SOFTWARE VALIDATION TEST REPORT FOR FRACMAN®, VERSION 2.6

Prepared for

U.S. Nuclear Regulatory Commission
Contract NRC–02–02–012
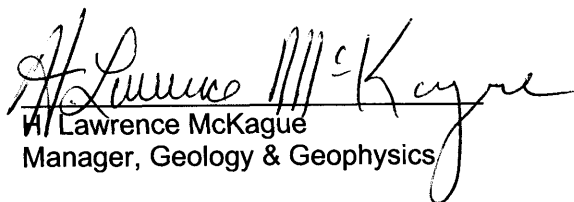
Prepared by

Danielle Wyrick
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Center for Nuclear Waste Regulatory Analyses
San Antonio, Texas

January 2005

Approved by:

H. Lawrence McKague
Manager, Geology & Geophysics

1/27/05
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CONTENTS

1   SCOPE OF THE VALIDATION

This document establishes the Software Validation Test Report for validating the functionality of the commercial code FRACMAN®, Version 2.6. FRACMAN® Version 2.6 is a software package developed by Golder Associates Inc. to model the geometry of discrete features, such as fractures in fractured rock masses, for rock mechanics and hydrologic applications. FracMan's data analysis capabilities include techniques for analyzing fracture orientation, size, and intensity. FracMan consists of several program modules that operate within a MSDOS shell (i.e., HeterFrac, FracSys, FracWorks) and one module (FracWorksXP) that has been ported to the Windows 95/NT/2000/XP environment. Software validation is restricted to those modules that are expected to be used for Center for Nuclear Waste Regulatory Analyses (CNWRA) activities. Specifically, this software validation test plan contains test cases for the modules HeterFrac and FracWorksXP.

2   REFERENCES

Dershowitz, W.S. and H. H. Herda. "Interpretation of Fracture Spacing and Intensity." *Rock Mechanics.* Edited by Tillerson and Wawersik. Balkema, Rotterdam. pp. 757–766. 1992.

Golder Associates Inc. "FracMan Interactive Discrete Feature Data Analysis, Geometric Modeling, and Exploration Simulation User Documentation, Version 2.6." Seattle, Washington. 1998.

Golder Associates Inc. "FracWorksXP Discrete Feature Simulator Module User Documentation." Seattle, Washington. 2002.

Wyrick, D. "Software Validation Test Plan for FRACMAN®, Version 2.6." San Antonio, Texas: CNWRA. 2004.

3   ENVIRONMENT

3.1   Software

FracMan, Version 2.6, is commercial software developed by Golder Associates Inc. Version 2.6 runs in MS-DOS™ Versions 3.0, 3.1, 3.3, 4.01, 5.0, 6.0, and 6.2. The FracWorksXP module requires a Microsoft Windows® operating environment (95, 98, 2000, NT, or XP). The following software items are required to perform the testing activity described in Section 6.1:

(i)   FRACMAN®, Version 2.6 software, including HeterFrac module
(ii)   MS-DOS™ 3.0, 3.1, 3.3, 4.01, 5.0, 6.0, or 6.2 operating system

The following software items are required to perform testing activities described in Sections 6.2 and 6.3:

(i)   FracWorksXP module version 4.1.1 software package
(ii)   Windows® 95, 98, 2000, NT, or XP operating system
(iii)   Microsoft Excel
(iv)   Rockware StereoStat Version 1.3

3.2   Hardware Requirements

FRACMAN® Version 2.6 runs on any MS-DOS™ compatible computer with an Intel CPU and math coprocessor – including 80286/80287 (IBM-AT), 80386/80387, i486, and Pentium™ class computers. FracMan will not run without a math coprocessor, except with i486 DX and Pentium™ computers, which include built in math coprocessor support. FracMan requires at least 1 Mb of installed memory and a graphics card that can operate in at least one of the following modes: (i) Video Graphics Array (VGA), 640 x 480 resolution, black and white or (ii) VGA, 640 x 480 resolution, 16-color. Although FracMan can run with just 1 Mb of RAM, an additional 2 to 4 Mb configure as a random access memory disk is recommended to improve performance on larger problems. A high-speed hard drive with a least 1 Mb free is also recommended. For the FracWorksXP module, any PC compatible computer that operates Windows may be used. A minimum of 128 Mb of RAM is required with a recommendation of 256 Mb. The computer must be equipped with an openGL compatible graphics card. No peripherals (e.g., tape drives, printers, plotters) are necessary to perform testing activities (Golder Associates Inc., 1998, 2002).

4   PREREQUISITES

Running FRACMAN® Version 2.6 requires installation of the commercially available software, per the developers' User Documentation (Golder Associates Inc., 1998, 2002).

5   ASSUMPTIONS AND CONSTRAINTS

The user of FRACMAN® Version 2.6 is assumed to be familiar with discrete fracture modeling and should familiarize themselves with the working definitions specific to the study of fracture systems as defined in the User Documentation (Golder Associates Inc., 1998, 2002) and the scientific literature (Dershowitz and Herda, 1992).

6   TEST CASES

The test cases described in this section were used to validate the specific modules of FracMan to be used within the CNWRA. The HeterFrac module of FracMan is designed to analyze actual fracture population data for statistical analysis of fracture size and intensity. The FracWorksXP module is designed to generate synthetic fracture populations based on user inputs that describe the orientation, intensity, and size characteristics of a natural fracture population.

6.1   Test Case 1 – FracSys: HeterFrac Fracture Data Analysis

HeterFrac geologic structure analysis allows the evaluation of trace plane maps containing linear fracture traces. The results provide statistical analysis of fracture size and intensity. The test case described in this section used a synthetic test case (an analog of actual fracture data) created to compare results from the analytical solution to the results obtained from FRACMAN® Version 2.6.

6.1.1 Test Input

Geologic structure analysis requires specification of two input files before execution. The first file (*.F2D) contains the specification of the fracture trace maps to be analyzed. This file contains the individual traces expressed as pairs of beginning and end coordinates of line segments in the coordinate system of the fracture trace data. The following information is required input for a HeterFrac (*.F2D) file:

*.SAB: The name of the sampling file associated with the .F2D file.
np: The number of the sampling structure. This is the traceplane identification number contained in the .SAB file.
x1, y1, x2, y2: The coordinates of the two endpoints of the fracture trace.
tr: The fracture trend in degrees.
pl: The fracture plunge in degrees.

Refer to the example test1_stvp.F2D (Appendix A) for specific ASCII file format requirements. For the purpose of testing, a simplified fracture network was created. The test file test1_stvp.F2D consists of six fractures. Four fractures are oriented with a trend of 45 degrees and plunge of 0; two fractures are oriented with a trend of 135 degrees and plunge of 0. This creates an overall fracture set with two fractures terminating at an intersection with other fractures.

The geometry of the trace plane was defined in a standard FracMan survey file (*.SAB). The following information is required input for a FracMan (*.SAB) survey file:

name: The name of .SAB file.
origin: Beginning x, y, z coordinates of traceplane as defined from the center of the right hand edge of the traceplane.
scan_trend: The scan vector trend from the center of the right hand edge of the traceplane to the center of the left hand edge of the traceplane.
scan_plunge: The scan vector plunge from the center of the right hand edge of the traceplane to the center of the left hand edge of the traceplane.
scan_length: The length of the traceplane.
tran_trend: The transverse vector trend from the center of the right hand edge of the traceplane to the top of the right hand edge of the traceplane.
tran_plunge: The transverse vector plunge from the center of the right hand edge of the traceplane to the top of the right hand edge of the traceplane.
tran_width: The width of the traceplane. This value is twice the length of the transverse vector from the center of the right hand edge of the traceplane to the top of the right hand edge of the traceplane.

Refer to the example STVP.SAB (Appendix B) for specific ASCII file format requirements. For the purpose of testing, a traceplane survey file with one traceplane was created. The traceplane is defined as a plane 12 meters in length and 2 meters in width, with a scan trend of 90 degrees, plunge of 0 and transverse trend of 0, plunge of 0. This traceplane was used in order to capture all sample fracture data.

6.1.2 Analytical Solution

HeterFrac provides the following fracture analysis functions. The statistics below were solved for the test1_stvp.F2D fracture network, using the SVTP.SAB survey file.

Statistical Definition	Analytical Solution	FracMan Solution
Total number of trace segments	6	**6**
Total length of all traces	14.14 m	**14.14 m**
Mean trace length	2.357 m	**2.357 m**
Trace length standard deviation	0.7303 m	**0.7303 m**
Traceplane dimension	12 m x 2 m	**12 m x 12 m**
Selected region area	24 m^2	**24 m^2**
Number of non-terminating intersection (X_S) *X_S is defined as the number of intersections that do not terminate against another fracture.*	0	**0**
Number of terminating intersections (T_S) *T_S is defined as the number of intersections that produce a termination*	3	**3**
Fracture intensity (P_{20}) *Fracture intensity P_{20} is defined as the number of fractures in a set per unit area of the traceplane*	0.25 #/m^2	**0.25 #/m^2**
Fracture intensity (P_{21}) *Fracture intensity P_{21} is defined as the total fracture length per unit area of the traceplane*	0.5893 m^{-1}	**0.5893 m^{-1}**
Intersection intensity (C_{20}) *Intersection intensity is defined as the number of intersections per unit area of the traceplane*	0.125 m^{-2}	**0.125 m^{-2}**
Termination probability (P[T/I]) *Termination probability is defined as the total number of intersections divided by the number of terminating intersections*	100%	**100%**
Termination percentage (T%) *Termination percentage is defined as the percentage of fracture terminations on the traceplane which are terminations at intersections with other fractures*	100%	**100%**

6.1.3 Test Procedure

The HeterFrac Traceplane Analysis was run from within the FracMan graphical user interface. The FracSys data analysis module was selected from the main FracMan screen, then the HeterFrac submenu was selected. Trace Plane Analysis was highlighted. The test file test1_stvp.F2D was loaded. The Statistics option was selected. The screen displayed a number of fracture statistics, which was saved to a text file.

6.1.4 Test Results

The analytical calculations were rounded to the number of decimal places that was generated by the software. The statistics calculated by FracMan were directly compared to analytical solutions outlined above. Calculated results were identical to the analytical solutions.

6.2   Test Case 2 – FracWorks XP: Analysis of Statistical Data

Within FracWorksXP, a wide variety of discrete features can be generated from stochastic descriptions and user inputs. Fracture realizations can be saved in a variety of formats for use in simulation and modeling. All stochastic generation begins with a random seed number. Given user inputs, a statistical analysis of fracture orientation, intensity, and size was performed. These results were compared to analytical solutions.

6.2.1 Test Input

Fracture generation began by defining the region. For this test case, the defining region was a box with dimensions of 20m x 20m x 20m (region name: STVP1_box). The parameters for the geometric fracture generation set were as follows:

Generation region = standard, STVP1_box
Clipping region = standard, STVP1_box
Generation model = Enhanced Baecher
Fracture intensity = measure by number of fractures
Parameters = 100 fractures
Fracture orientation: Constant, trend = 90, plunge = 0
Orientation specified by = Pole
Fracture size = Constant, parameter = 2
Fracture shape = 6 sides
Transmissivity = Constant distribution
Storativity = Constant distribution
Aperture = Constant distribution
Termination percentage = 0

6.2.2 Analytical Solution

Using the above user input values, the following statistics were calculated:

Statistical Definition	Analytical Solution
Number of fractures	100
Total fracture area	1256.64 m^2
Volume of model bounding box	8000 m^2
Fracture intensity P_{32} *Fracture intensity P_{32} is defined as the total fracture area per unit volume of the model bounding box*	0.157080 m^2/m^3
Mean orientation	90 trend, 0 plunge
Mean equivalent radius	2
Mean fracture area	12.5664 m^2

6.2.3 Test Procedure

Upon opening FracWorks XP module, select Insert −> Region Box. Box dimensions were set to test input values. The menu option Fracture −> Add Set −> Geometric was selected. The Windows™ interface was followed to enter the parameters needed to run the test. The values as described in Section 6.2.1 were used. The menu option Analysis −> Statistics was selected to fill in the Fracman statistics given in Section 6.2.2.

6.2.4 Test Results

The analytical calculations as described above were calculated for an ideal fracture generation in which all fractures fall entirely within the region box. Because of the stochastic nature of the program, fractures generated may partially fall outside of the region box defined. The test case described clips all fractures at the border of the region box. Therefore the mean equivalent radius, mean fracture area, and total fracture area generated by the test will always be less than or equal to the ideal. The tested values fall within −10 percent of the ideal fracture calculations, which falls within the acceptable range defined in the Software Validation Test Plan as shown in Table 1 (Wyrick, 2004).

Table 1: Test Case 2

Statistical Definition	Analytical Solution (Ideal)	Test 1 Seed #: 370719107		Test 2 Seed #: 40644329		Test 3 Seed #: 814325261		Test 4 Seed #: 189128564		Test 5 Seed #: 1999011013	
		Value	% change from Ideal	Value	% change from Ideal	Value	% change from Ideal	Value	% change from Ideal	Value	% change from Ideal
Number of fractures	100	100	0.00%	100	0.00%	100	0.00%	100	0.00%	100	0.00%
Total fracture area	1256.64	1152.55	8.28%	1161.21	7.59%	1144.16	8.95%	1148.99	8.57%	1168.06	7.05%
Volume of model box	8000 m^3	8000 m^3	0.00%	8000 m^3	0.00%	8000 m^3	0.00%	8000 m^3	0.00%	8000 m^3	0.00%
Fracture intensity P$_{32}$	0.15708	0.144069	8.28%	0.145151	7.59%	0.14302	8.95%	0.143624	8.57%	0.146007	7.05%
Fracture intensity P$_{32}$ is defined as the total fracture area per unit volume of the model bounding box											
Mean orientation	90 trend, 0 plunge	90 trend, 0 plunge		90 trend, 0 plunge		90 trend, 0 plunge		90 trend, 0 plunge		90 trend, 0 plunge	
Mean equivalent radius	2	1.90816	4.59%	1.91688	4.16%	1.90221	4.89%	1.90455	4.77%	1.92341	3.83%
Mean fracture area	12.5664	11.5255	8.28%	11.6121	7.59%	11.4416	8.95%	11.4899	8.57%	11.6806	7.05%

	Analytical Solution (Ideal)	Test 6 Seed #: 317381095		Test 7 Seed #: 1259921306		Test 8 Seed #: 960785390		Test 9 Seed #: 1803572040		Test 10 Seed #: 277228087	
		Value	% change from Ideal	Value	% change from Ideal	Value	% change from Ideal	Value	% change from Ideal	Value	% change from Ideal
Number of fractures	100	100	0.00%	100	0.00%	100	0.00%	100	0.00%	100	0.00%
Total fracture area	1256.64	1145.29	8.86%	1163.69	7.40%	1170.75	6.83%	1133.84	9.77%	1151.53	8.36%
Volume of model box	8000 m^3	8000 m^3	0.00%	8000 m^3	0.00%	8000 m^3	0.00%	8000 m^3	0.00%	8000 m^3	0.00%
Fracture intensity P$_{32}$	0.15708	0.143161	8.86%	0.145461	7.40%	0.146344	6.83%	0.14173	9.77%	0.143942	8.36%
Fracture intensity P$_{32}$ is defined as the total fracture area per unit volume of the model bounding box											
Mean orientation	90 trend, 0 plunge	90 trend, 0 plunge		90 trend, 0 plunge		90 trend, 0 plunge		90 trend, 0 plunge		90 trend, 0 plunge	
Mean equivalent radius	2	1.90127	4.94%	1.91589	4.21%	1.92481	3.76%	1.89134	5.43%	1.90856	4.57%
Mean fracture area	12.5664	11.4529	8.86%	11.6369	7.40%	11.7075	6.83%	11.3384	9.77%	11.5153	8.36%

FracMan v. 2.6, Test Case 2: Analysis of Statistical Data
Testing performed: 15DEC04, dyw

6.3   Test Case 3 – Verify Orientation and Distribution

Within FracWorksXP, generated fracture sets were plotted on an equal-area stereonet to visualize fracture orientation. Histograms of fracture size distribution were also be produced. All stochastic generation begins with a random seed number. This test was performed to confirm stereonet plots and histograms produced by FracWorksXP using similar software programs.

6.3.1   Test Input

Fracture generation began by defining the region. For this test case, the defining region was a box with dimensions of 20m x 20m x 20m (region name: STVP1_box). For this test, a new fracture property, FracRadius, must be added. On the Properties tab, click on the icon to Add Property. Name the property "FracRadius." Correlate the property to Size by selecting the equation A + B^C, where A=0, B=1, and C=1. This will make FracRadius equal to the fracture equivalent radius. Note: In FracMan, do not name properties using common terms such as radius, trend, plunge, etc.; some of these terms are used as code variables and may give null values. The parameters for the entire geometric fracture generation were set are as follows:

Generation region = standard, STVP1_box
Clipping region = standard, STVP1_box
Generation model = Enhanced Baecher
Fracture intensity = measure by number of fractures
Parameters = 100 fractures
Fracture orientation: Fisher distribution, trend = 10, plunge = 45, dispersion = 100
Orientation specified by = Pole
Fracture size = Log normal, parameter = 2, deviation = 0.5
Fracture shape = 6 sides
Transmissivity = Constant distribution
Storativity = Constant distribution
Aperture = Constant distribution
FracRadius = Correlate to size
Termination percentage = 0

6.3.2   Test Procedure

Upon opening FracWorksXP module, the menu option Insert −> Region Box was selected. Box dimensions were set to test input values. The menu option Fracture −> Add Set −> Geometric was selected. The Windows™ interface was followed to input the parameters needed to run the test. The values as described in Section 6.3.1 were used. A stereonet was plotted by selecting Analysis −> Stereonet. To verify the histogram, right click on the fracture definition set (located on the left hand side of screen) and select histogram −> FracRadius.

6.3.3   Result Verification Stereonet

To verify FracWorksXP is plotting fracture data correctly, the fracture data was exported and then imported into Rockware StereoStat Version 1.3. The menu option File −> Export −>

Fracture file was selected. This exported the data as a *.fab file (an ASCII text file). This ASCII text file was reformatted to be imported into Rockware StereoStat. In StereoStat, a lower hemisphere, equal area stereonet was plotted. The menu option Data Analysis −> Analyze Data −> Fisher axis was selected. StereoStat provided the mean fracture orientation (trend and plunge) and the Fisher dispersion coefficient (K value), which was compared to the original input values.
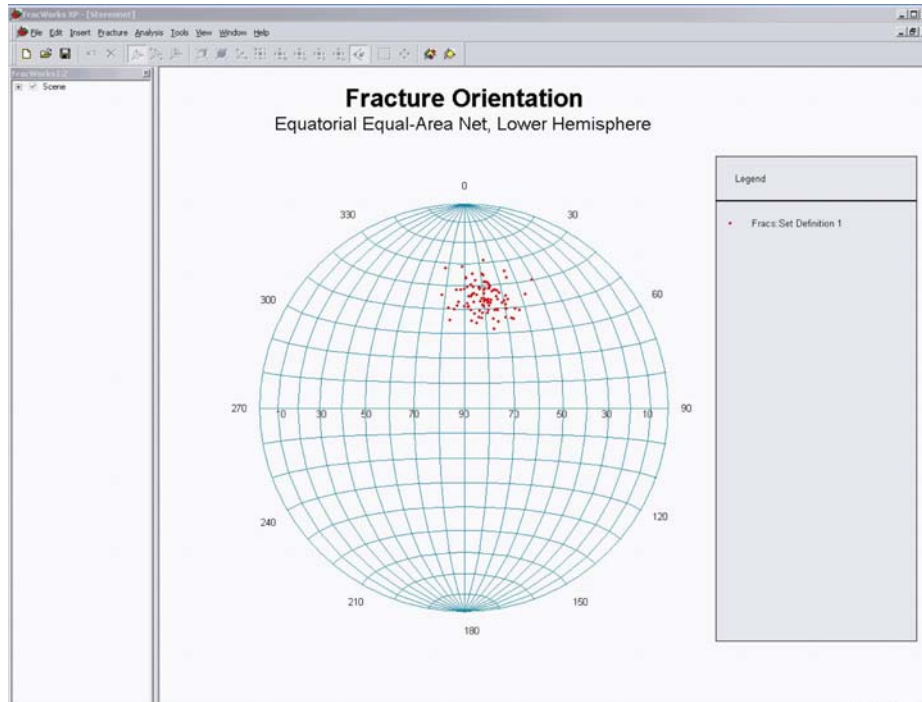

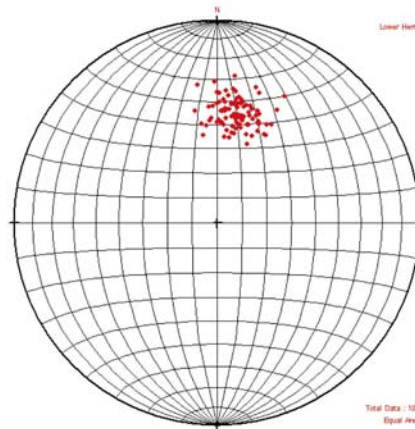**Figure 1: Equal Area Stereonet Generated from FracMan Using Test Inputs Described in Section 6.3.1**

Figure 2: Equal Area Stereonet Generated from StereoStat Using Test Inputs Described in Section 6.3.1

A visual comparison of stereonets was done (Figures 1 and 2). Although the two programs display the lower hemisphere, equal area plots slightly different, the data points plot identically. Because of the stochastic nature of FracWorksXP, there was an expected variation in the fracture data from the input values. For fracture orientation (trend and plunge), the values were ±5°, within the acceptable range defined in the Software Validation Test Plan as shown in Table 2 (Wyrick, 2004). The calculated K value was ±10 percent from the input dispersion value, within acceptable range (Table 2).

Table 2: Test Case 3

	Test Input Seed #	Test 1 1.88E+09	% change from test	Test 2 5.05E+08	% change from test	Test 3 82837036	% change from test	Test 4 1.14E+09	% change from test	Test 5 1.27E+09	% change from test
Trend =	10	11	1°	11	1°	10	0°	11	1°	8	-2°
Plunge =	45	45	0°	45	0°	46	1°	44	-1°	45	0°
K value =	100	97.036	2.96%	94.737	5.26%	104.58	-4.58%	100.96	-0.96%	102.75	-2.75%

	Test Input Seed #	Test 6 75004276	% change from test	Test 7 1.62E+09	% change from test	Test 8 2.14E+09	% change from test	Test 9 7.16E+08	% change from test	Test 10 1.73E+09	% change from test
Trend =	10	10	0°	10	0°	11	1°	11	1°	10	0°
Plunge =	45	46	1°	45	0°	45	0°	46	1°	45	0°
K value =	100	99.076	0.92%	107.72	-7.72%	98.441	1.56%	98.579	1.42%	108.58	-8.58%

6.3.4 Result Verification Histogram

The same fracture data file was imported into Excel. In Excel, a log normal histogram was created to compare to the plot generated in FracWorksXP. The histograms plotted the same (Figures 3 and 4).
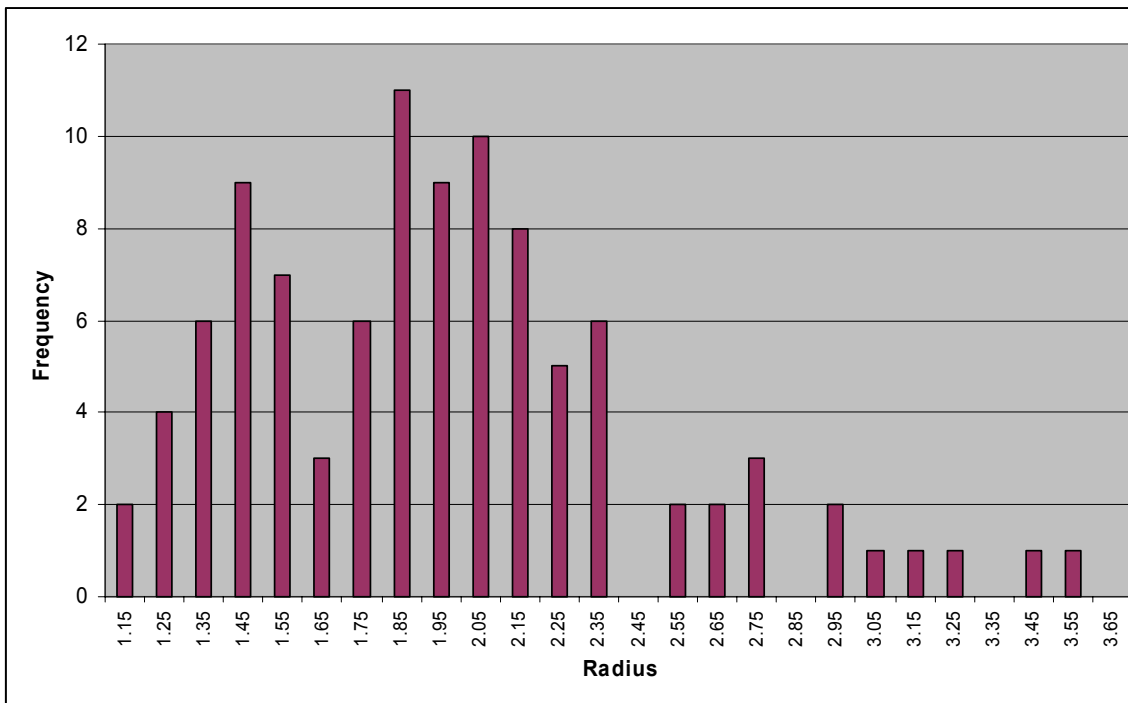

Figure 3: Histogram Plotted in Excel Using Fracture Frequency Versus Radius
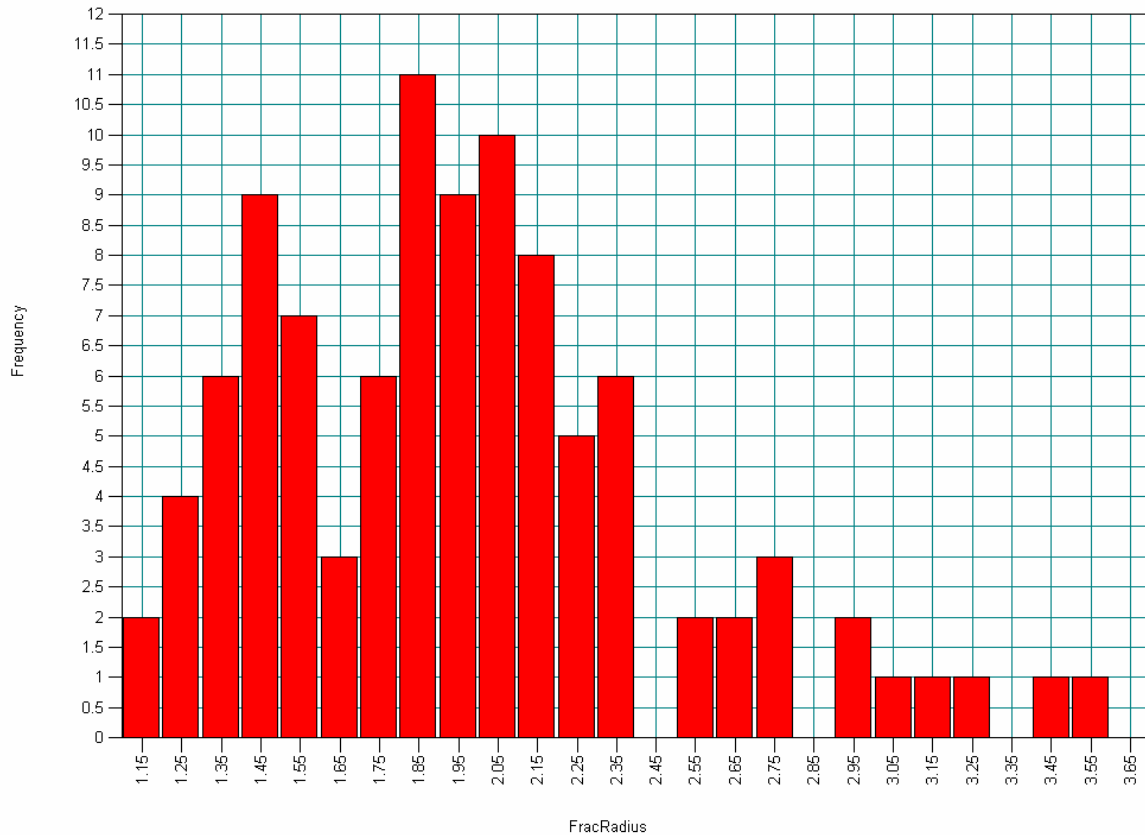
FracRadius

Figure 4: Histogram Plotted in FracMan Using Fracture Frequency Versus Radius

7 CONCLUSIONS

This Software Validation Test Report has validated the functionality of the commercial code FRACMAN®, Version 2.6. Software validation was restricted to those modules that are expected to be used for CNWRA activities, specifically the modules of HeterFrac and FracWorksXP. All tests performed in this report were completed successfully. This software, within the confines of its limited validation, should be acceptable for use in modeling discrete features, such as fractures in fractured rock masses, for rock mechanics and hydrological applications.

11

APPENDIX A — ASCII file test1_stvp.F2D

```
STVP.SAB                      [Sampling file name]
   0  [frac. orientation, 0:pole, 1:dip]
 ******* (np, x1, y1, x2, y2, tr, pl) *******
1    2    1    0    -1    45    0
1    4    1    2    -1    45    0
1    6    1    4    -1    45    0
1    8    1    6    -1    45    0
1    5    0    6    -1    135   0
1    7    0    8    -1    135   0
```

APPENDIX B — ASCII file SVTP.SAB

```
BEGIN traceplane
    name   = "dyw1"
    origin = 0.000      0.000 0.000
    scan_trend  =       90.000
    scan_plunge =       0.000
    scan_length =       12.000

    tran_trend  =        0.000
    tran_plunge =        0.000
    tran_width  =       2.000
END
```