ANALYSIS OF METHODS OF COMPRESSION-DEFLECTION TESTING OF PREFORMED ELASTOMERIC COMPRESSION SEALS

Douglas Huffman, The D. S. Brown Company

This paper is a study of some of the ways in which compression-deflection tests vary; specifically, the number of compression cycles that must be run and the effect of varying total deflection and crosshead speeds were studied. The study shows that 3 compression-deflection cycles must be run before the force-deflection curve produced approximates the equilibrium force-deflection curves. If fewer cycles are run, the results cannot be considered equal to the equilibrium values and hence characteristic of the seal's true performance in service. The study also pointed to 2 sources of variance in the test results. The first source was changing loads; as the loads or total deflection changes, values on the force-deflection curves also change. The result is that, if 2 different loads are chosen to test identical seals, values common to both force-deflection curves produced will not be equal. The second source was crosshead speeds. Though the speed variance was not so great as the variance caused by changing loads, it generally, for the speeds tested, produced results that were not equal. The results and accompanying conclusions show how those factors affected the tests and suggest possible solutions to the problem.

•A RELATIVELY new test for preformed elastomeric joint seals is the compression-deflection test. Its purpose is to measure the ability of the rubber seal to retain elastic properties and generate sealing forces after prolonged compressive stresses that might be encountered in actual use. Although this test is not an absolute indicator of performance, it serves as an excellent comparative test. Measurements taken show the minimum compression needed to make the seal remain in the joint, and the strength at the maximum compression indicates whether the seal can be installed properly without undue effort and indicates the seal's ability to resist deterioration of force generation as a result of overstressing.

Lack of standardization in the method of performing this test has led to uneconomical testing and a variability in the results obtained. This study attempted to find some of the sources of variability and wasted effort and to find a reliable and economic method of conducting the compression-deflection test.

PROCEDURE

Sample Preparation

In this study, random samples representing different types of joint seals from recently manufactured lots were secured for testing. A lot of a given type that was chosen for testing was used throughout the study to eliminate as much arbitrary variance as possible. Figure 1 shows the 4 types of seals used.

For each experiment, 10 samples were prepared. Preparation was done in accordance with ASTM D 15. Each specimen was cut to a length of 6 ± 0.1 in. These

Publication of this paper sponsored by Committee on Sealants and Fillers for Joints and Cracks.

specimens were then washed with water and air-dried. No further preparation of the sample was conducted. Each sample was marked with a number to be used as identification.

After the test seals were prepared, an information sheet was written up for each specimen. The information consisted of type of seal, lot number, production date, sample number, maximum and minimum pressures at which deflection would be recorded, weight of the sample, and dimensions of the seal. The dimensions were measured by a dial micrometer to the nearest 0.001 in. Four width measurements were taken: at the lugs, at the top, at the bottom, and at the maximum width. Height was measured on each side of the test seal. The samples were then ready for testing.

Testing Procedure

Regardless of the experiment, the testing procedure was basically the same. For this study, an Instron universal testing instrument, model TT-D equipped with a graphical recorder, was used.

At the start of each day, and whenever necessary, the testing instrument was calibrated according to the operating instructions of the machine. Before each test, the calibration was checked and, when necessary, recalibrated. The crosshead and chart speeds were set according to the specifications of the experiment. The balance on the chart was adjusted so that the force on the graphical recorder read zero.

The sample to be tested was placed between the 2 plates of the testing machine in the center of the lower plate. (The upper plate is the crosshead.) The balance was readjusted so the force once again read zero. That procedure removes the effects of the weight of the sample on the results.

The information sheet, mentioned earlier, was used to record the test date, the crosshead and chart speed, and the operator's initials. Throughout the testing procedure, all data were recorded on that same information sheet.

The load selector was set on the lightest load, and the crosshead was lowered manually until the first complete contact along any edge of the seal was made. The separation between the plates was read from the gauge length dials to the nearest 0.001 in. and recorded. There should be very little pressure on the test seal at this point. Before anything else was done, the seal was adjusted between the plates so that the top of the seal was perpendicular to the plates. The crosshead was manually lowered farther until the force on the seal was 2 percent of the full-scale load that had been selected for the test. The load selector was turned to the selected load. When a load had been selected, the machine automatically controlled the stopping of the crosshead. As the crosshead traveled downward, it stopped when a force of 90 percent of the selected load was reached. When the crosshead traveled in the opposite direction, the machine stopped when the force became only 2 percent of the selected load.

The graphical recorder was engaged. The graph paper used was divided into 1-in. squares, which were subdivided into $\frac{1}{10}$-in. squares. For convenience, the recorder was engaged so that when the test began the recording of the deflection started at the edge of one of the inch squares. The machine was now ready to begin the test.

The crosshead was started at the preselected crosshead speed. The chart was activated simultaneously. The crosshead stopped at 90 percent of the selected load; that was the maximum deflection. At that point, the distance between the plates was read and recorded. The whole operation of reading the separation between the plates took only a matter of seconds, and then the crosshead was started again. When the force was only 2 percent of the selected load, the crosshead once again stopped and the separation of the plates was read and recorded. That completed 1 cycle. This procedure was repeated for the number of cycles that were selected. At the end of every other cycle, however, the process was stopped momentarily so that a new graph could be started. That facilitated the reading of the graphs.

When a graph was completed, the machine was zeroed to check for changes in the balance. A new graph was then started in like manner. When all the cycles were completed, the machine was zeroed, and the graphs were removed in a group. They were labeled with the date, the full-scale load, the crosshead and chart speeds, the type of seal, and the number of the test sample. The graphs and the information sheet were used to analyze results.

The crosshead was raised, the sample was removed and dated, and the machine was then ready for the next test.

Test to Determine Adequate Number of Cycles

"It has been known for many years that deformation in softening of rubber and the initial stress-strain curve determined during the first deformation are unique and cannot be retraced. Further the effect of repeated deformation is to cause rubber asymptotically to approach a steady state with a constant or equilibrium stress-strain curve" (1).

The purpose of this set of experiments was to determine how many force-deflection cycles are necessary to achieve at least a statistical equilibrium.

A set of 10 samples of preformed joint seals was tested. In each case a crosshead speed of 0.5 in./min was used in accordance with ASTM D 575. In practice, The D.S. Brown Company uses 3 loads when testing each seal.

The middle load was chosen for the tests. Previous experience had shown that equilibrium is reached by at least the sixth cycle, so 6 cycles were run on each specimen.

This test was run on 4 types of preformed elastomeric joint seals in case the seals behaved differently under force-deflection. Successive cycles were compared to determine the cycles necessary before 2 cycles could be considered statistically equal.

Test to Check Effect of Different Loads

Currently the states do not specify any load to be used in the testing of the road seals. Because different loads result in different total deflection, the question arises as to whether the final force is affected at points of deflection of importance. This set of experiments was designed to answer that question.

The results of the first group were used as a control. Ten new samples of each type of seal were tested again in a similar manner. A crosshead speed of 0.5 in./min was used to compress the seals, but a different load was chosen. The results of that experiment were then compared with the original set of results to determine whether the load chosen could affect the final result.

Test to Determine the Effect of Crosshead Speeds

ASTM Test D 575 recommends a crosshead speed of 0.5 in./min when force-deflection tests are performed. Nevertheless, state specifications for this test vary from 0.2 in./min to no specified speed. There is a possibility that a seal may fatigue differently when different crosshead speeds are used and, therefore, affect the final results. This set of experiments was an attempt to determine whether there would be such an effect over a narrow range of crosshead speeds that might be used to run the force-deflection test.

Ten new samples were prepared for testing. They were divided into 2 sets of 5 specimens each. The first set was tested with a crosshead speed of 0.2 in./min, and the second set was tested at 1.0 in./min. For the given type of seal, the load chosen was the same as that chosen for the test to determine the adequate number of cycles. The results of the tests were compared to see whether they were statistically equal. When they proved not to be equal, each set was then individually compared to the results of the test to determine the adequate number of cycles because the only condition that was different in the 2 tests was the crosshead speed. Unequal results indicated that crosshead speeds could affect the results.

EVALUATION OF TEST RESULTS

Every graph of a force-deflection curve of a preformed joint seal has several points that are characteristic of that seal. For the purposes of this test, points x and y were used. x is the breaking point on the return cycle and represents the pressure at the widest opening at which a seal will remain in place. y, or the point of safe compressibility, is defined as the pressure at the point at which all webs initially make contact. Figure 2 shows the 4 seals compressed to y. x and y were read off the graph for every cycle. Figure 3 shows the points for the 6 cycles run on one seal sample. For those cycles, the load was 400 lb, the crosshead speed was 0.5 in./min, and the chart speed was 2.5 in./min. When the values are read, the base line is used as the reference for the force readings. The nearest 1-in. square line at the start of the graph is used as a reference for the deflection readings. Every $\frac{1}{10}$-in. square represents one unit. The x and y values for every cycle are recorded on the appropriate form.

A balance line reading was also taken. The balance line reading equals the force reading at A minus the force reading at B plus the force reading at C (Fig. 3).

Two more readings taken from the graph for each cycle were the initial chart and the final chart readings (Fig. 3). Those readings were taken on the deflection scale. The initial chart reading is at the start of the downward movement of the crosshead, and the final chart is the reading at the completion of the crosshead's downward movement.

The dimensions of the test seal, the full-scale loading used for the test, and all information read from the chart are fed into the programmed calculator. The pounds per square inch at x and y are calculated in the following manner:

$$\text{psi at } x = \frac{F_x}{L \times H}$$

$$\text{psi at } y = \frac{F_y}{L \times H}$$

where

F_x = force at x = $(f_x - BL)$ FS/100,
F_y = force at y = $(f_y - BL)$ FS/100,
H = average height = $(h_1 + h_2)/2$,
f_x = force reading at x from graph,
f_y = force reading at y from graph,
BL = balance line reading,
FS = loading selected for test,
L = length of test seal, and
h_1, h_2 = 2 recorded heights of test seal.

For each group of 10 samples, the above information was determined, and then a sample mean $\bar{x}$ and sample variance S^2 were calculated for the pounds per square inch at both x and y.

All 3 sets of tests conducted required calculations to determine whether 2 groups of samples were statistically equal. For this purpose a 2-sample t-test for the difference between 2 means was used whenever possible. This test was used rather than normal distribution tests because the population variance was unknown and small samples were being used. The t-test requires the assumption that the 2 population variances σ_1^2 and σ_2^2 are equal. Therefore, before the 2-sample t-test is used, this assumption must be tested. This was done by using an F-statistic.

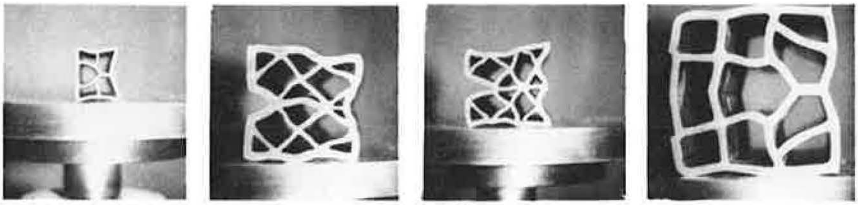
$$F = \frac{S_M^2}{S_m^2}$$

where

S_M^2 = larger of the sample variances, and
S_m^2 = smaller of the sample variances.

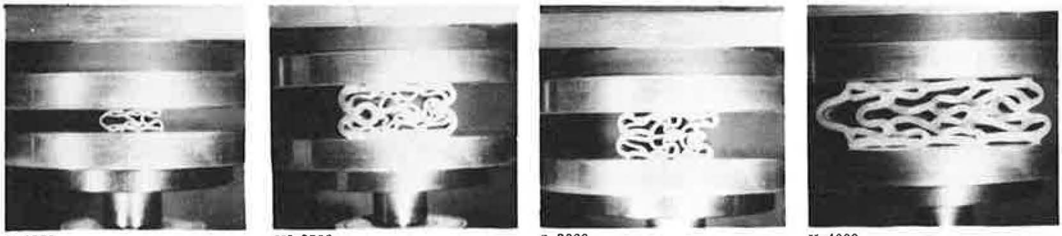
F is the value of the test statistic having an F-distribution with $(n_M - 1)$ and $(n_m - 1)$ degrees of freedom, where n_M and n_m are the respective number of values in each sample group. The null hypothesis H_0 is that $\sigma_1^2 = \sigma_2^2$, and the alternative hypothesis H_1 is that

Figure 1. Uncompressed samples of test seals.



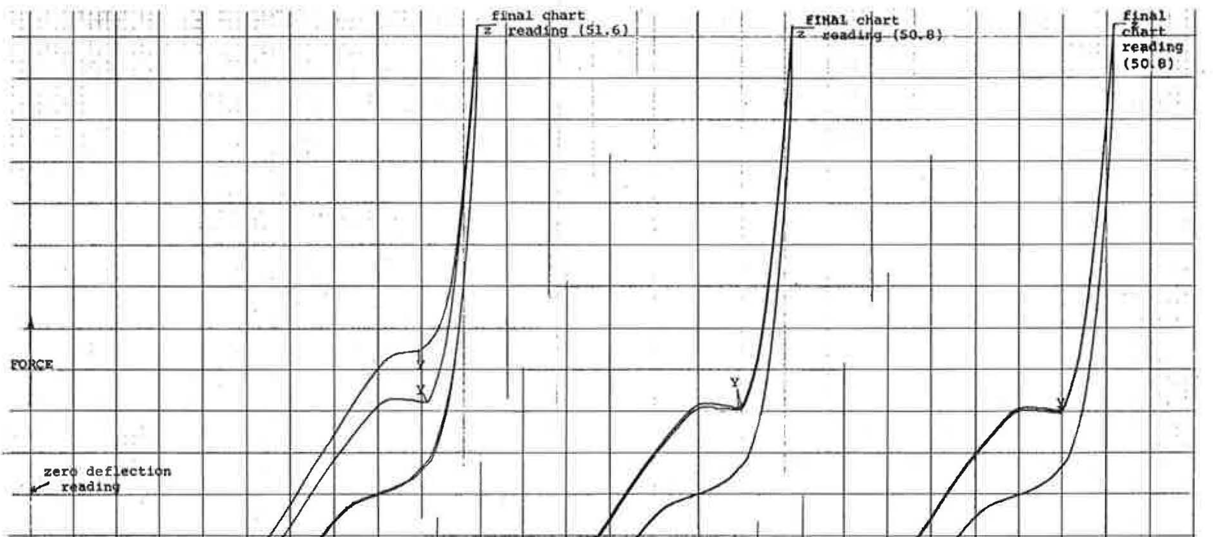
E-1250 CV-2500 B-2000 H-4000

Figure 2. Test seals compressed to limit of safe compressibility.



E-1250 CV-2500 B-2000 H-4000

Figure 3. Force-deflection curves for sample 8 of seal B-2000.



$\sigma_1^2 \neq \sigma_2^2$. A confidence value α of 95 percent was used. If $F < F_{\frac{\alpha+1}{2}}$, then the null hypothesis could not be rejected and it was justifiable to use the 2-sample t-test for that comparison. At this point, the assumption is made that the populations are normally distributed.

After it was determined that the population variances were equal, a 2-sample t-test could then be used based on the statistic

$$t = \frac{(\bar{x}_1 - \bar{x}_2) - \delta}{\sqrt{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}} \cdot \sqrt{\frac{n_1 n_2 (n_1 + n_2 - 2)}{n_1 + n_2}}$$

where

$\bar{x}_1, \bar{x}_2$ = sample mean of either x or y, in psi, of the 2 groups of data being compared,
δ = theoretical difference between the means (in all tests, $\delta = 0$),
S_1^2, S_2^2 = sample variances, and
n_1, n_2 = sample size.

The null hypothesis here is that the population means μ_1 and μ_2 are equal. In most cases, the alternative hypothesis was that the means were not equal. In the test for determining the necessary number of cycles, the alternative was that μ_1 was greater than μ_2 because during force-deflection cycles the seal will generally only lose strength until equilibrium is reached. Once again a confidence value of 95 percent was used. If $t > t_\alpha$ for $(n_1 + n_2 - 2)$ degrees of freedom, then the null hypothesis is rejected. Otherwise, it is accepted, and the 2 population means are considered equal.

In cases where the 2-sample t-test could not be used because the sample variances could not be considered equal, the Smith-Satlerthwaite test was used instead.

The test statistic is given by

$$t' = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}}$$

This sampling distribution can be approximated by a t-distribution having

$$\frac{\left(\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}\right)^2}{\frac{(S_1^2/n_1)^2}{n_1 - 1} + \frac{(S_2^2/n_2)^2}{n_2 - 1}}$$

degrees of freedom, where

$\bar{x}_1, \bar{x}_2$ = 2 values being compared for equality,
s_1^2, S_2^2 = 2 respective sample variances, and
n_1, n_2 = 2 respective sample sizes.

If t' lay between the critical values for a confidence value of 95 percent, the 2 values could be considered equal.

In the case of the test to determine an adequate number of cycles, the pounds per square inch at x and y in successive cycles were compared by the 2-sample t-tests until the means of those values were equal. When this had occurred it showed, temporarily, that the force-deflection curve had reached equilibrium and no further cycles were needed.

For the test to determine whether the size of the load has an effect on results, the pounds per square inch at x and y were compared for the same type of seal but with 2 different loadings. If the statistical test used showed that the means were equal, it proved that the loadings had no significant effect on the characteristic values on the force-deflection curve and therefore on the curve itself.

The same procedure was followed for the test to determine the effect of crosshead speeds on the force-deflection curve. In this case, the means of values for the tests with different crosshead speeds were compared. If the means were found to be equal, it could be assumed that the crosshead speeds tested had no significant effect on the force-deflection curves.

RESULTS

All 4 seals tested showed that the fourth cycle of the force-deflection curve was statistically equal to the third cycle curve. This indicates that the force-deflection curve of the third cycle approximates the equilibrium force-deflection curve.

In all the tests involving changes in loads, it was found that different loads gave different results. This indicates that the amount of total deflection will affect the entire force-deflection curve. No definite trend could be seen as the loads changed. The results seemed largely dependent on the type of seal being tested.

The results of the tests involving the crosshead speeds were inconclusive. In one test, the force-deflection curves for the 2 widely varied crosshead speeds proved to be equivalent. With the other 2 types of seals tested for force-deflection, curves were not equivalent. The one feature all 3 types had in common was a trend for the force at x and y to increase as the crosshead speed increased.

The values for the pounds per square inch at x and y are given in Tables 1 through 8.

CONCLUSIONS AND RECOMMENDATIONS

Many of the aspects affecting the compression-deflection test have been scrutinized in this study in an effort to determine a reliable and economic method of conducting this test. Experiments involving the proper number of cycles to run, the effect of different full-scale loads or total deflection on the preformed joint seals, and the effect of varying crosshead speeds have been conducted and analyzed.

The results show several things. First, only 3 cycles of the force-deflection test need to be run before the curve produced approximates the equilibrium force-deflection curve. The curve of the first deflection is unique and often even has a shape all its own. Generally this curve produces values that are not conclusive.

One of the greatest sources of errors or variance in results was the changing of the load or the total deflection used in the tests. Few states specify a load for testing seals, yet this study showed that the force-deflection curves are greatly affected by this factor. This calls for one of two things. Either a national or agreed-on standard load for different sizes of seal should be specified, or a standard that specifies compression to a given percentage of nominal width should be agreed on. Further study and consideration are needed before specific loads can be chosen for different sizes of seals. This study alone does not give sufficient data to set those loads. However, in respect to a standard for compressing to a given percentage of the nominal width of a seal, 35 percent seems like a reasonable value because all present state requirements could be met by using that compression.

Results involving crosshead speeds were inconclusive but did show that this factor may also be a substantial source of variance in the results. Further study needs to be done to determine conclusively the ranges that crosshead speeds can vary without affecting the final force-deflection curve.

REFERENCE

1. Mullins, L. Softening of Rubber by Deformation. Rubber Chem. and Technol., Feb. 1969, pp. 339-362.

Table 1. x-values for seal B-2000 at chart speed of 2.5 in./min.

Loading (lb)	Crosshead Speed (in./min)	Cycle	Sample 1	2	3	4	5	6	7	8	9	10	Σx	$(\Sigma x)^2$	$\bar{x}$	Σx^2	s_x^2
400	0.5	1	5.63	5.62	5.56	5.53	5.67	5.81	5.64	5.70	5.62	5.73	56.51	3,193.4	5.65	319.39	0.006667
		2	5.57	5.59	5.56	5.53	5.64	5.71	5.51	5.64	5.58	5.66	55.99	3,134.88	5.60	313.52	0.004000
		3	5.50	5.56	5.56	5.46	5.64	5.71	5.54	5.64	5.58	5.63	55.82	3,115.87	5.58	311.64	0.005778
		4	5.50	5.56	5.52	5.46	5.64	5.71	5.54	5.57	5.58	5.63	55.71	3,103.60	5.57	310.41	0.005444
		5	5.50	5.52	5.52	5.43	5.60	5.61	5.54	5.57	5.55	5.59	55.43	3,072.49	5.54	307.27	0.002889
		6	5.50	5.52	5.52	5.43	5.60	5.61	5.54	5.64	5.55	5.59	55.50	3,080.25	5.55	308.06	0.003889
1,000	0.5	1	5.73	5.77	5.71	5.47							22.68	514.38	5.67	128.65	0.01650
		1					5.81	6.27	5.96	5.96	5.68		29.68	880.90	5.94	176.37	0.04840
		Total											52.36	2,741.57	5.82	305.02	0.05076
		2	5.65	5.77	5.71	5.39							22.52	507.15	5.63	126.87	0.02817
		2					5.81	5.85	5.88	5.96	5.59		29.09	846.23	5.82	169.32	0.01910
		Total											51.61	2,663.59	5.73	296.19	0.02992
		3	5.65	5.77	5.63	5.31							22.36	499.97	5.59	125.11	0.03850
		3					5.81	5.85	5.88	5.88	5.51		28.93	836.94	5.79	167.49	0.02475
		Total											51.29	2,630.66	5.70	292.60	0.03750
		4	5.65	5.77	5.63	5.31							22.36	499.97	5.59	125.11	0.03850
		4					5.81	5.85	5.88	5.88	5.51		28.93	836.94	5.79	167.49	0.02475
		Total											51.29	2,630.66	5.70	292.60	0.03750
400	0.2	1	5.66	5.71	5.68	5.62	5.81						28.48	811.11	5.70	162.24	0.005250
	1.0	1						5.91	5.69	5.75	5.79	5.64	28.78	828.29	5.76	165.70	0.01060
	0.2	2	5.66	5.61	5.65	5.59	5.74						28.25	788.49	5.62	159.63	0.003350
	1.0	2						5.87	5.66	5.72	5.75	5.61	28.61	818.53	5.72	163.75	0.009900
	0.2	3	5.62	5.58	5.68	5.49	5.71						28.08	788.49	5.62	157.73	0.007450
	1.0	3						5.87	5.69	5.72	5.69	5.71	28.68	822.54	5.74	164.53	0.005900
	0.2	4	5.62	5.58	5.68	5.49	5.71						28.08	788.49	5.62	157.73	0.007450
	1.0	4						5.87	5.69	5.72	5.69	5.71	28.68	822.54	5.74	164.53	0.005900

Table 2. y-values for seal B-2000 at chart speed of 2.5 in./min.

Loading (lb)	Crosshead Speed (in./min)	Cycle	Sample 1	2	3	4	5	6	7	8	9	10	Σ_y	$(\Sigma y)^2$	$\bar{y}$	Σy^2	s_y^2
400	0.5	1	17.04	17.28	17.08	17.29	16.99	17.20	17.20	17.32	17.06	17.09	171.55	29,429.40	17.16	2,943.07	0.01389
		2	14.89	15.16	14.95	15.12	14.72	15.11	15.18	15.25	14.84	15.00	150.22	22.566.05	15.02	2.256.87	0.02900
		3	14.69	14.93	14.75	14.98	14.45	14.91	14.92	14.71	14.92	14.84	148.10	21,933.61	14.81	2,193.60	0.02622
		4	14.56	14.80	14.62	14.91	14.28	14.84	14.92	14.85	14.58	14.74	147.10	21,638.41	14.71	2,164.20	0.04022
		5	14.49	14.76	14.55	14.85	14.18	14.74	14.85	14.72	14.41	14.70	146.25	21,389.06	14.62	2,139.32	0.04622
		6	14.39	14.70	14.49	14.78	14.15	14.69	14.79	14.41	14.64	14.78	145.81	21,260.56	14.58	2,126.47	0.04556
1,000	0.5	1	17.36	17.65	16.80	15.93							67.74	4,588.71	16.94	1,148.90	0.5733
		1					18.37	18.47	18.40	17.15	16.46		88.85	7,894.32	17.77	1,582.21	0.8369
		Total											156.59	24,520.43	17.40	2,731.11	0.8271
		2	14.20	14.19	14.07	13.78							56.24	3,162.94	14.06	790.85	0.03817
		2					14.54	14.71	14.58	14.83	14.28		72.94	5,320.24	14.59	1,064.22	0.04280
		Total											129.18	16,687.47	14.35	1,855.07	0.1132
		3	14.04	14.02	13.74	13.53							55.33	3,061.41	13.83	765.53	0.05958
		3					14.38	14.54	14.34	14.66	14.12		72.04	5,189.76	14.41	1,038.12	0.04240
		Total											127.37	16,223.12	14.15	1,803.65	0.1354
		4	13.87	13.86	13.57	13.53							54.83	3,006.33	13.71	751.68	0.03326
		4					14.21	14.38	14.17	14.50	13.95		71.21	5,070.86	14.24	1,014.35	0.04430
		Total											126.04	15,886.08	14.00	1,766.03	0.1140
400	0.2	1	16.84	17.46	16.72	17.91	16.89						85.82	7,365.07	17.16	1,474.04	0.2554
	1.0	1						17.66	17.99	16.77	17.11	18.46	87.99	7,742.24	17.60	1,550.27	0.4560
	0.2	2	14.54	14.74	14.56	14.59	14.46						72.89	5,312.95	14.58	1,062.63	0.01065
	1.0	2						14.93	15.21	14.37	14.86	14.90	74.27	5,516.03	14.85	1,103.58	0.09235
	0.2	3	14.25	14.44	14.29	14.42	14.26						71.66	5,135.16	14.33	1,027.06	0.008200
	1.0	3						14.69	14.84	14.14	14.62	14.77	73.06	5,337.76	14.61	1,067.86	0.07655
	0.2	4	14.05	14.34	14.16	14.29	14.12						70.96	5,035.32	14.19	1,007.12	0.01440
	1.0	4						14.52	14.74	14.01	14.49	14.64	72.40	5,241.76	14.48	1,048.66	0.07900

Table 3. x-values for seal CV-2500 at chart speed of 2.0 in./min.

Loading (lb)	Crosshead Speed (in./min)	Cycle	Sample 1	2	3	4	5	6	7	8	9	10	Σx	$(\Sigma x)^2$	$\bar{x}$	Σx^2	s_x^2
1,000	0.5	1	4.40	4.42	4.47	4.32	4.23	4.33	4.39	4.29	4.38		39.24	1,539.78	4.36	171.13	0.005569
		2	4.40	4.31	4.35	4.32	4.17	4.21	4.33	4.23	4.32		38.64	1,493.50	4.29	165.94	0.005444
		3	4.34	4.31	4.23	4.26	4.11	4.15	4.39	4.23	4.26		38.28	1,465.36	4.25	162.88	0.007681
		4	4.34	4.19	4.23	4.26	4.11	4.09	4.27	4.17	4.26		37.92	1,437.93	4.21	159.82	0.006556
		5	4.28	4.25	4.29	4.20	4.11	4.03	4.21	4.17	4.26		37.80	1,428.84	4.20	158.82	0.007375
		6	4.28	4.25	4.29	4.20	4.11	4.03	4.21	4.17	4.26		37.80	1,428.84	4.20	158.82	0.007375
2,000	0.5	1	4.11	4.36	4.23	4.40	4.23	4.14	4.29	4.22	4.23		38.21	1,460.00	4.25	162.29	0.008792
		2	4.11	4.23	4.23	4.03	4.11	4.14	4.29	4.10	4.23		37.47	1,404.00	4.16	156.06	0.007236
		3	3.99	3.99	4.23	4.03	3.88	4.02	4.17	3.97	4.23		36.51	1,332.98	4.06	148.23	0.01539
		4	3.99	3.99	4.23	4.03	3.88	4.02	4.17	3.97	4.23		36.51	1,332.98	4.06	148.23	0.01539
1,000		5	3.92	4.11	4.23	4.10	3.94	3.90	4.05	3.97	3.99		36.21	1,311.16	4.02	145.78	0.01176
		6	3.92	4.11	4.23	4.10	3.94	3.90	4.05	3.97	3.99		36.21	1,311.16	4.02	145.78	0.01176
400	0.2	1	4.65	4.61	4.49	4.61	4.69						23.05	531.30	4.61	106.28	0.005600
	1.0	1						4.69	4.64	4.78	4.84	4.79	23.74	563.59	4.75	112.74	0.006600
	0.2	2	4.58	4.61	4.49	4.55	4.57						22.80	519.84	4.56	103.98	0.001950
	1.0	2						4.63	4.52	4.66	4.78	4.66	23.25	540.56	4.65	108.15	0.008600
	0.2	3	4.52	4.43	4.55	4.55	4.57						22.62	511.66	4.52	102.35	0.003050
	1.0	3						4.51	4.46	4.60	4.66	4.60	22.83	521.21	4.57	104.27	0.006300
	0.2	4	4.52	4.43	4.55	4.49	4.57						22.56	508.95	4.51	101.80	0.003050
	1.0	4						4.51	4.46	4.60	4.60	4.60	22.77	518.47	4.55	103.71	0.004350

Table 4. y-values for seal CV-2500 at chart speed of 2.0 in./min.

Loading (lb)	Crosshead Speed (in./min)	Cycle	Sample 1	2	3	4	5	6	7	8	9	10	Σy	$(\Sigma y)^2$	$\bar{y}$	Σy^2	s_y^2
1,000	0.5	1	20.57	20.26	20.29	20.48	21.04	20.76	20.51	20.71	20.32		184.94	34,202.80	20.55	3,800.83	0.06518
		2	18.12	18.94	18.25	18.88	17.83	18.13	18.34	18.62	18.31		165.44	27,370.39	18.38	3,042.23	0.1340
		3	17.94	18.46	17.53	18.29	17.35	17.64	17.74	17.90	18.07		160.92	25,895.25	17.88	2,878.28	0.1282
		4	17.82	18.28	17.41	18.29	17.23	17.64	17.50	17.72	17.95		159.84	25,548.83	17.76	2,839.84	0.1347
		5	17.63	18.40	17.35	18.29	17.23	17.70	17.50	17.36	17.64		159.10	25,312.81	17.68	2,813.88	0.1677
		6	17.51	18.40	17.35	18.23	17.17	17.52	17.50	17.36	17.64		158.68	25,179.34	17.63	2,799.06	0.1699
2,000	0.5	1	20.83	21.43	21.42	21.79	20.35	19.28	21.24	21.10	20.71		188.15	35,400.42	20.91	3,937.85	0.5583
		2	17.08	17.92	17.91	17.87	17.40	17.33	17.92	17.48	17.68		158.59	25,150.79	17.62	2,795.31	0.09675
		3	17.08	17.44	17.91	17.99	16.93	17.20	17.31	17.48	17.68		157.02	24,655.28	17.45	2,740.52	0.1308
		4	17.08	17.44	17.79	17.87	16.82	17.20	17.19	17.48	17.56		156.43	24,470.35	17.38	2,719.85	0.1158
1,000		5	17.33	17.74	17.79	17.68	16.46	17.08	17.62	17.24	17.50		156.44	24,473.47	17.38	2,720.69	0.1773
		6	17.33	17.68	17.73	17.68	16.43	17.08	17.62	17.18	17.50		156.21	24,401.56	17.36	2,712.73	0.1804
400	0.2	1	22.76	22.60	23.40	22.85	22.55						114.16	13,032.51	22.83	2,606.96	0.1152
	1.0	1						23.71	25.13	23.85	24.85	24.89	122.43	14,989.11	24.49	2,999.54	0.4293
	0.2	2	19.10	20.32	20.50	20.11	19.92						99.95	9,990.00	19.99	1,999.18	0.2951
	1.0	2						20.78	22.36	20.76	22.21	22.09	108.20	11,707.24	21.64	2,344.01	0.6400
	0.2	3	18.42	19.15	20.38	19.38	19.07						96.40	9,292.96	19.28	1,860.61	0.5053
	1.0	3						19.99	21.52	20.76	20.92	21.78	104.97	11,018.70	20.99	2,205.70	0.4908
	0.2	4	18.35	19.09	19.64	19.38	19.01						95.47	9,114.52	19.09	1,823.85	0.2352
		4						19.93	21.46	20.82	20.92	21.78	104.91	11,006.11	20.98	2,203.22	0.5006

Table 5. x-values for seal E-1250 at chart speed of 4.0 in./min.

Loading (lb)	Crosshead Speed (in./min)	Cycle	Sample 1	2	3	4	5	6	7	8	9	10	Σx	$(\Sigma x)^2$	$\bar{x}$	Σx^2	s_x^2
200	0.5	1	2.17	2.11	2.14	2.09	2.10	2.10	2.14	1.96	2.16	2.27	21.24	451.14	2.12	45.17	0.006222
		2	2.17	2.11	2.11	2.06	2.10	2.07	2.14	1.93	2.12	2.20	21.01	441.42	2.10	44.19	0.005444
		3	2.10	2.07	2.07	2.27	2.06	2.13	2.07	2.10	1.86	2.16	20.89	436.39	2.09	43.74	0.01067
		4	2.10	2.07	2.07	2.27	2.06	2.13	2.07	2.10	1.86	2.16	20.89	436.39	2.09	43.74	0.01067
		5	2.04	2.11	2.11	2.06	2.13	2.07	2.10	1.90	2.16	2.23	20.91	437.23	2.09	43.79	0.007556
		6	2.04	2.11	2.11	2.06	2.13	2.07	2.10	1.90	2.16	2.23	20.91	437.23	2.09	43.79	0.007556
400	0.5	1	2.21	2.35	2.28	2.07	2.35	2.34	2.27				15.87	251.86	2.27	36.22	0.04024
		1								2.49	2.37	2.44	7.30	53.29	2.43	17.77	0.003833
		Total											23.17	536.85	2.32	53.99	0.03412
		2	2.21	2.28	2.22	2.07	2.28	2.27	2.20				15.53	241.18	2.22	34.49	0.005429
		2								2.42	2.24	2.38	7.04	49.56	2.35	16.54	0.009167
		Total											22.57	509.41	2.26	51.03	0.009500
		3	2.28	2.21	2.22	2.07	2.22	2.34	2.20				15.54	241.49	2.22	34.54	0.006857
		3								2.49	2.31	2.38	7.18	51.55	2.39	17.20	0.008000
		Total											22.72	516.20	2.27	51.74	0.01336
		4	2.28	2.21	2.22	2.07	2.22	2.34	2.20				15.54	241.49	2.22	34.54	0.006857
		4								2.36	2.31	2.38	7.05	49.70	2.35	16.57	0.001167
		Total											22.59	510.31	2.26	51.11	0.006800
200		5	1.98	2.05	2.08	2.17	2.12	2.27	2.10				14.77	218.15	2.11	31.22	0.008548
		5								2.29	2.34	2.38	7.01	49.14	2.34	16.38	0.002000
		Total											21.78	474.37	2.18	47.60	0.01813
		6	1.98	2.05	2.08	2.17	2.12	2.27	2.10				14.77	218.15	2.11	31.22	0.008548
		6								2.29	2.34	2.38	7.01	49.14	2.34	16.38	0.002000
		Total											21.78	474.37	2.18	47.60	0.01813
200	0.2	1	2.64	2.74	2.77	2.72	2.79						13.66	186.60	2.73	37.33	0.003450
	1.0	1						2.64	2.48	2.51	2.64	2.65	12.92	166.92	2.58	33.41	0.006700
	0.2	2	2.64	2.78	2.74	2.68	2.76						13.60	184.96	2.72	37.01	0.003500
	1.0	2						2.58	2.44	2.48	2.54	2.58	12.62	159.26	2.54	31.87	0.003800
	0.2	3	2.64	2.78	2.74	2.65	2.76						13.57	184.15	2.71	36.85	0.004250
	1.0	3						2.44	2.38	2.38	2.41	2.58	12.19	148.60	2.44	29.75	0.006950
	0.2	4	2.64	2.78	2.74	2.65	2.76						13.57	184.15	2.71	36.85	0.004250
	1.0	4						2.44	2.35	2.35	2.41	2.58	12.13	147.14	2.43	29.46	0.008900

Table 6. y-values for seal E-1250 at chart speed of 4.0 in./min.

Loading (lb)	Crosshead Speed (in./min)	Cycle	Sample 1	2	3	4	5	6	7	8	9	10	Σy	$(\Sigma y)^2$	$\bar{y}$	Σy^2	s_y^2
200	0.5	1	6.39	6.39	6.40	6.39	6.30	6.35	6.29	6.38	6.31	6.37	63.57	4,041.15	6.36	404.13	0.001556
		2	6.05	6.06	6.09	6.09	5.99	6.02	6.02	6.07	5.98	5.99	60.36	3,643.33	6.04	364.35	0.001667
		3	6.02	5.99	6.02	6.02	5.99	5.95	5.96	6.04	5.94	5.99	59.92	3,590.41	5.99	359.05	0.001111
		4	6.02	5.95	6.02	6.02	5.99	5.95	5.96	6.04	5.94	5.99	59.88	3,585.61	5.99	358.57	0.001444
		5	5.99	5.99	6.05	6.05	5.99	5.95	5.96	6.04	5.91	5.99	59.92	3,590.41	5.99	359.06	0.002222
		6	5.99	5.99	6.05	6.05	5.99	5.95	5.96	6.04	5.91	5.95	59.88	3,585.61	5.99	358.58	0.002444
400	0.5	1	6.31	6.52	6.39	6.47	6.52	6.15	6.41				44.77	2,004.35	6.40	286.44	0.01748
		1								5.44	5.67	5.75	16.86	284.26	5.62	94.81	0.02583
		Total											61.63	3,798.26	6.16	381.25	0.1578
		2	5.97	6.18	6.06	6.07	6.05	5.88	6.08				42.29	1,788.44	6.04	255.55	0.008833
		2								5.37	5.34	5.42	16.29	260.18	5.38	86.73	0.001667
		Total											58.42	3,412.90	5.84	342.27	0.1094
		3	5.97	6.05	5.99	6.01	5.99	5.82	6.01				41.84	1,750.59	5.98	250.12	0.005381
		3								5.44	5.28	5.35	16.07	258.25	5.36	86.10	0.006667
		Total											57.91	3,353.57	5.79	336.21	0.09491
		4	5.97	6.05	5.99	5.75	6.01	5.99	6.01				41.77	1,744.73	5.97	249.31	0.009738
		4								5.24	5.28	5.35	15.87	251.86	5.29	83.96	0.003333
		Total											57.64	3,322.37	5.76	333.27	0.1142
200		5	5.97	6.05	6.02	6.07	5.99	5.88	6.11				42.09	1,771.57	6.01	253.12	0.005643
		5								5.34	5.37	5.38	16.09	258.88	5.36	86.30	0.001000
		Total											58.18	3,384.91	5.82	339.41	0.1023
		6	5.97	6.04	6.02	6.07	5.99	5.88	5.98				41.95	1,759.80	5.99	251.42	0.003762
		6								5.34	5.37	5.38	16.09	258.88	5.36	86.30	0.001000
		Total											58.04	3,368.64	5.80	337.72	0.09509
2.00	0.2	1	5.83	6.03	5.98	5.86	6.05						29.75	885.06	5.95	177.05	0.009850
	1.0	1						6.15	6.02	6.15	6.21	6.09	30.62	937.58	6.14	187.54	0.005300
	0.2	2	5.54	5.73	5.68	5.54	5.72						28.21	795.80	5.64	159.18	0.009050
	1.0	2						5.72	5.99	5.82	5.85	5.76	29.14	849.14	5.83	169.87	0.01075
	0.2	3	5.47	5.66	5.59	5.44	5.66						27.82	773.95	5.56	154.83	0.01090
	1.0	3						5.65	5.85	5.76	5.81	5.70	28.77	827.71	5.75	165.57	0.006600
	0.2	4	5.44	5.62	5.55	5.41	5.62						27.64	763.97	5.53	152.83	0.009750
	1.0	4						5.62	5.85	5.76	5.78	5.70	28.71	824.26	5.74	164.88	0.007550

Table 7. x-values for seal H-4000 at chart speed of 1.2 in./min.

Loading (lb)	Crosshead Speed (in./min)	Cycle	Sample 1	2	3	4	5	6	7	8	9	10	Σx	$(\Sigma x)^2$	$\bar{x}$	Σx^2	s_x^2
1,000	0.5	1	3.87	3.77	3.82	3.69	3.81	3.87	3.78	4.01	3.98	4.04	38.64	1,493.05	3.86	149.42	0.01300
		2	3.79	3.69	3.73	3.65	3.73	3.79	3.70	3.93	3.89	3.96	37.86	1,433.38	3.79	143.44	0.01144
		3	3.66	3.52	3.65	3.56	3.69	3.62	3.57	3.93	3.68	3.75	36.63	1,341.76	3.66	134.30	0.01344
		4	3.66	3.52	3.65	3.52	3.69	3.62	3.53	3.93	3.68	3.75	36.55	1,335.90	3.66	133.73	0.01556
		5	3.66	3.52	3.56	3.48	3.65	3.58	3.53	3.93	3.64	3.79	36.34	1,320.60	3.63	132.23	0.01911
		6	3.66	3.52	3.56	3.48	3.65	3.58	3.53	3.93	3.64	3.79	36.34	1,320.60	3.63	132.23	0.01911
400	0.5	1	4.09	4.20	4.05	4.10	4.31	4.25	4.03	3.92	3.94	4.62	41.51	1,723.08	4.15	172.70	0.04300
		2	4.02	4.13	4.00	4.03	4.23	4.15	4.00	3.86	3.89	4.57	40.88	1,671.17	4.09	167.49	0.04140
		3	4.02	4.05	4.03	3.96	4.21	4.13	3.90	3.88	3.90	4.57	40.65	1,652.42	4.07	164.25	0.04311
		4	4.02	4.05	3.95	3.95	4.21	4.11	3.90	3.88	3.86	4.55	40.48	1,638.63	4.05	164.25	0.04311

Table 8. y-values for seal H-4000 at chart speed of 1.2 in./min.

Loading (lb)	Crosshead Speed (in./min)	Cycle	Sample 1	2	3	4	5	6	7	8	9	10	Σy	$(\Sigma y)^2$	$\bar{y}$	Σy^2	s_y^2
1,000	0.5	1	12.01	11.41	11.58	11.46	11.78	11.71	11.62	11.95	11.48	11.72	116.72	13,623.56	11.67	1,362.72	0.04089
		2	11.29	10.90	10.86	10.65	11.08	10.99	10.90	10.13	10.73	10.97	109.50	11,990.25	10.95	1,199.34	0.03533
		3	11.33	10.48	10.56	10.61	10.92	10.49	10.86	10.56	10.73	11.05	107.59	11,575.6	10.76	1,158.26	0.07767
		4	11.25	10.40	10.48	10.52	10.84	10.44	10.82	10.52	10.73	10.97	106.97	11,442.5	10.70	1,144.94	0.07567
		5	11.29	10.44	10.39	10.57	10.71	10.44	10.73	10.52	10.63	11.01	106.79	11,404.10	10.68	1,141.13	0.08022
		6	11.21	10.40	10.39	10.52	10.63	10.44	10.65	10.52	10.69	10.97	106.42	11,325.22	10.64	1,133.15	0.06944
400	0.5	1	11.79	11.93	11.85	11.80	12.16	12.10	12.16	11.78	11.95	11.71	119.23	14,215.79	11.92	1,421.83	0.02763
		2	11.24	11.49	11.13	11.37	11.97	11.55	11.78	11.22	11.60	11.20	114.55	13,121.70	11.46	1,312.85	0.07574
		3	10.94	11.15	11.05	11.28	10.95	11.38	11.39	11.08	11.20	11.22	111.64	12,463.49	11.16	1,246.58	0.02578
		4	10.89	11.07	11.04	11.28	10.95	11.36	11.06	11.17	11.22	11.37	111.41	12,412.18	11.14	1,241.47	0.02758

DISCUSSION

George S. Kozlov, Division of Research and Development,
New Jersey Department of Transportation

To recap the history of the compression-deflection test, one should begin with the 1967 paper by Hall, Ritzi, and Brown (2). In that paper, the authors have directed attention, for the first time, to what is now recognized as the characteristic shape of pressure-deflection curves for preformed elastomeric sealers. In 1969, after considerable laboratory and field investigation, I proposed that this test be employed by sealer users as one of the means for judging the acceptability of an elastomeric sealer (3).

The compression or pressure-deflection test has been part of the New Jersey Department of Transportation specification for preformed elastomeric joint sealer since 1969.

Huffman's paper should be welcomed because he rightfully sets forth several important factors affecting pressure-deflection testing. However, certain of his resulting recommendations for test standardization are ill-conceived and will tend to confuse and possibly mislead the uninformed.

In essence, he has studied 3 factors:

1. Number of cycles necessary to achieve an equilibrium pressure-deflection curve,
2. Effect of "some loads" on this curve, and
3. Effect of crosshead speed or load application rate on the pressure-deflection curve.

The results of his study can be summarized as follows:

1. A reasonable equilibrium pressure-deflection curve is achieved on the third cycle, and
2. The investigations of "load effect" and "crosshead speed" were inconclusive.

However, in spite of the nature of his findings, he rather surprisingly concludes that

1. The force-deflection curve is greatly affected by the load factor, or, in essence, the amount of total deflection will significantly alter the magnitude of key parameters obtained from the curve; and
2. The factor of crosshead speed may also be a substantial source of variance in magnitude of key curve parameters.

Of further bewilderment is his recommendation for the establishment of national standards for either loads or degree of compression. Yet, at the same time he admits that this study does not give sufficient data to set these loads or deflections.

The question in my mind is, Why all this work? I can see a possible need for advising sealer users of the cycle level at which curve equilibrium is achieved, although it should already be widely known that equilibrium is reached between the third and fifth cycles, 3 cycles obviously being the least number that must be run. But what is the logical basis for considering the testing of sealers to a "specific load or loads"?

The amount of pressure needed to compress a sealer depends on

1. The amount of compression;
2. The ingredients from which a sealer is compounded, their quality and relative quantity, and batching techniques;
3. The sealer's extrusion techniques and quality;
4. The sealer's state of cure and possibly the curing procedures; and
5. The sealer's structural design.

All of those parameters vary from lot to lot, and some are different for each individual sealer.

The parameters given above are just some that affect a sealer's performance characteristics, of which structural strength is one. The various tests proposed and explained in my aforementioned paper to some degree control the parameters. However, the involved tests provide parameter limits broad enough to permit, literally, for each sealer a very wide variation of pressure (or loads, as Huffman terms it) for the same degree of compression. But most important, there is no evidence that this latitude of pressures in any way impedes or governs a sealer's efficiency. In essence, there is no possible way that any "specific load" could be used as a pass-failure criterion for a specific size of sealer in the pressure-deflection test. However, it remains quite obvious that, for any sealer to perform efficiently, a certain minimum pressure at the minimum degree of compression must be required.

Now to the subject of crosshead speed.

For sealers installed in the field and exposed to design limits, a full cycle lasts about 1 year. The speed of the cycle depends on the time and movement limits. A 4-in.-wide sealer, which is compressed 1.2 in., undergoes 2.4 in. of movement in one year. Therefore, the speed would be approximately 4.6×10^{-6} in./min, very slow indeed. If we could attain such a yearly pressure-deflection curve, its familiarity with the laboratory curve would not be surprising.

Huffman submits that his inconclusive research established "a trend for the force of x and y to increase as the crosshead speed increased," and "that this factor may also be a substantial source of variance in the results." If there is a variance, it is doubted that it is substantial or that it is in any way significant, unless of course tests are run haphazardly. However, the important word in the above quote is not "variance" but "results." Before a study is conducted on factors affecting variation of results, a determination must first be made as to the exact results that are desirable and meaningful.

The maximum value (the y-value), i.e., the pressure at the limit of safe compressibility (LSC), is of no practical consequence in reference to sealers and sealer users' application of the pressure-deflection test. The user is interested only in the degree of compression at the LSC and not in the pressure or force because the degree of compression is the factor that governs the field capabilities of the sealer. The identification of the degree of compression at LSC is independent of loading rate although a slow crosshead speed of 0.2 in./min does simplify somewhat the LSC identification process.

In this case, it is felt that, if there were a variance of pressure-deflection test results, it is of concern only in the determination of the minimum permitted pressure (Huffman's x-value).

In general, the relevance of Huffman's paper to furthering the sealer users' understanding of the compression-deflection test is questioned. The information available on load-cycling equilibrium is already widely known and understood. The data on testing to a specific load and on loading rate are in an area that can hardly be of any practical consequence to the industry; they are unrelated to sealer capabilities or current test usage.

Data to support such contentions have been presented in the aforementioned paper; additional supporting information obtained since that paper, but too complex for presentation in this discussion, is readily available upon request from the New Jersey Department of Transportation and was previously presented to ASTM Task Group J of Subcommittee D-4.34.

REFERENCES

2. Hall, F. K., Ritzi, J. H., and Brown, D. D. Study of Factors Governing Contact Pressure Generation in Neoprene Preformed Compression Seals. Highway Research Record 200, 1967, pp. 53-74.
3. Kozlov, G. S. Preformed Elastomeric Bridge Joint Sealers: Evaluation of the Material. Highway Research Record 287, 1969, pp. 59-75.

AUTHOR'S CLOSURE

Kozlov's discussion of my paper indicates that its intent and purpose might be misunderstood. Therefore, I offer, in rebuttal, the following comments.

Compression deflection testing of elastomeric seals is a means of characterizing different designs of seal by measuring the resistance force of deflection generated when a given shape is compressed. Because the seal functions in service under compression, it is desirable to know not only that the seal design retains sufficient force to effectively keep a joint watertight at the widest anticipated opening of a given joint but also that it will retain sufficient force to accomplish that purpose after being exposed to heat and compression far in excess of this minimum requirement when it is compressed during its service life to the minimum opening of the joint in question. Because rubber under stress loses its ability to rebound or recover in direct relation to the degree of overstressing (the higher the stress is, the faster the decay or loss of recovery force will be), it is desirable to undertake laboratory analysis to determine the optimum degree of stress the seal can resist so that a seal with a given design will not be placed in a joint configuration where excessive stressing will destroy at too fast a rate its ability to function and keep a joint watertight.

To measure the overstressed conditions of a seal requires that different loads for different sizes and designs be used to deflect the seal enough to reach a point where rubber-to-rubber contact across the cross-sectional design of a seal occurs. The pounds per square inch required to overstress any seal design is relatively the same and should not be confused with the loading applied to the sample to get the seal to the overstressed state. Overstressing does not occur until a given design is deflected to a point where rubber-to-rubber contact across the cross section occurs and the rubber making that cross section begins to flow or extrude. It is at that point that a rapid rise in force occurs, and the degree or amount of deflection varies from one style or design of seal to another. It should be pointed out that the service application of a given seal should avoid this area or degree of deflection.

It is my opinion that in this testing Kozlov has always disregarded the forces generated when various seal designs are deflected to given percentages of their nominal width; or, putting it another way, he has greatly overstressed seals and established limits of overstressing far exceeding the true working range of a given seal design.

His approach has been that bridge designers design in a structure a joint that should accommodate a seal capable of 50 percent deflection. What the force is to reach that deflection or whether the rubber is highly overstressed in reaching that deflection is apparently of no concern. To quote Kozlov, "The user is interested only in the degree of compression at the LSC and not in the pressure or force because the degree of compression is the factor that governs the field capabilities of the sealer." Thus, we ignore the resultant shortened life span of an overstressed seal and the fact that the seal will lose its ability to seal the joint at maximum opening quicker as a result of this overstressing in the warm or closed part of the joint cycle.

Because the forces required to deflect various seal designs, as well as sizes, to the point of overstressing vary with the style and size of the sample to be tested, I have suggested that all seals be deflected to 35 percent of their nominal width as a basis of standardization. It will take different loadings to accomplish this, but the point at which overstressing occurs will always be discernible—the total loadings will be different, but the point of overstressing will be relatively the same in pounds per square inch. From this, working limits of a given design of seal can be ascertained.

To have reproducibility among laboratories requires that the crosshead speeds used be constant. Varying the crosshead speeds changes the values along the curve. That is another reason for deflecting to 35 percent of nominal width to give reproducibility among laboratories in the pressure results. These simple standardizations would provide a worthy base to operate from.

In view of the foregoing, I respectfully submit that Kozlov's discussion is not pertinent to my paper.