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Forensic Engineering Data Collection For Stairway Incidents

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Key Word List

Forensic Engineering, Stairway, Stairs, Steps, Handrail, Tread, Riser, Trip, Fall, Uniformity, Height, Depth, Slope

Introduction

Forensic Engineers are often called upon to investigate injury events on stairs. A significant number of injuries and deaths occur on stairways. With a background in design, construction, and building codes, forensic engineers can identify the appropriate Codes with which the stairs might be required to comply, can determine whether deficiencies exist and to what extent, and whether deficiencies are related to the design or the construction of the facility. Data collection on stairways can be difficult and tedious. Measurements of tread depths and riser heights must be measured with precision to compare with allowable tolerances.

This paper presents various means of collecting data related to stairways, including documentation of tread depth, riser height, tread slope, nosing, handrails, and headroom clearances. The paper will also introduce a device that was developed and validated by the authors for measuring treads and risers. This paper focuses only on data collection methodologies, and does not present analyses or render opinions with regard to Building Code requirements. The Building Code requirements that are presented herein are only for the purpose of illustrating typical Code requirements, to illustrate why various data must be collected, and to review proper methods of data collection.

Review of Typical Building Code Requirements

Tread is defined as the flat surface of a step within a stairway that constitutes the stepping surface. A riser is the vertical surface (which can be either open or closed) between adjacent treads as shown in Figure 1. The landing is the flat area at the top or bottom of a stairway. The nosing is the area at the front of the tread where it meets the riser. Typical requirements for tread dimensions and uniformity for one and two-family dwellings are as presented below. Other applications may have different requirements, and these requirements may vary among different Codes:

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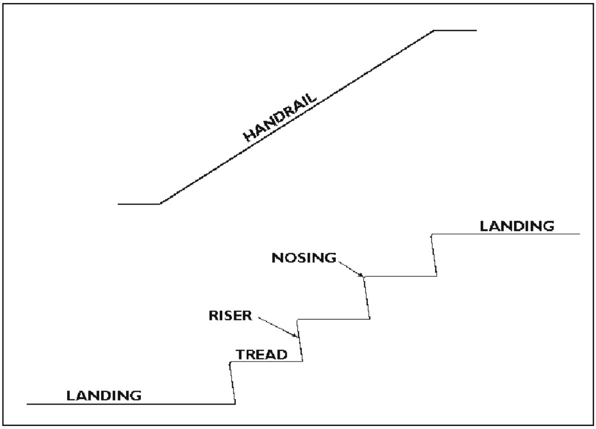

Figure 1
Stairway Diagram.

- Treads, exclusive of nosing, shall not be less than 9 inches wide.
- Every tread less than 10 inches wide shall have a nosing approximately 1 inch over the level immediately below.
- Tread depth shall be measured horizontally between the vertical planes of the foremost projection of adjacent treads and at a right angle to the tread's leading edge.
- Treads shall be of uniform depth.
- There shall be no variation exceeding 3/16 inch in depth of adjacent treads.
- The tolerance between the largest and smallest tread shall not exceed 3/8 inch in any flight.

Typical requirements for riser dimensions and uniformity for one and two-family dwellings are presented below. Other applications may have different requirements, and these requirements may vary among different Codes:

- The height of riser shall not exceed 7¾ inches.
- Risers shall be of uniform height.
- There shall be no variation exceeding 3/16 inch in height of adjacent risers.
- The tolerance between the largest and smallest riser shall not exceed 3/8 inch in any flight.
- Treads shall be so proportioned that the sum of two risers and a tread, exclusive of projection of nosing, is not less than 24 inches nor more than 25 inches.

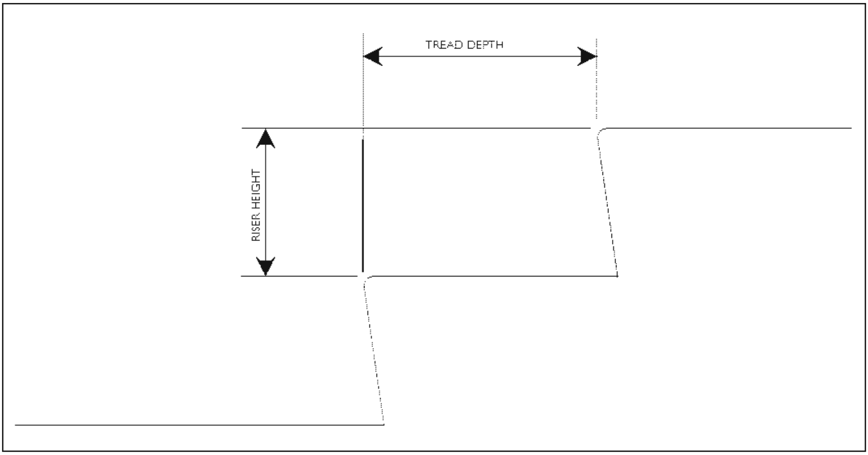

Figure 2
Tread and Riser Measurements.

With regard to measurement of treads and risers, some Codes provide the following instruction:

- Riser height shall be measured as the vertical distance between tread nosings.
- Tread depth shall be measured horizontally between the vertical planes of the foremost projection of adjacent treads and at a right angle to the tread's leading edge, but shall not include beveled or rounded tread surfaces that slope more than 20 degrees.
- At tread nosings, such beveling or rounding shall not exceed ½ inch in horizontal dimension.

The proper means of measuring treads and risers as described above is illustrated in Figure 2. The uniformity requirements highlight the importance of taking precise measurements when investigating stairway incidents. The dimensional requirements highlight the importance of taking measurements and documenting data related to treads, risers, and nosings in a proper manner. Simply put, the measurement of critical stairway dimensions involves more than simply placing a tape measure on a tread or against a riser.

Measurement of Treads and Risers

As described above, and as illustrated in Figure 2, tread depth is measured as the horizontal distance from the front of one tread to the front of the next tread, and may require an adjustment to adjust for rounded or beveled nosings, depending on the applicable Code requirements. Riser height is measured as the difference in height at the front of adjacent treads. Traditionally, forensic engineers have used two levels to take proper and precise measurements of tread depths and riser heights as shown in Figure 3. However, this method is rather cumbersome, and may require two people to take proper measurements and notes.

Figure 3
Measuring riser height with two levels.

As a result of the cumbersome nature of taking these measurements, the authors have developed and constructed a device which facilitates the taking of precise and proper measurements of treads and risers. An example of this tread and riser measuring device is shown in Figure 4. The device is constructed of the following components:

- Combination Square (2)
- 16" Sliding Ruler with 1/16" or smaller divisions
- Level Bubbles
- Bolts and Spacers
- 90-Degree End Bracket (2)
- 90-Degree Index Brackets
- JB Weld or Other Epoxy-Type Adhesive

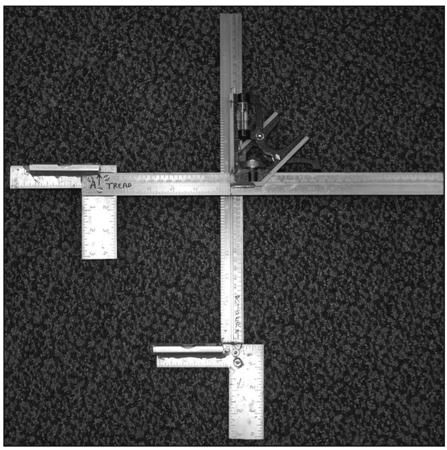

Figure 4
Stairway Tread and Riser Measuring Device.

The device is constructed by welding the bodies of the two combination squares together precisely at right angles as shown in Figure 5.

Each of the bodies of the combination squares should be equipped with a bubble level. The proper assembly of the two combination square bodies is the single most important part of the assembly. Once it is properly welded together, bolts should be installed at the locations indicated in Figure 5, with spacers between the bodies of the combination squares. This will help to hold the pieces together without putting unnecessary stress on the welded joints. The 90-degree index brackets should be welded to the device as shown. These will be used to

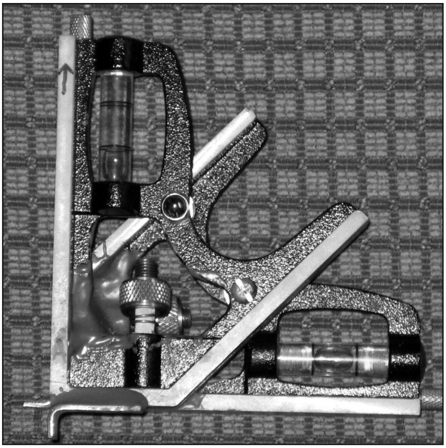

Figure 5
Welded Bodies of Two Combination Squares to Form Base of Tread and Riser Measuring Device.

mark the points where the ruler is to be read.

Next, a 90-Degree end bracket should be attached to the end of each sliding ruler as shown in Figure 6. A carpenter's square can be cut and used for the end bracket. This is useful as the carpenter's square will have ruler markings on it. One face of the end bracket should line up precisely with the end of the ruler. The other face of the end bracket needs to line up with the index bracket when the ruler is attached to the body of the device. The bracket should be both welded and bolted to the ruler. Line level bubbles should be attached to the end brackets at the locations indicated in Figure 6. The end brackets should be attached so that the faces of the bracket are precisely perpendicular or parallel with the ruler. The line level bubbles must be installed parallel with the top of the bracket.

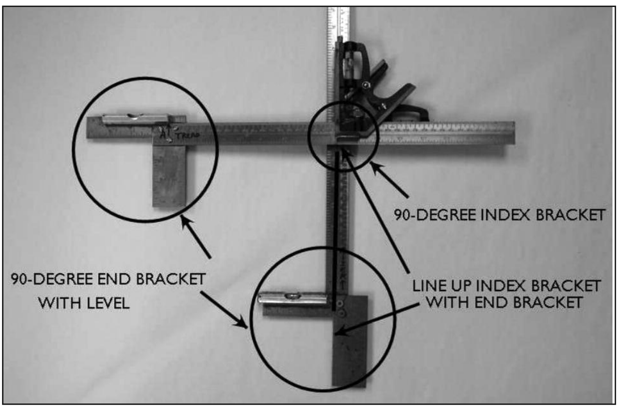

Figure 6
Construction of Tread and Riser Measuring Device.

Once the body and the rulers are properly assembled, the rulers can be attached to the combination squares that make up the body of the device. Once the device is constructed and assembled, the engineer should document the separation distance between the rulers. To use the device, two parallel chalk lines should be placed on the nose of each tread, separated by the same separation distance that is documented between the rulers. The screws that hold the rulers in place on the body of the device should be loosened. The end brackets are placed on the nose of adjacent treads on the chalk lines as shown in Figure 7. The rulers are then adjusted on the body of the device by sliding them in or out, maintaining the bracket snug against the nosing of the tread. Continue adjusting the device until the body of the device is level, and each end bracket is level, with the brackets still snug against the nosing of the adjacent treads. The screws are then tightened to secure the rulers within the body of the device. After the device is locked by tightening the screws, tread and riser measurements can then be taken by reading each ruler at the index bracket. The authors have constructed their device so that the reading is taken from the front face of the index bracket. The process is then repeated for the next tread and riser.

Figure 7
Proper use of Tread and Riser Measuring Device.

Figure 8
Application of Contour Gauge to Document Tread Nosing.

The authors have validated the measurements taken with the tread and riser measuring device by comparing their measurements with other methods, and by demonstrating that their measurements can be repeated. Treads and risers were measured repeatedly using two levels and using the tread and riser measuring device. In no case did the repeated measurements with the device differ from trial to trial by more than 1/16 inch. This variation was corrected by recording measurements to the nearest 1/32 inch when the measurement fell between the 1/16 inch divisions on the ruler. Each individual Tread and Riser Measuring Device should be independently validated for accuracy by the engineer that will use the device. Documentation of the validation tests should be preserved in the engineer's files in the event that it is required to support the engineering analysis and opinions.

Figure 9
Transfer of Tread Nosing Configuration from Contour Gauge to Paper.

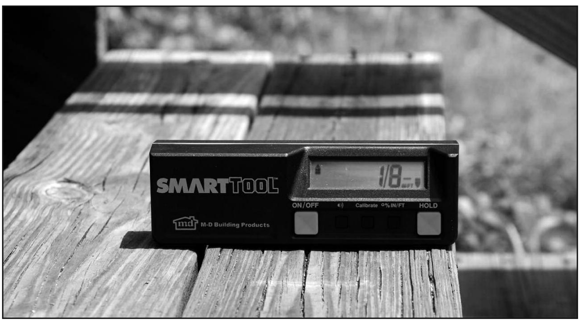

Figure 10
Application of SMART TOOL to Determine Tread Slope.

Adjustments for Nosing

As indicated, some Codes may require an adjustment to the tread depth based on the geometry of the nosing at the front of the tread. Some Codes require that “tread measurements shall not include beveled or rounded tread surfaces that slope more than 20 degrees.” Others have the requirement that “at tread nosings, such beveling or rounding shall not exceed ½ inch in horizontal dimension.” Therefore proper documentation of the nosing of each tread is critical to the proper reporting of the tread depth.

To document the geometry of the nosing of the tread, a Contour Gauge can be used. A typical Contour Gauge is shown in Figure 8. The Contour Gauge is made up of a series of pins held tightly together with a central binding. The pins of the Contour Gauge can be pressed against the nosing of the tread. As force is applied to the Contour Gauge, the pins slide within the central binder, allowing the pins to conform to the shape of the tread nosing surface as shown in Figure 8. Once the Gauge has been applied to the tread nosing surface, the pins within the Gauge can be traced onto a sheet of paper to create an actual size replica of the shape of the nosing as shown in Figure 9. This tracing can then be analyzed in the office to determine what portion of the nosing slopes more than 20 degrees, to determine whether the rounding exceeds ½ inch, or any other criteria that may be required by the applicable Code. Once this analysis has been performed, appropriate adjustments may be made to the recorded tread depth dimensions.

Tread Slope

Tread slope is addressed by some Codes. For example, one Code states that "Tread slope shall not exceed 1/4 inch per foot (a slope of 1 in 48). The authors recommend recording tread slope both parallel to and perpendicular to the direction of travel. Tread slope can be measured with a SMART TOOL which measures the slope of the surface and reports it on an LCD display as shown in Figure 10. This tool reports slope in degrees, percent, or in inches per foot. The engineer may select which unit is most appropriate for recording the slope of the treads.

Handrails

Handrail geometry and height requirements vary greatly among various Codes, and among various editions of those Codes. Typically, however, the Codes suggest that handrail height be measured vertically from the front of the tread. The engineer will also need to record the cross-sectional shape of the handrail and its distance from adjacent walls. There are strength requirements for handrails which include criteria for point loads and uniform loads. The engineer may elect to test the handrail for compliance with these Code requirements. However, retaining counsel should be consulted prior to such testing as testing of non-compliant handrails might fall into the realm of destructive testing if application of minimum loads cause the handrail to fail.

Overhead Clearance

The overhead clearance should be measured and documented by the engineer whenever possible. Overhead clearance is typically measured vertically from a straight line connecting the nosing of each tread. Proper measurement may be done by measuring vertically from the front of the treads.

Other Measurements and Documentation

Other measurements that might be considered by the investigating forensic engineer are the dimensions of the landings, width of the stairway, and lighting levels. Landings, the level areas at the top or bottom of stairways, or between stairways, typically have requirements for width, depth and slope. There are typical requirements for stairway width based on anticipated use and occupant load. The Code will typically address how to consider projections into the width of the stairway such as handrails. Codes may also address illumination levels, and may indicate whether the lighting levels are to be measured at the treads, or at some height above the treads.

Conclusions

Stairway documentation related to the analysis of injury events is an awkward, tedious and time-consuming process. An understanding of the applicable Codes is required to determine the proper manner in which stairway measurements must be made. The tools and techniques presented herein will assist the forensic engineer in taking proper and accurate stairway measurements.

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