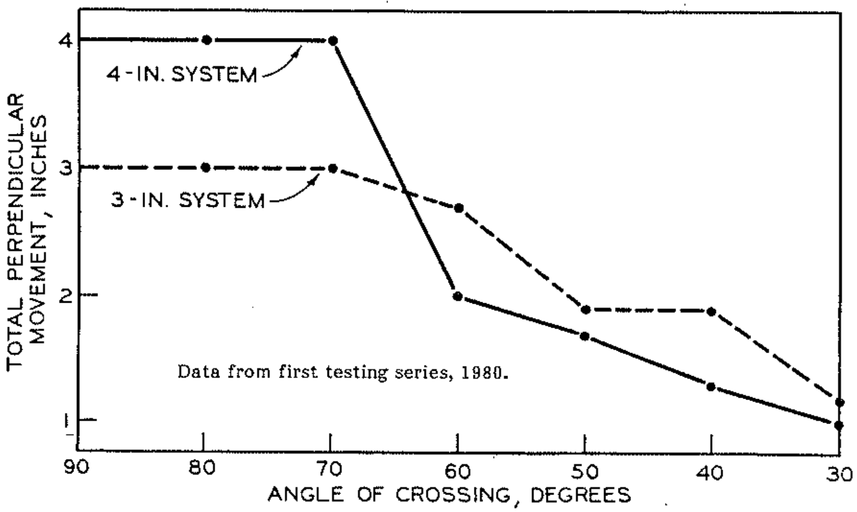
The seemingly logical assumption that a system which provides the most movement capability at a 90-degree angle of crossing will also provide the most movement at more severe angles of crossing is not always valid. Our test results show that some systems providing 4 in. of perpendicular movement at a 90-degree angle of crossing actually provide less movement at a 30-degree angle of crossing than a similar system which provides only 3 in. of perpendicular movement at a 90-degree angle of crossing.

APPENDIX



Data from first testing series, 1980.

Figure 1A. 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.



Data from first testing series, 1980.

Figure 2A. 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.

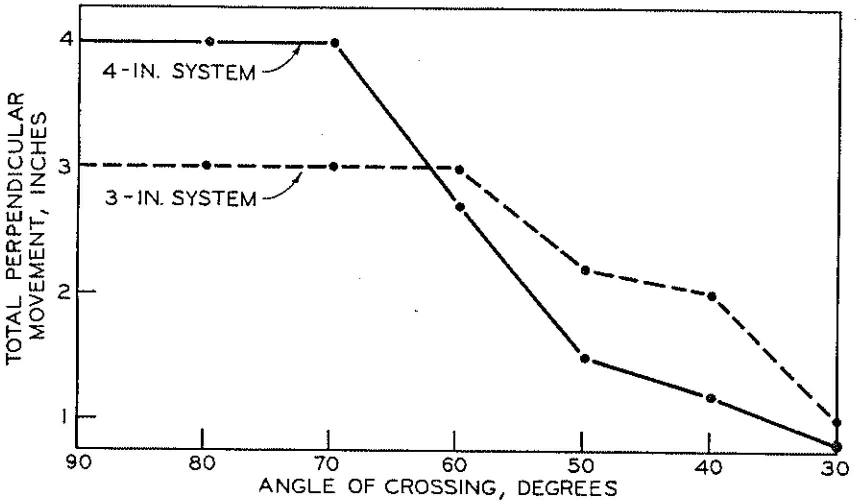


Figure 3A. A comparison of the perpendicular movement capabilities of a Steelflex RS 4-in. system vs. a Steelflex RS 3-in. system at various angles of crossing.

DATA FROM FIRST TESTING SERIES
1980

TABLE 1A
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

TABLE 2A
FEL-PRO FEL-SPAN CS T-20 (2 INCH)

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	0.95	0.95	0.80
Experimentally determined limit in closure, in., perpendicular (from midpoint)	0.95	—	—	0.90	0.90	0.80	0.65
Assigned limit, in., perpendicular (from midpoint)	0.95	—	—	0.90	0.90	0.80	0.65
Force in extension at assigned limit, lb/lin ft	70	—	—	100	400	180	240
Force in closure at assigned limit, lb/lin ft	540	—	—	550	530	560	500

TABLE 3A
FEL-PRO FEL-SPAN CS T-30A (3 INCH)

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	1.50	1.35	1.25	1.10
Experimentally determined limit in closure, in., perpendicular (from midpoint)	1.50	1.50	1.50	1.50	1.45	1.40	1.15
Assigned limit, in., perpendicular (from midpoint)	1.50	1.50	1.50	1.50	1.35	1.25	1.10
Force in extension at assigned limit, lb/lin ft	170	—	—	300	370	410	450
Force in closure at assigned limit, lb/lin ft	370	—	—	550	460	390	250

TABLE 4A
FEL-PRO FEL-SPAN CS T-40A (4 INCH)

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	1.95	1.90	1.75	1.60
Experimentally determined limit in closure, in., perpendicular (from midpoint)	2.00	2.00	2.00	2.00	1.90	1.75	1.65
Assigned limit, in., perpendicular (from midpoint)	2.00	2.00	2.00	1.95	1.90	1.75	1.60
Force in extension at assigned limit, lb/lin ft	240	—	—	340	420	330	540
Force in closure at assigned limit, lb/lin ft	400	—	—	600	530	510	480

TABLE 5A
ACME TROJAN TR 400 (4 INCH)

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	2.00	2.00	2.00
Experimentally determined limit in closure, in., perpendicular (from midpoint)	2.00	2.00	2.00	2.00	2.00	2.00	1.25
Assigned limit, in., perpendicular (from midpoint)	2.00	2.00	2.00	2.00	2.00	2.00	1.25
Force in extension at assigned limit, lb/lin ft	100	—	—	—	150	170	140
Force in closure at assigned limit, lb/lin ft	110	—	—	—	250	340	170

TABLE 6A
D. S. BROWN STEELFLEX RS-300 (3 INCH)

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	1.50	1.10	1.00	0.50
Experimentally determined limit in closure, in., perpendicular (from midpoint)	1.50	1.50	1.50	1.50	1.45	1.40	1.40
Assigned limit, in., perpendicular (from midpoint)	1.50	1.50	1.50	1.50	1.10	1.00	0.50
Force in extension at assigned limit, lb/lin ft	0	—	—	90	100	150	160
Force in closure at assigned limit, lb/lin ft	600	—	—	490	170	220	130

TABLE 7A
D. S. BROWN STEELFLEX RS-400 (4 INCH)

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	1.35	0.75	0.60	0.40
Experimentally determined limit in closure, in., perpendicular (from midpoint)	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Assigned limit, in., perpendicular (from midpoint)	2.00	2.00	2.00	1.35	0.75	0.60	0.40
Force in extension at assigned limit, lb/lin ft	0	—	60	50	60	60	110
Force in closure at assigned limit, lb/lin ft	270	—	360	90	60	70	60

TABLE 8A
D. S. BROWN DELASTIFLEX MT/CP 300 (3 INCH)

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	1.50	1.50	1.10	0.80
Experimentally determined limit in closure, in., perpendicular (from midpoint)	1.40	1.40	1.40	1.40	1.40	1.40	1.30
Assigned limit, in., perpendicular (from midpoint)	1.40	1.40	1.40	1.40	1.40	1.10	0.80
Force in extension at assigned limit, lb/lin ft	20	—	—	160	280	240	290
Force in closure at assigned limit, lb/lin ft	580	—	—	430	360	300	320

TABLE 9A
WATSON-BOWMAN WABO BENDOFLEX 250 (2.5 INCH)

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)	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Assigned limit, in., perpendicular (from midpoint)	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Force in extension at assigned limit, lb/lin ft	90	—	—	170	70	300	350
Force in closure at assigned limit, lb/lin ft	400	—	—	310	430	500	460

TABLE 10A
WATSON-BOWMAN WABO BENDOFLEX 450 (4.5 INCH)

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	2.25	2.25	2.25
Experimentally determined limit in closure, in., perpendicular (from midpoint)	2.05	2.05	2.05	2.05	2.05	2.05	2.00
Assigned limit, in., perpendicular (from midpoint)	2.05	2.05	2.05	2.05	2.05	2.05	2.00
Force in extension at assigned limit, lb/lin ft	70	—	—	100	140	180	240
Force in closure at assigned limit, lb/lin ft	520	—	—	550	480	540	520

TABLE 11A
GENERAL TIRE GEN-STRIP CCL (4 INCH)

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	2.00	2.00	0.85
Experimentally determined limit in closure, in., perpendicular (from midpoint)	2.00	2.00	2.00	2.00	2.00	1.20	0.55
Assigned limit, in., perpendicular (from midpoint)	2.00	2.00	2.00	2.00	2.00	1.20	0.55
Force in extension at assigned limit, lb/lin ft	60	—	100	100	130	90	80
Force in closure at assigned limit, lb/lin ft	60	—	270	120	200	150	100

TABLE 12A
ONFLEX STRIP SEAL 40-SF (4 INCH)

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	1.70	1.15	0.95
Experimentally determined limit in closure, in., perpendicular (from midpoint)	2.00	2.00	2.00	2.00	1.85	1.75	1.65
Assigned limit, in., perpendicular (from midpoint)	2.00	2.00	2.00	2.00	1.70	1.15	0.95
Force in extension at assigned limit, lb/lin ft	30	—	--	110	120	150	170
Force in closure at assigned limit, lb/lin ft	540	—	—	490	380	170	200