CALCULATING FIRE-RESISTANCE RATINGS OF CONCRETE MASONRY UNIT (CMU)
WALLS

By

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Abstract

This paper serves as a statement accompanying a capstone project for a degree in Information: Science and Technology. It details the work that went into creating the web page dedicated to helping specifications and codes writers to calculate fire-resistance ratings of concrete masonry unit (CMU) walls. It briefly examines what a CMU wall is and the calculations that are involved in calculating fire-resistance ratings. The paper delves into how the site itself works, what the user can expect to see when first accessing the page and how to follow the steps in order to get the correct output. Without getting too technical, the paper also describes the four programming languages that were involved with coding the web page and what they handle in accordance with the page's design and implementation. Finally, the paper concludes with an appendix containing the URL that will lead the reader to the web calculator and provides some practice problems that will allow the reader to test the calculator's abilities.

The purpose of this honors thesis and capstone project was to create a webpage dedicated to helping architects who specialize in applying building codes and specifications to calculate fire-resistance ratings of concrete masonry unit walls. The project was completed over two semesters, the spring and summer semesters of the 2016 school year, and will be live following the completion of the thesis. This accompanying statement regarding the project will detail the process I took in designing and implementing the web calculator as well as describe what exactly a concrete masonry unit wall is, how fire-resistance ratings are calculated, and why it is a topic important enough to merit an online calculator created for it. The URL for the page along with some practice calculations for testing purposes can be found in Appendix 1.

Calculating the fire-resistance of concrete masonry unit (CMU) walls is different than determining the fire-resistance of other walls that are based on testing constructed assemblies within a laboratory. Walls subjected to laboratory fire-resistance testing per the ASTM E 119, the "nationally recognized standard used to conduct tests in the United States...used to generate data to measure the integrity of building assemblies subjected to fire exposure"[1], or UL 263, the "standard for fire tests of building construction and materials"[2], are typically assemblies constructed of various materials such as metal or wood studs with single or multiple layers of gypsum board in various thicknesses and insulation. Unlike these assemblies, CMU walls consist primarily of a homogeneous material consisting of cement, aggregate,

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[1] Berhinig, Robert. "Protecting the Foundation of Fire-safety ‹ IAEI Magazine." *IAEI Magazine*. N.p., n.d. Web. 05 Aug. 2016.

[2] "Standard for Fire Tests of Building Construction and Materials." *Standard 263*. N.p., n.d. Web. 05 Aug. 2016.

and water; therefore, the fire-resistance performance of CMU alone is fairly predictable and does not require testing to determine the fire rating. Fire-resistance ratings of CMU walls are dependent on variables, such as the shape and size of the unit and the type of aggregate or aggregates used in the construction of the walls. The thicker the block material is, the higher the fire-resistance rating. Denser aggregates have low resistance to radiant heat transfer while lighter aggregates have high resistance.

Using the criteria provided in the *International Building Code* (IBC), one could determine the fire-resistance rating for a given CMU wall if the dimensions of the block and the type of aggregate (or types of aggregates and their proportions) are provided. Since most CMU are not solid, the voids or "cells," as they are called, add little to the fire-resistance performance of CMU wall; thus, the block must be considered as if the cells were nonexistent. For example, a nominal 8-inch-deep (7-5/8 inches actual depth) CMU does not provide 8 inches of material for resistance; therefore, it must be converted to an "equivalent thickness." The fire-resistance rating of a solid CMU of a given thickness with a single aggregate type is fairly easy to determine using IBC Table 722.3.2, as shown in Table 1 below. For example, a solid 4-inch nominal (3-5/8 inches actual--3.635 inches decimal) CMU with cinder aggregate would have 1-3/4 hour fire-resistance rating.

TYPE OF AGGREGATE	FIRE-RESISTANCE RATING (hours)														
	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4
Pumice or expanded slag	1.5	1.9	2.1	2.5	2.7	3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.5	4.7
Expanded shale, clay or slate	1.8	2.2	2.6	2.9	3.3	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	4.9	5.1
Limestone, cinders or unexpanded slag	1.9	2.3	2.7	3.1	3.4	3.7	4.0	4.3	4.5	4.8	5.0	5.2	5.5	5.7	5.9
Calcareous or siliceous gravel	2.0	2.4	2.8	3.2	3.6	3.9	4.2	4.5	4.8	5.0	5.3	5.5	5.8	6.0	6.2

Table 1. **International Building Code (IBC) Table 722.3.2**

To determine the equivalent thickness of a hollow CMU with cells, then the equivalent thickness will need to be calculated using the following equation:

$$T_e = \frac{V_n}{(L * H)}$$

where T_e is the equivalent thickness (in inches), V_n is the net volume of the CMU (in cubic inches), L is the length of the unit (in inches), and H is the height of the unit (in inches). If a CMU has blended aggregates, then the fire-resistance rating would be based on the percentages of aggregates used per the following equation:

$$T_r = (T_1 * V_1) + (T_2 * V_2) + (T_3 * V_3) + (T_4 * V_4)$$

where T_r is the total thickness required (in inches), T_1, T_2, T_3, and T_4 are the equivalent thicknesses required for the given aggregates and fire-resistance ratings (in inches), and V_1, V_2, V_3, and V_4 are the proportions for each aggregate type (given in decimal percentages, which must have a sum equal to 1).

This project started as a mere console driven calculation for my father, the architect responsible for inspiring and providing the knowledge of CMU walls necessary to complete the calculator. However, as I expanded the idea and transformed it into what would become my thesis and capstone project, the simple calculations done in Java and executed via the console became a four language web page that would be freely accessible from a link on my father's own architecture

company website (the link will be provided in the appendix).

Upon first accessing the page, the user will see step-by-step instructions that will guide him or her through the process of completing the fire-resistance rating calculation. The first step is to enter the dimensions of the brick – the length, height, and depth, all in inches – into the provided text boxes. Step two is where the user chooses the aggregates present in the CMU. There can be up to four different aggregates present in the CMU, so provided are four drop down menus from which the user can choose. After the user chooses the aggregate types, a small text box will appear to the right allowing the user to input the percentage of the aggregate present in the CMU. All percentages should add up to 100, therefore if the user enters in values that add up to more than 100, an alert box will prompt him or her to re-enter the values. Otherwise, an alert will pop up once a percentage of 100 is reached, prompting the user to check and make sure his or her percentages are correct and that he or she should continue with the calculation once checked.

After finishing inputting the aggregates, step three asks the user to choose an equivalent thickness method from one of the hover over dropdown menus to the right side of the page. Three choices are available – weight/density, measurement, and manufacturer-provided data – and when an option is clicked, the appropriate text boxes will appear, prompting the user to input more information about the block. Step four, similarly to step three, asks the user to choose an option from a hover dropdown menu to the right, but this time the user will be choosing the grouting method. The grouting method chosen will appear under the step 4 instructions, however there is no new information for the user to input.

At this point the user has provided all necessary information for the calculation to be completed and may hit the "submit" button. When the submit button is hit, the calculations will be completed and the output will be displayed. At the same time, the image of the block will be updated with the height, length, and depth values input by the user in step one. If the user would like to complete another calculation, a "New Calculation" button appears underneath the new output and will reset the page to its original state where the user can start anew.

The web page itself is a written combination of Hypertext Markup Language (HTML), Cascading Style Sheet (CSS), JavaScript, and PHP, working together to perform the necessary calculations and provide the necessary output. The base of the site is written in HTML, giving the page its structure, while most of the page's styling is handled by the CSS. The JavaScript controls the click events, for example, which Equivalent Thickness method or Grouting method is present on the screen based on which choice the user selects. Finally, the PHP takes the information provided by the user (height, length, depth, aggregate types, percentages, etc.), performs the calculations, then echoes (prints) the solutions.

Given that I had very little to no experience with any of the languages necessary to create this page, I was hesitant to begin. I feared I would not be able to complete the project in time or the resulting page would be less than satisfactory in the end. I began following what was being taught in my concurring Web Development course offered through the Department of Computer Science – thus I started with the HTML base of the site. I divided the site into the head and body; the head holds the title of the page and provides access to the associated CSS and

JavaScript documents and the body holds the headers, my personal information, the boxes and dropdown menus for the user to provide their input, and eventually the output. Furthermore the body is divided into a sidebar tag and section tag. The sidebar encapsulates the two mouse-hover dropdown menus (for equivalent thickness and grouting methods). The section houses the form where the user inputs the block dimensions and weights and chooses the aggregates. Also included in the section is the .png photo of a brick that updates with the user's recorded dimensions. In the beginning, the section tag also contained a table, which would be updated with the equivalent thicknesses based on the aggregate combinations provided by the user. From this table the user would be able to find the fire-resistance hours based on the equivalent thickness. However, this was omitted in favor of adding the correct fire-resistance hours to the output rather than having the user navigate the table.

The second step in creating the site was fashioning the CSS document that would control the visual aspects of the site. The CSS document governs the site's background image, the font style, size, and family of all the text displayed, all the colors on the page, the layout and location of all aspects of the site – the header, the sidebar, the input and output section – and handles what is hidden or visible on the page at certain times. For example, when the page is first loaded, the text areas for the aggregate percentages are not displayed. On the CSS page, this would be written as display: none. However, when the user chooses the aggregate type, the text area appears. This changes the CSS code to display: block. The actual code that changes the display value is done via JavaScript click event.

The JavaScript document, as stated before, handles the page's events. This means whenever something on the page changes, for example due to a button or link being clicked, a dropdown menu being hovered over, or text appearing or disappearing from the page, the code handling such events is the JavaScript. Finally, the PHP portion of the project collects the user's input as the user hits the submit button and completes the calculations. All the calculations are computed using PHP. The output is also printed to the screen – echoed in PHP terminology – from the PHP page.

All I set out to accomplish with this site has been completed, however as is with any good site I will continue to update it in order to enhance the user experience. In the future, I look forward to adding a database component that will allow the user to save multiple calculations completed at once and look back at the output rather than have to complete the calculations again in their entireties. As I receive feedback from architects – I will be adding a feedback submission section – using the site I will make modifications or additions based on their suggestions. Further, I will be making the site responsive, meaning the site will adjust and respond to the user's screen size and platform, and eventually I would like to turn it into an app for Android and Apple devices. A web-based calculator such as this one has not been created before, which is why this project is relevant and important. I sincerely hope this site will make future fire-resistance rating calculations easier and more fluent for codes and specifications writers.

Apendix A

URL: http://www.specsandcodes.com/CMU_Fire_Resistance/Calculator.php

Practice Test Problems:

1. Test Problem #1:
    a. Actual Length: 15.625"
    b. Actual Height: 3.625"
    c. Actual Depth: 7.625"
    d. Aggregate Proportions:
        i. Pumice: 20% (.2)
        ii. Siliceous Gravel: 80% (.8)
    e. Equivalent Thickness Method: Weight/Density Method
        i. Dry Weight: 21 lbs.
        ii. Density: 125 pcf
    f. Grouting Method: Partial or no grouting/fill
    g. Output:
        i. Actual Length: 15.625"
        ii. Actual Height: 3.625"
        iii. Actual Depth: 7.625"
        iv. Grout/Fill Condition: Partial or no grouting/fill
        v. Volume: 290 cu. in.
        vi. Equivalent Thickness: 5.13"
        vii. Fire-Resistance Rating: 3 hours
2. Test Problem #2:
    a. Actual Length: 15.625"
    b. Actual Height: 7.625"
    c. Actual Depth: 5.625"
    d. Aggregate Proportions:
        i. Expanded Shale: 35% (.35)
        ii. Expanded Slag: 65% (.65)
    e. Equivalent Thickness Method: Measurement Method
        i. Face Shell Thickness: 1"
        ii. Web Thickness: 3" (total width of all webs)
    f. Grouting Method: Partial or no grouting/fill
    g. Output:
        i. Actual Length: 15.625"
        ii. Actual Height: 7.625"
        iii. Actual Depth: 5.625"
        iv. Grout/Fill Condition: Partial or no grouting/fill
        v. Volume: 321.2 cu. in.
        vi. Equivalent Thickness: 2.7"
        vii. Fire-Resistance Rating: 1.25 hours
3. Test Problem #3:

a. Actual Length: 15.625"
b. Actual Height: 7.625"
c. Actual Depth: 7.625"
d. Aggregate Proportions:
    i. Pumice: 30% (.3)
    ii. Calcareous Gravel: 70% (.7)
e. Equivalent Thickness Method: Manufacturer-Provided Data Method
    i. Equivalent Thickness: 4.27"
f. Grouting Method: Partial or no grouting/fill
g. Output:
    i. Actual Length: 15.625"
    ii. Actual Height: 7.625"
    iii. Actual Depth: 7.625"
    iv. Grout/Fill Condition: Partial or no grouting/fill
    v. Volume: 508.73 cu. in.
    vi. Equivalent Thickness: 4.27"
    vii. Fire-Resistance Rating: 2.25 hours

4. Test Problem #4:
    a. Actual Length: 15.625"
    b. Actual Height: 7.625"
    c. Actual Depth: 3.625"
    d. Aggregate Proportions:
        i. Unexpanded Slag: 50% (.5)
        ii. Calcareous Gravel: 50% (.5)
    e. Equivalent Thickness Method: Weight/Density Method
        i. Dry Weight: 26 lbs.
        ii. Density: 135 pcf
    f. Grouting Method: Solid grouted
    g. Output:
        i. Actual Length: 15.625"
        ii. Actual Height: 7.625"
        iii. Actual Depth: 3.625"
        iv. Grout/Fill Condition: Solid grouted
        v. Volume: 431.88 cu. in.
        vi. Equivalent Thickness: 3.63"
        vii. Fire-Resistance Rating: 1.5 hours