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Standard Guide for Determining and Evaluating Causes of Water Leakage of Low-Sloped Roofs[1]

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1. Scope

1.1 This guide describes methods for determining and evaluating causes of water leakage in low-sloped roofs. For this purpose, water penetration is considered leakage and therefore problematic, is causing or is likely to cause premature deterioration of the roof, building or its contents, or is adversely affecting the performance of other components of the building A roof is considered an assembly including the membrane, insulation, vapor retarder (if required), deck, and structural components.

1.1.1 This guide excludes moisture-related problems in roofs caused by condensation.

NOTE 1—*Condensation*—Moisture-related problems in roof systems may be caused by condensation of humid air originating from within the building and be incorrectly attributed to leakage from rain water. The protocol for an investigation of dampness due to condensation and is complicated, requires special expertise, and is beyond the scope of this guide. For information regarding condensation problems as they relate to roofs, refer to ASTM MNL 18,[2] ASTM MNL 40,[3] and ASHRAE Handbook 2005 Fundamentals.[4]

1.2 Investigative techniques discussed in this guide may be intrusive, disruptive, or destructive. It is the responsibility of the investigator to establish the limitations of use, to anticipate and advise of the destructive nature of some procedures, and to plan for repairing and selective reconstruction as necessary.

1.3 This guide does not address steep-sloped roofs, standing or flat seam metal roofs, or architectural standing seam metal roofs.

1.4 *The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.*

2. Referenced Documents

2.1 *ASTM Standards:*[5]

C1153 Practice for Location of Wet Insulation in Roofing Systems Using Infrared Imaging

D1079 Terminology Relating to Roofing and Waterproofing

D7186 Practice for Quality Assurance Observation of Roof Construction and Repair

3. Terminology

3.1 Refer to Terminology D1079.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *condensation*—the conversion of water vapor to liquid as the temperature drops or atmospheric pressure rises.

3.2.2 *incidental water*-—unplanned water infiltration that penetrates beyond the primary barrier and flashing without causing adverse consequences.

3.2.3 *water infiltration*—a process in which water passes through a material or between materials in a system and reaches a space that is not directly or intentionally exposed to the water source.

3.2.4 *water leakage*—water entry that is uncontrolled, exceeds the resistance of a component, or causes subsequent damage or premature deterioration.

4. Significance and Use

4.1 This guide is intended to provide building professionals with a methodology for evaluating water leakage through low-sloped roofs. It addresses the service history of a roof, the various components of a roof, and the interaction between these components and adjacent construction. It is not intended as a construction quality control procedure, as specified in

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[2] Treschel, H. R., ed., *Manual on Moisture Control in Buildings,* MNL 18, ASTM International, 1994.

[3] Treschel, H. R., ed., *Moisture Analysis and Condensation Control in Building Envelopes,* MNL 40, ASTM International, 2003.

[4] *ASHRAE Handbook 2005 Fundamentals,* available from American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE), 1791 Tullie Circle, NE, Atlanta, GA 30329, http://www.ashrae.org.

[5] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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Practice D7186, nor as a preconstruction qualification procedure. It is intended for evaluating water leakage through a low-sloped roof.

4.1.1 *Qualifications*—Use of this guide requires a background as an architect, engineer, roof/waterproofing consultant, roofing contractor, or related profession with an understanding in building construction and the expertise in the design, installation, and maintenance of low-sloped roofs.

4.1.2 *Application*—The sequential activities described herein are intended to produce an evaluation program, but all activities may not be applicable or necessary for a particular evaluation program. It is the responsibility of the professional using this guide to determine the activities and sequence necessary to perform an appropriate leakage evaluation for a specific low-sloped roof on a building.

4.1.3 *Preliminary Assessment*—A preliminary assessment may indicate that water leakage problems are limited to a specific element or portion of a low-sloped roof. The evaluation of causes may be limited in scope, and the procedures recommended herein abridged according to the professional judgment of the investigator. A statement stipulating the limits of the investigation should be included in the report.

4.1.4 *Expectations*—Expectations about the overall effectiveness of an evaluation program must be reasonable, and in proportion to a defined scope of work. This guide is intended to address leakage of a low-sloped roof system, leading to conclusions that can generally be applied to similar or other locations on the roof. Since every possible location is not included in an evaluation program, it is probable that every leak source will not be identified. Leak sources that are localized and unique may remain, and require specific and localized evaluation effort.

4.2 This guide is not intended as a design guide. Reference is made to design features of a low-sloped roof only for the purpose of identifying items of interest for consideration in the evaluation process.

4.3 This guide does not address leakage through walls not associated with roof construction, fenestration, or leakage below-grade. It is not intended for use with structures designed to retain water, such as pools, fountains, and vegetative roofs.

SYSTEMATIC APPROACH TO AN EVALUATION

5. Overview

5.1 The methodology presented in this guide is intended to provide a systematic approach to evaluating roof leaks, and is applicable to any low-sloped roof system. The sequence of activities is intended to lead to an accumulation of information in an orderly and efficient manner, so that each step enhances and supplements the information gathered in the preceding step.

5.1.1 *Sequence of Activities*—The recommended sequence of activities, discussed in individual sections below are:

5.1.1.1 Review of project documents.

5.1.1.2 Evaluation of original roof design concept.

5.1.1.3 Determination and review of service history.

5.1.1.4 Inspection.

5.1.1.5 Investigative testing.

5.1.1.6 Analysis.

5.1.1.7 Report preparation.

5.2 *Analysis and Interpretation*—The information gathered during a leakage evaluation is analyzed as it is acquired. It is not the intent of this guide to imply that the analysis and interpretation of the information occurs only at the completion of all activities.

6. Review of Project Documents

6.1 Ideally, project documents, including roof component shop drawings, will be available and accessible for review. The discussion in this section assumes that a project was organized on a conventional owner/design professional/contractor model. Projects can be delivered in various ways, and the method used will dictate the appropriate organization of the project documents. The information discussed below should be available for review somewhere in the project documents.

6.1.1 *Design, Bidding, and Contract Documents*—These documents include architectural and engineering drawings, specifications, and may include correspondence, meeting minutes, addenda, substitution proposals, product literature, test reports, survey reports prepared by others, shop drawings, and so forth. They contain the information necessary to understand the performance criteria, the design intent, materials, and relationships among the roof components.

6.1.1.1 Documents may be revised or supplemented over the course of construction. Revisions to drawings are typically recorded by number and date, with a cross reference to other accompanying documents. Reviewing all revisions and understanding the differences between them and the reason for the differences is part of the evaluation.

6.1.1.2 Documents with the most recent issue date and the highest revision number establish the requirements for the project. A set of documents marked “as-built” or “record set” are intended to show the actual construction and may be available.

6.2 *Referenced Codes and Standards*—Project documents usually contain references to regulatory codes, industry standards, or manufacturer installation requirements. Standards, referenced codes, and manufacturer information often contain default or minimum criteria to establish the performance criteria for the roof. Conflicts between the referenced documents and those stated in the project documents should not be assumed to be a cause of leakage without further investigation.

6.2.1 Regulatory codes, industry standards, and manufacturer installation requirements change over time. The version of these documents examined as part of the review of project documents should be those listed with dates in the project documents, or if not listed with dates, those in effect when the building permit was issued.

6.3 *Submittals*—Additional documents are generated after the award of contracts and are submitted to the design professional for review and inclusion in the project record. The submittals usually apply to a specific material, component, assembly, or installation method, and the information contained will augment the project documents. There can be a number of revisions to submittals prior to final approval. The standard for the project is set by the submittals approved by the design professional. Submittals can include shop drawings, test

reports, product literature, manufacturers' recommendations, installation and maintenance guidelines, warranties, etc.

6.3.1 Test reports provided by manufacturers and suppliers should have been performed by an independent laboratory or witnessed by an independent agency (if requested by the customer). Review the test dates and the description of what was tested to determine if and how the information actually applies to the project.

6.3.2 Manufacturers' and suppliers' information, and the exclusionary language in warranties, may suggest circumstances under which one or more of the components may not function properly. Project conditions should be evaluated to determine if an appropriate product selection had been made.

6.3.3 Submittals should be reviewed for maintenance recommendations and guidelines.

6.4 *Pre-Qualification and Mock-Up Reports*—Compliance with specific project requirements may have been demonstrated by a mock-up test. The mock-up report should contain a clear and complete description of changes necessary to pass the test. Project documents should incorporate these changes, and they should be reflected in the actual construction. Failure to incorporate these changes should be considered as a possible cause of water leakage.

6.5 *Additional Construction Documents*—Additional construction documents that record changes, decisions, and activities during the construction phase may include bulletins, requests for information (RFI), clarifications, change orders, directives, progress photos, inspection and quality assurance reports, test reports, meeting minutes, and correspondence. The information in these documents may modify or supersede the design documents.

6.6 *Local Practices*—An understanding of local practices will permit a thorough assessment of the project roof design and construction. The actual construction may be influenced in an undocumented manner by local practices.

6.7 *Missing Documents*-—Project documents may be unavailable or have missing parts. This situation will require the determination of existing and as-built conditions. The information may need to be generated from observations and measurements of the building.

7. Evaluation of Design Concept

7.1 *Design Concept*—Review of the project documents should reveal what requirements had been specified for the roof.

7.2 *Efficacy of the Design*—The design shall include properly selected components. The details must provide for the interfacing and integration of components so that each one can perform collectively and function as a system. The details must also address issues such as construction tolerances, material compatibilities, terminations, penetrations, and building movement. A careful evaluation of the design will indicate inconsistencies that may contribute to leakage.

7.3 *Exposure*—Based on an analysis of local weather conditions and the location and geometry of the building, identify the actual weather conditions during periods of leakage. These conditions can be correlated with service history, described in the next section, to help establish a protocol for the evaluation process.

8. Determination of Service History

8.1 Gathering information on the service history related to leakage problems serves two purposes. First, patterns in the observed leakage and visible damage can provide an indication of the cause(s) and where to focus an investigation. Second, the information provides a checklist against which failure theories and conclusions can be evaluated. A comprehensive diagnostic program should result in an explanation for most, if not all, aspects of the observed leaks and damage.

8.1.1 *Document Physical Symptoms of Leaks*:

8.1.1.1 Make a detailed visual inspection of both the interior and exterior. Locations that should be checked for indications of leakage include but are not limited to:

(1) Intersection of the roof with walls, parapets, and curbs.
(2) Perimeter gravel stops.
(3) Roof drains, overflow drains, and scuppers.
(4) Base flashing.
(5) Roof slope.
(6) Mechanical units.
(7) Curbs and equipment rails.
(8) Expansion joints.
(9) Field seams and laps.
(10) Punctures, splits, or tears in membrane or flashing.
(11) Utility and building service penetrations.
(12) Gutters and downspouts.
(13) Cap flashing.
(14) Pitch pans.
(15) Door sills.
(16) Penthouse or parapet walls.
(17) Counterflashings.
(18) Surface-mounted flashing.
(19) Reglets.
(20) Weep holes in masonry walls.

8.1.1.2 Note all locations of past and existing water damage, including, but not limited to, the following:

(1) Wet, damp, or water-saturated surfaces in the building interior.
(2) Color differences caused by organic growth, staining, or corrosion in the building interior.
(3) Staining, indicating the flow or accumulation of water.
(4) Interior areas repaired or patched due to prior leakage.
(5) Blistering surface of interior finishes that can indicate wetting.

8.2 *Interviews*—Interview occupants, maintenance personnel, subcontractors, tradesmen, or other first-hand observers. Obtain information that will help correlate leakage with building features and other events, such as:

8.2.1 The apparent origination point of a leak.

8.2.2 The exterior environmental conditions under which the leak occurs.

8.2.3 The frequency and initiation of occurrence, especially if the occurrence is exceptional or occurs under extreme conditions.

8.2.4 For leaks that occur during rains, ascertain if a leak:

8.2.4.1 Occurs immediately after the onset of rain or after a period of time elapses.

8.2.4.2 Stops immediately when the rain stops, or continues for a period of time after the rain ends.

8.2.4.3 Occurs during every rain regardless of severity.

8.2.4.4 Occurs during every rain regardless of wind direction, or only with wind from certain directions.

8.2.4.5 Occurs during or immediately after cold weather, with or without accompanying rain.

8.2.4.6 Occurs because of different interior environmental conditions and the building operations. Weekend and evening operating conditions may differ from weekday business hour conditions.

8.2.4.7 Appears to be related to a particular feature or detail.

8.2.4.8 Is caused by the performance of the building piping system, including water supply and drainage, heating and air conditioning supply and return, and roof drains. Leaks from a piping system might be misinterpreted as a roof leak.

8.3 *Maintenance and Repair Records*—Buildings with chronic leakage problems are often subjected to several attempts at remediation before a comprehensive evaluation is made. An effort should be made to understand the earlier attempts at repairs because: (*1*) they may indicate a pattern of leakage; (*2*) repairs may be causing or contributing to current leakage; and (*3*) it will be necessary to distinguish between original construction and attempted repairs during the inspection and testing phases of a systematic evaluation. Where appropriate and possible:

8.3.1 Review the original project punch-list if available. Water infiltration problems can often occur because of stopgap repairs made in an effort to closeout the project.

8.3.2 Review purchase orders for building maintenance and repair records and other activities that may relate to water leakage problems.

8.3.3 Review work orders that deal repeatedly with the same leakage problem.

8.3.4 Evaluate the success or failure of previous repair attempts.

8.3.5 Compare original details to actual conditions observed to determine deviations from original construction intent or undocumented repair attempts.

8.3.6 Identify repairs that inadvertently seal weep holes in walls or parapets or other openings that are intended to dissipate or weep entrapped water in a wall system. These might have been sealed in an attempt to stop a roof leak.

8.3.7 Evaluate repairs against the original design intent. Common repairs made to leaking roofs include the application of roof cement, sealant, coating, incompatible or different roof membrane material, and underdeck gutter systems. Inappropriate use of these procedures can cause additional problems.

8.4 *Determine Extent of Leakage*—Use the information gained above to determine the extent of leakage.

8.4.1 Correlate historical leak occurrences with particular building features and details.

8.4.2 A graphical analysis is useful for correlation studies. Leak occurrences can be superimposed on building drawings to help reveal patterns that might be traceable to potential leak sources.

8.5 *Weather Records for the Vicinity*:

8.5.1 Detailed weather data for a specific time period, typically recorded at major airports, can be obtained from the National Weather Service. The data of particular interest for a leakage evaluation are: precipitation rate, wind speed during precipitation, wind direction, barometric pressure, and relative humidity.

8.5.2 Unusual events and severe leakage occurrences should be correlated.

8.6 *Correlations*—Correlate occurrence with other factors such as temperature, wind direction and speed, season of year, and building operations.

8.6.1 *Temperature*—Ambient air temperature and roof surface temperature can affect water leakage.

8.6.2 *Wind Direction and Speed*—A primary force for water leakage is wind-driven rain. The severity and location of leakage can often be correlated to the direction and speed of the wind.

8.6.3 *Season of Year*—Some buildings in northern climates only leak during the winter months. The accumulation of ice and snow on horizontal surfaces can feed water into a roof assembly during clear cold sunny days even when the outside temperature stays below freezing.

8.6.4 *Building Operations*—Although most building HVAC systems operate on positive pressure, parts of the building could be subjected to negative interior pressures when exposed to certain wind conditions. Building operating pressures are usually very small compared to the effect of wind, and are rarely the sole cause of leakage in occupied spaces. However, in the vicinity of louvers and equipment spaces, mechanically induced pressures can be significant.

8.6.5 *HVAC System Plenums*—The space between the underside of the roof deck and the interior ceiling can be an open return air plenum or a closed ducted plenum. Either system, including unsealed return air ducts, can pull untreated air through the building exterior walls, and cause condensation in both humid and cold climates. Cold air will chill surfaces, and internal humidity will condense. In hot climates, humid air that infiltrates can condense on cold surfaces inside the building.

9. Inspection

9.1 *Presentation*—Composite large-scale drawings are helpful in gathering and recording information about as-built conditions. A composite drawing can begin with the best available information from the project documents including pertinent information from the architectural, structural, and mechanical drawings and specifications, as well as the structural and roof assembly shop drawings. The drawing can serve as a form for recording actual field conditions. Differences between information in the project documents and the as-built conditions should be anticipated. These differences do not necessarily mean that a leak source has been identified. The purpose is to provide a basis for further inspection, testing, and remedial recommendations.

9.2 *Determine Current Conditions*—The physical condition of the roof and visible evidence of water infiltration, should be documented during the inspection. This information can then be correlated with information from the service history of the roof in formulating a hypothesis about the cause(s) of leakage. Examples of information that should be documented include:

9.2.1 Condition of flashing.

9.2.2 Functional aspects of roof slope and drainage systems.

9.2.3 Interfaces between roof and wall, or roof and eave.

9.2.4 Interface with other building components, such as copings, and roof penetrations by mechanical equipment or structural supports.

9.2.5 Other possible mechanisms for water entry into a roof such as capillary action or air movements.

9.2.6 Material conditions, including symptoms of deterioration, freeze-thaw damage, prolonged saturation and membrane delamination.

9.2.7 Indications of wear and tear, maintenance, attempted repairs, damage from non-weather related causes such as impacts, or structural movements.

9.2.8 General assessment of workmanship as it affects water infiltration.

9.3 *Planning*—Inspections shall be conducted in a planned and orderly fashion. Planning is necessary when concurrent sampling and testing are incorporated in the inspection program. The inspection plan should address the following issues:

9.3.1 *Scope*—Both typical and atypical conditions should be included. It is particularly important to include the terminations and interfaces of the components being inspected, such as corners, ends, joints, transitions to other materials, or changes in geometry. The inspection should also include both non-performing and performing locations. The differences between non-performing and performing locations can provide useful information about the cause(s) of leaks. The objective of the inspection program is to acquire information about the intrinsic properties of the roof system. A sufficient number of inspection locations must be selected to accomplish this objective. If constraints with the inspection program preclude including a sufficient number of locations, the results should so state.

9.3.2 *Selection*—It is normally not necessary to inspect an entire roof except in special situations where there is a specific issue to resolve that would require such extensive investigation. The selection of inspection areas is based primarily on the service history, review of project documents, and accessibility. Limitations of resources will often require the selection areas to be taken from seemingly equal choices of areas. A preliminary inspection of limited scope can help in the rational selection of areas where a more detailed inspection is warranted.

9.3.3 *Access*—"Interior and exterior" access for close-up inspection should be prearranged with the building owner or his representative. Interior access may require temporarily moving furniture, removing interior finish materials, or relocating or suspending the use of a space. Exterior access will probably require the assistance of a contractor to provide access and protection, and to cut the roof system, or associated building elements.

9.3.4 *Organizing Information*—A comprehensive inspection can generate a large amount of data. Determining how the information will be recorded and organized is part of the planning process. Building drawings can be made beforehand and used to record observations, thereby making the locations of information self-evident.

9.4 *Methods*—Inspection methods range from long range visual inspections to close-up observations and employing inspection openings. The method used depends on the information required. Rapid methods are particularly useful for preliminary inspections and to narrow the scope for more detailed inspections. A comprehensive inspection program will include some method for observing or evaluating concealed conditions, such as inspecting openings, using moisture detectors or infrared thermography scans, or employing mechanical penetrations.

9.4.1 Inspection openings involve the progressive removal of roof materials to reveal underlying, concealed conditions. Each layer may be changed or destroyed during the process, so it is important for the investigator to be present during the operation and to document each step. Possible safety issues such as the presence of asbestos must be considered, and the necessary notifications and precautions taken.

9.4.2 Commercially available moisture detectors of the capacitance and neutron backscatter type make it possible to estimate the moisture content of concealed roof materials. High moisture content may indicate proximity to a water entry point or location along a water migration path. Plotting the measured relative moisture content on a grid superimposed on a building roof drawing can provide a diagram of wet areas. Care must be taken in interpreting the values of the readings reported since calibration and operating techniques may affect readings. Knowledgeable users will recognize that these devices detect characteristics of the effect of water on a building component and do not detect moisture directly. This is unlike the procedure used to calibrate all such moisture detectors, that of gravimetric determination of water content by weight loss upon drying of a component suspected of being wet that does determine the presence and quantity of water directly.

9.4.3 Infrared thermography produces an image that, with proper interpretation, can indicate conditions such as concealed moisture within the roof, and roof materials. Infrared thermography should be performed as indicated in Practice C1153 and interpreted with the assistance of a specialist knowledgeable in this technology.

9.4.4 Moisture meters of the resistance/conductance type may be useful for indicating the simple presence of moisture. Since the type of material that is being investigated and the way it was exposed to water will have an effect on the readings obtained, the indicated quantity of moisture within a given component can vary widely from one component to another component, even if they are the same material type.

9.5 *Documentation*—Inspection findings should be recorded in writing with clarifying sketches where appropriate. The documentation should be supplemented graphically with photographs, video, or dictated notes, but these should not normally be relied upon as the only record of the inspection process because of the risk of accidental erasure, undetected camera or recorder malfunctions, or processing accidents unless suitable backup procedures are employed at the time the data is taken.

9.5.1 Written documentation should be complete enough for the evaluation process to be repeated, as well as for the information gathered to be interpreted in determining the cause(s) of leaks. In addition to recording observations, the following should be considered in making the written documentation:

9.5.1.1 The location of the observation should be clearly defined. References to column lines and roof penetrations can be used, as well as other reference points and lines.

9.5.1.2 Preliminary opinions formed and interpretations made during the inspection should be recorded separately from the inspection notes, and be distinct from observations of fact and measurements.

9.5.1.3 Keys for codified shorthand notations and symbols should be given.

9.5.1.4 If the procedures used are not self-evident, they should be described in detail.

9.5.1.5 The sequence of the inspection process should be clear from the written documentation.

9.5.1.6 The date, time, and name of the person(s) making the observation, should be recorded for each data sheet.

9.5.2 Supplementary photographs and video are useful for informing others of the inspection procedures and observations, and provide an opportunity to reconsider or check findings later. In making photographs or video recordings, the following should be considered:

9.5.2.1 It is necessary to orient the pictures. This may require a progression of photos from wide to narrow view, or zooming from wide to narrow view with a video camera. Including something of known size in a photograph will help viewers determine the size of the object of interest. For example, a person or a piece of equipment such as a pocket knife can be used. For a more accurate reference, a ruler or an extended length of a carpenter's tape can be included in the plane of interest.

9.5.2.2 The location of a picture should be identified. Labels in the picture, or markings directly on the roof or walls are useful for this purpose.

9.5.2.3 If the object of interest in a photograph is a membrane split or crack, it is helpful to add a pointer to focus attention, or to insert a tool in the split or crack. Pointers may be added in post-processing of the photograph, but the original unmodified photograph should be retained to satisfy objections of alteration.

9.5.2.4 Recording a sequential number or the time and date on the film, or including the time and date in the photo label, maybe helpful in organizing the pictures.

10. Investigative Testing to Reproduce the Leak

10.1 Leak testing can be an integral part of the evaluation process and should be thought of as a means to verify and extend hypotheses arrived at during the document review and inspection phases while using controlled and reproducible procedures. Implementing testing before completing the preceding steps in a systematic approach may significantly limit the potential benefits of the test, and can lead to incorrect conclusions. However, some leakage problems can be diagnosed and corrected with little or no leak testing.

10.1.1 *Objectives*:

10.1.1.1 *Recreate Leaks*—The primary purpose of investigative testing is to recreate leaks that are known to occur.

10.1.1.2 *Trace Internal Path of the Leak*—Leakage paths within a roof are difficult to trace during a rain. Testing provides the opportunity to recreate the leakage and water migration paths under controlled and reproducible conditions. The paths observed during testing should be compared to evidence of water paths during actual leaks by assessing existing staining, damage and residue accumulation.

10.1.1.3 *Correlate Test Results with Observed Damage*—The test procedure should produce the observed in-service leakage. Creating new leaks during a test may be useful information, but it is not a valid assessment of the existing leakage problem.

10.1.1.4 *Verify Hypothesis*—The controlled conditions during a leak test are an opportunity to verify hypotheses about the cause of the leaks. If a theory on the cause of a leak cannot be demonstrated by a reasonable and appropriate test, the theory is questionable. Remedial recommendations should not be based on unverified theories.

10.2 *Planning*:

10.2.1 *Service History*—The service history of the roof and the environmental exposure must be considered when planning a testing program. The selected test method should simulate the actual conditions under which the leak has been observed.

10.2.2 Investigative testing is a diagnostic procedure, not a quality assurance procedure. A distinction must be made between the cause of the leak and the design criteria. Focusing on the design criteria may interfere with the objectives of testing. Testing at an environmental exposure level that the roof will never experience or for which it was not designed to withstand may lead to incorrect conclusions.

10.2.3 For diagnostic purposes the roof should be tested in its current, as-found condition if the cause of the current leaks is to be determined. Upgrading components of the roof to their original design intent, so that they can "pass the test," prevents the acquisition of important information about current behavior. If original construction conditions or compliance with the original design intent are of interest, those tests can be performed separately after the diagnostic tests.

10.2.4 Previous remedial measures and modifications must be accounted for in the test plan. It may be desirable to undo modifications prior to or during testing to limit confusion and require that disruption of normal building operations be limited.

10.2.5 Agreement on testing methods and interpretation of results should be reached between the interested parties before testing begins. Items that should be addressed by the interested parties include:

10.2.5.1 Test criteria, methods, frequency, and location.

10.2.5.2 Participation by interested parties, and opportunity for close-up examination of test location(s) and test set-up(s).

10.2.5.3 Documentation.

10.2.5.4 Effects of age and use/abuse.

10.2.6 *Testing Duration*—Judgment is needed in determining the duration of leak testing, recognizing that the objective of diagnostic testing is to recreate existing leaks that occur in-service conditions. Factors that may influence the test duration required to recreate leakage paths include building or roof construction, the potential length of internal leakage paths, the absorption properties of the roof materials.

10.3 *Methods and Equipment*—Testing under controlled and reproducible conditions to recreate leaks can be divided

into two categories: (*1*) methods that simulate surface flow or ponding conditions; and (*2*) methods that simulate wind-driven rain.

10.3.1 *Simulating Surface or Flow Ponding*—Flow or ponding is capable of causing leaks under some circumstances even without wind-induced pressure

10.3.2 *Simulating Wind-Driven Rain*—Wind driven rain produces leaks because of the kinetic energy of the rain drops and the differential pressure caused by the wind. Under some wind conditions, rain water deposited on the face of roof component such as base flashing, cap flashing, and so forth may actually flow upward. Capillary action and absorption may also be operative.

10.3.3 Testing of isolated areas usually begins at the bottom of the test area, and progresses to the top. Starting at the bottom (that is, base flashing) helps eliminate ambiguity about the origin of a leak that might result from water running down the surface of the test area.

10.4 *Tracking Leaks*—Once testing produces a leak, the entry point and the path followed by the water within and through the roof should be traced. A single entry point may lead to several concealed water paths, or several entry points may merge together internally. Every source must be identified if a complete diagnosis and repair is to be developed.

10.5 *Isolation*—Effective diagnostic testing should result in the identification of entry points. If a leak is induced, only those components exposed to the water source need to be considered in identifying the entry points. Selective masking can then be progressively removed and the roof or its ancillary building elements retested.

10.5.1 It may also be useful to repair a water entry source during a progressive testing program to eliminate it from further consideration during the test. Thorough record keeping of the temporary repairs are necessary if this technique is used.

10.5.2 Materials that are useful for selective masking and temporary selective repairs/patches include duct tape, 6 mil clear plastic sheeting, bentonite clay, or other agreed methods appropriate to the roofing system.

11. Analysis

11.1 A leak evaluation is conducted in response to a problem situation, and may involve techniques and procedures specifically adapted and applied in a systematic manner to diagnose a specific problem.

11.2 The information accumulated during a leak evaluation is analyzed as it is acquired. The information may cause a change in the approach for subsequent steps in the evaluation process.

11.3 The evaluator shall establish a cause and effect relationship between roof characteristics and observed leaks. This requires an appropriate selection of activities and a logical analysis and interpretation of the acquired information. The analysis will address issues such as:

11.3.1 Reduction of quantitative data.

11.3.2 Resolution of conflicting data and observations.

11.3.3 Patterns and commonalities in the data and observations.

11.3.4 Identification and explanation of anomalies.

11.3.5 Correlation with known roof performance.

11.3.6 Significance of an observation or measurement, and its relevance to the behavior of the roof.

11.3.7 Corroboration between various investigative procedures used.

11.4 The conclusions and findings from an evaluation must be based on the activities and procedures undertaken and the information acquired.

11.5 The record should be complete so that any interested party can duplicate the evaluation program and acquire similar information. Notes on the acquired information should be clear and complete to be understood by any other professional skilled in roof leak evaluation.

12. Report

12.1 Prepare the report, if requested or as agreed, describing the conditions under which the evaluation was conducted, the methodology used, the observations and measurements made, and the findings, conclusions, and if required or requested recommendations. Reports should be prepared on paper with a letterhead, logo, or some other feature that will make it distinguishable from copies.

12.2 The writing style utilized shall be appropriate to the intended reader of the report, and also anticipate that the report may be reviewed by other professionals or experts.

12.3 *Report Organization*:

12.3.1 The report should contain the following sections in the sequence listed:

12.3.1.1 Title page with mandatory information.

12.3.1.2 Executive summary.

12.3.1.3 Statement of objective or scope.

12.3.1.4 Background, brief but definitive, including identification of the building.

12.3.1.5 Observations.

12.3.1.6 Discussion.

12.3.1.7 Description of evaluation process.

12.3.1.8 Analysis of acquired information.

12.3.1.9 Identification of cause(s) of leakage.

12.3.1.10 Distribution list.

12.3.2 Not all of the above headings may be required. Other headings may be used if they better describe the content and scope of work.

12.4 *Author*—First name and surname, and any professional license and registration, included at the end of the report.

12.4.1 Date(s) of evaluation and tests, and date of report.

12.4.2 Evaluating agency, if used with mailing address.

12.4.3 Sponsoring agency, if used with mailing address.

12.5 *Executive Summary*—Provide a concise statement of the investigation findings and recommendations.

12.6 *Statement of Objective or Scope*—State the reason(s) for undertaking the evaluation and the scope of the evaluation.

12.7 *Discussion*—Describe the methodology used in the evaluation process.

12.7.1 *Sources of Information*—List or describe the project documents, product literature, standards, reports by others, and so forth, reviewed in the course of the evaluation.

12.7.2 *Description of Design Intent*—Describe the specific designed roof system Identify items critical to performance of the roof system with respect to water leakage, such as

method(s) to accommodate structural movements, material compatibility, drainage, and so forth.

12.7.3 *Description of the Roof Components or System(s)*—Describe materials, primary components, include sketches and/or photographs as necessary. Describe the physical condition of the roof assembly, including damage, deterioration, prior repair attempts.

12.7.4 *Service History*—Describe the known performance record of the roof system, including the physical symptoms of water leakage, progression of leakage behavior, maintenance and repair history, extent and locations of leakage, correlation of leaks with wind direction, building operations, season, and so forth.

12.7.5 *Inspection*—Describe methods used in inspection of the roof system, including access, equipment, and documentation.

12.7.6 *Testing*—Describe the tests performed, including equipment, sequence, and modifications made to the test area.

12.7.7 *Conformance with Design Intent*—Describe any observed variations in the as-built roof assembly from the design, including any apparent modifications or prior repairs to the roof. The discussion can be qualified and limited to differences that are relevant to the causes of leakage.

12.8 *Analysis of Acquired Information*—Describe the analysis of observations and measurements in a manner appropriate to the scope of the report.

12.9 *Identify Cause(s) of Leakage*—List or describe those elements components, deficiencies, defects, and omissions of the system that contribute to the leakage. Describe the point(s) of water entry and the path(s) of the leakage. Describe the cause-and-effect relationship between roof characteristics and observed leakage.

12.10 *Recommendations*—If requested or required, should describe in general the basic remedial action that maybe required to correct or eliminate the source of water leakage.

13. Keywords

13.1 evaluation; inspection; leaks; low-sloped roof; roof; testing; water leakage

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