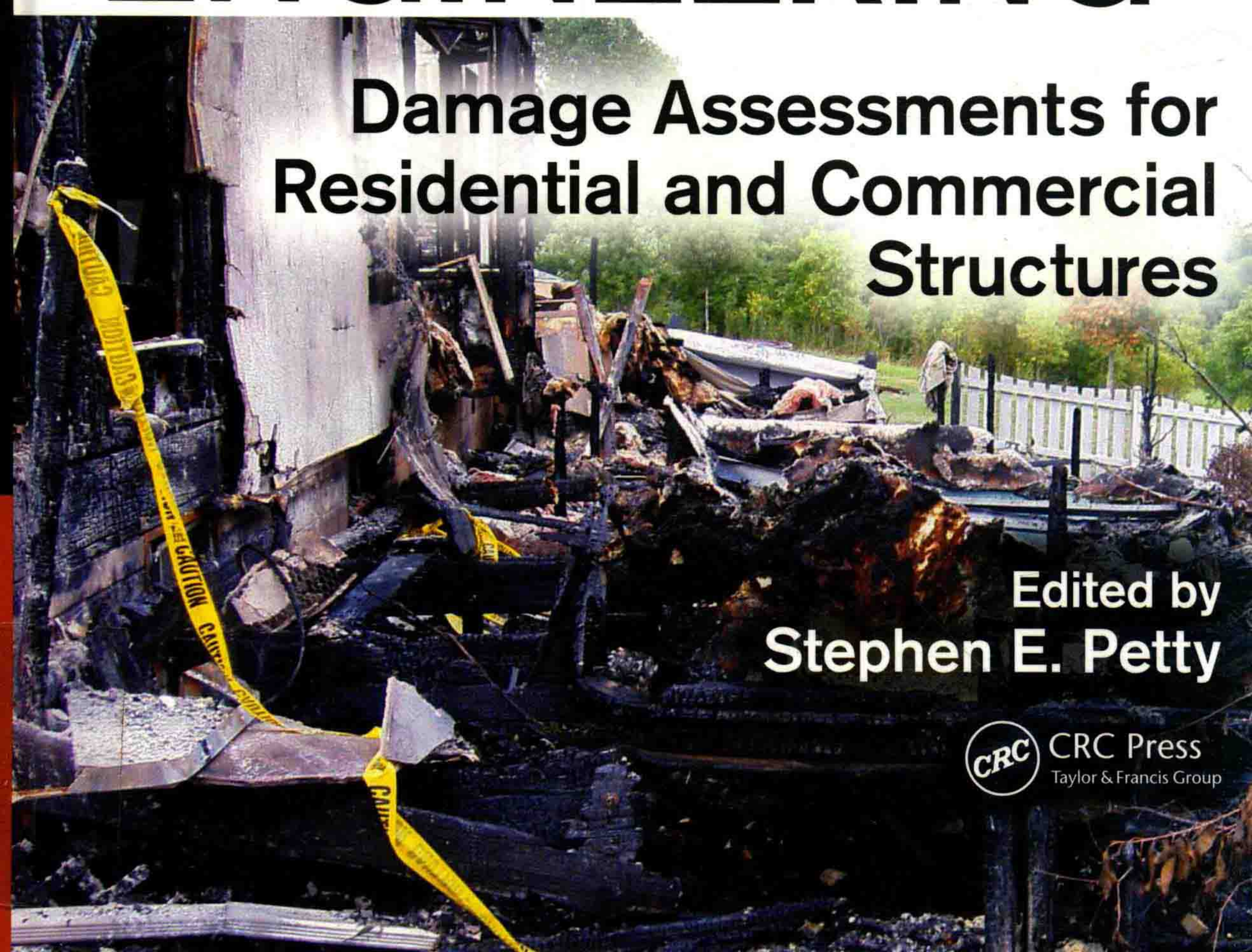
# FORENSIC ENGINEERING

## Damage Assessments for Residential and Commercial Structures



Edited by
Stephen E. Petty

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*This book is dedicated in loving memory to my son Mark Anthony Petty who passed away at the early age of 21 on September 3, 2011, in New York City due to complications of Crohn's disease. Mark had remarkable promise, excelling as one of the top students in his honors engineering and business administration programs during his senior year at the University of Cincinnati, along with an equally remarkable personality. He was a large part of EES Group, Inc., helping out on projects since he was 13 years old. Mark is tremendously missed by me, his colleagues here at EES, and everyone who knew him.*

# Preface

This book is intended to serve as a comprehensive resource to bridge engineering disciplines with the building sciences and trades (e.g., carpentry, masonry, HVAC, plumbing, and wiring disciplines). The blending of these skill sets is necessary to excel in the field of forensic engineering, particularly for those working for, or in, the insurance industry assessing claims. Oftentimes those who enter the field are engineers or those with a science background who lack the knowledge in building sciences, trades, and codes and standards associated with roofing systems, building envelope systems, carpentry, plumbing, wiring, and masonry.

In most textbooks, as is true for this one, a book cannot realistically cover an entire field—in this case the field of forensic engineering. Broadly speaking, forensic engineering is a subset of the field of forensic sciences and is defined as the field that applies engineering practices and principles to determine and interpret the causes of damage to, or failure of, equipment, machines, or structures.

The information provided in this book is primarily limited to forensic engineering associated with cause and origin determinations associated with claims in the insurance industry. As such, the focus is on hail and wind damage, water intrusion cause and origin, and structural failures. Other topics such as ventilation, indoor environmental quality (IEQ), performing appraisals, and serving as an expert witness are touched upon since those working for or in the insurance industry will be affected by, and encounter, these topics.

Many engineers, scientists, and insurance claims agents are employed in the business of attempting to determine the cause (what happened) and the origin (what was the event that caused something to happen). To answer these questions, an investigation is completed to determine whether the event is a covered peril. A simple example might be the failure of a refrigerator waterline to an ice maker that resulted in a water leak, which damaged the contents and structure of a residence and led to mold growth on surfaces. The question of what caused the failure might include one of more of the following:

- Improperly connected plumbing
- Failure of plumbing fitting or tubing
- Improper type of fitting or tubing
- Mechanical damage to fitting or tubing
- Freeze failure caused by a lack of heat
- Freeze failure caused by placement of the line in an uninsulated wall cavity

As can be seen, a failure may be caused by one or more factors. These factors are often secondary rather than primary causes for the failure. In other words, a longitudinal split in the tubing may make it apparent that the failure occurred because water in the tubing froze, causing the tube to split or rupture and allowing water to flood the residence. However, the next level causation question is: Why did the water in the tubing freeze? Thus, causation questions often must be answered at many levels.

For any given investigation, the forensic engineer must rely on education, training, and experience, with emphasis on experience and knowledge of best practices documents associated with the trades and codes and standards. When investigating a new failure situation and armed with little information regarding the specific situation, one must rely on past experience to ultimately make causation and origin decisions. At EES we have collected thousands of best practices documents and files easily accessible by staff to draw on and to contribute to. Information such as the life of equipment or a window seal may not be readily found in the literature, but it can be gained by conversations with manufacturers and will be not only helpful, but also be critical in determining the cause(s) for failures encountered. For example, following a hailstorm, an owner may claim that hail strikes from a hailstorm caused the window seals in their home to fail. However, if the windows are on the opposite side of the residence from the direction from which the storm arrived, or are approximately 15 years old (at or beyond expected life), then hail strikes from the hailstorm are not likely the cause of the window seal failure. Experiential knowledge is needed to recognize and compare damage to seals on windows facing, and opposite, the direction of the arriving storm. This information, coupled with knowledge of window seal life, allows the forensic investigator to make causation determinations of complex situations as illustrated in this example situation.

Each project is a bit of a mystery as to how and why it occurred. Solving these mysteries is what makes the forensic engineering field an interesting career choice.

This book provides our experiences, investigation methodologies, and investigation protocols used in, and derived from, completing thousands of forensic engineering investigations. It is intended to bridge the technical and practical worlds, which is essential in conducting forensic engineering investigations. Much of what must be known in this field is not learned in school, but it is based on experience since recognizing the cause of the failure requires a blending of skills from the white-collar and blue-collar worlds. Rarely, given the limits on time, does the academic community provide the necessary training regarding sciences such as carpentry, HVAC, plumbing, wiring, building design and construction, and construction management, which is needed to conduct forensic investigations. Such knowledge can be vital since building system failures (e.g., water entry) often result from construction activities completed out of sequence due to subcontractor timing or cost issues.

This book closes with some guidance in the area of serving as an expert witness. In time, as a forensic engineer/scientist becomes more experienced and as the projects become more complex, involvement in the litigation process is likely. Advice on the expert witness process and serving as an expert witness is offered to the reader based on the editor's experience in serving on over 200 expert witness projects.

# *Acknowledgments*

My thanks go to the staff at EES Group, Inc., who have invested tens of thousands of man hours developing the methodologies outlined in this book based on experiences in the field and encouraged me to write this book.

My thanks also to the administrative staff at EES Group, Inc., who contributed an immeasurable amount of time proofing and formatting the chapters, figures, and tables. Special thanks go to Alexandra Herion, Victoria Zimmer, Mike Ferraro, Clinton Standish, and Cinda Wickersham for their contributions in this area.

My thanks also to Taylor & Francis, CRC Press, for agreeing to issue this book, and in particular to Joseph Clements, senior editor for civil and environmental engineering, and Laurie Schlags, project coordinator, for their support, advice, and dedication to ensure that a quality textbook was issued.

I also extend my thanks to Marl A. Johnson, executive vice president, director of business development, at the International Code Council and to the International Code Council for their help and permissions in utilizing text and figures from the 2012 International Residential Code for One- and Two-Family Dwellings and the 2012 International Building Code throughout this book. The materials used in this book contain information that is proprietary to and copyrighted by International Code Council, Inc. Portions of the information copyrighted by International Code Council, Inc., have been obtained and reproduced with permission by International Code Council, Inc., Washington, DC. The acronym "ICC" and the ICC logo are trademarks and service marks of ICC. All rights reserved. www.iccsafe.org.

Thanks also go to my colleagues and coauthors, who made major contributions to this book as chapter authors, chapter coauthors, or with detailed comments to ensure that information contained in the chapters was based on the best information we had available. A special thanks to Herbert Layman, technical director, U.S. Micro-Solutions, for his contributions and review of Chapter 13 covering mold and bacteria; Thomas E. Schwartz, of Holloran White & Schwartz LLP, for his contributions and review of Chapter 23 on the topic of servicing as an expert witness; and to Zachary Schaff and Dominic Miller for their input to many of the chapters of this book.

My thanks also to the National Fire Protection Association, Dennis J. Berry, secretary of the Corporation and Director of Licensing. The materials used were reproduced with permission from NFPA 921-2011, *Guide for Fire and Explosion Investigations, Copyright 2010, National Fire Protection Association.*

Finally I extend my thanks to APA—the Engineered Wood Association; Asphalt Roofing Manufacturer Association (ARMA); Brick Industry Association (BIA); CertainTeed; Insurance Institute of Business and Home Safety (IBHS); National Roofing Contractors Association (NRCA); New York State Department of Health; National Oceanic Atmospheric Administration (NOAA); RCI Foundation; RISA Technologies; Spray Polyurethane Foam Alliance (SPFA); Weather Decision Technologies; and Weyerhaeuser NR Company for all of their contributions.

To all, thank you for providing the requested materials for this book. Without your contributions, this book would not have been possible.

# Editor

**Stephen E. Petty**, P.E., C.I.H., is president and owner of EES Group, Inc. (http://www.eesinc.cc), a forensic engineering and environmental health and safety (EHS) corporation. EES Group, Inc., was founded in 1996; since that time he has conducted thousands of forensic investigations and served as an expert witness in over 250 legal cases. He practices in the fields of structural, mechanical, chemical, and environmental engineering as well as the field of industrial health and safety. He is also a recognized expert in the field of heating, ventilation, and air conditioning (HVAC) and a holder of nine U.S. patents, eight of which are in the HVAC field:

| | |
|---|---|
| U.S. 6,649,062. | November 18, 2003. Fluid-Membrane Separation. Petty. |
| U.S. 6,109,339. | August 29, 2000. Heating System. Talbert, Ball, Yates, Petty, and Grimes. |
| U.S. 5,769,033. | June 23, 1998. Hot Water Storage. Petty and Jones. |
| U.S. 5,636,527. | June 10, 1997. Enhanced Fluid-Liquid Contact. Christensen and Petty. |
| U.S. 5,546,760. | August 20, 1996. Generator Package for Absorption Heat Pumps. Cook, Petty, Meacham, Christensen, and McGahey. |
| U.S. 5,533,362. | July 9, 1996. Heat Transfer Apparatus for Heat Pumps. Cook, Petty, Meacham, Christensen, and McGahey. |
| U.S. 5,339,654. | August 23, 1994. Heat Transfer Apparatus for Heat Pumps. Cook, Petty, Meacham, Christensen, and McGahey. |
| U.S. 5,067,330. | November 26, 1991. Heat Transfer Apparatus for Heat Pumps. Cook, Petty, Meacham, Christensen, and McGahey. |
| U.S. 4,972,679. | November 27, 1990. Absorption Refrigeration and Heat Pump System with Defrost. Petty and Cook. |

Mr. Petty began his working career in 1979 as a scientist for the Battelle Memorial Institute (BMI) in Richland, Washington, at the Pacific Northwest National Laboratory (PNNL), later transferring to their corporate headquarters in Columbus, Ohio, where he eventually worked as a senior research engineer on a variety of private and public research projects. In 1987, he moved to the Columbia Gas System, where he worked for approximately 10 years as a senior research engineer and section manager in the areas of residential, commercial, transportation, and fuel cell research and product development. During this time, he was nominated to, and served on, 11 industry advisory bodies—Gas Research Institute (GRI), American Gas Association (AGA), U.S. Department of Energy Funding Initiative—$2 billion (USDOE-FI), and Gas Utilization Research Forum (GURF). He also served as a U.S. DOE expert reviewer in the areas of cooling, heat pumps, desiccants, and power generation. In 1996, he formed EES Group, Inc., located in Dublin, Ohio, to serve the insurance industry in claims assessments and the legal community in litigation matters as an expert witness in the areas of insurance claims disputes and toxic tort.

He holds B.S. and M.S. degrees in chemical engineering from the University of Washington (1979 and 1982), where he graduated with honors, and an M.B.A. from the

University of Dayton (1987), where he received the Father Raymond A. Roesch Award of Excellence for Outstanding Academic Achievement in the M.B.A. program for finishing first in his class. He is a registered professional engineer in the states of Kentucky, Ohio, Pennsylvania, Texas, and West Virginia. He is also a certified industrial hygienist (CIH) from the American Board of Industrial Hygiene, an asbestos hazard evaluation specialist in Ohio, and a working member of ASHARE Standard 40—Heat Activated Heat Pumps.

He is a member of the American Industrial Hygiene Association (AIHA), an associate member of the American Conference of Governmental Industrial Hygienists (ACGIH), and a member of the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE), the American Institute of Chemical Engineers (AIChE), the Roof Consulting Institute (RCI), the Society of Automotive Engineers (SAE), and Sigma Xi.

Mr. Petty currently resides in Dublin, Ohio, with hopes of eventually spending more time at his second residence in Pompano Beach, Florida.

# *Contributors*

**George W. Fels**
EES Group, Inc.
Dublin, Ohio

**Shaun E. Gessler**
EES Group, Inc.
Dublin, Ohio

**Herbert D. Layman, B.S., S.M., C.I.E.C.**
U.S. Micro Solutions
Greensburg, Pennsylvania

**Ronald L. Lucy, R.R.O., R.R.C.**
EES Group, Inc.
Dublin, Ohio

**Stephen E. Petty, P.E., C.I.H.**
EES Group, Inc.
Dublin, Ohio

**Thomas E. Schwartz**
Holloran White & Schwartz LLP
St. Louis, Missouri

**Patrick W. Slattery, P.E.**
EES Group, Inc.
Dublin, Ohio

# Contents

# 1

# *Introduction*

**Stephen E. Petty, P.E., C.I.H.**

**CONTENTS**



**PURPOSE/OBJECTIVES:**

The purpose of this chapter is to:

- Define the term *forensic engineering* and learn why forensic engineering is needed.

- Define areas within the insurance industry where forensic engineering services are often required.
- Define a standard forensic engineering inspection protocol.
- Explain why written reports are needed along with key elements of the basic forensic report.
- Define the terms *not possible, possible, probable, likely,* and *certain.*

Following the completion of this chapter, you should be able to:

- Understand where forensic engineering services are likely to be needed, especially by the insurance industry.
- Conduct a forensic inspection using a standard protocol.
- Recognize the key components of a written forensic inspection report.
- Know and understand when and how to use the terms *possible, probable, likely,* and *certain.*

## 1.1 Definition of Forensic Engineering/Sciences

A detailed discussion of the definition of forensic engineering follows: "Forensic engineering is the application of engineering principals and methodologies to answer questions of fact. These questions of fact are usually associated with accidents, crimes, catastrophic events, degradation of property, and various types of failures. . . . Forensic engineering is the application of engineering principles, knowledge, skills, and methodologies to answer questions of fact that may have legal ramifications."[1]

Although this definition is applied to forensic engineering, it should be acknowledged that this field is not only practiced by engineers but also by other specialists involved with areas such as roofing system sciences, building envelope sciences, accident reconstruction, industrial hygiene (e.g., mold, bacteria, asbestos, and indoor air quality), and meteorology (rain, wind, snow, ice, hail, tornados, and hurricanes). Thus, the term *forensic engineering* in this book has been expanded to forensic engineering/sciences. The fundamental questions of fact to be addressed are:

- What is the failure or condition(s) of concern?
- What is the magnitude and extent of the failure(s)?
- When did it occur (if this determination is needed and desired)?
- Why did it occur?

As noted in the preface, the last question, Why did the failure(s) of concern occur?, is complex, and this causation question must often be answered at multiple levels. For example, if a high wind caused failure of the roof, the failure may be due to high winds, but may have occurred at lower than design wind speeds due to improper design or installation. This example touches on the issue of the ultimate "root cause" of the failure, which requires analysis based on detailed site inspection information and subsequent analysis and review of the literature, pertinent codes and standards, and other information such as that obtained from interviews. It is common to arrive at a topical conclusion regarding the cause of a failure (e.g., wind) that is not the root cause of failure (e.g., faulty installation). Often, whether in claims resolution discussions or in litigation, this differentiation between a topical cause and a root cause of failure is at the core of the arguments between opposing parties involved in a dispute.

What makes forensic engineering/sciences different from other fields of science is that it couples the academic fields of engineering and science with the practical fields of building/construction sciences and the trades, such as those associated with carpentry, masonry, and plumbing. Building and construction sciences consist of knowing terminology, practices, and methodologies of trades such as carpentry, heating ventilation and air conditioning (HVAC), plumbing, and wiring. Knowledge of residential and commercial codes and standards is also a must, as they bridge all these areas. New engineers and other science professionals are rarely adequately trained in the trades or codes and standards disciplines that must be learned by trained forensic investigation professionals through experience. The training of engineers and scientists in this field requires considerable training beyond academics since much of the information needed to make forensics causation opinions lies in the practical fields; areas typically not covered in colleges and universities. Interestingly, those who grew up in rural environments often have better entry-level skills in this field than those who grew up in urban environments; most likely, this is because those who live in rural environments must be creative problem solvers (i.e., cause versus effect), often with limited resources given the environment in which they live.

Regardless of experience, forensic investigators must be able to recognize when they may not have the skill set to solve a given situation and must feel comfortable to rely on other, more experienced professionals for their help. Extending into areas beyond their education, training, and experience could be problematic should their report be challenged in litigation.

## 1.2 Why Forensic Engineering/Sciences?

The reason why forensic professionals are needed is typically distilled down to the desire by one or more parties to determine why a failure or issue occurred. The desire to seek this information usually involves determining responsible parties so costs associated with the failure can be properly allocated. The two categories of parties most likely interested in employing forensic professionals to make these determinations are associated with the insurance industry and the legal community. Other parties, such as building owners, may have an interest in determining these answers, but they are generally unwilling to incur the costs or do not have the resources to employ such professionals.

Insurance companies are interested in making failure cause determinations for these primary reasons:

- Determine root cause failures and resulting responsible parties
- Determine if they have coverage of a submitted claim based on root cause failures and timing of failure

- Quantify the extent of damages
- Determine if other parties may have coverage for a submitted claim (i.e., concept of subrogation)

The interest of the legal community in using forensic professionals is typically associated with the need to:

- Determine root cause failures and resulting responsible parties
- Quantify the extent of damages
- Qualify necessary repairs
- Provide expert witness services for pending/actual litigation

The legal community typically uses this information to help determine responsible parties for damage or injured parties and to determine if claims have been appropriately addressed by insurance providers.

## 1.3 Insurance Industry Claims Statistics

This book focuses on forensic investigations typically associated with insurance industry property claims; therefore, it is helpful to briefly review what types of claims occur by topic and severity (i.e., cost of claims by type of claim).

Data on property claims are typically organized by type and severity of the claim on an annual and regional or state basis. Thus, existing data on the claims are limited by the fact that claims vary by differences in year-by-year storm histories and by geographic locations within the United States. For example, hurricane-related claims would be more prevalent in the southeastern states, tornado claims in the south central and midwestern states, and earthquake claims in the western states. With these limitations in mind, national data from the Insurance Information Institute (III)[2] are presented for claims by type and severity in Table 1.1 and illustrated graphically in Figures 1.1 and 1.2.

**TABLE 1.1**

Claim Types by Frequency and Severity (Cost)

| Type of Claim or Peril | Frequency[a] | Severity | Frequency (%) |
|---|---|---|---|
| Fire, lightning, and debris | 0.49 | $27,691 | 8.54 |
| Other, including mischief and vandalism | 1.12 | $5,481 | 19.51 |
| Theft | 0.50 | $2,805 | 8.71 |
| Water and freezing | 1.44 | $6,347 | 25.09 |
| Wind and hail | 2.19 | $6,881 | 38.15 |
| **Total** | **5.74** | | **100.00** |

*Source:* Adapted from the Insurance Information Institute, http://www.iii.org.

[a] Claims per 100 house years.

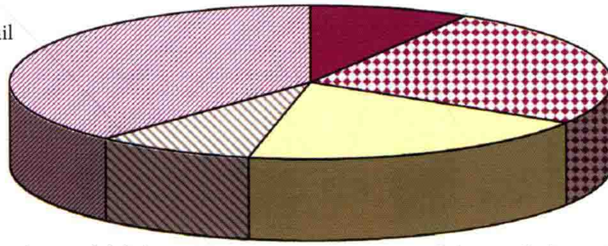


**FIGURE 1.1**
Claim frequency percentages by type of claim (2005–2009).

**TABLE 1.2**
Residential Claim Types by Frequency and Severity—Midwestern Insurance Company (6/2010 to 6/2011)

| Claim Type or Peril | Claims (#) | Claims (%) | $/Claim | $ (%) |
|---|---|---|---|---|
| Fire | 63 | 3.78 | $39,643 | 24.88 |
| Hail | 253 | 15.19 | $9,433 | 23.77 |
| Ice/snow | 176 | 10.56 | $2,914 | 5.11 |
| Mischief | 18 | 1.08 | $1,966 | 0.35 |
| Other | 32 | 1.92 | $2,135 | 0.68 |
| Sewer | 37 | 2.22 | $4,536 | 1.67 |
| Theft | 44 | 2.64 | $1,151 | 0.50 |
| Water | 480 | 28.81 | $3,539 | 16.92 |
| Wind | 527 | 31.63 | $4,688 | 24.61 |
| Vehicle | 36 | 2.16 | $4,216 | 1.51 |
| **Total** | **1,666** | **100.00** | | **100.00** |

*Source:* Adapted from the Midwestern Insurance Company.

For the five categories of property claims listed over the time interval of 2005 through 2009, the most frequent claims were for wind and hail (2.19/100 house years; 38.2%) followed by those for water and freezing (1.44/100 house years, 25.1%). However, as illustrated in Figure 1.2, the claim severity is highest, by a factor of approximately four, for fire claims (average of $27,691 per fire claim). The claim frequency can vary from year to year due primarily to differences in severe weather, as illustrated in Figure 1.3. Although the 2005 through 2009 average claim frequency was 5.73 claims per 100 house years, the rate varied over this five-year period from 4.86 to 6.84 (–15.2% to +19.4%).

Often regional or state claims data are more available for a given location since most insurance companies are authorized to provide insurance in specific states. An example of regional claims frequency and severity data for a midwestern insurance company for both residential and commercial claims is shown in Tables 1.2 and 1.3 and illustrated in Figures 1.4 through 1.7. Note that regional differences in claims will affect the needs for forensic engineers and scientists.