

CASE STUDY NO. 11

IMPROVEMENT OF EXISTING IDENTIFICATION METHODS FOR CV CABLE DETERIORATION, DEVELOPMENT OF TECHNIQUES TO ESTABLISH DIAGNOSIS* PRIORITY USING WEIBULL METHOD

**BY MIKIYA YASUHARA,
ASSISTANT MANAGER, DISTRIBUTION DEPARTMENT,
OSAKA-KITA BRANCH OFFICE**

1. INTRODUCTION

Modern society depends so heavily on electricity for its life and industry that power outages have an increasingly more serious impact from year to year. Hence, power companies are more and more concerned with the goals of identifying equipment faults and preventing failures.

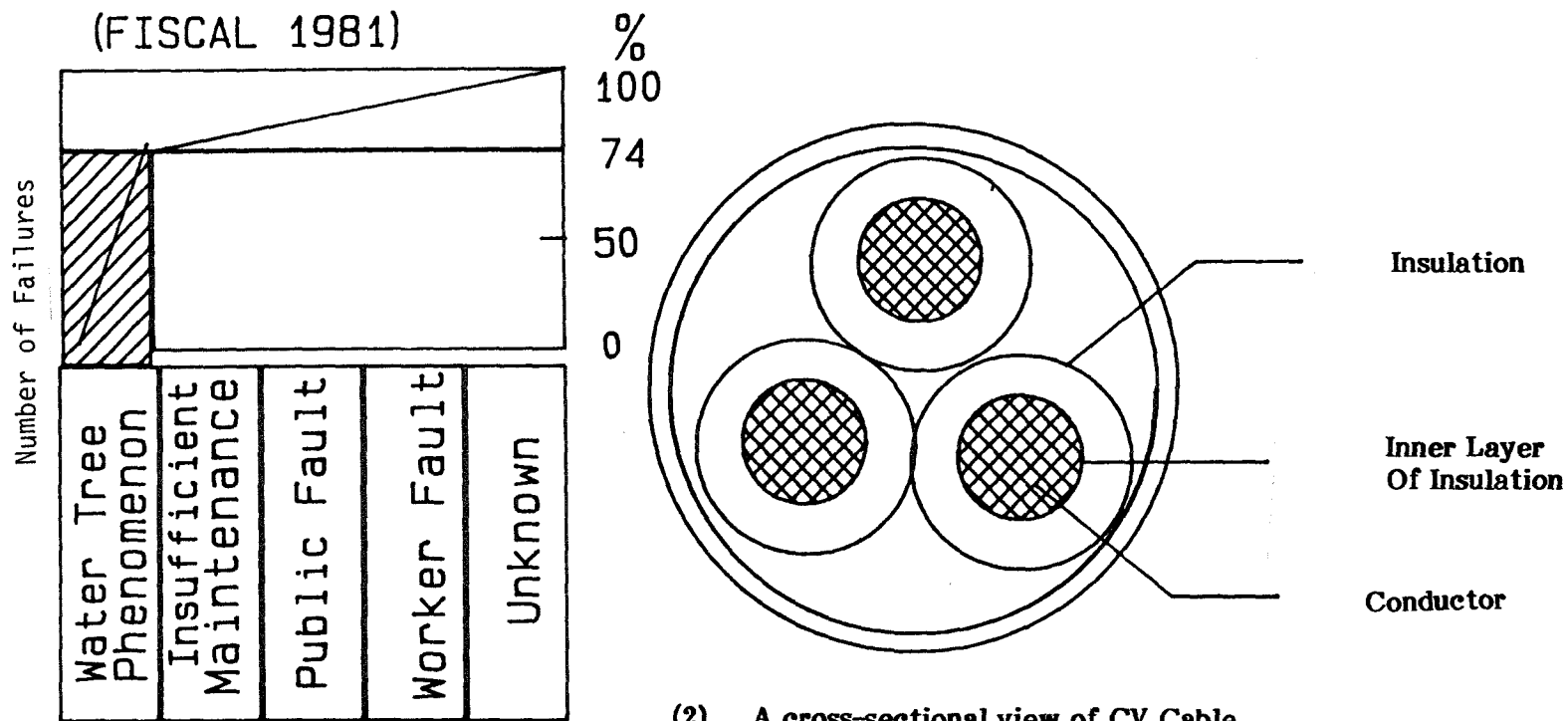
The author has developed techniques to establish the order of priority of diagnosis using the Weibull method as a means of preventing failures with underground distribution lines, and has successfully diagnosed deteriorations of CV cables by the use of these techniques. The progress of the development of these techniques is introduced.

2. REASON FOR SUBJECT SELECTION

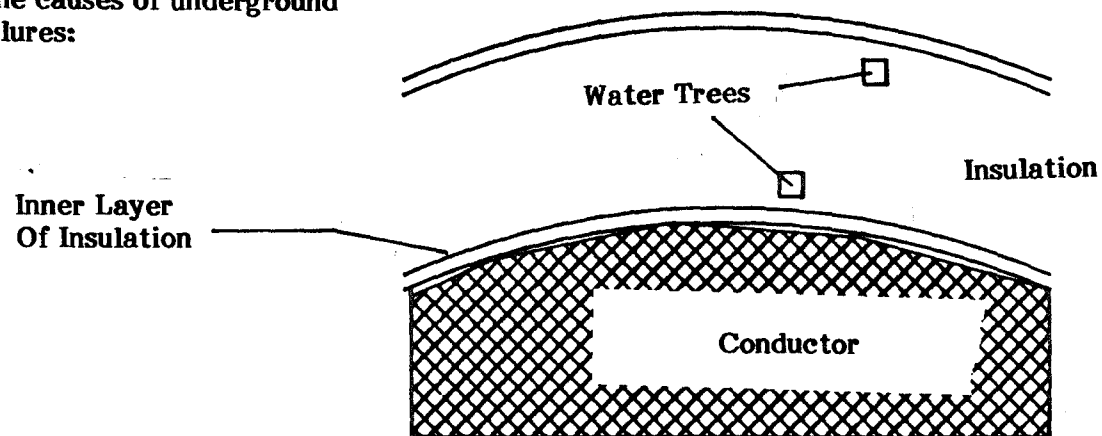
The incidence of failures related to underground distribution lines has been increasing in recent years. These failures are primarily attributable to the water tree phenomenon (**) in the CV cables manufactured in 1971 and earlier. It accounted for as much as 75% of the underground distribution line failures experienced by our Osaka-Kita Branch Offices during fiscal 1976, as shown in Fig. 1 (1), prompting the author to choose the improvement of identification methods for CV cable deterioration as an approach for decreasing failures caused by the water tree phenomenon.

* Diagnosis (or Diagnostic) = "megger test" or the process of measuring resistance of insulation.

** The water tree phenomenon is one in which moisture grows in tree-like form in the direction of the electric field in the insulation of CV cable through the interaction of water and the electric field, as shown in Fig. 1 (2) and (3), resulting in reduced insulation.



- (1) Pareto diagram showing the causes of underground power distribution line failures:



(3) Water Tree Phenomenon

3. UNDERSTANDING THE CURRENT SITUATION

The author identified the causes of the failures associated with the water tree phenomenon by using a cause and effect diagram and put into action a countermeasure for each true cause identified, but failures associated with improper diagnostic intervals continued in fiscal 1982 and 1983.

Hence, improving deterioration diagnostic intervals was found to be a key in preventing failures caused by the water tree phenomenon.

4. GOAL AND CONSTRAINT SETTING

Goal: To minimize power outages caused by water tree deteriorations.

Constraint: To limit the diagnostics workload to the extent that can be handled by the existing staff of maintenance personnel.

5. ANALYSIS APPROACHES

The efficient prevention of failures calls for:

- (i) Understanding what cables are most likely to become defective
- (ii) Implementing diagnosis in descending order starting with the greatest defect occurrence

The following approaches were taken in analysis:

- (i) Understanding the life characteristics of cables
- (ii) Determining the defect probabilities of individual cables
- (iii) Selecting the cables to be diagnosed for the next diagnostic year

6. ESTIMATING CV CABLE LIVES BY THE WEIBULL METHOD

6.1 DATA STRATIFICATION

In an effort to ensure increased analysis accuracy, failure trends were compared with regard to manufacturers, years of production, specifications and so on. Differences in lives are obvious as shown in Fig. 2 (1). The comparisons revealed the following two factors:

- (i) Material of the inner layer of the insulation → All failures had occurred with non-cotton CV cables.
- (ii) Cable size → 64% of the total failures had occurred with small-sized CV cables (150 mm² or less).

The life analysis was therefore stratified into the following four groups:

- CV cables with cotton insulation inner layers
 - Small-size (a)
 - Large-size (b)
- CV cable with non-cotton insulation inner layers
 - Small-size (c)
 - Large-size (d)

6.2 UNDERSTANDING CABLE LIFE CHARACTERISTICS

The Osaka-Kita Branch Office had laid CV cables over approximately 1,700 lines in the decade from 1962 to 1971.

Less than 3% of these lines developed failures related to water trees, and most of the cable life data available were censored data.* Therefore the author used the Johnson average failure order method ¹⁾ of Weibull analysis as a life estimation technique for evaluating the censored data (see Fig. 2 (2)).

The data used in the analysis were extracted under the following conditions:

- (i) Data on the cables determined to be defective by deterioration diagnosis were also treated as failure data, because the number of failures recorded was not sufficient for analysis.
- (ii) Cables falling in the same strata and in the same fiscal year were considered to have the same reliability level.

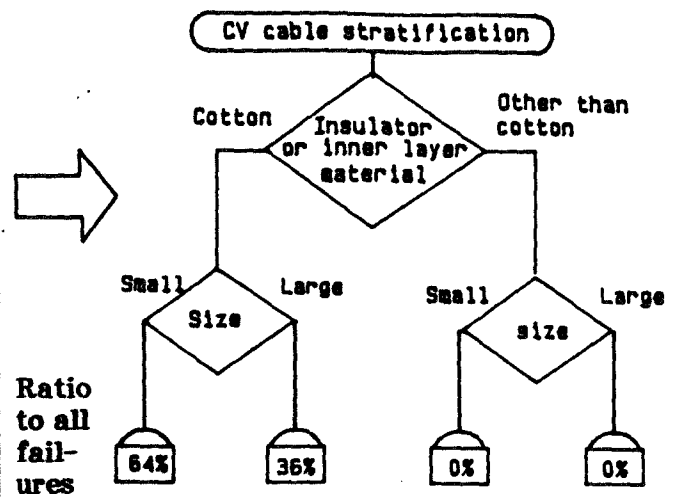
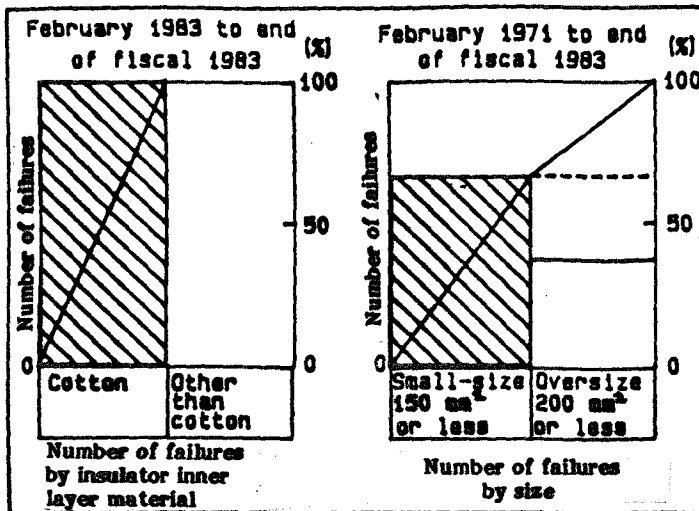
* Data are censored (suspended) when a "test" is aborted prior to failure of the equipment.

The data collected under these conditions were then subjected to life analysis in the following procedural steps (see Fig. 2 (2) and (3)):

- (i) Prepare Weibull analysis data sheets.
- (ii) Plot the data on Weibull probability paper and read from the paper.

As a result, the following facts have been found:

- (i) The defects developed in every group were wear-out failures, with a configuration parameter >1 . Wear-out began to develop five to eight years after production.
- (ii) The mean time to failure (MTTF) was shorter in the order of groups with higher failure ratios. Small-size cotton cables had an MTTF of 17.3 years, two to three years shorter than other groups.



Weibull analysis data sheet (cotton, small-size)						
Order	Age	Number of failures	Number of censored data	Failure increment	Median rank	Cumulative frequency
0	1	0	0			
	2	0	0			
15					15.0	3.6
38	12	21	2	1.062	36.0	8.7
88	13	12	38	1.161	48.7	11.8
123	14	19	16	1.258	70.8	17.2
227	15	22	82	1.849	98.5	23.9
324	16	17	80	3.592	130	31.6
365	17	9	32	6.111	162	39.5
386	18	10	11	9.951	223	54.3
401	19	8	7	18.77	303	73.7
408	20	1	5	36.02	322	78.3
410	21	0	2	89.29		
n = 410		134	276			

Number of censored ships (Cables replaced during service) + (cables currently in service free from failure)

Failure increment $\frac{(n+1) - (\text{previous average failure order})}{(\text{Amount of data subsequent to the current failure-free data set})}$

Average order 1 $[\text{Previous average order}] + [\text{Failure order increment}] \times \text{number of failures}$

Cumulative frequency $f(x)$ $\frac{\text{Average failure order 1} - 0.3}{n + 0.4}$

(3) Estimation of cable lives after production using the Johnson average failure order method

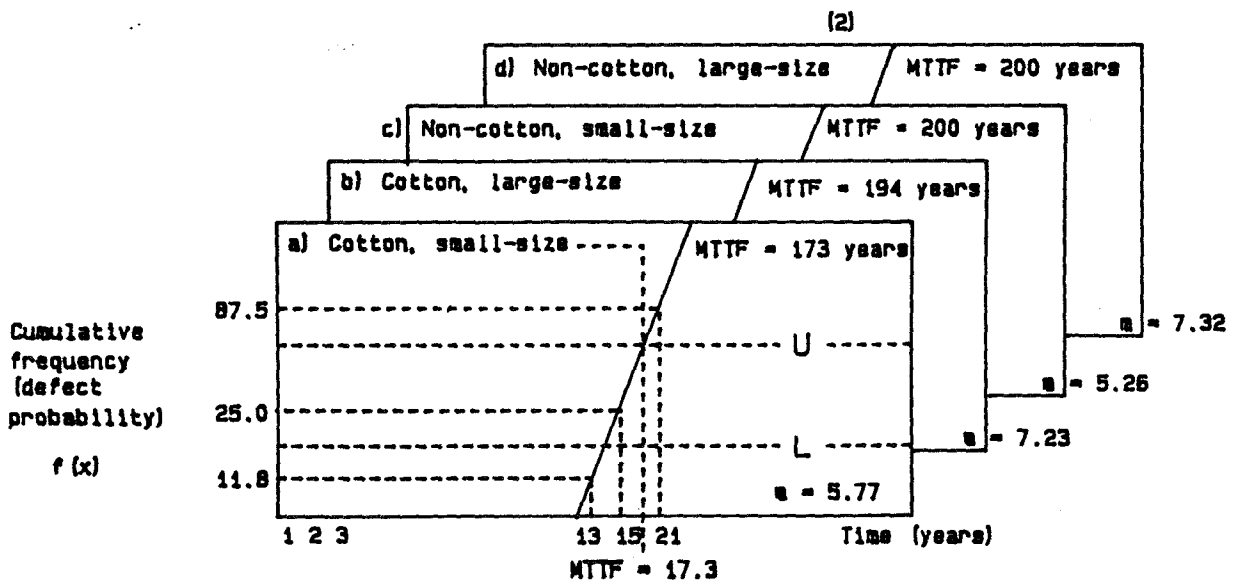


Figure 2

7. CALCULATING DEFECT PROBABILITIES OF INDIVIDUAL CABLES

The previous practice was to classify CV cables into three ranks on the basis of the findings of CV deterioration diagnosis:

- (i) Rank A (sound)
- (ii) Rank B (tendencies to deteriorate)
- (iii) Rank C (significantly deteriorated)

and to conduct deterioration diagnosis at the assumed rank reliability intervals of 7 years, 3 years, and 1 year, respectively. On the basis of the discussions in Section 6, it was necessary to have differences in the lives of CV cables with their specifications precisely reflected in the deterioration diagnostic intervals. Therefore, to gain a more precise understanding of the defect probabilities of individual cables, the author attempted to analyze secular defect probabilities by rank through adding a technique of stratification by year of production to the aforementioned stratification.

Since some groups with fewer occurrences of defects were found unanalyzable as a result of an in-depth stratification of the data, the author abandoned the technique of stratification by year of production and instead chose to determine secular defect probabilities by rank for all the years of production as shown in Fig. 3 (1).

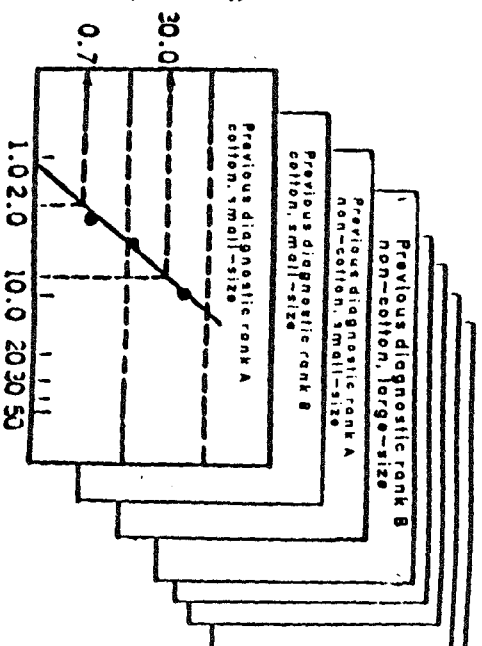
Differences in the defect probabilities due to differences in the years of production (differences in the length of service) that could not be stratified for the reason stated above were presumed present in the defect probabilities of the individual cables.

In determining the defect probabilities of individual cables, therefore, the author noted the equivalency in the evaluation of secular defect probabilities after cable production, as determined in Section 6.2, and that of secular defect probabilities after the aforementioned diagnosis. The author chose to create matrices as shown in Fig. 3 (2) and obtained averages between the two sets of fault probabilities.

Weibull analysis data sheet					
Previous diagnostic rank A, cotton, small-size					
order	age	number of failures	number at censored date	failure time - month	median rank cumulative frequency
43	1	0	43	1.00	0.7
95	2	5	47	1.07	5.35
154	3	11	48	1.16	18.1
222	4	20	48	1.27	43.4
306	5	33	51	1.42	90.4
390	6	30	54	1.59	138
495	7	49	56	1.95	224
550	8	45	40	2.42	342
634	9	42	12	3.08	472
668	10	29	5	3.30	560
709	11	29	12	3.54	656
734	12	14	11	3.01	698
744	13	6	4	3.54	719
757	14	12	1		94.9

(1) Secular defect probabilities by diagnostic rank

$F(x)$ Cumulative frequency (defect probability)



- 5 - aggregate rank
- 6 - specifications

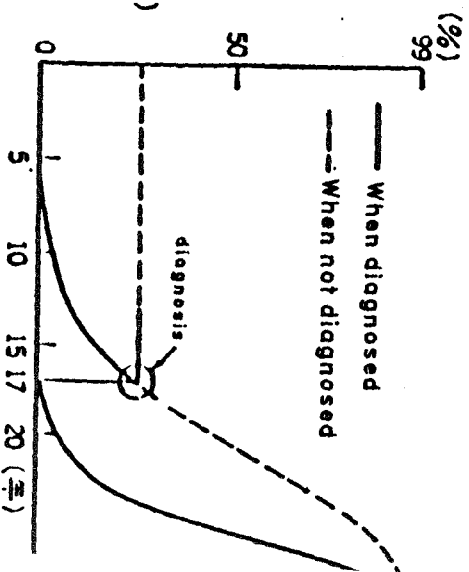
diagnostic rank A cotton small-size	Defect probabilities after diagnosis					$F(x)$
	1st year	2nd year	3rd year	4th year	10th yr.	
0.01	0.7	2.3	5.7	12	73.9	
0.3	2.9	5.2	8.2	17.1	29.5	
0.4	3.4	6.1	9.6	11.6	34.5	
0.5	4.2	7.6	11	14.1	43.0	

$$= \sqrt{F(x) \times F(x)}$$

Average defect probability

(2) Matrices of defect probabilities by cable

$F(x)$ Cumulative fraction defective



(3) Case study of changes in the defect probability of a cable

Figure 3

8. DISCUSSION OF TECHNIQUES OF DETERIORATION DIAGNOSIS

When the failures in the past years were plotted in a matrix of defect probabilities by cables, it was found the failures noted with cables having their insulation inner layers made of cotton had occurred from those with defect probabilities of 45-60% (see Table 1).

To minimize failures, the author recognized the need for diagnosis with lower defect probabilities than those of the cables in which failures had occurred. Hence, he developed and put into action the diagnostic methods for fiscal 1984 as summarized in the next section.

Table 1 Past occurrences of failures plotted in a matrix of defect probabilities by cable

Previous diagnostic rank A cotton small-size		Defect probabilities after diagnosis $F(x)'$									
		1st yr 0.01	2nd yr 0.7	3rd yr 2.3	4th yr 5.7	5th yr 11.9	6th yr 18.2	7th yr 30.8	8th yr 45.2	9th yr 62.2	10th yr 73.9
Defect probabilities after production $F(x)$	12th yr 11.8	0.3	2.9	5.2	8.2	11.8	14.7	19.1	23.1	27.1	29.5
	13th yr 16.1	0.4	3.4	6.1	9.6	13.8	17.1	22.3	27.0	31.6	34.5
	14th yr 25.0	0.5	4.2	7.6	11.9	17.2	21.3	27.7	33.6	39.4	43.0
	15th yr 34.2	0.6	4.9	8.9	14.0	20.2	24.9	32.5	39.3	46.1	50.3
	16th yr 45.0	0.7	5.6	10.2	16.0	23.1	28.6	37.2	45.1	52.9	57.7
	17th yr 57.0	0.8	6.3	11.4	18.0	26.0	32.2	41.9	50.8	59.5	64.9
	18th yr 68.0	0.8	6.9	12.5	19.7	28.4	35.2	45.8	55.4	65.0	70.9
	19th yr 78.0	0.9	7.4	13.4	21.1	30.5	37.7	49.0	59.4	69.7	75.9
	20th yr 87.5	0.9	7.8	14.2	22.3	32.3	39.9	51.9	62.9	73.8	80.4
	21st yr 96.0	1.0	8.2	14.9	23.4	33.8	41.8	54.4	65.9	77.3	84.2

LEGEND



Past occurrences of failures



Having defect probabilities higher than or equal to those of cables that have had failures

9. IMPLEMENTATION OF COUNTERMEASURES

- (i) For CV cables whose insulation inner layers are made of cotton, those with defect probabilities of 40% or more, which is 5% lower than the failed cables, were diagnosed.
- (ii) For CV cables whose insulation inner layers are made of material other than cotton, those with defect probabilities of 50% or higher were diagnosed within the limits of the diagnostic capacity, in consideration of zero failures in the past.
- (iii) Diagnosis was executed in the order of descending defect probabilities.

10. RESULTS

As a result of conducting diagnosis on the basis of defect probabilities, no failures have developed in association with the water tree deterioration phenomenon as of the end of February, 1983 (see Fig. 4).

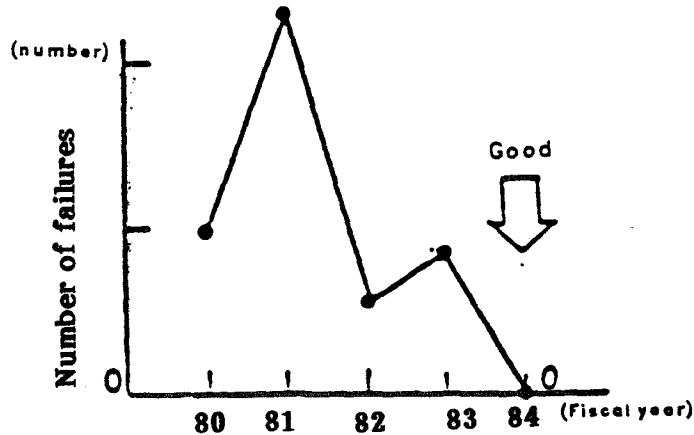


Figure 4 Changes in the number of water tree failures

11. CONCLUSIONS

The author has presented a case study of the improvement of the existing identification methods for CV cable deterioration. Naturally, the elimination of water tree accidents would require further product improvements, or the availability of cables free from the water tree phenomenon.

Active efforts are being directed in this field at domestic and overseas manufacturers as well as at the Kansai Electric Power Co., Inc.

Reference

- 1) Hajime Makabe (1969): "Using Weibull Probability Paper -Statistical Analysis for Reliability," Japanese Standards Association.

(May 1985)