INTRODUCTION

Building codes are intended to safeguard the health, safety, and welfare of occupants by regulating construction as well as the building components and materials used.1

In the United States, the history of building codes dates to the earliest settlers of the first American colonies, who brought with them a number of building safety regulations from Europe. These early regulations, which are incorporated into municipal laws, addressed such issues as the spacing between houses, basic sanitation requirements, construction and maintenance of fireplaces and chimneys, and materials used in roof coverings.1

Originally, three major model code groups developed and maintained model building codes in the United States. These groups included the Building Officials and Code Administrators International, Inc. (BOCA), the International Conference of Building Officials (ICBO), and the Southern Building Code Congress International, Inc. (SBCCI).

Of these three code groups, two listed “impact resistance” in the roofing-related performance requirements of “Roof Assemblies and Rooftop Structures.” These groups were BOCA and SBCCI. This article discusses the evolution of “impact resistance” in these codes and where the code performance requirement for “impact resistance” sits today. Outlined below is a brief history of code origin and when the performance requirement for “impact resistance” first appeared in the codes.


SBCCI published its first code edition in 1940, the same year the organization was established.2 Its first mention of the “impact resistance” requirement appeared in the 1999 edition.

Established in 1994 to develop and maintain a single set of national building-related model codes,3 ICC published its first edition in 2000. ICC’s codes replaced the model codes of BOCA, ICBO, and SBCCI, now referred to as “Legacy Codes.”2 Subsequent editions of these legacy codes were not released. The last editions were 1997, 1999, and 1999, respectively.

ICC’s first edition in 2000 contained 35 chapters, with Chapter 15, “Roof Assemblies and Rooftop Structures,” containing ten Section Titles (Figure 1). Section Title 1504 – Performance Requirements provides specific performance requirements for all roof assemblies, including requirements for physical properties as well as impact and wind resistances. The “impact resistance” requirement mirrored that of BOCA and SBCCI and reads as follows in the 2000 edition:

• Roof coverings installed on low-slope

| SECTION TITLES FROM IBC’S CHAPTER 15, “Roof Assemblies and Rooftop Structures” |
|-----------------------------|-----------------------------|
| SECTION 1501 | General |
| SECTION 1502 | Definitions |
| SECTION 1503 | Weather Protection |
| SECTION 1504 | Performance Requirements |
| SECTION 1505 | Fire Classification |
| SECTION 1506 | Materials |
| SECTION 1507 | Requirements for Roof Coverings |
| SECTION 1508 | Roof Insulation |
| SECTION 1509 | Rooftop Structures |
| SECTION 1510 | Reroofing |

Figure 1 — Section titles from the International Building Code’s Chapter 15, “Roof Assemblies and Rooftop Structures.”
Figure 2 — Guide tube, test table, and centering jig.

roofs (roof slope < 2:12) in accordance with Section 1507 shall resist impact damage based on the results of tests conducted in accordance with ASTM D 3746, ASTM D 4272, CGSB 37-GP-52M, or FM 4470.

Each of the groups listed the same four test methods, shown below, for impact resistance. The ICC 2000 and the SBCCI codes limited the requirement to low-slope roofs (roof slope < 2:12). There were no slope requirements given in the BOCA code.

**Standard Test Methods**

- FM 4470, “Test Standard for Class 1 Roof Coverings”

Brief descriptions of the test standards are as follows:

- **“Standard”**
  
  ASTM first published this standard in 1985, reapproved it in 1996, and again in 2002. The late Carl Cash chaired the committee and oversaw development of the standard. This test method subjects field and laboratory specimens of bituminous roofing systems to a series of four impacts in each quadrant of a 12 in x 12 in sample. A steel missile guided through a tube from a predetermined height impacts each sample with impact energy of 22 ft-lb (Figure 2). The test procedure allows for testing at different temperatures to study that effect on impact resistance. Following impact, the samples are desaturated and the mats examined for damage. A rating is given to the membrane’s impact damage, if any.

- **“Standard Elastomeric”**
  
  This Canadian standard was first published in October 1982 and applies to sheet-applied elastomeric membranes for use in roofing and waterproofing. Among others, the standard addresses requirements for thickness, tensile strength, breaking strength, elongation, and water absorption and weather resistance. The standard states “the membrane shall withstand impact energy of 1.8 ft-lb (2.45 Joule) without indentation to the extent that the membrane will not fail the watertightness test” listed therein.

  The test procedure uses a dynamic puncture device or a Gardner Heavy-Duty Variable Impact Tester (Type PF-1120) with modifications shown in Figure 4. The manufacturer changed the part number from IG-1120 listed in the standard to PF-1120. Three tests are carried out on each sample, with the results rated in accordance with the Puncture Rating Table.

- **“Standard Drop”**
  
  First published in 1983, reapproved in 1999, and again in 2003, this test method describes the determination of the total energy impact of plastic films by measuring the kinetic energy lost by a free-falling dart that passes through the film.

  The recommended size of the sample is 6 in x 6 in for a single determination. Specimens are taken from new material only. The test uses the free-falling dart of ASTM D 1709, Test Method A (Figure 3). Depending on the dart weight selected, the impact energies vary from 1.1 to 5.4 ft-lb. Each sample is impacted five times in different places. The energy to rupture a film sample is based on an average of five energy values for the test specimen.

  The standard states, “Evaluation of the impact toughness of film is important in predicting the performance of a material in applications such as packaging, construction, and other uses.” The author questions the applicability of this standard for impact resistance of most roof coverings.

Figure 3 — Free-falling dart.

The FM 4470 Test Standard for Class 1 Roof Coverings was first introduced in April of 1986. A part of this test procedure, “Susceptibility to Hail Damage – Moderate Hail (MH),” was designed to assess the potential for damage to roof covers when they are applied on various roof insulations, lightweight concrete roof decks, gypsum decks, or fire-retardant-treated wood roof decks. It was developed to determine the potential for puncture from hailstorms when a cover is applied over its tested substrate within a Class 1 assembly.

The MH test apparatus, Figure 5, consists of a tube in which a steel ball drops
from a predetermined height, dependent on the rating required. The current FM 4470 standard offers two hail ratings, Class 1-SH (Severe Hail) and Class 1-MH (Moderate Hail). The procedure tests both new and artificially aged materials (1,000 hours following ASTM G53).

The procedure drops a steel ball ten times on various sections of a sample. The impact energy for the SH determination is 14 ft·lb (19 Joule), and the MH determination impact energy is 8 ft·lb (10.8 Joule). Testing is performed at room temperature.

Another part of this FM 4470 standard is the “Foot Traffic Test.” This test procedure is designed to assess the potential for damage to roof covers at corners of insulation. The test apparatus consists of a square plate with weights added. This is a static load test, whereas the “Hail Resistance Test” is a dynamic test.

This test method was part of the original FM 4470 in 1986, as was the Moderate Hail (MH) test method. The Severe Hail (SH) test method was later added by a 1987 supplement. BOCA published its first impact-resistance performance requirement in 1990; therefore, the “Susceptibility to Hail Damage” test procedures were available, as was the Foot Traffic test method. Table 1, featuring the “Test Method Comparison,” lists only those “dynamic impact” test procedures available to BOCA when it first listed the impact-resistance requirement in 1990.

The code requirement for impact resis-
### TEST METHOD COMPARISON

<table>
<thead>
<tr>
<th>ASTM D 3746</th>
<th>(mm)</th>
<th>Hemispherical</th>
<th>Weighted Steel Dart</th>
<th>kg</th>
<th>cm</th>
<th>Joule</th>
<th>#</th>
<th>°C</th>
<th>Visual and after extraction; numerous ratings.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0 (50.8)</td>
<td></td>
<td></td>
<td></td>
<td>5.0</td>
<td>4.42</td>
<td>22.0</td>
<td>4</td>
<td>Optional</td>
<td>Optional</td>
</tr>
<tr>
<td>ASTM D 4272</td>
<td>1.5</td>
<td>Hemispherical</td>
<td>Stainless Steel</td>
<td>0.5-2.5</td>
<td>2.17</td>
<td>1.1-5.4</td>
<td>5 per specimen None</td>
<td>73.4 (23)</td>
<td>40 min.</td>
</tr>
<tr>
<td>CGSB37-GP-52M</td>
<td>0.44</td>
<td>Round &amp; flat, polished to 1 cm² Steel Rod</td>
<td>2.2</td>
<td>0.82</td>
<td>1.8</td>
<td>3</td>
<td></td>
<td>Rubber Stopper</td>
<td>73+7 (23+10)</td>
</tr>
<tr>
<td>FM 4470 Class 1-MH</td>
<td>2.0</td>
<td>Spherical</td>
<td>Steel Ball</td>
<td>1.63</td>
<td>5.0</td>
<td>8.0</td>
<td>10</td>
<td>Optional</td>
<td>Room Temperature</td>
</tr>
<tr>
<td>FM 4470 Class 1-SH</td>
<td>1.75</td>
<td>Spherical</td>
<td>Steel Ball</td>
<td>0.79</td>
<td>17.79</td>
<td>14.0</td>
<td>10</td>
<td>Optional</td>
<td>Room Temperature</td>
</tr>
</tbody>
</table>

**Table 1**

Distance provides a choice between test methods. As summarized in Table 1, the inequality of the test methods is clear as stated in earlier research by the author. The inequalities exist within impact energies, test temperatures, sample age, and damage evaluation methods as discussed below.

**Impact Energies**

Each of the methods use hemispherical, spherical, or flat-head-shaped steel projectiles of various diameters. The projectiles are dropped from predetermined heights, producing an impact energy, which can be compared to the impact energy produced by different diameters of hail.

Depending on the test method, the impact energy varies from 1.8 ft·lb to 22 ft·lb. With this wide range, one can determine the ineffectiveness of the impact resistance requirement of the IBC and the Legacy (BOCA and SBCCI) codes.

Prior research by Crenshaw and Koontz indicates roof coverings such as slate, concrete tile, or clay tile are fairly hail-resistant when impacted with ice spheres. When impacting these same materials with steel projectiles as outlined in the code, failure ratings are produced at low-impact energy levels.

**Test Temperature**

Another variable that can affect test results is test temperature. A review of the test methods indicates two of the four test methods, ASTM D4272 and FM4470, are performed at room temperature. Crenshaw and Koontz’s prior simulated hail research indicated some roof covering materials, such as tempered, aged thermoplastics, are temperature-sensitive.

Recall that Nick Lavato’s article, presented at the RCI 19th International Convention and Trade Show, focused on a case study of the replacement of an eight-year-old hail-damaged thermoplastic roof at the Denver International Airport as a result of a moderate hailstorm that occurred in June 2001.

It is a well-known fact that most thermoplastics are temperature-sensitive when it comes to impact; however, with some materials, such as composition shingles and modified roof materials, impact resistances can actually increase as test temperatures decrease.

**Aging**

Two of the four test methods also test artificially aged materials or materials from the field in addition to new roof coverings and material. FM 4470 tests new roof coverings and similar materials that have aged for 1,000 hours using ASTM G53. The late Carl Cash also recognized the importance of exposure with the inclusion of testing specimens from actual roofs in ASTM D3746. A paragraph from this standard reads as follows:

> Test specimens may be taken directly from an actual roof or cut from a laboratory-prepared sample using a 305 by 305-mm (12 by 12-in.) metal template as described in Practice D2829 and shall include all of the aggregate and insulation in the area of the specimen.

Great minds thought alike, with the late William Cullen noting the importance of testing aged materials in 1992, stating, “The results of testing new materials may not be valid since the hail-impact resistance of many roofing materials changes upon exposure to weather.”
Damage Evaluation

The damage evaluation methods used by the four test methods vary. ASTM D3746 requires separation and desaturation of the plies of bituminous roof systems. The standard for plastic films, ASTM D4272, requires visual examination to determine the type of failure. The examples given were holes, tears, shatter, etc. The Canadian standard, CGSB 37-GP-52M, outlines a visual examination and a water-tightness test (if required). The FMRC standard does not require separation, with a visual examination of top and bottom surfaces considered sufficient. Damage to interply, felts, or reinforcements may not be visible without separation and desaturation.

Discussion

Interestingly enough, the wording of the impact-resistance requirement of the IBC 2006 edition changed. It now reads as follows:

“Roof coverings installed on low-slope roofs (roof slope < 2:12) in accordance with Section 1507 shall resist impact damage based on the results of tests conducted in accordance with ASTM D3746, ASTM D4272, CGSB 37-GP-52M, or the ‘Resistance to Foot Traffic Test’ in Section 5.5 of FM 4470.”

The revision left the three previous test methods – ASTM D3746, ASTM D4272, and CGSB 37-GP-52M – the same and expounded on FM 4470 by inserting the “Resistance to Foot Traffic Test” in Section 5.5 of FM 4470.12 Recall that earlier code versions listed only FM 4470 and did not state a specific test procedure of the standard.

Investigating the reason for this change with the ICC, excerpts from proponent Robert J. Willis, PE, American Iron & Steel Institute, stated, “Currently, the IBC is not specific [about] which of these tests are intended by this section, leaving the selection of which test is appropriate up to the code user.” 13 Later, Willis states, “In summary, this proposal would clarify that the Foot Traffic test is appropriate to demonstrate the durability criteria that were intended by the code and not the hail damage test criteria.” The author disagrees with this, since BOCA published the impact-resistance test methods when FM 4470 contained the “Susceptibility to Hail Damage” Moderate and Severe Hail Test Standard for Class 1 Roof Covers, both dynamic impact tests, as well as the “Resistance to Foot Traffic Test,” a static load-type test. The other three test methods listed – ASTM D3746, ASTM D4272, and CGSB 37-GP-52M – are dynamic impact tests as well.

Table 2 documents differences in the IBC 2006 edition’s impact-resistance performance requirements.

The most recent editions of IBC 2003 and 2006 still list the same four test standards that appeared in the ICC’s first 2000 edition, which mirrored that of BOCA and SBCCI. The Canadian General Standards Board Web site shows the cancellation of CGS 37-GP-52M as of January 2005.14 This eliminates one of the four test methods listed in the 2006 IBC edition available for impact resistance, and it also eliminates the FM hail tests by specifically noting the “Foot Traffic Test” of FM 4470.

As the impact-resistance code requirement now stands, bituminous roof membranes are the only roof types subject to impact loads of 22 ft-lb under ASTM D3746, while nonbituminous roof system types fall to FM’s “Foot Traffic Test.”

### 2006 TEST METHOD COMPARISON

<table>
<thead>
<tr>
<th>Test Method</th>
<th>(mm)</th>
<th>(kg)</th>
<th>(cm)</th>
<th>(Joule)</th>
<th>#</th>
<th>(°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTM D3746</td>
<td>2.0</td>
<td>5.0</td>
<td>4.42</td>
<td>22.0</td>
<td>4</td>
<td>Optional</td>
</tr>
<tr>
<td></td>
<td>(50.8)</td>
<td>(2.27)</td>
<td>(135.0)</td>
<td>(30.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM D4272</td>
<td>1.5</td>
<td>0.5-2.5</td>
<td>2.17</td>
<td>1.1-5.4</td>
<td>5 per specimen</td>
<td>Optional</td>
</tr>
<tr>
<td></td>
<td>(38.1)</td>
<td>(0.23-1.13)</td>
<td>(66.0)</td>
<td>(1.49-7.32)</td>
<td></td>
<td>8 min.</td>
</tr>
<tr>
<td>CGSB 37-GP-52M</td>
<td>0.44</td>
<td>2.2</td>
<td>0.82</td>
<td>1.8</td>
<td>3</td>
<td>Rubber Stopper</td>
</tr>
<tr>
<td></td>
<td>(11.3)</td>
<td>(0.00)</td>
<td>(25.0)</td>
<td>(24.5)</td>
<td></td>
<td>73.4 (23)</td>
</tr>
<tr>
<td>FM 4470 Class 1-FT</td>
<td>3.0</td>
<td>200</td>
<td>-</td>
<td>5</td>
<td></td>
<td>Insulation Board</td>
</tr>
<tr>
<td></td>
<td>(76)</td>
<td>(90.7)</td>
<td>-</td>
<td></td>
<td></td>
<td>Unspecified</td>
</tr>
</tbody>
</table>

Table 2
How is that possible when the code lists four test standards? With the 2005 withdrawal of CGSB 37-GP-52M, ASTM D4272 for film type materials only, the elimination of FM 4470 Hail Resistance tests, and the Foot Traffic test specifically called out, only these two test methods are left. Are results obtained from the two remaining test methods comparable? Koontz authored “A Comparative Study of Dynamic Impact and Static Loading of One-Ply Roofing Assemblies,” which studied common test methods utilized by various organizations, including ASTM, CGSB, and others. This is an area that merits further study.

Hail is a common occurrence “impacting” roofs. Current hail research reviewed by this author typically utilizes test procedures featuring ice, steel, or polyamide balls. Most researchers employing the ice-ball method use either an air cannon or a slingshot apparatus for ice-ball delivery (Figure 6). Figure 7 depicts molds for the ice balls. FM subjects manufacturers’ systems to steel balls for hail ratings. Recall that Peter Flueler presented his hail research on inflatable structures utilizing polyamide balls at RCI’s 2006 Convention.

Roofing failures related to wind damage or collapse center litigiously around codes and whether the roof system met the minimum requirements outlined in the code regarding uplift resistance or drainage. One would believe the intent of the code is to set minimum performance criteria for wind, drainage, and impact. Impact, however, receives little recognition as a challenged performance characteristic.
The impact provisions of the current codes are plainly in need of reform. The ICC should clearly define a test procedure for impact resistance applicable to all roof coverings, taking into consideration the effects of temperature, aging, and examination methods.

References
13. ICC Public Hearing, FS144-03/04,


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Vickie A Crenshaw, PE, RRC, RRO, is president of Crenshaw Consulting Group, LP, a roof consulting firm with offices in Albuquerque, Hobbs, and Las Cruces, NM, as well as Amarillo, TX. She is a registered professional engineer in Texas and a member of the National Roofing Contractors Association, RICOWI, RCI, and SPRI. She earned a bachelor’s degree from Northern Arizona University. Crenshaw’s company will celebrate its fifth anniversary in 2008 with 24 employees in four locations.