Geosynthetic Institute
475 Kedron Avenue
Folsom, PA 19033-1208 USA
TEL (610) 522-8440
FAX (610) 522-8441

Adopted March 27, 1998

GRI GM14*

Standard Guide for

"Selecting Variable Intervals for Taking Geomembrane Destructive Seam Samples Using the Method of Attributes"

This specification was developed by the Geosynthetic Research Institute (GRI), with the cooperation of the member organizations for general use by the public. It is completely optional in this regard and can be superseded by other existing or new specifications on the subject matter in whole or in part. Neither GRI, the Geosynthetic Institute, nor any of its related institutes, warrant or indemnifies any materials produced according to this specification either at this time or in the future.

1. Scope

1.1 This guide is focused on selecting the spacing interval for taking destructive seam samples of field deployed geomembranes as a particular job progresses based on an installers ongoing record of pass - or - fail testing.

Note 1 - While subjective at this time, the guide is most applicable to large geomembrane seaming projects which require more than 100 destructive seam samples based upon the typical sampling strategy of 1 destructive sample per 150 m (500 ft).

1.2 This guide is essentially applicable to production seams. Caution should be exercised in using the guide for projects that involve complex geometries, multiple penetrations, or extreme weather conditions.

1.3 The primary target audiences for this guide are construction quality assurance (CQA) organizations, construction quality control (CQC) organizations, facility owner/operators and agency regulators having permitting authority.

*This GRI standard is developed by the Geosynthetic Research Institute through consultation and review by the member organizations. This specification will be reviewed at least every 2-years, or on an as-required basis. In this regard it is subject to change at any time. The most recent revision date is the effective version.

1.4 The outcome of using the guide rewards good seaming performance resulting from a record of passing destructive seam tests. It also penalizes poor seaming performance resulting from a record of excessively failing seam tests.

1.5 This guide does not address the actual seam testing procedures that are used for acceptance or failure of the geomembrane seam test specimens themselves. Depending on the type of geomembrane being deployed one should use ASTM D4437, D3083, D751 and D413 for testing details in this regard. The project-specific CQA plan should define the particular criteria used in acceptance or failure.

1.6 An appendix is offered using control charts which is intended to be of assistance to geomembrane installers, i.e., construction quality control (CQC) organizations, to identify salient aspects of good and poor seaming performance.

2. Referenced Documents

2.1 ASTM Standards:

D4437	Practice for Determining the Integrity of Field Seams Used in Joining Flexible Polymeric Sheet Geomembranes
D3083	Specification for Flexible Poly (Vinyl Chloride) Plastic Sheeting for Pond, Canal, and Reservoir Lining
D751	Method of Testing Coated Fabrics
D413	Test Methods for Rubber Property - Adhesion to Flexible Substrate

2.2 Other Standards
ANSI/ASQC Z1.4 [1993]
Sampling Procedures and Tables for Inspection by Attributes

3. Summary of Guide

3.1 Use of this guide requires the establishment of an anticipated geomembrane seam failure percentage (ranging from 1 to 8%) and an initial, or start-up, sampling interval.

Note 2 - The value of anticipated failure percentage is an important consideration. It dictates each decision as to a possible increase or decrease in interval spacing from the preceding value. The percentage itself comes from historical data of the construction quality assurance (CQA) organization or regulatory agency. It is related to a number of factors including criticality of installation, type of geomembrane, type of seaming method and local ambient conditions.

The actual value is admittedly subjective and should be made known in advance to the geomembrane installer before bidding the project. Use of an unrealistically low value of anticipated failure percentage, e.g., < 1.0%, will likely result in field difficulties insofar as decreased sampling intervals are concerned. Conversely, use of an unrealistically high value of anticipated failure percentage, e.g., > 8.0%, will likely result in very large sampling intervals and quite possibly sacrifice the overall quality of the seaming effort.

3.2 The guide then gives the procedure for establishing the initial number of samples needed for a possible modification to the start-up sampling interval. This is called the initial batch. Based upon the number of failed samples in the initial batch, the spacing is either increased (for good seaming), kept the same, or decreased (for poor seaming).

3.3 A second batch size is then determined and the process is continued. Depending on the project size, i.e., the total length of seaming, a number of decision cycles can occur until the project is finished.

3.4 It is seen that the number of samples required for the entire project is either fewer than the start-up frequency (for good seaming); the same as the start-up frequency (for matching the initial anticipated failure percentage); or more than the start-up frequency (for poor seaming).

4. Significance and Use

4.1 Construction quality assurance (CQA) and construction quality control (CQC) organizations, as well as owner/operators and agency regulators can use this guide to vary the sampling interval of geomembrane seam samples (i.e., the taking of field samples for destructive shear and peel testing) from an initial, or start-up, interval. This initial interval is often 1 destructive seam sample in every 150 m (500 ft) of seam length.

4.2 The guide leads to increasing the sampling interval for good seaming practice (hence fewer destructive samples) and to decreasing the sampling interval for poor seaming practice (hence additional destructive samples).

4.3 Use of the guide should provide an incentive for geomembrane installers to upgrade the quality and performance of their field seaming activities. In so doing, the cutting of fewer destructive samples will lead to overall better quality of the entire liner project, since the patching of previously taken destructive samples is invariably of poorer quality than the original seam itself.

Note 3 - It is generally accepted that field patching of areas where destructive samples had been taken using extrusion fillet seaming is less desirable than the original seam which was made by hot wedge welding.

4.4 Control charts are illustrated in Appendix A which can be used by geomembrane installers and their construction quality control (CQC) personnel for improvement in overall job quality and identification of poorly performing seaming personnel and/or equipment.

5. Suggested Methodology

Using the concepts embodied in the method of attributes, the following procedure is based on adjustments to sequential sampling.

5.1 Typical Field Situation - In order to begin the process, a project-specific total seam length must be obtained from the installers panel (roll) layout plan. Also, an initial, or start-up, sampling interval must be decided upon. From this information the total number of samples that are required based on the start-up sampling interval can be obtained.

Example 1 - A given project has 54,000 m (180,000 ft) of field seaming. The start-up sampling frequency is 1 sample per 150 m (500 ft). Therefore, the total number of samples required if the start-up interval is kept constant will be:

$$\frac{54,000}{150} = 360 \text{ samples}$$

5.2 Determination of Initial Batch Size - Using the table shown below, the initial batch size from which to possibly modify the start-up sampling interval is obtained.

Table 1 - Batch Size Determination, after ANSI/ASQC Z1.4 [1993]

No. of Required Samples Based on Initial or Modified Sampling Interval	No. of Samples Needed (Batch Size) to Determine Subsequent Sampling Interval
2 - 8	2
9 - 15	3
16 - 25	5
26 - 50	8
51 - 90	13
91 - 150	20
151 - 280	32
281 - 500	50
501 - 1200	80
1201 - 3200	125

Example 1 (cont.) - For 360 samples, a batch size of 50 is necessary. As production seaming progresses, these 50 samples are tested (either as they are taken or in a batch) and the number of failures is determined.

5.3 Verification of Start-Up Sampling Interval - A sampling table is now used which separates the number of failures within this initial batch size into three categories: a relatively low number of failures (where the sampling interval can be increased), the anticipated number of failures (where the sampling interval is maintained), or a relatively high number of failures (where the sampling interval should be decreased). Table 2 provides this information which is based upon the operation characteristic (OC) curves of Appendix B.

Example 1 (cont.) - Assuming an anticipated failure percentage of 2% (recall Note - 2), Table 2 results in the three categories shown below:

- 0 or 1 failure out of 50; the sampling interval can be increased
- 2 or 3 failures out of 50; the sampling frequency should remain at 1 sample per 150 m (500 ft)
- 4 or more failures out of 50; the sampling interval should be decreased

Table 2 - Sampling Table Containing the Number of Failed Samples to be used for Interval Sampling Interval Modification, see Appendix B for details

No. of Required Samples Based on Initial or Modified Sampling Interval	No. of Samples Needed (Batch Size) to Determine Subsequent Sampling Interval	Anticipated Failure Percentage*							
		1%		2%		3%		4%	
		I	D	I	D	I	D	I	D
2 - 8	2	0	1	0	1	0	1	0	1
9 - 15	3	0	1	0	1	0	2	0	2
16 - 25	5	0	1	0	1	0	2	0	2
26 - 50	8	0	1	0	1	0	2	0	2
51 - 90	13	0	1	0	2	0	2	0	3
91 - 150	20	0	2	0	3	1	3	1	4
151 - 280	32	0	2	1	3	1	4	2	5
281 - 500	50	0	3	1	4	2	5	3	6
501 - 1200	80	1	4	2	6	3	7	5	9
1201 - 3200	125	2	5	4	7	5	9	7	11

No. of Required Samples Based on Initial or Modified Sampling Interval	No. of Samples Needed (Batch Size) to Determine Subsequent Sampling Interval	Anticipated Failure Percentage*							
		5%		6%		7%		8%	
		I	D	I	D	I	D	I	D
2 - 8	2	0	1	0	2	0	2	0	2
9 - 15	3	0	2	0	2	0	2	0	2
16 - 25	5	0	2	0	2	0	3	0	3
26 - 50	8	0	3	0	3	1	3	1	4
51 - 90	13	1	4	1	4	1	4	1	5
91 - 150	20	1	5	2	5	2	5	2	6
151 - 280	32	2	6	3	6	3	7	4	7
281 - 500	50	4	7	4	8	5	9	6	10
501 - 1200	80	6	10	7	11	8	12	9	14
1201 - 3200	125	9	13	10	15	12	17	13	19

No: *To be selected by CQA, owner or regulatory organizations

I = Increase the sampling interval if the number of failed samples found in the batch does not exceed the tabulated value.

D = Decrease the sampling interval if the number of failed samples found in the batch equals or exceeds the tabulated value.

5.4 Modification of Start-Up Sampling Interval - Depending upon the outcome of the previous section, the start-up sampling interval may be modified to a new value which will then require a new batch size to verify the modification. The process is then continued until the project is finished. Two examples will be provided using the above sampling table both with anticipated failure percentages of 2.0%: Example 2 illustrates good seaming, and Example 3 illustrates poor seaming.

Example 2 - Using the same project seam length and start-up sampling frequency as in the previous example assume that the start-up batch of 50 samples in the previous example had 2-failures. The decision is then to continue at a 1 destructive sample in 150 m (500 ft) sampling interval. Thus the second batch size from Table 1 is again 50 samples, see Table 3. Table 3(a) is in S.I. units and Table 3(b) is in English units. Now assume in the second batch there are no failures. This allows the sampling interval to be increased, e.g., to 1 sample in 180 m (600 ft). From Table 1, the third batch size is then decreased to 32 samples. The process is continued in this manner until the project is concluded. For this hypothetical situation Table 3(a) illustrates that 265 samples (or 266 samples when using the English units in Table 3(b)) are necessary. Note that by using a constant interval of 1 sample in 150 m (500 ft), 360 samples would have been necessary. Also note that the maximum sampling interval was fixed at 310 m (1000 ft).

Note 4 - This example, and the following one, use a changing sampling interval of ± 20% from the previous value. That is, when good seaming allows for an increase in sampling interval; the progression being from 150, 180, 215, 260 to 310 m (500, 600, 720, 850 to 1000 ft), respectively. A maximum interval of 310 m (1000 ft) is recommended, but clearly this value is at the discretion of the organizations involved. Conversely, poor seaming requires a decrease in sampling interval; the progression being from 150, 120, 100, 80 to 65 m (500, 400, 320, 250 to 200 ft), respectively. A minimum interval of 65 m (200 ft) is recommended, but clearly this decision is also at the discretion of the organizations involved

Table 3(a) - Results of Example 2 (**in S.I. Units**) Illustrating the Variation of the Sampling Interval Based on a 2.0% Anticipated Failure Percentage With a "Good" Quality Installer

Batch number	Sampling Interval (m)	No. of Remaining Samples Required	Batch size	Cumulative Distance (m)	Number of failures	Decision made
1	150	360	50	7500	2	Stay
2	150	310	50	15000	0	Increase
3	180	217	32	20760	0	Increase
4	215	155	32	27640	2	Stay
5	215	123	20	31940	1	Stay
6	215	103	20	36240	0	Increase
7	260	68	13	39620	1	Stay
8	260	55	13	43000	0	Increase
9	310	35	8	45480	0	Stay
10	310	27	8	47960	0	Stay
11	310	19	5	49510	0	Stay
12	310	14	3	50440	0	Stay
13	310	11	3	51370	0	Stay
14	310	8	2	51990	0	Stay
15	310	6	2	52610	0	Stay
16	310	4	2	53230	0	Stay
17	310	2	2	53850	0	Done

Total Number of tests per 54,000 m of seam project = 265

Table 3(b) - Results of Example 2 (**in English Units**) Illustrating the Variation of the Sampling Interval Based on a 2.0% Anticipated Failure Percentage With a "Good" Quality Installer

Batch number	Sampling Interval (m)	No. of Remaining Samples Required	Batch size	Cumulative Distance (m)	Number of failures	Decision made
1	500	360	50	25000	2	Stay
2	500	310	50	50000	0	Increase
3	600	217	32	69200	0	Increase
4	720	154	32	92240	2	Stay
5	720	122	20	106640	1	Stay
6	720	102	20	121040	0	Increase
7	850	69	13	132090	1	Stay
8	850	56	13	143140	0	Increase
9	1000	37	8	151140	0	Stay
10	1000	29	8	159140	0	Stay
11	1000	21	5	164140	0	Stay
12	1000	16	5	169140	0	Stay
13	1000	11	3	172140	0	Stay
14	1000	8	2	174140	0	Stay
15	1000	6	2	176140	0	Stay
16	1000	4	2	178140	0	Stay
17	1000	2	1	179140	0	Done

Total Number of tests per 180,000 ft of seam project = 266

Example 3 - Using the same project seam length and start-up sampling frequency as Example 1, assume that the start-up batch of 50 samples had 3- failures. The decision is then to continue at a 1 destructive sample in 150 m (500 ft) sampling interval. Thus the second batch size is again 50 samples as it was with Example 2, see Table 4. Table 4(a) is in S.I. units and Table 4(b) is in English units. Now assume in the second batch there are 2-failures. The decision is to again continue at a 1 destructive sample in 150 m (500 ft) sampling interval. From Table 1, the third batch size is then decreased to 32 samples. The process is continued in this manner until the project is concluded. For this hypothetical situation Table 4 illustrates that 412 samples are necessary. Note that by a constant interval of 1 sample in 150 m (500 ft), 360 samples would have been necessary. Furthermore, a good seamer (as illustrated in Example 2) would only have had to take 265 samples.

Table 4(a) - Results of Example 3 (**in S.I. Units**) Illustrating the Variation of the Sampling Interval Based on a 2.0% Anticipated Failure Percentage With a "Poor" Quality Installer

Batch number	Sampling Interval (m)	No. of Remaining Samples Required	Batch size	Cumulative Distance (m)	Number of failures	Decision made
1	150	360	50	7500	3	Stay
2	150	310	50	15000	2	Stay
3	150	260	32	19800	2	Stay
4	150	228	32	24600	3	Decrease
5	120	245	32	28440	3	Decrease
6	100	256	32	31640	1	Increase
7	120	186	32	35480	1	Increase
8	150	123	20	38480	2	Stay
9	150	103	20	41480	1	Stay
10	150	83	13	43430	2	Decrease
11	120	88	13	44990	2	Decrease
12	100	90	13	46290	1	Stay
13	100	77	13	47590	1	Stay
14	100	64	13	48890	1	Stay
15	100	51	13	50190	0	Increase
16	120	32	8	51150	1	Stay
17	120	24	5	51750	1	Decrease
18	100	23	5	52250	0	Increase
19	120	15	3	52610	0	Increase
20	150	9	2	52910	1	Decrease
21	120	9	2	53150	1	Decrease
22	100	11	3	53210	0	Increase
23	120	7	2	53390	0	Increase
24	150	5	2	53510	0	Increase
25	180	3	2	53750	0	Done

Total Number of tests per 54,000 m of seam project = 412

Table 4(b) - Results of Example 3 (**in English Units**) Illustrating the Variation of the Sampling Interval Based on a 2.0% Anticipated Failure Percentage With a "Poor" Quality Installer

Batch number	Sampling Interval (m)	No. of Remaining Samples Required	Batch size	Cumulative Distance (m)	Number of failures	Decision made
1	500	360	50	25000	3	Stay
2	500	310	50	50000	2	Stay
3	500	260	32	66000	2	Stay
4	500	228	32	82000	3	Decrease
5	400	245	32	94800	3	Decrease
6	320	266	32	105040	1	Increase
7	400	187	32	117840	1	Increase
8	500	124	20	127840	2	Stay
9	500	104	20	137840	1	Stay
10	500	84	13	144340	2	Decrease
11	400	89	13	149540	2	Decrease
12	320	95	13	153700	1	Stay
13	320	82	13	157860	1	Stay
14	320	69	13	162020	1	Stay
15	320	56	13	166180	0	Increase
16	400	35	8	169380	1	Stay
17	400	27	5	171380	1	Decrease
18	320	27	5	172980	0	Increase
19	400	18	3	174180	0	Increase
20	500	12	2	175180	1	Decrease
21	400	12	2	175980	1	Decrease
22	320	13	3	176140	0	Increase
23	400	10	2	176780	0	Increase
24	500	6	2	177140	0	Increase
25	600	5	2	177980	0	Done

Total Number of tests per 54,000 m of seam project = 412

5.5 Summary

This guide illustrates by means of hypothetical examples how a CQA and/or CQC organization can modify the sampling interval for taking destructive samples from a geomembrane seaming project. It is based on the method of attributes which is common to statistical control methods. The methodology uses sequential sampling to proceed from one decision to the next until the project is complete.

The result in using this guide for the above purpose is to reward good seaming performance by taking fewer destructive samples, and to penalize poor seaming performance by taking additional destructive samples. In the example illustrations, good seaming resulted in taking 265 samples (versus 360), or a decrease of 26% from the originally set constant interval of 1 sample per 150 m (500 ft). Conversely, poor seaming resulted in taking 412 samples (versus 360), or a 14% increase in the originally set constant interval of 1 sample per 150 m (500 ft.) of seam length.

GM 14 - Appendix A - General Principles of Control Charts

In order to control a production process, like the field seaming of geomembranes, it is necessary to identify and quantify characteristics which reflect the quality of the product. Such quality characteristics can be either discrete or continuous variables. For example, the number of pin holes in a sheet of geomembrane is a discrete variable. Variation in the thickness of a sheet of geomembrane, however, is considered to be a continuous variable.

Whether quality characteristics are discrete or continuous, variability in the observed values is unavoidable. In the theory of control charts, this variation is considered due to either random (common) or assignable (special) causes, Wadsworth (1989) and Deming (1982). Random causes are generally smaller, uncontrollable influences which cannot be removed from the process without fundamental changes in the process itself. An assignable cause, however, is an influence considered to be significant, unusual, and capable of being removed form the process. Such causes may be due to human error, variation in raw materials, or the need for machine adjustment.

An important tool used to reduce process variation is the use of control charts. When using control charts, control limits are used to determine whether the variability of the statistic over time appears to be due to random variation only, or if an assignable cause is present. In other words, the purpose of control charts is to establish a "statistical control" of the assignable causes of variation within of a process.

The control chart generally used to monitor conforming or non-conforming data, called attributes, is the *p*-chart, where "*p*" stands for the proportion of non-conforming items in the entire population. In the case of inspecting the quality of the seams of field deployed geomembranes, the *p*-value would be the historic failure percentage of the installer.

Suppose we have *m* subgroups (e.g., *m* different operators, or *m* different welding machines, or *m* working days, etc.) of varying sample sizes n_1, n_2, ..., n_m. The number of non-conforming (failed) samples in the *i*th subgroup is D_i, i =1, 2, ..., m, so the proportion of non-conforming items (failure rate) in the *i*th subgroup is as follows:

$$\hat{p}_i = \frac{D_i}{n_i}, i = 1,2...,m \qquad \text{(A1)}$$

For the *p*-chart, the values of $\hat{p}_i$ are plotted against the subgroup number with a control limit, *CL*, set at the following:

$$CL = p + 3\left[\frac{p(1-p)}{\bar{n}}\right]^{1/2} \qquad \text{(A2)}$$

where $\bar{n} = \frac{1}{m}\sum_{i=1}^{m} n_i$ = average sample size.

Two examples follow:

Example A1 - Assume that a seaming project is expected to take 25-days for completion, i.e., m=25. The installer has a historic data indicating that the company's average failure percentage is 2.0%. As the work progresses, the number of destructive seam samples and the respective numbers of failures are listed in tabular form as shown in the following table. Note that the daily failure rates, i.e., $\hat{p}_i$, are also shown in the table. The control chart of this project can now be developed.

Subgroup No. (days)	No. of destructive samples	No. of failures in subgroup	Failure Percentage $\hat{p}$
1	12	0	0.000
2	14	0	0.000
3	9	0	0.000
4	7	0	0.000
5	13	1	0.077
6	15	0	0.000
7	19	1	0.053
8	13	0	0.000
9	14	1	0.071
10	9	0	0.000
11	17	1	0.059
12	16	0	0.000
13	7	0	0.000
14	22	1	0.045
15	18	0	0.000
16	16	0	0.000
17	15	0	0.000
18	16	0	0.000
19	14	0	0.000
20	16	0	0.000
21	22	1	0.045
22	18	0	0.000
23	16	0	0.000
24	9	0	0.000
25	13	1	0.077

Solution: From Equation (B2), the control limit is calculated as follows:

$$CL = 0.02 + 3\left[\frac{0.02(1-0.02)}{360/25}\right]^{1/2} = 0.13$$

The control chart can now be obtained by plotting the subgroup failure rate against the subgroup number (i.e., days) along with the control limit, *CL* = 0.13. The results are shown in the following figure, note that the 2.0% historic failure rate is also shown.

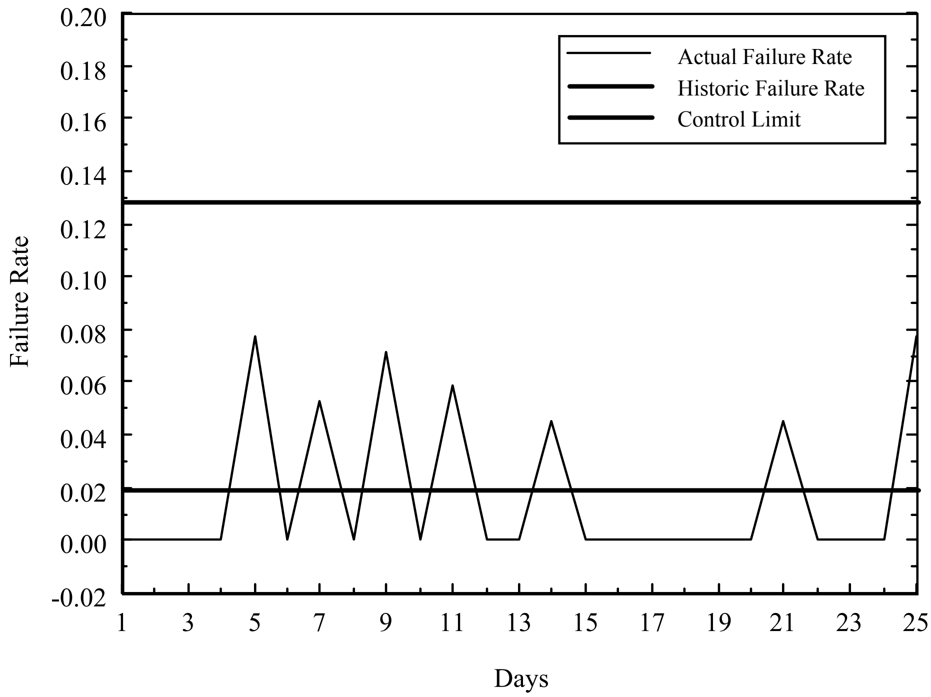

Figure A1 - The Resulted Control Chart of Example A-1.

As seen in the above control chart, the entire 25-day record of the failure rate of this project falls below the control limit set on the basis of the installer's 2.0% historic failure rate. That is to say, the variations in the daily failure record were due to random causes only and no assignable cause was identified. The above control chart indicates that no corrective action is necessary. This is an example of good seaming control.

Example A2 - For a similar size seaming project and historic record (i.e., 2% failure rate) as presented in Example A-1, a second installer has a poorer destructive seam record as shown in the following table. The control chart of this particular situation can also be developed.

Subgroup No. (days)	No. of destructive samples	No. of failures in subgroup	Failure Percentage $\hat{p}$
1	12	1	0.083
2	14	0	0.000
3	9	1	0.111
4	7	0	0.000
5	13	1	0.077
6	15	1	0.067
7	19	3	0.158
8	13	2	0.154
9	14	1	0.071
10	9	0	0.000
11	17	0	0.000
12	16	1	0.063
13	7	1	0.143
14	22	2	0.091
15	18	1	0.056
16	16	2	0.125
17	15	0	0.000
18	16	1	0.063
19	14	0	0.000
20	16	1	0.063
21	22	2	0.091
22	18	1	0.056
23	16	3	0.188
24	9	0	0.000
25	13	1	0.077

Solution: Since the historic failure rate is the same as shown in Example A-1.A new control chart can now be obtained by plotting the subgroup failure rate against the subgroup number (i.e., days) along with the control limit, *CL* = 0.13. The results are shown in the following figure. Again, the 2.0% historic failure rate is also shown.

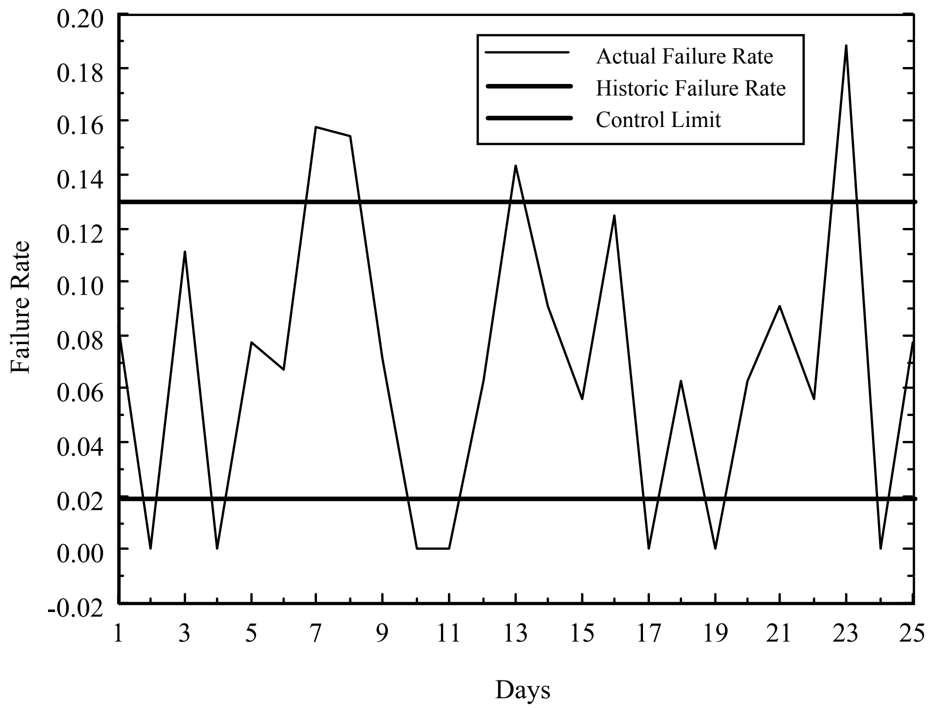

Figure A2 - The Resulted Control Chart of Example A-2.

As seen in the above control chart, the daily failure rates at day 7, 8, 13 and 23 exceed the control limit set on the basis of the installer's 2.0% historic failure rate. That is to say, there are possible assignable causes on those days. From the stand point of construction quality control, the installer should check the record on those days, identify the cause(s) of such variations, and take necessary corrective actions. This is an example of poor seaming.

GM 14 - Appendix B - The Selection of the "I" and "D" Values

In this appendix, the procedure used for selecting the "I" and "D" values listed in Table 2 is presented. The required background, e.g., the concept of sampling risk and the operating characteristics (OC) curves, are briefly discussed.

Sampling Risk

Sampling involves a degree of risk that the actual samples do not adequately reflect the conditions of the lot. For example, when using the sampling plan recommended in this guide, there are two common risks [see Juran and Gryna (1980)[1] and Juran el. al (1974)[2] for details]:

1. A good seaming practice might be penalized. This is generally referred as the installer's risk and denoted as the α risk.
2. A poor seaming practice might go undetected. This is generally referred as an owner/regulators risk and denoted as the β risk.

The effects (impacts) of the relative degree of these two risks are summarized in Table B1.

Table B1 - The Effects of the Relative Degree of α and β Risks.

Relative Degree	Types of Risks	
	Installers (α) Risk	Owner/Regulators (β) Risk
Low	Loose CQA control; low testing cost	Tight CQA control; high testing cost
High	Tight CQA control; high testing cost	Loose CQA control; low testing cost

Operating Characteristics (OC) Curves

Both of the risks can be quantified by sampling-plan-specific *operating characteristics* (OC) *curves*. The OC curve for a sampling plan is a graph whichs plots the probability that the sampling plan will accept a lot (i.e., the P_a value) versus the percent defective samples in that particular lot. Note that the term "sampling plan" used here corresponds to a batch of "*n*" destructive testing samples and the criteria for adjusting the sampling interval. Recall Table 2 in the main body of this guide. Figure B1 illustrates the concept of OC curves. In Figure B1, the dashed curve represents an "ideal" OC curve. Here it is desired to accept all lots having less or equal than 2% and reject all lots having greater than 2% failures. In reality, all sampling plans have risks that a "good" lot will be rejected or a "bad" lot will be accepted. This is illustrated by the solid S-shaped curve shown in Figure B1. It is seen that this particular sampling plan will

[1] Juran, J. M, and Gryna, M, (1980), Quality Planning and Analysis, 2nd. ed., McGraw-Hill Book Company, New York.
[2] Juran, J. M, Gryna, M, and Bingham, R. S., ed., (1974), Quality Control Handbook, 3rd. ed., McGraw-Hill Book Company, New York.

have a 5% risk (100% - 95%) of rejecting a lot having only 1% defects (i.e., a “good” lot) and a 10% risk of accepting a lot having 5% defects (i.e., a “bad” lot).

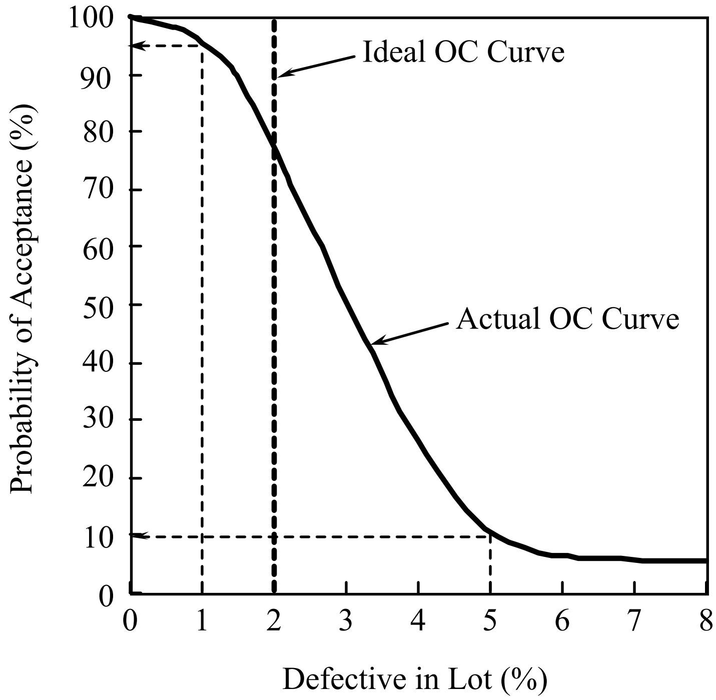

Figure B1 - Ideal and Actual Operating Characteristics Curves for a Sampling Plan

An OC curve can be developed by determining the probability of acceptance for several values of the percent defects. To do so, a statistical distribution of the acceptance probability has to be assumed first. There are three distributions which can be used: hypergeometric, binomial and Poisson distribution[3]. The Poisson distribution is generally preferable due to the ease of calculation. It is used in this guide. The Poisson distribution function to be applied to an acceptance sampling plan is as follows:

$$P\begin{pmatrix}\text{exactly "c" defects} \\ \text{in a batch of size "n"}\end{pmatrix} = \frac{e^{-np}(np)^{c}}{c!} \quad \text{(B1)}$$

Most statistics books provide Poisson distribution tables which give the probability of “c” or less defects in a batch of size “n” from a lot having a fraction of defect “p”.

The Selection of the “I” and “D” Values Listed in Table 2

As mentioned earlier, each of the sampling plans recommended in this guide consists of three variables: the batch size “n”, the values of “I” and “D”. Note that the values of “I” and “D” are specific values of “c” mentioned in Equation B1. The “I” value corresponds to the judgment

[3] Grant, E. L. (1972), Statistical Quality Control, 4th. ed., McGraw-Hill Book Company, New York.

criterion of rewarding good seaming practice, i.e., increasing the sampling interval if the number of failed samples does not exceed this particular value. The "D" value, on the other hand, corresponds to the judgment criterion of penalizing poor seaming practice, i.e., decreasing the sampling interval if the number of failed samples equals or exceeds this particular value.

The concept of the OC curves is used to determine the actual values of I's and D's for different sampling plans. The criteria used are as follows:

- For a batch of size "n", the "I" value should yield a 80~90% probability of rewarding good seaming practice, i.e., $80\% < P_a < 90\%$.

- For a batch of size "n", the "D" value should yield a risk of 0.5% or less of penalizing good seaming practice, i.e., $P_a \geq 99.5\%$. In other words, the probability for good seaming practice to be penalized is extremely small, i.e., less than 0.5%.

The above criteria is subjective. Nevertheless, it is felt to be adequate since the rights of both the installer and the owner/regulator are protected. Recognize that a sampling plan with tighter control (i.e., smaller values of "I" and "D") might seem to be more ideal at first glance, but it may result in a significant increase in the required number of destructive tests, i.e., it may be counter productive.

As an illustration, Figure B2 shows the graphic procedure of obtaining the "I" and "D" values for a batch of 50 samples (n=50) and an anticipated failure percentage of 4%. [In other words, it illustrates the procedure of obtaining one particular pair of numbers listed in Table 2, namely, "I" and "D" equal to 3 and 6, respectively.] Note that each OC curve shown in Figure B2 corresponds to a specific "c" value and is obtained via a Poisson distribution table.

Figure B2 can also used to determine the values of "I" and "D" for sampling plans with the same batch size (i.e., n = 50) but different anticipated failure percentage. The rest of the values listed in Table 2 can be verified in a similar manner using OC curves corresponding to different batch sizes.

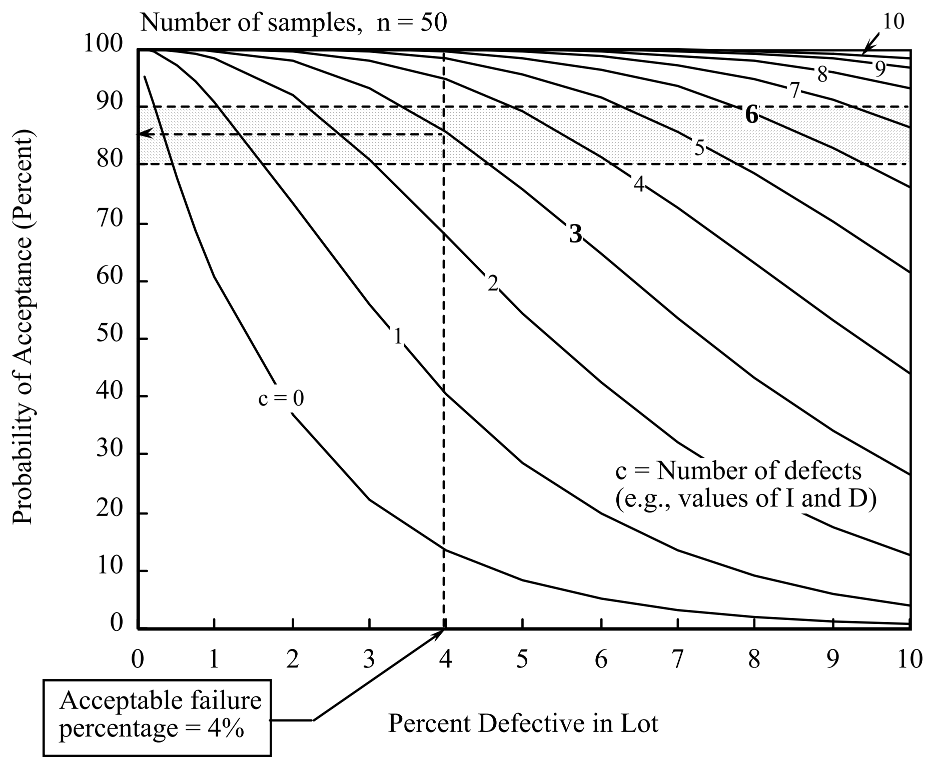

Figure B2 - The Determination of the Values of "I" and "D" for a Batch with 50 Samples and an Anticipated Failure Percentage of 4.0%.