Proposal for an Advanced Structural Elective Pertaining to Fire Protection

ARCE 453 - 06
Spring Quarter

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0.0 Overview

0.1 Introduction to Course

ARCE 401 Fire Protection is a class that will finally give ARCE students an introduction to fire-resilience and its major importance in the structural and planning spheres. The class would have a structural emphasis along with interdisciplinary qualities, unlike the graduate classes offered in the CE and ME departments. ARCE 401 covers a broad spectrum of topics and is meant to bring ARCE students closer to a comprehensive understanding of the overall work environment.

0.2 Learning Outcomes

1. Understand fire behavior and describe the processes for determining fire resilience of various materials.
2. Relate fire resilience to the overall goals: life safety, environmental protection, and property protection.
3. Describe the impacts fire has on regional planning and the overall design decisions for cities and rural areas.
4. Understand the overall function of fire-resistance requirements and its application in different room sizes/occupancies.
5. Describe the various building assemblies and how they relate to fire-resistance ratings and code.
6. Relate fire-resistance to other aspects of the professional field.

0.3 Syllabus

0.3.1 Catalog Data

Introduction to the effects of fire on structures and the planning of communities. Identification of building types and applicable code requirements. Definition of fire-resistance and the three main goals of fire protection: life safety, environmental protection, and property protection. Structural capabilities of timber, steel, and concrete materials and assemblies in regards to fire-resilience. Differences in design methods for urban and rural areas.

0.3.2 Prerequisites

Since this class requires the basic understanding of material behaviors, all design lectures (ARCE 303, 304, 305, and 444) are required. Knowledge of structural assemblies is also necessary, so ARCE 371 is required.

1.0 Week 1 - Introduction & History

1.1 Learning Outcomes

1. Understand an overview of the topics that will be covered in this course.
2. Understand how the fire code came to be and why.

1.3 Lecture Material

1.3.1. During the first lecture it is important that an overview of the fire protection course is covered so that students understand what they are expected to take away from the course. The course syllabus will be passed out and explained.

1.3.2. In order to understand why the fire codes are the way that they are it is necessary to understand what governs the changes in the fire code. The majority of the changes to the fire code throughout the years have been influenced by destructive fires that have suggested there is need for a change in building standards. Below are some examples that will be presented to the students.

> 1.3.2.1. The Great Chicago Fire (1871) started in a barn and spread to the city which at the time was made up of wooden buildings. The city had extensive damage and in response the fire code in that area got much more strict. Timber building materials that are not flame-resistant are no longer allowed to be used for prevention of destruction.
>
> 1.3.2.2. The Iroquois Theater Fire (1903) led to updates in the fire code in terms of egress. This fire was in a packed theater and when the civilians rushed to evacuate they found that many of the doors needed to open inward but were blocked by the people. As a result of this tragedy, panic bars were created to make it easier to exit a building, maximum building occupancies were enforced to prevent congestion in an evacuation, and other regulations were passed to ensure safe egress.

1.3.3. Over different time periods building characteristics have been driven by different things. In the 50's through 70's the fire code drove building design. During this time building layouts were compartment style meaning rooms were separated into small sections. The fire code influenced building design to be this way because if one room caught on fire it would not spread to the rest of the building. Starting in the 90's building design became architecturally driven. Open floor plans and wide open spaces became popular which means that when a fire starts in one room it can easily spread to more locations in the building. This will be covered in greater depth during week 4 but introduced at this time to explain how buildings have changed throughout time.

1.3.4. Although the topic of the goals of fire safety will be discussed in greater depth later in the course. It is important to introduce and establish them early on so that students understand the importance of fire protection. Below are the three goals in order of most important to least important.

a) Life safety
b) Property protection
c) Environmental protection

1.4 Activity

Students will be using the information they learned during lecture about changes in building layouts throughout time and finding real life examples right here on campus. Students will be responsible for choosing 3 different buildings on campus to analyze with different structural/material characteristics. They will need to find out the year each building was built and list some features relating to fire design that correlate the building to the time period in which it was built.

1.5 References

"Chicago Fire of 1871." *History*, A+E Networks, 2010, www.history.com/topics/great-chicago-fire. Accessed 18 June 2018.

1.6 Insight

A great way to understand the full history of fire code changes would be to read through all of the past codes and identify what changes were made in each new edition. This would be unrealistic due to the time constraint of this project. However, if the professor of this proposed course had experience in the field with fire code, he or she would be able to pull from personal experiences they have had with a change in the fire code and would be able to explain to the students why it was made.

2.0 Week 2 - General + Goals

2.1 Learning Outcomes

1. Understand fire behavior and describe the processes for determining fire resilience of various materials.
2. Relate fire resilience to the overall goals: life safety, environmental protection, and property protection.

2.2 Introduction

This week goes over the three main goals of the course, how they interconnect the topics within the subject, and how they are accomplished through fire-resilience, and definitions of the important terms. Reliability of fire-ratings is brought into question and means of egress is discussed. Like any other structural aspect, fire protection aims to protect the public in the most efficient manner. However, there is more to just the occupant and structure. A consideration for the space outside the normal boundaries must be taken into account.

2.3 Lecture Material

2.3.1 Goals for fire-resilience:

1) Life Safety
2) Environmental Protection
3) Property Protection

How are each of these accomplished? These three goals bring together the general scope of what this class aims to accomplish. Throughout the course, students will be able to connect these goals to each topic and relate them both to fire-protection and structural integration.

Life Safety is the priority for all aspects of our built environment. Studying structural engineering, students come to learn that occupant safety is of the utmost importance. Even the slightest of discomfort or displacement could be cause for a lawsuit. In addition, fire-protection brings upon its own limitations such as materials treated with fire-resistive coating or usage of certain assemblies to achieve a desired fire-rating.

2.3.2 What is fire-resistance? We can define it as the period of time the assembly will serve as a barrier to the spread of fire and how long the assembly can function structurally after it is exposed to a fire of standard intensity as defined by ASTM E119. It is also known as fire-endurance.

2.3.3 Why do we need fire-resistance?

There are several reasons why fire-resistance is needed for all structural scenarios. These include:

- To prevent building collapse
- To prevent fire spread from building to building
- To contain the fire from spreading horizontally through wall partitions and vertically through floor assemblies
- To maintain safe means of egress
- To control the movement of smoke
- To provide for firefighter safety

2.3.4 There are other terms necessary to understand what goes into determination of fire-protection protocols. Flame spread is the measure of a material's relative burning behavior in accordance with ASTM E84. A non-combustible material is a material that will not burn or contribute any appreciable amount of fuel to a fire, as determined through ASTM E136.

2.3.5 The actual numbers put into practice are known as fire-ratings. These are used to understand the performance of various constructions for fire containment purposes. They classify the ability of an assembly to confine and isolate fire within a zone comprised of fire-resistance rated walls, ceiling, and floor assemblies. Fire-ratings relate to fire tests designed to determine how quickly fire can raise the temperature to unacceptable levels.

2.3.6 Egress

- Definition: Method of safely and efficiently evacuating occupants within a structure.
- How do fire-ratings relate to egress?
- Are fire-ratings reliable?
  - How are fire-ratings developed?
  - Take into account specific assemblies, but how does this fit in with occupancy?

2.4 Activity

Students will be put into four groups and given a separate building (small/large) and regional (urban/rural) combination. The groups will then be asked to come up with appropriate building assemblies that they think would be most fitting for each situation, based on current intuition about how fire spreads and what materials are used in each setting.

2.5 References

Fire-Resistant Assemblies. United States Gypsum Company, 2013.

2.6 Insight

More thought can be put into the activity, as it sets up the rest of the course's activities. Along those lines, this week's topic sets-up the backbone for the class. Connections between fire-protection and the structural aspects of the class could also be developed more. More time creating this class could lead to a more cohesive aim for the course.

3.0 Week 3 - Material & Assemblies

3.1 Learning Outcomes

1. Understand fire behavior and describe the processes for determining fire resilience of various materials.
2. Describe the various building assemblies and how they relate to fire-resistance ratings and code.

3.2 Introduction

This week will delve into the the more structural aspects of the course, starting with materials. Students will be taught the general thermal properties of steel, concrete, and timber. With previous knowledge of material behaviors, students should be able to understand the reasonings behind each of these properties and how they affect each material in different manners. A basic introduction to assemblies will also be taught using the USG Catalog.

3.3 Lecture Material

3.3.1 Materials

1. General
   a. Standard fire temperature-time relations used in various countries for testing of building elements.
      i. For all countries, the graph begins to plateau around 1000 deg. Celsius, or 1900 deg. Fahrenheit and around the 1.5 hour mark.
      ii. Japan has the shallowest plateau, and the US/Canada have the steepest. Other countries fall between these two.
      iii. In the US, the peak temperature that occurs at the 8 hour mark is 2300 deg. Fahrenheit.
   b. Effects
      i. Adverse effects on material's strength and rigidity causes structural deterioration.
      ii. Such effects include burning, melting, spalling, warping, expanding, shrinking, or deflecting.
      iii. Influence of temperature will not become significant until or unless flashover occurs. A flashover is the near-simultaneous ignition of most of the directly exposed combustible material in an enclosed area. When certain organic materials are heated, they undergo thermal decomposition and release flammable gases.
2. Steel
   a. Thermal Conductivity
      i. The temperature rise in a steel member as a result of heat flow is a function of the thermal conductivity of the material.

ii. At elevated temperatures, this value may be considered identical for most structural steel.
iii. Because of its relatively high thermal conductivity, the assumption that steel is a perfect conductor, implying uniform temperatures of the steel section, is widely used in the determination of the fire performance of steel members.
iv. In reality, temperature gradients exist which may result in internal stresses.
v. Adjoining members can also affect the temperature differential across a structural section (i.e. a concrete slab resting on a steel beam).

b. Specific Heat
    i. The specific heat of the material is the characteristic that describes the amount of heat input required to raise a unit mass of material a unit of temperature.
    ii. At 540°C (1000°F) there is a steep increase in specific heat over a narrow temperature range.
    iii. 600 J/kg K for the specific heat of steel for the entire temperature range is a good approximation.

c. Thermal Diffusivity
    i. The thermal diffusivity of a material is a measure of how effectively the heat is dissipated through the material. It is equal to the ratio of the thermal conductivity to the volumetric specific heat of the material.
    ii. The larger the value of thermal diffusivity, the faster the heat is transported away from the surface being heated.

d. Modulus of Elasticity
    i. The modulus of elasticity of steel decreases with increasing temperature.
    ii. The modulus for ferrite steels decreases nearly linearly with temperature up to about 500°C (932°F). Above this temperature, the modulus decreases more rapidly. This relationship is also true for hot-rolled alloyed bars used in prestressed concrete.
    iii. The modulus of elasticity for cold-drawn steel (used for prestressing wire) is typically 20% lower than the values for hot-rolled steel over a temperature range of 20 to 700°C (68 to 1292°F).

e. Strength
    i. There are two values that typically characterize the strength of hot-rolled structural steel: yield and tensile strengths.
    ii. Yield strength is generally the basis for the design of steel structures at working loads. It is characterized (at room temperature) by a distinct point on the stress-strain curve at which a pronounced increase in strain is observed without a corresponding increase in applied stress.
    iii. At elevated temperatures, this characteristic diminishes until the curve becomes "rounded". Under these conditions, the value of yield strength is defined by the "offset" method.
    iv. The strength changes in cold-drawn steel are different in character from the changes found in hot-rolled steel at elevated temperatures. Cold-drawn steel loses its strength at relatively lower temperatures.

f. Thermal Expansion
    i. The thermal expansion of steels can be related to its temperature by a coefficient of expansion, which can be defined as the expansion of a unit length of the steel when it is raised one degree in temperature.
    ii. Expansion and contraction of the member on the surrounding structure must be taken into account in regards to the structural integrity of the building during exposure to elevated temperatures.
    iii. The coefficient of thermal expansion is reported to be basically the same for all typical structural steels. Its value increases with increasing temperatures.

g. Creep Properties
    i. Creep may be defined as the time dependent deformation of a material.
    ii. Creep is characterized by three periods: primary, secondary, and tertiary.
        1. Primary: Begins with load application and is reflected by a continuous but decreasing strain after the elastic deformation.
        2. Secondary: Deformation, which then continues at a constant strain rate for a given temperature.
        3. Tertiary: begins when, under the same conditions, the strain rate begins to increase, eventually leading to failure by rupture.
    iii. At the elevated temperatures of a fire, deformation proceeds at a varying rate depending on both temperature and length of time. Ultimate failure as a result of increasing strain will eventually result in failure at a load less than that sustained at its beginning.
    iv. Creep of structural steels becomes significant at temperatures above 450°C (842°F).

3. Concrete

*Thermal properties of concrete vary significantly due to type and quantity of the aggregate.

a. Thermal Conductivity
    i. The thermal conductivity of concrete ranges .1 to 1.8.
    ii. Taken as invariant with respect to the direction of heat flow
    iii. For normal weight concrete thermal conductivity decreases as the temperature increases.
    iv. The degree of crystallinity of the aggregate effects the thermal conductivity. A higher crystallinity leads to a higher thermal conductivity and a decrease in temperature.
    v. For lightweight concrete thermal conductivity increases as the temperature increases.

b. Specific Heat
    i. The specific heat of concrete is dependant upon the specific heat of the concrete paste and the amount of water in the paste.
    ii. The type of aggregate in the concrete does not affect the specific heat substantially.

c. Thermal Diffusivity

   i. Concrete is a complex material and behaves in a complex manner in regards to thermal diffusivity
   ii. The thermal diffusivity is a function of thermal conductivity, specific heat, and the density of the concrete.

d. Modulus of Elasticity
   i. With an increase in temperature there is a rapid loss in elastic modulus.

e. Strength
   i. The compressive strength of concrete at high temperatures is a function of the type of aggregate, cement to aggregate ratio, and many other factors.

f. Thermal Expansion
   i. The thermal expansion of concrete increases as the temperature increases nonlinearly.
   ii. The thermal expansion of concrete is a function of the cement, water content, aggregate type, and age.
   iii. Thermal expansion is reduced greatly as the level of stress increases.

g. Creep Properties
   i. Concrete buildings experience significant creep due to the curing process.
   ii. Some high fire risk infrastructures are designed for operation even when they are subjected to extreme high heat. Their long-term deformation under extreme temperatures is of significant concern to design engineers.
   iii. The most important factors of creep in concrete is temperature and stress in the concrete.
   iv. From experiments it shows that creep does not affect the overall behavior of the concrete for temperatures below 400 degrees Celsius.

h. Spalling
   i. Definition: the violent breaking off of pieces from the surface of concrete elements when exposed to rising temperatures.

4. Wood

* When a wood member is exposed to fire there is a char layer that is formed on the outer layer of the member

Rate of charing

a. Thermal Conductivity
   i. Thermal conductivity declines as the density of the wood decreases
   ii. Relatively low because of the porosity of timber
   iii. Increasing the moisture in wood increases the thermal conductivity

b. Specific Heat
   i. 2,300 J/kgoC is the specific heat for pine and spruce
   ii. The specific heat of wood has a linear relationship with temperature.

c. Kinetics

        i. Kinetic constants and char yield is found using thermal gravimetric analysis techniques (TGA).Heat Generation
        ii. Highly debated topic.
        iii. General range of the pyrolysis of wood is between 370 kJ/kg endothermic and 1700 kJ/kg endothermic
        iv. Recent studies show that is can be approximately zero.
    d. Modulus of Elasticity
        i. The modulus of elasticity of wood depends on the grade of the member.
        ii. For members with a moisture content between 0-12% the modulus of elasticity decreases slowly between 180-200 degrees Celsius and after 200 degrees Celsius it decreases at a more rapid rate.
    e. Tensile Strength
        i. A decrease in the temperature of wood usually causes an increase in strength
    f. Thermal Expansion
        i. In the direction of the grain there is very little thermal expansion.
        ii. Temperature movements are greater in the radial and tangential directions of the cross section
    g. Creep Properties
        i. In parallel-to-grain tensile tests, creep deformation as been correlated to a nonlinear (in stress) viscoelastic-plastic model which included terms for separate mechanically induced and thermally induced responses.

3.3.2 Using the USG Catalog, students can identify the types of assemblies and the corresponding fire-rating. The types of assemblies include partitions, floors/ceilings, roof/ceilings, horizontal membrane, structural fireproofing, exterior walls, and through-penetration firestops. The materials vary from steel framed to timber framed and a description of the makeup of the assembly is given.

3.4 Activity

The activity will involve materials testing within a testing lab. Students will observe and analyze the behavior of a steel rod exposed to heat at extreme temperatures, using proper guidance and equipment. Variable fixities will produce different results and would demonstrate the bending effects of steel under fire.

3.5 References

Lie, T. T., and E. L. Schaffer. *Structural Fire Protection*. American Society of Civil Engineers, 1992.

Fire-Resistant Assemblies. United States Gypsum Company, 2013.

3.6 Insight

More could be said on behalf of the relationship between materials and assemblies. Further research needs to be done in order to find specific relations between material properties and determination of assemblies. The inclusion of lateral systems and how each behaves would also be an interesting addition to this topic.

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4.0 Week 4 - Enclosed Spaces

4.1 Learning Outcomes

1. Understand fire behavior and describe the processes for determining fire resilience of various materials.
2. Understand the overall function of fire-resistance requirements and its application in different room sizes/occupancies.

4.2 Introduction

The purpose of this week's lecture is to introduce students to the concept of how fire spreads in an enclosed space and what factors play a role into predicting the characteristics of potential fire behaviors. Students will also be able to understand what principles guide our design choices to help protect structures from fires.

4.3 Lecture Material

4.3.1 Fire Development

Students will have to understand the key terms that are used in the theoretical and practical fields of fire protection. Fire development is known to be separated and analyzed in three stages: The Growth Period, The Period of Full Development, and The Decay Period. The Growth Period is the point of first ignition and the fire either dies out due to lack of fuel or continues into the Period of Full Development. The Growth Period is characterized by the ability of occupants to safely exit the building and the ability of the structure to remain perfectly safe. The Period of Full Development is the period during which flashover occurs and the fire becomes a threat to the structural integrity of the building. The fire expands and allows combustion outside of the room because it is ventilation-controlled. The Period of Decay is transition from a ventilation-controlled fire back to a fuel-controlled fire. Structural elements then lose strength from the thermal load imposed from the fire.

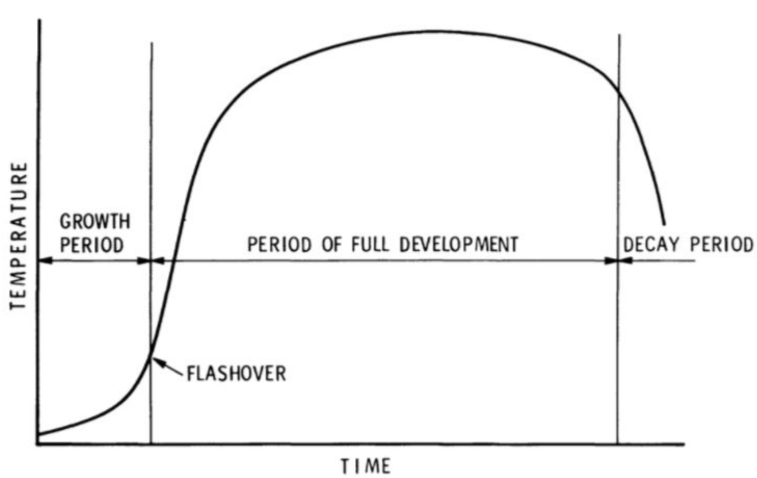

Figure 1: Generalized temperature course for fire in a room.

4.3.2 Fire Severity

Students will be able to distinguish how the severity of a fire can be determined. Students can begin by looking at the Temp. vs. Time graph to get a partial measure of severity, but it's much more than that. Students should understand that the room boundaries play a major role in this determination. The temperature within a room is a result of a strong and complex interaction between the fire gases and the room. Student must also understand how the normalized heat load is obtained, which is the amount of heat absorbed by the room boundaries per unit surface area. There are also five factors that play into this idea, which have been determined from experiments and post-fire analysis: Total fire load, Ventilation parameter, Total area of rooms internal surfaces, Thermal inertia of the room's boundaries, and the Fraction of energy of volatile combustibles released within the room per unit of time.

4.3.4 The Compartment Fire Framework

Students will be introduced to the Compartment Fire Framework, which in principle is that characteristic time scales for combustion are very short thus energy is assumed to be released as a function of reactant supply.

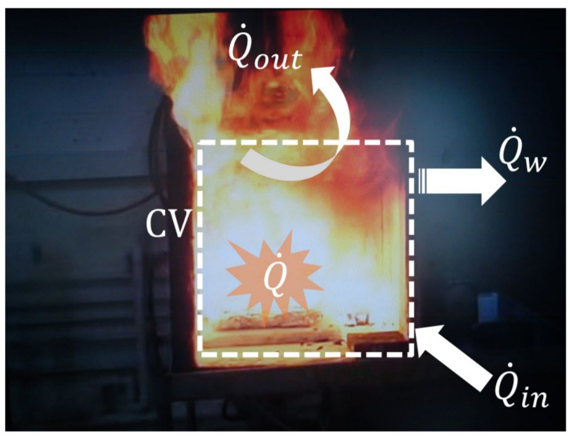

Figure 2: The Compartment Fire Framework

The reactant supplies are considered to be oxygen or fuel. This framework describes the temperature evolution within a building enclosure as complex processes occurring simultaneously. Fuel is pyrolyzed at a rate determined by the characteristics of the material and the net heat exchange between the fuel, the fire, the enclosure, the exterior environment and gas phase (hot and cold). The fuel mixes with oxidizer flowing through the compartment leading to a combustion reaction.The heat generated by the combustion reaction is partially lost at the openings and partially transferred to the enclosure and then fed back to the fuel.

The Framework looks at how fire develops in spaces with different characteristics. Two specific cases are known as Regime 1 and Regime 2 rooms. Regime 1 is characterized as a room with small vents. Due to low ventilation, the compartment will fill with smoke and the oxygen supply becomes limited leading to a fuel-controlled fire. In this case, combustion is rich and soot concentrations are high. The flow field within the enclosure is dominated by the thermal expansion of gases. The equilibrium temperature and other values are defined by the relative magnitude of heat generation, heat transfer to the enclosure, and heat loss through the vents. Regime 2 is characterized as a room with large vents. Due to greater ventilation, smoke evacuates the enclosure with little resistance allowing the fire to draw air leading to an oxygen-controlled fire. In this case, heat transfer times are short and soot concentrations are low. This regime is dominated by heat and mass transfer processes. Heat exchange to the structure is understood to be less severe than Regime 1. The larger vents allows large fractions of heat to escape which in turn decreases the net heat accumulation in the room.

4.3.4 Design Perspective

Code based restrictions on vent and compartment size can be imposed to avoid either regime. However, since Regime 1 is the worst case structures should be designed to withstand the thermal loads of this regime. As an alternative, designs could create better ventilation to effectively reduce fire-proofing demands. Students, would be able to then understand that there are multiple options to design a structure with these ideas in mind, for example, a structure could either be built with small windows and heavy fire-rated walls and floor, or built with larger windows and lighter non-combustible, low fire-rated elements.

4.4 Activity

This week's activity will consist of students forming small groups in which they will research case studies pertaining to their assigned structures. Assigned Structures include: Large Urban Structure(Skyscraper, Hospital, etc.) Small Urban Structure(Store, Restaurants, etc.), Large Rural Structure(Large Residential), Small Rural Structure(Small Residential).

Students will analyze structures to understand what types of assemblies, geometries, materials were used.

Students will then present how they think their assigned structure type will perform in a fire that starts in various areas of the structure.

Students will also present what types of additions/changes could be made to the structure to make it more fire-resistant.

4.5 References

Lie, T T, editor. "Principles of Structural Fire Protection." *Structural Fire Protection*, American Society of Civil Engineers, 1992, pp. 11–14.

TORERO, JOSÉ L, et al. *Revisiting the Compartment Fire*. INTERNATIONAL ASSOCIATION FOR FIRE SAFETY SCIENCE, 2014, pp. 28–45.

Ingberg, S H. *Tests of the Severity of Building Fires*. National Fire Protection Association, 1928.

4.6 Insight

In order to make this section complete, more research would be required in the understanding of the complex processes that occur within the sections above. The current information regarding the processes is a simplified version of the information from the sources above.

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5.0 Week 5 - Midterm/Review

5.1 Learning Outcomes

1. Understand fire behavior and describe the processes for determining fire resilience of various materials
2. Describe the various building assemblies and how they relate to fire-resistance ratings and code
3. Understand the overall function of fire-resistance requirements and its application in different room sizes/occupancies.
4. Relate fire resilience to the overall goals: life safety, environmental protection, and property protection

5.2 Introduction

This week is dedicated to a Review Session of all previous material as well as a Midterm. Inform students what should be focused on for the Midterm and review that material.

5.3 Lecture Material

All previous sections will be reviewed.

5.4 Activity

Midterm Possible Questions(Short Answers):

1. What are the 3 goals for fire-resilience?
2. What is fire-resistance?
3. Why do we need fire-resistance?
4. What is flame spread?
5. What is a non combustible material?
6. What are fire-ratings?
7. List all Fire Related properties for any of the three building materials. Give a short description for three of the properties listed.
8. List the three stages of fire development and describe their characteristics.
9. What is the normalized heat load with respect to fires in an enclosed space.
10. What is the principle definition for the Compartment Fire Framework?
11. Describe the differences between Regime 1 and Regime 2 in the Compartment Fire Framework.

5.5 References

N/A

5.6 Insight

N/A

6.0 Week 6 - Rural

6.1 Learning Outcomes

- Describe the impacts fire has on regional planning and the overall design decisions for cities and rural areas.
- Relate fire resilience to the overall goals: life safety, environmental protection, and property protection.

6.2 Introduction

6.2.1.The purpose of this week's lecture is to inform students about the important contributions the environment has on rural construction. There will be a focus on the interdisciplinary aspects of the construction process and a deeper look at planning, zoning and mitigations. Students will understand the necessities and be able to make connections to structural engineering.

6.3 Lecture Material

6.3.1. Rural living is any geographic area that is located outside of a town or city and typically consists of farmlands and countrysides. If it is not considered urban living, it is most likely rural living. The rural living environment encompasses forests, deserts, and other natural habitats.

6.3.2. The Wildland-Urban Interface is any location where structures and communities meet with undeveloped wildlands. These interaction spots are responsible for the destruction of most structures during any natural disasters involving wildfires. It is the most important interface in the construction community that raises lots of challenges during construction.

6.3.3. The concept and application of rural living is important to structural engineers because it is a lifestyle pursued by many people. As we have seen in the past and will to see in the future; where people go, structures follow. This expands the wildland-urban interface interaction area and makes these areas more appealing to the construction process in these locations. Recent studies show that about 13% of California's population (38,292,687) are part of the wildland-urban interface. While about 21% of the U.S. population (285,230,516) contributes to the interface.

6.3.4. To understand the challenges presented by the wildland-urban interface we must recognize that humans are the invaders. Nature follows a cycle presented by the corresponding ecosystem, which then leads to a possible chain reaction of disasters. For examples, a chaparrals ecosystem is meant to catch on fire and burn about every 50 years or so naturally. Of course this process can be sped up by human interference, especially for chaparrals because they are highly flammable. When presented by this situation, there are only two solutions. The first solution is to understand the possibilities and mitigate the effects of wildfires on your property and structure. However you must understand that nature has a mind of its own, and anything could happen no matter how prepared you become. The second solution is to avoid living in these conditions and settle for a more urban location, or clear a space in the environment to make a safe space for the structure. Although, would that even be rural living then?

6.3.5. An analysis of some of the challenges corresponding to the wildland-urban interface could potentially help mitigate them. Although this class proposal focuses on fire, there are many other possible challenges facing the wildland-urban interface. Some immediate situations are: Floods (Maryland), Earthquakes (Mexico), Landslides (Conchita), Tsunamis (Japan) and Eruptions (Hawaii). Like mentioned before, in this class proposal we will be looking at fires like the ones in Santa Barbara or Santa Rosa. Taking a look at some of the long-term situations, we have climate change as an important one. Climate change is affecting the atmospheric gases which directly affect wildfires, while sea levels rising directly affects structures. Not only presenting potential wildfire treats but also other disasters that we should keep an eye out for.

6.3.6. The effects of wildfires on the wildland-urban interface can be substantial. During an average wildfire season, hundreds of structures are affected or destroyed. During an extreme wildfire season, thousands of structures are affected or destroyed. Due to recent studies there are about 80,000 wildfires each year and about 2-3% of those fires spread into and destroy the wildland-urban interfaces. There are about 46 million structures in the wildland-urban interface communities and about over 70,000 communities at risk which contain about 120 million people. This leads to about 3,000 structures lost every year to wildfires.

6.3.7. Some fire hazards can be avoided by improving human incompetence. With all the fire prevention advertisement during wildfire season, one would think people would be more careful. Some of the leading fire causes are from human incompetence which include: campfires, cigarettes, burning of debris, and intentional acts of arson. Hazards like these can be prevented. Natural phenomenons can occur at any time and anywhere for the most part. As we see in Hawaii (2018) the volcanic eruption brings lava in contact with vegetation and causes fires. Another method of ignition is lightning; hot lightning to be exact. Hot lightning is low voltage but it comes in contact with the ground for a longer period of time.

6.3.8. As stated before wildfires have been a part of the ecosystem's life cycle long before human interaction. Human incompetence can be prevented but nature can only be dealt with. As part of the construction community, there are goals that must be met when construction is being planned. Property protection is the most obvious of the three. No one wants to keep building a new house every couple of years due to destruction. New innovations are always encouraged and applied. Environmental protection is probably the most overseen. Due to the fact that nature is everywhere and clearing a small space will not affect anything within the ecosystem. Although, this is not true. The slightest of changes in an ecosystem creates a ripple effect. Even if at the moment it's not obvious, with time it will be noticeable. Lastly, of course is life safety which is the most important. No matter the structure or location, human life is set before the rest. People must be able to occupy the structure and still have the ability to survive if something were to happen around the structure.

6.3.9. When we think about the construction team, three disciplines come to mind right away: the architect, the engineer and the construction manager. These are the three big ones sitting around the table with the owner thinking about the next steps to take. Let us not forget about the supporting disciplines: Environmental Engineer, Landscape Architect, City/Regional Planner. These disciplines really come into play when designing a structure in a rural environment. The hazards are endless and any knowledge about the terrain and environment is appreciated from the supporting disciplines.

6.3.10 Understanding the hazards is one thing, implementing them into the construction site is another. The construction process starts the minute someone decides to build a structure, thus all disciplines on the project should interact. If there is a structural design in progress, the landscape and environmental engineers should know of it, and vise versa with a site. Communication is very important in any instance, and should never be neglected in order for max efficiency to be achieved.

> 6.3.10.1. Selecting the location of construction is the most important part of the process. One must consider wind, topography and vegetation when searching. We have to understand how each of these play off each other and what is the best outcome to minimize hazards. For example, fire moves faster uphill due to wind and heat rising, the south and west sides of a hill’s vegetation drys out faster, and valleys act like a funnel for wind carrying embers.
>
> 6.3.10.2. In order to minimize casualties both in lives and property, means of egress must follow code. The code states that any road leading up to the structure must accommodate emergency vehicles at any time. The road must be well maintained at all times, in case of an emergency. Turnarounds must be located at the end of any road or driveways that are longer than 150 ft. Roads leading up the the structure must meet the weight requirement in order to support heavy emergency vehicles. Most scenarios have code requirements that must be followed.
>
> 6.3.10.3. Establishing a defensible space before the construction of the structure will be most efficient. Defensible space consists of three zones. Zone one has a range from the wall of the structure to about 30 feet out. In this general area there should be no combustible or artificial vegetation. Under zone 2, which would fall between 30 ft and 60ft out, one must regularly maintain the vegetation. Clearing dead branches and debris will allow for a healthy ecosystem with fire mitigation. Zone three is from about 60 ft to 100 ft, which should be periodically maintained. Meaning this is the space which

encloses the transition from the wildland to the domestic domain of the structure. This zone should keep the illusion of wildland, yet still be maintained enough to mitigate fires.

6.3.10.4. Picking the appropriate construction materials is the last defence against a wildfire if every other mitigation fails. When choosing materials for the exterior of the structure one must recognize the three possible threats presented by fire: flames, conductive heat and radiant heat. In order to protect from the flames make sure to choose a non combustible material, but also recognize that it may be conductive under heat exposure. Even if it may not be combustible or conductive, exposure to radiant heat may cause materials to melt or deform causing potential mechanism failures. Thanks to week three of the class proposal students will have a greater understanding of material properties and fire rated assemblies. Once the exterior walls are designed, the doors, windows and MEP system should not be the weak links of the structure. If debris breaks a window the fire may enter the building, which can also happen if vents are not properly covered. The structure will then be internally compromised and it must be designed to withstand internal support failures. Most important for the structural integrity of the building is the roof design. The roof is the portion of the structure that is the most vulnerable to ignition. The arege areas allow for firebrands to land on and penetrate unless treated. Proper fire rating and non combustible assemblies should be chosen for higher protection, along side avoiding valleys and intersections in the roof design.

6.3.11. This was a quick in depth overview of the many different mitigations one must consider when designing in a rural environment. For more in depth requirements and code visit the references acknowledged below. This week could also use some more research and personal experience from a professional to flush out completely. This week should be reviewed by more than one discipline when being fleshed out and ready to be taught. No doubt through the hand of an experienced member of the construction community this week can be very informational and applicable for future students.

6.3.12. In order to put these mitigations into perspective, some case studies where found. In 2015 a man home in Okanogan County Washington survived a blazing wildfire across his property. When interviewed the man explained he made sure the design of the home would survive the worst, anticipating a wildfire due to the dry wildland surrounding the property. The structure was built in 1999, as a thin shell concrete dome. The three layer concrete house consisted of polyvinyl chloride, polyurethane and cement. Allowing for no firebrand or embers to land of the roof and compromise the structure as it penetrated the roofing material. Likewise the dome shape did not provide a suitable landing spot for the debris. Another case study shows a 1932 house surviving a wildfire due to defensible space along with other factors. Before evacuating the house, the owners worked for hours drenching any wood and clearing a perimeter of combustible material around the house. This, in combination with the house being made out of stone, helped mitigate the destruction of the house itself. The neighbouring wooden sheds did not fall under the same faith.

6.4 Activity

- **<u>Week Activity</u>**
    - Activity Objectives
        - Material and assembly review
        - Understand all the factors in construction not just the structure
        - Learn the steps to construction in a rural location
        - Learn to incorporate this new knowledge into building design
        - Understand the hierarchy of the requirements
    - Reading Assignments
        - Read FEMA facts sheets number 1 through 17
        - Read case studies
            - USA Today, Surprised California fire survivor: 'Oh, my God, I have a home'
            - ABC News, Man's Concrete Home Survives Raging Wildfire in Washington
    - Assignment
        - Using the readings modify the structure from weeks 2 and 3 to fit the material and assemblies required for rural living. Explain in 2-3 sentences why the change in material or assemblies was required and reference the reading (do this to every single thing you change in the structure).
        - Using the readings establish a location, means of transit, etc… Basically you are designing the entire lot the structure will be sitting on. Explain in 2-3 sentences why you choose what you did and reference the readings.
        - Understand that most situations you are not the designer or the person paying for all of this. This means possibly losing some of the fights on the design table. There is no right or wrong answer to this question. Explain in a paragraph (5+ sentences) where would you be willing to lose and why? Also in another paragraph, where would you not be willing to lose and why?

6.5 References

Carlson, Cheri. "Surprised California Fire Survivor: 'Oh, My God, I Have a Home'." USA Today, Gannett Satellite Information Network, 8 Dec. 2017, www.usatoday.com/story/news/nation-now/2017/12/08/surprised-california-fire-survivor-oh-my-god-have-home/933675001/.

"FEMA P-737, Home Builder's Guide to Construction in Wildfire Zones." *What Is Disaster Assistance? | FEMA.gov*, 2008, www.fema.gov/media-library/assets/documents/15962.

Hawatmeh, Rachel. "Man's Concrete Home Survives Raging Wildfire in Washington." ABC News, ABC News Network, 24 Aug. 2015, abcnews.go.com/US/mans-concrete-home-survives-raging-wildfire-washington/story?id=33286398.

Quarles, Steve. "Using Science to Improve Wildfire Outcomes." Https://Fireadaptednetwork.org/, 4 Oct. 2016, fireadaptednetwork.org/using-science-improve-wildfire-outcomes-interview-steve-quarles/.

"Wildfire Causes and Evaluations (U.S. National Park Service)." National Parks Service, U.S.Department of the Interior www.nps.gov/articles/wildfire-causes-and-evaluations.htm.

6.6 Insight

6.6.1 In order to finalize this section of the class more research on the rural fire code and building code will have to be researched. FEMA provides expectations and guidance to prevent fire disasters. For the actual state laws, one must read the code book. Experience will also play a role in the finalization of this section, along with experience in the city and regional planning aspect. Do people follow the law or can the state be pursued otherwise and how this affects the community.

7.0 Week 7 - Urban

7.1 Learning Outcomes

- Describe the impacts fire has on regional planning and the overall design decisions for urban and rural areas.
- Relate fire resilience to the overall goals: life safety, environmental protection, and property protection.

7.2 Introduction

7.2.1 The purpose of this week's lecture is to inform students about the effect fires have in the urban and city communities. Going over possible fire spread methods through the communities and how these can be mitigated. Taking a look not only at the structural effects of the fire, but also on the overall effect on the community. We'll take a look at what some professional structural engineers have to say about the situation some communities have been put through and some solutions they propose. Analyzing articles about people's reactions to the devastation, and predicting what the next move should be overall.

7.3 Lecture Material

7.3.1. An urban community consists of an area with both high population density and infrastructure within the built environment. This encompasses the following: cities, towns, conurbanations and suburbs.

7.3.2. Due to the nature of urbanization, the more structures that can be fit in the least amount of space is ideal. For example, the city of San Francisco was widely affected by this concept when it was expanding throughout the years. For example, having the exterior wall of one house actually being the interior wall of another house. It is easy to see how effective and efficient this was for the construction process, although at what cost? In the likelihood of a house fire in one of these units, the devastation could be surely catastrophic for the city. Then came suburbs, which allowed for more room between structures. This allowed for the mitigation of fire spread from structure to structure through physical contact. As we saw in Santa Rosa, physical contact was not always necessary. The ability and encouragement to have vegetation does play a role in the fire spread from property to property. Although, as seen through the Santa Rosa fire analysis, it is minimal. There were structures burned to the foundation, yet vegetation around the structure was alive and well. Fire spread is less likely in large high rise cities given the choice of construction materials, but in the case of an interior fire for high rise structures, structural failure can be devastating. Based on studies done on tower one and tower two during 9/11, structural failure was accelerated by fire. High temperatures were enough to cause deformations in the structural integrity of supporting members, therefore compromising the structural system. Students will learn to analyze each situation and propose potential solutions.

7.3.3. The way fire spread varies by the situation presented, even though all methods have a contribution. When analyzing situations like San Francisco, fire spread through physical flame contact is obvious. Though firebrands and embers have a high chance of being carried by the wind and land on the adjacent structures across the street. From the studies in Santa Rosa, firebrands have the most impact in a suburban environment. Especially when the roofs of structures are not designed to protect from firebrands and embers. If the structures are close enough heat radiation will play a role into the transfer of heat to the adjacent structures. Not to mention if the vegetation catches on fire and carries the flames over to the adjacent structure. Lastly, radiative and conductive heat through a high rise structure can be seen as observed on 9/11. Fires will either cause parts of the structure to fail or the neighboring structure to weaken. Even if the heat radiation is not strong enough to affect the adjacent structure, the collapse of the affected structure might.

7.3.4. The main problem with urban communities, like suburbs and towns, is that timber is cheaper than steel and more elegant than concrete. Timber is the number one construction material in these communities. Even though fire rating are provided, sometimes it is not enough to save the occupants. Students will take their understanding of material properties and assemblies from the previous lecture and apply it to urbanization as well as analyzing previous fires and coming up with solutions that could potentially satisfy the owner and design team.

7.3.5. A non-flammable structure would consist of non-flammable exterior cladding and a concrete, masonry or steel roof. This was Kevin Zucco's, an executive principle of ZFA structural engineers, comment on the matter. Along with John Cook, senior principal at MKM & Associates structural engineers, who have proposed their solutions to the problem. The solution of installing exterior sprinkler system to the structure could save structure from burning, due to studies of structures surviving because of being soaked by water. The two potential setbacks would be if people don't mind the aesthetics and if the funds are there. Another great concern are the windows and the strength of doors in these situations. Shutters that would deploy if if fires are close enough to cause damage. Roofs being a great concern in these situation would have to be improved heavily through possibly heavy timber construction in the attic and metal sheeting on the roof. One innovative idea to this point was brought up by owners to the structural engineers which is the idea of a fire panic room underground for families to wait out the fire and not risk evacuation in a short period of time.

7.3.6. Student will be exposed to articles and a case study report that will highlight the important factors in urbanization construction in relation with fire. This section should not only educate students, but also inspire them to research innovations. With help from structural engineers like John/Kevin and city & regional planners, communities could someday be fire resistant as a whole and will set a standard for the rest of the country and the codes throughout the states. For more information on the stated above, see the references below.

7.4 Activity

7.4.1. For this weeks activity students will be asked to find case studies about the most recent fires in California. Giving the students the liberty to choose the living style in which they are most interested. Whether they want to analyze rural articles or urban articles they will individually have to write a 500+ word summary/analysis of the situation and outcome using the knowledge acquired through this course so far.

7.5 References

Dunn, James. “Rebuilding to Resist Fire.” The North Bay Business Journal, 2 Dec. 2017, www.northbaybusinessjournal.com/northbay/sonomacounty/7670271-181/sonoma-napa-mendocino-fire-construction-design?artslide=6&slide=GAL.

Himoto, Keisuke, et al. Risk and Behavior of Fire Spread in a Densely-Built Urban Area. INTERNATIONAL ASSOCIATION FOR FIRE SAFETY SCIENCE, 2008, Risk and Behavior of Fire Spread in a Densely-Built Urban Area, citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1000.9412&rep=rep1&type=pd.

Keeley, Jon. “Why Were California's Wine Country Fires so Destructive?” *The Conversation*, The Conversation, 24 June 2018, https://theconversation.com/why-were-californias-wine-country-fires-so-destructive-86043

Moritz, Max. “California Needs to Rethink Urban Fire Risk, Starting with Where It Builds Houses.” The Conversation, The Conversation, 20 June 2018, theconversation.com/california-needs-to-rethink-urban-fire-risk-starting-with

-where-it-builds-houses-88825.

7.6 Insight

7.6.1. In order to complete this section more research should be done on the fire codes and what each section pertains to. How the codes are structured to save lives and if in fact people follow the codes. More research on fire mitigation could be done as well, to prevent homes from catching on fire. Test could be done to determine the best material for the necessary situation and potentially include it in the code. Research on possible innovation like the panic room idea should be continued and supported.

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8.0 Week 8 - Resilience

8.1 Learning Outcomes

- Understand the importance of resilience in society
- Understand the cycle of emergency management

8.2 Introduction

This week's lecture will cover information relating to resilience in communities and emergency management. As a structural engineer it is beneficial to understand the entire process of resolving a natural disaster such as a fire in order to identify how structural engineers can work with other disciplines.

8.3 Lecture Material

8.3.1. Resilience is the ability to recover in a timely manner after a difficulty such as a natural disaster. Resilience is crucial because fires can wipe out entire communities and damage the environment so it is important to have a plan in order to recover as quickly as possible in the time of disaster,

8.3.2. Emergency Management is a cycle that contains four steps that are used to develop resilience in communities. The students will be responsible for understanding this cycle and identifying what roles they will play in the process.

8.3.2.1. The first step in the cycle of Emergency Management is prevention. Up until this point in the course students will have covered a great deal of topics that fall under this category. Prevention involves learning how to design buildings to be as fire resistant as possible, for example, changing out wooden roofs for roofs of a non combustible material. Structural engineerings are involved in this step because we play a role in the design of buildings. Prevention is essentially mankind's way of trying to control nature and keep fires from occuring all together. This is not going to happen in the foreseeable future so it is important to have an alternative plan which leads to step number two.

8.3.2.2. Step two is preparedness which involves making arrangements. Some ways in which this is done includes studying the forensics of previous fires, looking at past scenarios (project studies), analyzing loss estimations, and using risk maps to identify the communities at risk. By studying past fire activity we are able to identify a pattern that will allow us to prepare for the future. However, it is also important to note that due to changes in global characteristics fire frequencies are increasing at an exponential rate.

8.3.2.3. The third step in this process is response, which takes place once the fire has occurred. Response includes identifying which groups of individuals will live during the fire and which groups will stay, and when will they return. A good rule of thumb is that if more than 20% of a community is destroyed by a fire, the entire community will be largely affected. Included in this step is also identifying if the community is still at risk of a reoccuring disaster such as another fire, landslide, or flood. Data collected in this step will then be used to decide whether or not it is an appropriate time to rebuild.

8.3.2.4. Step four is recovery. Recovery is a process, in and of itself, that can take a long time. In some cases the recovery process can take years or even decades. This is another step in which Structural Engineers are highly involved. By providing support and rebuilding the community, Structural Engineers are a significant part of the recovery process.

8.3.3. As mentioned in step two of the Emergency Management cycle studying the past may not sufficient enough to prepare for the future. This is because fires are proving to be a dynamic risk. With climate change fires are increasing at an exponential rate. Therefore, it is important to study the past, but also plan for the future to be worse.

8.4 Activity

This week's activity will utilize a resource through a website called cal-adapt.org. This website includes a tool that is accessible to the public that creates risk maps for California's expected fires through the year 2100. Students will use this website to analyze changes in wildfires. There is also the option to pinpoint a specific community in California and see how that area may be affected by wildfires in the future.

8.5 References

8.6 Insight

The steps in the cycle of emergency management can vary slightly. It is important that students understand that there is a process to emergency management and that by following the process, communities will be more resilient in the case of a natural disaster.

9.0 Week 9 - City & Regional Planning

9.1 Learning Outcomes

1. Relate fire-resistance to other aspects of the professional field.
2. Relate fire resilience to the overall goals: life safety, environmental protection, and property protection.

9.2 Introduction

9.2.1. The purpose of this week's lecture is to inform students about the effect climate change has between the fires and communities. Analyze the effect that one has on the other and how it will progress over the years. How this will affect current fire building codes and the possible notification that might have to be done in order to protect property and lives. This section will also consist of the effect city and regional planning have on the matter of fire spread and means of egress. As well as the possibility of poorly fire resistant city/urban designs and what will have to be done to change the outcomes in the future.

9.3 Lecture Material

9.3.1. City and regional planning is the process of developing strategies for land usage that will result in a sustainable community. The plans must accommodate population growth and change. It is important that city and regional planners and structural engineers work together to develop projects that will have a positive impact on the community.

9.3.2. Climate change is affecting city and regional plans at an exponential rate.

9.3.3. When a project is located on a dead end or one way street it is important that there is a means of egress for the people who inhabit those buildings. This being said it is important that city and regional planners are able to identify multiple escape routes in case the main route is blocked out a fire.

9.4 Activity

This week’s activity will be a continuation of the previous week’s work. The most recent progress for the group projects should be a completion of a presentation detailing assemblies and specifications for each groups site. In addition, students should have added landscape and architectural features to their urban or rural site. Students will then use their new knowledge of resilience and planning to improve their structures and sites.

9.5 References

Moritz, Max. “California Needs to Rethink Urban Fire Risk, Starting with Where It Builds Houses.” *The Conversation*, The Conversation, 20 June 2018, theconversation.com/california-needs-to-rethink-urban-fire-risk-starting-with-where-it-builds-houses-88825.

Keeley, Jon. “Why Were California's Wine Country Fires so Destructive?” *The Conversation*, The Conversation, 24 June 2018, theconversation.com/why-were-californias-wine-country-fires-so-destructive-86043.

9.6 Insight

As with other topics, this week’s activity could be investigated more and better fleshed out. More research in regards to regional planning could be done in order to create a more In addition, connection to the structural emphasis needs to be established, a similar problem previous topics have.

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10.0 Week 10 - Review

10.1 Learning Outcomes

10.2 Introduction

This week is dedicated to a Review Session of all previous material in preparation for the Final. Inform students what should be focused on for the Final and review all material covered in the course.

10.3 Lecture Material

All previous sections will be reviewed, however, most of the questions will come from weeks 6-9.

10.4 Activity

Final Possible Questions(Short Answers):

1. Describe what WUI is and how it is important in the built environment.
2. What are the 3 goals for fire-resilience?
3. What is fire-resistance?
4. Why do we need fire-resistance?
5. List and explain the cycles of Emergency Management
6. Explain the main differences between urban and rural design
7. List the three stages of fire development and describe their characteristics.
8. What is the normalized heat load with respect to fires in an enclosed space.
9. What is the principle definition for the Compartment Fire Framework?
10. Pick a case-study discussed in class and describe how fire-protection was or was not used properly.

10.5 References

N/A

10.6 Insight

N/A

11.0 Conclusion

Fire-protection and related subjects ended up being harder to concentrate than expected. Each topic provided its own challenges, mainly in regards to deciding corresponding activities and interconnected coursework. It was also difficult relating back to structure for some of these topics. For example, the rural/urban and resilience sections dealt more with the interdisciplinary aspect of the class. Relating those subjects back to structural engineering, more specifically assemblies, was a challenge. In order to do so, a relation back to the three main goals of the class had to be established, which tied back into the reason why certain assemblies/materials were used to accomplish life safety, environmental protection, and property protection.

Going forward, this proposal for the class needs to be fully researched and better linked to structural engineering. Currently, it provides more of an interdisciplinary approach to fire-protection rather than an emphasis on structure and could be offered to students outside of architectural engineering, even though it is meant for the latter.

Fire-protection is still a crucial topic that needs to be placed within the architectural engineering curriculum. This proposal for an advanced structural elective pertaining to such a topic is just a step in the right direction for such an introduction. More research and time are required for this to become a reality, however, the topics discussed in this proposal lay down a good foundation for what could be.