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Roofing Maintenance Management System

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Membrane and Flashing Condition Indexes for Built-Up Roofs

Volume I: Development of the Procedure

by
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Because no systematic procedure exists to determine priorities and select repair strategies for low-slope roofs, the U.S. Army Construction Engineering Research Laboratory (USA-CERL) is developing a roof maintenance management system that will provide a practical decisionmaking procedure to identify cost-effective repairs. This volume describes part of the overall system; the development and verification of roof condition indexes for rating built-up roofs, based on a visual distress survey. Separate indexes were developed for the membrane and flashing components. Each index is expressed as a numerical rating ranging from 0 to 100, and provides a measure of the component's ability to perform its function, needed level of maintenance, and leak potential.

The roof condition indexes have been field tested and validated through the assistance of several roof experts from both the military and private sectors. The testing was conducted at seven different military installations located in widely different climates. Field tests indicated that computed condition indexes correlate highly with the mean subjective ratings of experienced roof experts.

Volume II presents the distress manual required to perform the condition survey. It includes definitions of distress types, severity levels, and measurement criteria. The manual also presents procedures for distress density calculations necessary to determine the indexes.

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FOREWORD

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**MEMBRANE AND FLASHING CONDITION
INDEXES FOR BUILT-UP ROOFS
VOLUME I: DEVELOPMENT OF
THE PROCEDURE**

1 INTRODUCTION

Background

Each of the U.S. armed services has a very large inventory of low-slope roofs. The need for roof repairs and reconstruction work is steadily increasing as the roofs approach the end of their service lives, making it increasingly important to better manage maintenance funds. Currently, there is no systematic procedure available to determine priorities and select repair strategies which will ensure a maximum return on investment.

In response to this need, the U.S. Army Construction Engineering Research Laboratory (USA-CERL) is developing a roofing maintenance management system which will provide military installations with a practical decisionmaking procedure to identify maintenance needs and cost-effective repairs on low-slope roofing systems. The complete roof maintenance management system is initially being developed for built-up roofs and is expected to include:

1. Improved and field-validated condition survey procedures.
2. An objective method for determining roofing condition indexes based on data obtained from visual roof inspections and from nondestructive roof moisture surveys.
3. Guidelines for selecting best maintenance strategies based on roof condition.
4. Methods for assigning maintenance priorities which will ensure efficient and economic use of available maintenance funds.
5. A method for correcting specific defects identified during the inspection through either localized maintenance and repair action or partial/total replacement planning.
6. A computerized version of the roofing maintenance management system.

Objective

The objective of this phase of work was to develop and validate a roof condition index procedure for built-up roofs, based on a visual inspection survey.

Approach

This report presents the results of work performed during fiscal years 1984 through 1986. Based on the 1982 evaluation of the existing U.S. Air Force roof condition index

(RCI) procedure¹ at Fort Jackson, SC, it was indicated that the procedure needed modifications to reduce field effort and increase its usefulness. Considerable modifications and improvements were made, field tested, and revised based on results obtained at seven military installations located in different climates.

Early in the development stage, it became apparent that one index for both the membrane and flashing would not yield meaningful results for developing maintenance and repair (M&R) strategies. Therefore, separate indexes were developed for the two components. Figure 1 summarizes the condition rating procedure and indicates the five steps in determining the membrane condition index (MCI). The same procedure is used to determine the flashing condition index (FCI).

The development of the MCI and FCI followed the same concepts used to develop the pavement condition index (PCI) for airfields² and roads³. The PCI has been accepted and adopted both nationally and internationally for use in pavement condition rating and maintenance management. Although the MCI and FCI together are designed to provide a measure of the roof surface condition, the overall evaluation can be enhanced by evaluating the insulation as well. A condition index for evaluating moisture in the insulation is being developed under a separate work effort.

Organization of Report

Chapter 2 of this volume describes procedures for evaluating low-slope roofs and discusses their ability to provide the requirements of a maintenance management system. Chapter 3 presents the concepts and theory used to develop the roof condition indexes. A discussion of how the indexes were field validated is also presented. Chapter 4 discusses the development of the membrane and flashing condition indexes. Chapter 5 presents conclusions and recommendations.

Volume II is an inspection and distress manual. Membrane and flashing distresses are defined and pictured, and procedures for condition index calculations are provided.

Mode of Technology Transfer

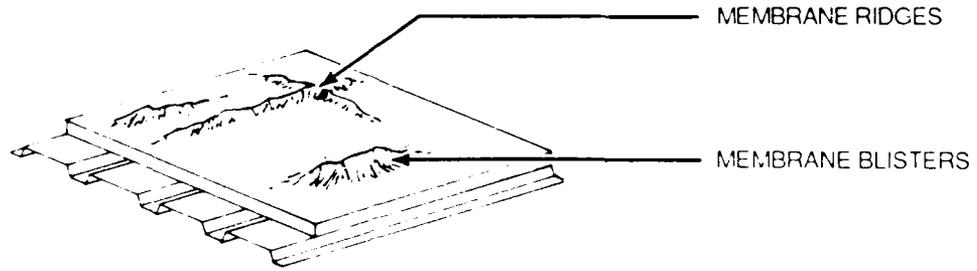
It is anticipated that this procedure will be incorporated into a technical manual concerning maintenance management of built-up roofs. The technology transfer will be through the Facilities Technology Applications Test (FTAT) program, field demonstrations, and formal training.

Air Force Manual (AFM) 91-36, *Built-Up Roof Management Program* (3 September 1980).

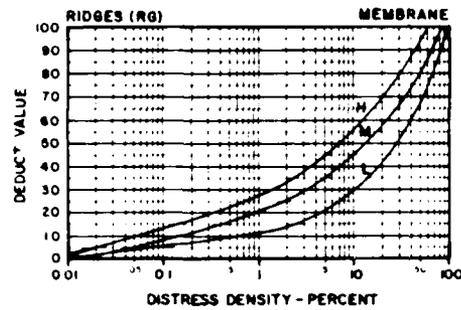
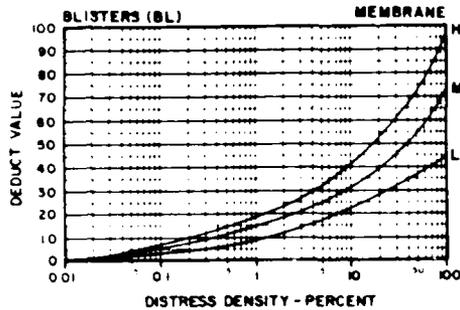
M. Y. Shahin, M. I. Darter, and S. D. Kohn, *Development of a Pavement Maintenance Management System, Vol V: Proposed Revision of Chapter 3, AFR 93-5*, Technical Report No. CEEDO-TR-77-44 (U.S. Air Force Civil and Environmental Engineering Development Office, October 1977).

M. Y. Shahin and S. D. Kohn, *Pavement Maintenance Management for Roads and Parking Lots*, Technical Report M-294/ADA110296 (U.S. Army Construction Engineering Research Laboratory [USA-CERL], October 1981).

STEP 1 INSPECT ROOF DETERMINE DISTRESS TYPES AND SEVERITY LEVELS.
DETERMINE QUANTITIES AND CALCULATE DENSITIES

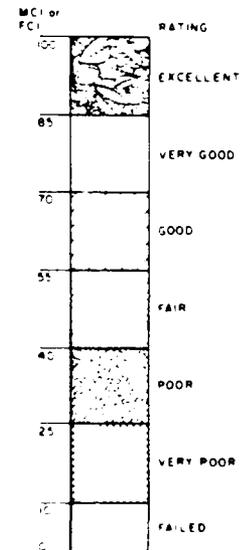
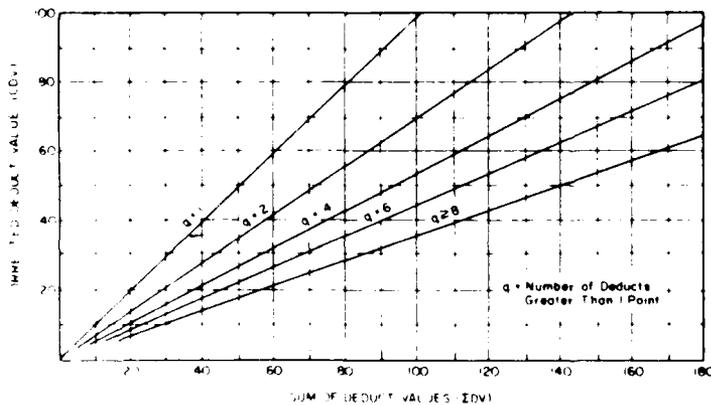


STEP 2 DETERMINE DEDUCT VALUES



STEP 5. DETERMINE MEMBRANE
CONDITION RATING.

STEP 3 COMPUTE CORRECTED DEDUCT VALUE.



STEP 4 COMPUTE MEMBRANE CONDITION INDEX (MCI) = 100 CDV

Figure 1. Steps for determining roof membrane condition rating.

2 CURRENT LOW-SLOPE ROOF CONDITION SURVEY PROCEDURES

Introduction

Several of the available condition survey procedures use measured observable roof distress to determine roof condition. Almost all of the systems provide project analysis. Only a few provide network analysis. Project analysis is limited to one building or roof section and generally gives detailed information on specific M&R needs without relation to other buildings or roof sections. Network analysis, however, summarizes the information from a large number of buildings, such as all those on an installation or within a command, and sets priorities and repair strategies for a group of roofs based on comparable ratings.

This chapter summarizes the existing survey procedures and comments on their ability to evaluate existing roof systems.

Government Sector

Air Force Condition Survey Procedure

Air Force Manual AFM 91-36 outlines a complete roof management system, including design, construction, and maintenance. One chapter presents procedures for inspecting, rating, and selecting treatment alternatives for existing roofs. The manual includes instructions for conducting a visual inspection, descriptions of roofing problems, and definitions of levels of severity (low, medium, and high). Density calculations, which relate to the amount of affected area, are computed for each combination of distress and severity level. The density factors are used on a series of curves that provide deduct values for each of the identified distress types. The total sum of the deduct values for the roof section is adjusted to account for the effect of multiple distresses. The end result of this procedure is a roof condition index and a forecast of the remaining life of each surveyed roof.

Although the Air Force work was an excellent first step in developing varying degrees of engineering expertise, it has several shortcomings.

1. The list of distresses is not complete. Additional distresses, such as ponding, counterflashing, slippage, and patching, need to be identified and defined.
2. The distress definitions need clearer explanations and improved photographs. It is difficult to determine which distresses are present and to differentiate between the severity levels. For example, the definition of low severity blisters indicates that "most of the bitumen and aggregate is still in place" yet the photographs show what appears to be bare areas.
3. The distress densities need redefinition. The combination of square feet and lineal feet is suspect. For example, the density calculation for base flashing defects is typical of this approach.

$$\text{Problem Density} = \frac{A}{B + \frac{C}{100}}$$

where A = length of bituminous base flashing defects (ft)
 B = total length of bituminous base flashing (ft)
 C = total area being rated (sq ft)

It is obvious that the units (ft and sq ft) cannot be combined and the result has no meaningful unit dimension.

4. The deduct value system needs reevaluation and validation. For example, 100 percent high severity base flashing defects rates 15 deduct points while 25 percent low severity blisters rates 77 deduct points. The flashing distress is far more severe yet results in fewer deduct points.

5. A serviceability factor based on the rate of deterioration needs to be developed. The Air Force method does not track deterioration but assumes a standard deterioration rate based on age.

Army Condition Survey Procedure

The U.S. Army Facilities Engineering Support Agency (FESA) offers the Roofing Systems Analysis⁷ (RSA) program which includes infra-red (IR) scans, visual inspection, training, and a final report with recommendations. The inspection requests are initiated by the installation Directorate of Engineering and Housing (DEH) or equivalent office, and are accomplished by FESA teams.

The RSA program uses aerial infra-red thermography to identify wet insulation in roofing systems. Following the aerial IR scan, a comprehensive visual inspection and evaluation and core sampling are conducted on all roofing systems that show areas of suspected wet roof insulation. During the visual inspection, all components of the roofing system are evaluated, including the interior, exterior, and surface areas.

A final report is provided for all roofing systems surveyed. The report includes roof plans showing all deficiencies noted, the location of any wet insulation, photographs highlighting specific problems and a summary and analysis of all surveyed buildings. The summary and analysis includes recommended corrective actions, cost estimates, and a priority of urgency for repair. The evaluation is based on specific defects and severity levels. Severity levels are based on maintenance, repair, or replacement requirements and require some judgement by the inspector when assigning them. The system does not have an overall rating procedure to provide a comprehensive network analysis.

Private Sector

Several roofing materials manufacturers have some form of roof management system as a means of serving their clients' needs. The manufacturers' technical personnel implement these programs. The project-oriented programs include a condition survey (visual and/or nondestructive testing) of the roofs and a report identifying the

⁷A. Knepps and S. Birch, *Roofing System Analysis*, Brochure (FESA, December 1986).

problems, possible solutions, and budgets. The evaluations are subjective, relying on the expertise of the inspection team rather than on predefined distresses and levels of severity. The inspections must be carried out by highly qualified personnel with considerable roof evaluation experience or poor results will be obtained.

As part of the program, the company will employ contractors to do minor repairs, and bill the owner for contractor charges plus an overseeing fee. If the roof needs major repair or replacement, they can also prepare specifications, take competitive bids, and oversee the work. Most companies don't offer network analysis or evaluation and few companies offer performance warranties for the system or semiannual inspection service including recommendations for repairs.

"Roof management" companies offer independent services including roof surveys, photographic records, preparation of roof plans, detail drawings of flashings, sheet metal, etc., and a computer-prepared budget for each inspected roof. The reports provide the locations and extent of existing problems as well as the approximate repair costs and a recommended time frame for each repair. Unlike the manufacturers' services, few of these services include an estimate of roof life expectancy, reroof cost, and calculations comparing maintenance costs to reroof costs. Where more than one building is managed by the owner, a master budget report may include all buildings, but there is no rating procedure to provide a comprehensive network analysis.

Summary

The current survey procedures are project-oriented and do not offer complete network analysis techniques or are lacking in the refinements necessary for a usable management system. A repeatable system based on trained technicians using objective criteria that are well defined and documented is needed. The system must not depend on highly skilled roofing experts. Although the survey procedures discussed above do offer useful information, they are all lacking in some phase of the procedure needed by the military to support a viable roof management system.

3 ROOF CONDITION INDEXES - CONCEPTS AND THEORY

Introduction

A built-up roof system comprises several components, such as deck, insulation, vapor retarder, membrane, surfacing, and flashing. A comprehensive roof condition evaluation procedure would require examining the condition of each of these components using elaborate measurement and testing techniques. However, such an evaluation is too expensive, labor-intensive, and time consuming. Pavement condition survey techniques based on visual observation of physical distress, such as the pavement condition index procedure, have proven successful in evaluating present condition and predicting future condition. This same concept can be applied to built-up roofs to produce a roof condition evaluation procedure. The procedure should be complemented with nondestructive techniques for moisture survey analysis of the insulation in order to provide a complete evaluation of the roofing system.

The visual roof condition evaluation procedure is based on surveying and measuring distresses in the two visible components on the rooftop, the membrane and flashing. These existing distresses provide a measure of the roof's condition and waterproof integrity. They also provide an early indication of possible roof system failures, maintenance and repair requirements, and a basis for scheduling a more comprehensive evaluation, if necessary. This chapter presents the concepts and theory used to develop the membrane and flashing condition indexes based on observable distresses. The index for moisture in the insulation is being developed under a separate work effort.

Concepts and Theory

The degree of roof component deterioration (membrane or flashing) is a function of:

1. Types of distress.
2. Severity of distress (i.e., extent of felt deterioration).
3. Amount or density of distress, which can be expressed as a percentage of roof area for the membrane or a percentage of the flashed perimeter for the flashing.

Each of these distress characteristics is significant in determining the overall amount of physical deterioration. If any of these characteristics are ignored, developing a meaningful condition index is not possible.

There are several different types of distresses, several possible degrees of severity for each type, and a wide range of amount or density for each combination. Combining the effects of these three characteristics into a single index requires the use of deduct weighting factors. The model selected for this purpose was the same one used to develop the PCI procedure. It is based on the assumption that the condition index can be

adequately estimated by summing all visible distresses over their severity and density levels using appropriate weighting factors as follows:

$$\text{MCI or FCI} = C - \sum_{i=1}^r \sum_{j=1}^{m_i} a(T_i, S_j, D_{ij}) F(t, d) \quad (\text{Eq 1})$$

where

- MCI = membrane condition index
- FCI = flashing condition index
- C = a constant depending on desired maximum scale value
- a() = deduct weighting value depending on distress type T_i , level of severity S_j , and density of distress D_{ij}
- i = counter for distress types
- j = counter for severity levels
- r = total number of distress types for component under consideration
- m_i = number of severity levels on the i^{th} type of distress
- F(t, d) = an adjustment factor for multiple distresses that varies with total summed deduct value (t) and number of deducts (d)

The condition indexes can be determined from Equation 1 only when the distress types, distress severity, deduct weighting values, and adjustment factors for multiple distresses are known (Figure 2).

Distress Types

Each distress type existing in the roofing component (membrane or flashing) under evaluation must be identified and described. Figure 3 is an example description for membrane blisters.

Distress Severity

Distress types occur in various levels of severity, which must be explicitly defined. These definitions must be written so that engineers and technicians can consistently identify a distress type and severity. Figure 3 also gives an example description of the levels of severity for membrane blisters.

Deduct Weighting Values

Deduct values as functions of distress type (T_i), severity level (S_j), and density (D_{ij}) must be determined. An example is given here to illustrate the concept. Deduct weighting values must be determined over a range of density (i.e., percent area) of distress. The deduct values must be based on some selected rating scale, such as a scale ranging from 0 to 100, with 0 deduct value indicating the distress has no impact on condition and 100 indicating an extremely serious distress which causes the roof component to fail. Deduct values can then be assigned to a given density and severity level based on the impact of the distress on the roof condition. Figure 4 gives example deduct value curves for blisters for three severity levels (low, medium, and high) and densities ranging from 0 to 100 percent of total membrane area. A roof section having 1 percent of low severity blisters as its only membrane distress, would have a deduct value of 9, and the MCI (maximum = 100) would be:

$$\text{MCI} = 100 - 9 = 91$$

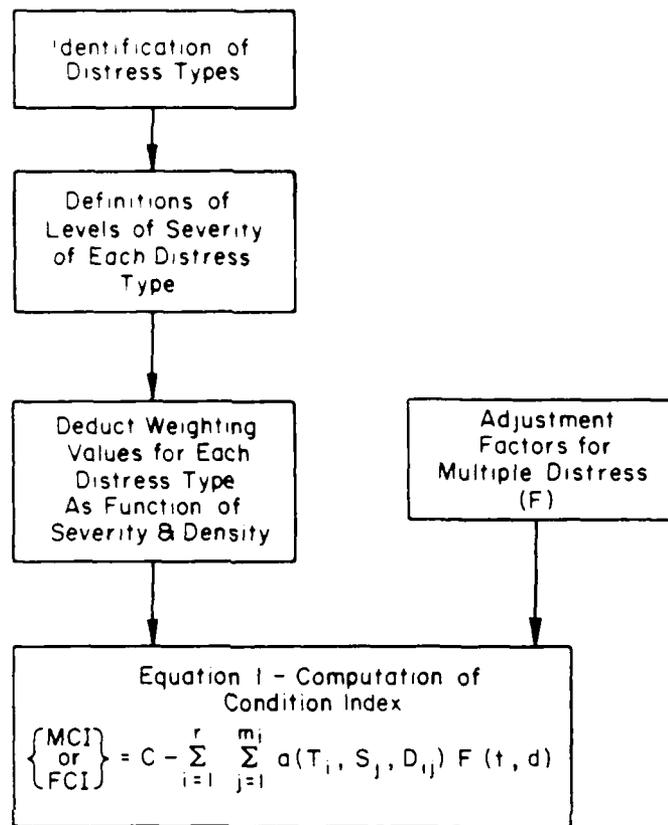


Figure 2. Information needed to determine the condition indexes. (Source: M. Y. Shahin, M. I. Darter, and S. D. Kohn, *Development of a Pavement Maintenance Management System, Volume I: Airfield Pavement Condition Rating*, Technical Report No. CEEDO-TR-77-44 [U.S. Air Force Civil and Environmental Engineering Development Office, October 1977].)

Curves like those shown in Figure 4 were derived for each distress type and severity level. These curves are based on the assumption that only one distress type at a given level of severity exists in the roof component, and are based on a scale from 0 to 100. (All the curves are in Volume II, Appendix A.)

Adjustment Factor for Multiple Distress Types

It is important to note that the deduct values are not linearly additive, because as additional distress types and/or severity levels occur in a given roof section, the resulting impact of those distresses becomes smaller. Because of this, an adjustment factor was developed so that roof sections having more than one distress could be evaluated using the curves described above. For example, for a roof section containing four membrane distress types, the deduct values are determined based on individual distress ratings (Table 1). The total deduct value for the distresses shown in the table is 61 points; however, the MCI cannot be determined by subtracting 61 points from 100, because the deduct values were originally developed for only 1 distress type. The total must be

BLISTERS

Description: Blisters are round or elongated raised areas of the membrane which are filled with air.

Note: Blisters and ridges are difficult to differentiate at the low and medium severity levels. The rating error will be insignificant because of the similarity in the deduct curves. At high severity, however, it is important to distinguish between the two distresses due to their different leak potentials.

Severity Levels:

Low:

1. The raised areas are noticeable by vision or feel. The surfacing is still in place and the felts are not exposed.

Medium:

1. The felts are exposed or show deterioration.

High:

1. The blisters are broken.

Measurement:

1. Measure the length and width of the blister in lineal feet and calculate the area (length times width). If the distance between individual blisters is less than 5 ft, measure the entire affected area in sq ft.
2. When large quantities of this problem are present (especially on large roofs), the representative sampling technique can be used.

Density:

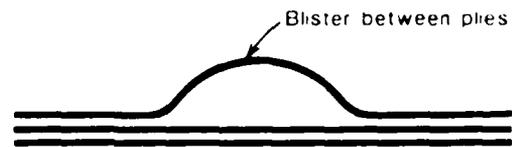
$$\frac{A}{B} \times 100 = \text{Problem Density}$$

where A = total area of membrane blisters (sq ft)
B = total area of roof section being rated (sq ft)

Note: The problem density is calculated for each existing severity level.

Causes: Blisters are caused by voids or lack of attachment within the membrane. Moisture and gasses within the void greatly increases the potential for growth.

Blisters (BL)



Graphic Representation
of Blister

Figure 3. Example description of a distress and three severity levels.

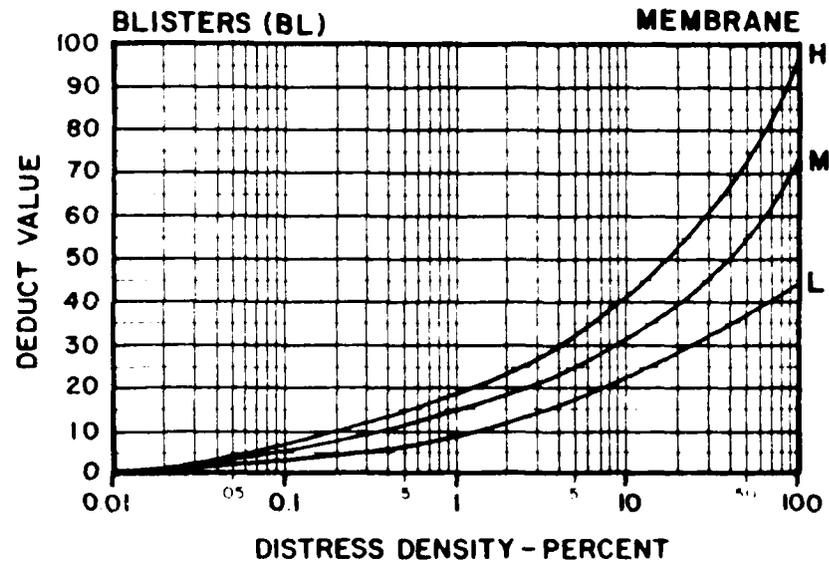


Figure 4. Example of deduct value vs. density curve for blisters.

Table 1

Example of Calculation of Deduct Values for Membrane

Distress type	Severity	Density	Deduct Values
Blisters	Low	1	9 pts.
Surface Deterioration	High	5	25 pts.
Debris & Vegetation	Medium	11	10 pts.
Ponding	Low	8	17 pts.
Total Deduct Value			61 pts.

modified by a factor, F, which is a function of the magnitude of the total sum of the deduct values and the number of deduct values (four in this example).

$$F = f(\text{total sum of the deduct values, number of deduct values}).$$

The function F is derived from experimental rating data and reflected in corrected deduct value curves, as described in Chapter 4. The value of F in this example is 0.54; hence an MCI which gives a more accurate evaluation of membrane condition is:

$$\text{MCI} = 100 - 61(0.54) = 67$$

Development of Deduct Weighting Values

Developing deduct weighting values was the most difficult and yet most critical part of the MCI and FCI. Ideally, the deduct values should be based on the measured impact that each distress situation (i.e., combination of type, severity level, and density) has on the roof system's condition and waterproof integrity. However, measuring this effect requires extensive field testing. The complexity of built-up roofing systems would require a large research effort to develop an analytical or theoretical determination of this effect.

However a subjective approach based on the collective judgment of experienced roofing experts can be used to "bridge the gap" and develop reasonable deduct weighting values that can be used with confidence. This subjective approach was carefully planned and carried out in an iterative manner; the deduct values were first determined based on existing knowledge, then field tested and evaluated, and revised where necessary (Figure 5).

Selecting the initial distress definitions and deduct values required a rating scale that was subdivided into distinct subjective categories (Table 2). The scale provided the descriptive index needed to permit a rational subjective rating of the impact of a given distress. For example, several roof experts could independently rate a roof membrane having 15 percent of its area blistered with the surfacing in place and felts unexposed (i.e., low severity) according to the scale in Table 2 based on their experience as to the impact on the membrane. If the mean of their ratings was 75, which is "very good" condition, the deduct value for this situation would be 25 points (100-75). This process was then repeated for other distresses, severity levels, and densities.

After the first set of distress definitions were developed and deduct value curves determined based on the experience of the roof experts, several roof sections were surveyed and the existing distresses measured. In addition, the roof experts subjectively rated each combination of distress and severity level present according to the indicated scale. The means of these ratings were then used to compute deduct values, which were compared with the deduct values generated from the initial deduct value curves. The results were evaluated and modifications made when necessary.

This entire process was repeated to improve the definitions and deduct values. The process was conducted at different locations due to widely varying roof designs, climates, materials, and distress conditions. After several iterations, however, the procedure became adequate for field use.

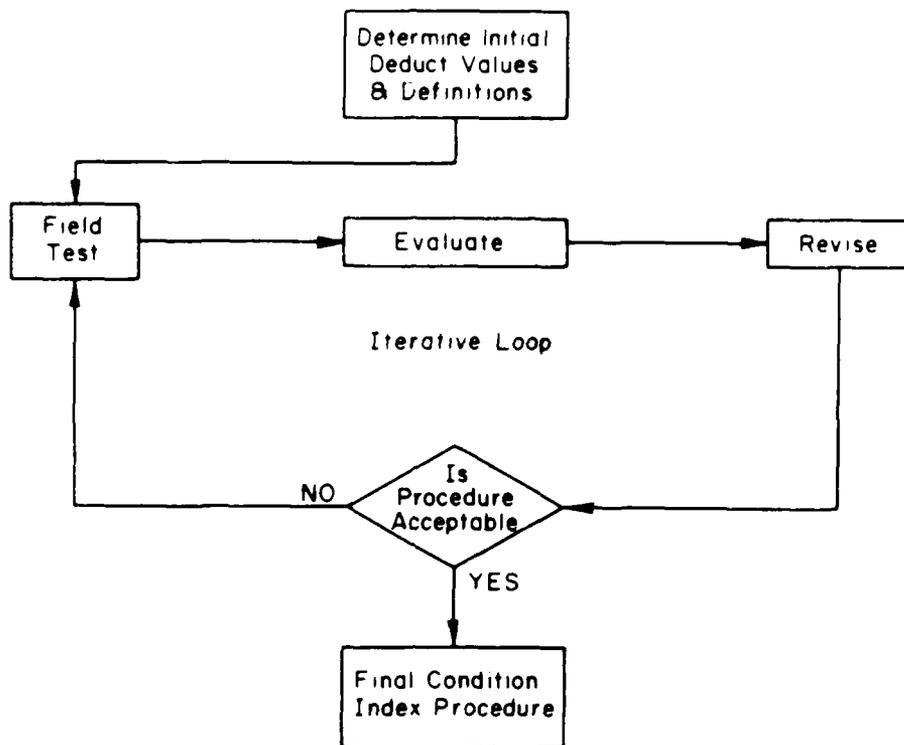


Figure 5. Iterative procedure to determine realistic distress deduct values and distress definitions using a subjective approach (Source: Air Force Manual 91-36, *Built-Up Roof Management Program* [3 September 1980].)

Table 2

Descriptive Rating Scale

Rating Scale	Descriptive Categories
100-86	Excellent
85-71	Very Good
70-56	Good
55-41	Fair
40-26	Poor
25-11	Very Poor
10-0	Failure

4 DEVELOPMENT OF ROOF CONDITION INDEXES FOR BUILT-UP ROOFS

Introduction

This section describes the details of developing the membrane condition index and flashing condition index. A panel of roof experts representing the Army, Air Force, Navy, and private industry, participated in the effort.

Initial Distress Definitions

An initial list of distresses (Table 3) was identified based on the Air Force RCI procedure,² a built-up roofing literature review, and input from the roofing experts. For each distress, severity levels were established using the following criteria:

- Low severity - some indication of deterioration; no repair is required.
- Medium severity - noticeable deterioration; should be scheduled for repair during next maintenance cycle.
- High severity - excessive deterioration with high risk to integrity of roofing system; immediate repair or replacement is required.

To test this initial set of distresses and severity levels, several built-up roofs at Charleston Naval Station, SC and Alameda Naval Air Station, CA were surveyed. These surveys indicated two major deficiencies:

1. The definitions of several distress types and severity levels were incomplete. Additional distresses found in the field were not included in the current definitions.
2. The conditions of the roofs were insufficiently described by the initial list of distresses.

The distress definitions and severity levels were revised and expanded and three new distresses were added: ponding, improper equipment supports, and drains. After these modifications were made, initial deduct value development began.

Initial Deduct Value Curves

The first step in developing the initial deduct value curves was to determine the proper method for calculating the density for each distress. From rating numerous hypothetical cases, it was found that flashing distress densities should be based on the total length of flashed perimeter (including flashings for penthouses, courtyards, and curbed projections) of the roof section being surveyed and membrane distress densities should be based on the total area of roof membrane.

Once the density calculations were established for each distress, deduct values were determined. This work was performed by a panel of roof experts in a "classroom"

Table 3

Initial and Final Distresses

Initial distresses	Final distresses
Flashing - base flashing counterflashing cap flashing embedded edge-metal plumbing vents other penetrations pitch pans	Flashing - base flashing metal cap flashing embedded edge-metal flashed penetrations pitch pans interior drains and roof level scuppers
Membrane - blisters ridges splits holes exposed felts alligatoring slippage debris & vegetation	Membrane - blisters ridges splits holes surface deterioration slippage patching debris & vegetation improper equipment supports ponding

environment. The deduct values were developed in the following manner for each distress type at a particular severity level.

1. Four roof experts independently rated 100 ft by 100 ft roof sections having varying amounts of a particular distress using the qualitative scale in Figure 6. Each rater gave the roof section a subjective rating such as "excellent", "good", or "fair", and a numerical value within that rating.

2. The ratings were performed for 4 to 5 levels of density. For example, blisters were rated at densities of 1, 10, 50, and 100 percent.

3. The mean of the four subjective ratings for the membrane condition rating (\overline{MCR}) or flashing condition rating (\overline{FCR}) was computed for each density level, and the mean deduct value (\overline{DV}) computed as follows: $\overline{DV} = 100 - (\overline{MCR} \text{ or } \overline{FCR})$

A plot of density of distress versus mean deduct value was developed, and a best fit smooth curve was plotted through the points. Figure 7 is an example of these curves for the blisters distress.

Field Test, Evaluation, and Revision of Definitions

The deduct value curves could not be field tested until the definitions of the distresses, severity levels, and density equations were field tested and modified to assure repeatability between inspectors. Any major changes to these definitions would alter the existing deduct curves. Field tests were conducted at Point Mugu Naval Air Station (NAS), CA and Chanute Air Force Base (AFB), IL for this purpose.

DISTRESS: _____

SEVERITY LEVEL: _____

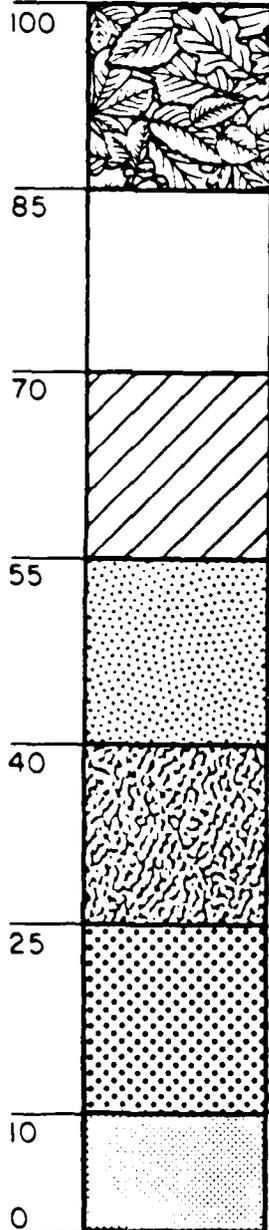
DENSITY: _____

RATER'S NAME: _____

DATE: _____

MCI or
FCI

RATING



INSTRUCTIONS: Please rate roof component with regard to its overall integrity, maintenance requirements, and leak potential. (Excellent rating indicates none or very minor distress present and very poor rating indicates severe distress and imminent failure).

On the rating scale shown here, how would you rate this feature?

Give an approximate numerical score.

Major factors influencing your rating:

Figure 6. Subjective rating form used for developing deduct value curves.

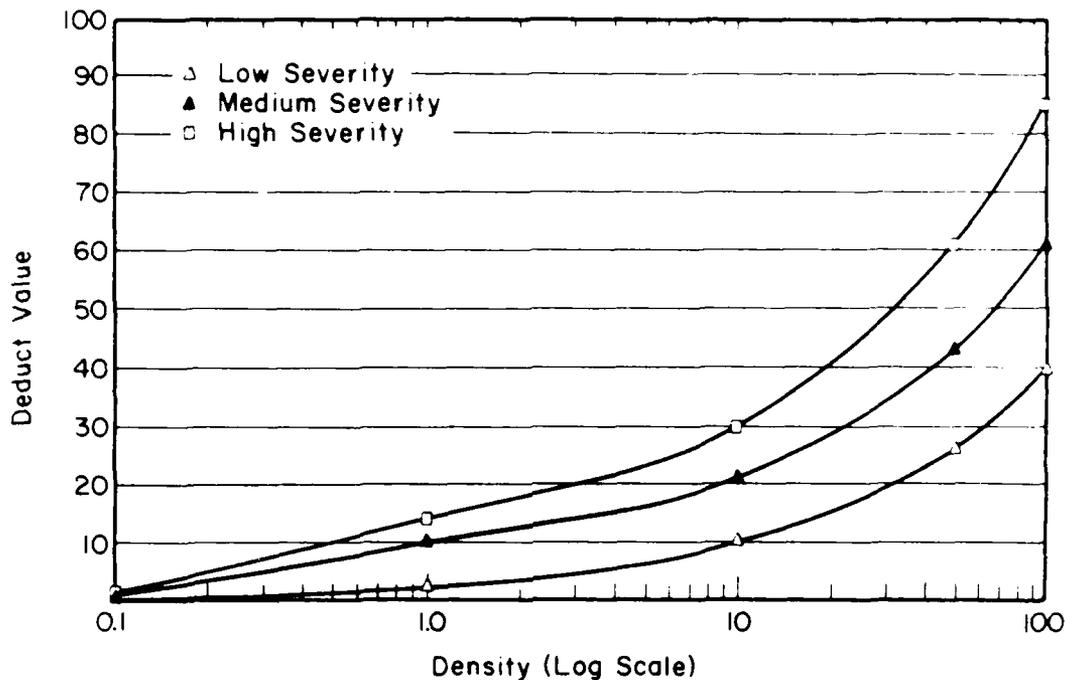


Figure 7. Initial deduct value curves for blisters.

At Point Mugu NAS, the working group was divided into three separate survey teams, each team performing condition surveys on the same three preselected roofs. The teams completed a rating worksheet for each roof and computed densities for every combination of distress and severity level. Through evaluation of the discrepancies between teams, the following deficiencies in distress definitions were identified:

1. Some definitions did not clearly describe existing distresses.
2. A membrane patching distress should be added.
3. Roof level scuppers should be added to the drain distress.
4. Plumbing vents stack and other penetrations should be combined into one distress, Flashed Penetrations.

Several of the distress definitions were revised and modified to reflect the experience gained during the field test and new deduct value curves were determined for patching and flashed penetrations.

After the revisions were made, another field test was conducted at Chanute AFB. As in the previous field test, three teams surveyed three roofs using the same procedures as those used at Point Mugu NAS. Evaluation of the results indicated that only a few distress and severity level definitions required modification. After these changes were made, the group agreed that the distress and severity level definitions had reached the completeness and accuracy required for field testing of the deduct value curves.

Field Test, Evaluation, and Revision of Deduct Value Curves

A field test of the deduct value curves was conducted on nine roof sections at Tyndall Air Force Base, FL. The roofing survey panel was divided into two teams. Each team inspected and rated all nine roofs using the rating system. Densities were computed for each combination of distress and severity level. Using the scale in Figure 6, the experts individually rated each combination of distress and severity level present as if it was the only distress-severity level combination present on the roof. The experts then rated the overall MCR and the overall FCR using the same procedure but considering all distresses.

After all surveys were completed, the individual distress ratings and the overall condition ratings were compared. Discrepancies were found between some of the ratings. After much discussion of these differences, it was evident that some raters were emphasizing different factors when determining their ratings. One rater would rate a distress according to its leak potential, another according to its level of required repair and another according to its future performance. It was agreed that each of these factors affect the condition of the roof and that they all should be considered when assigning a rating.

To correct these discrepancies, the following "consideration factors" were written on the rating sheets used by the team members:

1. Effect of distress on roof's ability to perform function (i.e., a base flashing less than 6 in. high is likely not to perform its intended function).
2. Effect on future performance (i.e., embedded edge-metal joints will likely cause future splits in the strip-in felts).
3. Needed level of maintenance and repair (i.e., splitting of the membrane due to poor attachment is likely to require a much higher level of repair than ridging).
4. Leak potential (i.e., a hole has a higher leak potential than a broken blister).

It was also decided that on future validation tests the ratings would be discussed before leaving the rooftop to ensure that each expert had considered all effects which the distresses could have on the roof.

Two additional field tests were conducted at Nellis AFB, NV and Key West NAS, FL. Each expert provided a "rating" for each combination of distress and severity level present as well as overall membrane and flashing condition ratings for each roof section. Twenty roof sections were surveyed. The results indicated that the discrepancies between individual ratings were much less than those of the Tyndall AFB survey. Table 4 summarizes the subjective ratings for one test roof section.

These field data were plotted as density of distress versus mean deduct value for each distress and severity level. A best fit smooth curve, minimizing error, was fitted through these points to establish the revised deduct value curves. Figure 8 illustrates the curve for high severity blisters.

Initial Corrected Deduct Value Curves

From the field data collected at Nellis AFB and Key West NAS, a comparison was made between the total deduct values (i.e., the sum of all membrane or flashing deducts

Table 4
Individual Ratings for Building 156 at Nellis AFB

Flashing Distresses								
Distress Type	Sev.	Density (%)	Deduct Values*					Mean Deduct Value
			R1	R2	R3	R4	R5	
Base flashing	H	2.10	6	10	10	16	5	9.4
Base flashing	L	5.40	4	2	2	5	3	3.2
Embedded edge-metal	H	93.00	95	85	90	82	90	88.4
Flashed penetration	H	3.60	14	15	10	25	1	13.0
Flashed penetration	M	0.20	1	1	2	2	10	3.2
Pitch pan	H	0.70	4	10	12	10	6	8.4
Pitch pan	L	0.20	1	1	5	5	1	2.6

Membrane Distresses								
Distress Type	Sev.	Density (%)	Deduct Values*					Mean Deduct Value
			R1	R2	R3	R4	R5	
Blisters	M	0.07	1	2	5	4	2	2.8
Debris & vegetation	M	5.40	1	1	2	4	2	2.0
Patching	M	0.24	12	4	4	22	5	9.4
Ponding	L	0.40	1	2	5	1	2	2.2
Ridges	L	2.50	16	15	10	35	10	17.2
Surface deterioration	L	0.42	2	2	4	16	3	5.4
Surface deterioration	M	4.10	10	20	10	40	15	19.0

*The values were assigned by five different raters.

for a roof section) and the \overline{MCR} and \overline{FCR} for each roof section. Analysis of this data indicated that the deduct values are not linearly additive; as additional distresses and severity levels occur on a roof section, their resulting impact becomes smaller. The analysis also indicated that a deduct value of one has little effect on the roof condition evaluation. The sum of deduct values must therefore be adjusted to reflect the number of deducts (distress type/severity level combinations) having values greater than 1 and the magnitude of the total deduct value.

For example, the membrane of a roof may have four distresses, two being very minor. A correction considering all four distresses would give too large an adjustment. Table 5 presents data for such a roof.

This adjustment function for multiple distresses was determined by subjectively rating the flashing and membrane components of many hypothetical roof sections containing from two to eight distress type/severity level combinations. The total sum of calculated deduct values determined using the individual deduct value curves and the corrected deduct value determined by subtracting the \overline{MCR} and \overline{FCR} from 100 for each section were plotted.

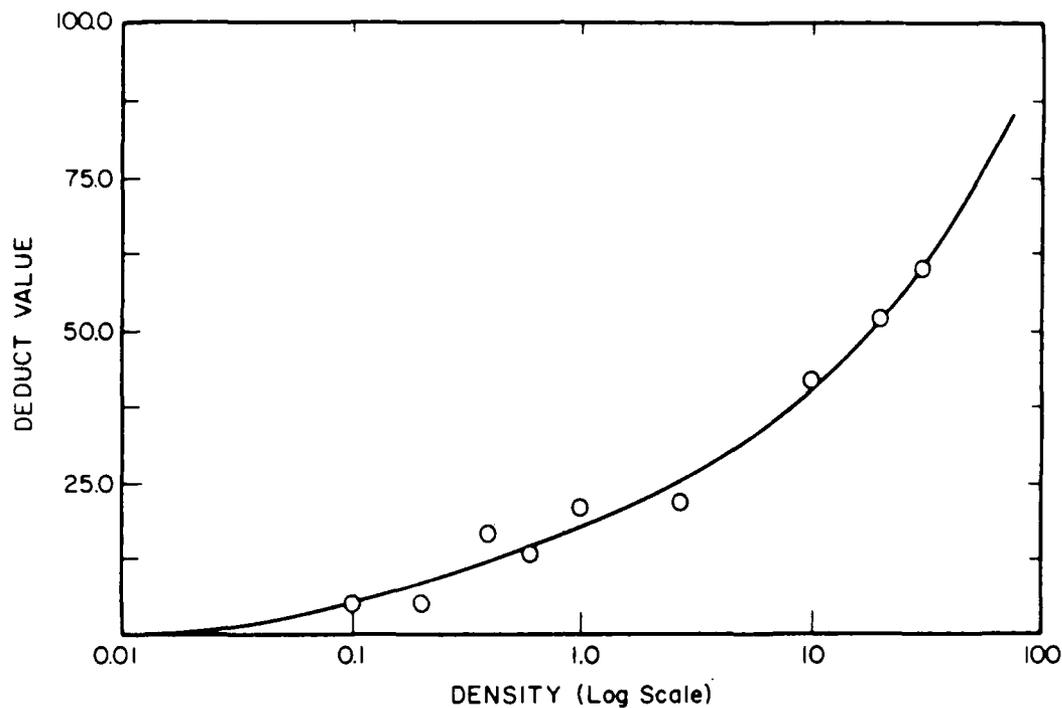


Figure 8. Example showing how deduct value curves were developed for high severity blisters.

Table 5

Example Roof Data

Distress	Severity	Density (%)	Deduct Value
Surface Deterioration	Medium	5.0	15
Surface Deterioration	Low	0.04	1
Holes	High	0.11	27
Blisters	Low	0.03	<u>1</u>

Total Deduct Value = 44*
 $q = \text{number of deducts} > 1 = 2$

*The MCR of this section (determined in the field) was 69. The sum of the deduct values of 44 (computed from the deduct curve) is too large and must be adjusted toward 31 ($69 = 100 - 31$). Refer to Volume II for exact procedure for calculating the corrected deduct value.

Figure 9 shows an example plot of deduct values for sections where $q = 2$ (q is the number of individual deduct values exceeding 1). All the data points lie below the line of equality (where $q = 1$) and the deviation tends to increase as the total sum of calculated deduct values increases.

This analysis was repeated for $q = 4, 6,$ and 8 to obtain the graphs in Figures 10 and 11. The results show that the curves deviate further from the line of equality as q increases.

Evaluation of Procedure

The roof condition index procedure was evaluated using the field results from the 20 roof sections at Nellis AFB and Key West NAS. The MCI and FCI of each section were computed using the revised procedure and compared with the mean subjective ratings (MCR and FCR) of the team members. Table 6 summarizes these data. The mean absolute difference between the condition ratings and the calculated indexes for all roof sections is relatively small at 6.2 points. The differences range from 0 to 18 points.

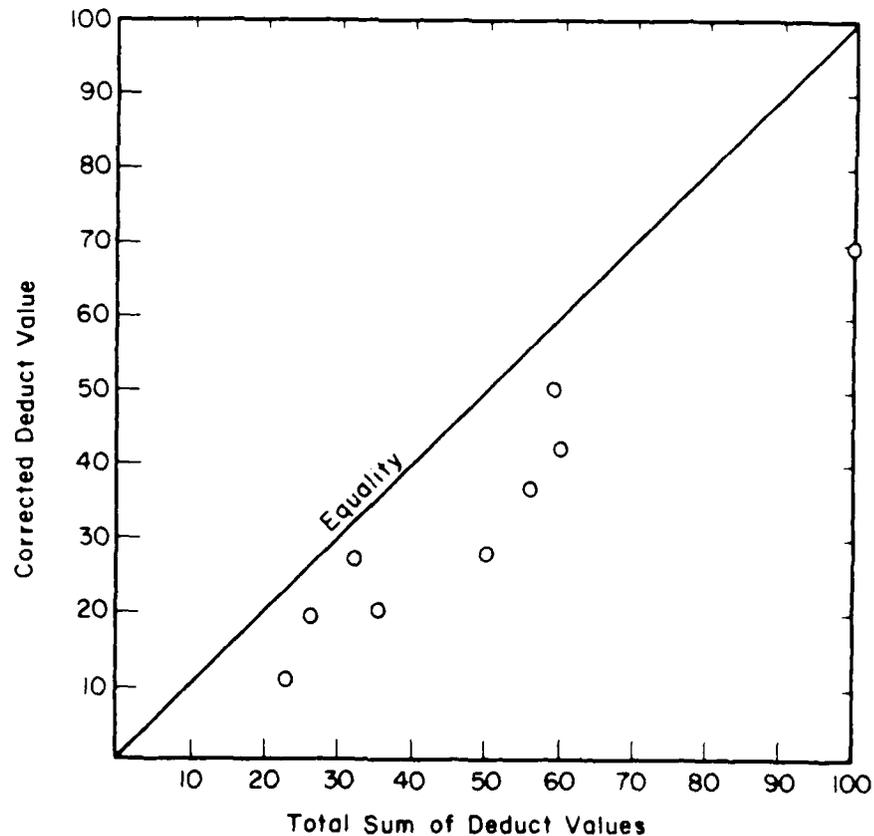


Figure 9. Example plot of total sum of deduct values vs. corrected deduct value where $q = 2$.

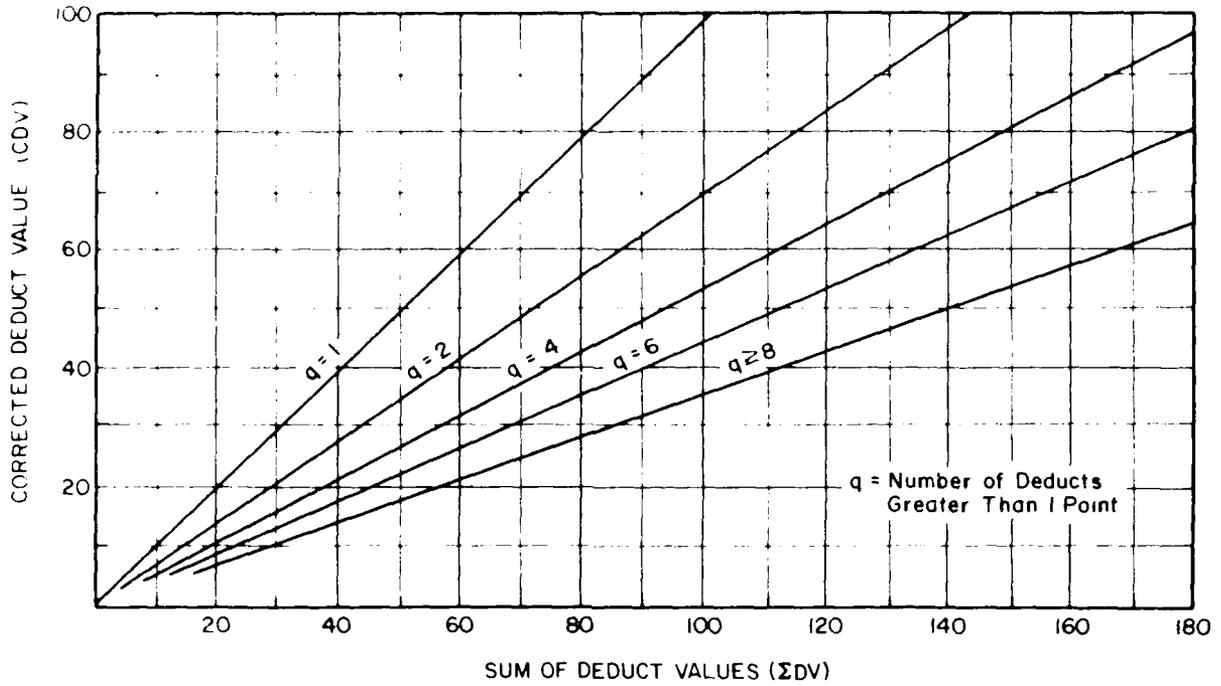


Figure 10. Corrected deduct value curves for membrane.

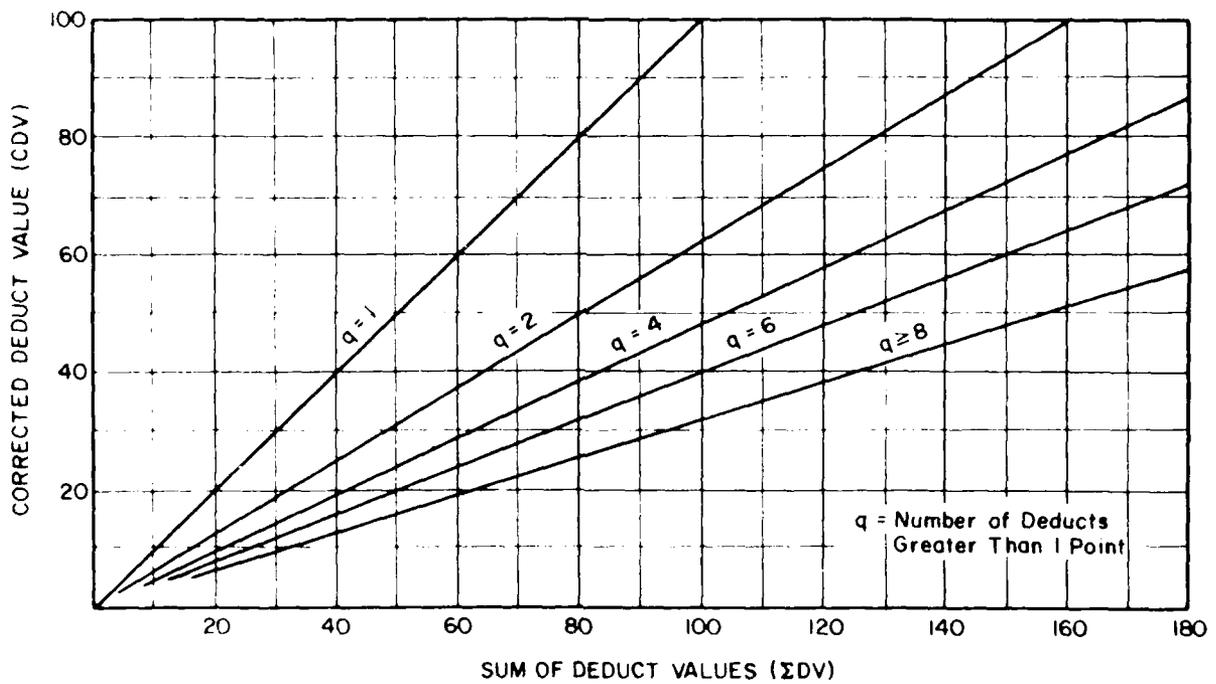


Figure 11. Corrected deduct value curves for flashing.

Figures 12 and 13 respectively, show the correlation between $\overline{\text{MCR}}$ and MCI and between $\overline{\text{FCR}}$ and FCI for the same 20 roof sections. Analysis of the data resulted in the following statistics:

1. The correlation between the $\overline{\text{MCR}}$ and the MCI is 0.97.
2. The mean MCI for all sections is 66.0.
3. The mean $\overline{\text{MCR}}$ for all sections is 67.7.
4. The difference between the mean MCI and the mean $\overline{\text{MCR}}$ for all sections is +1.7.
5. The correlation between the $\overline{\text{FCR}}$ and the FCI is 0.94.
6. The mean FCI for all sections is 56.5.
7. The mean $\overline{\text{FCR}}$ for all sections is 58.8.
8. The difference between the mean FCI and the mean $\overline{\text{FCR}}$ for all sections is +2.3.

These results provide good verification that the calculated indexes closely predict the mean subjective ratings of the team members. The inspection procedure and two indexes can be very significant in evaluating the condition of built-up roofs.

Table 6

Summary of Mean Condition Ratings and Condition Indexes
for 20 Roof Sections

LOCATION	BLDG.#	20 Roof Sections			
		$\overline{\text{MCR}}$	MCI	$\overline{\text{FCR}}$	FCI
Nellis AFB	156	73	79	9	11
	173	22	22	19	37
	174	71	69	59	51
	330	72	78	77	80
	6	78	78	63	59
	765	50	66	64	50
	880	89	83	88	81
	98	76	75	66	67
	COMM	37	39	49	45
Key West NAS	1125	49	44	18	11
	225	11	16	13	30
	244	69	52	79	77
	290	93	90	71	62
	332	69	59	80	75
	350	86	77	72	60
	437	58	64	52	59
	648	72	71	70	63
	726	99	99	77	70
	727	94	99	60	58
	931	75	60	89	83

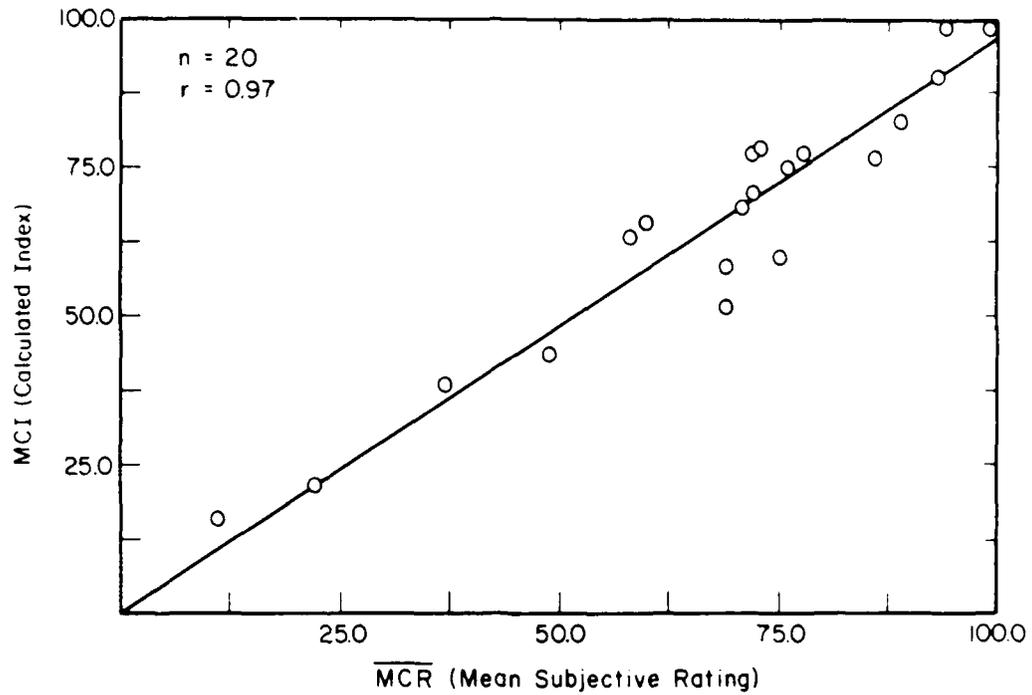


Figure 12. Correlation between $\overline{\text{MCR}}$ and MCI for 20 surveyed roof sections.

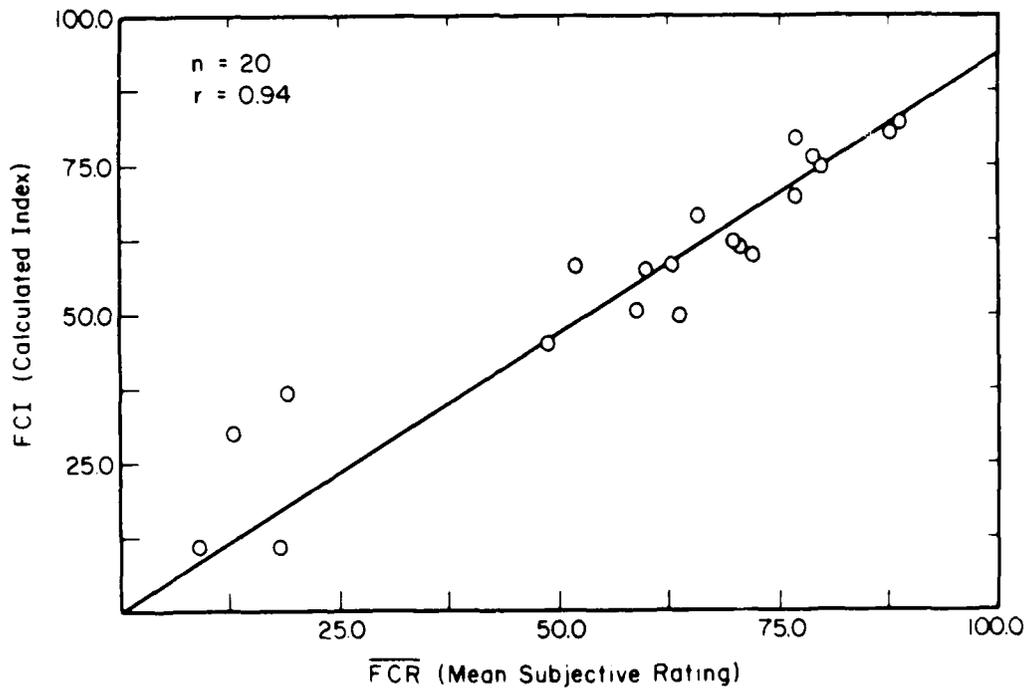


Figure 13. Correlation between $\overline{\text{FCR}}$ and FCI for 20 surveyed roof sections.

5 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. Evaluation of existing roof condition procedures indicates that none provide both an accurate and objective distress survey which allows for both a project and network analysis.

2. The MCI and FCI are accurate and objective tools for rating the condition of built-up roofs. The calculated MCI and FCI for a roof section correlate highly with the mean condition ratings (\overline{MCR} and \overline{FCR}) obtained by averaging the individual ratings of a group of roof experts.

3. The condition index procedure measures the waterproof integrity and surface condition for the membrane and flashing components; however, it does not measure the amount of wet insulation or other defects within the remaining components of the roof system (e.g., vapor barrier or deck).

4. The MCI and FCI provide a common index for comparing the condition and performance of built-up roofs.

Recommendations

1. The MCI and FCI have been field tested and verified and should be implemented on a trial basis. The procedure is being demonstrated at three sites (Fort Meade, MD; Fort Lee, VA; and New Cumberland Army Depot, PA) where Facilities Technology Applications Test (FTAT) programs are conducted. Successful implementation will require training the inspection personnel.

2. Guidelines for determining maintenance and repair strategies, prioritization and budget optimization should be developed to enable engineers to conduct meaningful economic analysis for selecting optimum alternatives. This work is now in progress.

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