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**TECHNICAL NOTES**

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# Fire Resistance of Concrete for Electrical Conductors

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**FINAL REPORT BY:**

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## **FOREWORD**

Electrical feeders for critical fire protection equipment such as fire pumps and emergency systems need to be protected from the thermal effects of fire. The 2017 edition of the National Electric Code (NEC) allows conductors to be installed under 2-inches of concrete to provide this thermal protection in several places including sections in Articles 230, 695, 700, and 708. This is intended to provide a 2-hour fire rating equivalent to locating the conductor outside of the building. The fire resistance and thermal protection of concrete is dependent on several factors including aggregate and application. The goal of this project is to synthesis the parameters that effect the thermal protection of concrete for electric wiring through a thorough literature review and gap analysis. Project tasks include:

- Literature Review: Search the literature for studies, research reports, and peer reviewed journals that pertain to the fire resistance capabilities of concrete.
- Gap Analysis: Identify gaps in available information for determining required concrete thickness for providing thermal protection of electrical conductors.
- Final Report: Synthesis findings from task 1 (literature review) and task 2 (gap analysis) to provide clarity on the thermal resistance of concrete to protect electrical conductors.

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The content, opinions and conclusions contained in this report are solely those of the authors and do not necessarily represent the views of the Fire Protection Research Foundation, NFPA, Technical Panel or Sponsors. The Foundation makes no guaranty or warranty as to the accuracy or completeness of any information published herein.

### **About the Fire Protection Research Foundation**

The [Fire Protection Research Foundation](#) plans, manages, and communicates research on a broad range of fire safety issues in collaboration with scientists and laboratories around the world. The Foundation is an affiliate of NFPA.



### **About the National Fire Protection Association (NFPA)**

Founded in 1896, NFPA is a global, nonprofit organization devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazards. The association delivers information and knowledge through more than 300 consensus codes and standards, research, training, education, outreach and advocacy; and by partnering with others who share an interest in furthering the NFPA mission.



[All NFPA codes and standards can be viewed online for free.](#)

NFPA's [membership](#) totals more than 65,000 individuals around the world.

**Keywords:** electrical conductors, concrete, thermal protection, National Electric Code, fire resistance.

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## **PROJECT SPONSORS**

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## **EXECUTIVE SUMMARY**

This report outlines the findings of the Fire Resistance of Concrete for Electrical Conductors project conducted by the Fire Protection Research Foundation through Tasks 1-3, which conduct a literature review, information analysis, and overall summary. The Project was conducted in order to create a set of parameters that effect the thermal protection of concrete for electrical conductors. This report will be able to provide insight to the National Electric Code (NEC) on possible new requirements for the concrete protecting electrical conductors.

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# Overview

Different codes and standards have been developed in order to ensure the safety of buildings and their occupants. The National Electric Code (NEC) provides the requirements and parameters for electrical equipment. Within the NEC, fire safety and protection is referenced in many sections. In terms of fire protection equipment, such as fire pumps and emergency systems, the electrical feeder associated with these systems needs to be protected from the thermal effects of fire. The 2017 edition of the National Electric Code (NEC) allows conductors to be installed under 2-inches of concrete to provide this thermal protection. This is stated in several places including sections in Articles 230, 695, 700, and 708. This is intended to provide a 2 hour fire rating equivalent to locating the conductor outside of the building. Concrete itself is pretty reliable for a low rate of heat transfer in the presence of a fire. However, concrete has some flaws. These flaws can be a major problem for the materials within the concrete. Different types of concrete have different fire resistance and thermal protection levels that are dependent on several factors, including aggregate and application.

This project takes a closer look at the factors connected to concrete's fire resistance and thermal protection. This research aims to provide the background information needed through a literature review to help the NEC determine the needs to update safety standards for electrical conductors protected by concrete.

## **Project Objective:**

The goal of this project is to synthesis the parameters that effect the thermal protection of concrete for electric wiring through a thorough literature review and gap analysis.

***Task 1: Literature Review***

Search the literature for studies, research reports, and peer reviewed journals that pertain to the fire resistance capabilities of concrete.

***Task 2: Information Gap Analysis***

Identify gaps in available information for determining required concrete thickness for providing thermal protection of electrical conductors.

***Task 3: Final Report***

Synthesis findings from task 1 (literature review) and task 2 (gap analysis) to provide clarity on the thermal resistance of concrete to protect electrical conductors.

## **Background Information**

Currently in the United States, building design codes are based on fire resistance ratings for each individual component of a structure. Because of this, there is a need to develop certain guidelines for structural fire designs. Within the guidelines of the designs, guidelines for the materials used to make a building safe are also important. Concrete is one such material that needs a set of guidelines according to the building codes. Many different codes refer to concrete for many different purposes like structures, interior finishes, and fire protection applications. The National Electric Code offers a few requirements for when concrete is used to protect electrical conductors in Articles 230, 695, 700, and 708<sup>1</sup>.

According to ACI 216.1-07, the heat transfer of a concrete wall is governed by its ability to confine a fire over a specified period of time<sup>2</sup>. That time according to the International Building Code requires a standard of 2 to 3 hours depending on the height of the wall for both exterior and interior locations<sup>3</sup>. Because of this, there has been a considerable amount of research on concrete beams, columns, and slabs and their fire resistance level.

Concrete for the most part does not require any additional fire protection, but there is always room for error. Such errors can be found in climates that are known to have cold freeze–thaw cycles that causes the water in the concrete to expand, which creates pressure. This is a major

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<sup>1</sup> Earley, M. W., Sargent, J. S., Coache, C. D., & Roux, R. J. (2011). *National electrical code handbook*. Quincy, Mass: National Fire Protection Association.

<sup>2</sup> *Code requirements for determining fire resistance of concrete and masonry construction assemblies* (2007). Retrieved from [https://global.ihs.com/doc\\_detail.cfm?gid=DXSXKCAAAAAAAAAAAAA&input\\_doc\\_number=ACI\\_216.1M](https://global.ihs.com/doc_detail.cfm?gid=DXSXKCAAAAAAAAAAAAA&input_doc_number=ACI_216.1M)

<sup>3</sup> ICC. International building code. Retrieved from <https://codes.iccsafe.org>

issue in concrete and can cause failure very quickly. This is known as spalling, but there have been a lot of conflicting results and the significance of each variable have yet to be completely ironed out. Compressive strengths and moisture content are the two most referenced variables relating to spalling. Most results suggest high compressive strengths and high moisture content cause more spalling, and therefore failure. Another problem to consider is that concrete is reinforced with wire mesh, which has been generally shown to increase spalling. Fractural cracking is another phenomenon which is more likely to occur under load, and helps prevent spalling by releasing pressure and reducing stress. Lastly there has been some work into including polypropylene fibers in concrete, because they evaporate and escape and produce a similar effect to the cracking, therefore reducing spalling<sup>4</sup>. Because of these flaws, there have been requirements set in place to avoid these. The requirement is found in the NFPA 5000: Building Construction and Safety Code, which specifically requires ACI 318 for making and use of concrete. It references durability and use in determining thickness as well. Interestingly, many of these uses require a thickness greater than 2 inches.

There are two standards in relation to fire testing. The most commonly used and required by most if not all NFPA standards is ASTM E119: Testing and Materials standard for Fire Tests of Building Constructions, but NFPA 251: Standard Methods of Tests of Fire Resistance of Building Construction and Materials is also a fire testing standard. Both require testing by a standard fire test, with the temperature at 2 hours being equal to 1850 °F, or 1010 °C. Each has requirements for measuring the temperature at different locations with thermocouples. This includes the exposed

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<sup>4</sup> Beland, B. Spalling of concrete. Retrieved from <https://www.ncjrs.gov/App/Publications/abstract.aspx?ID=145790>

and not exposed surface and different depths into the material. Additionally they require maximum times between temperature readings, ASTM E119 requires not less than 15 minutes at temperatures less than 100 °C and not less than 5 minutes for the remainder. Additionally each standard requires that the specimen be a true representation of its use, including dimensions and loading. One small, but important standard in ASTM E119 is that if there is a limitation on the rise of temperature on the unexposed surface, then the period will end if any point on the unexposed surface reads a temperature of 30% excess.

The NEC references 2 inches (50 mm) of concrete in a few different locations. Originally, the permitted use of 2 inches of concrete comes from 230.6. In this case 2 inches of concrete allows the electrical conductor to be considered outside of the building. The 2 inches was then added into 695, 700, and 708 as a means of protecting electrical feeders from fire<sup>5</sup>. Since this is a flip in objective of the 2 inches of concrete, we are not certain that this use is valid.

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<sup>5</sup> Earley, M. W., Sargent, J. S., Coache, C. D., & Roux, R. J. (2011). *National electrical code handbook*. Quincy, Mass: National Fire Protection Association.

## Literature Review

A few online resources were searched to find information regarding the thickness of concrete required to achieve an adequate fire resistance rating.

### **Online Sources:**

#### *UpCodes Calculated Fire Resistance<sup>6</sup>*

UpCodes is a platform that provides sections and excerpts of different building codes. The website provided important tables and sections referencing the thickness and fire resistance rating of concrete. The tables tell us how long the different type of concrete walls maintain their fire rating per cubic inch. The sections refers to different types of insulation, concretes reaction to fire, and exposure to fire. Below are two tables from UpCode that were helpful in determining standard concrete slab thicknesses.

*Table 1: TABLE 722.2.1.1 - Minimum Equivalent Thickness of Cast-in-Place or Precast Concrete Walls, Load-Bearing or Non-Load-Bearing<sup>7</sup>*

Concrete Type	Minimum Slab Thickness (inches) for Fire Resistance of				
	1 hour	1½ hours	2 hours	3 hours	4 hours
Siliceous	3.5	4.3	5.0	6.2	7.0
Carbonate	3.2	4.0	4.6	5.7	6.6
Sand-lightweight	2.7	3.3	3.8	4.6	5.4
Lightweight	2.5	3.1	3.6	4.4	5.1

<sup>6</sup> “Section 722 Calculated Fire Resistance” UpCodes Searchable platform for building codes. Published 2015 Retrieved from <https://up.codes/s/calculated-fire-resistance>

<sup>7</sup> “Section 722 Calculated Fire Resistance” UpCodes Searchable platform for building codes. Published 2015 Retrieved from <https://up.codes/s/calculated-fire-resistance>



Table 2: TABLE 722.2.1.2(1) - Values of  $R_n^{0.59}$  for Use in Equation 7-4<sup>8</sup>

Type of Material	Thickness of Material (inches)											
	1 ½	2	2 ½	3	3 ½	4	4 ½	5	5 ½	6	6 ½	7
<b>Siliceous Aggregate Concrete</b>	5.3	6.5	8.1	9.5	11.3	13.0	14.9	16.9	18.8	20.7	22.8	25.1
<b>Carbonate Aggregate Concrete</b>	5.5	7.1	8.9	10.4	12.0	14.0	16.2	18.1	20.3	21.9	24.7	27.2 <sup>c</sup>
<b>Sand-Lightweight Concrete</b>	6.5	8.2	10.5	12.8	15.5	18.1	20.7	23.3	26.0 <sup>c</sup>	Note c	Note c	Note c
<b>Lightweight Concrete</b>	6.6	8.8	11.2	13.7	16.5	19.1	21.9	24.7	27.8 <sup>c</sup>	Note c	Note c	Note c
<b>Insulating Concrete</b>	9.3	13.3	16.6	18.3	23.1	26.5 <sup>c</sup>	Note c	Note c	Note c	Note c	Note c	Note c
<b>Airspace<sup>b</sup></b>	--	--	--	--	--	--	--	--	--	--	--	--

Notes for Table 722.2.1.2(1):

- a. Dry unit weight of pcf or less and consisting of cellular, perlite, or vermiculite concrete.
- b. The  $R_n^{0.59}$  value for one ½” to 3 ½” airspace is 3.3. The  $R_n^{0.59}$  value for two ½” to 3 ½” airspaces is 6.7.
- c. The fire-resistance rating for this thickness exceeds 4 hours.

***The Concrete Centre<sup>9</sup>***

The Concrete Centre is part of the Mineral Products Association (MPA) website. The MPA is the trade association for aggregates, asphalt, cement, concrete, dimension stone, lime, mortar and silica sand industries. Specifically, The Concrete Centre provides material, design and construction guidance in terms for concrete. The article itself describes how

<sup>8</sup> “Section 722 Calculated Fire Resistance” UpCodes Searchable platform for building codes. Published 2015 Retrieved from <https://up.codes/s/calculated-fire-resistance>

<sup>9</sup> MPA. Fire resistance. Retrieved from [https://www.concretecentre.com/Performance-Sustainability-\(1\)/Fire-Resistance.aspx](https://www.concretecentre.com/Performance-Sustainability-(1)/Fire-Resistance.aspx)

concrete is a good material for fire resistance because it is non-combustible. It also mentions information about concrete as a structural material in the presence of a fire.

***The Constructor – Civil Engineering Home<sup>10</sup>***

The Constructor – Civil Engineering Home website had an article that provides fire-rating criteria for different types of concrete/masonry. With each type the article comments on the fire resistance ratings of concrete and masonry structural elements, and how the element is tested. The different types of elements that are commented on are concrete slabs, mixes, foundations, and slab foundations. Below are three tables from The Constructor that were helpful in determining standard concrete slab thicknesses.

*Table 3: Fire Resistance Rating of Concrete Masonry Assemblies<sup>11</sup>*

Aggregate Type Used in the Concrete Masonry Unit	Minimum Equivalent Thickness ( $T_{ea}$ ) for fire ratings (inches)						
	0.5 Hours	0.75 Hours	1 Hour	1.5 Hours	2 Hours	3 Hours	4 Hours
Calcareous or Siliceous gravel	2.0	2.4	2.75	3.5	4.3	5.3	6.1
Limestone, Cinder, or Slag	2.0	2.4	2.75	3.3	3.9	4.9	5.9
Expanded Clay, Shale, or Slate	1.8	2.2	2.6	3.3	3.5	4.3	5.1
Expanded Slag or Pumice	1.6	2.0	2.2	2.8	3.1	3.9	4.7

<sup>10</sup> Hamakareem, M. I. (2017). Fire resistance ratings of concrete and masonry structures. Retrieved from <https://theconstructor.org/concrete/fire-resistance-rating-concrete-masonry/16406/>

<sup>11</sup> Hamakareem, M. I. (2017). Fire resistance ratings of concrete and masonry structures. Retrieved from <https://theconstructor.org/concrete/fire-resistance-rating-concrete-masonry/16406/>

Table 4: Fire Resistance of Clay Masonry Walls<sup>12</sup>

Material Type	Minimum Equivalent Thickness ( $T_{ea}$ ) for fire ratings (inches)			
	4 Hours	3 Hours	2 Hours	1 Hour
<b>Solid Brick of Clay or Shale</b>	5.9	4.9	3.8	2.8
<b>Hollow Brick or Tile Clay or Shale, Unfilled</b>	4.9	4.3	3.3	2.4
<b>Hollow Brick or Tile Clay or Shale, Grouted or Filled with Specified Materials</b>	6.7	5.5	4.3	3.0

Table 5: Fire Resistance Rating of Single Layer Concrete Walls, Floors and Roofs<sup>13</sup>

Aggregate Type Used in Concrete Masonry Unit	Minimum Equivalent Thickness for Fire Resistance Rating (inches)				
	4 Hours	3 Hours	2 Hours	1.5 Hours	1 Hour
<b>Siliceous</b>	6.9	6.2	4.9	4.3	3.5
<b>Carbonate</b>	6.7	6.1	4.5	3.9	3.1
<b>Semi-Lightweight</b>	5.3	4.5	3.7	3.3	2.8

These above tables have been modified from millimeters to inches

***Code Requirements for Determining Fire Resistance of Concrete and Masonry<sup>14</sup>***

This website is used to implement a standard, ACI 216.1M, that describes approved ways to determine the fire resistance of concrete and masonry building assemblies and or

<sup>12</sup> Hamakareem, M. I. (2017). Fire resistance ratings of concrete and masonry structures. Retrieved from <https://theconstructor.org/concrete/fire-resistance-rating-concrete-masonry/16406/>

<sup>13</sup> Hamakareem, M. I. (2017). Fire resistance ratings of concrete and masonry structures. Retrieved from <https://theconstructor.org/concrete/fire-resistance-rating-concrete-masonry/16406/>

<sup>14</sup> *Code requirements for determining fire resistance of concrete and masonry construction assemblies* (2007). Retrieved from [https://global.ihc.com/doc\\_detail.cfm?gid=DXSXKCAAAAAAAAAA&input\\_doc\\_number=ACI216.1M](https://global.ihc.com/doc_detail.cfm?gid=DXSXKCAAAAAAAAAA&input_doc_number=ACI216.1M)

structural elements. These assemblies and elements include walls, floor and roof slabs, beams, columns, lintels, and masonry fire protection for structural steel columns. These methods shall be used for design and analysis purposes and shall be based on the fire exposure and applicable end-point criteria of ASTM E 119.

### ***Fire and Concrete Structures***<sup>15</sup>

This paper provides structural engineers with a summary of behaviors of structures made from concrete when exposed to fire. The paper also simplifies techniques which have been used successfully for many years to design concrete structures to resist the effects of severe fires. This online report contains a lot of useful information including the effect of high temperatures on the compressive strength of concrete, and the effect of high temperatures on the modulus of elasticity of concrete. Depending on the type of concrete, the compressive strength and the modulus of elasticity decrease at a faster rate due to high temperatures. These trends could help in determining a suitable concrete type for protection of electrical feeders. Below are four tables from this source that were helpful in determining standard concrete dimensions and thicknesses.

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<sup>15</sup> Kamara, M. E., & Bilow, D. N. Fire and concrete structures. *Structures congress 2008* (pp. 1-10) doi:10.1061/41016(314)299 Retrieved from [http://ascelibrary.org/doi/abs/10.1061/41016\(314\)299](http://ascelibrary.org/doi/abs/10.1061/41016(314)299)

Table 6: Minimum Thickness for Cast in Place Floor and Roof Slabs, inches<sup>16</sup>

Concrete Type	Fire Resistance Rating Thicknesses (inches)				
	1 Hour	1.5 Hours	2 Hours	3 Hours	4 Hours
Siliceous Aggregate	3.5	4.3	5.0	6.2	7.0
Carbonate Aggregate	3.2	4.0	4.6	5.7	6.6
Sand-Lightweight	2.7	3.3	3.8	4.6	5.4
Lightweight	2.5	3.1	3.6	4.4	5.1

Table 7: Minimum Concrete Column Dimensions, inches<sup>17</sup>

Concrete Type	Fire Resistance Rating Thickness (inches)				
	1 Hour	1.5 Hour	2 Hours	3 Hours	4 Hours
Siliceous Aggregate	8	9	10	12	14
Carbonate Aggregate	8	9	10	11	12
Sand-Lightweight	8	8.5	9	10.5	12

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<sup>16</sup> Kamara, M. E., & Bilow, D. N. Fire and concrete structures. *Structures congress 2008* (pp. 1-10) doi:10.1061/41016(314)299 Retrieved from [http://ascelibrary.org/doi/abs/10.1061/41016\(314\)299](http://ascelibrary.org/doi/abs/10.1061/41016(314)299)

<sup>17</sup> Kamara, M. E., & Bilow, D. N. Fire and concrete structures. *Structures congress 2008* (pp. 1-10) doi:10.1061/41016(314)299 Retrieved from [http://ascelibrary.org/doi/abs/10.1061/41016\(314\)299](http://ascelibrary.org/doi/abs/10.1061/41016(314)299)

Table 8: Minimum Cover for Floor and Roof Slabs, inches<sup>18</sup>

Concrete Type	Fire Resistance Rating Thickness (inches)					
	Unrestrained					Restrained
	1 Hour	1.5 Hours	2 Hours	3 Hours	4 Hours	4 Hours or Less
Siliceous Aggregate	0.75	0.75	1	1.25	1.625	0.75
Carbonate Aggregate	0.75	0.75	0.75	1.25	1.25	0.75
Sand-Lightweight	0.75	0.75	0.75	1.25	1.25	0.75

Table 9: Minimum Cover Requirements to Main Reinforcement in Beams (All Types), inches<sup>19</sup>

Restrained or Unrestrained	Beam Width (inches)	Fire Resistance Rating Thickness (inches)				
		1 Hour	1.5 Hours	2 Hours	3 Hours	4 Hours
Restrained	5	0.75	0.75	0.75	1	1.25
	7	0.75	0.75	0.75	0.75	0.75
	≥ 10	0.75	0.75	0.75	0.75	0.75
Unrestrained	5	0.75	1	1.25	-	-
	7	0.75	0.75	0.75	1.75	3
	≥ 10	0.75	0.75	0.75	1	1.75

<sup>18</sup> Kamara, M. E., & Bilow, D. N. Fire and concrete structures. *Structures congress 2008* (pp. 1-10) doi:10.1061/41016(314)299 Retrieved from [http://ascelibrary.org/doi/abs/10.1061/41016\(314\)299](http://ascelibrary.org/doi/abs/10.1061/41016(314)299)

<sup>19</sup> Kamara, M. E., & Bilow, D. N. Fire and concrete structures. *Structures congress 2008* (pp. 1-10) doi:10.1061/41016(314)299 Retrieved from [http://ascelibrary.org/doi/abs/10.1061/41016\(314\)299](http://ascelibrary.org/doi/abs/10.1061/41016(314)299)

### ***Fire and Concrete Structures***<sup>20</sup>

This source talks about walls on the technical aspects of fire resistance and concrete structural components. It provides a brief history of concrete and the fire rating behind it. The paper provides information on different concrete types' strength when exposed to high temperatures. This information is displayed in a graph that outlines that the different types react differently to these conditions further proving that all concrete reacts differently. This source is helpful because it further confirms the thickness requirements given by other sources.

### **Other Literature**

#### ***Effect of Wall Thickness on Thermal Behaviors of RC Walls under Fire Conditions***<sup>21</sup>

This paper helped to clarify the effects of thickness and moisture content on the temperature distributions of reinforced concrete walls under fire conditions. The study proved that the different prepared walls did have different effects on the temperature. The different walls were tested to code and it was proven that the thicker walls generated an unsafe level of heat.

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<sup>20</sup> Ashley, E. (1982). *Design of concrete structures for fire resistance*. Paris: Tech Talk.

<sup>21</sup> Jiyeon Kang, Hyunah Yoon, Woosuk Kim, Venkatesh Kodur, Yeongsoo Shin, & Heesun Kim. (2016). Effect of wall thickness on thermal behaviors of RC walls under fire conditions. *International Journal of Concrete Structures and Materials*, 10(3), 19-31. doi:10.1007/s40069-016-0164-5

***Influence of Steel and/or Polypropylene Fibers on the Behavior of Concrete at High Temperature: Spalling, Transfer and Mechanical Properties***<sup>22</sup>

In this report a study explained the effects of different fibers in the concrete. Some of the effects that were looked at were the microstructure, thermal, hydric, and mechanical properties. This study is important to our research because it allows us to take a look at the different ways concrete can be prepared and used. This leads us to the conclusion that different thicknesses are needed in order to have the same fire rating per different types of concrete.

***Performance of Geopolymer High Strength Concrete Wall Panels and Cylinders When exposed to a Hydrocarbon Fire***<sup>23</sup>

The report cited above was another source that further proves that the strength, spalling resistance, and fire resistance can all be effected by the type of concrete or the additives within it. This study proved this by looking at the effect of hydrocarbon fire exposure on the residual compressive strength properties of geopolymer concrete panels and cylinders. A general consensus was that the geopolymer concrete has little to no spalling and minimal weight loss due to heat.

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<sup>22</sup> Yermak, N., Pliya, P., Beaucour, A. -, Simon, A., & Noumowé, A. (2017). *Influence of steel and/or polypropylene fibers on the behavior of concrete at high temperature: Spalling, transfer and mechanical properties* doi://doi.org/10.1016/j.conbuildmat.2016.11.120

<sup>23</sup> Mohd Ali, A. Z., Sanjayan, J., & Guerrieri, M. (2017). *Performance of geopolymer high strength concrete wall panels and cylinders when exposed to a hydrocarbon fire* doi://doi.org/10.1016/j.conbuildmat.2017.01.099



### ***A Model for Evaluating the Fire Resistance of High Performance Concrete Columns***<sup>24</sup>

This report outlines a study done where a numerical model, in the form of a computer program, traced the behavior of high performance concrete (HPC) columns exposed to fire. The program tracked the concrete samples from pre-loading stage to failure. Basically, this is helpful because it is possible to understand the behavior of the concrete without running a multitude of fire tests. After reviewing, the next step to this concrete protective research could be to use a similar program to perform simulations to determine the correct and safest thickness of concrete to protect the feeders.

### ***High-Strength Self-Compacting Concrete Exposed to Fire Test***<sup>25</sup>

This report shows the results from experimental work on the high-temperature behavior of conventional vibrated high-strength concrete and self-compacting high-strength concrete. The study further proved that different types of concrete behave differently and that the code needs to be updated as it currently addresses concrete as a whole. The study explains the way aggregate types and thicknesses of different concrete belong in different subsections of concrete and that concrete is not a general term.

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<sup>24</sup> Kodur, V. K. R., Wang, T. C., & Cheng, F. P. (2004). *Predicting the fire resistance behavior of high strength concrete columns* doi://doi.org/10.1016/S0958-9465(03)00089-1

<sup>25</sup> Noumowe, A., Carre, H., Daoud, A., & Toutanji, H. (2006). High-strength self-compacting concrete exposed to fire test. *Journal of Materials in Civil Engineering*, 18(6), 754-758. doi:6(754)

***Extracting Concrete Thermal Characteristics from Temperature Time History of RC Column Exposed to Standard Fire<sup>26</sup>***

This was a study that created a numerical method to identify thermal conductivity in different forms of concrete. The study considered the importance of the change of specific heat and thermal conductivity with respect to temperature. A standard RC Column was tested in comparison to the ISO-834 standard fire curve, which is represented by the following equation:  $T_g = 345 \log(8t+1) T_0$  [°C]. Where  $T_g$  is the gas temperature in the fire test at time,  $t$ , in minutes, and  $T_0$  is the ambient temperature. It is concluded that the proposed method/equation can be used to conservatively estimate thermal conductivity of concrete for design purposes.

***Fire Protection of Critical Circuits – A Life and Property Preserver<sup>27</sup>***

This report looks at the importance of fire protection in terms of the electrical conductors/circuits that feed the important fire protection equipment in buildings. It explains how proper encasement in concrete could be a way to ensure the equipment continues to work well. The study goes on to analyze the different methods for protection and what changes may be needed in the electrical code and the building code.

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<sup>26</sup> Jung J. Kim, Kwang-Soo Youm, and Mahmoud M. Reda Taha, “Extracting Concrete Thermal Characteristics from Temperature Time History of RC Column Exposed to Standard Fire,” The Scientific World Journal, vol. 2014, Article ID 242806, 10 pages, 2014.  
<https://www.hindawi.com/journals/tswj/2014/242806/>

<sup>27</sup> Milne, I. J. Fire protection of critical circuits - A life and property preserver [Abstract]. *IEEE*, (4) 689-696. Retrieved from  
<http://www.refworks.com/express/expressimport.asp?vendor=IEEE&filter=RefWorks%20Tagged%20Format&data base=&url=https%3A%2F%2Fieeexplore.ieee.org%2Fexpl%2FrefWorkGen%3Farnumber%3D703959%26dlSelect%3Dcite%26fileFormat%3DRefWork&encoding=65001>

# NEC Update Proposals

This section will go through a few National Electric Code Update Proposals to fix the code to make better guidelines for the concrete that is to protect electrical conductors that lead to important fire equipment. This topic has been a concern for quite some time as seen by the fact that the updates presented are from 1998 to 2011.

The first NEC Update Submittal<sup>28</sup> that has to do with the electrical conductors in question, was submitted in 1998. It suggests making a code update to standardize the thickness, fire rating, and concrete type used to protect the electrical conductors. The 1996 NEC stated that the wiring must be protected by at least a one hour rating, and they specified that this could be achieved by 2 inches of concrete (of proper composition).

The request was denied because where the conductors are installed in the building, the 2 inches barrier allows the conductors to be considered outside of the building. Once considered outside they are not subject to a fire rating. This makes creating a standard for protecting these electrical feeds difficult because while it needs to be protected the code states that it is outside the building.

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(Log #2038)

15-119 - (700-9(e)): Reject  
**SUBMITTER:**  
**COMMENT ON PROPOSAL NO:** 15-130a  
**RECOMMENDATION:** Revise 700-9(c)(1) as follows:  
(e) Be embedded in concrete of proper composition and thickness to achieve a minimum fire rating of 1 hour.  
**SUBSTANTIATION:** Equating 2 in. (50.8 mm) encasement of concrete to a one hour fire rating is not necessarily accurate. Although 2 in. encasement is a means of achieving "conductors considered outside of building" (230-6 of the 1996 NEC), it doesn't necessarily follow that it will result in one hour fire resistance for electrical wire. In addition to specifying the thickness of the encasement (which may or may not be 2 in.), the type of concrete must be specified to assure the proper fire resistivity rating. The proposal is too vague to expect effective and consistent emergency wiring installations.  
**PANEL ACTION:** Reject.  
**PANEL STATEMENT:** Where the conductors are installed under 2 inches of concrete in accordance with Section 230-6, they are considered to be outside the building and therefore are not subject to a fire rating.  
**NUMBER OF PANEL MEMBERS ELIGIBLE TO VOTE:** 19  
**VOTE ON PANEL ACTION:**  
**AFFIRMATIVE:** 19  
**COMMENT ON AFFIRMATIVE:**  
The two-inch concrete or brick covering was established as an acceptable barrier for a multitude of code cycles and has had a flawless track record. The one-hour standard could be questioned as a standard. Is 50 minutes enough? Maybe 90 minutes is the right rating. The fact is that the existing codes reflect comparable ranges of safety, not exact formulas as in chemistry.

*Figure 1: NEC Update Proposal*

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<sup>28</sup> "Log # 2038" in *A 1998 Report on Proposals (ROP) [Article 513-Chapter9]* (Quincy, MA: National Fire Protection Association, 1998), 709. <https://www.nfpa.org/Assets/files/AboutTheCodes/70/NEC-ROCA-1998-Articles%20411%20to%20Chapter%209.pdf>

The second NEC Update Submittal<sup>29</sup>, was also from 1998. The proposal connects the NFPA 20 to the NEC to show that the feeders need a better guideline for fire resistance. The overall conclusion by the NEC panel was that the submittal was correct in principle, however no changes would be made because the wording of the NFPA 20 code was providing the option of a 2 inch thickness or a 2 hour rating. The wording is confusing and may allow for contractors to cut costs went applying the encasement. This would also possibly cut down on the safety rating for the electrical conductors for fire protection systems. A more specific wording could be beneficial in here.

(Log #3638)

15-108 - (695-8(a), Exception No 1) Accept in Principle  
**SUBMITTER.**  
**RECOMMENDATION** Revise Exception No 1 to read as shown  
 Exception No 1 Fire pump supply conductors on the load side of the disconnecting means as permitted by Section 695-3(c), Exception No 1, shall be permitted to be routed through buildings by (a) encasing the conductors in not less than 2 inches (50.8 mm) of concrete, or (b) using listed electrical circuit protective systems with a minimum of 1-hour fire resistance. Where (b) is used, the installation shall comply with the restrictions provided for in the listing of such systems  
**SUBSTANTIATION** It seems clear that the panel intends on allowing 2 inches of concrete for the protection of the fire pump circuit from thermal damage due to a fire within a building since it is allowed in the main paragraph for service conductors. Although the concrete as permitted in Section 230-6 was intended to protect the building from the "unprotected" service conductors, the NFPA 20 committee has accepted it for protection of the fire pump conductors from building events. The proposed wording would permit the conductors on the load side of a permitted disconnecting means to also be ran in 2 inches of concrete and not just a 1 hr listed electrical circuit protective system. Presently, considering 2 inches of concrete as adequate thermal protection for the service conductors and permitting only a listed electrical circuit protective system for a feeder does not make sense.  
**PANEL ACTION** Accept in Principle  
**PANEL STATEMENT** The intent of this proposal is covered by Proposal 15-99, see proposed Section 695-6(b) of the proposed text.  
**NUMBER OF PANEL MEMBERS ELIGIBLE TO VOTE** 18  
**VOTE ON PANEL ACTION**  
**AFFIRMATIVE** 18

Figure 2: NEC Update Proposal - 1998 Edition 2

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<sup>29</sup> "Log # 2036" in *A1998 Report on Proposals (ROP) [Article 513-Chapter9]* (Quincy, MA: National Fire Protection Association, 1998), 709. <https://www.nfpa.org/Assets/files/AboutTheCodes/70/NEC-ROCA-1998-Articles%20411%20to%20Chapter%209.pdf>

**Submitter:** :

**Recommendation:** Revise text to read as follows:

**695.6(B) Circuit Conductors.** Fire pump supply conductors on the load side of the final disconnecting means and overcurrent device(s) permitted by 695.4(B) shall be kept entirely independent of all other wiring. They shall supply only loads that are directly associated with the fire pump system, and they shall be protected to resist potential damage by fire, structural failure, or operational accident. They shall be permitted to be routed through a building(s) using one of the following methods:

(1) Be encased in a minimum 50 mm (2 in.) of concrete with a sufficient thickness to achieve a minimum 2 hour fire rating.

(2) Be protected by a fire-rated assembly listed to achieve a minimum fire rating of 2 hours and dedicated to the fire pump circuit(s).

(3) Be a listed electrical circuit protective system with a minimum 2-hour fire rating

FPN: UL guide information for electrical circuit protective systems (FHIT) contains information on proper installation requirements to maintain the fire rating.

*Exception: The supply conductors located in the electrical equipment room where they originate and in the fire pump room shall not be required to have the minimum 1-hour fire separation or fire resistance rating, unless otherwise required by 700.9(D) of this Code.*

**Substantiation:** Methods (2) and (3) are 2 hour fire ratings. Method (1) should be changed to be consistent, hence the addition of the 2 hour rating. In various applications e.g. slabs versus columns or with different concrete, e.g. lightweight, siliceous, or carbonate; different concrete thickness may be required to meet the rating, hence the deletion of the 2 inches of concrete.

**Panel Meeting Action:** Reject

**Panel Statement:** The 2 in. of concrete has provided the industry with a prescriptive benchmark that has served the industry well. The substantiation does not demonstrate that use of 2 in. of concrete has compromised the integrity of the circuit. The recommendation does not provide an alternative prescriptive requirement that can be easily applied.

**Number Eligible to Vote:** 14

**Ballot Results:** Affirmative: 14

Figure 3: NEC Update Proposal - 2001 Edition

The fourth submittal is shown to the right<sup>31</sup>, and was from 2011. This proposal connects the NEC to the 20<sup>th</sup> Edition of the NFPA Fire Protection Handbook. Within the NFPA Fire Protection Handbook, Section 19 provides the minimum slab thicknesses for fire resistance ratings. The section provided these ratings per different types of concrete as well.

The third submittal was from 2001<sup>30</sup>. The proposal was to allow the choice in how the feeders were protected while allowing a little more symmetry in the code across the different choices. The pro to the choices given is that, based on the research on this topic, all concrete types studied are considered to have a two hour rating when the slab has a thickness of 5 inches or more.

(Log #2293)

15- 90 - (700-9(d)(1), Exception): Reject

**SUBMITTER:** :

**COMMENT ON PROPOSAL NO:** 15-128

**RECOMMENDATION:** This Proposal should be Accepted in Principle.

Add the following Exception following Section 700-9(d)(1)(f). This Exception applies to 700-9(d)(1).

Exception: Where an internal combustion engine is used as the prime mover of a generator set in accordance with 700-12(b)(2), the feeder-circuit wiring shall meet one of the following conditions:

- (a) Be installed within buildings that are fully protected by an approved automatic fire suppression system
- (b) Be a listed electrical circuit protective system with a minimum 2-hour fire rating
- (c) Be protected by a listed thermal barrier system for electrical system components with a minimum 2-hour fire rating
- (d) Be protected by a fire-rated assembly listed to achieve a minimum fire rating of 2 hours
- (e) Be embedded in not less than 125 mm (5 in.) of concrete

Figure 4: NEC Update Proposal - 2011 Edition

<sup>30</sup> “Log # 2910” in *A 2001 Report on Proposals (ROP) [Article 513-Chapter9]* (Quincy, MA: National Fire Protection Association, 2001), 709. <https://www.nfpa.org/Assets/files/AboutTheCodes/70/70-A2001-ROP.pdf>

<sup>31</sup> “Log # 2293” in *A 2010 Report on Proposals (ROP) [Article 513-Chapter9]* (Quincy, MA: National Fire Protection Association, 2010), 709. <https://www.nfpa.org/assets/files/AboutTheCodes/70/70-A2010-ROP.pdf>

## **Information Gap Analysis**

After a thorough literature review and combing through the NEC Update Proposals from past years, an analysis has been conducted to identify missing information on a current issue in the NEC. All the information gathered has been beneficial in determining a possible recommendation that could be proposed as a code update for protecting the electrical conductors leading to fire protection systems like fire pumps.

Based on the literature review, a few facts have been determined about concrete fire resistance ratings per different types and thicknesses.

- All types of concrete behave differently in severe fire conditions due to the additives, moisture content, and assembly.
- Different fire ratings can be achieved at different thicknesses for different types of concrete.
- A 2 inch thickness does not always equate to a 2-hour fire rating.

Because of these observations, the code does not supply criteria that gives consistent protection for electrical feeders.

After reviewing the NEC Update Proposals, the 2001 and 2011 proposals supply the clearest possible solution for an NEC update. Both provide choices to the contractor as well as making sure that the electrical conductors are protected. One of the biggest issues with updating the code is that in today's NEC, Section 230.6, it states that the conductors are considered outside the building if installed within a building or other structure in a raceway that is encased in concrete

or brick not less than 50 mm (2 in.) thick<sup>32</sup>. NEC Section 695.6(A) (2) provided confusion because the fire rating code for the fire protection system feeders contradicts Article 230 (NEC). Section 695.6(A) (2) states that feeders located **inside** the building should be encased in 2 inches of concrete. Section 695.6(A) (2) implies that the encasement still allows the feeders to be considered inside where they would be subject to a fire rating. This is permissible, since Article 695 can modify the general requirements in

chapters 1-4 of the NEC. The current code on electrical feeders from the 2017 Edition of the NEC is shown above and to the right. It states that the conductors must be protected from fire and when inside of the building that protection shall be for a rating of 2 hours provided by 2 inches of concrete or an approved cable raceway. From a few different code books including the IBC, there is only one way a concrete slab can have a thickness of 2 inches and a rating of 2 or more hours.

In the IBC (2015 Edition) Table 721.1(3) below (partial) the thickness required to get a 2 hours rating is shown. However the only type of concrete that gets such a rating at 2 inches is

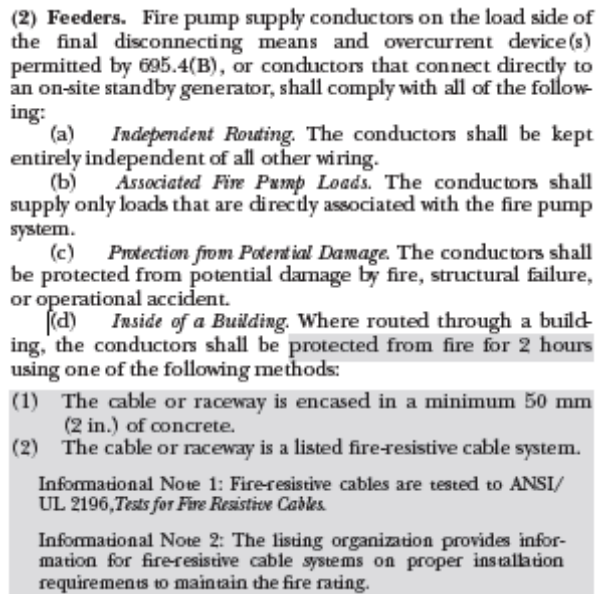


Figure 5: NEC 2017 Edition Requirements for Feeder Protection

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<sup>32</sup> Earley, M. W., Sargent, J. S., Coache, C. D., & Roux, R. J. (2011). *National electrical code handbook*. Quincy, Mass: National Fire Protection Association.

reinforced concrete<sup>33</sup>. The reason that the NEC requirements are recommended to be updated is because the code currently does not tell contractors a standard to protect the electrical feeders. Besides reinforced concrete, a 2 hour rating (the protection requirement) cannot be reached. The following thicknesses get a two hours rating for different concrete types:

- Siliceous Aggregate Concrete – 5.0 inches
- Carbonate Aggregate Concrete – 4.6 inches
- Sand-Lightweight Concrete – 3.8 inches
- Lightweight Concrete – 3.6 inches

TABLE 721.1(3)  
MINIMUM PROTECTION FOR FLOOR AND ROOF SYSTEMS<sup>a, 9</sup>

FLOOR OR ROOF CONSTRUCTION	ITEM NUMBER	CEILING CONSTRUCTION	THICKNESS OF FLOOR OR ROOF SLAB (inches)				MINIMUM THICKNESS OF CEILING (inches)			
			4 hours	3 hours	2 hours	1 hour	4 hours	3 hours	2 hours	1 hour
1. Siliceous aggregate concrete	1-1.1	Slab (no ceiling required). Minimum cover over nonprestressed reinforcement shall be not less than $\frac{3}{4}$ " <sup>b</sup> .	7.0	6.2	5.0	3.5	—	—	—	—
2. Carbonate aggregate concrete	2-1.1		6.6	5.7	4.6	3.2	—	—	—	—
3. Sand-lightweight concrete	3-1.1		5.4	4.6	3.8	2.7	—	—	—	—
4. Lightweight concrete	4-1.1		5.1	4.4	3.6	2.5	—	—	—	—
5. Reinforced concrete	5-1.1	Slab with suspended ceiling of vermiculite gypsum plaster over metal lath attached to $\frac{3}{4}$ " cold-rolled channels spaced 12" on center. Ceiling located 6" minimum below joists.	3	2	—	—	1	$\frac{3}{4}$	—	—
	5-2.1	$\frac{3}{8}$ " Type X gypsum wallboard <sup>c</sup> attached to 0.018 inch (No. 25 carbon sheet steel gage) by $\frac{7}{16}$ " deep by $2\frac{5}{16}$ " hat-shaped galvanized steel channels with 1"-long No. 6 screws. The channels are spaced 24" on center, span 35" and are supported along their length at 35" intervals by 0.033" (No. 21 galvanized sheet gage) galvanized steel flat strap hangers having formed edges that engage the lips of the channel. The strap hangers are attached to the side of the concrete joists with $\frac{5}{32}$ " by $1\frac{1}{4}$ " long power-driven fasteners. The wallboard is installed with the long dimension perpendicular to the channels. End joints occur on channels and supplementary channels are installed parallel to the main channels, 12" each side, at end joint occurrences. The finished ceiling is located approximately 12" below the soffit of the floor slab.	—	—	2 $\frac{1}{2}$	—	—	—	$\frac{5}{8}$	—

Figure 6: IBC Table 721.1(3) - Minimum Protection for Floor and Roof Systems

<sup>33</sup> ICC. International building code. Retrieved from <https://codes.iccsafe.org>



These thicknesses are all above 2 inches so 230.6 (NEC) says that the feeders are considered to be outside of the building and therefore do not need a fire rating. However, section 695.6 (A)(2)(d)(1) is supplying requirements for feeders **inside** the building. The section requires a two hour rating to protect these systems, and one of the methods is listed as encasement in 2 inches of concrete. Even though Article 230.6 (2) considers the feeders to be outside the building when encased in 2 inches of concrete, section 695.6 requires that the feeder be protected from fire for 2 hours. As stated above 695.6 requirements are permitted to modify the requirement of 230, and if it was clear that 695.6 is more important code would be easier to follow. Based on this information, recommendations are supplied below.

### **Summary of Information:**

The following statements are based solely on the literature review and NEC Update Proposals reviewed above. Firstly, it is suggested that the definition of outside versus inside the building be more strictly defined within the code. Currently, the code says that electrical feeders can both be encased or under two inches of concrete to be outside the building, but both are very different. Secondly, it is suggested that electrical feeders are to be encased in 5 inches of concrete when this is the method of fire protection. This is because at 5 inches all types of concrete, when properly casted, have a fire resistance rating of 2 or more hours. By making the requirement 5 inches you remove the need to specify the type of concrete to use. The above are suggestions based on the literature research done in this report. More research in the form of modeling or experimental testing may be necessary, if further substantiation is required.

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