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The Various Roles for Using MARV

by

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Abstract

As it has transpired over the 35-years since the origin of the minimum average roll value (or MARV) concept, its use in many quality roles have targeted quite different segments of the geosynthetic industry. They are manufacturing quality control and assurance (MQC and MQA), as well as construction quality control and assurance (CQC and CQA). The essential concept depending upon the party involved is to have a product's minimum property within the mean value minus two standard deviations, or $\overline{X} - 2S$ of the lot. Similarly, the concept is $\overline{X} + 2S$ if the focus is on the maximum property and it is then called the maximum average roll value (or MaxARV).

The MARV concept was originated to address the relatively high test property variation of lightweight nonwoven geotextiles. As such, the concept is felt to be quite appropriate for geotextiles. However, over the years it has tended to spread to other geosynthetic materials and we feel that this is quite unfortunate. In this regard, the annual Specifiers Guide of Geosynthetic Magazine requests that manufacturers submit MARV or MaxARV values ($\boldsymbol{\bar{X} \pm 2S}$) for the majority of the index test values of their listed products with the proper exception of geomembranes and drainage products. Its use is certainly appropriate for geotextiles, but not necessarily so for other geosynthetics since their statistical variation is much less than for geotextiles.

This White Paper describes the background of the MARV concept and its role within specific aspects of product quality for MQC MQA, CQC and CQA as well as for field conformance practice is concerned.

The Various Roles for Using MARV

Explained in the text to follow is (i) an explanation of the overall quality control process, (ii) the background of MARV, (iii) its method of calculation, its role in (iv) product manufacturing and (v) field construction along with examples of its use.

1.0 The Overall Quality Control Process

It is critical to define and understand the differences between geosynthetic manufacturing and field installation and to counterpoint where the different activities contrast and/or complement one another. The following definitions explain each aspect of quality and are taken directly from the U.S. EPA (1986) Technical Guidance Document.

- Manufacturing Quality Control (MQC): A planned system of inspections that is used to directly monitor and control the manufacture of a material which is factory originated. MQC is normally performed by the manufacturer of geosynthetic materials and is necessary to ensure minimum (or maximum) specified values in the manufactured product. MQC refers to measures taken by the manufacturer to determine compliance with the requirements for materials and workmanship as stated in certification documents and construction specifications.
- Manufacturing Quality Assurance (MQA): A planned system of activities that provides assurance that the materials were manufactured as specified in the certification documents and contract specifications. MQA includes manufacturing facility inspections, verifications, audits and evaluation of raw materials (resins and additives) and geosynthetic products to assess the quality of the manufactured materials. MQA refers to measures taken by the MQA organization to determine if

the manufacturer is in compliance with the product certification and contract specifications for the project.

- Construction Quality Control (CQC)*: A planned system of inspections that is used to directly monitor and control the quality of a construction project. Construction quality control is normally performed by the geosynthetics installer, and is necessary to achieve quality in the constructed or installed system. Construction quality control (CQC) refers to measures taken by the installer or contractor and workmanship as stated in the plans and specifications for the project.
- Construction Quality Assurance (CQA)*: A planned system of activities that provides the owner and permitting agency assurance that the facility was constructed as specified in the design. Construction quality assurance includes inspections, verifications, audits, and evaluations of materials and workmanship necessary to determine and document the quality of the constructed facility. Construction quality assurance (CQA) refers to measures taken by the CQA organization to assess is the installer or contractor is in compliance with the plans and specifications for a project.

2.0 Background of MARV vis-à-vis Minimum Average

While there have been several articles explaining the concept of minimum average roll value (MARV) of geotextiles, e.g., Narejo, Hardin and Ramsey (2001) and Koerner (2005), the topic continues to be less than universally understood and the cause of several serious disputes.

*When CQC and/or CQA personnel are approving field shipments of geosynthetics they oftentimes conduct tests and are said to be performing “field certification testing”.

The minimum average roll value (MARV) concept was jointly developed by geotextile users and manufacturers while crafting acceptance protocols in the early 1980's. The concept was actually a negotiated middle-ground between the engineer/specifier (often a civil engineer) accustomed to requiring <u>absolute minimum values</u> and the textile manufacturers accustomed to providing <u>average values</u> in their product listing of numeric test values. Since the difference between absolute minimum and average can be large when manufacturing lightweight nonwoven geotextiles, a compromise was necessitated. It must be emphasized that the original MARV concept applied only to geotextiles. No other geosynthetic materials; geomembranes, geosynthetic clay liners (except for their geotextile components) geonets, geocomposites (except for their geotextile components), geogrids, geofoam, geopipe, etc. were included in the original discussions.

On occasion, a maximum value is specified and this becomes a MaxARV value, e.g. as with apparent opening size for geotextiles. That said, we will only refer to MARV herein since it is appropriate for the vast majority of properties which are invariably focused on minimum values.

Manufacturers of all types of geosynthetics evaluate <u>average roll values</u> of many test properties on an ongoing basis. It is these values, tempered by statistical variations, which are published in their literature and on their websites. They often publish their mean values, sometimes expressed as a minimum average value. Alternatively, if they publish the mean value minus two standard deviations ($\bar{X} - 2S$) of a particular test property they are indeed following the MARV protocol. In today's specification listings this is the case with geotextiles (and sometimes erosion control materials). Other geosynthetic manufacturers, e.g., for geomembranes, geosynthetic clay liners, geocomposites, geocells, simply publish minimum average values, or $\overline{X}$.

In quite a different role, from manufacturing, field construction personnel tasked with evaluating a shipment of rolls of geosynthetics for a specific project are confronted with a very challenging question, i.e., should they accept the shipment or not? This is a somewhat different issue to which MARV is addressed. To be sure, field CQC and CQA personnel are at liberty to test and evaluate as many, even all, of the rolls sent to a specific job site. On the other hand, the MARV protocol addresses selected rolls of the entire shipment sent to the job site. The entire shipment is generally referred to as the "lot" of rolls for that particular job. The ASTM hierarchy of terminology (from largest to smallest) is as follows:

- lot = the collective group of rolls for the entire project
- roll = any individual roll within the lot
- sample = a cut portion (often the roll width by 3 ft [1.0 m] of length) of any roll sent to a laboratory for testing
- coupon = a portion of the sample sometimes used for conditioning as with incubation in a weathering device
- specimen = the precise size and shape which is die cut from a sample or coupon for laboratory testing per the relevant test method

The MARV protocol per ASTM D4354 calls for determining the number of rolls in the entire lot and taking a limited sampling within it. See Tables 1, 2 and 3 for guidance as to manufacturers quality control (MQC), manufacturers quality assurance (MQA) and purchasers specification conformance by construction quality control (CQC) and/or construction quality assurance (CQA) personnel, respectively.

Table 1 – Number of Rolls to be Selected as the Lot Sample for Manufacturers' Quality Control (MQC)

Number of Rolls in Lot	Number of Rolls Selected
1 to 2	1
3 to 8	2
9 to 27	3
28 to 64	4
65 to 125	5
126 to 216	6
217 to 343	7
344 to 512	8
513 to 729	9
750 to 1000	10
1001 or more	11

Table 2 – Number of Rolls to be Selected as the Lot Sample for Manufacturers' Quality Assurance (MQA)

Number of Rolls in Lot	Number of Rolls Selected
1 to 200	1
201 to 500	2
501 to 1000	3
1001 or more	4

Table 3 – Number of Rolls to be Selected as the Lot Sample for Purchaser's Specification Conformance (CQC and/or (CQA)

Number of Rolls in Lot	Number of Rolls Selected
1 to 200	1
201 to 500	2
501 to 1000	3
1001 or more	4

Thus, for a manufacturer practicing MQC, a project consisting of 210 rolls (i.e., the lot), six rolls should be randomly selected for sampling and subsequent laboratory testing. If the minimum average of these six meets the specification, the entire lot of 210 rolls is accepted. If not, six different rolls are tested and if they meet the specification the entire lot is accepted. However, if this second set of samples also fails, the entire lot of 210 rolls is rejected. For manufacturers quality assurance (MQA), the number of rolls to be tested is considerably lower as shown in Table 2. In this case only two rolls would be selected for testing. Lastly, for field conformance acceptance via construction quality control (CQC) and/or construction quality assurance (CQA) they also require two rolls as in Table 3.

3.0 Obtaining the Minimum Average Roll Value (MARV)

Depending upon the particular geotextile being manufactured there is invariably some amount of property variation. Additionally, the equipment and procedures used in testing of these products introduces some degree of variability. Together, these items result in a statistical variation of physical, mechanical, hydraulic and endurance test values of any given product. Even when a number of replicate samples are tested and averaged together there is a spread in the results. This spread is statistically addressed using the average (or mean) value of a particular property and its standard deviation.

Average (or Mean) Value

Figure 1 following shows a normal distribution of a data set which is generated when many test results are measured on a specific test property value. This applies to properties such as mass/unit area, tensile strength, puncture, tear, etc. By the law of large numbers, the curve is usually symmetrical (statistically, it is called a Gaussian distribution or even an “bell-shaped” curve) and the most frequently measured value is defined as the average (or mean) value. As mentioned earlier, prior to 1980±, this was the usually reported value by many geotextile manufacturers.

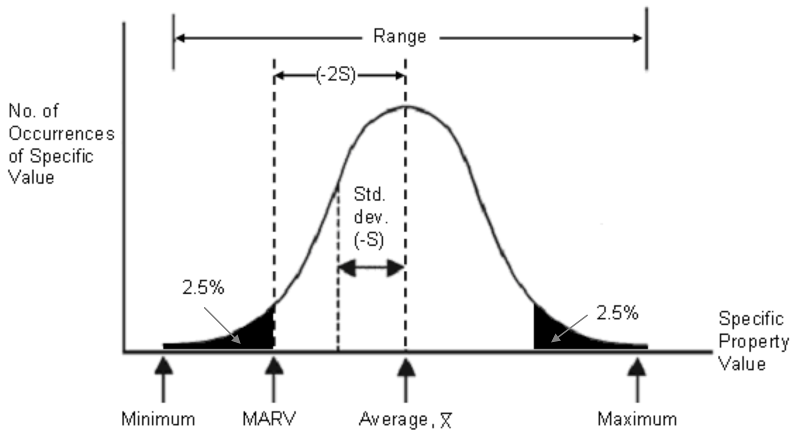

Figure 1 – Graphical Interpretation of Various Qualifying Values, i.e., Minimum, MARV, Average, Maximum, and Range

Standard Deviation

One measure of the variation involved in the product's manufacturing and testing processes is the standard deviation of the test values in question. Statistically, standard deviation(s) is defined as follows:

> "The square root of the arithmetic mean of the squares of the deviation of each of the class frequencies from the arithmetic mean of the frequency distribution."

Mathematically, the two parameters of average (or mean) and standard deviation are defined by the following two equations:

$$\overline{X} = \Sigma X_i / N \tag{1}$$

$$S = \left[\frac{(X_1 - \overline{X})^2 + (X_2 - \overline{X})^2 + \ldots + (X_N - \overline{X})^2}{N - 1} \right]^{1/2} \tag{2}$$

where

$\overline{X}$ = average (or mean) value,

X_i = any measured value, and

N = number of measurements

S = standard deviation (from the average, or mean)

The significance of standard deviation lies in the variation in material properties and testing procedures of the particular property under investigation. For a normally distributed curve, plus and minus one standard deviation ($\overline{X} \pm S$) from the average will include approximately 67% of all measured values. This is indicated on Figure 1. Plus and minus two standard deviations ($\overline{X} \pm 2S$) includes approximately 95% of all measured values and it is also indicated. Additionally, indicated on Figure 1 are the absolute minimum and maximum values (close to $\overline{X} \pm 3S$), which in the past have been the specified values used by many regulatory agencies and engineering specifiers.

Minimum Average Roll Value (MARV)

After many discussions in the early 1980's over a mutually acceptable value to be reported in product specifications of geotextiles (varying from absolute minimum-to-average) the average minus two standard deviations was agreed upon. Thus, it is generally agreed upon (at least in North America) that manufacturers should report geotextile product values of $\overline{X}$ - 2S and regulators and designers should specify values in an identical manner. *This is defined as "MARV".* Note, that when maximum values are required the concept shifts from *MARV to MaxARV and is calculated on the basis of* $\overline{X}$ *+ 2S.* MARV represents 97.5% of the possible measured values since all values in excess of MARV are acceptable. Likewise, when MaxARV is involved again 97.5% of the values are included since the "tail" of the curve in both cases exceeds the relevant value.

4.0 MARV's Role for Geotextile Manufacturers Following MQC Concepts

Having test property data for thousands of rolls of a particular product, a geotextile manufacturer should have no problem with obtaining reliable statistics of mean and standard deviation for the various test properties that are being measured. The total number of like rolls being produced is generally called a lot, but is also sometimes called a "campaign" due to the ongoing production of like product over days, weeks, months, or years. These values of MARV, i.e., the $\bar{X}$ - *2S* values of all properties being measured, is what should appear on the manufacturer's websites and product literature. The point is that a geotextile manufacturer with a relatively large statistical variation in product test values can and should give $\bar{X}$ - *2S* values thereby referencing it as MARV. Consider the following to be an example in this regard.

Assume that a manufacturer is to ship 210 rolls of a given type of geotextile to a job site; thus the "lot" in this regard is 210.

Samples from the specific number of rolls are removed from the entire shipment to the job site (i.e., the lot) and sent to a laboratory for testing; recall Table 1 for the required number of rolls which is six. Specimens are then taken from six random rolls and these samples are evaluated according to the appropriate test method. Furthermore, assume that the number of test specimens per sample is ten per the relevant test method. The measured values of these ten specimens are averaged for each roll as shown in Table 4 below. The specimen test values are then averaged and by observation the lowest average test value for any roll is seen to be a numerical value of 623. This defines MARV for this set of limited rolls within the entire lot.

Table 4 – Example of MARV Obtained for Six Roll Samples

Test Number	Roll Number					
	1	2	3	4	5	6
1	643	627	637	642	652	637
2	627	615	643	646	641	624
3	652	621	628	658	639	631
4	629	616	662	641	657	620
5	632	619	646	635	642	618
6	641	621	633	642	651	633
7	662	622	619	658	641	641
8	635	628	636	662	645	625
9	641	631	627	627	651	635
10	659	625	642	660	647	641
Average =	642	623	637	647	647	631

On this specific project, the minimum average test value (the 623) must meet or exceed the regulatory, designer's, or manufacturer's specified MARV value for the product. In that case, the complete shipment or lot, is acceptable. Note that there are several test specimen values lower than 623 in Table 4. They represent the 2.5% of the normal distribution shown in Figure 1 to the left of the MARV value.

If any of the minimum roll values in Table 4 do not meet the specified value then resampling of a new set of six rolls from the lot is allowed. If then, this second set of six rolls meets the specified value the entire lot shipment of 210 rolls are accepted. If, however, this second sequence of tests has one or more average roll values which do not meet the specified value, the entire lot shipment of 210 rolls is rejected. This is the role of the MARV concept with respect to manufacturing quality control (MQC) protocol.

5.0 MARV's Role for Geotextile Manufacturers Following MQA or Field Specification Conformance (i.e., CQC and/or CQA)

In both MQA and field specification conformance (per CQC and CQA) situations, the method of arriving at the number of rolls to be sampled and tested is significantly lower than with MQC. This is logical to expect since, in all cases, they are meant to be a verification check on the manufacturing process. Tables 2 and 3 (which are identical) give the required number of rolls in the lot to be tested. In the example shown previously, this number for a lot of 210 rolls is two rolls for sampling. The testing protocol beyond the number of rolls to be sampled is identical.

6.0 Recommendations

For the first mentioned manufactures role for MARV, i.e., MQC, geotextile project specifications should definitely use MARV, it being statistically equal to $\overline{X}$ - 2S. The exception being for apparent opening size (where MaxARV becomes necessary it being $\overline{X}$ + 2S) and for UV exposure (where the establishment of MARV would require excessive testing of this long-term endurance type of test). For regulatory purposes and for design engineers, the use of MARV or MaxARV in geotextile specifications will result in unequivocal communication with manufacturers, resulting in a lower number of rejected rolls and a more economical overall situation.

The second mentioned role for MARV, namely the product field conformance to a specification, i.e., MQA or specification conformance (CQC and/or CQA), MARV or MaxARV takes on a different role than for manufacturers in that only a select few rolls from the "lot" are sampled, tested, and assessed accordingly. Admittedly, the ASTM procedure is somewhat subjective (e.g., the cube root of the lot, the protocol if the first or second set of samples fails, etc.) but it is reasonable for geotextiles which can have rather large statistical variations. This procedure is not recommended for other geosynthetics such as geomembranes, geogrids, geonets, composites, GCLs, etc., which must be tested per the project-specific plans and specifications. It is clearly the design engineer's role to make the field conformance decision on whether to use a MARV procedure or not on a project-specific basis.

7.0 References

AASHTO M288-06 Standard Specification for Geotextile Specification for Highway Applications, Appendix "A", Washington, DC, 12 pgs.

ASTM D4354, Standard Practice for Sampling of Geosynthetics for Testing, ASTM, West Conshohocken, PA.

ASTM D4759, Standard Practice for Determining the Specification Conformance of Geosynthetics, ASTM, West Conshohocken, PA.

Koerner, R. M., 2005, "Designing with Geosynthetics," 5th Edition, Prentice Hall, Upper Saddle River, NJ, 796 pgs.

Narejo, D., Hardin, K. and Ramsey, B., "Geotextile Specifications: Those Vexing Qualifiers," Geosynthetics Magazine (GFF), Vol. 19, No. 7, September 2001.

U.S. EPA "Technical Guidance Document, Construction Quality Assurance for Hazardous Waste Land Disposal Facilities," 1986, EPA/530-SW-86-031, U.S. Environmental Protection Agency, Cincinnati, Ohio.