NIST Special Publication 1137

Summary of Workshop for Fire-Structure Interaction and Urban and Wildland-Urban Interface (WUI) Fires

Operation Tomodachi: Fire Research

Samuel L. Manzello
Sayaka Suzuki
Tokiyoshi Yamada

National Institute of Standards and Technology • U.S. Department of Commerce

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Patrick D. Gallagher, Under Secretary of Commerce for Standards and Technology and Director

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1. Introduction

1. 1 Workshop Objective

Dr. Samuel L. Manzello of NIST's Engineering Laboratory (EL) served as the USA organizer of the 2nd Japan-USA workshop held in Tokyo, Japan from July 1 to July 4, 2012. This workshop was known as "*Operation Tomodachi - Fire Research*". Tomodachi means friendship in Japanese. This workshop, led by Dr. Samuel L. Manzello of EL-NIST and Dr. Tokiyoshi Yamada of the University of Tokyo, was conducted in partnership with the Japan Association of Fire Science and Engineering (JAFSE). The objective is to open a dialogue for new research collaborations between Japan/USA in an effort to develop scientifically based building codes and standards that will be of use to both countries to reduce the devastation caused by unwanted fires. This is a formal continuation of the kickoff meeting held at NIST's Engineering Laboratory in June 2011. EL-NIST signed a Statement of Intent with JAFSE to hold this workshop, and a follow on workshop at EL-NIST in 2014. On July 1, participants from the USA learned about research at the Tokyo University of Science (TUS) during an optional laboratory tour event. On July 2, the state of the art in Fire Structure-Interaction Research was presented from leading researchers from both countries. EL-NIST's new National Fire Research Laboratory (NFRL) was presented. From July 3 to July 4, the state of art in Wildland-Urban Interface (WUI)/Urban Fire Research was presented from leading researchers from both countries. An overview of focused research in WUI fires by EL-NIST was provided in two presentations. USA side participants learned about post-tsunami fires that occurred in Japan after the March 11, 2011 Great East Japan earthquake. USA delegates enjoyed laboratory tours of the Building Research Institute's facilities as well as those of the National Research Institute of Fire and Disaster (NRIFD). Of special interest was BRI's Fire Research Wind Tunnel Facility (FRWTF) since Manzello of EL-NIST has used this unique facility for WUI fire research over the past six years. USA presentations were delivered from: NIST, Purdue University, University of Texas-Austin, Michigan State University, University of Michigan, Insurance Institute for Business and Home Safety (IBHS), Worcester Polytechnic Institute (WPI), University of California-Berkeley, California Polytechnic University (CALPOLY), Underwriters Laboratories (UL), and the University of Delaware (organizations are listed based on the order of oral presentation). Japanese presentations were delivered from: The University of Tokyo, Building Research Institute (BRI), Takenaka Corporation, Center for Better Living, Shimizu Corporation, TUS, National Institute for Land and Infrastructure Management (NILIM), Kyoto University, NRIFD, Yamagata University, and Kobe University (organizations are listed based on the order of oral presentation). The workshop closed with an open discussion of the future workshop to be held at EL-NIST.

STATEMENT OF INTENT

ON

INTERNATIONAL COOPERATION

BETWEEN

JAPAN ASSOCIATION FOR FIRE SCIENCE AND ENGINEERING (JAFSE)

AND

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY (NIST)

The Engineering Laboratory (EL), National Institute of Standards and Technology (NIST) and the Japan Association for Fire Science and Engineering, intend to open a dialogue for new research collaborations between both countries in an effort to develop scientifically based building codes and standards that will be of use to both countries to reduce the devastation caused by unwanted fires. This is a formal continuation of the kickoff meeting held at NIST in June 2011. Details of this agreement are delineated below:

1. As part of this agreement, the parties intend to hold two meetings over a period of four years:

    - One meeting will be held in Japan (in Tokyo; venue organized by JAFSE) in 2012
    - One meeting will be held at NIST (Gaithersburg, MD) in 2014

2. The initial meeting will be focused on the areas of:
    - Urban and Wildland-Urban Interface (WUI) Fires
    - Fire Structure Interaction and EL's new National Fire Research Laboratory (NFRL)

3. Both organizations shall faithfully consult with each other and do their utmost to communicate any problems or issues arising from activities based on this Statement.

4. Other research interests could be explored for the 2014 meeting, according to mutual interest within the spirit of international exchange and collaboration.

5. This Statement shall be effective on the date of the last signature. The effective period of the Statement is four (4) years after the date executed. If either party wishes to terminate this memorandum, written notice should be given at least two (2) months before the termination date. If both parties desire, this memorandum may be renewed upon mutual written agreement.

6. Activities contemplated and conducted under this Statement are subject to the availability of funds and other necessary resources to the parties. No funds are obligated by this Statement and no party is required to obligate funds in support of this agreement. Both organizations

acknowledge that visits by staff from one organization to the other shall be subject to the entry, visa, and other regulations of the United States and Japan.

7. This Statement of Intent of the parties is not a legally binding agreement. No legal rights or obligations are created by this Statement.

For JAFSE:

Kenji Sato

Prof. Kenji Sato, President
JAFSE

12/3/2011
Date

For NIST:

S. Shyam Sunder

Dr. S. Shyam Sunder, Director
Engineering Laboratory,
National Institute of Standards Technology

11/21/2011
Date

1.2 Program of Workshop

July 2nd	At Building Research Institute (BRI)
10:00 - 10:10	Workshop Objective Coordinator Yamada, T. (University of Tokyo, Japan) Manzello, S. (National Institute of Standards and Technology, USA)

I. Fire-Structure Interaction
Session Chair: Kohno, M. (Tokyo University of Science, Japan)
Jeffers, A. (University of Michigan, USA)

10:10 - 10:30	Suzuki, J. (Building Research Institute, Japan) Effect of Deformation of Structural Frame on Fire Resistance of Compartmentation
10:30 - 10:50	Varma, A. (Purdue University, USA) Experimental Evaluation of Column Stability and Its Influence on Overall Structure Collapse under Fire Loading
10:50 - 11:10	Nishimura, T. (Takenaka, Corporation) Fire Safety of Curtain Wall Spandrel -Proposal for Curtain Wall Spandrel Board Supported by Structural Members-
11:10 - 11:30	Coffee Break
11:30 - 11:50	Engelhardt, M. (University of Texas, USA) Barriers to Performance-Based Structural Fire Safety Design
11:50 - 12:10	Mizukami, T. (Center for Better Living, Japan) Calculation methods for Temperature Rise of Compartment Walls Exposed to Fire Heating
12:10 - 12:30	Morita, T. (Shimizu Corporation, Japan) An Experimental Study on Fire Resistance of Composite Structure Consisting of Steel Beam and Partition Wall
12:30 - 13:40	Lunch
13:40 - 14:00	Garlock, M. and Kodur, V. (Princeton University/Michigan State University, USA) Performance and Research Needs for Bridges Subject to Fire
14:00 - 14:20	Kohno, M. (Tokyo University of Science, Japan) Strategic Measure for Ensuring Fire Safety of Buildings after An Earthquake
14:20 - 14:40	Jeffers A. (University of Michigan, USA) Response Sensitivity and Reliability Analysis of Structures in Fire
14:40 - 15:00	Coffee Break
15:00 - 15:20	Manzello, S (National Institute of Standards and Technology, USA) National Fire Research Laboratory
15:20 - 15:40	Nii, D. and Yoshioka H. (National Institute for Land and Infrastructure Management, Japan) Full-scale Fire Test for Wooden 3-Story School Building (Preliminary Test)
15:40 - 16:20	Discussion (Structural Fire) Adjourn

July 3rd	At Building Research Institute (BRI)
II. Urban/Wildland-Urban Interface (WUI) fires - 1 Session Chair: Himoto, K. (Kyoto University, Japan) Suzuki, S. (National Institute of Standards and Technology, USA)	
10:00 - 10:20	Himoto, K. (Kyoto University, Japan) Urban Fire Spread Modeling and Loss Prevention Planning
10:20 - 10:40	Manzello, S. (National Institute of Standards and Technology, USA) Overview of NIST's Wildland-Urban Interface (WUI) Fire Research
10:40 - 11:00	Shinohara, M. (National Research Institute of Fire and Disaster, Japan) Fire Whirls Caused by Urban Conflagration
11:00 - 11:20	Coffee Break
11:20 - 11:40	Quarles, S. (Insurance Institute for Business and Home Safety, USA) Evaluating the Vulnerability of Buildings to Wildfire Exposures
11:40 - 12:00	Simeoni, A. (Worcester Polytechnic Institute, USA) Wildland Fire behavior: Combustion and Dynamics
12:00 - 12:20	Suzuki, S. (National Institute of Standards and Technology, USA) Determining Firebrand Production from Full Scale Structures and Building Components
12:20 - 13:30	Lunch
13:30 - 13:50	Fernandez-Pello, C. (University of California, Berkeley, USA) Effect of Physical Properties on the Capability of Hot Particles to Ignite Vegetation
13:50 - 14:10	Kuwana, K. (Yamagata University, Japan) Scale-model Experiment of Large-scale, Wind-aided Fires
14:10 - 14:30	Discussion (WUI + Post-EQ fire #1)
14:30 - 14:45	Coffee Break
14:45 - 15:00	Introduction of Laboratory Tour #1 Ohmiya, Y. (Tokyo University of Science, Japan) Introduction of Center for Fire Science and Technology, TUS
15:00 - 15:15	Hagiwara, I. (Building Research Institute, Japan) Introduction of Research Laboratory, BRI
15:15 - 16:15	Laboratory Tour #1 (Building Research Institute)
	Adjourn

July 4th	At National Research Institute of Fire and Disaster (NRIFD)
II. Urban/Wildland-Urban Interface (WUI) fires - 2 Session Chair: Hirokawa, Y. (National Research Institute of Fire and Disaster, Japan) Fernandez-Pello, C. (University of California, Berkeley, USA)	
9:30 - 9:50	Tamura, H. (National Research Institute of Fire and Disaster, Japan) Investigation and its Characteristic of Post Earthquake Fire at the 3.11.
9:50 - 10:10	Dicus, C. (California Polytechnic State University, USA) Fuel Treatment Impacts to Fire Behavior and Ecosystem Services in the Wildland-Urban Interface.
10:10 - 10:30	Nishi, H. (National Research Institute of Fire and Disaster, Japan) Fires and Damages of Oil Tanks Caused by the 3.11 Earthquake
10:30 - 10:50	Matsuyama, K. (Tokyo University of Science, Japan) Experimental Study on the Possibility of the Vehicles Fire in Urban and Tsunami Fire - About the Burning Behavior for Motorcycles -
10:50 - 11:10	Coffee Break
11:10 - 11:30	Iwami, T. and Kagiya, K. (National Institute for Land and Infrastructure Management, Japan) Fires in Non-inundated Area Following the 3.11 Earthquake
11:30 - 11:50	Fabian, T. (Underwriters Laboratory, USA) Fire Exposure of Roof-Mounted Photovoltaic Systems
11:50 - 12:10	Nishino, T. (Kobe University, Japan) Qualitative Aspect of the Fires Fueled by the Combustibles Arriving in the Vicinity of the Tsunami Refuge Buildings
12:10 - 12:30	Davidson, R. (University of Delaware, USA) Statistical Modeling of Post-earthquake Ignitions
12:30 - 13:00	Discussion (WUI + Post-EQ fire #2)
13:00 - 14:00	Lunch
14:00 - 15:10	Future Collaboration and Workshop Coordinator Manzello, S. (National Institute of Standards and Technology, USA) Nakamura, Y. (Hokkaido University, Japan)
15:10 - 15:20	Introduction of Laboratory Tour #2 Wakatsuki, K. (National Research Institute of Fire and Disaster, Japan) Introduction of Research Laboratory, NRIFD
15:20 - 15:30	Coffee Break
15:30 - 16:45	Laboratory Tour #2 (National Research Institute of Fire and Disaster)

2. Discussions

2.1 Inputs related to the Future Workshop

As discussed, EL-NIST will host a follow-on workshop in 2014. A discussed session was held for input to the next meeting. Ideas discussed during the open discussion are delineated below.

Open Discussion on areas of Future Collaboration

- Regarding workshop size (the number of topics and the number of people) the following suggestions were obtained:
  - There was general agreement that the size of the workshop was ideal
    - One session, with no parallel sessions, should be kept for 2014
    - The size of workshop was appropriate to promote more collaboration since people could get to know each other quickly than in a typical conference
    - More discussion time would be desirable after each session to gain more knowledge about fire problem in Japan and USA
  - It was desired combine topics that have commonality for the 2014 workshop, such as was done for this meeting (e.g. WUI fire spread and post-earthquake fire spread)
    - It was suggested to expand the Fire Structure Interaction (FSI) session
      - USA participants were interested in FSI research in Japan and would like to learn more about that topic
      - Perhaps in 2014 EL-NIST will have actual results from the new National Fire Research Laboratory (NFRL)
    - WUI fires spread and urban fire spread may be grouped under the topic of Large Outdoor Fires
      - This would allow more topics to be considered in 2014 under the same umbrella
        - Personal protective equipment for WUI/urban firefighters
        - Post-fire disaster data collection – no standard methods in either Japan or USA

- It is also important to foster collaboration amongst next generation researchers
  - Future of fire research depends on the next generation
  - The need also exists to have representation from experienced researchers as well
  - Such experience is useful to help shape the future

2.2 Summary

The workshop was considered a success and was intended to bring together a diverse group of researchers and code officials after the initial workshop in NIST on June 2011. The valuable input received for future efforts will be considered by Dr. Manzello when considering the next workshop to be held in 2014.

The purpose of this NIST special publication is to document presentations and discussions. Six of participants from the workshop, led Dr. Manzello (Dr. Yamada, Dr. Jeffers, Dr. Omiya, Dr. Fernandez-Pello, and Dr. Himoto), will prepare a joint review paper for publication in *Fire Safety Journal*, a leading international archival publication in fire safety science. The publication in *Fire Safety Journal* is currently in process.

3. Acknowledgements

The organizing local organizing committee (Dr. Hagiwara, Dr. Ohmiya, Dr. Wakatsuki, Mr. Yoshinaga, and Ms. Takahashi) is gratefully acknowledged for their hard work. All are indebted to the Building Research Institute (BRI) and the National Research Institute of Fire and Disaster (NRIFD) for hosting the meeting. The Tokyo University of Science (TUS) is also acknowledged for handling the optional laboratory tour. The excellent presentations from all the presenters are really appreciated. Dr. Nakamura is acknowledged for assisting the discussion for the future collaboration and workshop. The valuable input of all participants is warmly appreciated. The support from the Kajima Foundation is really appreciated. Finally, Dr. Manzello would like to extend a special thank you to Professor Takeyoshi Tanaka of Kyoto University. Without Professor Tanaka's his unwavering support, this event would not have been possible.

Appendix 1

List of Poster Presentations (posters not provided)

1. **National Research Institute for Earth Science and Disaster Prevention (NIED)**
2. **National Research Institute of Police Science (NRIPS)**
3. **Forestry and Forest Products Research Institute (FFPRI)**
4. **National Research Institute of Standards and Technology (NIST/EL/Fire Research Div.)**
5. **Tokyo University of Science (TUS)**
6. **National Research Institute of Fire and Disaster (NRIFD)**
7. **National Institute for Land and Infrastructure Management (NILIM)**
8. **Building Research Institute (BRI)**

Appendix 2

List of Participants

(USA)

1. DAVIDSON, R. University of Delaware
2. DICUS, C. California Polytechnic State University
3. ENGELHARDT, M. University of Texas
4. FABIAN, T. Underwriters Laboratory
5. FERNANDEZ -PELLO, C. University of California, Berkeley
6.
7. JEFFERS, A. University of Michigan
8. KODUR, V. Michigan State University
9. MANZELLO, S. National Institute of Standards and Technology
10. QUARLES, S. Insurance Institute for Business and Home Safety
11. SIMEONI, A. Worcester Polytechnic Institute
12. SUMATHIPALA, K. American Wood Council
13. SUZUKI, S. National Institute of Standards and Technology
14. VARMA, A. Purdue University

(Japan)

15. HAGIWARA, I. Building Research Institute
16. HAYASHI, Y. Building Research Institute
17. HIMOTO, K. Kyoto University
18. HIROKAWA Y. National Research Institute of Fire and Disaster
19. HOKUGO, A. Kobe University
20. IWAMI, T. National Institute for Land and Infrastructure Management
21. KAGIYA, K. National Institute for Land and Infrastructure Management
22. KAKAE, N. Kajima Corporation
23. KAMIKAWA,D. Forestry and Forest Products Research Institute
24. KOHNO, M. Tokyo University of Science
25. KUWANA, K. Yamagata University
26. KUWANA,H. Kajima Corporation
27. MATSUBARA, Y. National Research Institute of Fire and Disaster
28. MATSUYAMA, K. Tokyo University of Science
29. MIZUKAMI, T. Center for Better Living
30. MORITA, T. Shimizu Corporation
31. MURAOKA, K. Ohbayashi Corporation
47. TOYODA, K. General Building Research Corporation of Japan
48. WAKATSUKI, K. National Research Institute of Fire and Disaster
49. YAMADA, T. University of Tokyo
50. YOSHINAGA, J. University of Tokyo
32. NAKAMURA, I. National Research Institute for Earth Science and Disaster Prevention
33. NAKAMURA, Y. Hokkaido University
34. NARUSE, T. National Institute for Land and Infrastructure Management
35. NII, D. National Institute for Land and Infrastructure Management
36. NISHI, H. National Research Institute of Fire and Disaster
37. NISHIMURA, K. Kajima Corporation
38. NISHIMURA, T. Takenaka, Corporation
39. NISHINO, T. Kobe University
40. NIWA, H. Ohbayashi Corporation
41. OHMIYA, Y. Tokyo University of Science
42. SEKIZAWA, A Tokyo University of Science
43. SHINOHARA, M. National Research Institute of Fire and Disaster
44. SUZUKI, J. Building Research Institute
45. TAMURA, H. National Research Institute of Fire and Disaster
46. TANAKA, T. Kyoto University
51. YOSHIOKA, H. National Institute for Land and Infrastructure Management

Appendix 3

Abstracts provided in this workshop

Fire-Structure Interaction #1

Effect of Deformation of Structural Frame on Fire Resistance of Compartmentation

Jun-ichi Suzuki
Building Research Institute

Abstract

The objective of this study is to clarify the influence of the interaction between structural frames and non-structural elements on fire resistance of buildings. Fire resistance of steel buildings depends on the structural stability of steel frames and performance of partition walls to mitigate fire spread. Partition walls or fire protection of steel frames would be damaged by the deformation of a steel frame because of the response of partition walls following the steel frame when the frame is heated in a fire. Similar or severer situations of damage would also occur after an earthquake. If the damaged partition walls lose their fire resistance significantly, the assumption in fire resistance design that fire in a single compartment does not spread to adjacent rooms will fail.

Many researches on fire resistance of heated structural elements and partition walls during a fire have been conducted until now. Most of them, however, only examined the fire resistance of each element without the interaction between structural elements and non-structural elements. Partition walls or fire protections fixed on structural frames might not have enough performance to prevent fire spread or to insulate thermal input because the present fire resistance tests do not replicate realistic deformation or thermal restriction of heated frames in a fire.

The experiments in this study focused on the behavior of protected steel columns and gypsum partition walls with light gauge steel during a fire. Three types of experimental studies were conducted in this study. The first experiment was the fire testing of partition walls damaged by in-plane shearing tests. Deformation in the in-plane shearing tests of partition walls were rough approximation of horizontal deformation of a heated frame in a fire and reenacted damage by seismic movement of the frame. The second experiment was the fire testing of protected steel columns that were horizontally deformed with the increase in steel temperature. The horizontal deformation represented the extension of a heated beam in a frame. The third experiment was the fire testing of non-load bearing partition walls with thermal stress and/or forced deformation. The thermal stress and deformation were induced by the surrounding frame of the walls.

As a result of the experiment, the followings became obvious. Fire resistance of damaged walls depended on the fastening methods and layouts of gypsum boards and the adherence property between under lining boards and top lining boards. Horizontal deformation weakened fire resistance of protected steel columns because the deformation caused opening of joints or cracks of fire protection. Fire protection of modeled boards especially required additional fire protection under the joints. Partition walls with common light gauge steel tended to buckle under thermal stress and forced deformation in fire testing. The partition walls with lower axial stiffness and strength had a possibility to increase deformation capacity. The next experiment related to the interaction is planning to develop a new fire resistance design.

Fire-Structure Interaction #2

Experimental Evaluation of Column Stability and Its Influence on Overall Structure Collapse under Fire Loading

Anil Agarwal[1], Amit H. Varma[2], Lisa Choe[1]
Purdue University

Abstract

Investigation into the collapse of World Trade Center towers underlined the need for performance based design guidelines for structures under fire conditions. Development of such guidelines requires comprehensive research into the failure behavior of different structural components and their assemblies in realistic fire. This paper conducts several case-studies on a mid-rise (10 story) steel building and compares simulation results from these studies to understand the collapse behavior of a typical steel structure built in the USA. The study makes specific recommendations to reduce the risk of fire induced disproportionate collapse of steel structures.

A 10 story steel building is designed following the current design specifications for buildings in a moderate seismic zone. Lateral load resistance (wind and earthquake) is provided by using moment resisting frames (MRFs) on the perimeter or a rigid elevator shaft in an interior compartment. Eurocode based parametric fire time-Temperature (t-T) curves are used to develop a representative fire loading. The representative fire has heating as well as cooling phase. In order to see the effects of various levels of temperatures in different components, three different thicknesses of fire protection are used (no fire protection, 1 hr FRR, and 2 hr FRR).

All the structural components, namely, steel columns, composite floor systems and connections are modeled in an FEM based software using macro level elements. The elements used for modeling various structural components and their sub-assemblies were validated for accuracy and applicability in fire conditions against experimental data. The fire effects are simulated by assigning the pre-calculated temperature values to different structural components. The analysis scheme includes the effects of degradation in material properties at elevated temperatures, concrete cracking, plastic deformations in steel and concrete, thermal strains, etc.

The paper will present the results and findings from these analytical case studies. Some of the preliminary findings indicate that: (1) If all the components are designed for same level for fire protection, gravity columns are most likely to fail first in a typical steel building. (2) After a column fails, reinforcement in the floor system plays an important role in safely redistributing the loads to the neighboring columns. (3) A shear-tab connection (that is not designed to resist any moment) carries significant negative moment in fire conditions, which helps increase the overall load capacity of the floor system.

1 Ph.D. student, anilag@purdue.edu
2 Associate Professor, ahvarma@purdue.edu

Fire-Structure Interaction #3

Fire Safety of Curtain Wall Spandrel
-Proposal for Curtain Wall Fire Resistant Spandrel Board Supported by Structural Members-

Toshihiko Nishimura
Takenaka Corporation

Abstract

In Japan, many buildings using curtain walls as the external wall are built for architectural and other reasons.

Curtain walls consist of glass in the visible portions and fire resistant board in the spandrels. When a fire breaks out, the purpose of the spandrels is to prevent it from spreading to the upper floors. Aluminum is used as the framing members in curtain walls, and ordinarily, the four corners of fire resistant spandrel boards are supported by aluminum framing members. Aluminum melts at about 660°C, so the aluminum framing members melt when the fire is in full blaze, and there is a possibility of spandrel fire resistant boards falling off. If the fire resistant board falls off, the danger of fire spreading to the upper floor is extremely high. Therefore, preventing fire resistant board from falling off is an important issue in fire safety. In Japan, technical advice was issued by the Ministry of Land, Infrastructure, Transport and Tourism in 2008, which required that fire resistant boards be directly supported from structural members such as columns, beams, floors, etc. However, specific methods of support were not proposed, so in practical design excessive specifications were required from the approval authorities, and this frequently resulted in problems of cost and constructability. Therefore we attempted to develop a rational method of the structural members directly supporting fire resistant board. In this technology a joint fitting is inserted in advance into the fire resistant board, and both sides of the fire resistant board are covered with a steel plate. By covering both sides of the fire resistant board with the surface members, it is possible to prevent local stress concentrations at the joint surface of the fitting and the fire resistant board, and obtain excellent performance against imposed deformations due to earthquakes or wind. The structural performance was verified in various structural tests. The performance in a fire was also verified using tests.

During a fire, the curtain wall fire resistant board is heated from both sides by the fire on the interior and by the flames gushing out from the window. For this development, a new test method was proposed in which the curtain wall fire resistant board is heated from both sides, in order to perform the evaluation in accordance with reality. The results of the fire resistance tests confirmed that the curtain wall fire resistant board that has been developed has excellent fire resistant performance during a fire. Using this technology, it is possible to dramatically improve fire resistant performance of curtain walls, without increasing the cost or reducing the constructability.

Fire-Structure Interaction #4

Barriers to Performance-Based Structural-Fire Safety Design

Michael D. Engelhardt
University of Texas at Austin

Abstract

There is increasing interest in the U.S. and elsewhere in transforming building fire safety design from a prescriptive to a performance-based environment. An engineered performance-based structural-fire safety design includes three major components: modeling the fire; conducting heat transfer analysis to determine temperatures of structural elements; and structural analysis to determine structural response to fire. A great deal of research has been conducted worldwide in the area of structural-fire engineering over the last 20 to 30 years. However, this large base of research appears to have had very little practical impact on building design practice. Structural-fire safety in the vast majority of buildings is still addressed using traditional prescriptive based hourly ratings for individual structural members and assemblies.

There appear to be a number of major barriers standing in the way of more widespread application of engineered performance-based structural-fire safety design of buildings. These barriers include issues related to professional practice, education, technical knowledge, and design tools. This presentation will focus on one key technical barrier: inadequate information and characterization of “design fires” for structural-fire safety design. Currently, inadequate guidance is available to structural engineers for characterizing fires in modern buildings that generally have little or no compartmentation.

There are a number of documents that provide guidance on design fires for structural-fire safety design, including Eurocode 1 and a recently released SFPE standard. However, these documents, like the vast majority of literature in this field, are focused on compartment fire analysis, typically using one-zone fire models. Guidance is also available on localized fires that may occur, for example, with a burning vehicle in a parking structure. Models for compartment fires or localized fires, however, do not adequately address the nature of large fires in modern buildings that generally have large open plans with little compartmentation. Experience with large building fires generally shows both horizontal and vertical (floor to floor) spread of fires. It may be possible to model such large moving fires with programs like FDS. However, such an approach is impractical for routine design practice.

This presentation will make the case that more research is needed to understand and characterize moving fires in modern uncompartmented buildings, and the effect of these moving fires on structural response. Such an effort will require close cooperation between structural engineers and fire modeling specialists, and is essential for moving forward with performance-based structural-fire safety design.

Fire-Structure Interaction #5

Simple Calculation Methods for Temperature Rise of Compartment Walls Exposed to Fire Heating

Tensei Mizukami
Center for Better Living

Abstract

The fundamental quantities that relate heat transfer at unsteady state are the thermal diffusivity, thickness and time. The diffusivity is a measure of how quickly a body can change its temperature, and is expressed as

$$\alpha = \frac{\lambda}{\rho C_w}$$

where α is the thermal diffisivity, λ is the thermal conductivity, C_w is the specific heat, and ρ is the density. In addition to these thermal properties, most of the building material contains some extent of moisture, for example, about 21% of the mass of gypsum board are water of hydration, and mud-plastered wall is known for its moisture absorption and desorption characteristic. A temperature plateau near boiling point is observed in the fire resistance test for such walls, and it makes significant contribution to the thermal resistance.

In our research, a series of fire resistant test for mud-plastered wall is carried out changing thickness and moisture content, and derive a hypothesis that the thermal resistant time of moisture containing wall can be expressed as

$$t_{wet} = t_{dw} + t_v$$

where t_{wet} is total thermal resistant time to a certain temperature for moisture containing-wall, which is consisted of the thermal resistant time to the certain temperature for dry wall, t_{dw}, and the thermal retardant time by moisture, t_v.

Thermal resistant time for dry wall is derived by the theoretical solution of the transient one dimensional heat conduction problem in a semi-infinite medium. And the retardation effect by the moisture only focused on the latent heat of vaporization and is treated as moving boundary problem. Therefore we have made the further assumptions:

1. Only laminar transport processes are considered in the transverse x direction.
2. Semi-infinite solid methodology is applied and the temperature of the exposed surface suddenly raised to *s T* and is maintained all the time.
3. Thermal properties are constant and uniform through the wall and independent of temperature.
4. Internal moisture migration is ignored.

In real fire occasion, these assumptions will not lead to accurate quantitative results unless we ultimately make some adjustments later. However, taking the advantage of simplified description, the equations can be taken as guide and to give insight into the interaction of thermal diffusivity and moisture. The equations are validated by one-dimensional thermal conductive model and test results under ISO-fire conditions.

Fire-Structure Interaction #6

An Experimental Study on Fire Resistance of Composite Structure Consisting of Steel Beam and Partition Wall

Takeshi Morita
Institute of Technology, Shimizu Corporation

Abstract

Structural fire safety design is normally based on the assumption that fire is enclosed in a compartment. Partition walls are a main element of the compartment and usually placed under structural beams or slabs. The beam exposed to fire deforms by the result of its elevated temperature. It is a question that the deformation of the beam which is a part of a compartment leads to failure of the partition wall.

This study focuses on a compartment element which consists of a steel beam and a partition wall. The fire side of the beam is covered with fire proofing material, and the other side of the beam, i.e. non fire side, is not covered and directly exposed to ambient temperatures. The interaction of deformation between beam and partition wall, the thermal insulation capacity of steel beams, and the possibility of simplified calculation method of steel temperatures are experimentally investigated.

Specimens for fire resistance test consist of steel beam, partition wall and fireproof cover for steel. Brief specifications of these elements and materials are as follows;

- Steel beam section: H-250*125*6*9 and H-400*200*8*13 (mm)
- Partition wall: 2 or 3 layers of enhanced gypsum board (thickness: 21mm)
- Fireproof cover: Thermal resistant rock wool (thickness: 40 or 65mm)

A full scale compartment specimen and six small scale compartment specimens are constructed by combining these elements and materials. The specimens are heated only from one side under standard fire temperature-time curve prescribed in ISO834.

As the result of full scale fire resistance test, it is confirmed that the deformation of steel beam does not significantly affect the performance of partition wall, if surface temperatures on the beam of non fire side do not exceed allowable surface temperatures. (allowable average temperature rise: 140K, allowable maximum temperature rise: 180K) Fire resistance of specific combinations of beam size and fireproof cover thickness are made clear as the result of small scale fire resistance test. Fire resistance of up to 120min could be achieved by the combination of beam size, fireproof cover thickness and partition wall.

The calculation method of steel temperature rise which is a part of technical basis of the fire-resistance performance verification method in Japanese building code is referred here in order to get a simplified calculation method. As the result, temperatures of steel beam exposed to fire from one side can calculate with the referred calculation method with applying thermal properties identified by analysis on the experimental data.

Fire-Structure Interaction #7

Performance and Research Needs for Bridges Subject to Fire

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Abstract

Structural fire safety has been traditionally focused on buildings and has paid little or no attention to bridges. One cannot extend fire design guidelines from buildings to bridges since the behavior of a steel bridge girder (i.e., a deep beam) under fire is different to that of a steel beam in a building under fire. These differences include the cause of fire, fire load, fire protection, and beam depth.

Bridge fire events cannot be ignored due to the number of occurrences and the social and economic consequences. Further, a recent Department of Transportation survey has shown that three times more bridges have collapsed due to fire compared to earthquakes; but not many studies have been carried out on this topic.

This presentation summarizes three parts of an ongoing collaborative effort between Princeton University and Michigan State University to evaluate the performance of steel bridge girders subject to fire. The first part reviews the state-of-the-art in bridge fire design and the historical performance of bridges subject to fire. The second part analyzes, with a 3D numerical model, the response of a typical bridge of 12.20 m. span length. A parametric study is carried out considering (1) the axial restraint of the bridge deck, (2) types of structural steel for the girders (carbon steel and stainless steel) (3) different constitutive models for carbon steel, and (4) fire loads (the hydrocarbon fire defined by Eurocode 1 and a fire corresponding to a real fire event). Results show that restraint to deck expansion coming from an adjacent span or abutment should be considered in the numerical model. In addition, the times to collapse are very small when the bridge girders are built with carbon steel (around 10 minutes for the hydrocarbon fire and around 18 minutes for a real fire event) but they can almost double if stainless steel is used for the girders.

The third part of this presentation examines the post-fire residual strength of steel bridge girders. Results from a set of numerical studies on fire exposed steel girders will be presented. The analysis is performed using finite element computer program ANSYS in two stages, namely during exposure to fire and then after cooling of the bridge girder. In the first stage of analysis, thermal and structural response of the bridge girder is traced under specified fire exposure and loading conditions. In the second stage (after the bridge girder cools down), the girder is loaded to failure to evaluate the residual capacity of the girder. Results from numerical studies indicate that the maximum fire temperature (and associated temperature in steel) is the most critical factor that influence the residual strength of fire exposed bridge girders. A girder exposed to typical external fire conditions, with maximum fire temperatures reaching 600-700 °C, retains about 70 to 80% of its strength on cooling. On the other hand, a steel bridge girder exposed to hydrocarbon fire with maximum temperature of about 1100 °C, looses most of its strength during heating phase of the fire and experiences failure.

Fire-Structure Interaction #8

Strategic measure for ensuring fire safety of buildings after an earthquake

Mamoru Kohno

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Abstract

Up to early 1980's, the objective of seismic design was to prevent the building from collapsing, so that the life safety of residents inside the building was protected. As time progressed, not only the life safety but also the quality of life in the aftermath of a disaster became significant issue. Huge earthquakes are expected imminent in many places in Japan including Tokyo metropolitan area. If such an earthquake occurs, buildings near the epicenter are subjected to a strong ground quake of upper six or larger on the seven-point Japanese scale, and continuous use of those buildings might not be possible because buildings might be damaged to some extent even if they do not collapse. A ground shaking of upper five to lower six on the Japanese scale in the surrounding wider area may cause a damage or incomplete function of nonstructural elements or fire safety equipment of buildings.

There are many high-rise apartment buildings in urban area and each building accommodates a large number of residents. Residents in those buildings need to decide if they can continue to stay in their apartment or move to safe place such as evacuation center in case a large earthquake occurs. Generally, residents are apt to keep staying because of the quality of life. It will be helpful for the local area if residents in the high-rise building can continue to stay at their apartment because the capacity of evacuation center is limited.

The risk of fire is higher than ordinary circumstances in the aftermath of an earthquake because the chance of fire ignition is higher and the fire safety of building can be lower due to the potential damage of building elements and incomplete function of fire safety equipment.

A strategic plan against fire after an earthquake is needed. It is important to consider the internal and external conditions of the building to develop the plan. Internal conditions include living situation of individual resident, states of structural and nonstructural elements of the building and fire safety equipment. External conditions include the state of lifeline, such as electricity, gas and water supply and sewerage systems, availability of public fire service and so on. In the aftermath of earthquake the internal and external conditions change as time goes.

A four phase plan is discussed here. The phases are defined based on the varying internal and external conditions of the building. Results of interview and questionnaire surveys after the Great East Japan Earthquake 2011 are referenced to set up the phases. The plan focuses on appropriate fire safety requirements, permissible living conditions, what should be checked and who should do that in each phase. It is recommended that each high-rise apartment building develops specific post-earthquake fire safety plan and share it with the residents to ensure better quality of life even in the aftermath of a disaster.

Fire-Structure Interaction #9

Response Sensitivity and Reliability Analysis of Structures in Fire

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Abstract

Structural performance in fire is governed by thermal and mechanical processes that are typically evaluated by three sequentially coupled analyses: (1) a fire model that describes the transient fire properties, (2) a heat transfer model that describes the propagation of temperature through the structure, and (3) a structural model that captures the temperature-dependent mechanical response of the structure. At present, the analysis and design of structures for fire is based on purely deterministic models, in which uncertainty in the model parameters is completely ignored. A few recent works have explored stochastic models for fire-structure interaction; however, research to date is limited to simulation-based studies that are rooted in Monte Carlo simulation (MCS). Despite its versatility, MCS requires extensive computational resources that make the method impractical for use in industry and furthermore becomes problematic when evaluating structural reliability in regions with low probabilities of failure.

To overcome existing limitations, the present study explores the extension of the perturbation-based stochastic finite element method to the analysis of structures in fire. In particular, response sensitivity analysis in the fire, thermal, and structural domains is derived based on direct differentiation of the governing finite element equations. While the direct differentiation method (DDM) has been studied extensively in structural mechanics, there has been very limited research to explore its use in problems that exhibit strong coupling between the thermal and structural domains. The DDM formulation for nonlinear thermo-structural analysis is therefore presented here and used to evaluate the sensitivity of the structural response to various parameters in the fire, thermal, and structural models. Accuracy is assessed based on comparison to the finite difference approximation of the response sensitivities.

Because the ultimate goal of the research is to assess the reliability of structures in fire, the response sensitivity analysis is incorporated into a first-order reliability analysis based on the improved Hasofer-Lind-Rackwitz-Fiessler algorithm. To demonstrate the effectiveness of the approach, the methodology is used to assess the reliability of a protected steel beam given uncertainty in the fire, thermal, and structural parameters. Comparisons between the first order reliability analysis and MCS demonstrate that the proposed formulation accurately predicts the probability of failure and does so with much greater computational efficiency. Thus, the perturbation-based stochastic finite element method offers much promise for the performance-based design of structures for fire.

Acknowledgement

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Fire-Structure Interaction #10

THE NIST NATIONAL FIRE RESEARCH LABORATORY: A UNIQUE NEW FACILITY FOR INTERNATIONAL COLLABORATIVE RESEARCH ON REAL-SCALE FIRE/STRUCTURE INTERACTIONS

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National Institute of Standards and Technology

Abstract

The National Fire Research Laboratory (NFRL), located on the National Institute of Standards and Technology (NIST) Gaithersburg campus, has been designed for conducting real-scale experimental research to provide the technical basis for improvements in standards, codes, and practices associated with buildings and structural systems subjected to fire. The NFRL is operated by the NIST Engineering Laboratory (EL), whose mission includes promoting U.S. innovation and industrial competitiveness by anticipating and meeting the measurement science and standards needs for the design and construction of buildings and infrastructure systems to resist the effects of fire.

The facility is being expanded to provide the following capabilities for simultaneous application to a full-scale structural assembly or system: controlled multi-axial mechanical loads up to 1.5 MN, controlled fire exposures up to 20 MW for up to 4 h, measurement of structural deflections up to incipient collapse, and continuous measurement of heat release rate, heat flux, and structural temperatures. The expanded NFRL is currently under construction and is scheduled for completion in December 2012, followed by a 12 month commissioning phase. When fully operational in 2014 the NFRL will provide unique-in-the-world experimental capabilities for real-scale structural systems up to 9 m high constructed on a strong floor that is 18 m by 27 m in plan.

The NFRL is designed primarily for conducting experiments on steel and structural assemblies and systems. It can also be used for experiments on timber construction, polymeric-based composite structures, load-bearing wall assemblies, materials for enhancing fire resistance (e.g SFRM, gypsum board, and intumescents) and other designs and materials for buildings, bridges, and tunnels.

The scientific objectives of the NFRL are to develop an experimental database on the performance of materials, components, connections, assemblies and systems under fire loading and to gain knowledge, quantify performance, and validate physics-based predictive models, including a library of component and connection models. Data from experiments conducted in the NFRL will provide the technical basis for performance metrics; acceptance criteria for different levels of performance objectives; mitigation strategies based on evaluated performance to provide adequate fire protection for the structure; and the measurement science to support a transformation from prescriptive to performance-based standards in design of structures for fire resistance.

Research in the NFRL will be supported through a combination of other government agency sponsorship, grants and cooperative agreements, collaborative research funded by private sector organizations, and consortia. NIST invites international organizations with shared interest in structural fire safety engineering to participate in NFRL research.

Full-scale Fire Test for Wooden 3-Story School Building (Preliminary Test)

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Abstract

In order to achieve 3-story wooden school building beyond 3,000 m2 constructed as a quasi-fire-resistive building, which isn't permitted in the Building Standard Law in Japan, it's necessary to make the way of thinking of the fire protection measure in the framework of the current regulations. The main purpose of this project is to clarify the problem on fire protection by understanding fire behavior in 3-story wooden school. In this presentation, main features of this experimental building including the detail specification of construction members, objectives of full-scale experiment and experiment result will be mentioned.

3-story wooden school building of 2,260 square meters of total floor area was designed and constructed in accordance with the specification of 1-hour quasi-fire-resistive building.

When designing this building, the recent trend of floor planning of elementary school etc. was reflected and wooden interior finish which would be likely used in wooden building was reproduced.

In this building, two construction methods, one of which is wood-frame construction method and another is 2 x 4 construction method, were applied in order to investigate the influence of construction method to fire behavior.

The part of post-beam construction method was divided by fire-resisting wall which was placed perpendicular to the corridor to investigate the effect of fire spread prevention.

As a result of experiment, fire had rapidly spread to upper floor and all over the building due to large-scale external flame. Although combustible fire load of each room was designed with total heat release rate based on the actual survey, review may be necessary from the aspect of heat release rate or surface area of combustible.

Because building structure could maintain self-sustainability for over one hour, it achieved 1-hour quasi-fire-resistive construction performance as required by regulation. Fire had spread beyond the fire-resistive wall because flame run through the fire protection door of the opening. The reason would be the pressure increase due to temperature rise in fire room.

Large amount of firebrands seems to have flown leeward from the attic before the collapse of the building.

It will be necessary to consider provisions to delay fire spread, reduce the impact to around and evacuation safety in the building.

WUI + Post-EQ fires -1 #1

An Analysis on the Burn-down Probability of Historical Temple- and Shrine-Structures in Kyoto City in the Case of Fires Following Earthquake

Keisuke Himoto
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Abstract

Burn-down probability of 2,131 historical temple- and shrine-structures in Kyoto city in the case of fires following post-earthquake fire is analyzed. In the present analysis, ignition is assumed to occur following an earthquake due to the shift of Hanaore fault located in the north-east of Kyoto city. If the fire-fighting activity fails to extinguish the fire at its initial stage, the fire enlarges inside the building and spreads to adjacent buildings. This may be followed by broader fire spread within the urban area which consists of buildings with variable level of structural damage due to seismic motion. Damage of historical structures is caused when such fire spread is not prevented on the way.

The analysis is conducted by using a physics-based urban fire spread model formerly developed by the authors. In the fire spread model, urban fire is interpreted as an ensemble of multiple building fires, that is, the fire spread is simulated by predicting behaviors of individual building fires under the thermal influence of neighboring building fires. Adopted numerical technique for the prediction of individual building fire behavior is based on the one-layer zone model. Governing equations of mass, energy, and chemical species in the component roomsare solved simultaneously, for the development of temperature, concentrations of chemical species, and other properties. As for the building-to-building fire spread, three phenomena are considered as contributing factors, i.e.: (I) thermal radiation from fire involved buildings; (II) temperature rise due to wind-blown fire plumes; and (III) firebrand spotting.

With the model, the Monte Carlo simulation was conducted in order to obtain the burn-down probability of the historical structures. Factors of uncertainty considered in the analysis were the conditions on: (1) outbreak of fire; (2) firefighting activity at initial stage of fire; (3) structural damage of individual buildings due to seismic motion; and (4) change of weather in time series.

Target historical structures includes (a) 82 national treasure and important cultural properties designated by the national government, (b) 117 important cultural properties designated or registered by the local government, (c) 235 structures added to the list of nominees for important cultural properties, and (d) 1,697 structures with the age over 70 years. The result shows that the burn-down probability of structures in the higher categories was lower than that in the lower categories.

WUI + Post-EQ fires -1 #2

Overview of NIST's Wildland-Urban Interface (WUI) Fire Research

Samuel L. Manzello
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Abstract

Wildfires that spread into communities, referred to as Wildland-Urban Interface (WUI) fires, are a significant problem in Australia, Europe, and the United States. Little understanding exists on how to contain and mitigate the hazard associated with such fires. This is due, in part, to the fact that WUI fire spread is extraordinarily challenging.

From a simple point of view, the WUI fire problem can be seen as a structure ignition problem. For example, post-fire damage studies have suggested for some time that firebrands are a significant cause of structure ignition in WUI fires, yet research on firebrands conducted over the past 40 years has focused on how far firebrands fly (known as spotting distance). Japan has been plagued by structural ignition from firebrand showers in urban fires as well.

Building codes and standards are needed to guide construction of new structures in areas known to be prone to urban/WUI fires in order to reduce the risk of structural ignition. Proven, scientifically based retrofitting strategies are required for homes located in areas prone to such fires. It is difficult to develop measurement methods to replicate wind-driven firebrand bombardment on structures that occur in actual WUI fires. Entirely new experimental approaches are required to address this problem.

To this end, NIST developed (in 2006) the NIST Firebrand Generator (the NIST Dragon) to generate controlled, repeatable firebrand showers. Since wind plays a critical role in the spread of WUI fires in the USA and urban fires in Japan, NIST has established collaboration with the Building Research Institute (BRI) in Japan. BRI maintains one of the only full scale wind tunnel facilities in the world designed specifically for fire experimentation; the Fire Research Wind Tunnel Facility (FRWTF). The coupling of the NIST Firebrand Generator and BRI's FRWTF has enabled the study of building vulnerabilities for the first time and these findings are being considered as a basis for performance-based building standards with the intent of making structures more resistant to firebrand attack.

The other major activity in WUI fire research in NIST's Fire Research Division is a well-coordinated post-fire data collection effort to gather fire behavior/structure ignition data in from actual WUI fires. Post-fire studies have been conducted in California and Texas.
Experimental research on structure ignition and the post-fire data collection effort work closely together towards the same goal of reducing WUI structure losses. A summary of these projects is presented.

WUI + Post-EQ fires -1 #3

Fire whirls caused by urban conflagration

Masahiko Shinohara[1], Sanae Matsushima[1] and Ai Sekizawa[2]

[1] *National Research Institute of Fire and Disaster* [2] *Tokyo University of Science*

Abstract

The study describes two fire whirls caused by urban conflagrations after earthquakes in Japan on March 11th, 2011 and September 1st, 1923.

A fire whirl was witnessed in the early morning of March 15th, 2011 over a conflagration at Nainowaki-cho in Kesennuma City, which was struck by a Tsunami on March 11th. To elucidate the characteristics of the fire whirl, the situation, and possible causes of the conflagration, we conducted a field investigation that included gathering eyewitness accounts. The results suggest that the fire whirl was at least 70 m high, and possibly as high as 230 m; the estimated diameter was 55–130 m. The wide range of these values result from differences in eyewitnesses' testimonies. 55 m and 130 m are roughly equivalent to the width of one and two blocks of the area, respectively. The conflagration broke out because the fire spread easily over debris-filled roads, empty lots, and a park. The debris and houses were probably dry, as the tsunami water had receded from the area before March 14th, when the fire broke, there was no rain after March 11th, the temperature rose rapidly from the morning of March 13th, and the relative humidity dropped to 25 % by noon on March 14th. Possible generation mechanisms of the fire whirl include the horizontal shear caused by variations in surface roughness over the urban area and a river adjacent to the fire scene, and the interaction of air entrainment into fires at the scene.

For comparison, we introduce our hypothesis regarding a fire whirl that struck Hifukusho-ato (an empty lot where 40,000 people had taken refuge) in the 1923 Great Kanto Earthquake. Eyewitness testimonies, the recorded fire and weather conditions, and previous experimental work suggest that at least one fire whirl occurred downwind of a large fire on the other side of the Sumida River adjacent to Hifukusho-ato. The vortex did not contain fire when it was formed. It crossed the river and struck Hifukusho-ato, which was surrounded by fire at that time. The violent wind of the fire whirl and/or strong local winds carried firebrands into Hifukusho-ato from the area around. The strong winds (80 m/s) of the fire whirl spread the fire rapidly over evacuees and flammable household goods, blowing everything away. These violent winds and the rapid spread of the fire resulted in 38,000 deaths in this one evacuation area.

WUI + Post-EQ fires -1 #4

Evaluating the Vulnerability of Buildings to Wildfire Exposures

S. Quarles

Insurance Institute for Business & Home Safety

Abstract

In October 2010, the Insurance Institute for Business & Home Safety (IBHS) opened their natural hazards research facility in Richburg, South Carolina. During 2010-11 IBHS collaborated with the Savannah River and Oak Ridge National Laboratories and the USDA Forest Service in the developing and conducting the Wildfire Ignition Resistant Home Design (WIRHD) program. This program was funded by the Department of Homeland Security Science and Technology Directorate.

The primary goal of the WIRHD program was to develop a home evaluation tool that could assess the ignition potential of a structure subjected to wildfire exposures. It was based on the Structure Ignition Assessment Model (SIAM) developed by the USDA Forest Service over a decade ago. The resulting interactive software product was named the Wildfire Ignition Resistance Estimator (WildFIRE) Wizard and allows the user to create a home or building using software tools and specify and position vegetation and other components located in the area surrounding the building.

To provide material property data and to support the educational component of the software IBHS and the Savannah River National Laboratory (SRNL) performed ember (firebrand) and radiant exposure tests at the IBHS Research Center. Ember testing were conducted to document vulnerabilities associated with near-building vegetation and mulch products, vents, roof coverings and design features and attached decks. Burning embers were produced from each of the five ember generators inside the test chamber. The ember generators were loaded with dried mulch and wood dowels of various sizes. The duration of the ember exposure for each test was about 10 minutes.

Similarly, common exterior-use construction materials were exposed to radiant heat to demonstrate vulnerabilities. The test subjects consisted of exterior siding materials, window glass, frames, fiberglass screening and curtains and re-entrant corners.

The objective of this presentation is to describe the tests that were conducted, summarize the principal results, and discuss some of the implications with regard to the vulnerabilities of typical wildfire exposures to homes and buildings.

WUI + Post-EQ fires -1 #5

Wildland Fire behavior: Combustion and Dynamics

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Abstract

Over the last 5 years a consistent set of studies were developed at the University of Edinburgh and at WPI that are geared towards a better understanding of how wildland and solid fuels ignite and burn in the context of wildland and wildland-urban interface fires.

The whole approach is based on experiments conducted with the Fire Propagation Apparatus. This device was used because of its versatility that allows testing wide ranges of various conditions applied to different fuels. To simplify the approach, well-characterized fuels were used in the form of dead pine needles and solid polymers. The main factors that were studied were the time to ignition and the heat release rate as the third component of flammability, rate of spread, has been extensively studied in wildland fire research.

To represent this specific context, two kinds of approaches were developed. Concerning wildland fuels, the effects of an air flow through porous pine needle beds was thoroughly investigated; this configuration was considered as fundamentally representing the effect of wind. Some bulk properties of wildland fuels were determined experimentally to understand their effect on the coupling between the fuel and the flow. This coupling is an essential aspect that fire spread models need to capture to provide good predictions under wind conditions.

Regarding solid fuels, the influence of a time-varying heat flux was investigated as a representative of the impact of a fire front approaching a structure at the wildland-urban interface. The objective of this approach is to provide a mechanism to assess the potential for ignition while not adding an excessive computational burden to fire-spread models.

This is particularly true for CFD models as adding the full description of the interaction between the fire and the structure would be too costly computationally. To avoid resolving the building the objective is to extract information from the CFD model that can then be used directly to establish if the material has ignited or not without requiring the modeling of the solid fuel itself.

The results show that this approach enhances our understanding of wildland fire behavior and impact in general but also at the Wildland-Urban Interface. These experimental data, along with the models developed for describing ignition represent a successful application and extension to wildland fires of approaches and techniques developed for fire safety studies.

WUI + Post-EQ fires -1 #6

Determining Firebrand Production from Full Scale Structures and Building Components

Sayaka Suzuki
National Institute of Standards and Technology (NIST)

Abstract

Wildfires that spread into communities, commonly referred to as Wildland-Urban Interface Fires (WUI Fires), are a significant international problem. Post-fire damage studies have suggested for some time that firebrands are a significant cause of structure ignition in WUI fires. While firebrands have been studied for decades, most of research focused on the spotting distance which is how far firebrands could fly and little research has been conducted to investigate firebrand production. In order to develop scientifically based mitigation strategies, it is necessary to understand the firebrand generation from structures and the vulnerabilities of structures to firebrand showers.

NIST developed the NIST Firebrand Generator (NIST Dragon), which has the ability to produce controlled and repeatable firebrand showers. The firebrand sizes generated by the NIST Dragon have been tied to those measured from full-scale tree burns and a real WUI fire (Angora, 2007). It is believed that the structures themselves may be a large source of firebrands as well as the vegetation. Due to limited studies, it cannot be determined if firebrand production from structures is similar to the one from vegetations.

To this end, firebrand production from real-scale building components under well-controlled laboratory conditions was investigated. Specifically, wall and re-entrant corner assemblies were ignited and during the combustion process, firebrands were collected to determine the size/mass distribution generated from such real-scale building components under varying wind speed. Finally, the size and mass distributions of firebrands collected in this study were compared with the data from an actual full-scale structure burn (conducted by NIST in Dixon, California) to determine if simple component tests such as these can provide insights into firebrand generation data from full-scale structures. The results are presented and discussed.

WUI + Post-EQ fires -1 #7

Effect of physical Properties on the Capability of Hot Particles to Ignite Vegetation

Casey D. Zak, Daniel C. Murphy and A. Carlos Fernandez-Pello
University of California, Berkeley

Abstract

According to the National Fire Protection Association of the United States, "outside and other" fires caused more than $500 million dollars in property damage and killed 55 civilians in the year 2010 alone. These fires are also responsible for significant biomass consumption and a large source of combustion emissions to the atmosphere. Clearly, wildland and wildland urban interface (WUI) fires have caused severe environmental and property damage, as well as the loss of life. Many of these fires are allegedly ignited by heated particles generated by powerline interactions, hot work/welding, overheated catalytic converters, seized train brakes, and other sources of hot particles. Currently, the exact process by which the ignition of vegetation by hot particles occurs and the conditions necessary to initiate a spot fire are not well understood. Consequently, current wildland fire models lack capabilities for accurately predicting the initiation of spot fires. A greater understanding of the ignition process and the conditions necessary for ignition could lead to improved predictive models and reduced losses due to fire. This work presents an experimental and theoretical study of ignition of powdered cellulose fuel beds by hot metal particles. Stainless steel and brass spheres with diameters in the range from 1.59 mm to 12.7 mm were heated to temperatures between 500C and 1200C and dropped onto cellulose fuel beds with moisture contents of 1.5% and 4.5%. The effects of varying particle diameter, temperature and thermal conductivity and fuel bed moisture content on flaming ignition propensity of the particles are discussed. Additionally, high-speed videos taken of the ignition event are presented and used in conjunction with phenomenological arguments to develop a simplified model of the ignition process. The results of this work indicate that ignition of fuel beds by large hot particles is a rapid surface phenomenon that most strongly depends on particle size and temperature. It is found that for a given material a minimum size and temperature are needed for a metal particle to ignite the fuel. This minimum becomes more stringent as the moisture of the fuel increases.

WUI + Post-EQ fires -1 #8

Scale-model Experiment of Large-scale, Wind-aided Fires

Kazunori Kuwana
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Abstract

Fire phenomena are very complicated—knowledge of fluid mechanics, heat transfer, chemical kinetics, material science, and other areas is required to study these phenomena. The complicated nature of the phenomena can be seen in a number of different stages that they cover: for example, ignition, flame spread over combustible materials, and continuous burning of combustible materials such as pool fires. Each stage has a different length scale; ignition may occur in a relatively small space, while a large-scale wildland fire can burn an area of greater than 1 km2. The time scale associated with a fire scenario also greatly varies.

A number of dimensionless parameters (or Π numbers) are associated with fire phenomena. Each fire scenario, in principle, has a different set of the parameters, each having a specific value to the scenario. Therefore, one way of studying a fire phenomenon is its full-scale reconstruction either experimentally or computationally.

Full-scale experiments as well as numerical simulations, however, are usually costly and time consuming (if not impossible). Another approach of the study is scale modeling based on an appropriate scaling analysis, the topic of this presentation.

When designing a scale-model experiment, we need to disregard the effect of minor Π numbers (otherwise full-scale experiment would be the only way of research). Consequently, a scale-modeling study is a journey to identify important parameters. Important Π numbers are often different from scale to scale. For example, in small-scale fires the effect of viscosity may be important and the Reynolds number may be a governing Π number, whereas the buoyancy effect may be important in large-scale fires, making the Froude number an important parameter. On the other hand, a strikingly simple scaling law sometimes holds to different scales, enabling us to design a simple scale-model experiment.

This presentation first discusses difficulties in designing scale-model experiments of large-scale wind-aided fires. A method to relax the scaling requirement is then proposed. The proposed method is demonstrated by reconstructing a wildland fire whirl that occurred in Brazil in 2010.

WUI + Post-EQ fires -2 #1

Investigation and its Characteristic of Post Earthquake Fire at the 3.11.

Tamura, H.
National Research Institute of Fire and Disaster

Abstract

Since March 23, 2011, the National Research Institute of Fire and Disaster in Japan (NRIFD) has been investigating a specific area damaged by fires as a result of the March 11, 2011, Great East Japan Earthquake.

To obtain useful information in the prevention of fire outbreaks and spreading fires following future large-scale disasters, we investigated the following particulars: Cause of the fire, Area where the fire spread, Cause of stopping the fire, Photos and video records of the stricken area, Collection of testimonies. The districts where the NRIFD investigated fire are as follows: Iwate prefecture (1) Noda village (2) Miyako city (3) Yamada-machi (4) Ootsuchi-cho, Miyagi prefecture (5) Kesen-numa City (6) Ishinomaki city (7) Sendai City (8) Natori city, Fukushima prefecture (9) Iwaki city

Characteristics of the fire in the Great East Japan Earthquake had the following features:

(1) Many of the affected fire sites covered a wide spreading area (over 100,000 m^2).

(2) Fires occurred in a lot of prefectures.

(3) The total area of a large urban fire was very wide.

Forest fires also occurred in places, such as Yamada-cho, Kesennuma City, etc. Some of these fires spread over an area of 1,000,000 m^2 or more.

The main features of the cause of the fire, spread of the fire, and stopping the fire's spread end are as follows based on the fire survey:

Cause of the fire (a) Fire broke out from rubble carried away by the tsunami.

(b) Fire broke out from cars that were carried away by the tsunami or were soaked in seawater once.

(c) Electric power equipment, such as the integrating wattmeter, was soaked in seawater once and caught fire when electric power was restored.

Spread of the fire (a) Fire spread in places where burned cars and rubble were carried away by the tsunami.

(b) Gas cylinders carried away by the tsunami leaked their contents. There is a possibility that this gas became a factor in the fire's spread.

(c) Fire spread from urban areas to the forest.

Stopping the fire's spread

(a) A wide road, fireproof buildings, a graveyard, and a rice field stopped the fire's spread.

(b) There were a lot of fire sites that the fire brigade was not able to approach. However, fire's spread was halted in places where the fire brigade fought the blaze.

WUI + Post-EQ fires -2 #2

Fuel Treatment Impacts to Fire Behavior and Ecosystem Services in the Wildland-Urban Interface

Christopher A. Dicus
California Polytechnic State University

Abstract

To best insure sustainable communities in the wildland-urban interface (WUI), management strategies for a given area must be developed that minimizes both fire risk and also the residual impact to the ecosystem services (carbon sequestration, vegetative air pollution removal, etc.) that distinct vegetation types provide.

This presentation discusses ongoing research into how various WUI fuel treatments in shrub- and forest-dominated ecosystems simultaneously impact potential fire behavior and environmental benefits provided by vegetation. Multiple scales, including stand- and landscape-levels, are evaluated. Methodologies for these types of evaluations will be provided to assist land managers in making sound decisions in their local communities. The presentation also discusses critical elements necessary for holistic, sustainable fire management in the wildland-urban interface."

WUI + Post-EQ fires -2 #3

Fires and Damage of Oil Tanks Caused by the 3.11 Earthquake

Nishi Haruki
National Research Institute of Fire and Disaster

Abstract

The 2011 off the Pacific coast of Tohoku Earthquake (M9.0) occurred on March 11, 2011 and shook Miyagi Prefecture with a strong earthquake of magnitude 7 (Japanese scale) . A vast range over an east part of Japan suffered damage by a strong ground motion, moreover wide range of the pacific coast of Tohoku area suffered damage by Tsunami. The earthquake caused damage to oil storage tanks and other hazardous material facilities in petrochemical industrial complex. For example, some of them caught fire after the earthquake and large amount of oil leaked from oil storage tanks. Therefore, National Research Institute of Fire and Disaster have investigated damage including the fires and failures of the oil storage tanks and other hazmat facilities.

In this paper, the author reports the outline of the result of the investigation. The damage of the oil storage tanks and hazmat facilities has a different aspect by area. The oil storage tanks and other hazmat facilities damaged mainly by the Tsunami on the pacific coast and the strong ground motion caused the liquefaction of the foundation ground. On the coast of the Sea of Japan, the earthquake generated sloshing of liquid in large oil storage tanks and caused oil spill on the floating roofs and caused damage to the pontoon of the floating roofs. Moreover, on the shore of the Bay of Tokyo, one of the floating roofs sank after the earthquake because the deck of the floating roof cracked during the earthquake and lost buoyancy.

The author will examine the results in order to suggest the measure against same kind of accidents.

WUI + Post-EQ fires -2 #4

Experimental Study on the Possibility of the Vehicles Fire in Urban and Tsunami Fire - About the Burning Behavior for Motorcycles –

Ken Matsuyama
Tokyo University of Science

Abstract

The Great East-Japan Earthquake occurred on March 11, 2011, inflicted serious damage such as the collapse of buildings, accidents at a nuclear power plant, the spread of fire and others caused by main shocks, aftershocks and huge-scale tsunami. Tsunami-induced fire was one of most characteristic circumstances in the Great East-Japan Earthquake. Especially, as the further shocking circumstance, burning buildings and debris floating on top of the tsunami as well as many burning cars and motorbikes consecutively were recognized. The ignition trigger of tsunami-induced fires is still unclear, however the various causes such as electricity accidents, acceleration of the oxidation of metals by seawater and others were assumed. In any case, the debris of buildings, ships, cars and motorbikes carried by the tsunami ignited and burned, and the large-scale tsunami-induced fires occurred after ignited floated heavy and light oil, LPG or gasoline on the sea flowed from collapsed storage tanks in industrial areas burned.

As the focus for discussion in this study, the full-scale burning experiments of motorbikes were carried out to understand the burning behaviors of the single and multiple, and also combustion properties of the used materials were investigated in detail by using cone calorimeter. Firstly, the amount of combustible materials used in it was investigated. And then, full-scale experiments of two series were carried out to reveal the burning behavior as free burning. The first series of full-scale experiments was conducted to realize the single motorbike burning characteristics, for instance heat release rate (HRR) and flame height. In the series, each of twelve motorbikes which are different from the engine displacement and type was burned. The engine displacement was grouped into 4 sizes, and the motorbike types were classified into 3 categories. Experimental results indicated that the maximum HRR depended on motorbike type, not displacement.

In the other series, two motorbikes set which offset distance was 1m, and ignited one motorbike. Non-ignited motorbike was received heat flux from a burning motorbike, and side plastic parts ignited. The side part burned speedily and HRR of non-ignited motorbike increased rapidly because of a pyrolysis development of plastic materials. The maximum HRR of non-ignited motorbike was greater than it of one motorbike.

WUI + Post-EQ fires -2 #5

Fires in Non-inundated Area Following the 3.11 Earthquake

Iwami, T. and Kagiya, K.
National Institute for Land and Infrastructure Management

Abstract

Large number of fires occurred in wide area due to the 3.11 Earthquake and the tsunami following the earthquake brought severe damage to buildings.

Mass media have reported intensively fire due to the tsunami, but many fires due to earthquake motion in non-inundated area are also identified in the damaged areas which did not have the damage of tsunami.

In this presentation, it is introduced that outline of the fires reported in the municipalities damaged by the earthquake and the features of the building fires occurred in non-inundated area.

The total 284 fires including non-building fires reported (as of the end of March, 2012) by Fire and Disaster Management Agency (FDMA) of Ministry of Internal Affairs and Communications (MIC). Among the prefectures damaged by the earthquake, more than half of the total numbers of fires were occurred in Miyagi prefecture. These 284 fires include not only fires occurred in the mainshock at 14:46 on March 11, but also ones in aftershocks. According to the data, out of 284 fires, 112 fires are reported in the municipalities in non-inundated area. In order to get the detailed information about the fires, such as damage, cause of fire, circumstances of firefighting at that time, investigations have been conducted. Investigation by interview with personnel of the local firehouses in charge of the area where the fire occurred, and visit to some of the typical fire scenes were made.

As a result, it is found that major cause of the fire in non-inundated area is heat sources contacting surrounding combustibles with the earthquake motion and electric fires at the recovery of power supply from power failure and misuse of the candle which is used for the light in the midst of blackout nights which were also seen as past time.

The main feature of the fire in non-inundated area following the 3.11 Earthquake is as follows:

1) Fire break-out ratio in non-inundated area of the earthquake is approximately 1/4 of the ratio of 2004 Chuetsu earthquake and 1/12 of the ratio of 1995 Hyogo-ken Nanbu (Kobe) earthquake.
2) In non-inundated area, many fires occurred immediately after mainshock (in the period from 14:46 to 18:00 on March 11).
3) Except immediately after the mainshock, the occurrences of fire were concentrated on the day of the mainshock and in the period from 18:00 to 24:00 on the following days.
4) For the most cases, firefighting worked effectively and all of the fires died down in a single building of fire origin or with a few buildings.
5) Many fires occurred due to the effect of the recovery of power supply and the activity of residents rather than the effect of the earthquake motion.

WUI + Post-EQ fires -2 #6

FIRE EXPOSURE OF ROOF-MOUNTED PHOTOVOLTAIC SYSTEMS

Robert Backstrom, Mahmood Tabaddor PhD, Thomas Fabian PhD, and Pravinray D. Gandhi *PE PhD*
Corporate Research, UL LLC

Abstract

The growth of solar photovoltaic (PV) has been substantial in the last few years, especially in the state of California (USA), that had approximately 58% of all grid-tied PV capacity in the US in 2007. As a consequence of the prevalence of solar PV modules on roofs, and plans for additional deployments as homeowners seek avenues for energy efficiency, fire and code officials are concerned about the potential fire hazards when a rack mounted PV array is installed on a rooftop[1]. Funded by the U.S. Department of Energy, Underwriters Laboratories Inc. (UL) in partnership with Solar America Board for Codes and Standards (Solar ABCs) designed and conducted tests to characterize the effects of stand-off mounted (elevated, parallel to roof surface) PV modules on the fire class rating of common roof covering materials.

Flammability of roofing systems and PV modules are assessed by UL 7902/ASTM E 1083 Spread of Flame and Burning Brand tests (PV modules are assessed under UL 17034). These flammability tests, however, are ordinarily performed on the roof covering or a PV module in isolation. The tests conducted for this investigation were designed to examine the combined effects of modules and roof coverings as a system when exposed to fire.

The presence of a rack mounted PV module on a roof assembly was found to have an adverse effect on the fire performance of the roof regardless of the fire rating of the roof or the Class rating of the PV panel. Greater temperatures and heat flux were observed on the roof surface in the area underneath the PV module. The magnitude of these effects was dependent on the gap size between the module and the roof, as well as the setback distance of the module from the roof leading edge.

The extent of the impact was also found to be dependent on the angle of the module relative to the roof and the type of roofing system.

1 Website: osfm.fire.ca.gov/photovoltaics.php
2 UL 790, Standard Test Methods for Fire Tests of Roof Coverings, 8th Edition, Underwriters Laboratories Inc., 2004
3 ASTM E 108, Standard Test Methods for Fire Tests of Roof Coverings, ASTM International, 2011
4 UL 1703, Standard for Safety for Flat-Plate Photovoltaic Modules and Panels, 3rd Edition, Underwriters Laboratories Inc., 2002

Qualitative Aspect of the Fires Fueled by the Combustibles Arriving in the Vicinity of the Tsunami Refuge Buildings

Tomoaki NISHINO, Dr.Eng.
Kobe Univ.

Abstract

We present a part of the aspect of the fires in the vicinity of the tsunami refuge buildings in Kesennuma city qualitatively with attention to the combustibles conditions based on the image records and the eyewitness testimonies. Even if fires approach the tsunami refuge building, it is difficult for the housed evacuees to escape from the building because of the surrounding seawater and debris. Therefore, when smoke or fire flows into the building, the evacuees are likely to be put themselves in danger. To find the measures controlling the fire spread to the tsunami refuge building, it is essential to solve a problem how much degree we should expect as the heating strength due to the tsunami-induced fire.

As a result, we obtained the following types of the combustibles conditions expected in the vicinity of the tsunami refuge building: (1) a mass of fine debris heaped up around the tsunami refuge building such as a broken piece of a member; (2) a mass of minor-damaged houses retaining the original form of the upper part arriving around the tsunami refuge building; (3) fine debris floating on leaked oil making a long line in the bay; and (4) a fire-resistant building originally in the neighborhood of the tsunami refuge building. The combustibles (1) and (2) made the open-space around a tsunami refuge building expected to prevent the usual fire spread disappear. Whereas slow combustion was observed for the fire fueled by the combustibles (1), the fire fueled by the combustibles (2) led to ignite the rooms of a tsunami refuge building and the evacuees housed in the building waited moving from room to room till the fire was extinguished. The combustibles (3) formed about two kilometers line fire inside the Gulf of Kesennuma and released the huge fire plumes. Fortunately, the tsunami refuge buildings were never exposed to the plumes because of the calm weather conditions. The fire fueled by the combustibles (4) involved the whole of a three-story fire-resistant building in the neighborhood of a tsunami refuge building and the flames vented from openings were observed.

From now, the following efforts are thought to be needed: (1) fire experiments to estimate the heat strength to the tsunami refuge building quantitatively; and (2) a method to predict the drifting behaviors of the above combustibles.

WUI + Post-EQ fires -2 #8

Statistical Modeling of Post-earthquake Ignitions

Rachel A. Davidson
University of Delaware

Abstract

This paper presents a new rigorous approach to statistical modeling of post-earthquake ignitions and data compilation for such modeling. An application to late 20th century California is described, as is a current effort to apply it to Japan. Specifically, generalized linear and generalized linear mixed models (GLMs and GLMMs) are developed that can be used to estimate the number of ignitions in each area unit (census tract) as a function of tract characteristics and the ground shaking experienced in a specified earthquake.

This presentation begins with challenges associated with data to support ignition models. Several important issues are highlighted, including the need to explicitly and consistently define which ignitions are considered, which region data are collected for, and what the geographic unit of study is. These decisions influence the conclusions that can be drawn from subsequent statistical analysis. The data set developed for the California application is then described, followed by background on the models used and the model selection process.

The statistical modeling approach offers some advantages over previous efforts. Using GLMs and GLMMs provides a more natural treatment of discrete nonzero ignition counts. Unlike previous models that focus on a single predictor, many covariates are examined and several are ultimately identified as significant. Using census tracts as the unit of study also allows simulation for future earthquakes to produce estimates at a finer geographic resolution. Including all tracts that experience nonzero ground shaking allows better estimation of zero ignition counts. For loss estimation and policy analysis, it is important to be able to estimate where ignitions are *not* likely to occur, as well as how many there will be in areas where they do occur.

The final recommended models developed for California are presented, including a discussion of how they can be interpreted and applied in a predictive mode for future or hypothetical earthquakes. Two data sets were developed to explore the effect of missing ignition data, each with a different assumption about the missing data. For one data set, the recommended model includes instrumental intensity; percentage of land area that is commercial, industrial, or transportation; total building area; percentage of building area that is unreinforced masonry; and people per square kilometer. The other includes the same, except area of high-intensity residential development replaces total building area, and median year built over all housing units is also included. Finally, the current effort to apply this ignition modeling approach in Japan is discussed, including the data required to support the effort.

Appendix 4

Presentations delivered in this workshop

Fire-Structure Interaction & Urban and WUI fires

"Operation TOMODACHI: Fire Research"

日本火災学会

Dr. Tokiyoshi YAMADA
The University of Tokyo
Chair of International Cooperation Committee of
JAPAN ASSOCIATION FOR SCIENCE AND ENGINEERING

Dr. Samuel L. Manzello
Engineering Laboratory (EL)
National Institute of Standards and Technology (NIST)
Gaithersburg, MD. USA

USA/JAPAN Workshop
July 2nd, 2012

Kick-Off Japan-USA Workshop

Japn/US Workshop
held at NIST June 27,2011
To explore areas of mutual collaborative interest on Fire Spread in urban and WUI fires.

Focused on urban/WUI fires

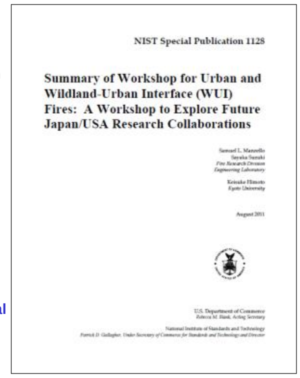
Intended to Generate Momentum for future workshops

Documented as:

NIST Special Publication

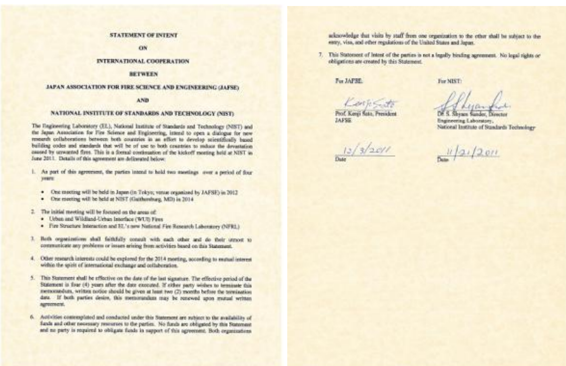
Special Issue in Fire Safety Journal

Manzello/Himoto (Eds.)


NIST Special Publication 1128

Summary of Workshop for Urban and Wildland-Urban Interface (WUI) Fires: A Workshop to Explore Future Japan/USA Research Collaborations

JAFSE and NIST Statement of Intent


STATEMENT OF INTENT
ON
INTERNATIONAL COOPERATION
BETWEEN
JAPAN ASSOCIATION FOR FIRE SCIENCE AND ENGINEERING (JAFSE)
AND
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY (NIST)

日本火災学会 **JAFSE** JAPAN ASSOCIATION FOR SCIENCE AND ENGINEERING

STATEMENT OF INTENT ON INTERNATIONAL COOPERATION BETWEEN JAFSE 日本火災学会 AND NIST

1. As part of this agreement, the parties intend to hold two meetings over a period of four years:
   One meeting will be held in Japan (in Tokyo; venue organized by JAFSE) in 2012
   One meeting will be held at NIST (Gaithersburg, MD) in 2014 !

2. The initial meeting will be focused on the areas of:
   Fire Structure Interaction and EL's new National Fire Research Laboratory (NFRL)
   Urban and Wildland-Urban Interface (WUI) Fires

3. Both organizations shall faithfully consult with each other and do their utmost to communicate any problems or issues arising from activities based on this Statement.

4. Other research interests could be explored for the 2014 meeting, according to mutual interest within the spirit of international exchange and collaboration.

(* snif *)

FIRE-STRUCTURE INTERACTION (IN JAPAN)

NIMLI Full-scale Fire Test for Wooden 3-Story School Building February 22, 2012

Japanese Perspective (I. Fire-Structure Interaction)

1. **Effect of Deformation of Structural Frame on Fire Resistance of Compartmentation**
   Suzuki, J. (Building Research Institute)
2. **Fire Safety of Curtain Wall Spandrel -Proposal for Curtain Wall Spandrel Board Supported by Structural Members-**
   Nishimura, T. (Takenaka, Corporation)
3. **Calculation methods for Temperature Rise of Compartment Walls Exposed to Fire Heating**
   Mizukami, T. (Center for Better Living)
4. **An Experimental Study on Fire Resistance of Composite Structure Consisting of Steel beam and Partition Wall**
   Morita, T. (Shimizu Corporation)
5. **Strategic Measure for Ensuring Fire Safety of Buildings after An Earthquake**
   Kohno, M. (Tokyo University of Science)
6. **Full-scale Fire Test for Wooden 3-Story School Building (Preliminary Test)**
   Nii, D. and Yoshioka H. (National Institute for Land and Infrastructure Management)

Total 6 Titles

NATIONAL FIRE RESEARCH LABORATORY (NFRL)

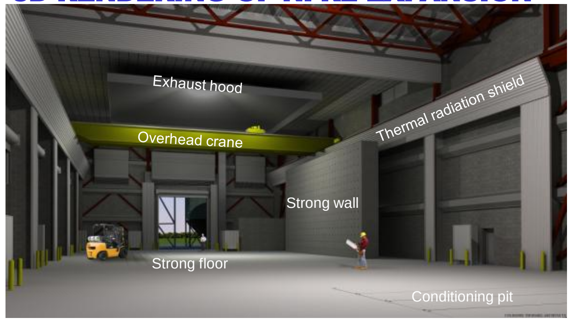
At present, there are no science-based, established measurement tools to evaluate the performance of an entire structure, including connections, under realistic fire loads (e.g., uncontrolled fire).

The expanded facility will enable:

- Study of real-scale structural components or systems
- Controlled hydraulic loading simulating service load conditions
- Up to 20 MW fire exposure for 4 hrs
- Measurement of structural performance to incipient collapse
- Characterization of fire intensity (heat release rate)

This combination of features is unique in the world and will enable the development of measurement science needed for performance-based design methodologies for structures in fire.

3D RENDERING OF NFRL EXPANSION



USA Perspective (I. Fire-Structure Interaction)

1. Experimental Evaluation of Column Stability and Its Influence on Overall Structure Collapse under Fire Loading
   Varma, A. (Purdue University)
2. Barriers to Performance-Based Structural Fire Safety Design
   Engelhardt, M. (University of Texas)
3. Performance and Research Needs for Bridges Subject to Fire
   Garlock, M. and Kodur, V. (Princeton University/Michigan State University)
4. Response Sensitivity and Reliability Analysis of Structures in Fire
   Jeffers A. (University of Michigan)
5. National Fire Research Laboratory
   Manzello, S (National Institute of Standards and Technology)

Total 5 Titles

URBAN FIRES FOLLOWING GREAT EARTHQUAKE

1995 Kobe Earthquake January 17, 1995

WILDLAND-URBAN INTERFACE (WUI) FIRES FOLLOWING THE GREAT EARTHQUAKE

the Great East Japan Earthquake March 11, 2011

WILDLAND-URBAN INTERFACE (WUI) FIRES FOLLOWING THE GREAT EARTHQUAKE

Japanese Perspective (II. Urban/WUI fires)

1. Urban Fire Spread Modeling and Loss Prevention Planning
   Himoto, K. (Kyoto University)
2. Fire Whirls Caused by Urban Conflagration
   Shinohara, M. (National Research Institute of Fire and Disaster)
3. Scale-model Experiment of Large-scale, Wind-aided Fires
   Kuwana, K. (Yamagata University)
4. Investigation and its Characteristic of Post Earthquake Fire at the 3.11.
   Tamura, H. (National Research Institute of Fire and Disaster)
5. Fires and Damages of Oil Tanks Caused by the 3.11 Earthquake
   Nishi, H. (National Research Institute of Fire and Disaster)
6. Experimental Study on the Possibility of the Vehicles Fire in Urban and Tsunami Fire - About the Burning Behavior for Motorcycles –
   Matsuyama, K. (Tokyo University of Science)
7. Fires in Non-inundated Area Following the 3.11 Earthquake
   Iwami, T. and Kagiya, K. (National Institute for Land and Infrastructure Management)
8. Qualitative Aspect of the Fires Fueled by the Combustibles Arriving in the Vicinity of the Tsunami Refuge Buildings
   Nishino, T. (Kobe University)

Total 8 Titles

WILDLAND-URBAN INTERFACE (WUI) FIRES

WUI – structures and wildland vegetation coexist

Of the 10 largest fire loss incidents (> $1B) in U.S. history, 5 were WUI fires - all within the last 17 years

Wildland-Urban Interface (WUI) Fires

2003
Southern California Fire

2007 Southern California Fire

USA Perspective:(II. Urban/WUI fires)

1. Overview of NIST's Wildland-Urban Interface (WUI) Fire Research
   Manzello, S. (National Institute of Standards and Technology)
2. Evaluating the Vulnerability of Buildings to Wildfire Exposures
   Quarles, S. (Insurance Institute for Business and Home Safety)
3. Wildland Fire behavior: Combustion and Dynamics
   Simeoni, A. (Worcester Polytechnic Institute)
4. Determining Firebrand Production from Full Scale Structures and Building Components
   Suzuki, S. (National Institute of Standards and Technology)
5. Effect of Physical Properties on the Capability of Hot Particles to Ignite Vegetation
   Fernandez-Pello, C. (University of California, Berkeley)
6. Fuel Treatment Impacts to Fire Behavior and Ecosystem Services in the Wildland-Urban Interface.
   Dicus, C. (California Polytechnic State University)
7. Fire Exposure of Roof-Mounted Photovoltaic Systems
   Fabian, T. (Underwriters Laboratory)
8. Statistical Modeling of Post-earthquake Ignitions
   Davidson, R. (University of Delaware)

Total 8 Titles

Other Programs for future collaboration

Laboratory Tours

#0 Tokyo University of Science: Fire Resrach and Test Laboratory: 1st JUL.
#1 Building Research Institute : 3rd JUL.
#2 National Research Institute of Fire and Disaster : 4th JUL.
boraFire Spread in urban and WUI fires of great interest

Additional Session:Future Collaboration and Workshop

By exchanging information and ideas, we will discuss to explore areas of mutual collaborative interest on two topics.
Also future collaboration possibility in other topics will be welcomed.

Workshop Documentation

NIST will issue a Special Publication
All presentations will be included

A summary manuscript will be published in
Fire Safety Journal
Authored By:

Manzello (NIST) and Yamada (University of Tokyo)

Fernandez-Pello (Berkeley) and Himoto (Kyoto)

Jeffers (U. of Michigan) and Ohmiya (TUS)

Objective of the Workshop

Japn/US Workshop at NIST June 27,2011

To explore areas of mutual collaborative interest on Fire Spread in urban and WUI fires of great interest o Japan and USA these topics.

Kickoff Meeting

Nov.2011 : STATEMENT OF INTENT
on International cooperation between JAFSE and NIST
JAFSE : JAPAN ASSOCIATION FOR SCIENCE AND ENGINEERING
NIST : NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY)

Formal continuation meeting

US/Japn Workshop at BRI/NRIFD July 2-4,2012

To open a dialogue for new research collaborations between both countries in an effort to develop scientifically based building codes and standards.

Effects of Deformation of Structural Frame on Fire Resistance of Compartmentation

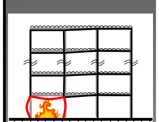
Jun-ichi Suzuki
Department of Fire Engineering
Building Research Institute, Japan

Contents

Background

Fire resistance design

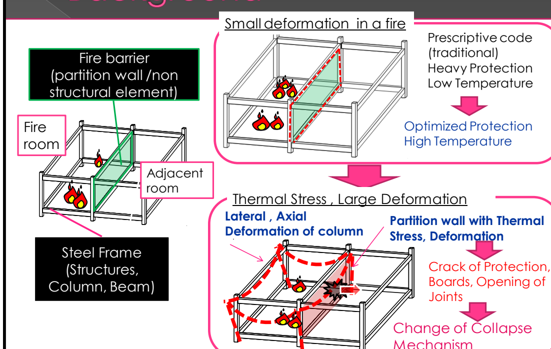
- Structural Stability
- Compartmentalization
- Collapse Temperature



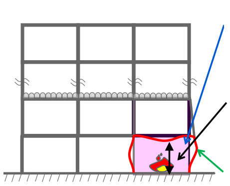
Assumption in design

- Collapse temperature(Plastic theory)
  - Stress redistribution capacity of the frame Structural Frames ≧ a single structural element
  - Residual strength after column buckled
- Fire protection and fire compartment
  - Maintain performance until structures collapse

Background



Objective



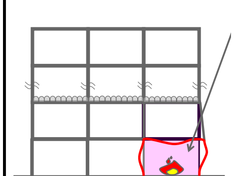
1- **Behavior of Partition Walls with Horizontal Deformation**
-Influence of thermal extension of a heated beam

2- **Behavior of Partition Walls with thermal stress and forced axial deformation**
-Influence of deflection of a heated beam

3- **Behavior of heated columns with Horizontal Deformation**
- Influence of thermal extension of a heated beam

- Three types of Experiments to clarify the performance

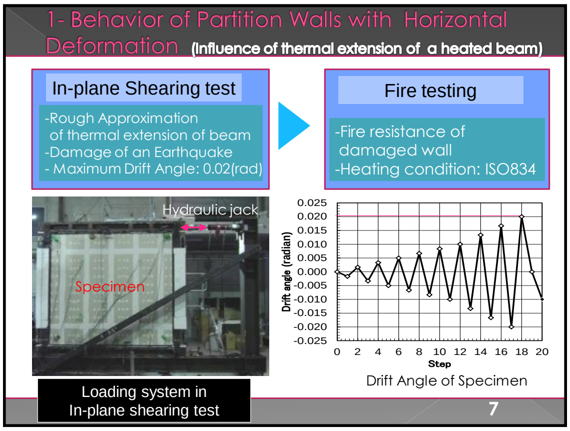
First Experiment



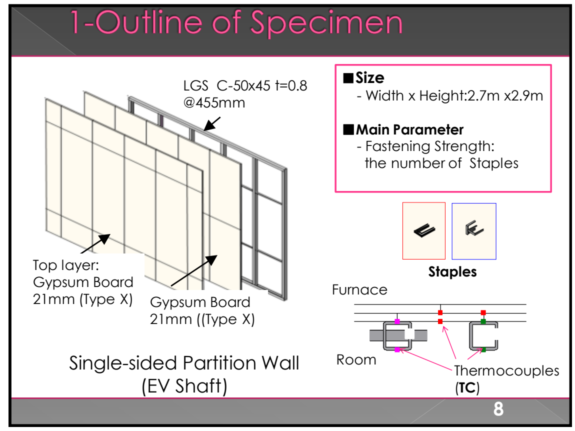
1- **Behavior of Partition Walls with Horizontal Deformation**
-Influence of thermal extension of a heated beam

2- **Behavior of Partition Walls with thermal stress and forced axial deformation**
-Influence of deflection of a heated beam

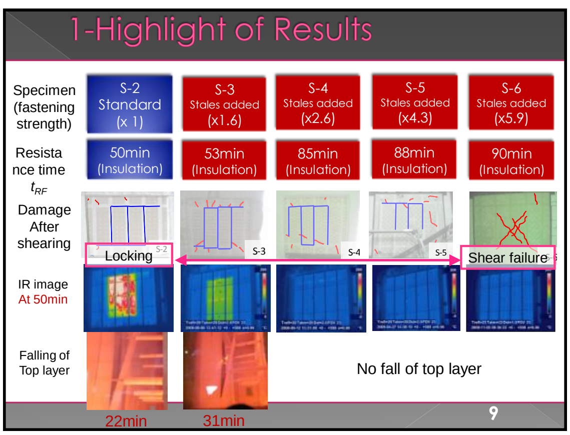
3- **Behavior of heated columns with Horizontal Deformation**
- Influence of thermal extension of a heated beam



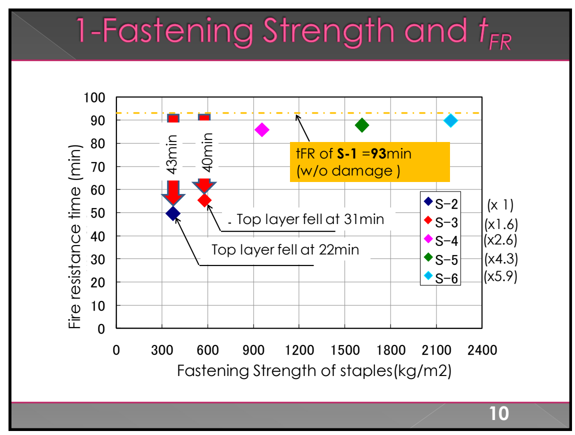
1- Behavior of Partition Walls with Horizontal Deformation (Influence of thermal extension of a heated beam)
In-plane Shearing test
-Rough Approximation of thermal extension of beam
-Damage of an Earthquake
- Maximum Drift Angle: 0.02(rad)
Fire testing
-Fire resistance of damaged wall
-Heating condition: ISO834
Hydraulic jack
Specimen
Loading system in In-plane shearing test
Drift angle (radian)
Step
Drift Angle of Specimen
7



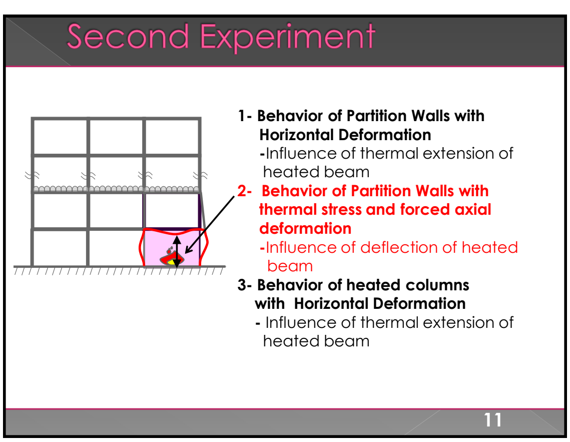
1-Outline of Specimen
LGS C-50x45 t=0.8 @455mm
Top layer: Gypsum Board 21mm (Type X)
Gypsum Board 21mm ((Type X)
Single-sided Partition Wall (EV Shaft)
■Size
- Width x Height:2.7m x2.9m
■Main Parameter
- Fastening Strength: the number of Staples
Staples
Furnace
Room
Thermocouples (TC)
8



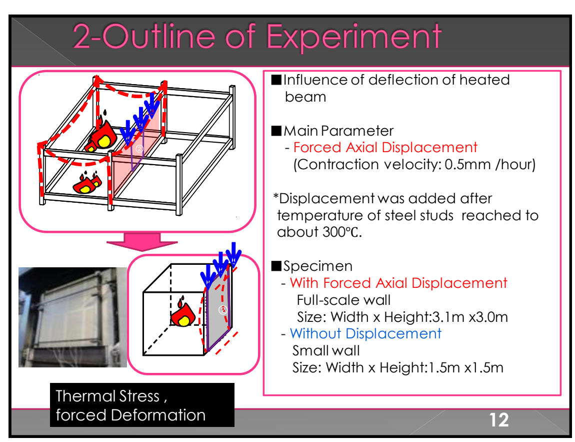
1-Highlight of Results
Specimen (fastening strength)
S-2 Standard (x 1)
S-3 Stales added (x1.6)
S-4 Stales added (x2.6)
S-5 Stales added (x4.3)
S-6 Stales added (x5.9)
Resistance time t_{RF}
50min (Insulation)
53min (Insulation)
85min (Insulation)
88min (Insulation)
90min (Insulation)
Damage After shearing
Locking
Shear failure
IR image At 50min
Falling of Top layer
22min
31min
No fall of top layer
9



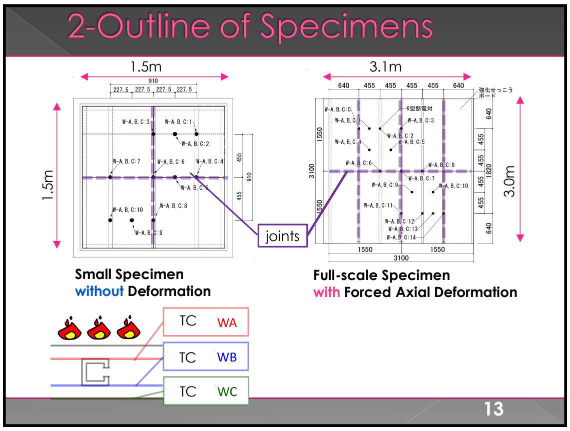
1-Fastening Strength and t_{FR}
Fire resistance time (min)
43min
40min
tFR of S-1 =93min (w/o damage)
Top layer fell at 31min
Top layer fell at 22min
S-2 (x 1)
S-3 (x1.6)
S-4 (x2.6)
S-5 (x4.3)
S-6 (x5.9)
Fastening Strength of staples(kg/m2)
10

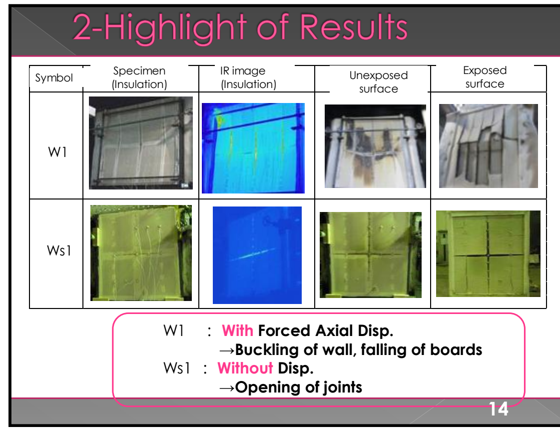


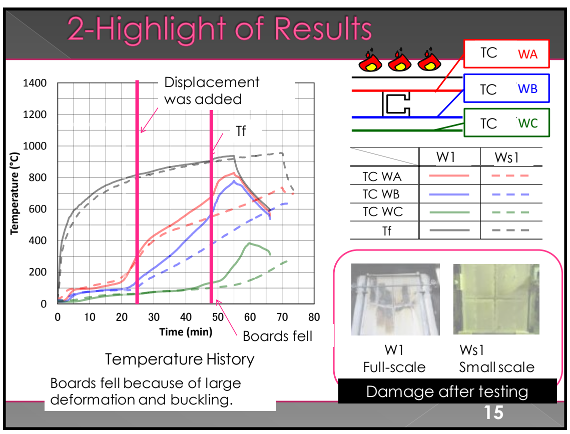
Second Experiment
1- Behavior of Partition Walls with Horizontal Deformation
-Influence of thermal extension of heated beam
2- Behavior of Partition Walls with thermal stress and forced axial deformation
-Influence of deflection of heated beam
3- Behavior of heated columns with Horizontal Deformation
- Influence of thermal extension of heated beam
11

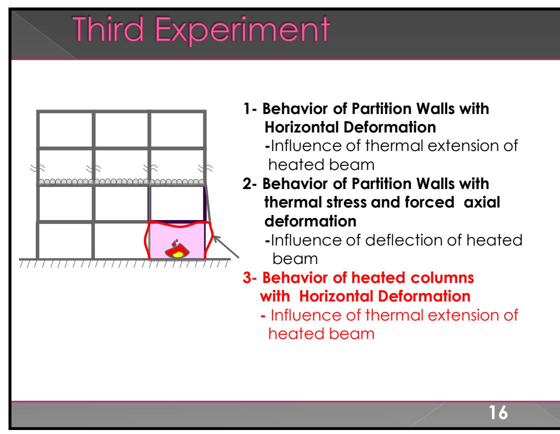


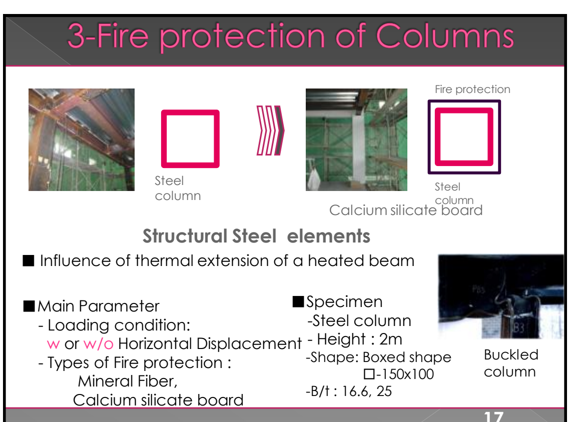
2-Outline of Experiment
■Influence of deflection of heated beam
■Main Parameter
- Forced Axial Displacement
(Contraction velocity: 0.5mm /hour)
*Displacement was added after temperature of steel studs reached to about 300℃.
■Specimen
- With Forced Axial Displacement
Full-scale wall
Size: Width x Height:3.1m x3.0m
- Without Displacement
Small wall
Size: Width x Height:1.5m x1.5m
Thermal Stress , forced Deformation
12

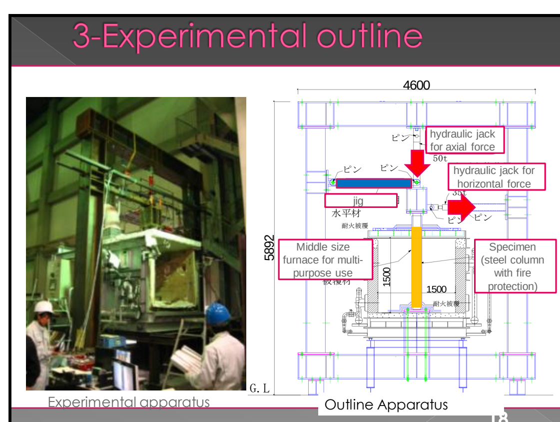

2-Outline of Specimens
1.5m
3.1m
1.5m
3.0m
joints
Small Specimen
without Deformation
Full-scale Specimen
with Forced Axial Deformation
TC WA
TC WB
TC WC
13


2-Highlight of Results
Symbol
Specimen (Insulation)
IR image (Insulation)
Unexposed surface
Exposed surface
W1
Ws1
W1 : With Forced Axial Disp.
→Buckling of wall, falling of boards
Ws1 : Without Disp.
→Opening of joints
14


2-Highlight of Results
Displacement was added
Tf
Temperature (°C)
Time (min)
Boards fell
Temperature History
Boards fell because of large deformation and buckling.
TC WA
TC WB
TC WC
W1
Ws1
TC WA
TC WB
TC WC
Tf
W1 Full-scale
Ws1 Small scale
Damage after testing
15

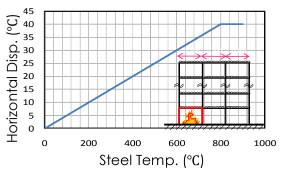

Third Experiment
1- Behavior of Partition Walls with Horizontal Deformation
-Influence of thermal extension of heated beam
2- Behavior of Partition Walls with thermal stress and forced axial deformation
-Influence of deflection of heated beam
3- Behavior of heated columns with Horizontal Deformation
- Influence of thermal extension of heated beam
16

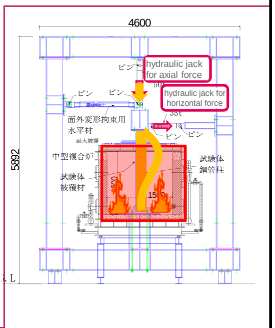

3-Fire protection of Columns
Steel column
Fire protection
Steel column
Calcium silicate board
Structural Steel elements
■ Influence of thermal extension of a heated beam
■Main Parameter
- Loading condition:
w or w/o Horizontal Displacement
- Types of Fire protection :
Mineral Fiber,
Calcium silicate board
■Specimen
-Steel column
- Height : 2m
-Shape: Boxed shape
□-150x100
-B/t : 16.6, 25
Buckled column
17


3-Experimental outline
Experimental apparatus
4600
hydraulic jack for axial force
hydraulic jack for horizontal force
jig
5892
Middle size furnace for multi-purpose use
Specimen (steel column with fire protection)
1500
1500
G. L
Outline Apparatus
18

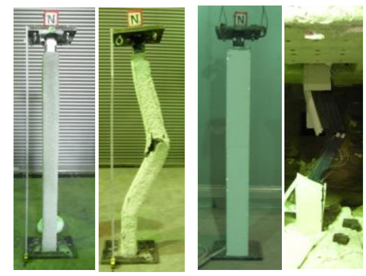
3-Experimental Procedure

①Axial Force : P = 0.5 Py
②Heating : ISO834
③Horizontal Disp. At Top of Column with the increase in steel Temperature
(up to 40mm(1/50 rad.))
④Compress 5% of height after column buckled





Specimens(steel column with fire protection)



Experimental results (Sprayed mineral fiber)

Axial Strain 5%

Width to thickness ratio 17

Elapsed time	83(min)
Temp. avg.	720(° C)
Temp. max	819(° C)
Vertical disp.	110 (mm)
Horizontal disp.	41 mm

Width to thickness ratio25

Elapsed time	56(min)
Temp. avg.	580(° C)
Temp. max	615(° C)
Vertical disp.	105 (mm)
Horizontal disp.	39 mm

Experimental results (Calcium silicate boards)

Axial Strain 5%

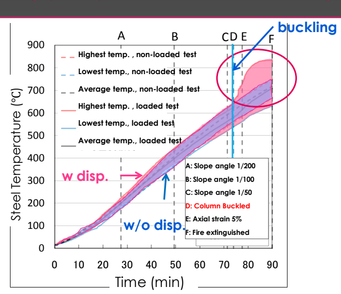
Width to thickness ratio 17

Elapsed time	61.5(min)
Temp. avg.	606(° C)
Temp. max	763(° C)
Vertical disp.	101 (mm)
Horizontal disp.	39 mm

Width to thickness ratio25

Elapsed time	49.5(min)
Temp. avg.	734(° C)
Temp. max	888(° C)
Vertical disp.	106 (mm)
Horizontal disp.	40.1 mm

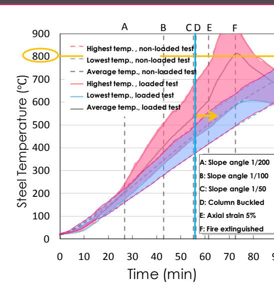
Results (sprayed mineral fiber)



Width to thickness ratio =17

Horizontal Displacement didn't have any effect on steel temperature.
Buckling caused increase in steel temperature.

Results(calcium silicate board)



Width to thickness ratio =17

Horizontal Displacement have greater effect on steel temperature.

Summary

- 1- Behavior of Partition Walls with Horizontal Deformation
  - Fire testing following In-plane shearing test was conducted.
    - In-plane shearing test replicated the rough approximation of extension of a heated beam and damage of an earthquake.
  - Horizontal deformation decreased the fire resistance of partition walls because adherence property between boards lost.
  - Higher Fastening strength provided greater fire resistance.
- 2- Behavior of Partition Walls with thermal stress and forced deformation
  - Thermal stress and deformation decreased fire resistance of partition walls
- 3- Behavior of heated columns with Horizontal Deformation
  - Steel columns protected with Sprayed mineral fiber had greater performance than those with board assemblies.
- The interaction between structures and non structural elements is important to estimate accurate performance.

Column Stability and Influence on Structural Collapse under Fire Conditions

Amit H. Varma, Anil Agarwal, and Lisa Choe
Purdue University, Bowen Laboratory

Acknowledgments

- Graduate PhD students at Purdue
- Sponsors
- NIST
- NSF
- AISC
- AISI
- Purdue University

Outline

- Introduction - Researcher, University, and Laboratory
- Goal and Objectives
- Part 1 - Collapse Simulation of Building Structures
- Part 2 - Column Stability Analysis
- Part 3 - Experimental Verification
- Summary and Conclusions

Introduction

- Amit H. Varma

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- Bowen Laboratory for Large-Scale Testing

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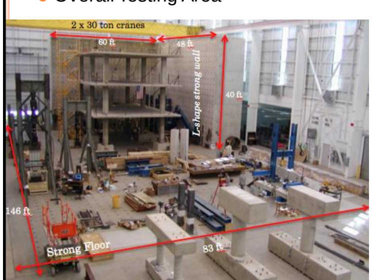
Bowen Laboratory

- Overall Testing Area



Hydraulic Equipment
120 gpm MTS pump and cooler
2 x 330 kip dynamic actuators
4 x 220 kip dynamic actuators
5 x 100 kip static actuators
4 x 1000 kip cyclic actuators
2 x 500 kip cyclic actuators

MTS Flex-Test GT Controller with 8 channels and 4 independent stations
Several MTS independent (458) controllers
Several Hydraulic Service Manifolds (HSM) to facilitate dynamic testing.

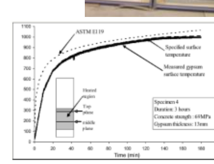
Special HSMs to use MST pump and hydraulic system to control Enerpac actuators

Bowen Laboratory

- Heating and Control Equipment

Moveable Power distribution panel for Radiant Heaters

More than 25 heaters
Each heater is 16 in. x 40 in. or, 0.4 m x 1.0 m



Comparison of target or measured T-t columns under fire loading

Goal and Objectives

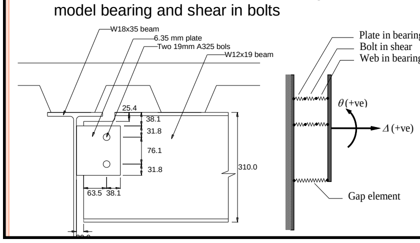
- The goal of the presentation is to familiarize with our research approach and some resulting achievements
- The research objectives were to:
  - Investigate the collapse behavior of typical steel building structures designed and fire protected in the US
  - Identify and further analyze the structural components and configurations having significant influence on the collapse behavior of typical steel building structures.
  - Experimentally verify the findings and hypothesis developed using analytical investigations and simulations
  - Develop simple design guidelines that could be used to have maximum impact on the fire safety of building structures.

Part 1 – Building Collapse Simulation

- Two different building designs were considered
- Structure is loaded with 1.0DL+ 0.5 LL
- Compartment fire load calculated by using Eurocode parametric fire *T-t* curves
- Heat transfer analysis is conducted to calculated T-t across columns, beams, and slabs exposed to fire.
  - All heat transfer modes modeled and verified using test data
- Explicit dynamic analysis to be able to model instability and collapse

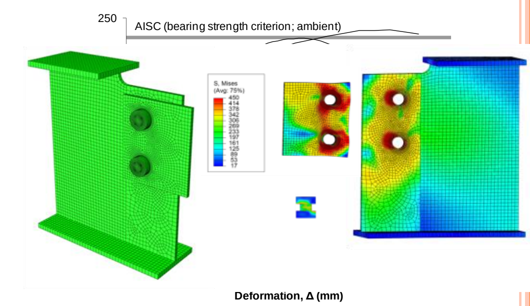
Part 1 – Building Collapse Simulations

- Columns are modeled as a series of 2-node linear beam (B31)
- Composite beams are modeled using
  - B31 elements for steel beams
  - Shell (S4R) elements for slab
- Shear connections modeled using Sarraj's (2007) springs to model bearing and shear in bolts



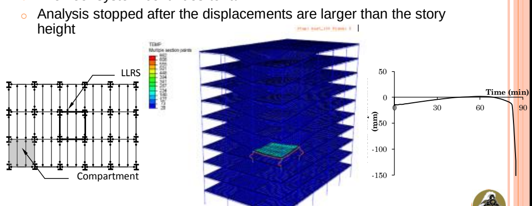
Part 1 – Building Collapse Simulations

- Shear Connection Model Verification



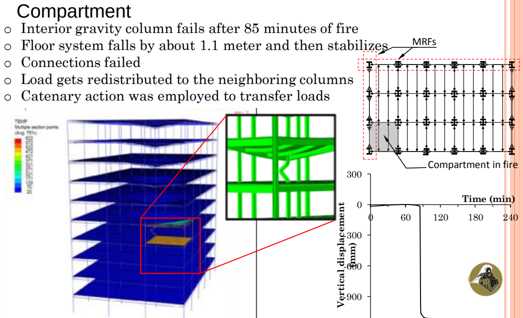
Part 1 – Building Collapse Simulations

- Case Study 1 – Interior Core + Design FRR + Corner Compartment
  - All four columns fail after 85 minutes of fire
  - Column temperature = 560°C
  - The floor system continues to fall
  - Analysis stopped after the displacements are larger than the story height



Part 1 – Building Collapse Simulations

- Case Study 2 – Perimeter MRF + Design FRR + Corner Compartment
  - Interior gravity column fails after 85 minutes of fire
  - Floor system falls by about 1.1 meter and then stabilizes
  - Connections failed
  - Load gets redistributed to the neighboring columns
  - Catenary action was employed to transfer loads

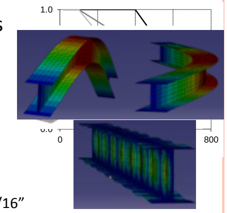


Conclusions from Part 1 and Goal for Part 2

- Gravity Columns are the *weakest links*
- Behavior of gravity columns ought to be studied further in detail
- Uniformly heated columns
  - Simply supported
  - Continuous
- Columns with thermal gradient in the cross section
  - Gradient along the web
  - Gradient along the flanges
- Scope
  - Loaded concentrically in compression
  - W-shape hot-rolled sections
  - Jumbo sections not included

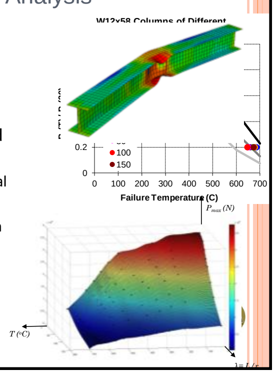
Part 2 – Column Stability Analysis

- Modeling using shell elements
  - Shell (S4R) elements
  - Residual Stresses $\pm 0.3F_y$
  - Eurocode Material Properties
  - Geometric imperfections
    - Buckling mode shapes
    - Amplitude : Length/1500
    - Amplitude for local imperfection: 1/16”
- Modeling using beam elements
  - Use a number of 2 node beam elements connected in series



Part 2 – Column Stability Analysis

- All columns buckle in weak axis
- Global imperfection governs the direction of buckling
- Columns with different slenderness values were analyzed
  - Degradation in column strength is bounded by degradation in material properties
  - Stocky columns are correlated with yield stress of steel
  - Slender columns are correlate with elastic modulus
  - A surface can be interpolated from the results



Part 3 – Experimental Verification of Steel Columns under Uniform Temperature Loading

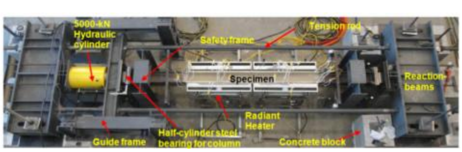
- Axial load-axial displacement-temperature responses
- Axial load-end rotation-temperature responses
- Axial load-lateral displacement-temperature responses

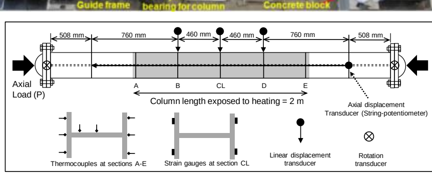
Test matrix for steel column test under uniform thermal loading

Specimen	Slenderness (L/r_y)	Steel temperature (T_s)	Steel yield strength (f_y)
W8X35-AMB	69 (Length = 11’-6”)	Ambient	58
W8X35-T300	69	300 °C	58
W8X35-T500	69	500 °C	58
W8X35-T600	69	600 °C	58
W14X53-T500	71 (Length = 11’-4”)	500 °C	54
W14X53-T600	71	600 °C	54

Part 3 – Experimental Verification

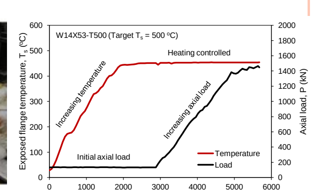
Self-Reacting Column Test Setup





Part 3 – Experimental Verification

Test Procedure



1. Initial axial loading of 133 kN to align the specimen and to confirm the concentricity of loading
2. Increase the steel temperatures until the target value is achieved.
3. Increase axial loads until the buckling occurs. Heating is controlled to maintain the target steel temperature.

Column Deflected Shape

At the onset of buckling

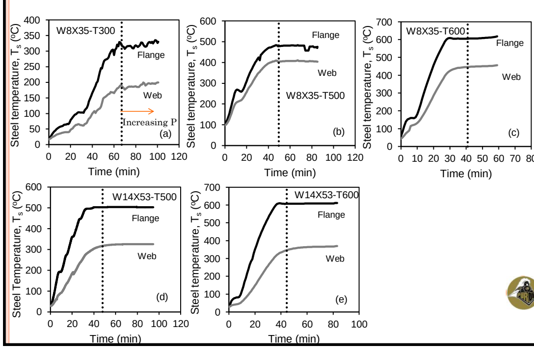
- Failure mode: Flexural buckling (weak-axis)
- No local flange distortion was observed.

Permanent deflected shape

ANALYTICAL MODELS FOR COLUMN SPECIMENS

- Detailed 3D finite element models (3D FEM)
  - 4-node quadrilateral shell element with reduced integration (S4R elements) → Uniform temperature test
  - Experimentally measured load histories
  - 3D conduction heat transfer analysis (Eurocode-3 thermal properties)
  - 3D structural analysis (Eurocode-3 mechanical properties)

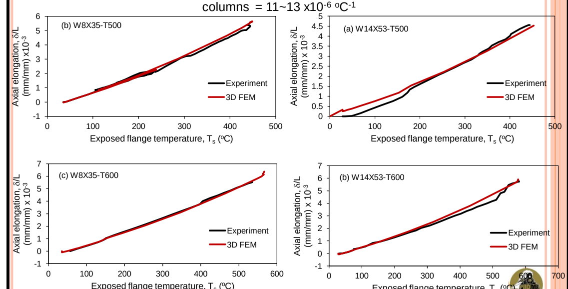
Steel Temperature-Time Responses



Analytical Predictions Vs. Experimental Results

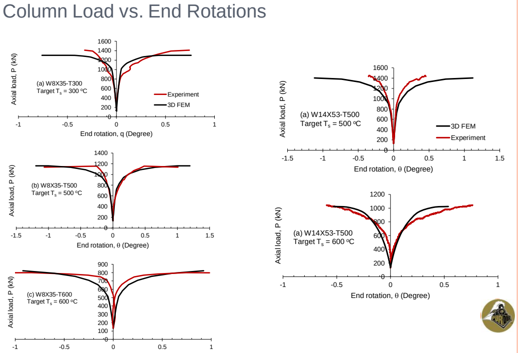
Thermal Expansion

The measured expansion coefficient of the structural steel columns = 11~13 x10^{-6} °C^{-1}



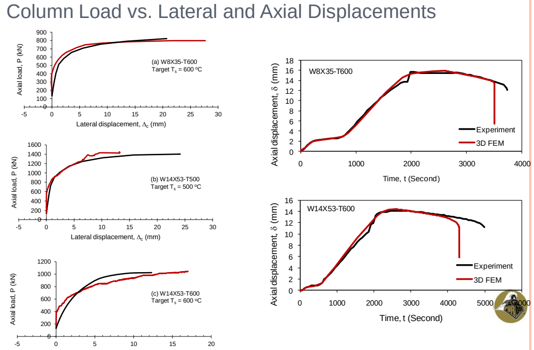
Analytical Predictions Vs. Experimental Results

Column Load vs. End Rotations



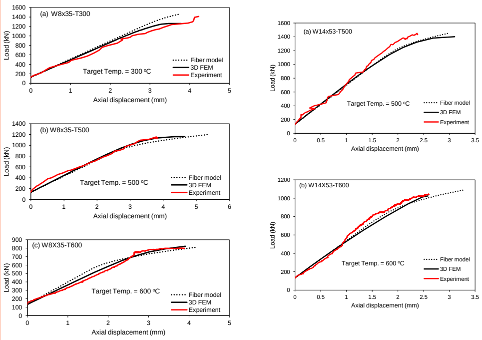
Analytical Predictions Vs. Experimental Results

Column Load vs. Lateral and Axial Displacements

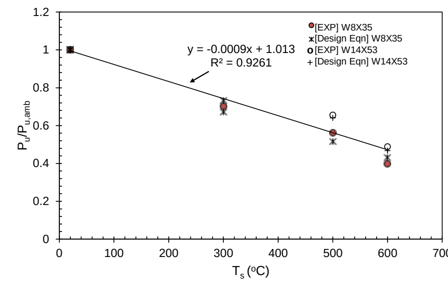


Analytical Predictions Vs. Experimental Results

Column Load vs. Axial Displacement



Part 3 – Experimental Verification
Test Results vs. Predictions
Column Load Capacity vs. Temperature



Summary and Conclusions

- Research approach was to:
  - Investigate the overall collapse behavior of gravity frames in steel building structures. Identify the critical components contributing to this collapse
  - Investigate the fundamental behavior and stability of the critical components identified by system analysis (in this case columns).
  - Conduct experimental investigations to verify the results of analytical simulations on components
    - Uniform heating of columns
    - Behavior of continuous columns
    - Effects of thermal gradients on columns
  - Develop structural performance based design guidelines for columns.

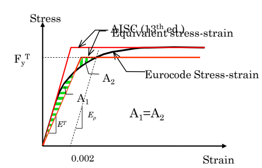
Design Guidelines for Columns

- Use AISC ambient equations
- With equivalent bilinear stress-strain curves

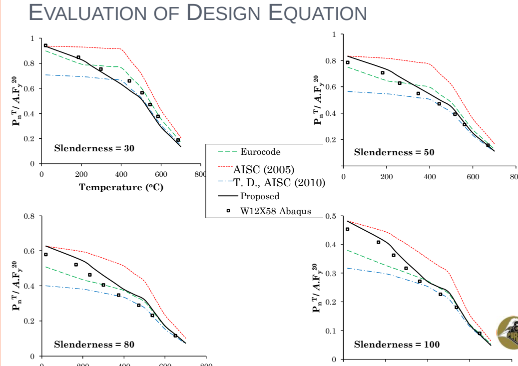
$$P_n^T = A F_y^T (0.658)^{\frac{F_y^T}{F_e^T}} \quad , \text{if } F_e^T > 0.44 F_y^T$$

$$P_n^T = A(0.877\, F_e^T) \quad , \text{if } F_e^T \le 0.44 F_y^T$$

$$\text{where, } F_e^T = \frac{\pi^2 E^T}{\lambda^2}$$

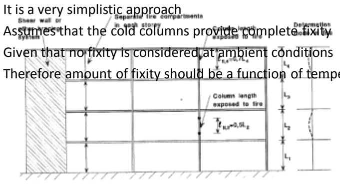


Evaluation of Design Equation



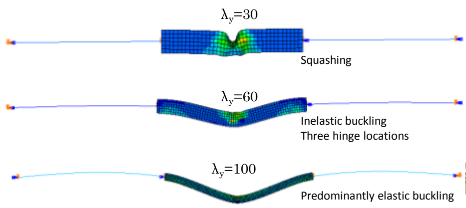
Uniformly Heated Continuous Columns

- Cold columns above and below the heated column provide rotational restraints
  - Desirable behavior
  - Reduces the effective length or 'k' value to less than 1.0
- Eurocode recommends
  - k =0.5, if restrained at both ends
  - k =0.7, if restrained at one ends
  - It is a very simplistic approach
  - Assumes that the cold columns provide complete fixity
  - Given that no fixity is considered at ambient conditions
  - Therefore amount of fixity should be a function of temperature too.

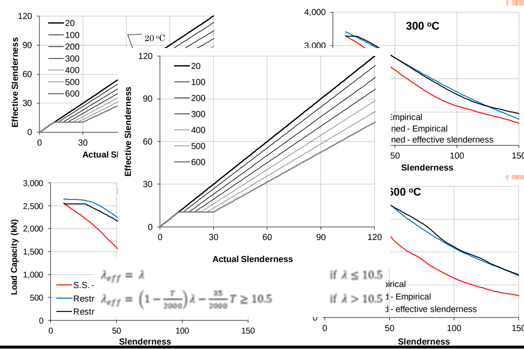


Uniformly Heated Continuous Columns

- Modeling
  - 3-column sub-system modeled in ABAQUS.
  - Intermediate column modeled using shell elements
  - Boundary columns modeled using beam elements
  - Rest of the procedure remains same as simply-supported column



Design Equation
(Uniformly Heated Continuous Columns)

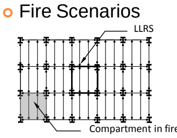


Future Work

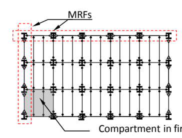
- Collapse simulations used to determine next critical component after columns
  - Gravity floors and associated shear connections
- Simulations of behavior done
- Experimental verifications of findings ongoing

Part 1 – Building Collapse Simulations

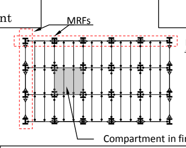
- Fire Scenarios



Building with Interior core
5th story
Corner compartment



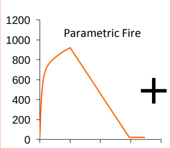
Building with perimeter MRFs
5th story
Corner compartment



Building with perimeter MRFs
5th story
Interior compartment

Part 1 – Building Collapse Simulations

- Thermal Loading + Fire Protection Parameter



+

All the components rated for 1 hr FRR (design FRR) = Gravity columns fail

or

Columns: 2 hr FRR (safe); Other components: 1 hr FRR = No failure

or

Columns: 2 hr FRR (safe); Beams: unprotected = Gravity beam fails in the heating phase; Shear connections fail in the cooling phase

2nd US Japan Fire Workshop 2012

Fire Safety of Curtain Wall Spandrel

– Proposal for Curtain Wall Spandrel Board Supported by Structural Members –

Toshihiko Nishimura

Research & Development Institute,
Takenaka Corporation

INTRODUCTION

Toshihiko NISHIMURA

Research & Development Institute,
Takenaka Corporation

Business: Building construction work, etc
Founded: 1610
No. of employees: 7,570 (as of January 2012)

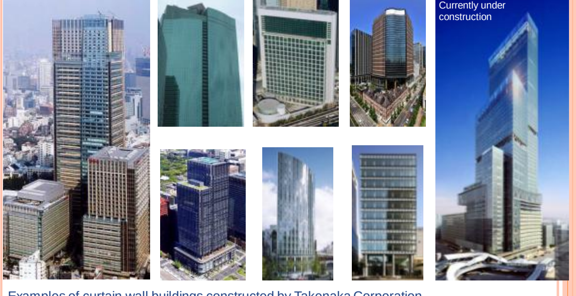
Specialities (Main Work)

Research & Develop & Design
for fire-resistance of building structure

- ✓ RC structures (column, beam, slab)
- ✓ Steel Structures (column, beam, truss)
- ✓ SC structures (CFT column, SC beam)
- ✓ Fire compartment (partition wall, curtain wall)

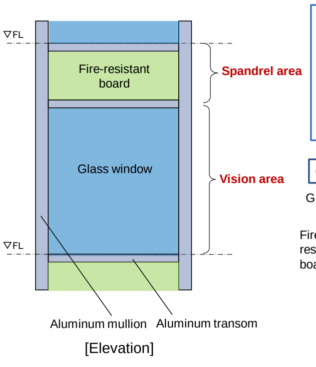
OBJECT OF RESEARCH

Metal Curtain Wall

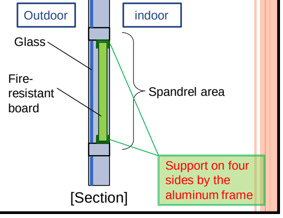


Examples of curtain wall buildings constructed by Takenaka Corporation

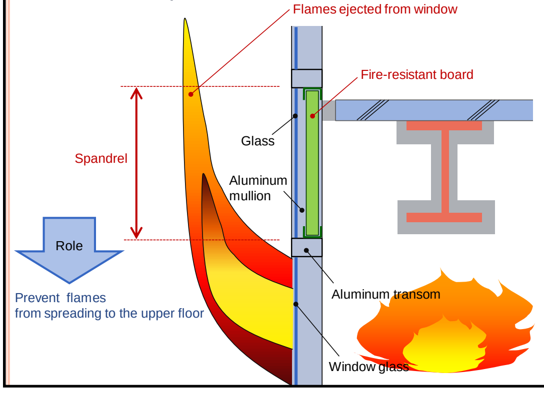
Composition of Curtain Wall



- ✓ Frames normally formed from aluminum mullions and transoms
- ✓ Consist of a vision area and a spandrel area
- ✓ In the spandrel area, Fire-resistant board fitted to the inside of the glass



Role of the spandrel



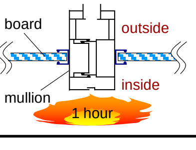
Issue of Japanese Curtain Wall

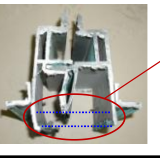
- ✓ Fire-resistant board is supported by an aluminum frame
- ✓ Aluminum melts at about 660°C
- ✓ The temperature of fires fully developed is about 1000°C

There is a highly possibility

The aluminum will melt and the fire-resistant board will fall out

＜Example of the test＞





TEST RESULTS
- ✓ The two layers melted
- ✓ Only one layer remained
(board escape falling somehow)

Technical Advice

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Technical advice was issued（2008ad by the Ministry）

■Purpose

to prevent the fire-resistant board from falling out

■Contents －Regulation Pont －

- Fire-resistant boards to be directly supported by a structural member (column, beam, slab)
- Fire-resistant boards to be structurally separated from aluminum frame
- Indoor side of mullions to be given the fireproof covering

Confusion Caused by the Technical Advice

8

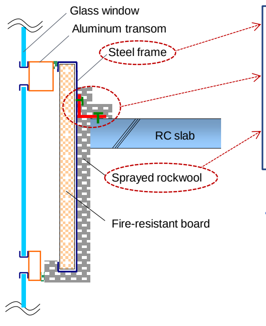
Technical Advice

- Aim was appropriate
- Only the concepts were given
- No specific methods were given

Demanded overspecified design
by the performance evaluation organization

Specifications Recommended by Performance Evaluation Organizations

9



- Fire-resistant board supported by steel frame
- Steel frame directly supported by a structural member
- Steel frame protected with fire-resistive covering

Following problems araise

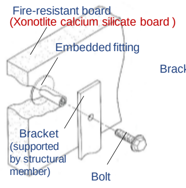
- Bad Workability
- Jamed detail
- High cost

Development of New Support Method

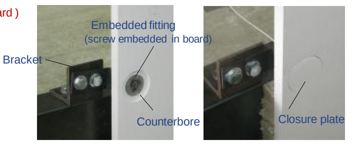
10

（A joint development by Takenaka Corporation and Japan Insulation Co., Ltd. ）

■ Basic composition



■ Method of support on the floor



Embedded fitting　　Closure plate

■ Feature

- ✓ The fitting is embedded in the fire-resistant board
- ✓ A bracket is connected to the embedded fitting with a bolt
  - → supported by structural member

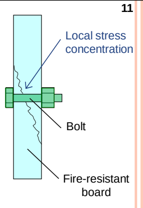
  } ・good cost ・good workability
- ✓ A counterbore is provided, by applying a closure plate the joint fixture cannot directly seen from outside } ・good design

Characteristics of the Technology Developed

11

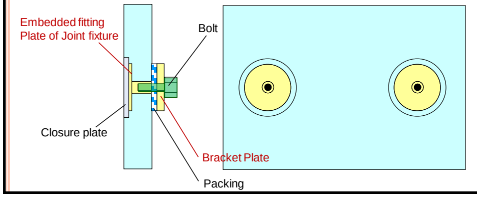
- Performance evaluation organizations never allow penetration by a bolt

  A crack can occur in the board when subjected to earthquake or wind



- In this new technology the board is supported on the surface

  Prevents local stress concentration ⇨ shows superior performance in earthquakes and wind



Structural Tests

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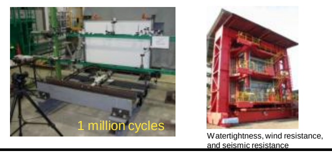
- Structural tests was carried out
- Superior structural performance was confirmed



Fire-resistance Tests
– Problem Points in the Conventional Method –

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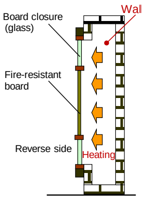
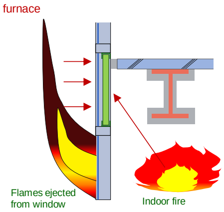
■ Conventional testing method of Japan

■ Actual building





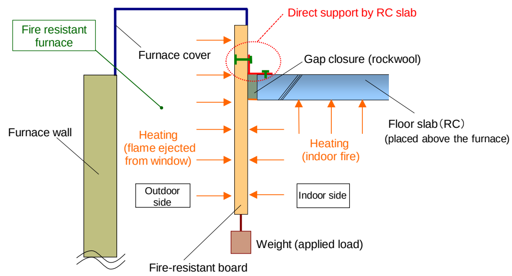
Board is heated from one side

Board is heated from both sides

Conventional test method cannot reflect the situation of fire appropriately

Fire-resistance Tests
– Proposal of a New Test and Evaluation Method –

14

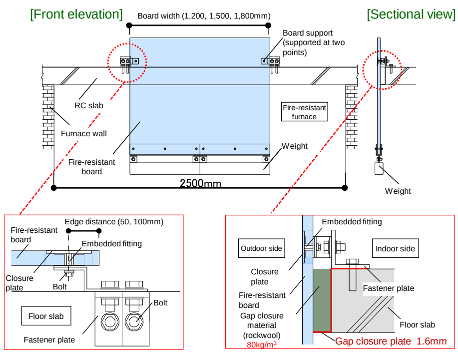


- ✓ Fire-resistant board directly supported by RC slab
- ✓ Heating from both sides
- ✓ Weight placed below the board

This method can reflect the situation of building fire appropriately

Outline of the specimen (1)

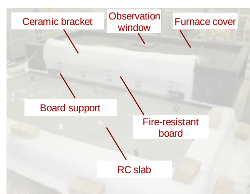
15

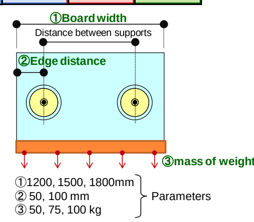


Outline of the specimen (2)

16

Specimen NO.	Fire-resistant board (xonotlite calcium silicate board with fiber)					Mas of weight (kg)
	Thickness (mm)	Height (mm)	Width (mm)	Distance between supports (mm)	Edge distance (mm)	
1	25	1000	1200	1100	50	50
2						100
3			1500	1400		50
4			1800	1700	50	100
5				1600	100	75





①1200, 1500, 1800mm
②50, 100 mm
③50, 75, 100 kg
} Parameters

Test Results

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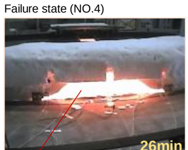
Specimen NO.	Failure time (minutes)		Failure position
	During heating	After completion of two-hour heating	
1	119	–	At board support
2	–	122	At weight support
3	–	156	At board support
4	26	–	At board support
5	–	153	At board support

Failure state (NO.4)



- ➢ Crack appeared at support
- ➢ board fell down

✓ NO.4 failed at 26 min.

Board width : 1800 mm, edge distance : 50 mm, load : 100 kg

most severe condition

✓ Other specimen showed 2-hours fire-resistance.

Consideration of the Tests

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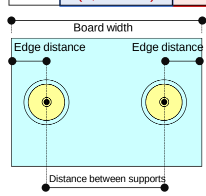
No.	Board width (distance between supports)	Edge distance	Weight	Fire-resistane time
2	1,200mm (1,100mm)	50mm	100kg	More than 2 hours
4	1,800mm (1,700mm)	50mm	100kg	26 min.
5	1,800mm (1,600mm)	100mm	75kg	More than 2 hours



- ➢ The board width and the edge distance especially affect the fire-resistance.
- ➢ Even when the board width is long, it is possible to ensure the fire-resistance if the edge distance is long.

Conclusion

- A new method of supporting CW fire-resistant board has been proposed.
- A new fire-resistance test and evaluation method of CW fire-resistant board has been proposed.
- It has been confirmed that the proposed method is capable of ensuring a 2-hour fire-resistance.
- Using the developed technology, it is possible to dramatically improve fire-resistance of curtain walls without increasing the cost and reducing the workability.

END

Thank you for your attention

Barriers to Performance-Based Structural-Fire Safety Design

Michael D. Engelhardt

Department of Civil, Architectural and Environmental Engineering
The University of Texas at Austin

***US-Japan Workshop* for**
Fire-Structure Interaction and Urban and Wildland-Urban Interface (WUI) Fires

July 2-4, 2012
Tsukuba and Chofu, Japan

What is Performance-Based Structural-Fire Safety Design ?

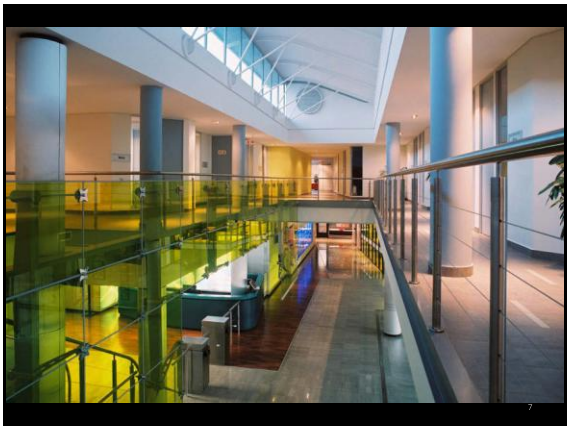
- Structure and structural-fire protection is <u>engineered</u> to achieve specific performance requirements.

Why Performance-Based Structural-Fire Safety Design ?

- Reduce cost of structural-fire protection.
- Enhance structural-fire safety of large, complex, or important buildings.
- Provide more quantifiable levels of structural-fire safety.
- Accommodate changing architectural trends in buildings.
- Mitigate risks of fire following other extreme events (earthquakes, terrorist attacks, vehicle impact, accidental explosions, etc.)

Architectural trends in building design…….

- Large open floor plans.
- Little compartmentation.
- Most partitions not fire rated and not full story height.
- Large floor-to-floor openings.
- More varied and complex architectural and structural forms.



Key Elements of Performance-Based Structural-Fire Safety Design……

Model Fire

↓

Heat Transfer Analysis

↓

Structural Analysis

Key Elements of Performance-Based Structural-Fire Safety Design……

Prescriptive Structural-Fire Safety Design → Performance-Based Structural-Fire Safety Design

Element Level Analysis → System Level Analysis

Barriers to Performance-Based Structural-Fire Safety Design……

- Inadequate education of structural engineers.
- Building design culture.
- Inadequate building standards.
- Lack of consensus based performance criteria.
- Technical knowledge gaps.
- Lack of design tools.

Critical Barrier to Performance-Based Structural-Fire Safety Design……

Design fires for structural-fire safety design

Design Fires Structural-Fire Safety Design……

Options for **Element Level** analysis:

- Code specified standard fires:
  - ASTM E119
  - ISO 834
  - Etc.
- Compartment fire models
  - One-zone
  - Two-zone
- Parametric time-temperature curves
- Empirical time-temperature curves
- Local fire models

Good guidance in codes and in literature

Inadequate for system-level structure-fire analysis

Design Fires Structural-Fire Safety Design……

Options for **System Level** analysis:

- CFD Analysis (FDS)
- Judgment ???
- Others ???

Little guidance in codes and in literature

CFD analysis impractical for routine design

Key technical barrier to performance-based structural-fire safety design:

Lack of information and guidance on ***Design Fires*** for ***System Level*** analysis and design.

Some Examples of Major Structure Fires……

Meridian Plaza

Parque Central East

Windsor Tower

Delft – Faculty of Architecture Building

WTC 1 & 2

One Meridian Plaza

Philadelphia
38 stories
Fire: February 1991
Fire burned 19 hours over 8 stories

Parque Central East Tower

Caracas, Venezuela
56 stories
Fire: October 2004
Fire burned 24 hours over 17 stories

Windsor Building

Madrid, Spain
32 stories
Fire: February 2005
Fire burned approx. 24 hours
Large portions of upper stories collapsed.

Faculty of Architecture Building

Technical University at Delft, Netherlands.
14 story Reinforced Concrete Building.

Fire: May 28, 2008
Fire burned for about 7 hours.

Fire caused complete collapse of wing of building.

World Trade Center Collapses
September 11, 2001

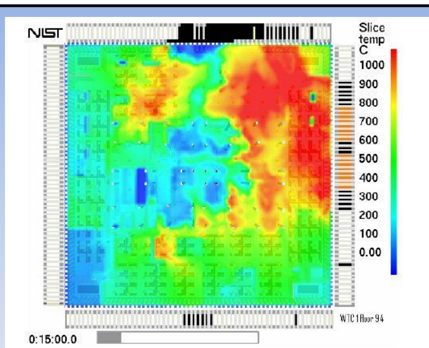


Figure 6–36. Upper layer temperatures on the 94th floor of WTC 1, 15 min after impact.

Ref: Report NCSTAR1- ***Final Report on the Collapse of the World Trade Center Towers***, NIST 2005

Some Characteristics of Major Structure Fires……

- Fires move horizontally and vertically through building.
- Horizontal extent of very high temperatures (temperatures significant to structural response) does not include entire space.
- Multiple adjacent floors burning simultaneously.
- Doubtful that fire environment can be adequately characterized by simple fire models (standard fires, compartment fire models, etc.)

Key Research Need for Performance-Based Structural-Fire Safety Design…

- Better understand and characterize fires in building with large non-compartmented spaces with horizontal and vertical (floor-to-floor) movement of fire.
- Develop guidance for ***Design Fires*** for system-level structural-fire safety design that makes sense for modern building architecture.

Some Key Questions and Issues…

- What is the horizontal variation of gas temperatures for a fire in a large open space or for a fire in a partitioned space (but not fire rated partitions); and how does this affect structural response ?
- How do fires move horizontally and how does this affect structural response ?
- Are simultaneous fires on adjacent floors important for structural response ?
- How can we simplify this for structural-fire safety design ?

How do we move forward ?......

- Need close collaboration between fire modeling specialists and structure-fire specialists.
- Need to study past major fires in greater detail.
- Need detailed analysis (FDS + heat transfer to structure + structural analysis) for a range of building layouts representative of modern building design practice……analysis similar to NIST WTC study.
- Need to understand and simplify.

Simple Calculation Methods for Temperature Rise of Walls and Partitions Exposed to Fire Heating

Tensei Mizukami
The Center for Better Living

Scope

- Back ground & Fire Test for mud-plastered wall ~ Basic Concept ~
- Model description & validation for uniform heating temperature
- Application for time-temperature curve

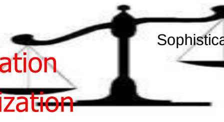
Performance-based approach

Numerical models are being developed…but,

- Limited experimental data

→Make use of existing FR test results

- For fire safety design, evaluation on the safety side is OK



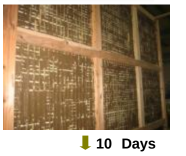
→Simplification & generalization

Experiment

Mud-plastered wall

Bamboo lath

Foundation coat



⬇ 10 Days

Back side

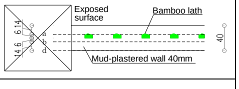
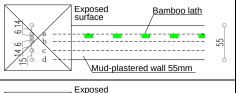
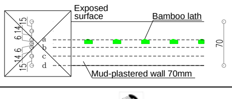
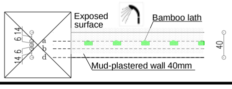
⬇ 4 weeks

Middle coat

⬇ 4 weeks

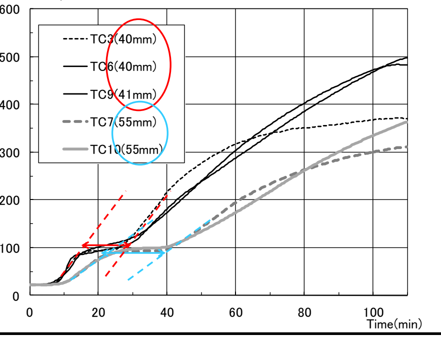
Finishing coat

Specimen

Assembly A-1		Moisture content	Thermocouple number (the distance from the surface) a---TC 1 (14mm) b---TC 2 (26mm) d---TC 3 (40mm)
Assembly A-2		3.8±0.4%	Thermocouple number (the distance from the surface) a---TC 4 (14mm) b---TC 5 (26mm) c---TC 6 (40mm) d---TC 7 (55mm)
Assembly A-3			Thermocouple number (the distance from the surface) a---TC 8 (29mm) b---TC 9 (41mm) c---TC10 (55mm) d---TC11 (70mm)
Assembly B-1		Moisture content 7.6%	Thermocouple number (the distance from the surface) a---TC12 (14mm) b---TC13 (26mm) d---TC14 (40mm)

Result

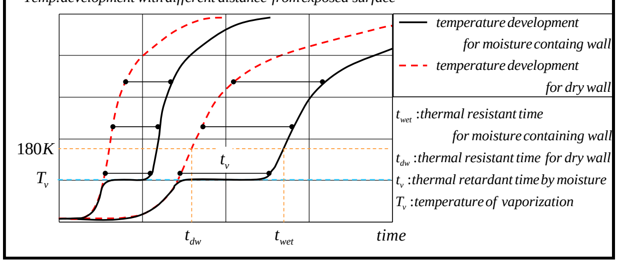
Temperature development on equal distance and moisture content



Hypothesis

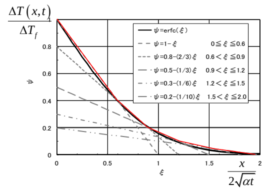
$$t_{wet} = t_{dw} + t_v$$

Temp. development with different distance from exposed surface

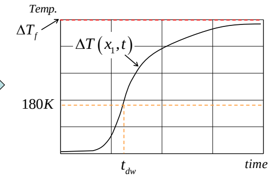


Dry wall model

Semi-infinite body theory



Temperature development



$$\frac{T(x,t)-T_0}{T_s-T_0} = erfc\left(\frac{x}{2\sqrt{\alpha t}}\right) \Rightarrow t_{dw} = \left(A_n - B_n\frac{\Delta T(x,t)}{\Delta T_s}\right)^{-2} \cdot \left(\frac{x}{2\sqrt{\alpha}}\right)^2 \quad \left\{R_{n-1} < \frac{\Delta T(x,t)}{\Delta T_s} \le R_n\right\}$$

Thermal resistant time for dry wall

$$t_{dw} = \left(A_n - B_n\frac{\Delta T(x,t)}{\Delta T_s}\right)^{-2} \cdot \left(\frac{x}{2\sqrt{\alpha}}\right)^2 \quad \left\{R_{n-1} < \frac{\Delta T(x,t)}{\Delta T_s} \le R_n\right\}$$

$\Delta T(x,t) = T(x,t) - T_0$

: *determined temperature rise*

R_{n-1}, R_n : *upper and lower limit of the non-dimentional temp. rise to apply the approx.#*

A_n, B_n : *coefficient given by the range of non-dimentional temp. rise*

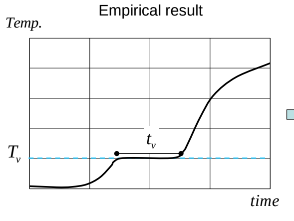
Approx. #	A_n	B_n	The range of application R_{n-1}		Non-dimentional temp.		R_n
1	2	10	0	≦	$\Delta T(x,t)/\Delta T_s$	≦	0.05
2	1.8	6	0.05	≦	$\Delta T(x,t)/\Delta T_s$	≦	0.1
3	1.5	3	0.1	≦	$\Delta T(x,t)/\Delta T_s$	≦	0.2
4	1.2	1.5	0.2	≦	$\Delta T(x,t)/\Delta T_s$	≦	0.4
5	1	1	0.4	≦	$\Delta T(x,t)/\Delta T_s$	≦	1.0

Re-defined moisture effect

Moving boundary approach

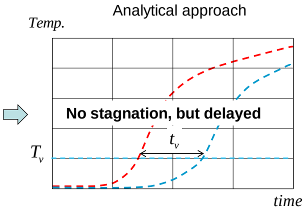
- Stagnation time should be smoothed out so as not to be affected by resolution

Empirical result



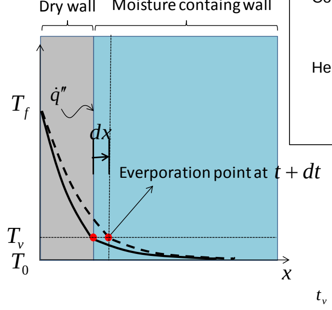
Stagnation time

Analytical approach



Thermal retardation time

Moisture retardant model



Conservation of energy :

$$\dot{q}'' \cdot dA \cdot dt = L_w \phi(\rho \cdot dx \cdot dA)$$

Heat flux to evaporation point :

$$\dot{q}'' = D \times \lambda \frac{T_f - T_v}{x}$$

$$dt = \frac{1}{D}\frac{\rho L_w \phi}{\lambda(T_f - T_v)} x dx$$

$$t_v = \frac{4.9\times10^3}{D}\left(\frac{\phi}{C_w(T_f - T_v)}\right) \cdot \left(\frac{x}{2\sqrt{\alpha}}\right)^2$$

Thermal retardant time by moisture

$$t_v = \frac{4.9\times10^3}{D}\left(\frac{\varphi}{C_w(T_f - T_v)}\right) \cdot \left(\frac{x}{2\sqrt{\alpha}}\right)^2$$

T_f : *temperature at fire exposed surface*

T_v : *evaporation temperature*

D : *propotionality constant for convective heat flux*

ϕ : *moisture content of the wall (dry base)*

C_w : *specific heat of the wall*

Total thermal resistant time

TR time for dry wall — Retardant time by moisture

$$t_{wet} = \boxed{\left(A_n - B_n\frac{\Delta T(x,t)}{\Delta T_s}\right)^{-2} \cdot \left(\frac{x}{2\sqrt{\alpha}}\right)^2} + \boxed{\frac{4.9\times10^3}{D}\left(\frac{\varphi}{C_w(T_f - T_v)}\right) \cdot \left(\frac{x}{2\sqrt{\alpha}}\right)^2}$$

Validation

Dry wall model

- Surface temp. ≒ Heating temp. ?

Moisture retardant model

- The proportional constant D ?

⇨ Validation

by numerical 1-D conductive model

Numerical model

Fourier's law of conduction in 1-D with heat absorption by vaporization :

$$\rho C_w \frac{\partial T}{\partial t} = \lambda \frac{\partial^2 T}{\partial x^2} - \dot{q}_v$$

Boundary condition :

$$\left.\begin{aligned} -\lambda \frac{\partial T}{\partial x} &= \dot{q}_i'' \quad (x=0) \\ -\lambda \frac{\partial T}{\partial x} &= -\dot{q}_o'' \quad (x=L) \end{aligned}\right\}$$

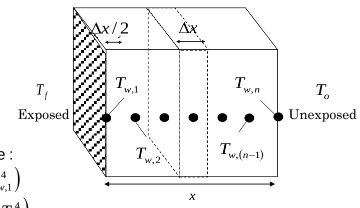
Incident heat flux to the surface :

$$\dot{q}_i'' = h_i\left(T_f - T_{w,1}\right) + \varepsilon_i \sigma\left(T_f^4 - T_{w,1}^4\right)$$

$$\dot{q}_o'' = h_o\left(T_{w,n} - T_o\right) + \varepsilon_o \sigma\left(T_{w,n}^4 - T_o^4\right)$$

At evaporation temperature:

$$\dot{q}_v = \lambda \frac{\partial^2 T}{\partial x^2}, \quad \frac{\partial W}{\partial t} = -\frac{\dot{q}_{v,i}}{L_w}$$

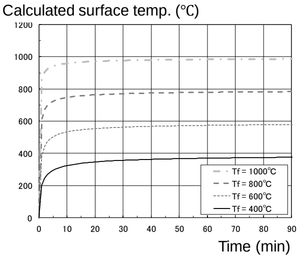


Material properties:

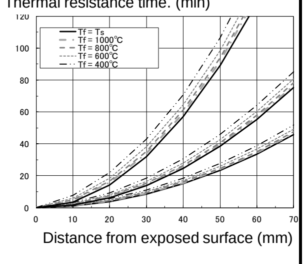
density [kg/m³]	Heat capacity [kJ/kg K]	Conductivity ×10⁻³[kW/m K]
1360	0.88	0.4

Validation Ⅰ
Surface temp. ≒ Heating temp.

Calculated surface temp. (℃)

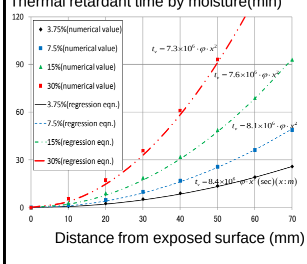


Thermal resistance time. (min)

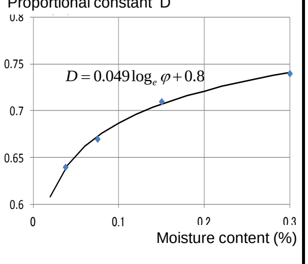


Validation Ⅱ
The proportional constant D

Thermal retardant time by moisture(min)



Proportional constant D



Application for FR test
Equivalent averaged heating temp.

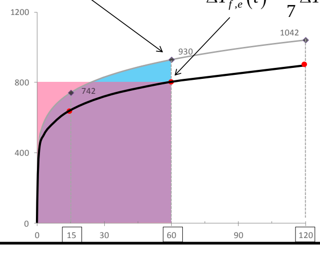
Standard time-temp. curve（β=460） ⇨ Equivalent averaged heating temp.

$$T_f - T_0 = \beta t^{1/6}$$

β : fire growth rate

$$T_{f,e} - T_0 = \left(\beta \int_0^t t^{1/6} dt\right) / t = \frac{6}{7}\beta t^{1/6}$$

$$\Delta T_{f,e}(t) = \frac{6}{7}\Delta T_f(t)$$



Application for FR test
Dry wall model

Thermal resistant time for dry wall

$$t_{dw} = \left(A_n - B_n \frac{\Delta T(x,t)}{\Delta T_{f,e}(t_{dw})}\right)^{-2} \cdot \left(\frac{x}{2\sqrt{\alpha}}\right)^2 \qquad \left\{R_{n-1} < \frac{\Delta T(x,t)}{\Delta T_{f,e}(t_{dw})} \le R_n\right\}$$

Distance reached temp. criteria at given time

$$x = 2\sqrt{\alpha}\left(A_n - B_n \frac{\Delta T(x,t)}{\Delta T_{f,e}(t_{dw})}\right) \cdot t_{dw}^{1/2} \qquad \left\{R_{n-1} < \frac{\Delta T(x,t)}{\Delta T_{f,e}(t_{dw})} \le R_n\right\}$$

Application for FR test
Moisture retardant model

Thermal retardant time

$$t_v = \frac{4.9\times10^3}{D}\left\{\frac{\phi}{C_w\left(T_{f,e}(t_v)-T_v\right)}\right\}\cdot\left(\frac{x}{2\sqrt{\alpha}}\right)^2$$

Since $T_{f,e}(t_v) >> T_v$, let

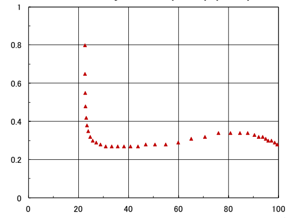
$$T_{f,e}(t_v)-T_v \approx T_{f,e}(t_v)-T_0 = \frac{6}{7}\beta t_v^{1/6}$$

Thermal retardant time (Approx. equation)

$$t_v = \left\{\frac{4.9\times10^3}{D}\,\frac{7}{6}\,\frac{\phi}{C_w\beta}\cdot\left(\frac{x}{2\sqrt{\alpha}}\right)^2\right\}^{6/7}$$

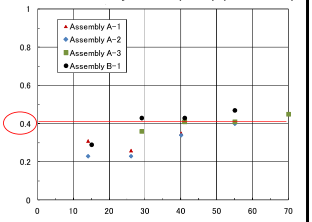
Application for FR test
Apparent thermal diffusivity

Thermal diffusivity x 10^{-6} (m^2/s) (TC6)



Temperature(℃)

Thermal diffusivity x 10^{-6} (m^2/s) (each TCs)

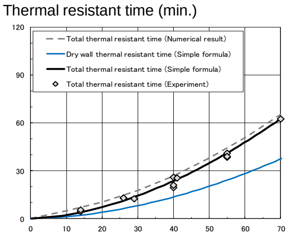


Distance from exposed surface (mm)

$$\alpha = \left(A_n - B_n\frac{\Delta T(x,t)}{\Delta T_{f,e}(t_{dw})}\right)^{-2}\cdot\left(\frac{x}{2\sqrt{t_{dw}}}\right)^2$$

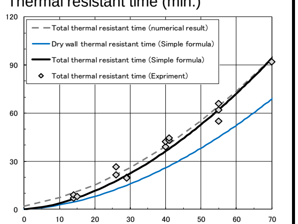
Comparison

Thermal resistant time (min.)



Distance from exposed surface (mm)

Thermal resistant time (min.)



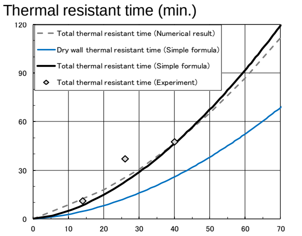
Distance from exposed surface (mm)

ΔT(x,t)=80K, φ=3.75% — ΔT(x,t)=180K, φ=3.75%

Contribution ratio of moisture is 1/3 — Contribution ratio of moisture is 1/5

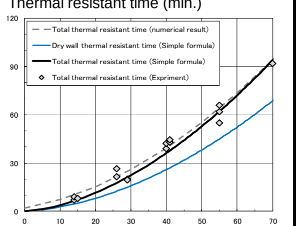
Comparison

Thermal resistant time (min.)



Distance from exposed surface (mm)

Thermal resistant time (min.)



Distance from exposed surface (mm)

ΔT(x,t)=180K, φ=7.5% — ΔT(x,t)=180K, φ=3.75%

Summary

- Fire resistant test for Mud-plastered wall was investigated with different x and φ.
- Hypothesis was derived: $t_{wet}=t_{dw}+t_v$
- Simple equations were proposed for thermal resistant time.
- A good agreement was obtained and identified the contribution ratio of moisture

Future work

- Application for multi-layer wall
- The use of cone calorimeter for quick reference

An Experimental Study on Fire Resistance of Composite Structure Consisting of Steel Beam and Partition Wall

JAFSE – NIST Workshop
July 2, 2012

Takeshi Morita, Shimizu Corporation

Contents of Presentation

- Objective
- Performance to be Validated
- Full Scale Fire Test – with loading
- Small Scale Fire Test – without loading
- Simplified Calculation for Temperature on Back Side Surface of Steel Beam
- Conclusions

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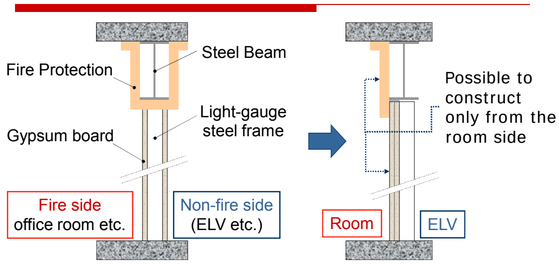
Objective

- To reduce fire protection on steel beams
  - Especially steel beams around ELV shaft
  - Because of
    - Time consuming process for construction
      ex. Assembling scaffold in the shaft
    - Very low fire load

Schematic Diagram of Composite Structure consisting of Beam and Wall



Conventional   Development

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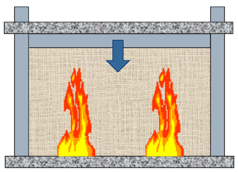
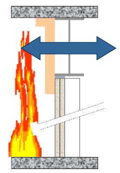
- Results

Performance to be Validated

- Integrity: Steel beam – wall interaction
  - Is the wall collapsed as the result of deformation of a steel beam?



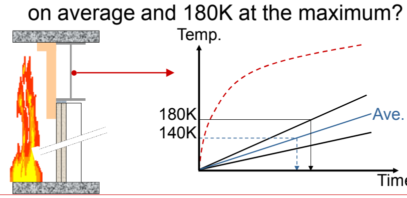
Front View



Cross-sectional View

Performance to be Validated

- Thermal Insulation: Temperatures on non heated surface of steel beam
  - When does the temperature rise exceed 140K on average and 180K at the maximum?



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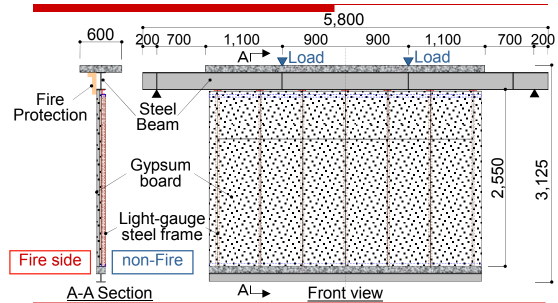
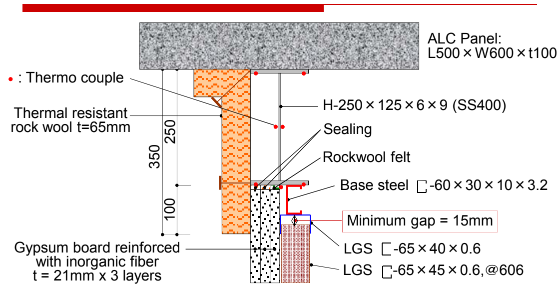
Specimen

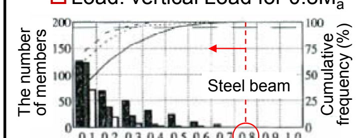


Specimen (Detail and Material)



Test Method

- Fire temperature – time curve: ISO834
- Heating period of time: 120 min.
- Load: vertical Load for $0.8M_a$

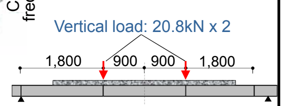


M_d/M_a at midspan

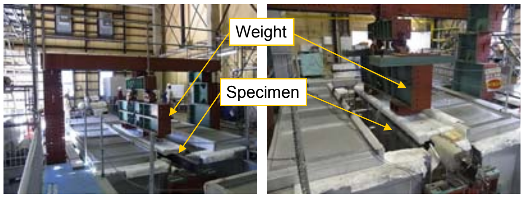
Long-term bending moment

M_d : design, M_a : allowable

Investigated by Building Contractors Society

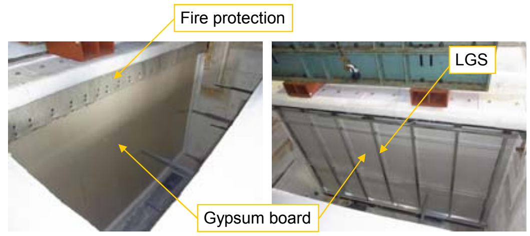


Experimental Setup



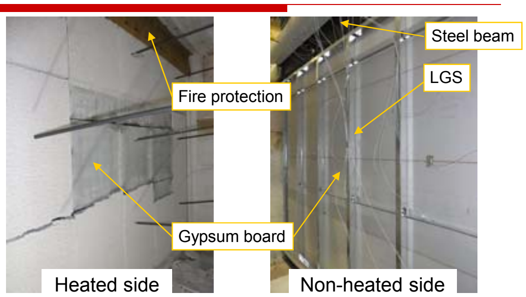
Appearance

Specimen before Fire Test

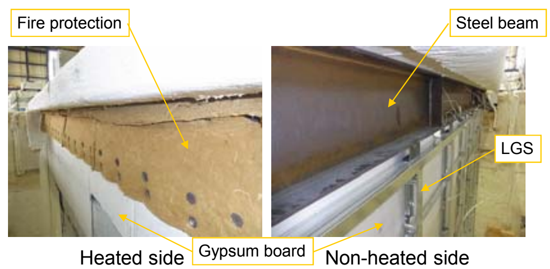


Heated side Non-heated side

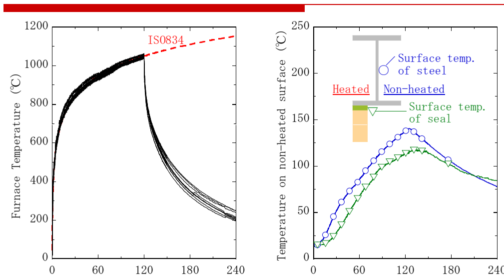
Specimen after Fire Test



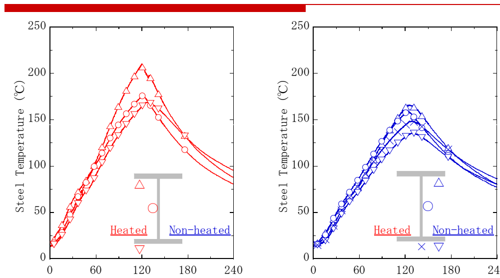
Specimen after Fire Test



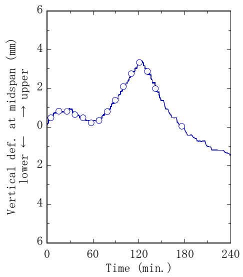
Results
– Furnace temp. and temp. on surface of beam –

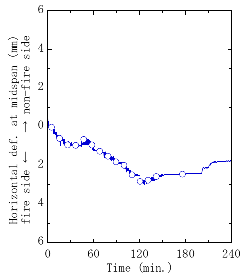


Results
– Steel temperature –



Results
– Deformation –





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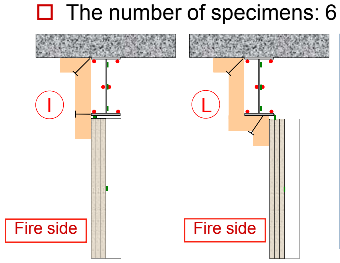
Specimen

- The number of specimens: 6



I-shaped Section L-shaped Section

◆Steel beam:
H-250×125×6×9 (SS400)
H-400×200×8×13 (SS400)

◆Fire protection:
Thermal resistant rock wool
t = 40, 65mm

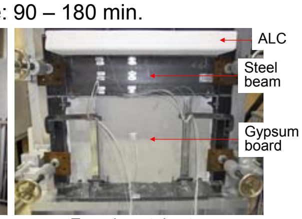
◆Wall:
Gypsum board reinforced with inorganic fiber
t = 21mm x 2 or 3 layers

• : Thermo couple (steel temp.)
• : Thermo couple (surface temp.)

Test Method

- Fire temperature – time curve: ISO834
- Heating period of time: 90 – 180 min.

Small scale wall type furnace
(1.3m x 1.3m)



Experimental setup
(non-heated side)

Results

I-shape section L-shape section

◆Steel beam:
H-250×125×6×9
◆Fire protection:
t = 40mm
◆Wall:
(I) t = 21mm x 2
(L) t = 21mm x 3
◆Heating period:
90min.

◆Max. temp. rise
Steel:
(I)225K (ave.152K)
(L)242K (ave.177K)
Steel surface:
(I)166K (ave.146K)
(L)193K (ave.172K)

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Basic Equation for Calculating Steel Temperatures

- MLIT Notification No.1433 gives basic equations.
- The equations are arranged to suit to the matter here.

$T_s = T_f(t)\{1\text{-}\exp(-ht)\}$ ……………………………….Eq.[1]

where

h: Eq.[2]

T_s: maximum temperature rise [K]

$T_f(t)$: $T_f(t) = 345\log_{10}(8t+1)$

t: heating period of time [min.]

Basic Equation for Calculating Steel Temperatures

$$h = \frac{\varphi K_0(H_s/A_s)}{\{1+\varphi R/(H_i/A_i)\}\ \{1+(\varphi/2)(H_s/A_s)C/\ (H_i/A_i)\}} \quad \text{……..Eq.[2]}$$

where

A_i, A_s: sectional area of fire protection and steel

H_i, H_s: circumferential length

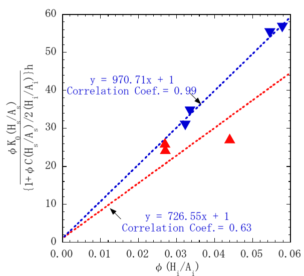
C: heat capacity ratio ($\rho_i c_i/\ \rho_s c_s$)

K_0: 0.00067

R: thermal resistance ratio derived from test results

φ: $\varphi = H_i/H_s$

Thermal Resistance Ratio: *R*

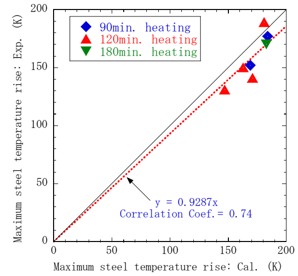


I-shaped protection
▲ : Experimental data
……: Linear regression
R = 726

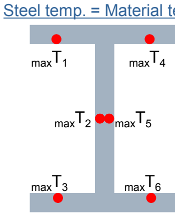
L-shaped protection
▼ : Experimental data
……: Linear regression
R = 970

Comparison between Exp. and Cal.

- Averaged maximum steel temperature rise -

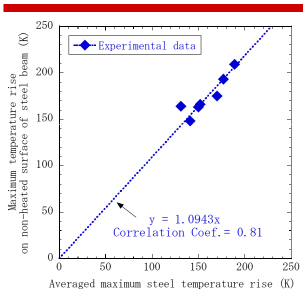


Steel temp. = Material temp.

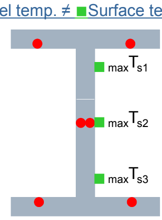


Ave. max. steel temp. rise
$= ({}_{max}T_1 + \cdots + {}_{max}T_n)/6$

Relationship between Steel Temp. and Surface Temp.



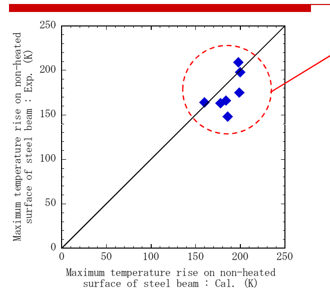
Steel temp. ≠ Surface temp.



Max. surface temp. rise
$= \max({}_{max}T_{s1}, \cdots, {}_{max}T_{s3})$

Comparison between Exp. and Cal.

- Maximum temperature rise on steel surface -



A simplified calculation method for temperatures on non-heated surface of steel beam gives temperatures on almost safe sides.

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Conclusions

- Steel beam – wall interaction
  - No significant influence was observed during the heating period of 120min and afterward.
- Simplified calculation method for evaluating temperatures on the non-heated surface of steel beam
  - Thermal properties for the calculation was identified by analysis on one full scale test and 6 small scale tests.
  - The thermal insulation capacity can be evaluated by a simplified calculation method on non-heated surface temperature of steel beam.

US-Japan Fire Research Workshop July 2-4, 2012, Japan

Performance and Research Needs for Bridges Subject to Fire

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Princeton University

Venkatesh Kodur
Professor
Department of Civil and Environmental Engineering
Michigan State University

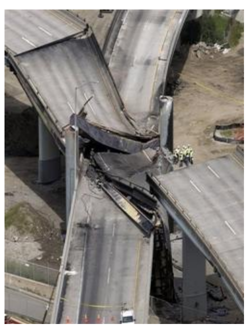
Outline

- Background - Fire Problem in Bridges
- Motivation for Research
- Response of Bridge Girder During Fire
- Residual Strength of Fire Exposed Bridge Girder
- Research Needs

Hazel park bridge fire, MI

Background
Fire Safety

- Fire - severe condition
  - Fire safety - design requirements
    - loss of life and property
- Fire can be
  - Primary
  - Secondary
    - Earthquake, Blast, Explosion, Impact
  - Accidental
- Fire resistance (FR)- structural elements
  - safe evacuation of occupants & fire personnel
  - minimize property damage
  - control spread of fire



Oakland bridge fire, CA

Background
Fire Problem in Bridges

Bridge fires have become a growing concern due to rapid development of urban ground transportation system, as well as increasing transportation of hazardous materials.

Common Cases:

- Gasoline tanker strikes the bridge
- Gasoline tanker hits other automobiles near the bridge
- Electrical problems or lighting
- Repair work- welding etc.

Impact:

- loss of life
- Traffic delay (detours)
- Significant economic and public losses
- Partial or complete collapse of structural members

Background
Fire Problem in Bridges

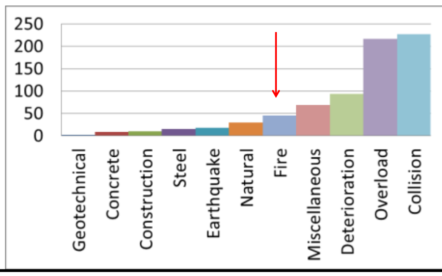
- Recent years → numerous fires in bridges; some of these fires resulted in the collapse of steel girders. Therefore, fire hazard in bridges is becoming a growing concern.
- Fires in bridges can result in significant economic and public losses, as well as traffic routing issues.
- **Fire is not considered by AASHTO in the design of bridges**

Background
Major Bridge Fires in the Last 10 Years in USA

Bridge/Location	Date	Cause of fire	Bridge material
Bridge over I-75 near Hazel Park, MI	July 15, 2009	Crashing of a gasoline tanker	Steel girders + RC slab
Big Four Bridge, Louisville, KY	May 7, 2008	Electrical problem	Steel truss bridge
Stop Thirty Road, State Route 386 Nashville, TN	June 20, 2007	Crashing of a gasoline tanker	Concrete hollow box-beam bridge
I-80/880 interchange in Oakland, CA	April 29, 2007	Crashing of a gasoline tanker	Steel girders + RC slab
Bill Williams River Bridge, AZ	June 20, 2007	Crashing of a gasoline tanker	Prestress I girders + cast in place RC slab
Belle Isle Bridge in NW Expressway, Oklahoma City, OK	January 28, 2006	Crashing of a gasoline tanker	Prestress I girders + cast in place RC slab
Bridge over the Norwalk River near Ridgefield, CT	July 12, 2005	Crashing of a gasoline tanker	Prestress box girders + cast in place RC slab
I-95 Howard Avenue Overpass in Bridgeport, CT	March 26, 2003	Car striking a truck carrying 8,000 gallons of heating oil	Steel girders + RC slab

Background
Major Bridge Fires in the Last 10 Years in USA

1876 to 2008 Survey: 1746 total recorded collapses; 1003 hydraulic failures; remainder shown in plot



Background
Examples o f Fire Induced Collapse in Bridges

- **I-75 expressway near Hazel Park, MI**
  - Steel girder + RC slab
  - Tanker carrying 13,000 gallons gasoline crushed beneath the bridge
  - Intense heat from the fire reached about 1100ºC
  - Bridge girder collapsed within 20 min.

Hazel Park overpasscollapse, MI

- **MacArthur Maze I-80/880 interchange in Oakland, CA**
  Steel girder + RC slab
  Tanker carrying 8600 gallons gasoline crushed beneath the bridge
  - Intense heat from fire reached 1100ºC
  - Bridge girder collapsed within 22 min.
    - Direct Loss – 22 million USD

Oakland highway bridge collapse, CA

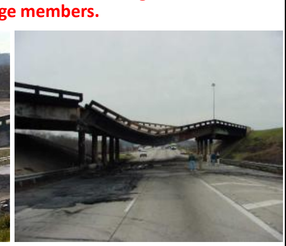
Background
Examples o f Fire Induced Collapse in Bridges

I-65 / I -20 - I 59 Interchange, Birmingham, AL, 2002

References: Garlock, M., Payá-Zaforteza, I. Kodur, V., Gu, L., (2011). "Fire Hazard in Bridges: Review, Assessment and Repair Strategies", *Engineering Structures*, Elsevier, V. 35, p. 89-98.
Kodur V.K.R., Gu L., Garlock, M, (2009), "Review and assessment of fire hazard in bridges", *Journal of the Transportation Research Board*, Vol. 2172/2010, ISSN 0361-1981, pp. 23-29, 2010.

Motivation and Need

- **There is very limited information and research data in the literature on the fire resistance of structural members in bridges**
- **Much of the data on fire resistance is from building elements and can not directly be used for bridge members.**



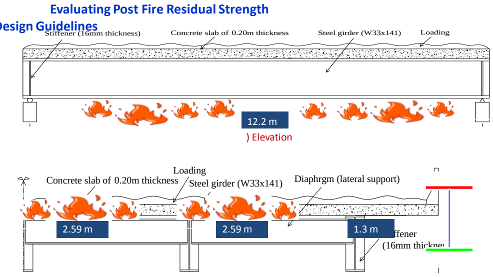
Motivation and Need
Bridge Fire vs. Building Fires

Scenario	Building	Bridge
Fire source	wood/plastic based material	Gasoline based
Fire severity	ASTM E119/ISO 834/ Natural fire	Hydrocarbon fire/ ASTM E1529
Fire protection	Active and passive	None
Failure limit state	Flexural	Flexural/Shear
Connections	web and/or the flange	Bearing of the bottom flange
Sectional slenderness	web slenderness ratio (50)	web slenderness ratio (150 with no longitudinal stiffeners)

PU-MSU Research Project
Fire Resistance of Bridge Girders

Literature Review
Fire Tests on Girders
Numerical Model – ABAQUS and ANSYS Models
  Evaluating Response during Fire
  Evaluating Post Fire Residual Strength
Design Guidelines

(DL+0.3LL)

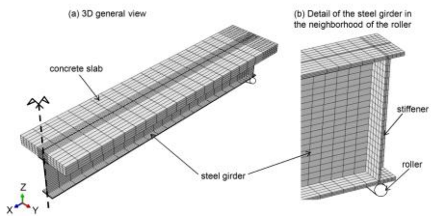


(b) Section near the supports

Evaluating Response during Fire

// Prototype

FHWA 12.2 m (40 ft) span, W33 x 141, noncomposite - ABAQUS Model



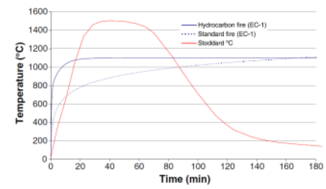
Reference: Payá-Zaforteza, I, Garlock, M. (2011). "A numerical investigation on the fire response of a steel girder bridge, *Journal of Constructional Steel Research*, Elsevier, Vol. 75, p 93-103.

Evaluating Response during Fire

/ Parameters & Results

Influence of Live Load:
Parameters: D + L ; D + 0.3L ; D + 0.5L; D
Result: essentially no effect

Influence of Fire Load:
Parameters: Hydrocarbon vs. real bridge event (Stoddard)
Result: Stoddard has longest survival time (~20 min vs ~10 min)

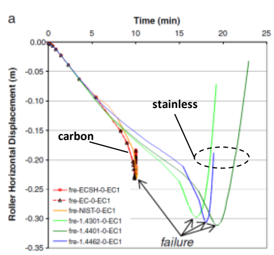


Evaluating Response during Fire

// Parameters & Results

Influence of Steel Type:
Parameters:
Carbon vs. Stainless 304, 316, and duplex 2205 (EN No. 1.4301, 1.4401, and 1.4462)

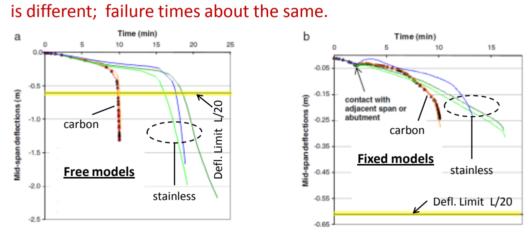
Result:
Stainless models > 60% longer survival than carbon



Evaluating Response during Fire

// Parameters & Results

Influence Axial Restraint:
Parameters:
Free expansion vs. Fixed expansion after 0.036 m.
Result: Fixed models have smaller midspan deflection; failure mode is different; failure times about the same.



Evaluating Post Fire Residual Strength

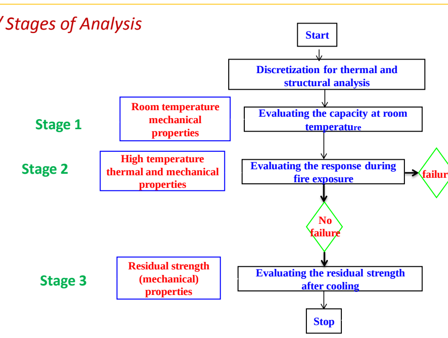
// Objectives

- Develop an approach for evaluating residual strength of fire exposed steel bridge girders.
- Develop strategies for retrofitting structural members in bridges.
- Establish factors governing residual capacity of fire exposed bridge girders.

References: Kodur V.K.R., Essam A. and Dwaikat M.A.S., "Evaluating fire resistance of steel girders in bridges", **in Press:** *Journal of Bridge Engineering (ASCE)*, 2012.
Essam A. and Kodur V.K.R., "An approach for evaluating the residual strength of fire exposed bridge girders", Seventh International Conference on Structures in Fire, Zurich, Switzerland, 2012.

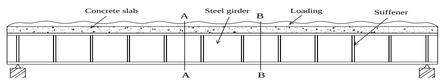
Evaluating Post Fire Residual Strength

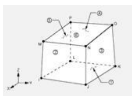
// Stages of Analysis



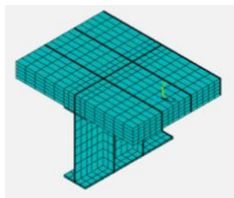
Evaluating Post Fire Residual Strength

ANSYS - Finite Element Thermal Model





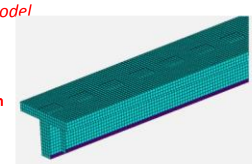
(a) Typical girder in a bridge



❑ **Solid70 element :**
- -3D-thermal solid element for both slab and girder.
- - 8 noded element with single degree of freedom (temperature).

Evaluating Post Fire Residual Strength

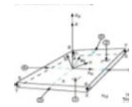
ANSYS - Finite Element Strucutral Model



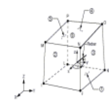
❑ **Shell181 element :**
- -Used to idealize the steel girder .
- -4 noded element with six degree of freedom
- -(3 translations +3 rotations) per node.

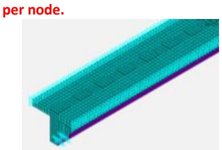
❑ **Solid65 element :**
- ed to idealize the concrete slab.
- -8 noded element with three degree of freedom per node.

Shell181 element



Solid65 element





Boundary Conditions

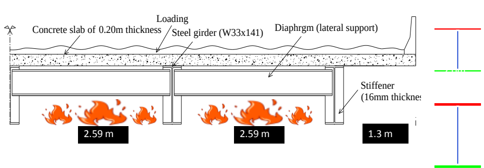
Evaluating Post Fire Residual Strength

Case Study

❑ **ypical simply supported bridge girder selected from literature.**

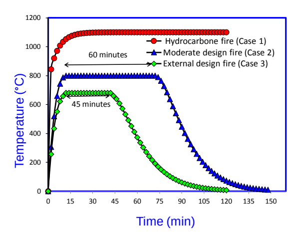
❑ **Residual strength analysis carried out.**

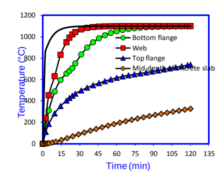
❑ **Analyzed after exposure to different fire scenarios**



Evaluating Post Fire Residual Strength

Thermal Analysis Results





Case 1

Fire scenarios used in analysis and thermal analysis results

Evaluating Post Fire Residual Strength

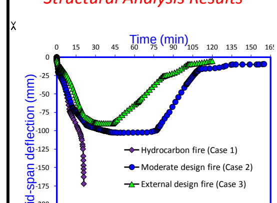
/ Structural Analysis Results

Table 1. Residual strength analysis results of fire exposed bridge girder

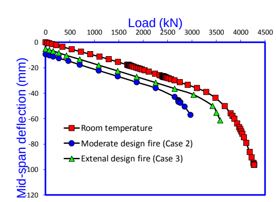
Case	Fire scenario	Max. fire temperature	Max. steel temperature	Room temperature capacity load (kN)	Residual capacity load (kN)	% of original capacity
Case 1	Hydrocarbon fire	1100°C	1000°C	4270	Failure under fire	----
Case 2	Moderate fire	800°C	795°C	4270	2974	70%
Case 3	External fire	680°C	670°C	4270	3579	84%

Evaluating Post Fire Residual Strength

Structural Analysis Results



Response of girder during fire exposure (stage 2)



Response of girder after exposure to fire (residual capacity) (stage 3)

Post Fire Residual Strength – Findings thus Far

- ANSYS can successfully be applied to evaluate the response of fire exposed bridge girders. The thermal response can be simulated using SOLID70 elements, while structural response can be simulated using SHELL181 and SOLID65 elements.
- Type of fire exposure and fire severity has significant influence on the resulting residual capacity of fire exposed steel bridge girders.
- A bridge girder when exposed to external design fire with maximum fire temperature of 680 °C, has a residual capacity of about 84% as compared to 70% when exposed to moderate design fire with a maximum fire temperature reaching 800°C.
- A steel bridge girder experiences failure under fire conditions when the maximum fire temperatures is around 1100°C, as in the case of typical hydrocarbon fires.

Research Needs

- Effect of parameters such as transverse stiffeners, other span lengths & beam depths, composite action.
  - Effect of Web shear buckling at elevated temp. (study begun at Princeton)
- Design and retrofit recommendations (guidelines for Department of Transportation)
- Fire tests on replicate bridge girders to generate data for validating models
- Parametric studies to evaluate the critical factors governing the residual strength of fire exposed bridge girders.
- A methodology for assessing the residual strength of fire exposed bridge girders
- Strategies for mitigating fire hazard in steel bridge girders.

Acknowledgements

Funding Agencies

- NSF CMMI-1068252 (Princeton University)
- NSF CMMI-1068621 (Michigan State University)
- Michigan State SPG 71-4434 (Michigan State University)

Researchers

- Ignacio Paya-Zaforteza, Universitat Politècnica de València
- Jonathan Glassman, Ph.D. student Princeton University
- Esam M. Aziz, Ph.D. student, Michigan State University
- Lensir Gu, PDF (formerly), Michigan State University

STRATEGIC MEASURE FOR ENSURING FIRE SAFETY OF BUILDINGS AFTER AN EARTHQUAKE

PROF. MAMORU KOHNO
TOKYO UNIVERSITY OF SCIENCE

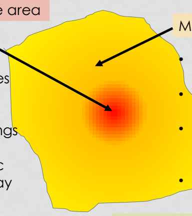
CONTENTS

RESEARCH BACKGROUND (1/2)

If very large earthquake occurs in urban area;

Devastating damage area

- Old wooden houses collapse.
- Some of old engineered buildings may collapse.
- Few of new seismic design building may collapse.
- Life Safety is the issue.



Major to slight damage area

- Some of wooden houses collapse.
- A few of engineered buildings may collapse.
- Partial damage in seismic design building.
- Quality of Life is the issue.

A large number of high-rise residential buildings in urban area.

RESEARCH BACKGROUND (2/2)

Damaged building after a large earthquake

It may have enough structural resistance to aftershocks.
Following items must be secured for continuous use:
- Lifeline is available. (Quality of Life)
- It will not collapse even a fire occurs. (Fire Resistance)
- Residents can evacuate from the building in fire. (Evacuation Safety)

Residents

Continue to live in the high-rise apartment building.
(Limited capacity of public evacuation centers.)

Is fire safety the same as that of before earthquake?

In case of fire:
Faster fire spread (Impaired fire compartment, Less firefighting.)
Evacuation Difficulty (Obstruction in path, Impaired fire compartment.)

Higher risk of fire than usual

TARGET BUILDING

High-rise apartment building are the main target.
"Mansion" in Japanese wording.

Building characteristics:

- Residential use. Accommodates a lot of people.
- Heat source is used.

"**Self-help**" and "**mutual assistance**" of residents are necessary.

Fire Service Law does NOT require:

- Self fire brigade.
- Emergency preparedness manager.

to these builgings.

DISASTER PREVENTION CAPABILITY OF HIGH-RISE APARTMENT BUILDING IN AFTERMATH OF EARTHQUAKE

Assumed Situation

- Maintain seismic strength.
- Priority in safety confirmation and life saving.

Immediate evacuation for apparent danger

Disaster prevention capability

- Obstructed evacuation path.
- Limited rescue operation.

If fire safety equipment is impaired…

Vulnerable to fire

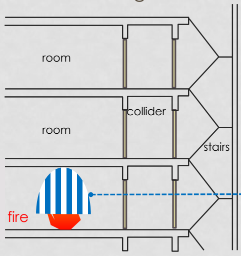
Discussion and proposal

- Phases considering internal and external conditions.
- Fire safety requirements appropriate to each phase.
- Strategic restoration plan and checkup methods.

IF

A fire started in 10th floor of 30-story high-rise apartment building.

Before earthquake

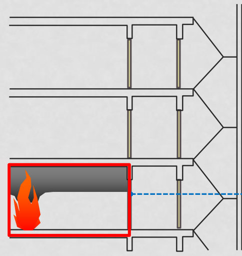


SP suppresses the fire.

7

OR

Before earthquake



Fire will not spread beyond the compartment

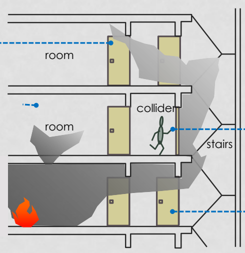
8

HOWEVER, IF

A fire started in 10th floor of 30-story high-rise apartment building.

After earthquake

Smoke invasion thru open door.



Staircases are filled with smoke. Unable to escape.

Fire or smoke spreads thru damaged walls and floors.

Smoke spreads thru open door.

9

DAMAGE BY LIQUEFACTION

Temporary repairs of level difference and sewage pipe.

Inclined wall of parking

Photo taken in August 10, 2011

10

DAMAGE IN EXTERNAL WALLS

External wall

Expansion joints

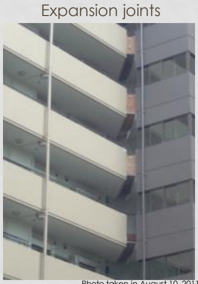


Photo taken in August 10, 2011

11

DAMAGE NEAR EXTERIOR STAIRWAY

Exterior door (view from collider)

Exterior wall

Photo taken in August 10, 2011

12

Damage in Expansion Joints

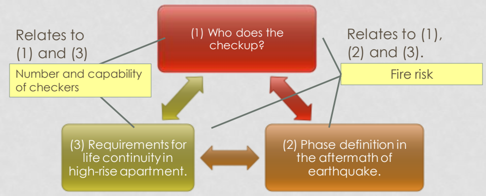
Detached exterior stairway

Closer look at exp. joint

Photo taken in August 10, 2011

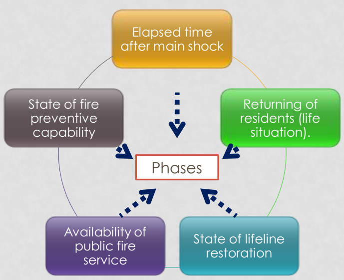
Items Extracted From Interview And Questionnaire Surveys

Three items;



An appropriate phase division clarifies who can conduct checkups and what items to be checked at each phase.

Definition of Phases



Summary of Phases

Phase	Period	Residents	Lifeline	Public fire service	Fire usage
1	A day and a night	Partial return	Shutdown	Unavailable	Fire ban
2.0	Two days to four weeks	Full return	Partial recovery	Unavailable	Fire ban
2.5			Full recovery	Available	Restricted usage
3	Six to twelve months	Full return	Full recovery	Available	Allowed
4	Usual state				

Detailed Description - Phase 1

Period	A day and a night after earthquake	Confusing period
Expected situation	Part of residents cannot return home. Lack of manpower for checkup.	
	Heat source may not be available due to shutdown of lifeline.	
	Fire fighting nor rescue operation cannot be expected.	
	Functionality of fire preventive equipment is not checked.	
Requirements	Reduction in fire ignition (Fire ban)	
	Securement of evacuation path especially evacuation stairs.	

Detailed Description - Phase 2.0

Period	After the second day.
Expected situation	Most of residents returns home. Increased manpower for checkup.
	Partial recovery of lifeline. Increased chance for usage of heat source.
	Neither firefighting nor rescue by public fire service is available.
Requirements	Reduction in fire ignition. (Fire ban or restricted fire use)
	Securement of evacuation path.
	Prevention of fire spread

Detailed Description - Phase 2.5

Period	Up to four weeks.	
Expected situation	Quasi-compliant fire preventive capability.	
	Chance of fire source usage increases as lifeline recovers.	
	Firefighting and rescue by public fire service are available. However, building equipment for fire brigade is not checked or confirmed.	
Requirements	Reduction in fire ignition. (Restricted fire usage)	
	Securement of evacuation path.	
	Prevention of fire spread.	
	Assistance for fire brigade.	

Detailed Description - Phase 3

Period	Until six to twelve months
Expected situation	Lifeline and public fire service is fully recovered.
	Fire preventive capability is restored to quasi-compliant level by temporal repairs of damaged building and equipment.
Requirements	Normal fire safety.

Period for full repairs of damaged building elements and fire safety equipment.
Periodic checkups are necessary until complete recovery.

Detailed Description - Phase 4

- The building restored its original safety level.
- The life gets back to usual, unrestricted, state.

Strategic Restoration Plan and Checkup Methods

For each phase, determine the permissible states of;
- Structural elements,
- Fire compartments, and
- Fire preventive equipment

for the life continuity plan.

↓

Select appropriate checker from residents or building experts.

Emergency checkup methods, temporary and full repairs are discussed.
Focus on **who** should do it.

Checkup Method in Phase 1

Checkup of evacuation paths, such as colliders and stairs, in parallel to the safety confirmation by **residents**.

Earthquake

↓

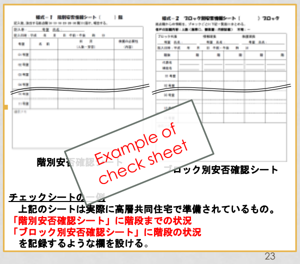
Residents will check and record following information.
- safety confirmation
- state of individual rooms
- State of path to designated place

↓

Gather at designated place of each floor

↓

Report to the emergency headquarters



Checkup Items in Phase 2.0

- Check of evacuation path, building elements and equipment by **residents**.
- Fire ban may be relaxed if following items are all confirmed.

Items to be confirmed.
(1) Evacuation paths. (Re-check of Phase 1)
(2) Inclination of building.
(3) Cracks in columns, girders, or floors.
(4) Major damage in party wall.
(5) Major damage in wall between an apartment and collider.
(6) Falling of external wall or tiles on it.
(7) Falling of exterior opening elements, such as glazing.
(8) Damage in fire extinguisher.
(9) Functionality check of automatic fire alarm equipment (at control panel)
(10) Functionality check of fire alarm and warning system. (at control panel)
(11) Functionality check of emergency lightning system. (at control panel)

Checkup Methods In Phase 2.0

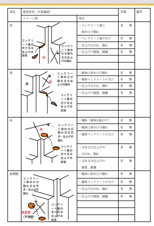
- Conduct basic checkup by **residents**.
- Prepared manualized methods will be helpful.

From interview survey

Emergency response

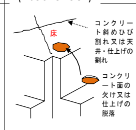
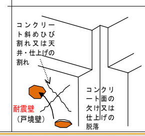
- Facility and equipment checkup. Repair request.
- Safety confirmation of residents
- Information share
- Acceptance of relief goods
- Setting up evacuation center
- Meals outdoors
- Volunteer activities

Emergency warning system, and walkie-talkies are helpful.



Example of a check sheet for structural elements.
Itemize checkup parts for "Anyone can do it."

An Example of Check Sheet for Structural Elements (Floors and Walls)

Element	Damage state (visual check)	項目	有無	備考
Floor		• Inclination • Diagonal crack • Concrete spalling • Cracked ceiling finish • Falling of ceiling finish	y/n y/n y/n y/n y/n	
Wall		・躯体に斜めひび割れ	有　無	
		・躯体コンクリートの欠け	有　無	
		・仕上げはがれ、割れ	有　無	
		・仕上げの脱落、破壊	有　無	

Checkup Items In Phase 2.5

- Confirmation of equipment for firefighting by **experts**.
- Phase 3 will start if following items are all confirmed.

Items to be confirmed

Equipment for firefighting
- Emergency elevator
- Indoor fire hydrant
- Water supply pipes
- Water for firefighting
- Emergency outlet

Water supply pipes

Water for firefighting

Items and Methods of Repairs in Phase 3

- Full Repairs are conducted to restore original fire safety by **building experts**.
- Proceed to Phase 4 (usual state) if following items are restored.

Items to be restored.

- Fire preventive elements and equipment,
- Structural elements,
- Fire compartment constructions, such as floor and wall, and
- Disaster prevention equipment.

Summary of Phases

Phase	Period	Residents	Lifeline	Public fire service	Fire usage
1	A day and a night	Partial return	Shutdown	Unavailable	Fire ban
2.0	Two days to four weeks	Full return	Partial recovery	Unavailable	Fire ban
2.5			Full recovery	Available	Restricted usage
3	Six to twelve months	Full return	Full recovery	Available	Allowed
4	Usual state				

Concluding Remarks (1/2)

- If a large earthquake affects a high-rise building, the fire safety of the building can be lower than usual, even though its structural damage is slight.
- In the aftermath of the earthquake, quality of life of the residents will be the most important issue.
- A four-phase recovery plan was proposed.
- The phases were determined considering elapsed time, internal and external conditions of the building.
- Permissible life state (usage of fire) was proposed to each phase.

Concluding Remarks (2/2)

- Checkup items and viable methods at each phase were discussed.
- In the earlier phase the checkup and temporary repairs should be conducted by available residents.
- In the later phase, however, building experts should investigate the building elements and safety equipment. Then full repairs would be done accordingly to restore the original safety level.
- Each high-rise apartment is recommended to prepare its recovery plan before an earthquake strikes. The quality of life of the residents will be highly dependent to the appropriateness of the plan.

Response Sensitivity and Reliability Analysis of Structures in Fire

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Assistant Professor

Qianru Guo
PhD Student

Department of Civil and Environmental Engineering
University of Michigan
Ann Arbor, MI USA

Motivation

- Structural performance in fire is highly sensitive to a number of parameters (e.g., temperature, level of fire protection, magnitude of applied load)
- Current methods for fire resistant design do not provide a quantitative measure of structural reliability
- Reliability analysis is a key component of performance-based design

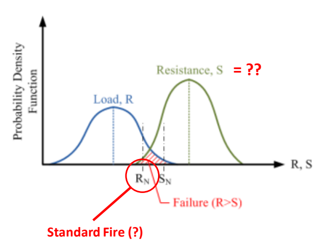
Sources of Uncertainty

Fire Behavior
- Compartment geometry, amount and distribution of fuel, ventilation
- Fire temperature, Surface flux

Thermal Response of the Structure
- Material properties, boundary conditions
- Temperature in the structure

Mechanical Response of the Structure
- Material properties, applied loads, mechanical boundary conditions
- Deformation, Force

Principles of Structural Design



- Structural systems are defined in terms of load R and resistance S
- R and S are continuous random variables that are dependent on parameters $\boldsymbol{X}$ that are random in nature
- Generally, we treat the system as **deterministic** and conservatively choose design values S_N and R_N based on a factor of safety

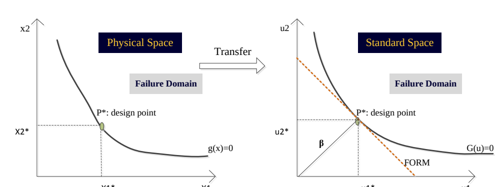
Quantification of Structural Reliability

- **Monte Carlo Simulation**
  - Extremely versatile
  - Computationally inefficient
- **First Order Reliability Method**
  - Linear approximation for the limit state function
  - Only requires the response and response gradient

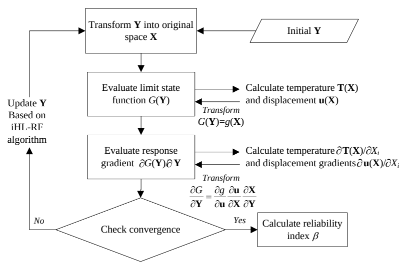
Quantification of Structural Reliability

- **First Order Reliability Method**

Performance function: $g(\mathbf{X}) = R(\mathbf{X}) - S(\mathbf{X})$
In the present study, $g(\mathbf{X}) = u(\mathbf{X}) - L/30$



First Order Reliability Method



Response Sensitivity Analysis

- **Finite Difference Method (FDM)**

$$\frac{\partial u}{\partial X} \approx \frac{\Delta u}{\Delta X}$$

  - Inefficient (for N parameters, need to run analysis $N + 1$ times)
  - Accuracy is dependent on perturbation size

- **Direct Differentiation Method (DDM)**
  - Response gradient obtained directly by differentiating governing finite element equations
  - Accurate and no iteration needed

DDM in Structural Mechanics

$$\mathbf{P}_n^{int} = \mathbf{P}_n^{ext}$$

Differentiate with respect to parameter X

$$\mathbf{K}_n \frac{\partial \mathbf{u}_n}{\partial X} = \frac{\partial \mathbf{P}_n^{ext}}{\partial X} - \left.\frac{\partial \mathbf{P}_n^{int}}{\partial X}\right|_{\mathbf{u}\text{ fixed}}$$

?

$$\left.\frac{\partial \mathbf{P}_n^{int}}{\partial X}\right|_{\mathbf{u}\text{ fixed}} = \sum_{N_{els}} \int \left(\left.\frac{\partial \mathbf{B}^T}{\partial X}\right|_{\mathbf{u}\text{ fixed}} \boldsymbol{\sigma}_n + \mathbf{B}^T \mathbf{E}_n \left.\frac{\partial \boldsymbol{\varepsilon}_n}{\partial X}\right|_{\mathbf{u}\text{ fixed}} + \mathbf{B}^T \left.\frac{\partial \boldsymbol{\sigma}_n}{\partial X}\right|_{\boldsymbol{\varepsilon}\text{ fixed}} \right) dV$$

(Haukaas, 2006)

DDM in Structural Fire Engineering

$$\mathbf{P}_n^{int} = \mathbf{P}_n^{ext}$$

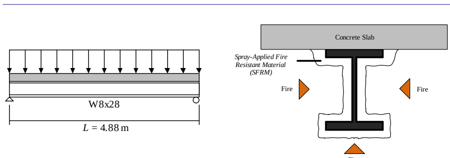
Differentiate with respect to parameter X

$$\mathbf{K}_n \frac{\partial \mathbf{u}_n}{\partial X} = \frac{\partial \mathbf{P}_n^{ext}}{\partial X} - \left.\frac{\partial \mathbf{P}_n^{int}}{\partial X}\right|_{\mathbf{u}\text{ fixed}}$$

$$\left.\frac{\partial \mathbf{P}_n^{int}}{\partial X}\right|_{\mathbf{u}\text{ fixed}} = \sum_{N_{els}} \int \left(\left.\frac{\partial \mathbf{B}^T}{\partial X}\right|_{\mathbf{u}\text{ fixed}} \boldsymbol{\sigma}_n + \mathbf{B}^T \mathbf{E}_n \left.\frac{\partial \boldsymbol{\varepsilon}_n}{\partial X}\right|_{\mathbf{u},\mathbf{T}\text{ fixed}} + \mathbf{B}^T \mathbf{E}_n \left.\frac{\partial \boldsymbol{\varepsilon}_n}{\partial \mathbf{T}_n}\right|_{\boldsymbol{\varepsilon}\text{ fixed}} \frac{\partial \mathbf{T}_n}{\partial X} + \mathbf{B}^T \left.\frac{\partial \boldsymbol{\sigma}_n}{\partial X}\right|_{\boldsymbol{\varepsilon},\mathbf{T}\text{ fixed}} + \mathbf{B}^T \frac{\partial \boldsymbol{\sigma}_n}{\partial \mathbf{T}_n} \left.\frac{\partial \mathbf{T}_n}{\partial X}\right|_{\boldsymbol{\varepsilon}\text{ fixed}} \right) dV$$

Dependent on temperature $\mathbf{T}$

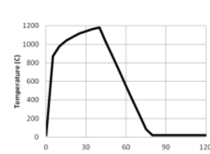
Application



- Design based on the AISC steel design specification and the ANSI/UL 263 requirements for prescriptive fire resistant design in the U.S.
- A cementitious spray-applied fire resistant material was selected to provide a one-hour fire resistance rating
- Concrete slab only affected the heat transfer to the beam and did not contribute to the structural response

Fire Model

- **Parametric fire curve (EN1991-1-2)**

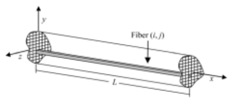


Parameters:

- Fuel load density q_t
- Ventilation factor F_v
- Thermal inertia of surroundings b

Thermo-Structural Model

- **Fiber-based thermal and structural elements**
  (Jeffers and Sotelino 2012)



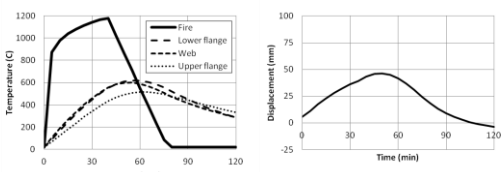
Parameters:
- Surface boundary conditions (convection, radiation)
- Thermal properties of spray applied fire resistant material
- Thermal and mechanical properties of steel
- Applied load

Model Input

	Parameter	Mean	COV	Distribution
Fire	Ventilation factor, F_v	0.04 m$^{1/2}$	0.05	Normal
	Fire load density, q_t	564 MJ/m^2	0.62	Extreme I
	Thermal inertia, b	423.5 Ws$^{1/2}$/m^{2}K	0.09	Normal
Thermal	Heat transfer coeff., h	35 W/m^{2}K	--	Unknown
	Emissivity, ε	0.80	--	Unknown
	Thickness, t_{sfrm}	Nominal + 1.6mm	0.20	Lognormal
	Density, ρ_{sfrm}	300 kg/m^3	0.29	Normal
	Conductivity, k_{sfrm}	0.120 W/m-K	0.24	Lognormal
	Specific heat, c_{sfrm}	1200 J/kg-K	--	Unknown
	Thermal props. of steel	EC3	--	Unknown
Structural	Dead load, w_{DL}	1.05 x Nominal	0.10	Normal
	Live load, w_{LL}	0.24 x Nominal	0.60	Gamma
	Yield strength, F_y	380 MPa	0.08	Normal

Results

Deterministic analysis:

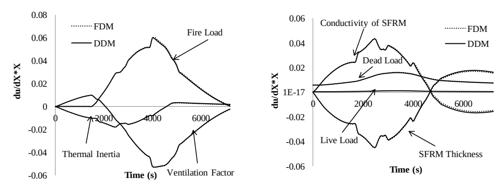


(a) Fire and steel temperatures under natural fire exposure

(b) Mid-span displacement

Results

Response sensitivity to various parameters:

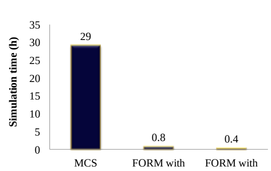


(a) Fire model

(b) Thermal and structural models

Results

- Probability of failure
  - 7.9% by Monte Carlo simulation (10,000 samples)
  - 8.4% by First Order Reliability Method
- Simulation time



Conclusions

- This research is an initial step towards reliability-based design of structures for fire
- The first order reliability method exhibits good accuracy and significant savings in computational cost.
- For calculating the response gradients, both the FDM and DDM offer excellent agreement, but the DDM results in considerable time savings.
- Additional research is need to study structural systems, which have multiple failure surfaces and exhibit interactions between structural components.
- Discussion is warranted regarding what might be considered an acceptable level of risk for structural fire design

Acknowledgments

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engineering laboratory

National Fire Research Laboratory (NFRL)

Dr. Samuel L. Manzello

Fire Research Division

Engineering Laboratory (EL)

National Institute of Standards and Technology (NIST)

A Brief History

- Large Fire Laboratory (LFL) – NFRL predecessor
  - Commissioned in 1972
  - Advance real-scale fire measurements
    - Fire sizes
    - Material ignition propensities
    - Fire growth and spread
    - Tenability
    - Fire suppression and detection
    - Fire fighting
  - Enable experimental validation studies of fire models
  - Conduct experiments to support post-fire studies
  - Enable advances in fire & building codes and standards

LFL + Expansion = NFRL

Recent Experiments at NFRL (before Expansion)

Doorway flow PIV measurements

Wind Effects on Fire

World Trade Center Study

Mattress Fires

Compartment Fires

Fire Brands

Staffing

- Current level
  - 4 technical staff (3 with PhD and 1 with MS)
  - 3 technical support staff
  - 1 administrative assistant
- FY13 level
  - 6 technical staff (5 with PhD and 1 with MS)
  - 4 technical support staff
  - 1 administrative assistant
  - 3 guest scientists

Why NFRL Expansion?

- At present, there are no science-based, established measurement tools to evaluate the performance of an entire structure, including connections, under realistic fire loads (e.g., uncontrolled fire).
- The expanded facility will enable:
  - Study of real-scale structural components or systems
  - Controlled hydraulic loading simulating service load conditions
  - Up to 20 MW fire exposure for 4 hrs
  - Measurement of structural performance to incipient collapse
  - Characterization of fire intensity (heat release rate)
- This combination of features is unique in the world and will enable the development of measurement science needed for performance-based design methodologies for structures in fire.

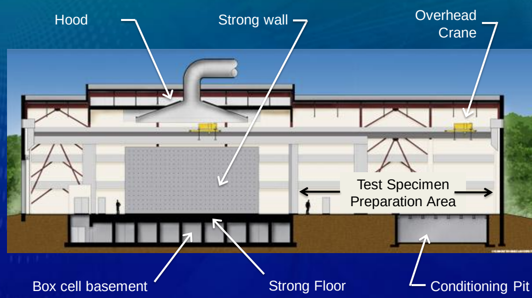
NFRL Expansion Timeline

- Oct 2003 NIST/SFPE Roadmapping Workshop
- … 2008 Stakeholder meetings and workshops
- Apr 2009 Selected for ARRA funding
- Nov 2010 Construction “Notice to Proceed”
- Dec 2012 Construction completed
- Dec 2013 Commissioning completed

NFRL Expansion

Specification	Existing Laboratory	New Expansion
Total Floor Area	10,800 sq. ft.	21,400 sq. ft.
Fire Capacity	1 MW (small hood) 3 MW (medium hood) 10 MW (large hood)	20 MW
Strong Floor/Strong Wall	None	60 ft. x 90 ft. x 4 ft. thick strong floor and 60 ft. x 30 ft. x 4 ft. thick strong wall.
Structural Loading	None	Reconfigurable hydraulic loading system, 55-215 kip actuators; 30 inch stroke

Section through the Building



3D Rendering of NFRL Expansion

9/25/2011 – Basement Shear Walls

11/1/2011 – Align Floor Anchors

4/1/2012 –Strong Wall / Floor

6/7/2012

Unique Challenges:

NFRL's uniqueness poses significant challenges not faced by other structural or fire research facilities

- Structural loading in a fire environment
- Thermal protection of facility (strong wall/floor) and equipment (hydraulic system and reaction frames)
- Measure structural response (deformations, strains) in a fire environment

Research Focus:

- Measure the performance of real-scale structures under realistic fire and structural loading in controlled laboratory conditions.
- Develop an experimental database on the performance of large-scale structural connections, components, subassemblies and systems under realistic fire and loading.
- Validate physics-based models to predict fire resistance performance of structures.
- Provide the technical basis for performance-based standards for fire resistance design of structures and foster innovation in the building design and construction industry.

Anticipated Outcomes and Impact

- Public databases, models, guidelines, and improved standards, codes, and practices for the built environment;
  - Affected codes and standards include: ICC, ASCE 7, AISC, ACI, ASTM, SFPE, NFPA
- Accelerated transformation from prescriptive to performance-based fire safety design of buildings and infrastructure;
- Enhanced safety of buildings, infrastructure, emergency responders, and the public at large.

Working with NIST

- Informal collaborations
  - Joint peer-reviewed papers; laboratory visits; sharing of research methods
- CRADAs
  - Formal partnering agreement to work with universities, industry, and other organizations on joint R & D projects
- Guest researcher arrangements
  - Scientists and engineers from universities (faculty, post-docs, students), non-profits, industry, and government agencies working with NIST researchers on projects of mutual interest
- Use of facilities at NIST
  - Cost-reimbursable basis

Thank you.
Questions?

http://www.nist.gov/el/

Full-scale Fire Test for Wooden 3-storey School Building – Preliminary Test

Daisaku NII

Hideki YOSHIOKA

National Institute for Land and Infrastructure Management (NILIM)

Introduction

- **Legislation**: Building Standard Law of Japan has mandated fire-resistive building for 3-storey school buildings. It is practically difficult to construct 3-story wooden school as fire-resistive building.
  The Act for Promotion of Use of Wood in Public Buildings (enacted Oct 2010) requires promotion of research activities to review building code regulations for the utilization of wood in building applications.
- **Feasibility**: This full-scale fire test was planned to verify that quasi-fire-resistive wooden building can be treated equally to fire-resistive building.
- **Research project**: Research project will be conducted from FY2011 to FY2013. Based on the information from this preliminary test (FY2011), it is scheduled to conduct another full-size fire tests in FY2012. Other issues on fire safety ,ex. evacuation safety, will be investigated in FY2013.

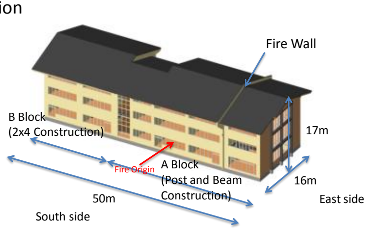
Objectives of this Full-scale test

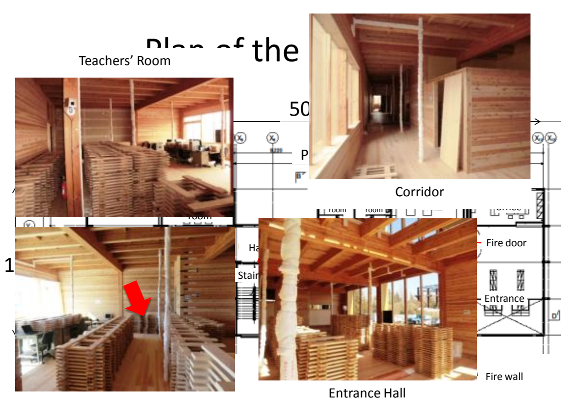
- **Indoor Fire Spread**:
  - ✓ compartment penetration
  - ✓ Horizontal spread
  - ✓ external flame
- **Indoor Smoke Flow Characteristics**:
  - ✓ on the floor of fire origin
  - ✓ via staircases, floor cracks and compartment penetrations
- **Influence to adjacent buildings**:
  - ✓ Radiation heat to adjacent buildings
  - ✓ Fire brands scattering
- **Influence of long-time fire to building structures**:
  - ✓ Possibility of collapse

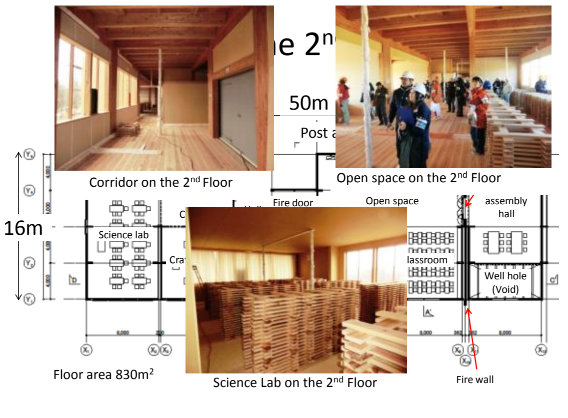
Overview of the Test Building

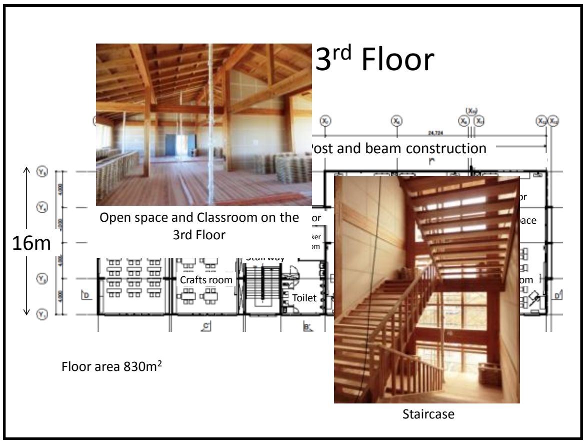
Full-scale Fire Test Overview

- Conducted on 22nd February in experimental site of NILIM (large open field)
- Building area: 830m^2 : Total Floor Area: 2,260m^2
- Designed and built in accordance with 1-hour quasi-fire-resistive construction









Main Features of Test Building (1)

- **Floor Plan**: Class rooms located on 2 – 3 storey levels are designed as "open-type" being popular in recent years. Other rooms are also allocated to simulate teachers' rooms and special.
- **Type of Construction**: For the purpose of pursuing the difference in fire behavior between construction types, the combination of post & beam (P&B) construction and wood frame construction (2x4 construction / PFC: platform wooden construction) was applied.

  Almost floor and wall members were composed by the combination of gypsum board, Japanese Cedar panel and structural plywood. Columns and beams were made of Japanese Larch. It was verified that these were satisfied quasi-fire-resistive performance by furnace test



Main Features of Test Building(2)

- **Interior Finishing**: Interior for the 1st floor level (floor to be ignited) was finished entirely with wooden materials considering that wooden interior finishing is potentially demanded for wooden school buildings.
- **Exterior Finishing**: In principal, exterior is finished not with wooden but with ceramic-type siding to clarify the influence of external flam for upward fire spread. It was expected that large external flame would be ejected from the window openings.
- **Fire Wall**: Effectiveness of fire wall is to be verified by isolating one classroom or entrance by self-standing fire wall from other compartments. This fire wall was installed in the North-South direction with 1-hour fire rate.

Main Features of Test Building(3)

- **Ignition**: Teachers room was ignited. Result of statistical survey shows school fire originates at highest probability from teachers' rooms where much combustible materials tend to be located.
- **Fire Load**: Each room will be loaded with fuel (Japanese Cedar lumber) of the heat amount of 400 MJ/m2 simulating furniture, etc. The lumber volume has been determined by the equivalent heat per unit mass 18 MJ/kg for wood.

Measurement

- **Temperature**: About 700 points of inside/outside of air temperature, temperature of surface and inside of fire walls and beams are measured by thermocouples.
- **Heat flux**: Over 60 points of heat flux (most of all is outside) are measured by heat flux gauges in order to quantify the thermal effect to surroundings.
- **Video**: Video and thermal images on each side of the building are recorded.

  CCD video cameras are installed in fire origin and corridors of each floor in order to capture smoke movement and fire spread.
- **Detector and sprinkler**: Fire detectors, smoke detectors and sprinkler heads (without water) are installed in order to measure the activation time.
- **Environmental conditions**: Wind speed and direction, air temperature, humidity are measured around the building.

Briefing on Fire Test Results

- Overview of fire scenario
  – shown by still pictures. Collapse of building.
- Characteristic points of this fire
  – 1-hour semi-fireproof construction performance
- Some major events in this fire test:
  – Fire spread within the room of fire origin
  – Vertical fire spread to upper floors by flame ejected out of the broken window
  – Horizontal fire spread over the fire wall
  – Impact to Surroundings/neighborhood
    - Incident Heat Flux at surroundings.
    - Firebrands scattering.

Start of the Fire Test

8 minutes after ignition

30 minutes after ignition

1 hour and 18 minutes after ignition

1 hour and 36 minutes after ignition

Approx. 2 hours after ignition

Characteristics of this Fire Test

- Rapidly spread of fire all over the building was due to large-scale blowout fire.
- Fire spread all over the building, but it could maintain self-sustainability for over 1 hour. Therefore, it achieved 1-hour **semi-fireproof construction** performance as required by the Standard.
- Combustible volume of each room was designed with total heat release based on the actual survey, but review is necessary from the aspect of heat generation rate.
- Fire spread beyond the fire protection wall because the fire protection door of the opening area was run through.
- Large amount of firebrands seems to have flown on the lee from the attic area before collapse of the building.

I. Hagiwara, T. Naruse, etc.

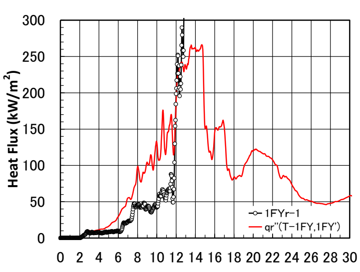
Fire spread in the room of fire origin

2 min:
Flame reached ceiling.
HF: 10 kW/m^2.

6 min:
Glass in the south broken.
Air flowed into the room.
HF: 50 kW/m^2.

10 min:
Glass in the north broken.
HF: 100 kW/m^2.

12 min:
Flashover. 1,200℃
HF: 300 kW/m^2.



Incident heat flux at desktop in the room of fire origin

Black : measured by heat flux meter
Red : calculated by temperature

J. Suzuki, etc.

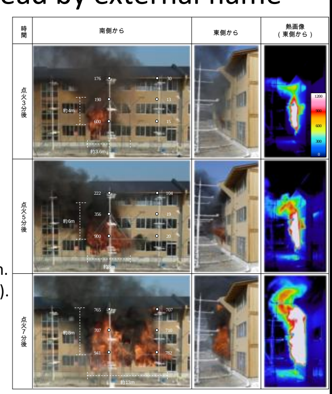
Vertical fire spread by external flame

3 min:
Glass broken partially,
and flame ejected.
Flame: 3.8m(width), 5m(height).

5 min:
Glass broken entirely,
Flame: 8m(width), 6m(height).
Then, 2nd Floor ignited.

7 min:
Glass in adjacent opening broken.
Flame reached eaves (8m height).

8 min:
3rd Floor ignited.



D. Nii, H. Yoshioka, etc.

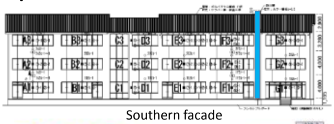
Horizontal fire spread over Fire Wall

1.5 min: (inside)
Fire door on 1st floor opened,
Smoke moved through the gap of 20cm.

17 min: (southern facade)
External flame from openings, crossed over the fire-wall to the next compartment, horizontally under the eaves.

26 min: (eastern facade)
Glass at X1 was broken, and flame ejected from there.

27 min:
Glass at X2 and X3 were broken.
All three stories burned together.



Southern facade

Eastern facade

画像 3　点火後 15 分の東側の可視画像と熱映像

Eastern facade

画像 4　点火後 20 分の東側の可視画像と熱映像

I. Hagiwara, K. Kagiya, etc.

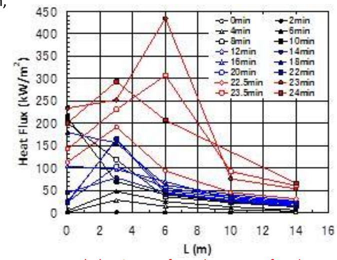
Incident Heat Flux at Surroundings

Maximum value measured by heat flux meter at each position, is described in the picture.

L=0(m): eastern facade.

23min, 23.5min:
Huge flame emerged from openings.
Maximum at 6(m) from facade, over 300 (kW/m²).
Even at 14(m) from facade, 70 (kW/m²).

Other than above:
HF decreases, as distance increases from the facade wall.



L (m) : Distance from the eastern facade.

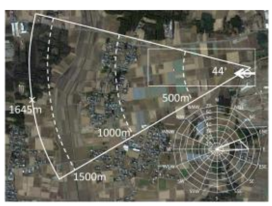
J. Suzuki, etc.

Firebrands scattering

Firebrands generated when roof was broken, caused another fire at a leeward place after scattering.
Brand size: 20 ~ 30 cm.

Wind direction: east-northeast ~ east.
Wind velocity: 4.6(m/s) Average.

Firebrands landed at large leeward area (fan-shaped, angle of 44°).
Especially, many landed at 700~800m.



Brands size.
Within 100m: 10cm ~ 30cm ~
500~600m: 2~3cm

Total weight of brands landed: 170 kg, 0.2 % of total wooden material in test building.

Y. Hayashi, T. Hebiishi, etc.

Tentative future plan

- This test: February 22nd, 2012
- Final test: November, 2012
- After 2013: Planning to revise BSL

Y. Hasemi, I. Hagiwara, T. Naruse, M. Kohno, etc.
and All the members.

Thank You for Your Attention

Specifications (Exterior)

	Exterior Finishing		
	Roof	Eave	Exterior Wall
A Block	Coloured Steel Sheet Structural Plywood Horizontal Rafter Structural Plywood	Structural Plywood (Exposed Rafter) Blocking	(South, North and West) Ceramic-Type Siding (East) J-C Siding
B Block	Coloured Steel Sheet Roof Sheathing Boards Rafter	J-C Boards Fibre-Reinforced Cement Boards	Ceramic-Type Siding

*J-C: Japanese Cedar

Specifications (Interior)

		Interior Finishing		
		Floor	Wall	Ceiling
1st Floor Level	A Block	J-C Flooring Type X Gypsum board Structural Plywood	J-C Panelling Structural Plywood	Structural Plywood
	B Block	Gypsum board Structural Plywood	J-C Boards Type X Gypsum board Structural Plywood	J-C Panelling Type X Gypsum board
2nd and 3rd Floor Level	A Block	J-C Flooring Type X Gypsum board Structural Plywood	Type X Gypsum board Structural Plywood	Structural Plywood (Rafter Exposed)
	B Block	Gypsum board Structural Plywood	Gypsum board Structural Plywood	Gypsum board
Each Floor Level	A Block		(Fire Wall) 2-Layer of Type X Gypsum board	

*J-C: Japanese Cedar
*Columns and Beams: Domestically manufactured Larch glulam, Domestically manufactured J-C glulam and J-C sawn lumber also used

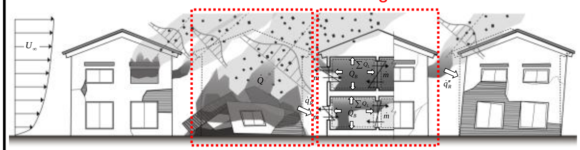
An Analysis on the Burn-down Probability of Historical Temple- and Shrine-Structures in Kyoto City due to Fires Following Earthquake

Keisuke HIMOTO
(Kyoto University)

Post-earthquake Fire Spread Model

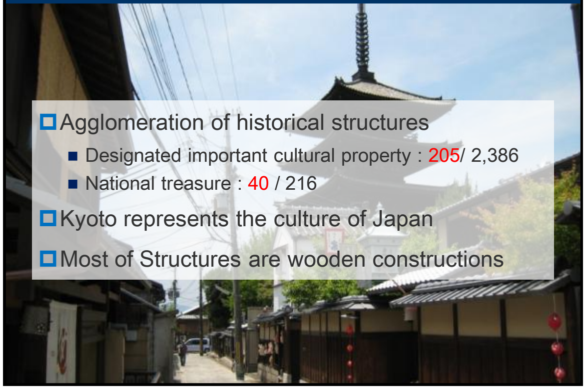
- Urban Fire = Group of Building Fires
  - Fire behavior of individual building:
    - One-layer zone model for uncollapsed buildings
    - Flame model for collapsed buildings
  - Building-to-building fire spread

Two Modes of Building Fire:



II. Crib Fire (Flame Model) I. Compartment Fire (One-Layer Zone Model)

Historical Structures in Kyoto City



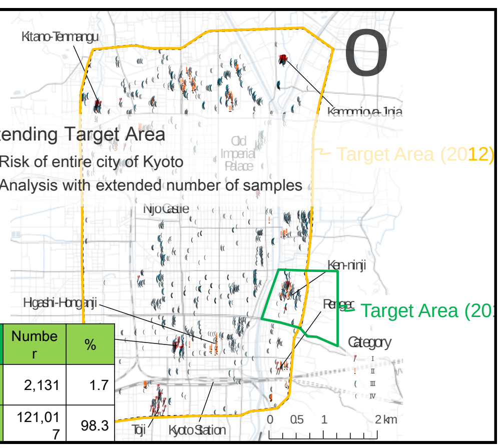
- Agglomeration of historical structures
  - Designated important cultural property : 205/ 2,386
  - National treasure : 40 / 216
- Kyoto represents the culture of Japan
- Most of Structures are wooden constructions

Location of Historical Structures in Kyoto City

Kobe in 1995 and Kyoto in 20XX

- Fires following earthquake in Kyoto
  - Fire may involve loss of historical structures
  - Historical structures are essential features of Kyoto

- Extending Target Area
  - Risk of entire city of Kyoto
  - Analysis with extended number of samples

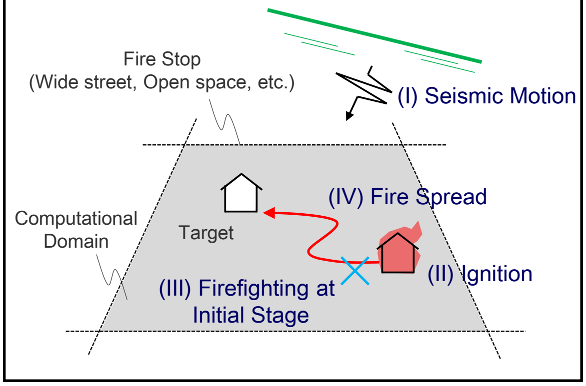


	Number	%
Historical Structure	2,131	1.7
Others	121,017	98.3

Category of Historical Structures

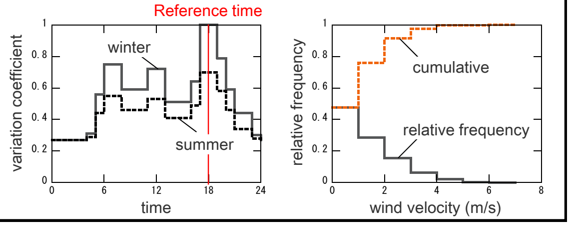
	Category	Time of Construction 1 (-1708)	2 (1708 -1788)	3 (1788 -1884)	4 (1884 -1945)	Total
I	National Treasure	15	0	2	0	82
I	Important Cultural Property	63	1	1	0	
II	Tangible Cultural Asset	0	0	2	14	117
II	Designated Cultural Property (Prefecture of Kyoto)	14	3	21	0	
II	Registered Cultural Property (Prefecture of Kyoto)	0	1	0	0	
II	Designated Cultural Property (City of Kyoto)	21	12	27	2	
III	No Registration / No Designation (in the nominee list)	45	59	121	10	235
IV	No Registration / No Designation (not in the nominee list)	34	77	791	795	1,697

Assumed Burn-down Scenario

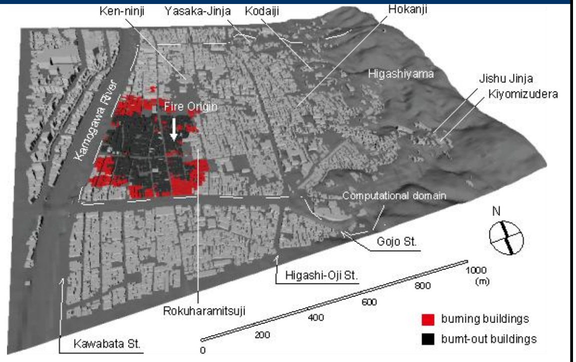


Monte Carlo Simulation

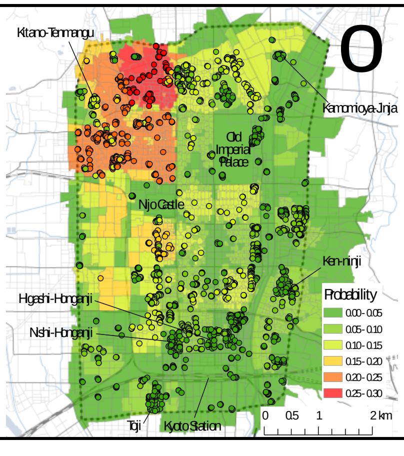
- Uncertain Factors
  - Ignition (date and time, number, location)
  - Firefighting (extinguishment at initial stage)
  - Damage level of buildings (5 grades)
  - Weather (wind velocity, direction)



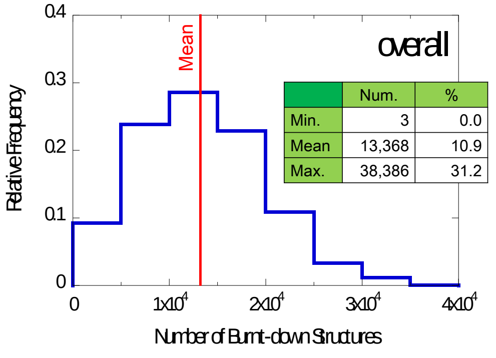
An Example of the Fire Spread Simulation



* Hanaore Fault case

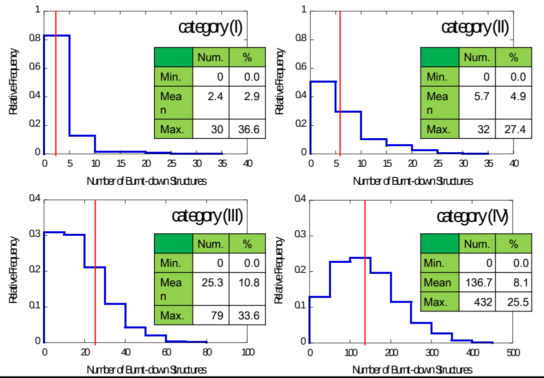


Overall Number of Burnt-down Structures



	Num.	%
Min.	3	0.0
Mean	13,368	10.9
Max.	38,386	31.2

Number of Burnt-down Historical Structures



category(I)

	Num.	%
Min.	0	0.0
Mean	2.4	2.9
Max.	30	36.6

category(II)

	Num.	%
Min.	0	0.0
Mean	5.7	4.9
Max.	32	27.4

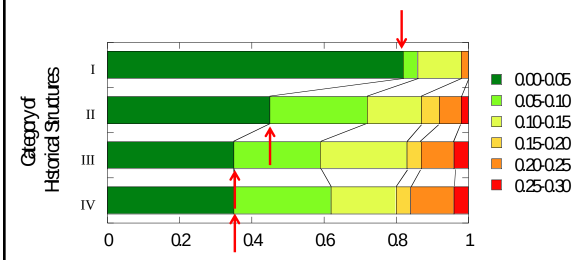
category(III)

	Num.	%
Min.	0	0.0
Mean	25.3	10.8
Max.	79	33.6

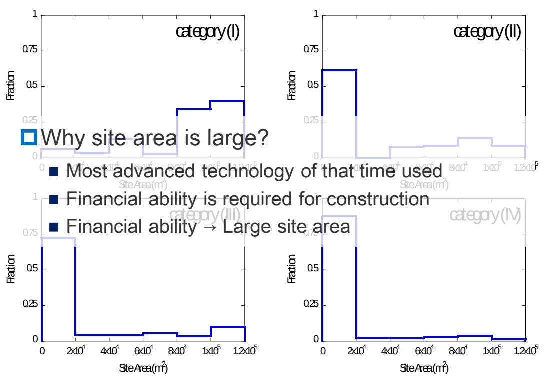
category(IV)

	Num.	%
Min.	0	0.0
Mean	136.7	8.1
Max.	432	25.5

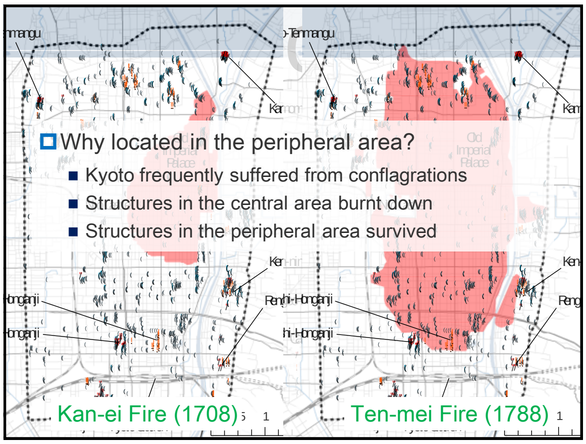
Burn-down Probability of Historical Structures



Site Area



- Why site area is large?
  - Most advanced technology of that time used
  - Financial ability is required for construction
  - Financial ability → Large site area



- Why located in the peripheral area?
  - Kyoto frequently suffered from conflagrations
  - Structures in the central area burnt down
  - Structures in the peripheral area survived

Summary

- Burn-down Probability of Historical Structures
  - Burn-down probability of 2,131 historical structures in Kyoto evaluated
  - Burn-down probability of category (I) lower than those of the other categories

Overview of NIST's Research On Wildland-Urban Interface (WUI) Fires

Dr. Samuel L. Manzello

Mechanical Engineer
Wildland-Urban Interface (WUI) Group
Engineering Laboratory (EL)
National Institute of Standards and Technology (NIST)
Gaithersburg, MD 20899-8662 USA
samuelm@nist.gov; +1-301-975-6691 (office)

Japan/USA Workshop
July 3rd, 2012

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Wildland-Urban Interface (WUI) Fires

WUI – structures and wildland vegetation coexist

Of the 10 largest fire loss incidents (> $1B) in U.S. history, 5 were WUI fires - all within the last 17 years

Proven risk assessment and mitigation tools are needed

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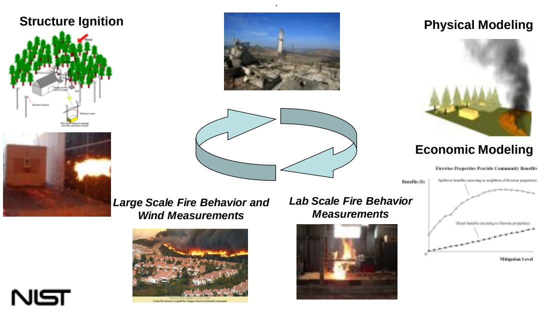
Integrated Approach to Reducing Losses in the WUI

Pre- and Post-Fire Data Collection & Analysis



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WUI Field Data Collection Studies

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The Trails

- Identify structure ignitions and fire/firebrand exposure
- Develop timeline
- Identify suppression actions
- Firewise analysis
- Modeling
- Post fire incident data collection methodology

- **274 residences**
- **245 within fire line**
- **74 residences completely destroyed**
- **16 partly damaged**

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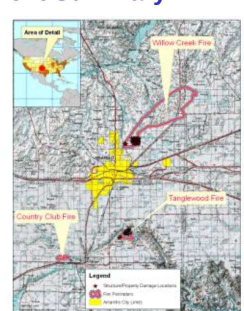
Amarillo Deployment Summary

- Primary focus: Tanglewood Complex Fire
- Secondary focus: Willow Creek Fire
- 21 days
- Field data collection initiated within 48 hours of ignition



Locations of fires around Amarillo Texas

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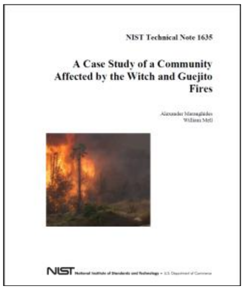
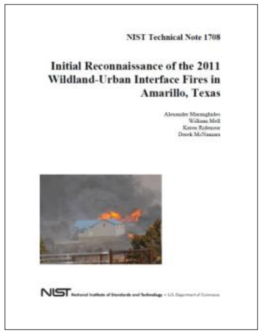
California and Texas Fires

Fire behavior reports


NIST Technical Note 1635

A Case Study of a Community Affected by the Witch and Guejito Fires

Alexander Maranghides
William Mell


NIST Technical Note 1708

Initial Reconnaissance of the 2011 Wildland-Urban Interface Fires in Amarillo, Texas

Alexander Maranghides
William Mell
Karen Ridenour
Derek McNamara

Structure Ignition Studies

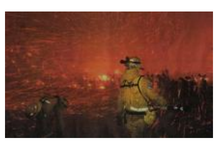
Firebrands

- Post-fire studies – firebrands a major cause of ignition
- Understanding firebrand ignition of structures – important to mitigate fire spread in communities

Improved understanding of structure ignition in WUI fires

- Major recommendation (GAO 05-380)
- National Science and Technology Subcommittee on Disaster Reduction
- Homeland Security Presidential Directive (HSPD 8; Paragraph 11)


2007 Southern California Fire


2003 Southern California Fire

Who cares?

- Codes and standards
  - ICC
  - ASTM
  - NFPA
  - CALFIRE
- GAO
- USFS
- DHS
- Insurance industry
- Homeowners
- Construction Industry

Homeland Security

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INTERNATIONAL CODE COUNCIL CHAPTER

International Collaboration
BRI (Japan) and EL-NIST (USA)

- **Firebrands: generation, transport, ignition**
- **Research focused on how far firebrands travel for 40 yrs!!**
- **Nice Academic Problem – Not helpful to design structures**
- **Vulnerable points where firebrands may enter structure**
  - **Unknown/guessed!**
- **Difficult to replicate firebrand attack!**
- **Entirely new experimental methods needed!**

Goals

Science - Building Codes/Standards; Retrofit construction

Design structures to be more resistant to firebrand ignition

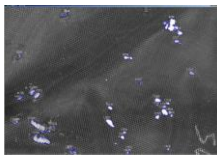
Douglas-Fir Tree Burns at NIST

- **Firebrand Collection using water pan array**
  - **Range of crown heights: 2.4 m – 4.5 m**
  - **Different moisture regimes**
- **Mass loss using load cells**

4.5 m Douglas Fir, MC = 25%

Firebrand Sizes from Angora Fire

Image analysis:
Determine firebrand size



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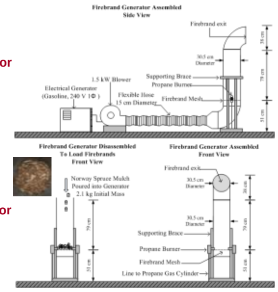
Firebrand Generator (NIST Dragon) 龍

Capable of producing controlled and repeatable size and mass distribution of firebrands

Firebrand Generator Side View

Firebrand Generator Front View



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Building Research Institute (BRI)

- **Fire Research Wind Tunnel Facility (FRWTF)**
- **Unique facility – investigate influence of wind on fire**
  - **Constructed more than 10 years before IBHS wind tunnel**

Fire Research Wind Tunnel Facility (FRWTF)

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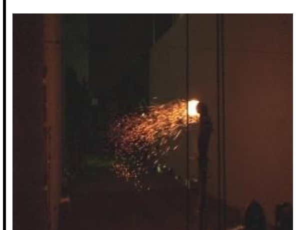
NIST Dragon 龍



Firebrand size/mass commensurate to full scale tree burns and actual WUI fire (2007 Angora Fire)

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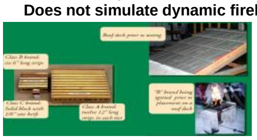
Current Roofing Standards

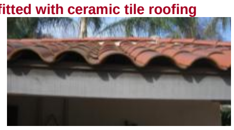
Roofing test: ASTM E108; UL 790
Does not simulate dynamic firebrand attack!

Japan/USA Use This Test!



12 mi/hr
(5.3 m/s)

Mitchell &Patashnik [2007] – possible correlation homes ignited in 2003 Cedar Fire with those homes fitted with ceramic tile roofing



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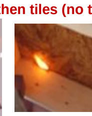
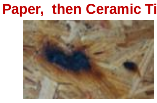
Ceramic Roofing

Aged Roofing Simulated: OSB, then tiles (no tar paper)



U_∞ (m/s)	OSB/TP/CT No Bird Stops	OSB/TP/CT With Bird Stops	OSB/CT No Bird Stops	OSB/CT With Bird Stops
7	SI	NI	SI to FI	SI
9	SI	NI	SI to FI	SI

New Roofing Construction: OSB, Tar Paper, then Ceramic Tiles



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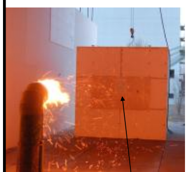
Firebrand Penetration Through Vents

Experiments conducted in 2007

Worked with CALFIRE as part of a task force (invitation only) to reduce mesh size used to cover building vent openings to lessen the potential hazard of firebrand entry into structures



Changes were formally adopted into the 2010 California Code of Regulations, Title 24, Part 2, Chapter 7A, and are effective January, 2011

Screen Behind Vent

Three sizes tested 6 mm , 3 mm , and 1.5 mm

Workshops for Input

NIST Special Publication 1111

Summary of Workshop on Research Needs for Full Scale Testing to Determine Vulnerabilities of Siding Treatments and Glazing Assemblies to Ignition by Firebrand Showers

Samuel L. Manzello
Sayaka Suzuki
Fire Research Division
Building and Fire Research Laboratory

June 2010

Hosted by CALFIRE

U.S. Department of Commerce
Gary Locke, Secretary

National Institute of Standards and Technology
Patrick D. Gallagher, Director

NIST Special Publication 1129

Summary of the 2011 Workshop on Research Needs for Full Scale Testing to Determine Vulnerabilities of Decking Assemblies to Ignition by Firebrand Showers

Samuel L. Manzello
Sayaka Suzuki
Fire Research Division
Engineering Laboratory

August 2011

Hosted by ICC

U.S. Department of Commerce
Rebecca M. Blank, Acting Secretary

National Institute of Standards and Technology
Patrick D. Gallagher, Under Secretary of Commerce for Standards and Technology and Director

Input to conduct experiments necessary to provide scientific basis for code change and new test methods

Research Plan

- Determine siding treatment vulnerability to firebrand showers
  - Do firebrands become trapped within corner post/under siding itself?
- Determine glazing assembly vulnerability to firebrand showers
  - Do firebrands accumulate inside corner of framing of glazing assemblies, and lead to window breakage?
- Determine eave vulnerability to firebrand showers
  - Do firebrands become lodged within joints between walls/eave overhang?
- Determine if fine fuels adjacent to structure can produce ignition

First experiments ever conducted

Siding Treatments

- Corner - believed that firebrands may become trapped within the corner post and under the siding itself
- OSB, moisture barrier applied (OSB dried; 11 %)

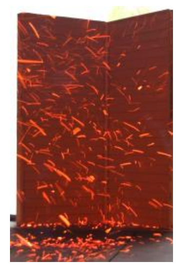
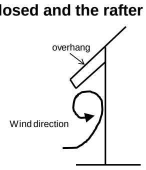


Image of vinyl siding (from bottom) after firebrand exposure at 7 m/s

Eave Vulnerability

- A very important, long standing question is whether firebrands may become lodged within joints between walls and the eave overhang
- There are essentially two types of eave construction commonly used in California and the USA
  - Open eave
  - Boxed in eave
- In open eave construction, the roof rafter tails extend beyond the exterior wall and are readily visible
- In the second type of eave construction, known as boxed in eave construction, the eaves are essentially enclosed and the rafter tails are no longer exposed

Firebrand accumulation in eaves
Does this really happen??



Side view

Wall Fitted With Eave Exposed to Firebrand Showers

Wall Fitted With Eave Results

- The base of the wall actually ignited due to the accumulation of firebrands (9 m/s)
- It was very easy to produce ignition outside the structure since many firebrands were observed to accumulate in front of the structure during the tests
- Although some firebrands were observed to enter the vents, the ignition of the wall assembly itself demonstrates the dangers of wind driven firebrand showers
- The base of wall assembly ignited without the presence of other combustibles that may be found near real structures (*e.g.* mulch, vegetation)

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Firebrand Accumulation

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Continuous Firebrand Showers

Improved Dragon!

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Motivation for Bench Scale Test Methods

- NIST Firebrand Generator (NIST Dragon) shown the vulnerabilities of structures to ignition from firebrand showers for first time
- Full scale experiments are required to observe the vulnerabilities
- Bench scale test methods afford the capability to evaluate firebrand resistant building materials/technologies
- Bench scale test methods may serve as the basis for new standard testing methodologies

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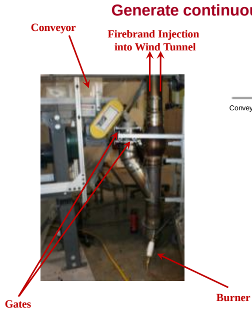
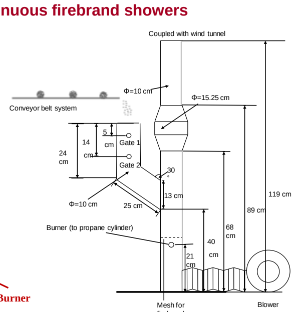
Continuous Feed Baby Dragon

Generate continuous firebrand showers





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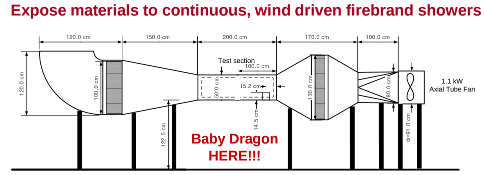
Coupled to Dragon's LAIR

NIST Dragon's LAIR (Lofting and Ignition Research)

Expose materials to continuous, wind driven firebrand showers



- Coupled continuous feed baby dragon with bench scale wind tunnel
- Ability to evaluate and compare material performance to firebrand showers

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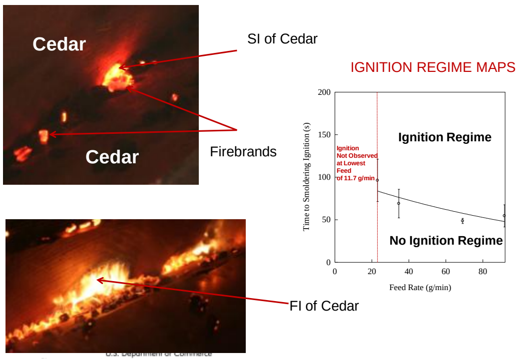
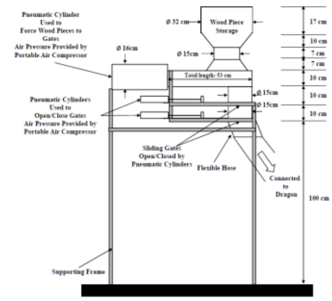
Improved NIST Dragon's LAIR



Full Scale Continuous Firebrand Generator

Developed and Characterized

Decks exposed!



Developing Rapid Response Instrumentation Packages to Quantify Structure Ignition In Wildland-Urban Interface (WUI) Fires

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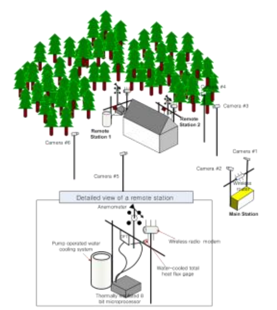
U.S. Department of Commerce

WHAT IS THE NEW TECHNICAL IDEA?

Field deployable instruments – heat flux, wind speed, firebrand generation

Quantify WUI Fire Exposures



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Video Sequence

Instrumentation Setup In 20 minutes

Fire started 4 hours Later For Desired Wind Conditions

Time	Camera #2	Camera #3	Camera #5
4h 5m 28s			
4h 5m 41s			
4h 5m 54s			
4h 6m 07s			
4h 6m 20s			
4h 6m23s			
4h 6m 26s			

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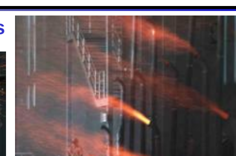
Recent Impacts



IBHS Cloned
Full Scale Firebrand Generator (NIST Dragon)

IDAI – Largest WUI Fire Research Institute in Europe Cloned
Bench Scale Continuous Feed Firebrand Generator

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NIST working with industry

Guest Editor of Fire Safety Journal too

National Institute of Standards and Technology
U.S. Department of Commerce

Recent Publications


Fire Safety Journal

Exposing siding treatments, walls fitted with eaves, and glazing assemblies to firebrand showers

Samuel L. Manzello, Sayaka Suzuki, Yoshihiko Hayashi

ARTICLE INFO

ABSTRACT

1. Introduction


Fire Safety Journal

Experimental investigation of structure vulnerabilities to firebrand showers

Samuel L. Manzello, Seul-Hyun Park, Sayaka Suzuki, John R. Shields, Yoshihiko Hayashi

ARTICLE INFO

ABSTRACT

1. Introduction

U.S. Department of Commerce

Special Thanks

- Dr. Sayaka Suzuki (NIST)
- LFL Staff (Dr. Matthew Bundy – Supervisor)
- Dr. Yoshihiko Hayashi (BRI)

Homeland Security

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U.S. Department of Commerce

Summary

- NIST Dragon coupled to BRI's FRWTF
  - Capability to experimentally expose structures to wind driven firebrand showers for first time!
- Structure vulnerability experiments conducted for:
  - Roofing (cermaic/asphalt)
  - Vents/mesh (gable/different mesh sizes)
  - Siding (vinyl, polypropylene, cedar)
  - Eaves (open)
- NIST Dragon's LAIR Facility
  - Capability to expose materials/firebrand resistant technologies to wind driven firebrand showers
  - With newly developed Continuous Feed Baby Dragon, evaluate and compare relative performance

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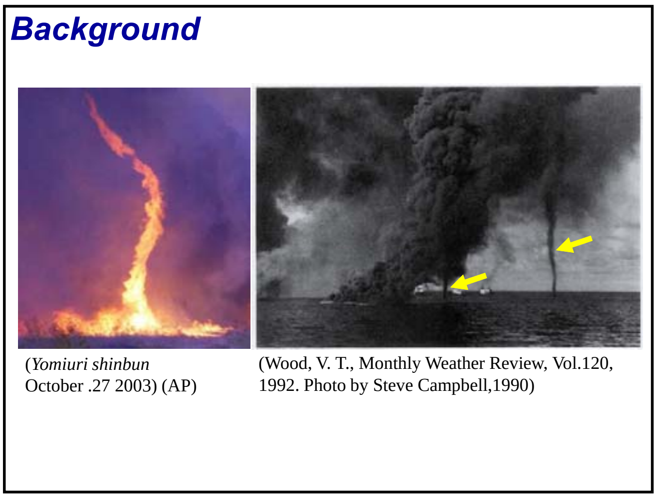
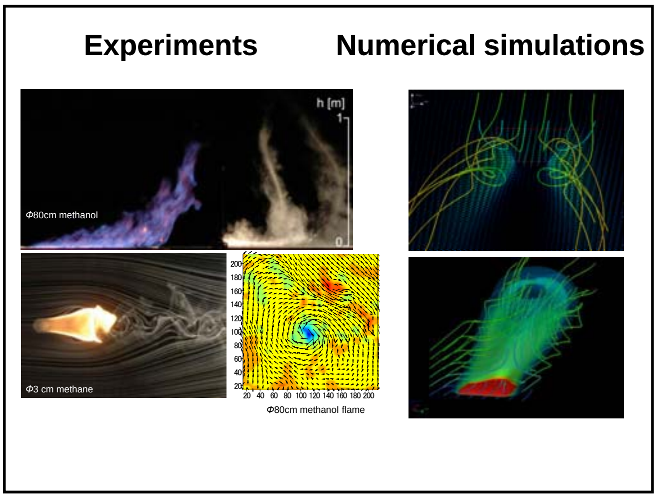
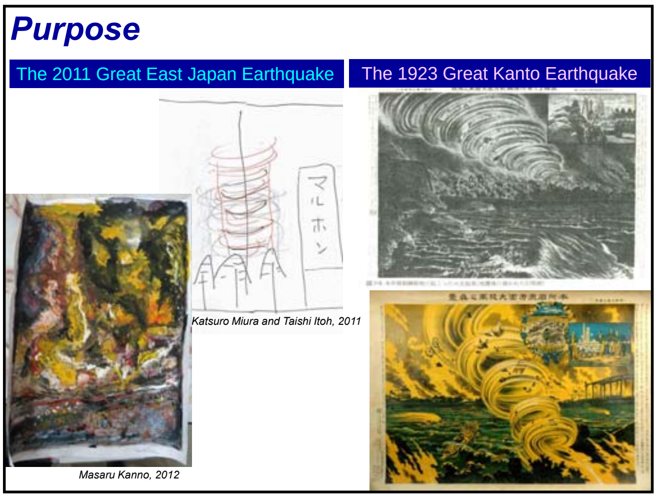
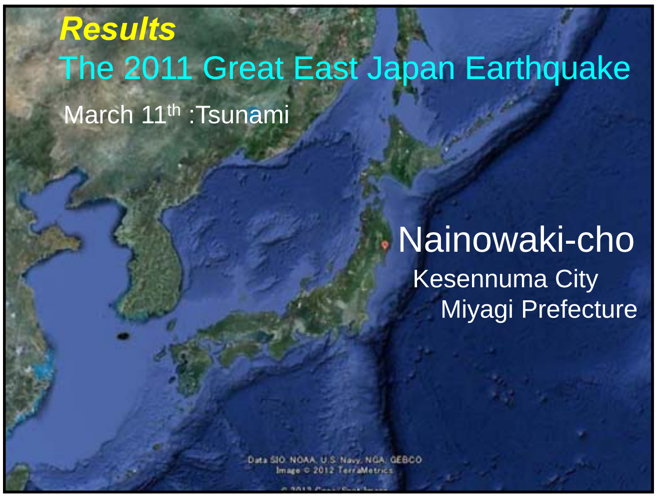
Fire Whirls Caused by
Urban Conflagration
Masahiko Shinohara1, Sanae Matsushima1, Ai Sekizawa2
1 National Research Institute of Fire and Disaster, Japan
2 Tokyo University of Science, Japan
N R I F D
311 まるごとアーカイブス提供(311Marugoto archives)


Fire Whirls Caused by
Urban Conflagration
Contents
1. Background
2. Purpose
3. Results
The 2011 Great East Japan Earthquake
The 1923 Great Kanto Earthquake
4. Conclusions
311 まるごとアーカイブス提供(311Marugoto archives)


Background
(Yomiuri shinbun
October .27 2003) (AP)
(Wood, V. T., Monthly Weather Review, Vol.120,
1992. Photo by Steve Campbell,1990)


Experiments
Numerical simulations
h [m]
Φ80cm methanol
Φ3 cm methane
Φ80cm methanol flame

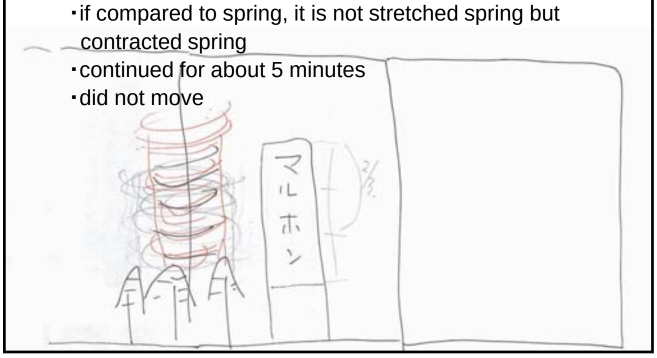

Purpose
The 2011 Great East Japan Earthquake
The 1923 Great Kanto Earthquake
マルホン
Katsuro Miura and Taishi Itoh, 2011
Masaru Kanno, 2012


Results
The 2011 Great East Japan Earthquake
March 11th :Tsunami
Nainowaki-cho
Kesennuma City
Miyagi Prefecture
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2012 TerraMetrics

Eyewitness testimony

Characteristics of the fire whirl

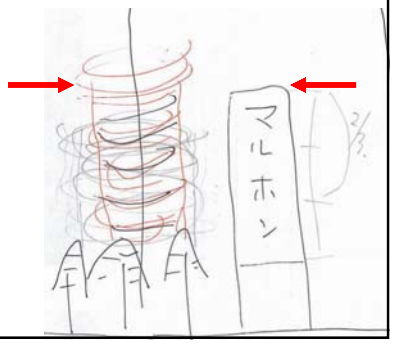
- vortex containing fire
- straight
- if compared to spring, it is not stretched spring but contracted spring
- continued for about 5 minutes
- did not move



Eyewitness testimony

Height of the fire whirl

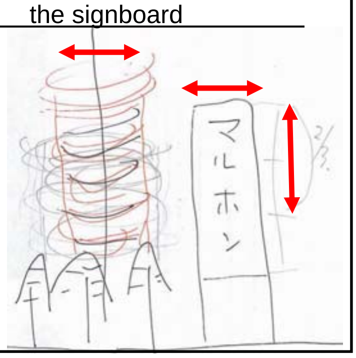
Eyewitness A	= the height of the signboard
Eyewitness B	< the height of the signboard

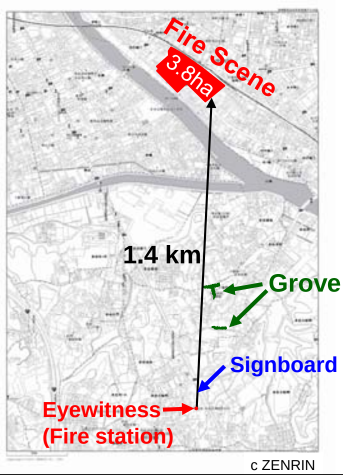


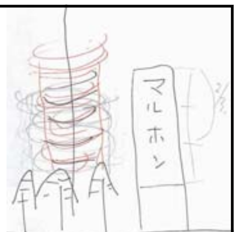
Eyewitness testimony

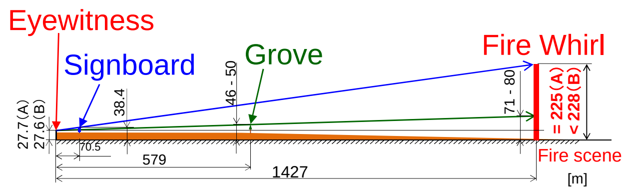
Width of the fire whirl

Eyewitness A	= the width of the signboard
Eyewitness B	= 2/3 of the longitudinal length of the signboard









Eyewitness Testimonies

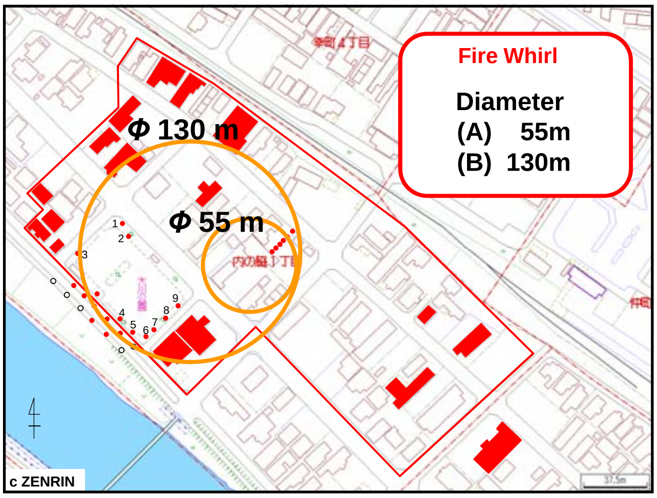
Height
above the grove
(A) = the height of the signboard
(B) < the height of the signboard

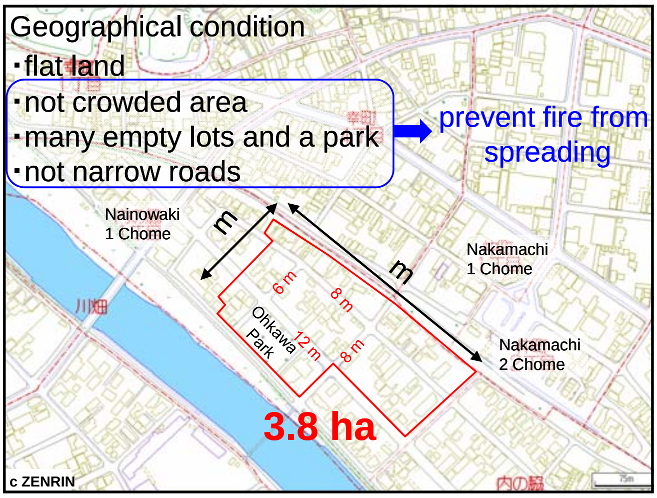
Width
(A) = the width of the signboard
(B) = 2/3 of the longitudinal length of the signboard

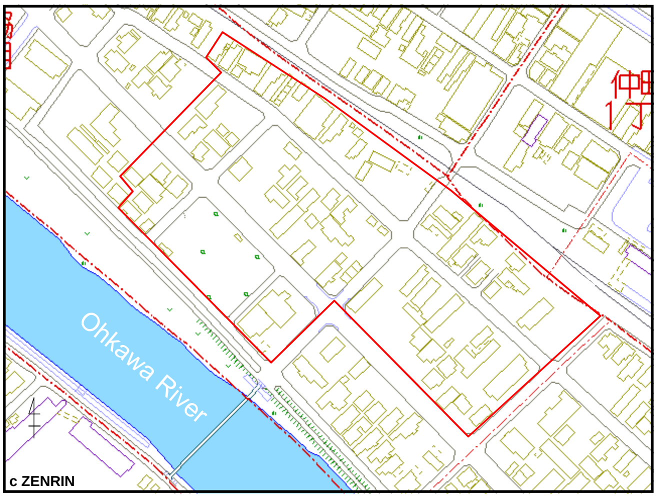
Fire Whirls

Height
> 70m
(A) 230m
(B) < 230m

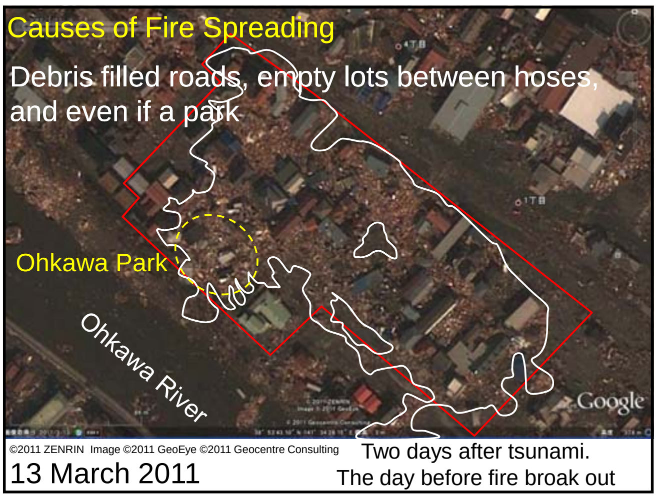
Diameter
(A) 55m
(B) 130m


Fire Whirl
Diameter
(A) 55m
(B) 130m
Φ 130 m
Φ 55 m
c ZENRIN

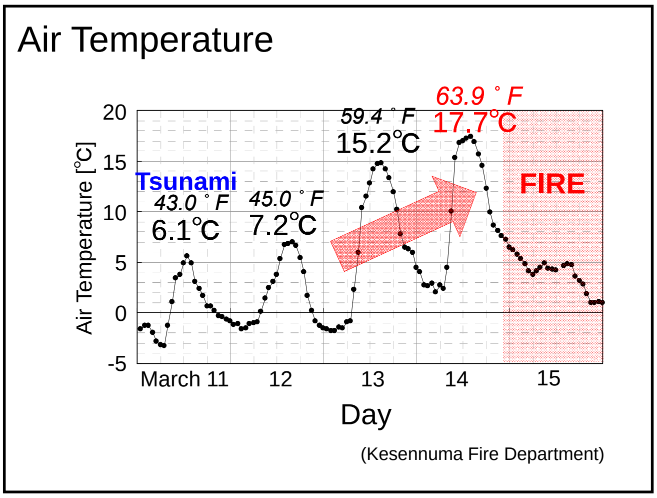

Geographical condition
・flat land
・not crowded area
・many empty lots and a park
・not narrow roads
prevent fire from spreading
Nainowaki 1 Chome
Nakamachi 1 Chome
Nakamachi 2 Chome
Ohkawa Park
6 m
8 m
12 m
8 m
3.8 ha
c ZENRIN

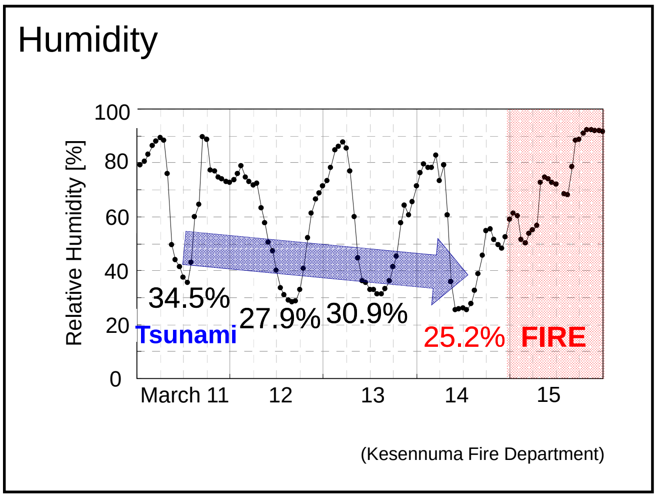

Ohkawa River
c ZENRIN

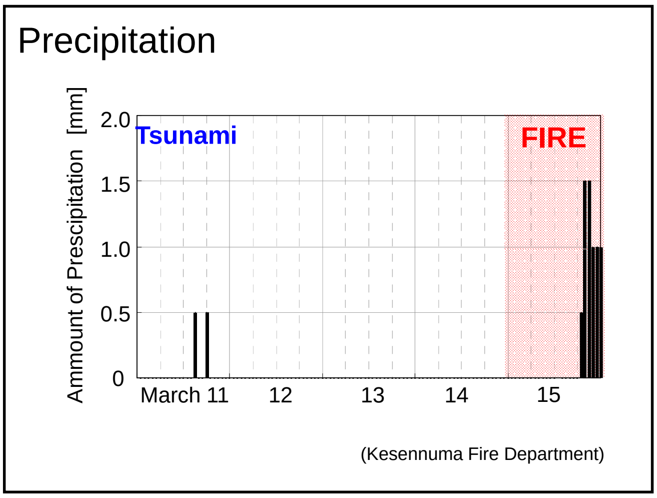

Causes of Fire Spreading
Debris filled roads, empty lots between hoses, and even if a park
Ohkawa River
Google
©2011 ZENRIN Image ©2011 GeoEye ©2011 Geocentre Consulting
13 March 2011
Two days after tsunami.
Before fire break out

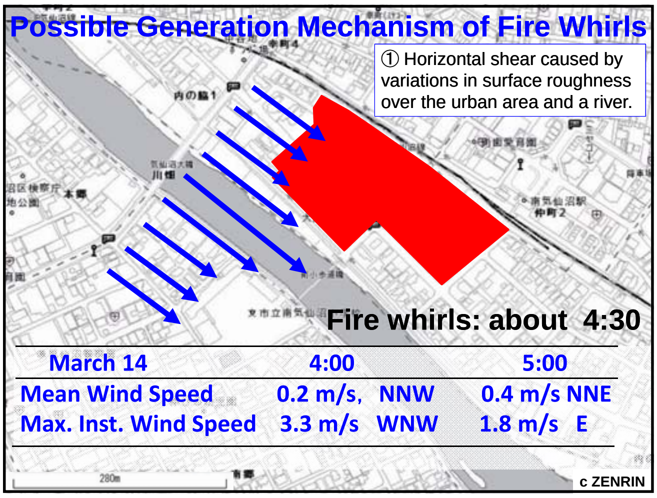

Causes of Fire Spreading
Debris filled roads, empty lots between hoses, and even if a park
Ohkawa Park
Ohkawa River
Google
©2011 ZENRIN Image ©2011 GeoEye ©2011 Geocentre Consulting
13 March 2011
Two days after tsunami.
The day before fire broak out

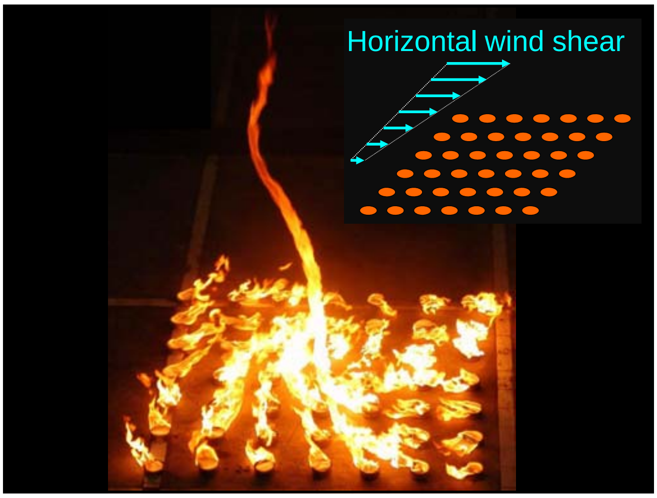

Causes of Fire Spreading
Debris and houses: probably dry
- Tunami water had receded from this area
Nainowaki 1-Chome
15 March 2011 about 1:30 a.m.

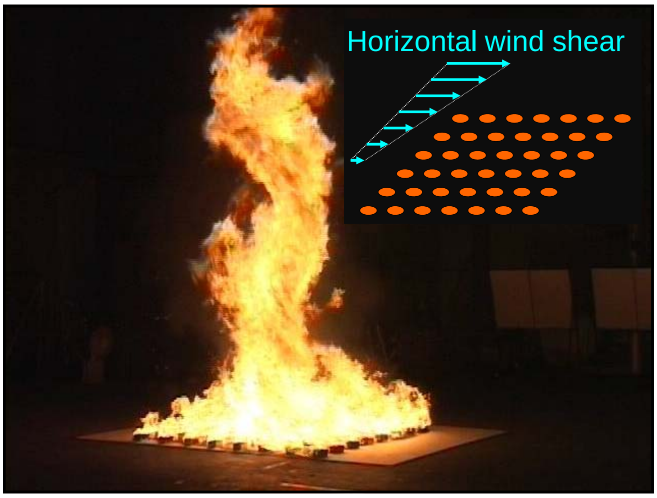

Air Temperature
Air Temperature [℃]
20
15
10
5
0
-5
Tsunami
43.0 ˚F
6.1℃
45.0 ˚F
7.2℃
59.4 ˚F
15.2℃
63.9 ˚F
17.7℃
FIRE
March 11
12
13
14
15
Day
(Kesennuma Fire Department)

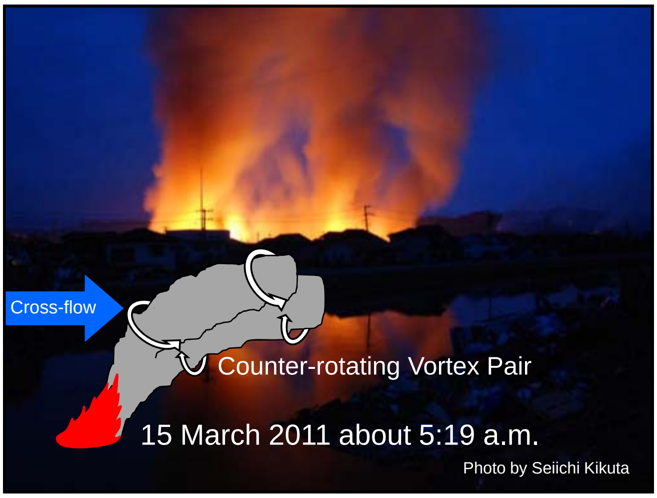

Humidity
Relative Humidity [%]
100
80
60
40
20
0
34.5%
27.9%
30.9%
25.2%
Tsunami
FIRE
March 11
12
13
14
15
(Kesennuma Fire Department)

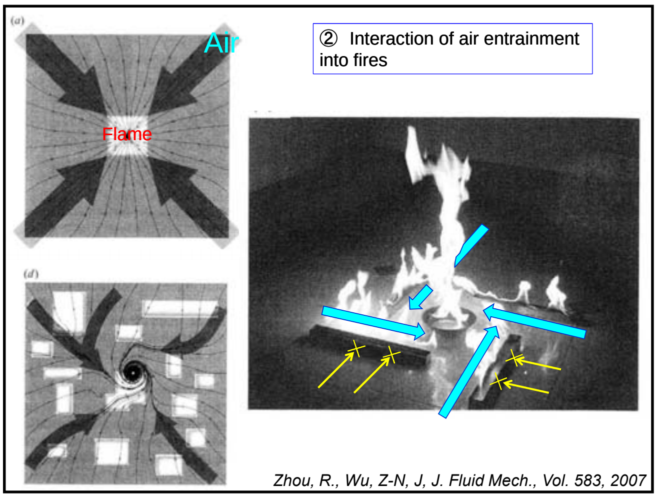

Precipitation
Ammount of Prescipitation [mm]
2.0
1.5
1.0
0.5
0
Tsunami
FIRE
March 11
12
13
14
15
(Kesennuma Fire Department)


Possible Generation Mechanism of Fire Whirls
① Horizontal shear caused by variations in surface roughness over the urban area and a river.
Fire whirls: about 4:30
March 14 | 4:00 | 5:00
Mean Wind Speed | 0.2 m/s, NNW | 0.4 m/s NNE
Max. Inst. Wind Speed | 3.3 m/s WNW | 1.8 m/s E
c ZENRIN


Horizontal wind shear

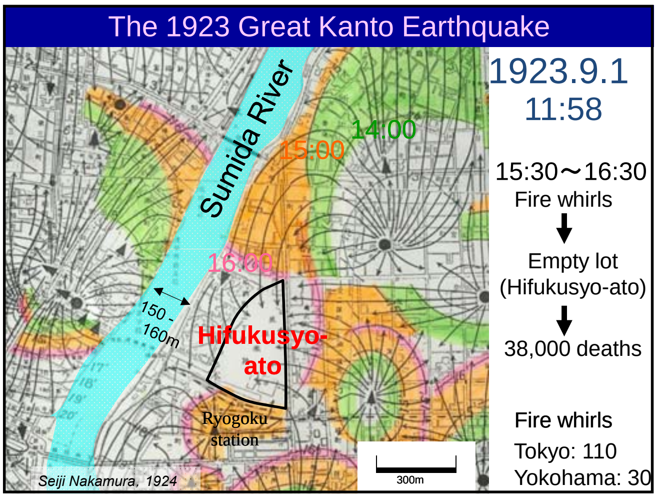

Horizontal wind shear

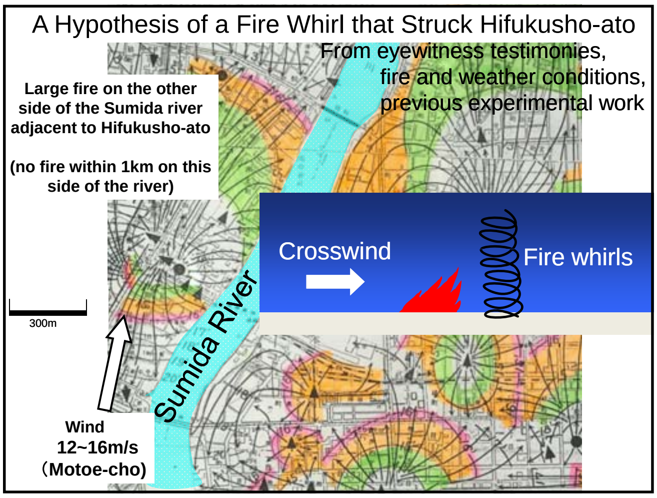

Cross-flow
Counter-rotating Vortex Pair
15 March 2011 about 5:19 a.m.
Photo by Seiichi Kikuta

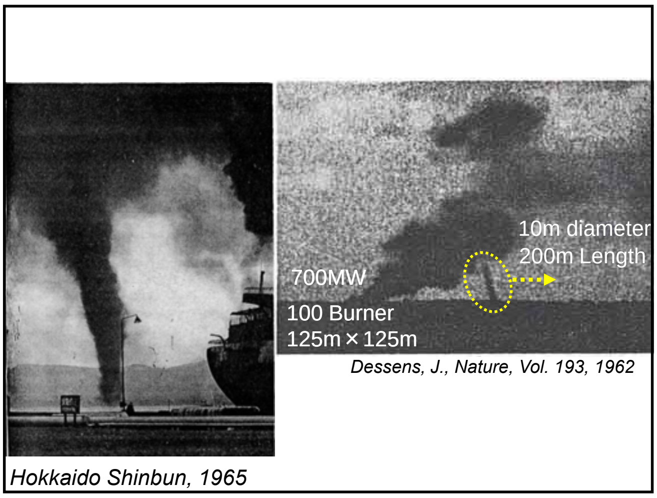

(a)
Air
Flame
(d)
② Interaction of air entrainment into fires
Zhou, R., Wu, Z-N, J, J. Fluid Mech., Vol. 583, 2007


The 1923 Great Kanto Earthquake


The 1923 Great Kanto Earthquake

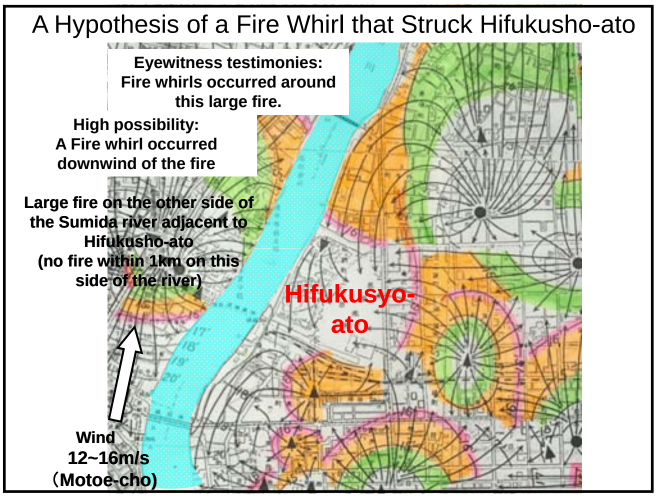

The 1923 Great Kanto Earthquake
Sumida River
14:00
15:00
16:00
150 - 160m
Hifukusyo-ato
Ryogoku station
Seiji Nakamura, 1924
300m
1923.9.1
11:58
15:30～16:30
Fire whirls
Empty lot (Hifukusyo-ato)
38,000 deaths
Fire whirls
Tokyo: 110
Yokohama: 30


A Hypothesis of a Fire Whirl that Struck Hifukusho-ato
From eyewitness testimonies,
fire and weather conditions,
previous experimental work
Large fire on the other side of the Sumida river adjacent to Hifukusho-ato
(no fire within 1km on this side of the river)
Crosswind
Fire whirls
300m
Sumida River
Wind
12~16m/s
(Motoe-cho)

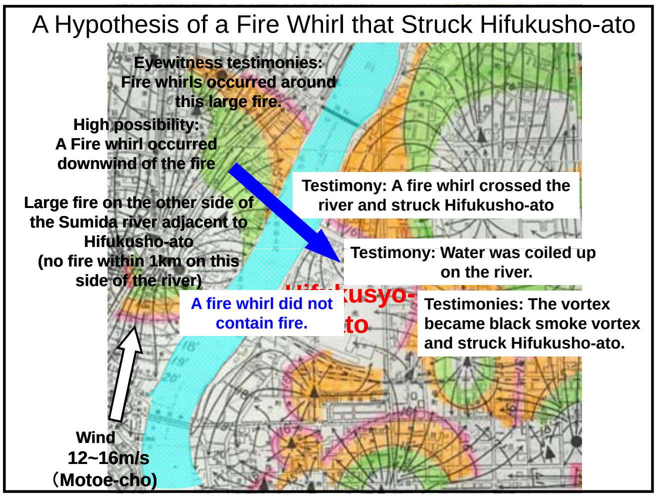


10m diameter
200m Length
700MW
100 Burner
125m × 125m
Dessens, J., Nature, Vol. 193, 1962
Hokkaido Shinbun, 1965

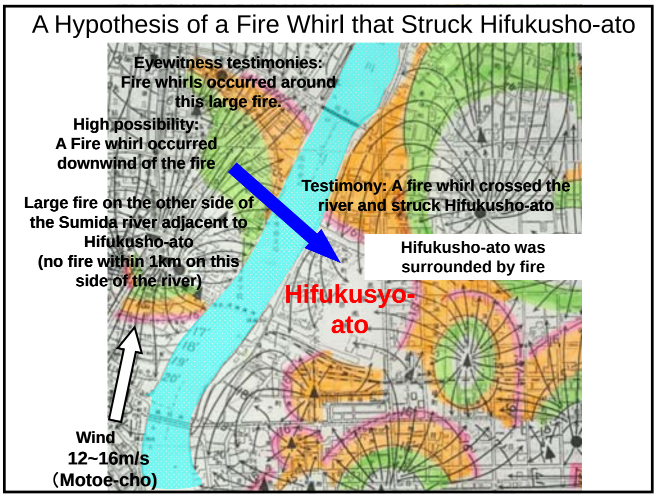
Side view of fire whirls D = 3cm U_0 = 0.18m/s Fuel: Methane
M. Shinohara, 2008



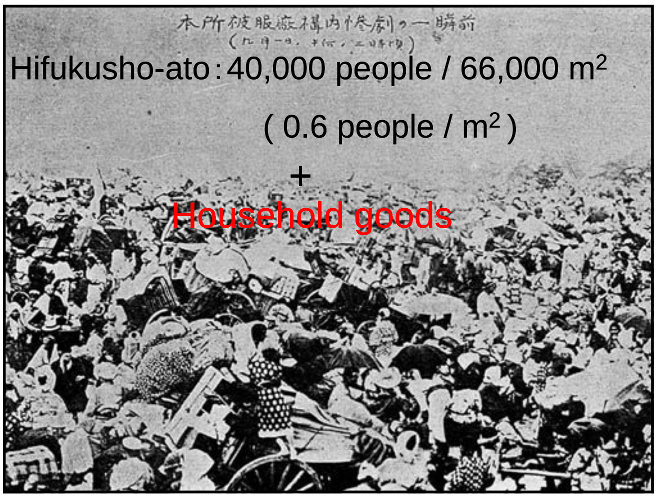
A Hypothesis of a Fire Whirl that Struck Hifukusho-ato
Eyewitness testimonies: Fire whirls occurred around this large fire.
High possibility: A Fire whirl occurred downwind of the fire
Large fire on the other side of the Sumida river adjacent to Hifukusho-ato (no fire within 1km on this side of the river)
Hifukusyo-ato
Wind 12~16m/s (Motoe-cho)



A Hypothesis of a Fire Whirl that Struck Hifukusho-ato
Eyewitness testimonies: Fire whirls occurred around this large fire.
High possibility: A Fire whirl occurred downwind of the fire
Large fire on the other side of the Sumida river adjacent to Hifukusho-ato (no fire within 1km on this side of the river)
Testimony: A fire whirl crossed the river and struck Hifukusho-ato
Testimony: Water was coiled up on the river.
A fire whirl did not contain fire.
Testimonies: The vortex became black smoke vortex and struck Hifukusho-ato.
Wind 12~16m/s (Motoe-cho)

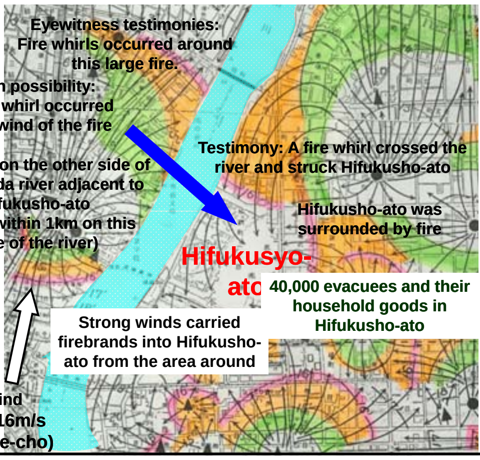


A Hypothesis of a Fire Whirl that Struck Hifukusho-ato
Eyewitness testimonies: Fire whirls occurred around this large fire.
High possibility: A Fire whirl occurred downwind of the fire
Large fire on the other side of the Sumida river adjacent to Hifukusho-ato (no fire within 1km on this side of the river)
Testimony: A fire whirl crossed the river and struck Hifukusho-ato
Hifukusho-ato was surrounded by fire
Hifukusyo-ato
Wind 12~16m/s (Motoe-cho)

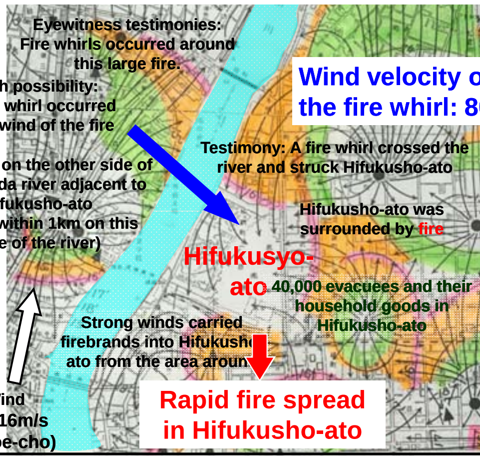


本所被服廠構内惨劇の一瞬前
Hifukusho-ato : 40,000 people / 66,000 m²
(0.6 people / m²)
+
Household goods

A Hypothesis of a Fire Whirl that Struck Hifukusho-ato



A Hypothesis of a Fire Whirl that Struck Hifukusho-ato

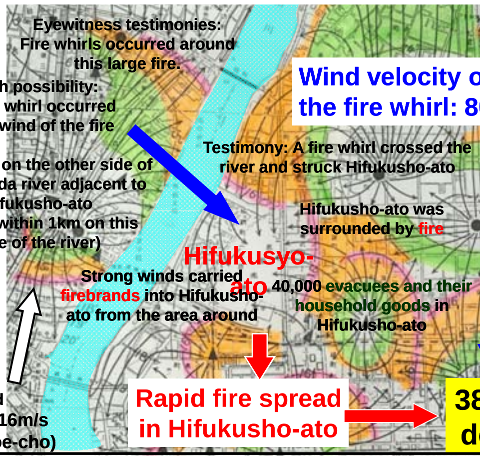


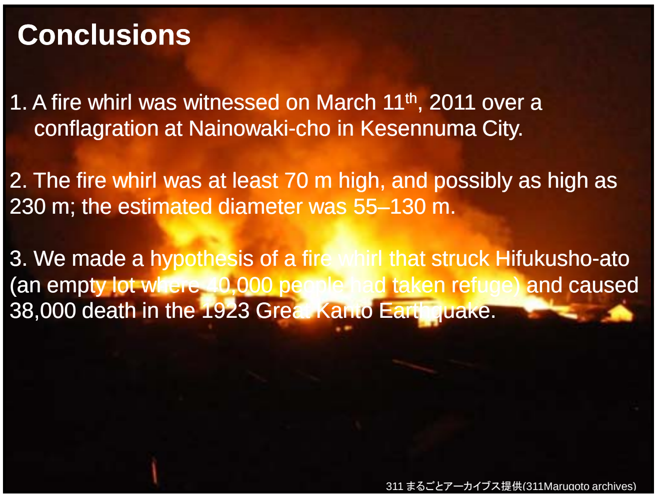
Cause of death

Metropolitan Police Department : Death of fire

Eyewitnesses testimonies :
Death of fire
Hundreds of people were lift up in the air.
Faces and teeth were stick into a stone wall.
Dead caused by flying objects

A Hypothesis of a Fire Whirl that Struck Hifukusho-ato





Conclusions

1. A fire whirl was witnessed on March 11th, 2011 over a conflagration at Nainowaki-cho in Kesennuma City.

2. The fire whirl was at least 70 m high, and possibly as high as 230 m; the estimated diameter was 55–130 m.

3. We made a hypothesis of a fire whirl that struck Hifukusho-ato (an empty lot where 40,000 people had taken refuge) and caused 38,000 death in the 1923 Great Kanto Earthquake.

311 まるごとアーカイブス提供(311Marugoto archives)

Acknowledgements

・The Kesennuma Fire Department
・The citizen of Kesennnuma-City
・Seiichi Kikuta, Former fire chief of Kesennuma Fire Department

311 まるごとアーカイブス提供(311Marugoto archives)

Evaluating the Vulnerability of Buildings to Wildfire Exposures

Presented at the Fire Research Workshop
July 3, 2012

by

Steve Quarles
Insurance Institute for Business & Home Safety

The Insurance Institute for Business & Home Safety is a nonprofit initiative of the property insurance industry.

The IBHS mission is to conduct objective, scientific research to identify and promote effective actions that strengthen homes, businesses, and communities against natural disasters and other causes of loss.

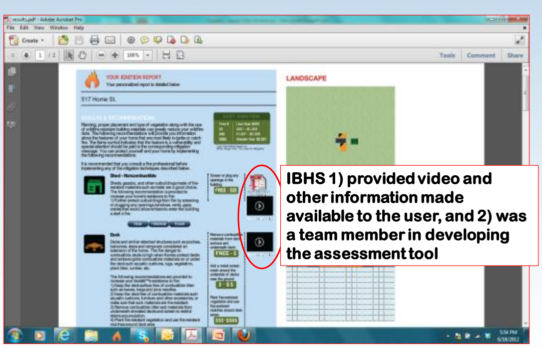
Wildfire Ignition Resistant Home Design (WIRHD) program:

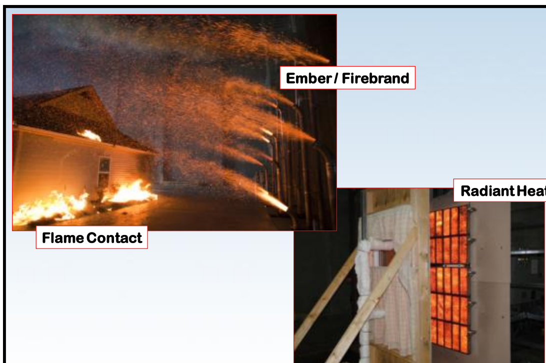
✓ **Funded by DHS Science & Technology Directorate**

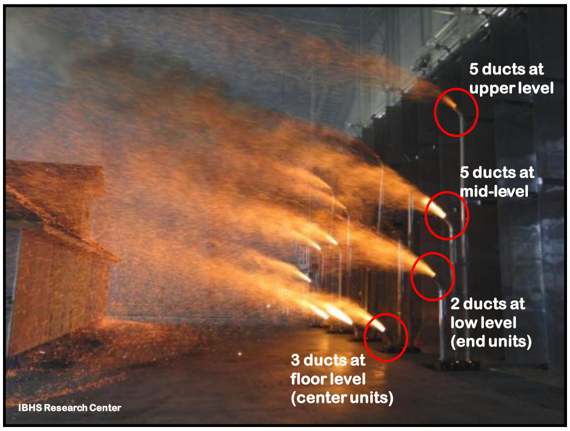
✓ **Develop a home evaluation tool that could assess the ignition potential of a structure subjected to wildfire exposures**

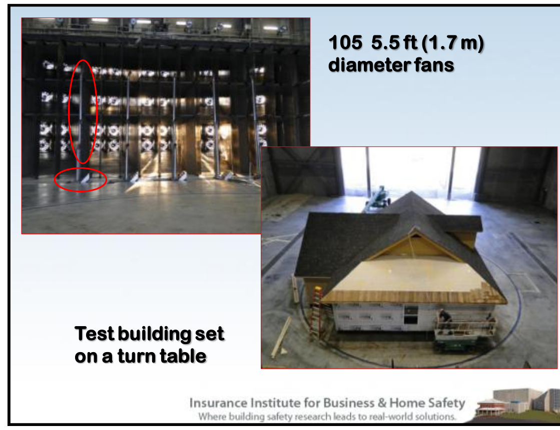
✓ **Update SIAM (Structural Ignition Assessment Model) – home ignition assessment tool**

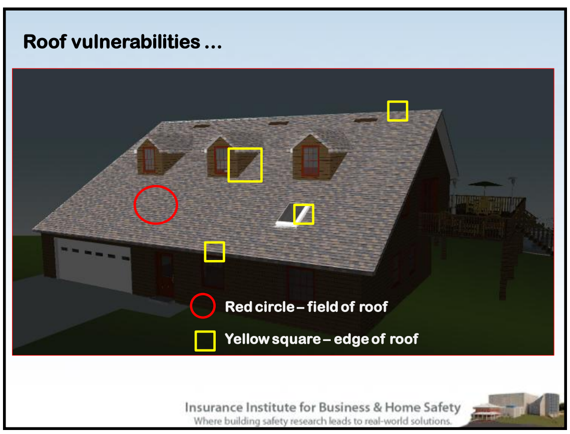
✓ **Collaborators included USDA Forest Service, Savannah River National Laboratory, Insurance Institute for Business & Home Safety, Oak Ridge National Laboratory, Clemson University.**



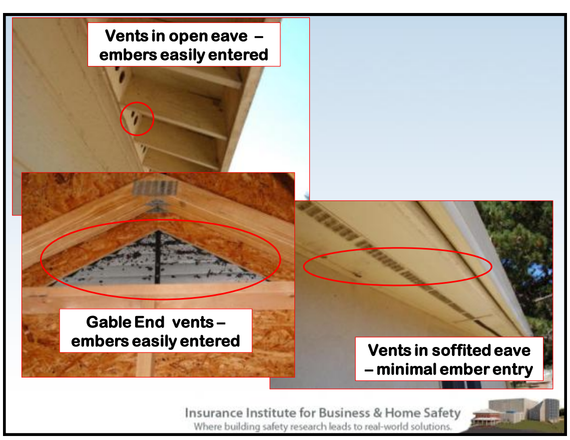



5 ducts at upper level
5 ducts at mid-level
2 ducts at low level (end units)
3 ducts at floor level (center units)
IBHS Research Center

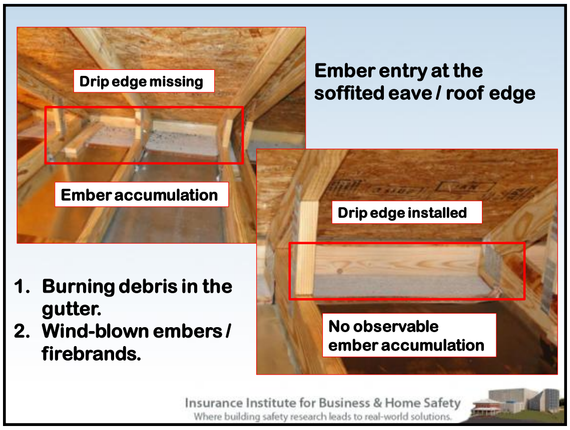

105 5.5 ft (1.7 m) diameter fans
Test building set on a turn table
Insurance Institute for Business & Home Safety
Where building safety research leads to real-world solutions.

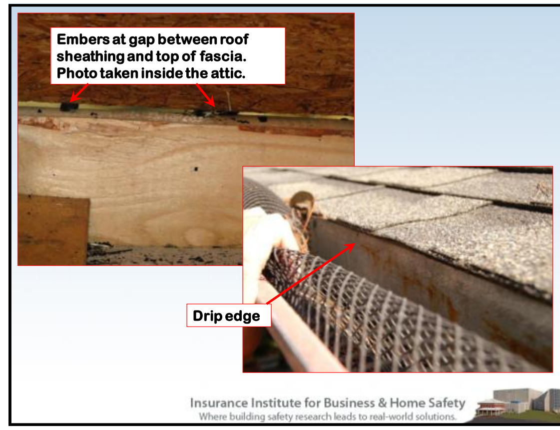

Roof vulnerabilities …
Red circle – field of roof
Yellow square – edge of roof
Insurance Institute for Business & Home Safety
Where building safety research leads to real-world solutions.

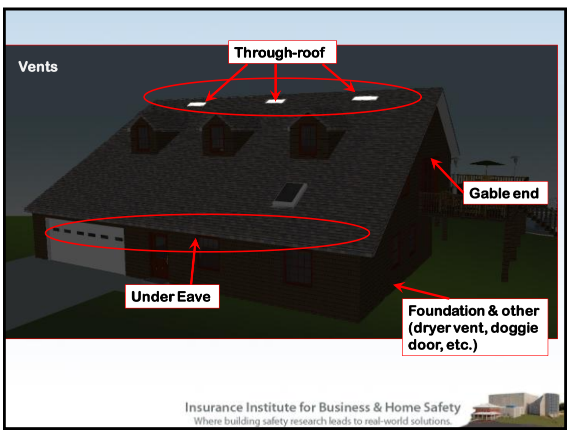

Edge of Roof Vulnerability
Insurance Institute for Business & Home Safety
Where building safety research leads to real-world solutions.

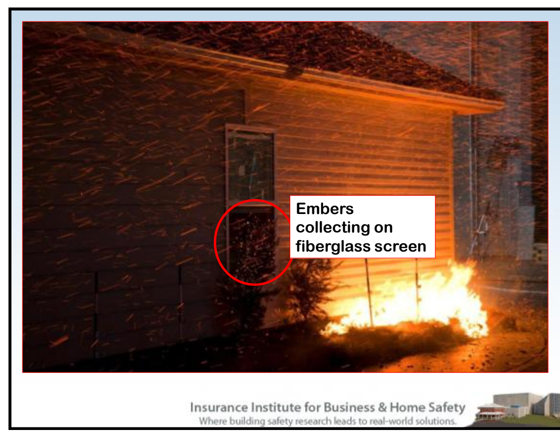

Vents in open eave – embers easily entered
Gable End vents – embers easily entered
Vents in soffited eave – minimal ember entry
Insurance Institute for Business & Home Safety
Where building safety research leads to real-world solutions.

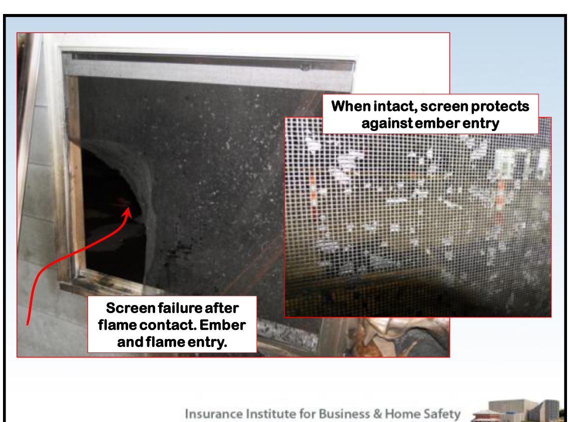

vinyl gutter
metal gutter
Insurance Institute for Business & Home Safety
Where building safety research leads to real-world solutions.

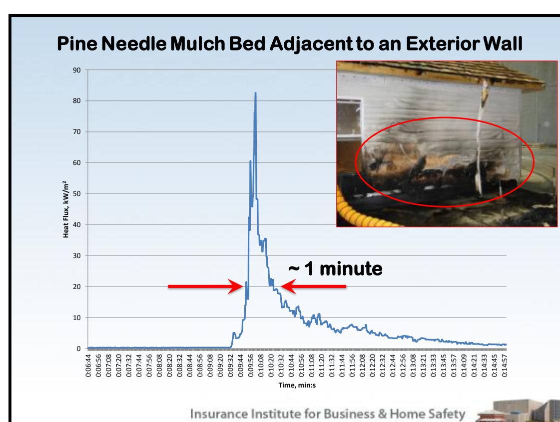

Drip edge missing
Ember accumulation
Ember entry at the soffited eave / roof edge
Drip edge installed
No observable ember accumulation
1. Burning debris in the gutter.
2. Wind-blown embers / firebrands.
Insurance Institute for Business & Home Safety
Where building safety research leads to real-world solutions.

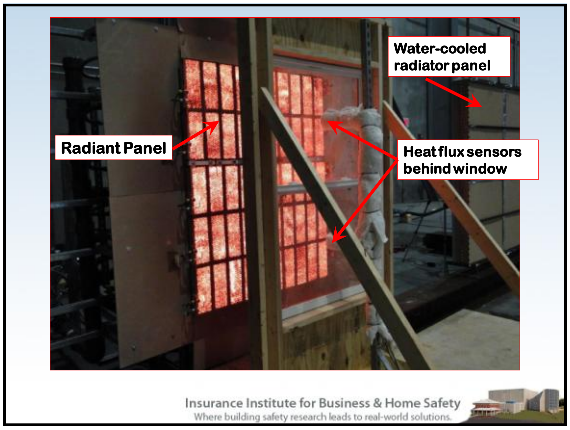

Embers at gap between roof sheathing and top of fascia. Photo taken inside the attic.
Drip edge
Insurance Institute for Business & Home Safety
Where building safety research leads to real-world solutions.

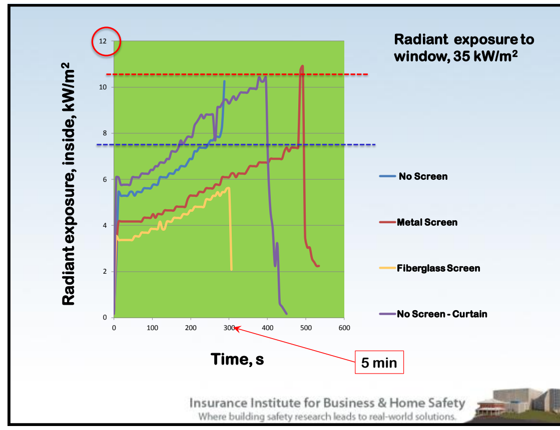

Vents
Through-roof
Gable end
Under Eave
Foundation & other (dryer vent, doggie door, etc.)
Insurance Institute for Business & Home Safety
Where building safety research leads to real-world solutions.


Embers collecting on fiberglass screen
Insurance Institute for Business & Home Safety
Where building safety research leads to real-world solutions.

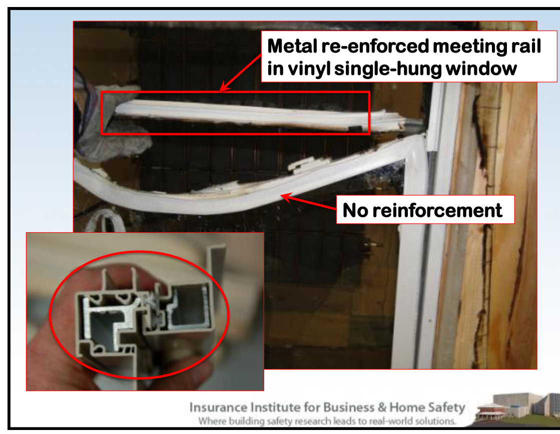

When intact, screen protects against ember entry
Screen failure after flame contact. Ember and flame entry.
Insurance Institute for Business & Home Safety
Where building safety research leads to real-world solutions.

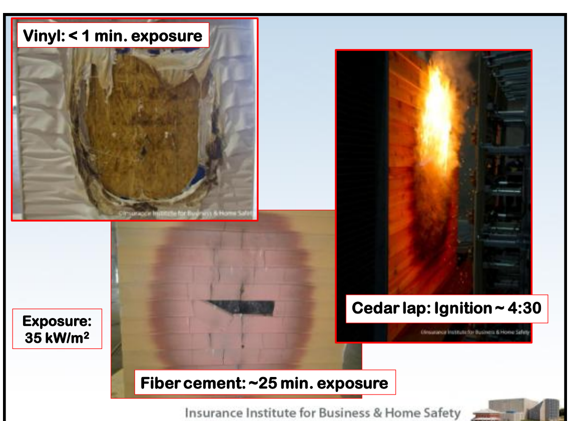

Pine Needle Mulch Bed Adjacent to an Exterior Wall
~ 1 minute
Time, min:s
Insurance Institute for Business & Home Safety
Where building safety research leads to real-world solutions.

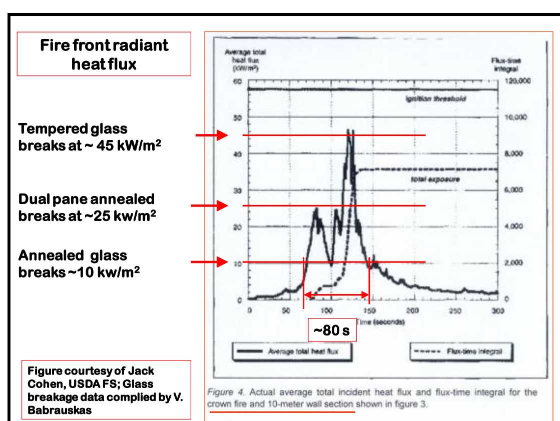

Water-cooled radiator panel
Radiant Panel
Heat flux sensors behind window
Insurance Institute for Business & Home Safety
Where building safety research leads to real-world solutions.


Radiant exposure to window, 35 kW/m²
Radiant exposure, inside, kW/m²
Time, s
5 min
No Screen
Metal Screen
Fiberglass Screen
No Screen - Curtain
Insurance Institute for Business & Home Safety
Where building safety research leads to real-world solutions.


Ignition of curtain occurred after both panes of glass in upper light fell out.
Insurance Institute for Business & Home Safety
Where building safety research leads to real-world solutions.


Metal re-enforced meeting rail in vinyl single-hung window
No reinforcement
Insurance Institute for Business & Home Safety
Where building safety research leads to real-world solutions.


Vinyl: < 1 min. exposure
Cedar lap: Ignition ~ 4:30
Exposure: 35 kW/m²
Fiber cement: ~25 min. exposure
Insurance Institute for Business & Home Safety
Where building safety research leads to real-world solutions.


Fire front radiant heat flux
Tempered glass breaks at ~ 45 kW/m²
Dual pane annealed breaks at ~25 kw/m²
Annealed glass breaks ~10 kw/m²
~80 s
Figure courtesy of Jack Cohen, USDA FS; Glass breakage data complied by V. Babrauskas
Figure 4. Actual average total incident heat flux and flux-time integral for the crown fire and 10-meter wall section shown in figure 3.

Longer term radiant exposure from near by burning building, firewood pile, etc.

Thanks for your attention!

Steve Quarles
squarles@ibhs.org

http://www.disastersafety.org

http://www.eXtension.org/surving_wildfire

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Wildland Fuel Behavior: Combustion and Dynamics

Focus on the Ignition Process

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Outline

- Introduction
- Time to ignition of pine needles
  (Protocol, results, and conclusions)
- Time to ignition of polymers
  (Protocol, results, and conclusions)

Introduction

- In fires, CFD-based fire models (and almost every kind of model) are closed thanks to a variety of sub-models
- The accuracy of the models depends on the reliability of the sub-models but many sub-models are based on empirical data with a lack of understanding of the underlying chemical and physical processes
- This is particularly true for wildland fires because of the complexity of wildland fuels
- The WUI adds a level of complexity with the fire/structure coupling
- We will focus on ignition of wildland and solid fuels

Introduction

Combustion ↓ *Thermal transfer* ↓ *Turbulence*

Maximal control ↑ *No control*

Microscopic (TGA, DSC)

Bench laboratory scale (small scale static fires or spreads)

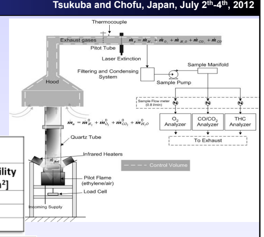
Large laboratory scale (large scale static fires or spreads)

Field scale (from small shrub to tree canopy)

Uncontrolled fires (observation)

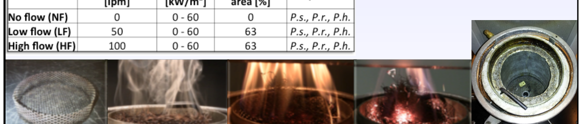
TI of Pine Needles

- Modified FPA experiments
  - Moisture content: 4.9-6.4%
  - Three flow levels
  - Heat fluxes from 0 to 60 kW/m^2



	Needle Properties		Bulk Properties		
	Density [kg/m^3]	SVR [m^{-1}]	Porosity [%]	Density* [kg/m^3]	Permeability [x10^{-7} m^2]
White pine, *P.s.*	620	10,788	94	40	-
Red pine, *P.r.*	797	5,658	95	40	-
Aleppo pine, *P.h.*	789	7,377	95	40	0.906

	flow magnitude [lpm]	heat flux [kW/m^2]	basket open area [%]	Species
No flow (NF)	0	0 - 60	0	*P.s., P.r., P.h.*
Low flow (LF)	50	0 - 60	63	*P.s., P.r., P.h.*
High flow (HF)	100	0 - 60	63	*P.s., P.r., P.h.*



TI of Pine Needles

Two different models:

- Solid fuel model: 1D, thermally thick, semi-infinite solid:

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha_T}\frac{\partial T}{\partial t} \qquad \text{BC: } x = 0, -k\frac{\partial T}{\partial x} = \dot{q}''_S(0,t), \quad \begin{matrix} t = 0 \\ x \to \infty \end{matrix} \quad T = T_\infty$$

$$\dot{q}''_S(0,t) = a\dot{q}''_e - h_T(T(0,t) - T_\infty)$$

Global parameters representative of the ignition process

- Porous fuel model: 1D, thermally thick, thermal equilibrium:

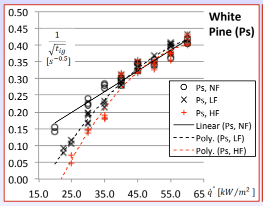
$$\alpha_s\rho_s c_{ps}\frac{\partial T}{\partial t} + \alpha_g\rho_g c_{pg}V_{g,x}\frac{\partial T}{\partial x} = k_R\frac{\partial^2 T}{\partial x^2} + \dot{q}''_e K e^{-Kx}$$

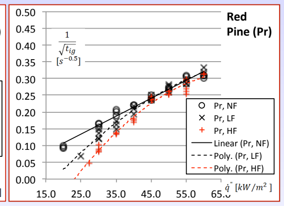
$$K = \frac{\alpha_s\sigma_s}{4}$$ (attenuation coefficient)

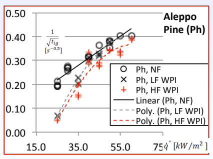
Parameters come from literature or from measurements (here Ph):

ρ_s [kg/m^3]	σ_s [m^{-1}]	α_s [m^3/m^3]	a_s	C_{ps} [J/kg K]
789	7377	0.0492	1	3100

TI of Pine Needles

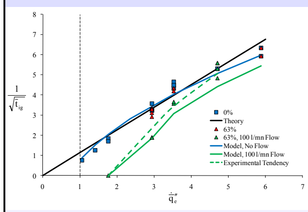


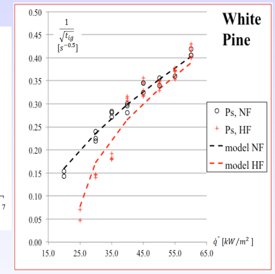




- Convergence at "critical" HF (radiation)
- Ps is linear after convergence
- Pr and Ph show a "plateau" after convergence
- < convergence: flow effects are complimentary to slow down TI
- > convergence: flow effects are competing

TI of Pine Needles





- Inflexion with no flow (in-depth radiation)
- Convergence at high fluxes underestimated
- Inflexion at high flows not represented

TI of Pine Needles

- If the flow is blocked, the fuel bed behaves like a solid fuel and solid fuel theory is sufficient to describe TI
- If the flow is allowed, a porous fuel model is necessary to describe TI
- Cooling and dilution effects are coupled in the same flow – Each effect must be investigated separately

Future work

- Changing inlet air temperature and O_2 concentration to decouple cooling and dilution effects
- Use of "simpler" fuels such as excelsior wood shavings
- Temperature distribution inside the sample

TI of Polymers

- The objective is to provide a mechanism to assess the potential for ignition while not adding an excessive computational burden to (CFD-based) fire-spread models.
- If it is assumed that the same functional dependency as before between external heat flux and time is valid, integration over time shows that time scales with:

$$\left(\int_0^t \dot{q}_e'' \, dt\right)^2$$

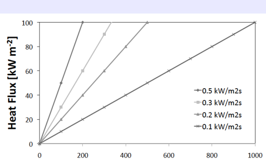
- The validity of the relationship between TI and a time evolving external heat flux remains to be tested.
- If the surface temperature and the ignition delay time can be presented as a function of the integral of the heat insult, then, a single curve can be used to completely decouple the solid and gas phases in the numerical modeling of the ignition process.

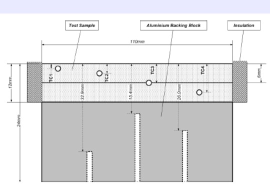
BRE Centre for Fire Safety Engineering

Borowiec P., Reszka P., Steinhaus T., Torero J.L. (2009) Characterization of ignition by direct radiation from flames for Urban/Wildland applications. 6th Mediterranean Combustion Symposium, Ajaccio, 7-11 June.

TI of Polymers

- **Similar protocol but**
  - 110 x 110 x 12 (4.9 for PMMA) mm samples (36 samples tested)
  - Three polymer fuels: PA6, PA6 with nano-compostites and PMMA
  - Quartz tube used (standard FPA test)
  - In-depth temperature measurement (PA6 and PA6 + nano-composites)
  - Ramping heat fluxes from 0.01 to 0.5 kW/m² s

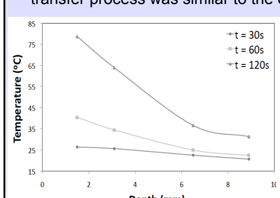


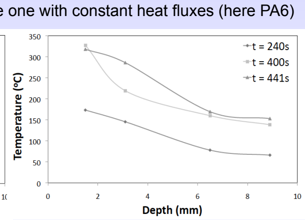


$$\dot{q}_e'' = m\,t$$

TI of Polymers

- In-depth temperature measurements were performed to ensure that the heat transfer process was similar to the one with constant heat fluxes (here PA6)



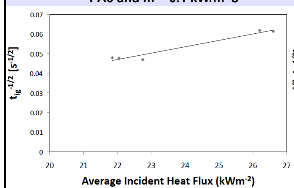


- Initial times: Inert heating with an increase in temperature close to the surface
- Longer times: Surface reaches pyrolysis temperature and signs of endothermicity (no further temperature evolution) but this period is close to ignition and endothermic pyrolysis has a weak effect on ignition

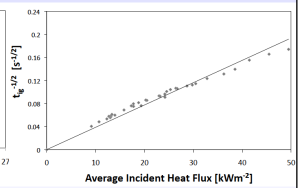
TI of Polymers

- Ignition delay times vs. average heat flux $\left(\dot{q}_e'' = m\,t\right)$

PA6 and m = 0.1 kW/m² s



PMMA and m = 0.01-5.0 kW/m² s

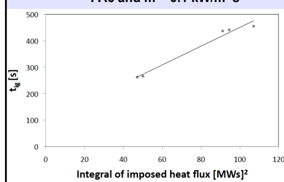


- The results are very similar to those obtained for the constant heat flux

TI of Polymers

- Ignition delay times vs. $\left(\int_0^t \dot{q}_e''\,dt\right)^2$

PA6 and m = 0.1 kW/m² s



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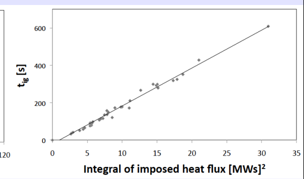

- The results are again very similar to those obtained for the constant heat flux
- Time can effectively be scaled by $\left(\int_0^t \dot{q}_e''\,dt\right)^2$ for a linear heat flux

TI of Polymers

- This work provides a realistic approach to the heat flux impacting a structure from a spreading fire by considering an incident heat flux that grows linearly with time.
- The adaptation of the ignition protocol, utilizing ramping heat flux on three different materials has shown that the scaling of the time to ignition by the integral of the square of the incident flux is possible.
- A future step will be to obtain an expression relating the ignition delay time to the incident heat flux for this particular case. This expression would completely decouple solid and gas phase processes and would serve as a tool to predict the time to ignition as a function of a realistic incident heat flux.

Acknowledgements

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http://www.iawfonline.org/2013FuelsConference/index.php

Determining Firebrand Production from Full Scale Structures and Building Components

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July 3rd, 2012
2nd Japan/USA Workshop

Structure Ignition in WUI Fires

- Post-fire studies – firebrands a major cause of ignition
- Understanding firebrand ignition of structures – important to mitigate fire spread in communities

Improved understanding of structure ignition in WUI fires
- Major recommendation (GAO 05-380)
- National Science and Technology Subcommittee on Disaster Reduction
- Homeland Security Presidential Directive (HSPD 8; Paragraph 11)

2007 Southern California Fire

2003 Southern California Fire

Previous Research on Firebrands

- Firebrands: generation, transport, ignition
- Research focused on how far firebrands travel for 40 yrs!!
- Nice Academic Problem – Not helpful to design structures
- NIST Dragon (ignition research)
  - Simulate firebrands by coupling with the wind tunnel in BRI, Japan
  - Firebrands by NIST Dragon are tied with the firebrand data from vegetation and from Angora fire (2007)

Douglas-Fir Tree Burns at NIST

- Firebrand Collection using water pan array
  - Range of crown heights: 2.4 m – 4.5 m
  - Different moisture regimes
- Mass loss using load cells

4.5 m Douglas Fir, MC = 25%

Firebrand Generation from Structures

- Firebrands are produced not only as vegetation burns but also as structures are ignited and burned
- Little data exists regarding firebrand production from actual structures
- Firebrand production from burning structures needed for EL-NIST's modeling of WUI fires
- Data will also enable the NIST Firebrand Generator to generate firebrand showers representative of burning structures

Previous Study by Vodvarka

- Measured firebrand generation by laying out 3 m x 3 m plastic sheets downwind from five separate residential buildings burned in full-scale fire experiments
- Measured firebrand size and transport distances of 4,748 firebrands that were collected from five full-scale experimental building fires
- Very small firebrands dominated the size distribution
  - *89% of the firebrands less than 0.23 cm² (0.1875 in x 0.1875 in)*

Research Plan

- **Firebrand production from an actual full-scale structure burn conducted by NIST in Dixon, CA**
  - proof-of-concept test
- **Firebrand production from real-scale building components under well-controlled laboratory conditions in BRI's wind tunnel**
  - Simple component test
- Firebrand production from a real-scale structure burn in BRI's wind tunnel

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Full Scale burn in CA

- **In collaboration with Northern California Fire Prevention Officers, (NORCAL FPO), a full scale, proof-of-concept experiment conducted to investigate firebrand production from burning structure**
- **The structure is mainly built from wood and brick**
- **Wind speed – 5.8 m/s**
- **This burn was as a part of firefighter training**

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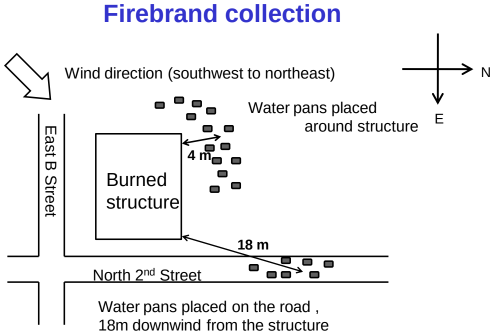
Firebrand collection



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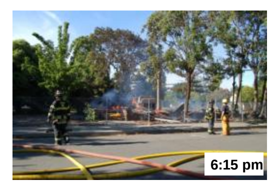
The dimensions and mass are measured after dried

4:15 House Burn started



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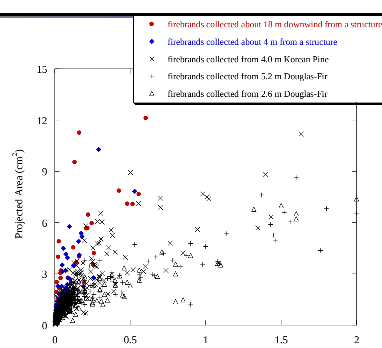
6:30 House Burn ended



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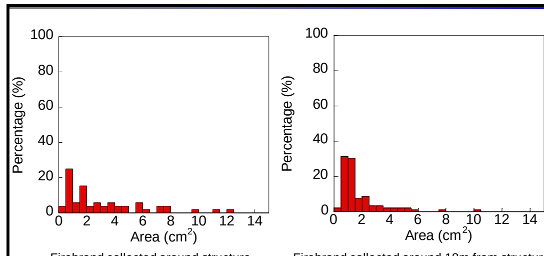
•The size distribution of firebrands at two different places were similar to the ones from vegetation
•Most firebrands with mass less than 1g



•Most firebrands collected at burn site, both around structure, and around 18 m from structure, have less than 10 cm^2 projected area
•Compared with Vodvarka (1969), the size distribution is bigger and broader

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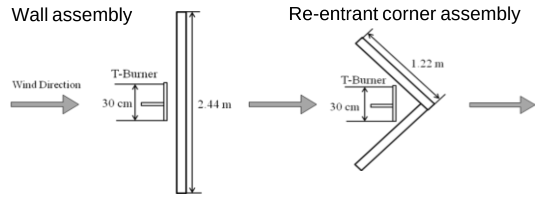
Firebrand Generation from Components

- **To determine if simple component tests can provide insights into firebrand generation data from full-scale structures**

- Simple building components
  - OSB & studs
- Two configurations
  - Wall & reentrant corner assembly
- Varying wind speed
  - 6 & 8 m/s

Wind Velocity – 8 m/s
Corner assembly

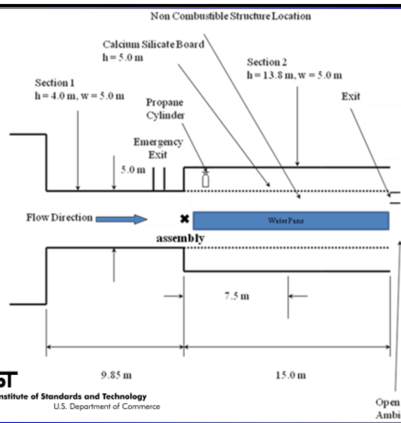
Experimental Condition

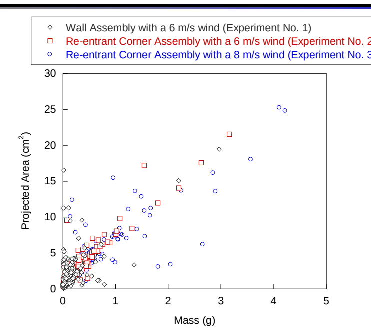


Experiment No. 1 6 m/s

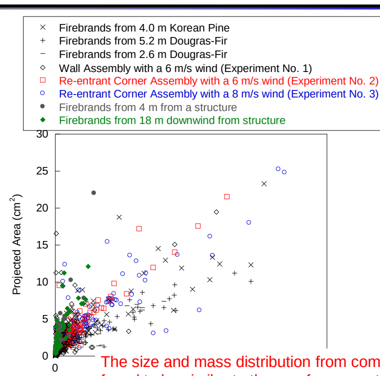
Experiment No. 2 6 m/s

Experiment No. 3 8 m/s

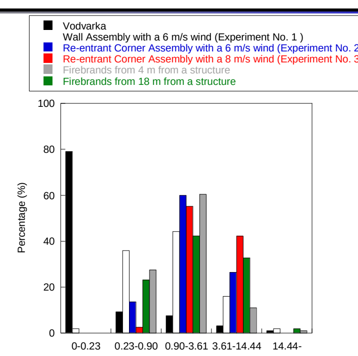




- The size and mass distribution of firebrands from experiment No.2 and No.3 were similar
- The one from experiment No.1 had more variety of projected area at a certain mass, especially within 10 cm² projected area



The size and mass distribution from components was found to be similar to the one from vegetation and the one from a full-scale burn



The size distributions of our studies are larger and broader than the one from Vodvarka

Summary

- Collaborative work between CAL CHIEFS Training, Operations, and Prevention officers sections and NIST was successfully accomplished
- Firebrands data were compared to that from vegetation
- The size distribution of firebrands at two different places (one 4 m around a structure, the other is 18 m from structure) were similar
- The size distribution of firebrands from structure was bigger and broader than those of Vovardka
- Most firebrands were less than 10cm^2 area and with mass less than 1g
- Important to note water applied during burn

Summary

- Wall assemblies were used in these experiments since it was expected that they are a significant source of firebrand production
- The mass/size distributions of firebrands from wall assemblies were similar to the one from vegetation and from structure test in CA
- The size distributions of firebrands from wall assemblies were similar to the one from structure test conducted in CA
- Individual building components provide insight into firebrand generation from full-scale structures as similar size/mass classes were found compared to the full-scale structure fire experiments

Research in progress

- Other generation tests were conducted. Analysis is in progress
  - Structure Test
    - OSB & stud
  - Components Test
    - Wall with cedar siding
      - Cedar siding & Tar paper added

Wind Velocity - 6m/s
OSB and Stud
Structure

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- Dr. Jun-ichi Suzuki from BRI

Effect of Physical Properties on the Capability of Hot Particles to Ignite Vegetation

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Workshop for Fire-Structure Interaction and Urban and Wildland-Urban Interface (WUI) Fires
Tsukuba and Chofu, Japan, 2-4 July 2012

Motivation: Fire Prevention

Costly wildland and building fires are often ignited when hot metal particles from grinding, welding or powerline interaction contact combustible fuels like forest vegetation or wood operations

Motivation: Fire Prevention and Fighting

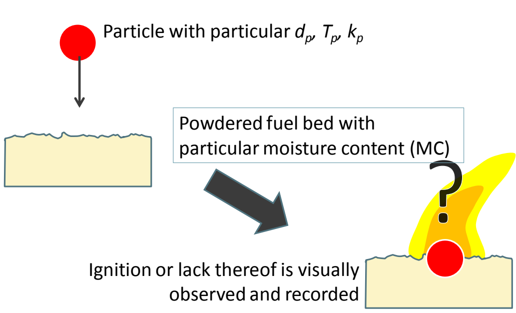
A greater understanding of the ignition of cellulosic fuels by metal particles and embers can help:

- Understand the fire danger conditions of particular wildland areas or construction materials
- Guide regulatory agencies in fire prevention (fire maps or codes, power lines inspection frequency, etc)
- Develop better wildland and building fire models
- Develop better fire fighting approaches

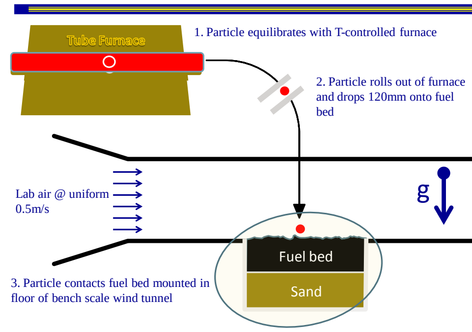
Overall Goals of Work

- Identify controlling mechanisms of the ignition of natural fuels by hot metal particles
- Better understand the fundamental ignition process through experiments and computational modeling
- Approach: determine the influence of problem parameters on the ignition of the fuel
  - Particle size, temperature, thermal properties, shape, etc.
  - Fuel bed composition, moisture content, porosity, etc.

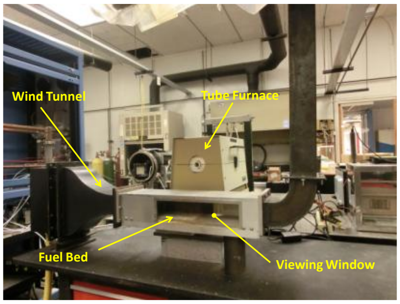
Basic Test



Experimental Setup



Experimental Setup



Particle Characteristics: Thermal properties

k, ρ, and c_p are pertinent thermal properties for particle energy content and energy transport by conduction

$$V\rho c_p (T_p - T_i) = E \qquad \frac{\rho c_p}{k}\frac{\partial T}{\partial t} = \nabla^2 T$$

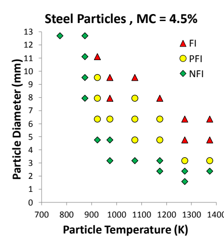
	Stainless Steel (302)	Brass (260)
k (W/mK)	21.5	120
ρc_p (MJ/m³K)	**3.2**	**4**
ΔT_m (°C)	1400 - 1420	915 - 955

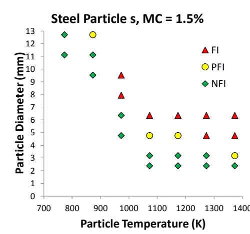
Fuel Bed Characteristics

- Composed of powdered α-cellulose
  - chemical and physical homogeneity → lab fuel
  - largest component of woody biomass
- Two moisture contents tested: ~4.5%(dry) and ~1.5%(driest)
- Bulk density held constant at 239 kg/m^3 from test to test

Effect of d_p and T_p and MC: Steel Particles

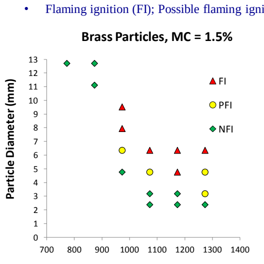
Flaming ignition (FI); Possible flaming ignition (PFI): No flaming ignition (NFI)

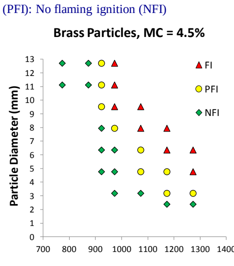




Effect of d_p and T_p : Brass particles

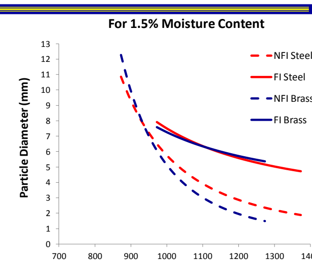
- Flaming ignition (FI); Possible flaming ignition (PFI): No flaming ignition (NFI)





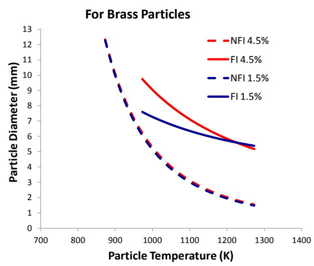
Effect of k_p

- Non-flaming limit dependent on k_p for small particles
  - All the energy of the particle needed to ignite material
- Flaming limit dependence on k_p less clear
- Results for MC~4.5% are very similar



Effect of Fuel Bed Moisture Content

- Flaming limit depends on MC for low temperatures but is independent of MC at high temperatures
  - Water content important when energy of the particle is small
- Non-flaming limit independent of MC for range studied
  - Suggests fuel characteristics more important at this limit
- Results for SS are very similar
- Range of MC's may be too small to reach conclusions



Concluding Remarks

- Primary ignition mechanism: Porous fuel is heated by the particle, causing its pyrolysis, pyrolyzate mixes with air forming a flammable mixture near the particle
- Ignition occurs when fuel/air mixture receives sufficient energy from particle to overcome losses to surrounding air
- Flame kernel develops into diffusion flame as long as pyrolysis continues to supply fuel
- Non-ignition occurs when V_p and T_p are such that particle and/or mixture cannot overcome losses
- These mechanisms are dependent of particle size and composition, and fuel bed properties and moisture content

Workshop for Fire-Structure Interaction and
Urban and Wildland-Urban Interface (WUI) Fires

7/3/2012

Scale-model experiment of large-scale, wind-aided fires

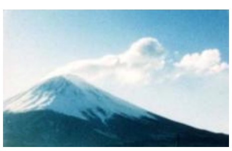
Kazunori Kuwana,
Yamagata University

Fires are …

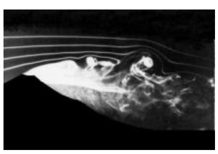
LPG tanks fire at oil refinery (3/11/2011)

Scale-model experiments

- Full-scale experiments (or CFD simulations) are extremely difficult.
- Scale-model experiments



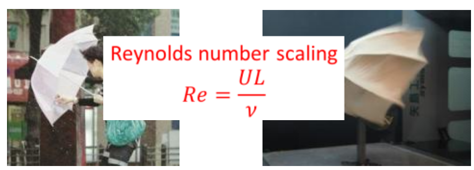
Turbulence near Mr. Fuji



(Courtesy K. Sekimoto)

Designing a scale-model experiment

- Identify the most important dimensionless parameter(s).
- Match the parameter of a scale model to that of the prototype.



Dimensionless heat release rate

- $Q^* = \frac{Q}{\rho c T g^{1/2} L^{5/2}}$
  - Q heat release rate [W]
  - ρ density [kg/m^3]
  - c specific heat [J/kg K]
  - T ambient temperature [K]
  - g acceleration due to gravity [m/s^2]
  - L horizontal dimension [m]

Flame height, plume temperature, plume velocity, etc. can be correlated using Q^*.

Wind-aided fire

- Example: fire whirl

Los Angeles, CA, 2006

Los Angeles, CA, 2009

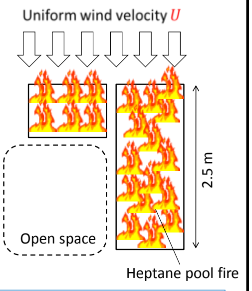
Orange county, CA, 2007

Fire whirls after Great Kanto Earthquake

(From *Newton*, August issue, 2012)

Scale-model experiment

Prototype mass fires



1/1,000th scale-model experiment

Scaling laws

- Dimensionless heat release rate
  - $Q^* = \frac{Q}{\rho c T g^{1/2} L^{5/2}}$
- Froude number
  - $Fr = \frac{U^2}{gL}$
- Difficulty
  - $\frac{H}{L} = f(Q^*)$

	Prototype	1/1000th scale model
L	~ 2500 m	~ 2.5 m
H	~ 10 m	~ 1 cm

Proposed modification

- Dimensionless heat release rate
  - $Q^* = \frac{Q}{\rho c T g^{1/2} L^{5/2}}$
- Froude number
  - $Fr = \frac{U^2}{gL}$
- Flame-height-based Froude number
  - $Fr = \frac{U^2}{gH}$

Reconstructed fire whirls

Scale models of different scales

1/1,000th scale model

1/10,000th scale model

The proposed scaling law can be validated by experiments of different scales.

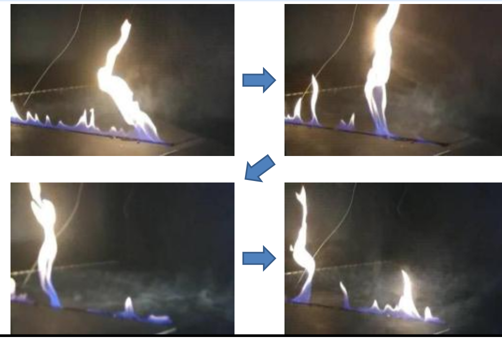
13

Fire whirl of other type

Brazil fire whirl in August, 2010

14

Scale-model experiment



15

Summary

- Fire research relies in a large part on scale-model experiments.
- There is a difficulty in matching Q^* of scale model to that of the prototype fire.
- Flame-height-based Froude number, $\frac{U^2}{gH}$, can be used to design scale-model experiments of a wind-induced fire whirl.

Investigation and its Characteristic of Post Earthquake Fire at the 3.11.

National Research Institute of
Fire and Disaster, Japan (NRIFD)
Hiroyuki Tamura

Objective of the survey and method

To obtain useful information in the prevention of fire outbreaks and spreading fires following future large-scale disasters, we investigated the following particulars:

Cause of the fire
Area where the fire spread
Cause of stopping the fire
Photos and video records of the stricken area
Collection of testimonies

Table 1 The area of the fire spread in the urban large fire

Characteristics of the fire in the Great East Japan Earthquake had the following features:

(1) Many of the affected fire sites covered a wide spreading area (over 100,000 m²).
(2) Fires occurred in a lot of prefectures.
(3) The total area of a large urban fire was very wide.

Great East Japan Earthquake.	
district	area (㎡)
Ohtsuchi town	116,000
Akahama, Ohtsuchi town	14,000
Taro Miyako city	40,000
Yamada town	170,000
Shishiori, Kesen-numa city	110,000
Nihohama, Kesen-numa city	27,000
Nainowaki, Kesen-numa city	38,000
Kadonowaki, Ishinomaki city	58,000
Hebita, Ishnomaki city	500
Yuriage 7chome, Natori city	12,500
Hiratabashi, Natori city	42,000
Hisanohama, Iwaki city	18,400

Investigation Site

(1) Otobe and Kerasu, Miyako City, Iwate Pref.
(2) Yamada Town, Iwate Pref.
(3) Funakoshi, Yamada Town, Iwate Pref.
(4) Ohtsuchi and Akahama, Ohtsuchi Town, Iwate Pref.
(5) Shishiori, Ninohama, Kogoshio, and Nainowaki, Kesen-numa City, Miyagi Pref.
(6) Kadonowaki and Hebita, Ishinomaki City, Miyagi Pref.
(7) Yuriage 7-chome and Hiratabashi, Natori City, Miyagi Pref.
(8) Hisanohama, Iwaki City, Fukushima Pref.

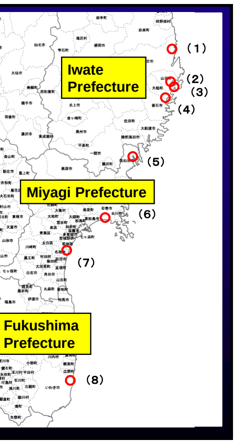


Fig. 1

(1) Otobe and Kerasu, Miyako City, Iwate Pref.

・The fire site was approximately 600-800 m inland.
・The fire broke out from the house that flowed by the tsunami and arrived.

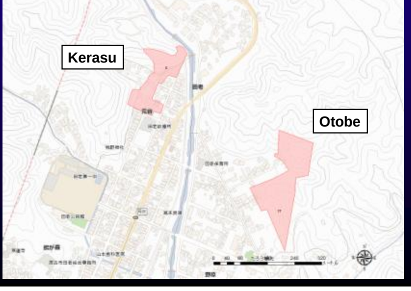


Fig. 2

Kerasu District

Because rubble gathered at the foot of a mountain by the tsunami, a fire spread to rubble after the fire had broken out.

Photo. 1 The fire damage in the Kerasu district

Otobe District

The fire ultimately spread to the forest.

The fire damage in the Otobe district

(2) Yamada Town, Iwate pref.

The fire broke out around the two places indicated by circles in Fig.3, immediately after the raid of the tsunami.

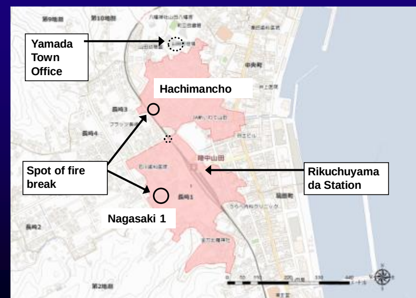
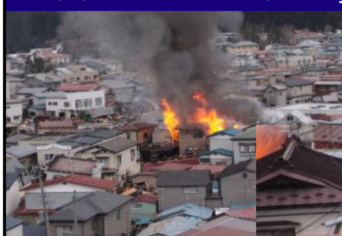


Fig. 3 The range of the fire in the vicinity of Yamada town office in Hachiman-cho and Rikuchuyamada station in Nagasaki 1

(2) Yamada Town (vicinity of Town office)

Photo 2 The fire damage as seen from the rooftop of the town office

(2) Yamada Town (vicinity of Town office)



Fire fighting in the rubble

3. 11 15:27 smoke
3. 11 16:05 fire

Rubble drifted on the road and between the building. And buildings were in the fire while standing.

(2) Yamada Town (Nagasaki 1)

The inhabitants heard gas leaking from gas cylinders broken as a result of the tsunami.

3.11
16:05

(2) Yamada Town (vicinity of Town office)

The fire expanded at nighttime.

The fire damage as seen from the rooftop of the town office

(3) Funakoshi District, **Yamada Town, Iwate Pref.**

The fire broke out from the house which was carried away by the tsunami. The fire broke out around the town block indicated by circles in Fig.4.

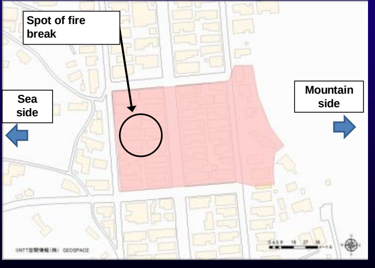


Fig. 4 The range of the fire in Funakoshi District

(3) Funakoshi District, **Yamada Town, Iwate Pref.**

Photo 3 The fire spread to the mountain side.

(3) Funakoshi District, **Yamada Town, Iwate Pref.**

There were some cars that had been abandoned on the road.
Therefore, the fire spread beyond the road as the medium of the cars.

Fire brigade had a fire fighting using a fire protection water tank of 40t. However, the supply of water was insufficient to prevent the spread of the fire.

(4) Ohtsuchi Town, Iwate Pref.

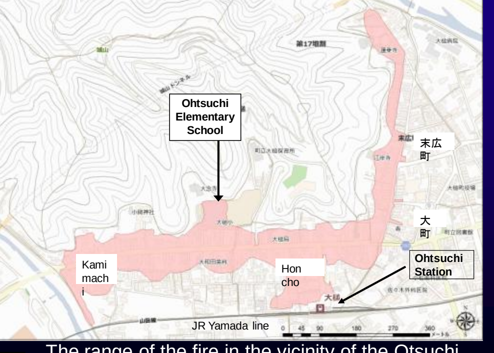


Fig. 5 The range of the fire in the vicinity of the Otsuchi Elementary School

(4) Ohtsuchi Town, Iwate Pref.

Photo 4 The fire damage around the north side of the Ohtsuchi Station

An urban area in a foot of a mountain to where the tsunami struck burnt. In addition, the forest adjacent to the fire-damaged urban areas burned.

(4) Ohtsuchi Town, Iwate Pref.

The fire spread to the forest from the urban area.
Fires that broke out from several sources joined and spread.

(4) Akahama, Ohtsuchi Town, Iwate Pref.

Fig. 6 The range of the fire in the Akahama District

(4) Akahama, Ohtsuchi Town, Iwate Pref.

This place was approximately 400m inland from a coast.
And the fire broke out after the tsunami struck.
The fire destroyed buildings that had not been damaged by the tsunami.
Inhabitants said that two ships made of FRP (Fiber Reinforced Plastics) drifted and burned for three days.

Photo 5 The fire damage seen from the inland in the Akahama district

(5) Shishiori, Kesen-numa City, Miyagi Pref.

The tsunami impact occurred after the electricity was cut by the earthquake, and fire started immediately afterwards in three places.

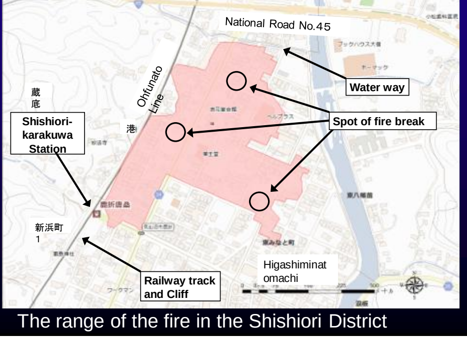


Fig. 7 The range of the fire in the Shishiori District

(5) Shishiori, Kesen-numa City, Miyagi Pref.

The fire brigade fought fires by using waterway, railway track, and the cliff. Fire was prevented by the fire fighting. Flooding hampered efforts to fight the fire on the south and east sides.

Photo 6 The fire damage seen from the vicinity of the Ofunato railway track

(5) Shishiori, Kesen-numa City, Miyagi Pref.

In the Kesen'numa bay, the rubble that drifted and burnt were taken of a picture by the helicopter of the Self Defense Forces at night.

(5) Ninohama and Kogoshio, Kesen-numa City, Miyagi Pref.

Fig. 9 The range of the fire in the Ninohama and Kogoshio District

(5) Ninohama and Kogoshio

A fishing boat ran aground on March 11, 2011. The boat caused a fire and continued to smolder for several days. The fire spread to the rubble on the road and then along a hill side.

The burning rubble was carried ashore by the tsunami. The fire was finally stopped by a cliff, gravel road, and cemetery.

Photo 8 The seashore road on the west side of the shrine

(6) Ishinomaki City, Miyagi Pref.

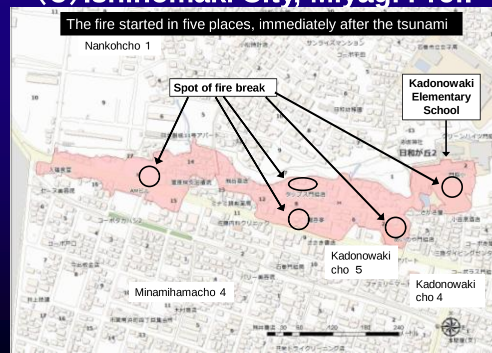


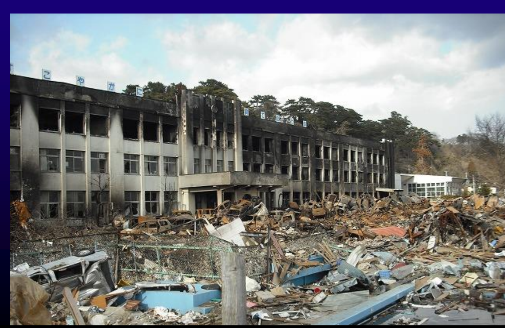
Fig. 10 The range of the fire in the vicinity of the Kadonowaki Elementary School

(6) Ishinomaki City, Miyagi Pref.

Photo 9 The fire damage seen from the north side of the Kadonowaki Elementary School

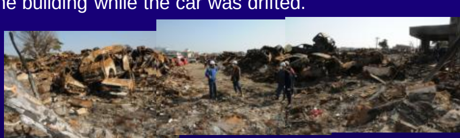
(6) Ishinomaki City, Miyagi pref.

Many cars belonging to the evacuees stopped in the schoolyard as they were inundated by the tsunami. **(3/15)**



(6) Ishinomaki City, Miyagi pref.

A fire broke out one of these cars. The burnt car set fire to the building while the car was drifted.



The fire brigade did the fire fighting activity using the cliff in the rising ground to obstruct the fire spread. And they defended the residential area on the rising ground.

(6) Hebita, Ishinomaki City, Miyagi Pref.

This fire was located 2 km inland near the river.
This fire broke out at about 0:20 on March 12, 2011.

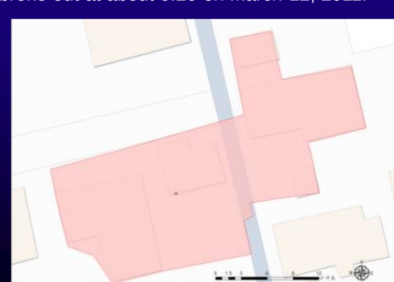


Fig. 11 The range of the fire in the Hebita district

（6）Hebita, Ishinomaki City, Miyagi Pref.

The person who lived in the neighboring second floor said that the fire broke out from the car when they saw the outside because the outside of the window became light in the night.

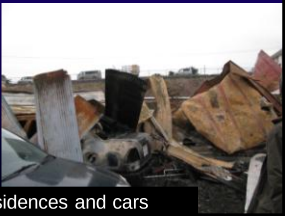


Photo 10 The fire damage to residences and cars

（7）Yuriage 7, Natori City, Miyagi Pref.

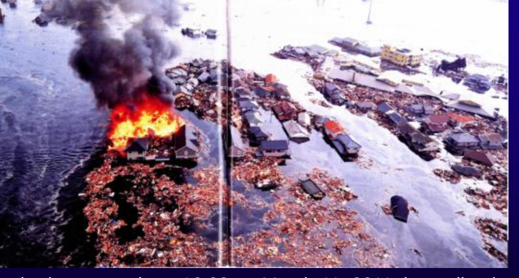
Fig. 12 The range of the fire in Yuriage 7chome

（7）Yuriage 7, Natori City, Miyagi Pref.

Photo 11

The fire damage in the Yuriage 7chome

（7）Yuriage 7, Natori City, Miyagi Pref.



Fire broke out at about 16:30 on March 11, 2011, immediately after the tsunami. It was difficult for the fire brigade to approach the fire site under the influence of the tsunami.
A lot of rubble gathered on the surface of the water around the building that was not broken. And the rubble burnt.

（7）Yuriage 7, Natori City, Miyagi Pref.

When we watched the picture on web, it was confirmed that gas cylinders were carried away while leaking the contents.

（7）Yuriage 7, Natori City, Miyagi Pref.

When we watched the picture on web, it was confirmed that gas cylinders were carried away while leaking the contents.

(7) Yuriage 7, Natori City, Miyagi Pref.

When we watched the picture on web, it was confirmed that gas cylinders were carried away while leaking the contents.

(7) Hiratabashi, Natori City, Miyagi Pref.

The range of the fire was confirmed along the small river to the north of prefectural road No. 10.

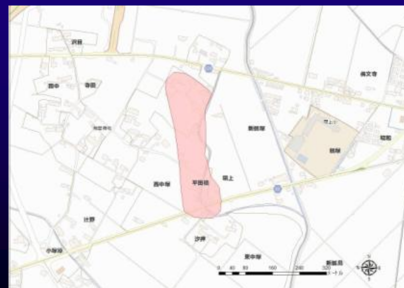


Fig. 13 The range of the fire in the vicinity of Hiratabashi

(7) Hiratabashi, Natori City, Miyagi Pref.

When we watched the news picture which shot this district from the air, the rubble that were carried away while burning gathered in the fields, and the fire spread.

(7) Hiratabashi, Natori City, Miyagi Pref.

Photo 12 The fire damage in the Hiratabashi district

When we watched the news picture which shot this district from the air, the rubble that were carried away while burning gathered in the fields, and the fire spread.

(8) Hisanohama, Iwaki City, Fukushima Pref.

The fire broke out immediately after the tsunami. Under the influence of the tsunami, it took more than 30 minutes for the fire brigade to go to the fire site.

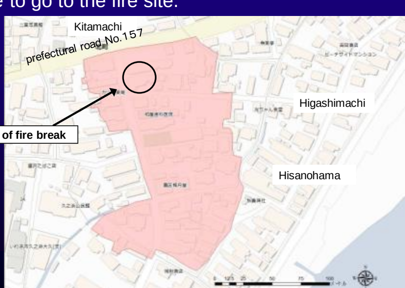


Fig. 14 The range of the fire in Hisanohama

(8) Hisanohama, Iwaki City, Fukushima Pref.

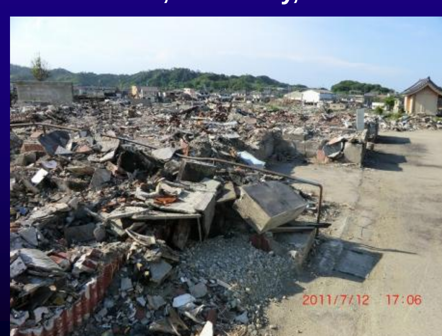


Photo 13 The fire damage in Hisanohama

（8） Hisanohama, Iwaki City, Fukushima Pref.

According to the photo of the magazine, some buildings were broken by the tsunami, but many buildings which were not broken by the tsunami received damage from spreading fire.

（8） Hisanohama, Iwaki City, Fukushima Pref.

The fire brigades could not approach the sea side of the fire site under the influence of the tsunami. Fire brigade pumped up water from a nearby river. They extended hoses and sprayed water on the burning buildings. The fire spread was prevented in the west and the south side by fire fighting.

Cause of the fire (1/2)

(1) Fire broke out from rubble carried away by the tsunami.

(2) Rubble was burning as it was carried away.

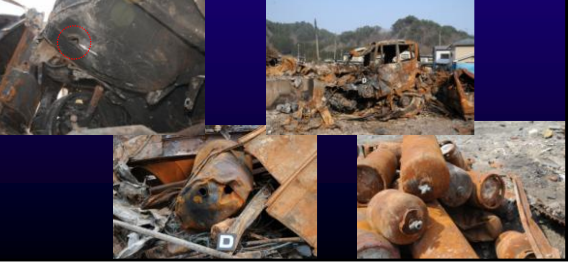
(3) Fire broke out from cars that were carried away by the tsunami.

(4) Electric power equipment, such as the integrating wattmeter, was soaked in seawater once and caught fire when electric power was restored.

(5) Fire broke out from ships that were carried away by the tsunami.

Cause of the fire (2/2)

(6) In the on-site survey, fire-damaged kerosene tanks, stoves, boilers, etc., were found in rubble from the vicinity where the fire erupted. However, positive proof that these items caused the fire to break out was not determined.



Spread of the fire (1/2)

(1) Fire spread in places where burned cars and rubble were carried away by the tsunami. Rubble and parked cars were deposited on the roads. Therefore, the road did not become a firebreak.

(2) Gas cylinders carried away by the tsunami leaked their contents. There is a possibility that this gas became a factor in the fire's spread.

(3) Fire spread from urban areas to the forest.

Spread of the fire (2/2)

(4) Although buildings were fireproof, their outside walls and windows were broken by the tsunami. Therefore, the buildings caught fire.

(5) In specific regions of a large-scale urban area, fire broke out from two or more places.

(6) Buildings that were not destroyed by the tsunami received damage from spreading fire.

Cause of stopping the fire (1/2)

(1) Spread of the fire stopped because combustibles disappeared in the tsunami, and the city block was soaked with water.

(2) A wide road, fireproof buildings, a graveyard, and a rice field stopped the fire's spread.

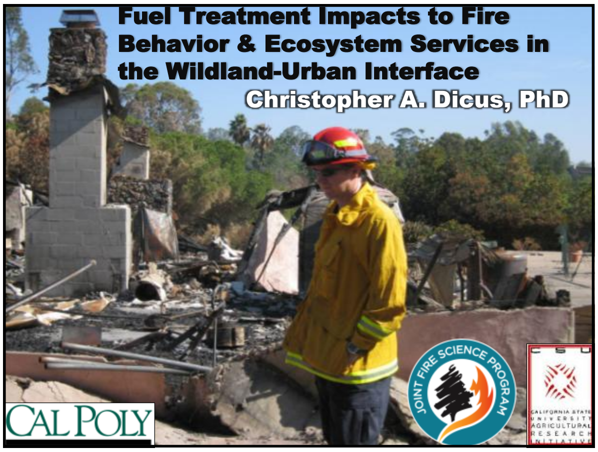
Cause of stopping the fire (1/2)

(3) There were a lot of fire sites that the fire brigade was not able to approach. However, fire's spread was halted in places where the fire brigade fought the fire. The fire brigade fought the fires by using the road, the waterway, the railway track, and the cliff.

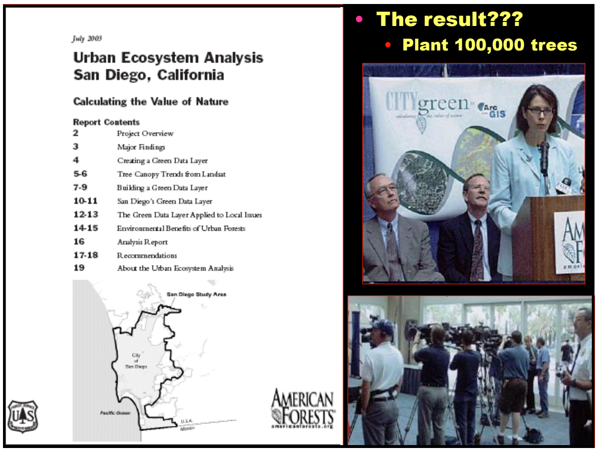
Concluding remarks

- The urban large area fire that the NRIFD surveyed was summarized. In the earthquake, there were not only the urban fire reported here but also residential fires, industrial complex fires, and forest fires.
- Because of the tsunami damage and the wide range of spreading fires, it was difficult to clarify what specifically caused the fires and how they spread.

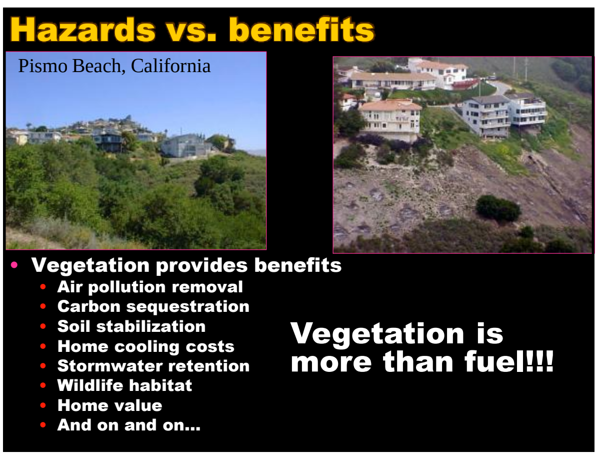
END

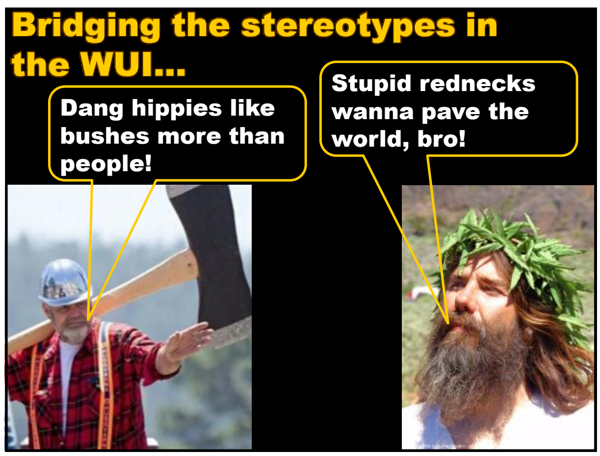

Fuel Treatment Impacts to Fire Behavior & Ecosystem Services in the Wildland-Urban Interface
Christopher A. Dicus, PhD
JOINT FIRE SCIENCE PROGRAM
CAL POLY


Tunnel Fire (Oakland/Berkeley Hills) – October 1991
• 2900 structures destroyed
• New law requires 10m of "Defensible Space"


July 2003
Urban Ecosystem Analysis
San Diego, California
Calculating the Value of Nature
Report Contents
2 Project Overview
3 Major Findings
4 Creating a Green Data Layer
5-6 Tree Canopy Trends from Landsat
7-9 Building a Green Data Layer
10-11 San Diego's Green Data Layer
12-13 The Green Data Layer Applied to Local Issues
14-15 Environmental Benefits of Urban Forests
16 Analysis Report
17-18 Recommendations
19 About the Urban Ecosystem Analysis
San Diego Study Area
AMERICAN FORESTS
• The result???
• Plant 100,000 trees
CITYgreen

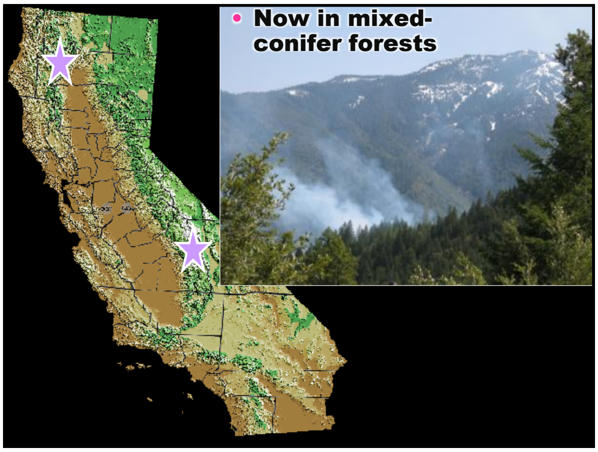

Cedar Fire (San Diego, October 2003)
• 4847 homes destroyed
• The result???
• Directly led to 30 m Defensible Space Law


Hazards vs. benefits
Pismo Beach, California
• Vegetation provides benefits
• Air pollution removal
• Carbon sequestration
• Soil stabilization
• Home cooling costs
• Stormwater retention
• Wildlife habitat
• Home value
• And on and on…
Vegetation is more than fuel!!!

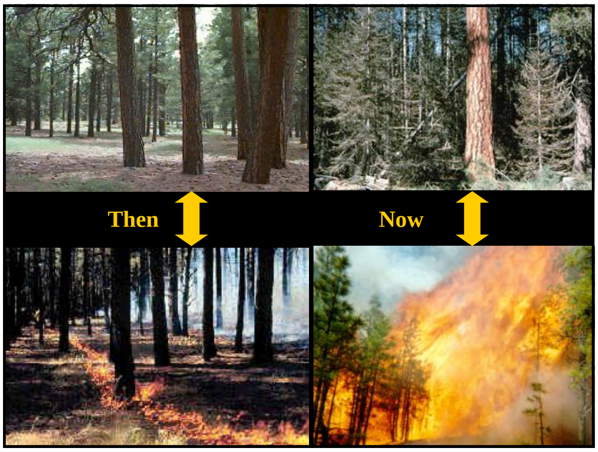

Bridging the stereotypes in the WUI…
Dang hippies like bushes more than people!
Stupid rednecks wanna pave the world, bro!

Early work…

- Shrubs & Grasses need not apply…
  - "CityGreen" (Dicus & Zimmerman 2007)
    - (San Diego still spends another $200,000 for follow-up)
  - "Stratum" (Dicus 2009a)
  - "UFORE" (Dicus et al. 2009b)



- Now in mixed-conifer forests



The Treatments…

The Methods…

Fire Behavior

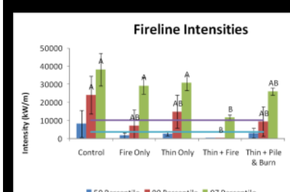
- Measure fuel complex before and after
- Model changes to fire behavior and ecosystem services

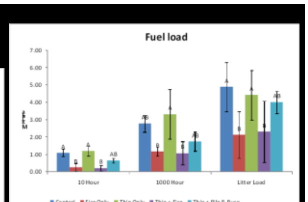
Ecosystem Services

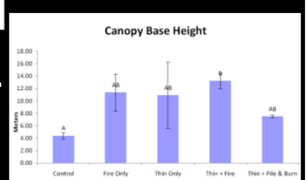
Tools for assessing and managing Community Forests

i-Tree

The Results



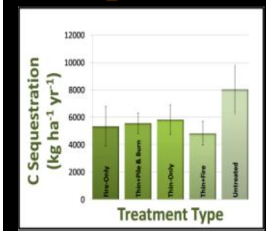




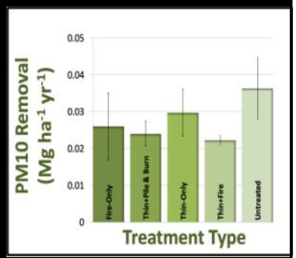
- Big differences in fire behavior affected by…
  - Weather (duh)
  - Changes to fuels
    - Surface fuels
    - Canopy fuels

Dicus et al. *in review*

Ecosystem Services



Annual carbon sequestration



Annual air pollutant removal

- Ecosystem services reduced slightly
- No differences between treatments

Dicus et al. *in review*

Treatments are like cuddly, innocent babies…

But forests grow up… and sometimes get scary

Same data, different methodology

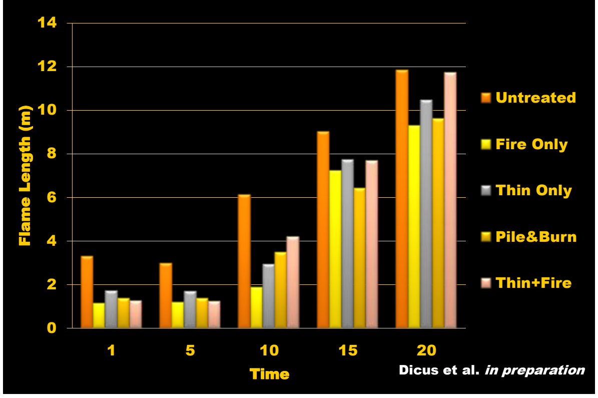
Fire Behavior

Ecosystem Services

Forest Vegetation Simulator FVS USDA Forest Service

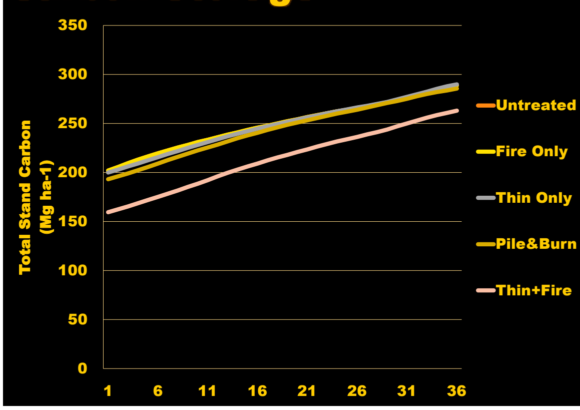
- Modeled out 50 years
  - Shows changes to…
    - Fuels
    - Fire Behavior
    - Carbon storage, sequestration, emissions

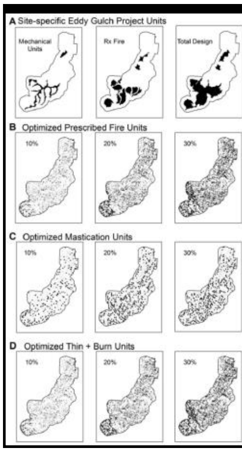
Flame Length



Dicus et al. *in preparation*

Carbon Storage

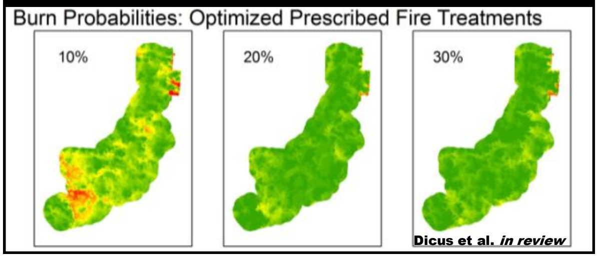




What about landscape???

- 4 Treatment Types
- 3 Treatment "Intensities"
- Arc Fuels
  - GIS extension
  - Models through time
    - Fuels
    - Fire Probability
    - Fire Behavior
    - Carbon Emissions
    - Carbon Storage

- Through time, treatments affected…
  - Fire probability
  - Fire behavior
  - Carbon storage and emissions
    - Through time Thin+Fire had most C storage
- Little impact after 20% intensity



- Fuels aren't always the problem…
  - All disciplines get tunnel vision

We must prepare the battlefield!!!

Thanks Kate Dargan and Tonya Hoover!

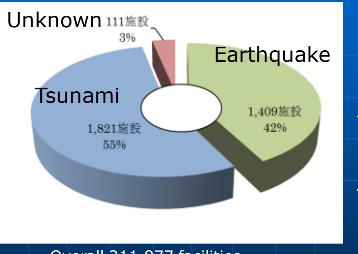
- Fuels
- Structures
- Fire infrastructure
- A whole lot else

Fires and Damage of Oil Tanks Caused by the 3.11 Earthquake

Haruki Nishi, Dr.

4th, July, 2012
Workshop for Fire-Structure Interaction and Urban and Wildrand-Urban Interface fires

Primary cause of the damage of the hazmat facilities



Earthquake
Fire:5
Hazmat leakage:79
Tsunami
Fire:36
Hazmat leakage:106
Total 226

Overall 211,877 facilities

Oil leakage in Refinery

②Bent and fractured pipelines → Heavy oil leakage (aprox. 4,000kL)

③Sea banks, piers, dykes collapsed heavily

④Sloshing height approx. 1m →Oil spill onto the floating roof

①Tsunami reached to 3.5m high from the bottom plate
※The tank was empty, but not displaced

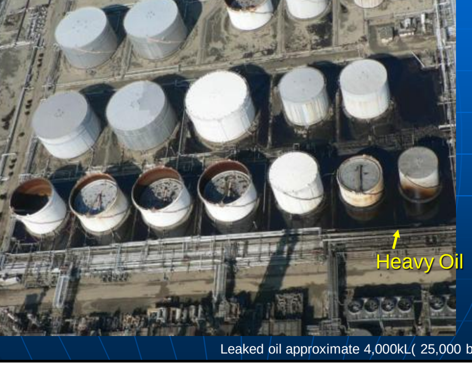
Pipelines swept away by the tsunami
(photo from the Pacific Ocean side)

Total 10 fractures on three pipelines

Displaced Oil Storage Tank

Floated and displaced tank (capacity 2,00kL)
*Empty at the arrival of the tsunami
Three other AST (all empty) displaced.

Heavy Oil Leakage

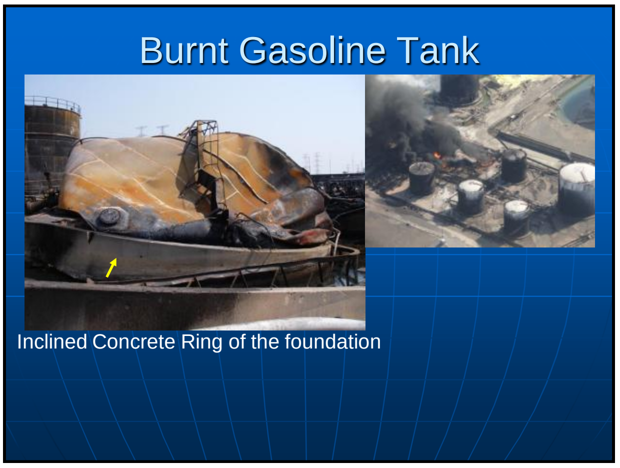


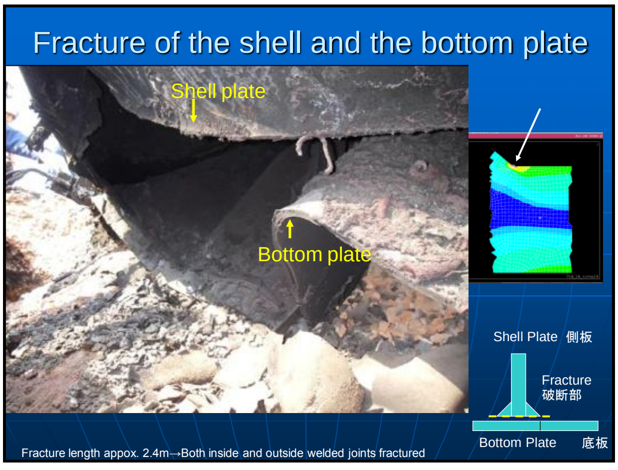
Leaked oil approximate 4,000kL(25,000 barrel)


Oil attached to the shell plate
Broken part of the pipe
Magnified view of the broken part
Broken earth wires


Fires at Refinery (3.13)
River
Pacific
Ocean


Collapsed Asphalt Tank
Inclined
after the
Tsunami
incursion
Leaked asphalt

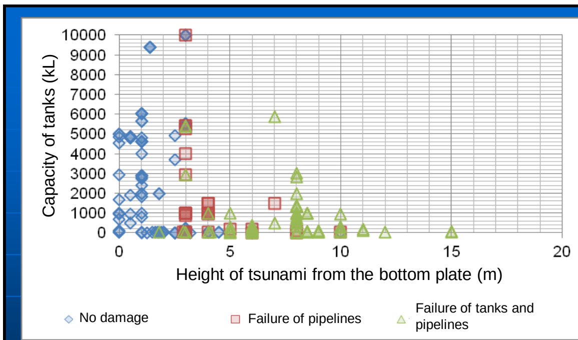

Burnt Gasoline Tank
Inclined Concrete Ring of the foundation

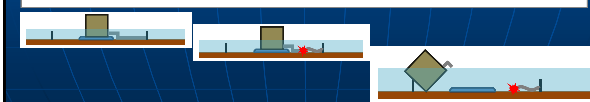

Fracture of the shell and the bottom plate
Shell plate
Bottom plate
Shell Plate 側板
Fracture
破断部
Bottom Plate 底板
Fracture length appox. 2.4m→Both inside and outside welded joints fractured


Tank lorry（gas）
Electric spark
Tank lorry（oil）

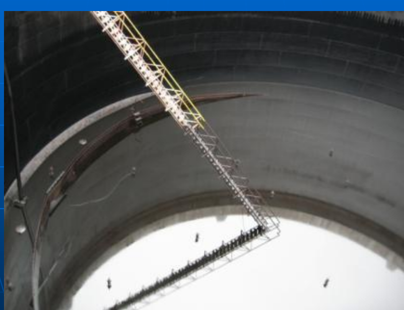
Oil Storage Tanks damaged by Tsunami

22 tanks out of 23 tanks located in Kesenmuna City flowed out by the momentum and the buoyancy of the Tsunami. Total amount of oil outflow is assumed approx. 11,521kL. The type of the oil is heavy oil, kerosene, diesel fuel and gasoline.





Sinking of the Floating Roof



Heavy Oil leaked onto the deck of the floating roof.
Completely sank three days after the leakage

Damage of the Inner Float Roof

Broken Float Tube 1

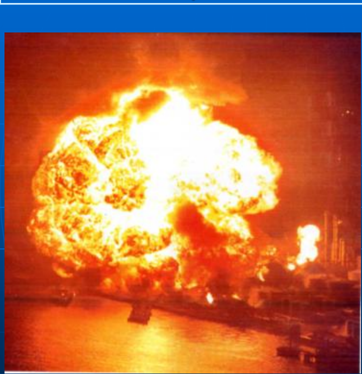
Completely Broken Inner Floating Roof

Gasoline tank
Cap. 2,000kL
Diameter 15.5m

Ruptured Deck Skins

Broken Float Tube 2

Fires and Explosions at Petro. Complex



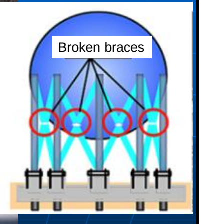
Fire Ball (LPG)

The largest BLEVE(Boiling Liquid Expanding Vapor Explosion) that have been occurred in Japan.

Diameter : approx. 600-750m

Debris of the LPG Tank

Fires and Explosions at Petro. Complex



All legs of the LPG tank collapsed and buckled by the earthquake and the aftershock. The LNG tank damaged the connecting pipelines after buckling. Then LNG leaked.

Pictures of the surveillance camera just after the ignition,15:47, 2011/03/11

Summary

- Few damage of the tank body by the earthquake
- Many pipelines were damaged by the tsunami. Emergency shutdown valves did not work because of the blackout after the earthquake. Then, large amount of oil spilled out to the dykes.
- Many fractures were found in the floating roofs which did not meet the technical standard of the earthquake proofness.
- Many small tanks were swept away by the tsunami. The bottom plates of the tanks were broken. However, even the empty tank did not sweep away by the tsunami.
- The tsunami washed away the foundations of the tanks and the ground inside the dykes. Some tanks tilted and collapsed after the tsunami.

Fires and Damage of Oil Tanks Caused by the 3.11 Earthquake

Any Questions?

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Experimental Study on the Possibility of the Vehicles Fire in Urban and Tsunami Fire
– About the Burning Behavior for Motorcycles –

Ken Matsuyama, *Dr., Assoc. Prof.*,
Center for Fire Science and Technology,
Tokyo University of Science, Japan

Topics

- Outline of the mechanism of "**Tsunami-induced Fires**" occurred after ignited floating debris and heavy oil .
  - Introduction; "**Tsunami-induced Fires by Small Scale Experiment**"
- Burning behavior of typical debris equipped with a fuel tank and battery
  - Introduction; **"Burning Behavior of Motorbikes"** as typical debris by experimental study, and investigation of fuel load
  - Consideration; Possibility of the Tsunami-induced fires

Acknowledgments

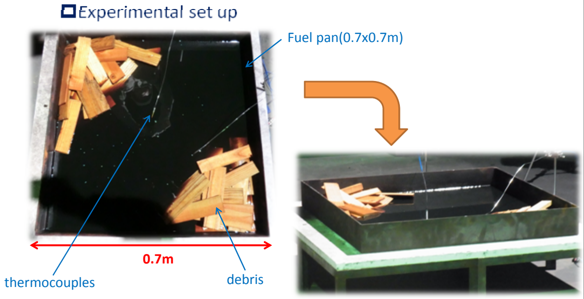
- Experimental study on "Mechanism of Tsunami-induced Fires"
  - Prof. *A. Sekizawa*, Tokyo University of Science
- Experimental study on "Burning Behavior of Motorbikes"
  - Prof. *S. Sugahara*, Tokyo University of Science
  - Prof. *Y. Ohmiya*, Tokyo University of Science
  - Dr. *N. Kakae*, Kajima Technical Research Institute
  - Dr. *W. Takahashi*, ING Cop.

Introduction

- "**Tsunami-induced Fires**" occurred after ignited the floating debris and heavy oil .

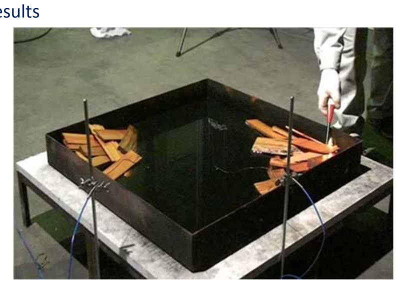
Experimental Study

- The mechanism of "**Tsunami-induced Fires**"
  - *Experimental set up*



Experimental Study

- The mechanism of "**Tsunami-induced Fires**"
  - Results



Burning Behavior of Motorbike

- The previous experiment indicated that flame spread on a sea doesn't depend on a kind of the debris if oil such as the heavy and light oil flowed out by a tsunami even though ships, car, train and motorbike.
- As a next topic, the full-scale experiments and investigation on the burning behavior of the motorbikes carried out in the past will be introduced.
- Finally, the possibility of the tsunami-induced fires will be considered through the experiments.
  - Because of no experimental data on HRR
    - Burning behavior of itself
    - Investigation on elements of combustible materials

Experimental Condition

< Individual Burning>

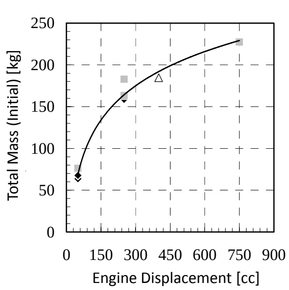
Size of motorbikes (Engine displacement [cc])		Types	Experimental
Small	～50	Scooter	1-5
		Road	6, 7
Middle	50～400	Scooter	8
		Road	9, 10
		Sports	11
Large	400～	Road	12

< Plural Burning>

Size of motorbikes (Engine displacement [cc])		Types	Experimental
Small ○	～50	Scooter	1
Small	～50	Scooter	
Small ○	～50	Scooter	2
Middle	50～400	Road	
Middle ○	50～400	Sports	3
Middle	50～400	Road	

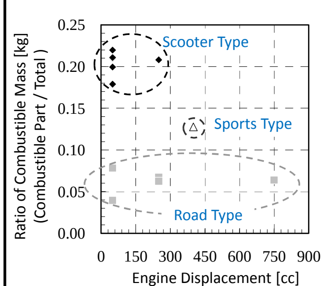
○ : Ignition side

Total Weight of Motorbikes



- Correlative between "Total weight" and "Engine Displacement"
  - ✓ Not depend on Types
  - ✓ Predictable roughly

Ratio of Combustible Mass



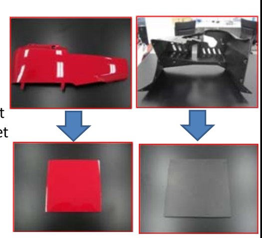
- Ratio of Combustible Mass (combustible parts / Initial Total weights)
  - ✓ Scooter Type : 20 [%]
  - ✓ Sports Type : 13 [%]
  - ✓ Road Type : 6 [%]

Ignitability of the Materials

- Type of Specimens

Representative Combustible Materials of Motorbikes

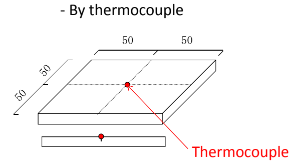
- ABS Resin : Cover for engine
- Polycarbonate : Windbreak
- Polypropylene : Fender and Covers
- Polyethylene (Low density) : mainly Foot rest
- Polyvinyl Chloride : Surface of the sheet
- Polyurethane : Cushion of the sheet



- Intensity of Radiation (Heat Flux)
  - 5, 10, 15, 20, 30, 40 and 50 [kW/m^2]

Outline of Specimen

- Measurement Items
  - **Time to Ignition**
  - **Heat Release Rate**
    - By using Oxygen consumption method installed in Conecalorimeter
  - **Surface Temperature of Specimens**
    - By thermocouple



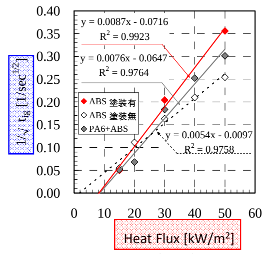
Specimen (ABS Resin)

Results of Ignitability

■ Relation between Heat Flux and Ignition time

$$\rho \cdot c \cdot \frac{\partial T_x(t,x)}{\partial t} = k \cdot \frac{\partial^2 T_x(t,x)}{\partial t^2}$$

$$\frac{1}{\sqrt{t_{ig}}} = \frac{1.18 \cdot \varepsilon}{\sqrt{k \cdot \rho \cdot c} \cdot (T_{ig} - T_0)} \cdot \dot{q}_e'' - \frac{1.18 \cdot h}{\sqrt{k \cdot \rho \cdot c}}$$

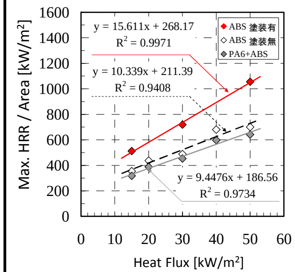


< ABS Resin>

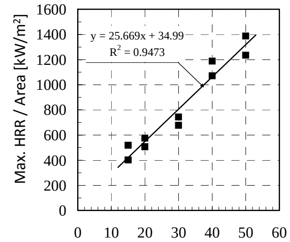
- Time to Ignition and Heat Flux is almost proportion
- Threshold of the ignition is about 10kW/m²

Results of Combustibility

■ Relation between max HRR and heat flux



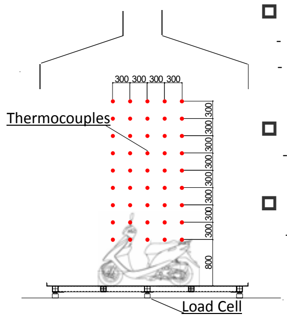
< ABS Resin>



< Low density Polyethylene>

Experimental Setup (1)

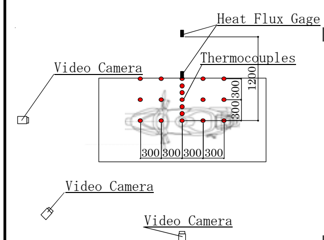
■ Measurement Items



- **Heat Release Rate**
  - Under the 5 x 5m Hood and Open Space
  - By using Oxygen Consumption Method
- **Mass Loss Rate**
  - By Load Cells
- **Distribution of Temperature**
  - By Thermocouples (at 300 mm intervals)

Experimental Set up (2)

■ Measurement Items

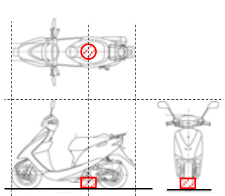


- **Heat Flux**
  - By 2 Heat Flux gages located at 600 and 1200 mm from Specimen

- **Video Record**
  - Form 3 directions

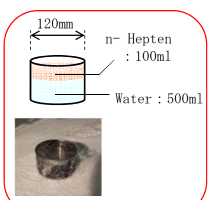
Experimental Set up (3)

■ Ignition Point



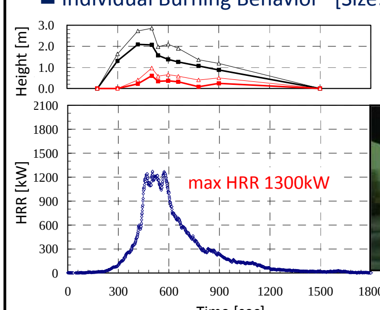
< Ignition Point >

: Ignition Point



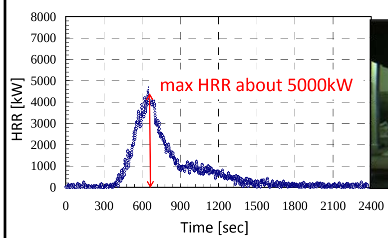
Results of Experiments

■ Individual Burning Behavior [Size: Small, Type: Scooter]



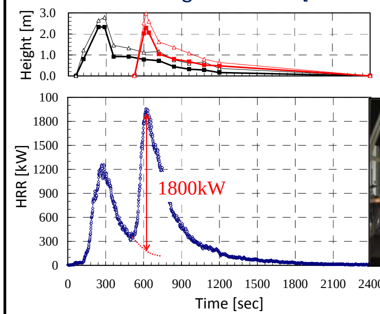
Results of Experiments

■ Individual Burning Behavior [Size: Middle, Type: Scooter]



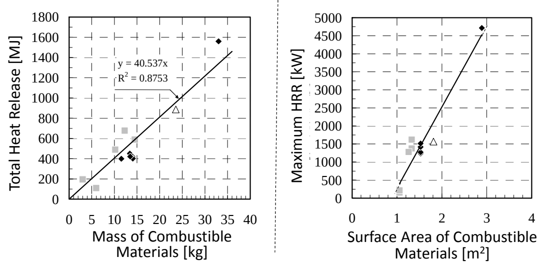
Results of Experiments

■ Plural Burning Behavior [Size: Small, Type: Scooter]



Consideration

■ Consideration of Burning Behavior



- Heat of Combustion of Motorbike is about 40.5 [MJ/kg]
- Max. HRR is relative to Surface area of combustible materials.

Summary

■ "Tsunami-induced Fires"

- Flame spread on a sea doesn't depend on a kind of the debris if oil such as the heavy and light oil spilled out by a tsunami even though ships, car, train and motorbike.

■ "Burning Behavior of Motorbikes"

- The ratio of combustible mass does not depend on the engine displacement.
- Two types of experiments were carried out. One is individual to check its burning behavior [total 12 cases]. Another one is plural to check the behavior of flame spread to next one [total 3 cases].
- Possibility of the Tsunami-induced fires will be investigated.

Thank you for your attention.

Workshop for
Fire-Structure Interaction and Urban and Wildland-Urban Interface(WUI) fires

Fires in Non-inundated Area Following the 3.11 Earthquake

Tatsuya IWAMI and Koji KAGIYA

National Institute for Land and Infrastructure Management(NILIM),
Ministry of Land, Infrastructure, Transport and Tourism (MLIT),
Japan

Both are important

Tsunami Fire

Non-Tsunami Fire

Overview

- Large number of fires occurred due to the 3.11 Earthquake
- It is very important to clarify
  - Why / How these fires occurred ?
  - How to mitigate damage of fire after earthquake ?

- Contents of Today

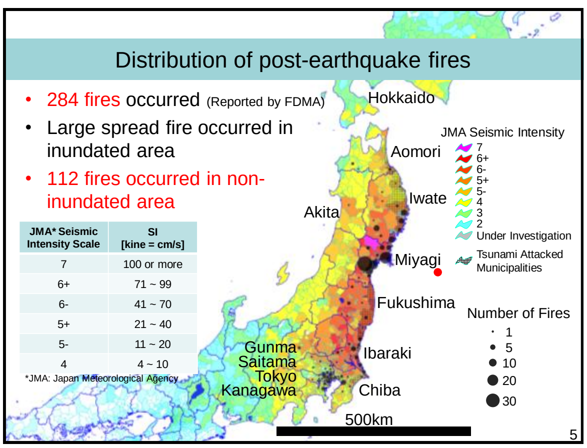
Outline of Fire after the Earthquake

Distribution of post-earthquake fires

- 284 fires occurred (Reported by FDMA)
- Large spread fire occurred in inundated area
- 112 fires occurred in non-inundated area

JMA* Seismic Intensity Scale	SI [kine = cm/s]
7	100 or more
6+	71 ~ 99
6-	41 ~ 70
5+	21 ~ 40
5-	11 ~ 20
4	4 ~ 10

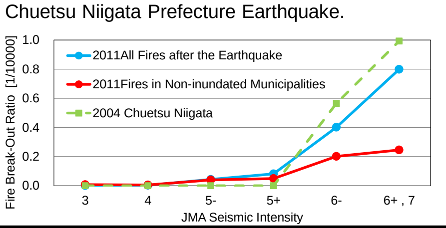
*JMA: Japan Meteorological Agency



Fire Break-Out Ratio

(Proportion of Number of Fires to Households)

- Seismic intensity raise the Fire break-out ratio.
- There is large Difference between less than 5+ and further than 6-.
- Fire break-out ratio in non-inundated area due to the 3.11 earthquake is less than the ratio of fire due to 2004 Chuetsu Niigata Prefecture Earthquake.



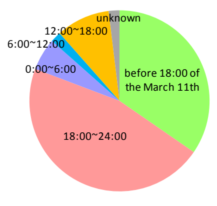
Characteristics of Fire
- Non-inundated area

Investigation by Interview

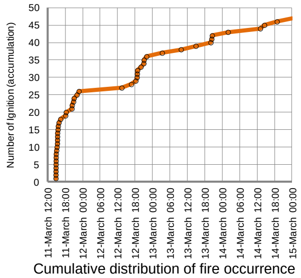
- Investigation period: April 2011～June 2011
- Target Area
  Aomori, Iwate, Miyagi and Ibaraki Prefecture
- We got detail information about 81 Fires
  - Non-inundated Area： 52 Fires
  - Inundated Area： 29 Fires
- Analysis in the following is based on the detail information of 52 fires in non-inundated area.

Time of Fire Occurence

- 1/3 of Fires occurred before 18:00 of the March 11th.
- Almost 1/2 Fires occurred a time zone from 18:00 to 24:00.



Ratio of fire occurrence by time

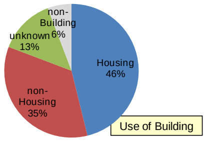


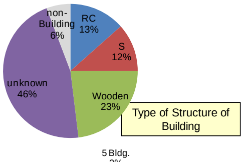
Cumulative distribution of fire occurrence since the mainshock attacked

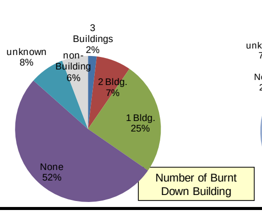
Major Cause of Fire

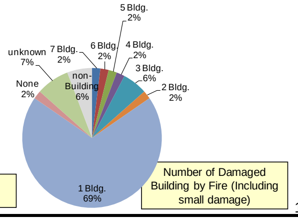
- Heat sources contacting surrounding combustibles with the earthquake motion
- Short-circuit at the recovery of power supply from power failure
- Misuse of the candle which is used for the light in the midst of blackout nights which were also seen as past time

Property of Fire Origin and Fire Spread









Examples of Fire






Characteristics of Fire - Inundated area

Features of Fire in inundated area

- Cause of Fire Outbreak (Example)
  - Most of fires are unidentified the cause of ignition.
  - In what has been identified, There are many fires by bad insulation of vehicles due to tsunami flood.
  - A fire broke out in stockyard of quicklime at a factory flooded by tsunami.
  - Some fires originated in integrating wattmeters flooded by tsunami.
- Cause of Fire spread (Example)
  - Accumulation of debris

    Many buildings collapsed by tsunami are poured inland → Accumulate at the edge of undated area → Fire brake out → Spread in the debris.
  - Advection of debris

    Factorys or warehouse bear tsunami → Collapsed buildings Accumulate around the factorys or warehouse → Debris carry fire to the borne buildings.
  - Aligned Vehicles

    Fire spread among a lot of vehicles which had aligned for export.

Summary

Summary

1. Fire break-out ratio in non-inundated area of the earthquake is approximately 1/4 of the ratio of 2004 Chuetsu earthquake and 1/12 of the ratio of 1995 Hyogo-ken Nanbu (Kobe) earthquake.

2. In non-inundated area, many fires occurred immediately after mainshock (in the period from 14:46 to 18:00 on March 11).

3. Except immediately after the mainshock, the occurrences of fire were concentrated on the day of the mainshock and in the period from 18:00 to 24:00 on the following days.

Summary (Cont'd)

4. For the most cases, firefighting worked effectively and all of the fires died down in a single building of fire origin or with a few buildings.

5. Many fires occurred due to the effect of the recovery of power supply and the activity of residents rather than the effect of the earthquake motion.

Acknowledgement

- We deeply appreciate offering the precious information of fires after the earthquake by personnel of local firehouses.

- The field survey to get the detail Information of fires was carried out with following researchers:
  - Ichiro Hagiwara (BRI)
  - Yoshihiko Hayashi (BRI)
  - Junichi Suzuki (BRI)
  - Hideki Yoshioka (NILIM)

Thank you!

2nd Japan-USA Fire Research Workshop
"Operation TOMODACHI: Fire Research"

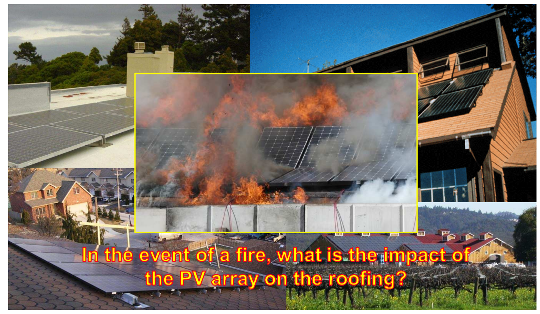
Photovoltaics in Fires

Robert Backstrom, Mahmood Tabaddor PhD,
Thomas Fabian PhD, and Pravinray D. Gandhi PE PhD

UL LLC
Corporate Research

4 July 2012

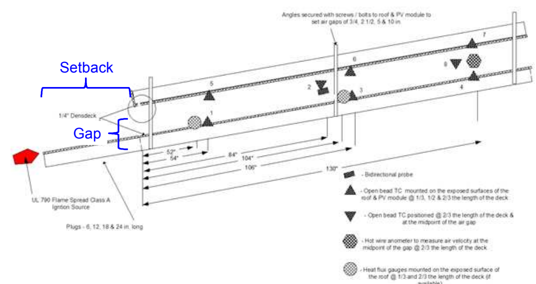
Photovoltaics in Fires



Applicable Standards

UL 790 *Standard Test Methods for Fire Tests of Roof Coverings*
UL 1703 *Standard for Flat-Plate Photovoltaic Modules and Panels*

Spread of Flame
Test Fixture & Instrumentation



Spread of Flame
Noncombustible Roof & PV

PV at 0 Set back & 25 cm Gap

PV at 0 Set back & 6.4 cm Gap

Spread of Flame Results
Noncombustible "PV" & Roof

Roofing	PV	Rail	Gap (cm)	Setback (cm)	Temperature (°C) at 5 min.			Max Heat Flux (kw/m^2)	
					1	3	4	1	2
Noncombustible	--	N/A	N/A	N/A	261	81	66	15	3
Noncombustible	Noncombustible	N/A	6.4	0.0	509	241	183	23	9
Noncombustible	Noncombustible	N/A	6.4	30.5	397	196	144	16	8
Noncombustible	Noncombustible	N/A	6.4	61.0	236	146	111	7	6
Noncombustible	Noncombustible	Vertical	12.7	0.0	523	409	294	29	22
Noncombustible	Noncombustible	Horizontal	12.7	0.0	542	399	318	34	17
Noncombustible	Noncombustible	N/A	25.4	0.0	332	189	164	19	9
Noncombustible	Noncombustible	N/A	25.4	30.5	288	190	167	17	7
Noncombustible	Noncombustible	N/A	25.4	61.0	254	158	138	11	7
Noncombustible	Noncombustible	N/A	12.7	0.0	574	382	302	41	25
Noncombustible	Noncombustible	N/A	12.7	61.0	316	221	187	12	9
Noncombustible	Noncombustible	N/A	12.7	30.5	463	270	208	23	12

Reference Critical Flux for Ignition (minimum radiant energy to ignite a material):
Paper ~ 10 kW/m^2 FR PVC ~ 35 kW/m^2 PTFE ~ 50 kW/m^2

- **Increasing setback distance diminishes temperature and heat flux**
- **Gap distance affects air flow and therefore cooling and fire spread**

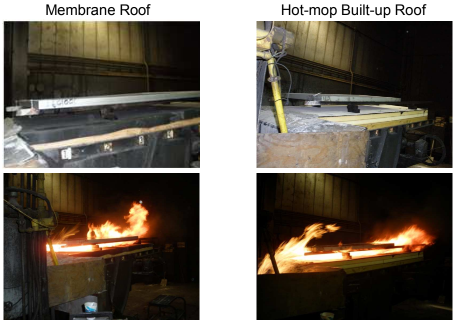
Spread of Flame: Class A Shingle Roof w/ Class C PV – 0 Set Back, 12.7 cm Gap

Spread of Flame
5:12 Sloped Roof

Wood Shake Roof | Architectural Shingle Roof

Spread of Flame
Low Sloped Roof

Membrane Roof | Hot-mop Built-up Roof



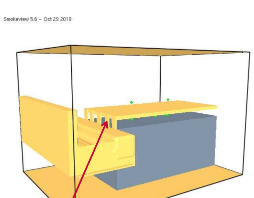
Spread of Flame Results
Different Class Rated PV & Roofs

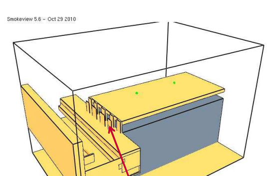
Roof Type - rating	PV Rating	Gap (cm)	Setback (cm)	Flame Spread (ft)	Time (mm:ss)
3 tab shingle - A	A	12.7	0	> 8	4:17
Noncombustible	C	12.7	0	> 8	2:03
Wood shake - C	C	12.7	0	> 8	0:47
Membrane - A	A	12.7	0	> 8	1:00
Architectural shingle - A	C	12.7	0	> 8	1:57
Hot Mopped - A	C	12.7	0	> 8	1:43

UL 790 flame spread ratings (from leading edge of the sample):
- Class A: 6 ft (1.82 m)
- Class B: 8 ft (2.4 m)
- Class C: 13 ft (3.9 m)

Mitigation Concepts

- FDS: Fire Dynamics Simulator v5 developed by NIST for fire modeling
- 12.5 cm gap between module and roof (both non-combustible)
- No incline



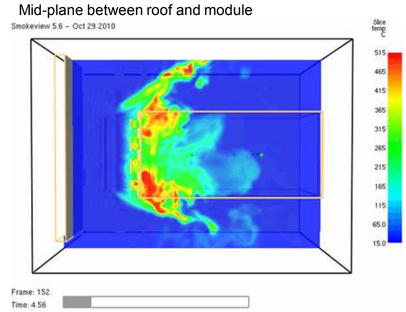


Single Screen | Staggered Screens

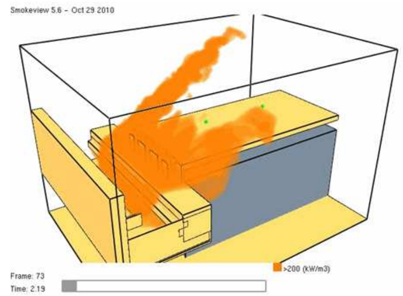
Each opening and spacing about 10 cm

Gas Temperature Contours

Mid-plane between roof and module



Flame Visualization



Summary

- Rack mounted PV module on a roof has an adverse effect on the roof Spread of Flame fire performance
- Extent of fire performance degradation depends upon setback and gap distances
- The same air flow conditions that cool panels also promotes fire propagation
- FDS modeling of a staggered screen appears to provide significant heat blocking versus single screen
- PV panels at an angle to a flat roof also degrade roof fire rating

Photovoltaics and Fire Fighter Safety (DHS Assistance to Firefighters Grant)

Focused on firefighter concerns of:

- Shock hazard from direct contact with energized components during firefighting operations
- Shock hazard from water and PV power during suppression activities
- Potential shock hazard from damaged PV modules and systems
- PV power during low ambient light, artificial light and light from a fire
- Emergency disconnect and disruption techniques
- Severing of conductors

Photo courtesy of College Park MD Fire Department

PV and Fire Fighter Safety

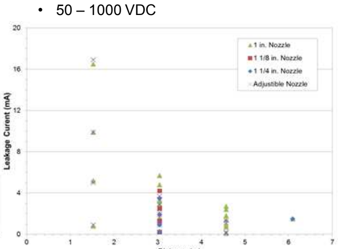
Pre-fire
20 panels = 480 VDC, 12 A

Post fire
No power: 5 panels
Partial power: 3 panels
Full power: 12 panels

Current (mA)	Hazard
Leakage	Safe
2	Perception
40	Lock On
240	Electrocution

PV and Fire Fighter Safety
Suppression Shock Hazard Potential

- 2 nozzles: smooth bore and adjustable
- 3 – 60 PSI (21 – 414 kPa)
- 50 – 1000 VDC



PV and Fire Fighter Safety
Power Generation, Fireground Illumination Highlights

Experiments using ground lighting towers indicate that artificial light at night (e.g. ground scene lighting) can cause a typical rooftop PV array to generate current at hazardous levels.

1000 Volt Array with Night-Time Illumination from Fire Truck(s) Lighting

Truck #1 Bed 12 kW Boom 6 kW	Truck #2 Bed 6 kW Boom 4.5 kW	Total Lighting kW	Distance from Array (Feet)	Volts	MilliAmps	Hazard
		None		48	0	Safe
Bed + Boom		18	25	812	132	Lock On
	Bed + Boom	10.5	38	780	88	Lock On
	Boom	4.5	38	738	50	Lock On
Bed + Boom	Bed + Boom	28.5	25 & 38	836	212	Lock On
Partial Bed		3	25	657	22	Perception
Partial Bed		1.5	25	575	11	Perception
Bed + Boom		18	50	735	37	Perception
	Bed + Boom	10.5	75	700	22	Perception
Bed + Boom	Bed + Boom	28.5	50 & 75	773	49	Lock On
Partial Bed		1.5	50	340	1.5	Safe

PV and Fire Fighter Safety
Power Generation, Fire Illumination Highlights

A stack of burning wood skids illuminating a PV module resulted in high hazardous power levels at various distances from the fire.

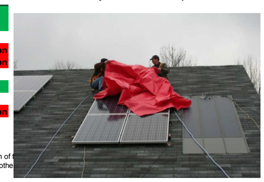
Light from a Fire (Single Module)

Distance from Fire (Feet)	Open Circuit Volts	Short Circuit MilliAmps	Hazard
75	30	52	Lock On
50	31	57	Lock On
40	32	59	Lock On
15	33	62	Lock On
Full Sun	37	7500	

PV and Fire Fighter Safety
Depowering by Shielding Highlights

The effectiveness of commercially available salvage tarps and generic plastic sheet tarps ranged from minimal impact on voltage output to null as compared to a baseline measurement.

Photo above courtesy of San Jose Fire Department..

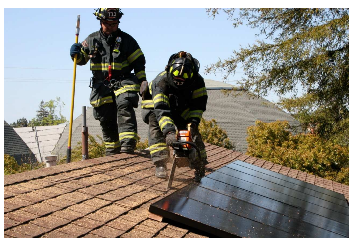


Use of Various Tarps to Block Illumination

Tarp	Color	Layers	Open Circuit Volts	Short Circuit Amps	Hazard
4.0 mil sheet	Black	1	33	0	Safe
4.0 mil sheet	Black	2	0.5	0	Safe
5.1 mil tarp	Dark Blue	1	126	2.1	Electrocution
5.1 mil tarp	Dark Blue	2	121	1	Electrocution
Salvage Canvas	Dark Gray	1	3.2	0	Safe
Salvage Vinyl	Red	1	124	1.8	Electrocution
Full Sun			148	8.1	

PV and Fire Fighter Safety
Severing of conductors

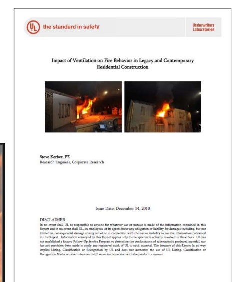
- Cable cutter, rotary saw, chain saw, axe
- Various wiring systems and wiring cables
- Different voltages



PV and Fire Fighter Safety
Dissemination

http://www.ul.com/fireservice

- Formal Report
- Web Based Outreach



the standard in safety

Impact of Ventilation on Fire Behavior in Legacy and Contemporary Residential Construction

THANK YOU!

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http://www.ul.com/fireservice

Qualitative Aspect of the Fires Fueled by the Combustibles Arriving in the Vicinity of the Tsunami Refuge Buildings

Tomoaki NISHINO

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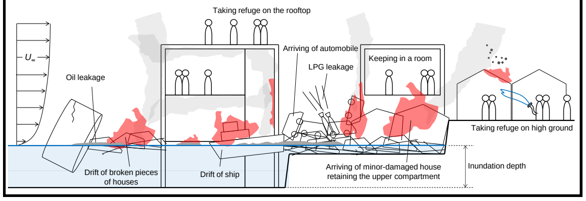
Outline of tsunami-fire

- Tsunami-fire scenario
  - Some kind of heat sources lead to ignitions of combustibles washed away by tsunami.
  - Certain fires repeat ignition drifting in the flooded area.
  - Certain fires develop into conflagrations in the easy places for combustibles to densely arrive.



A formidable problem caused by tsunami-fire

- Fire spread to tsunami refuge building
  - Escaping from tsunami refuge building is difficult because of the surrounding seawater and debris.
  - Fire fighting and rescue from outside are not expected immediately.
  - When smoke or fire flows into the building, the evacuees are likely to be put themselves in danger.

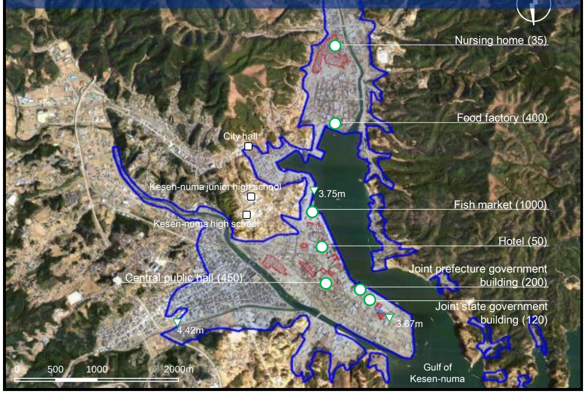

People on the rooftop of tsunami refuge building


Fires drifting nearby tsunami refuge building

Planning for fire spread controlling

- One basic question
  - How much degree we should expect as the heating strength to the tsunami refuge building due to the tsunami-fire? (What fire conditions are potential in the vicinity of the tsunami refuge building?)
- Contents of this presentation
  - I present a part of the fires in the vicinity of the tsunami refuge buildings in Kesen-numa area based on the image records and the eyewitness testimonies.
  - I arrange the idea of the fire types expected in the vicinity of the tsunami refuge building qualitatively.

Tsunami refuge buildings in Kesen-numa area

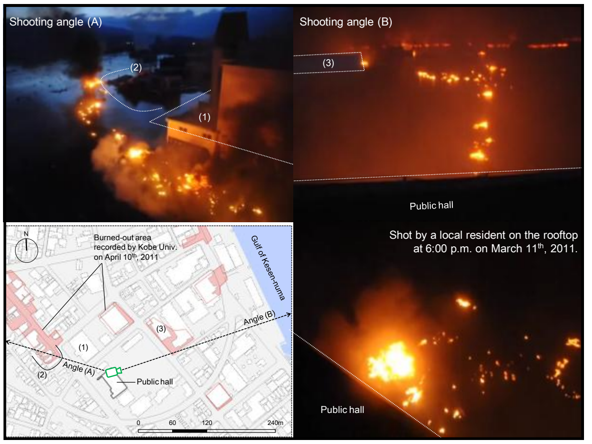


List of tsunami refuge buildings

ID	District	Usage	Floor number	Flooded floor number	No. of evacuees	Fire sighting	Fire catching	Analysis target
A	Asahi	Government building	5	2	120	○	×	×
B	Asahi	Government building	5	—	200	—	×	×
C	Uoichiba-mae	Fish market	3	2	1000	○	×	×
D	Shiomi	Public hall	2	1	450	○	×	○
E	Hama	Food factory	4	—	400	○	×	×
F	Benten	Hotel	6	2	50	○	×	○
G	Nakami-nato	Nursing home	3	2	35	○	○	○

Outline of tsunami refuge building (D)

Usage (construction type)	Public hall (RC)
Floor number (inundated)	2 (1)
Number of evacuees	450
Fire sighting	○
Fire catching	×

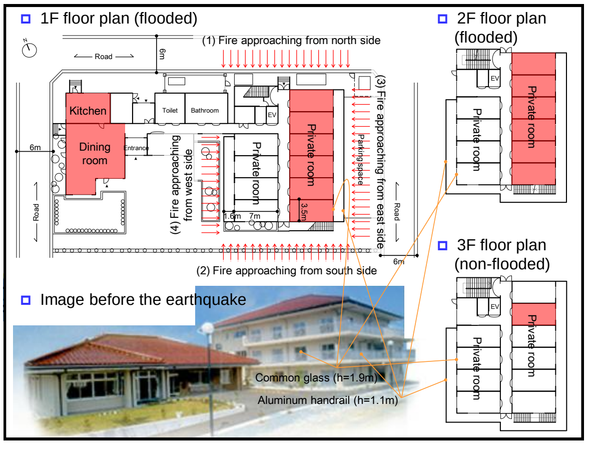



Outline of tsunami refuge building (F)

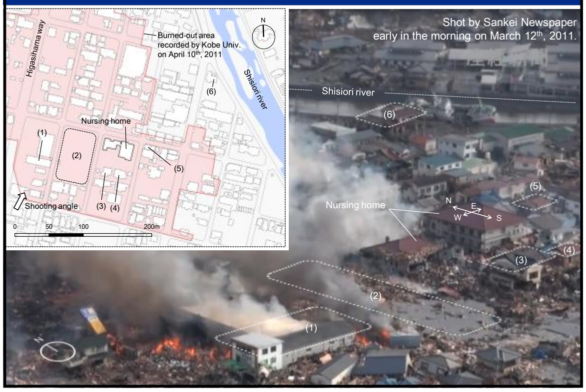
Usage (construction type)	Hotel (RC)
Floor number (inundated)	6 (2)
Number of evacuees	50
Fire sighting	○
Fire catching	×

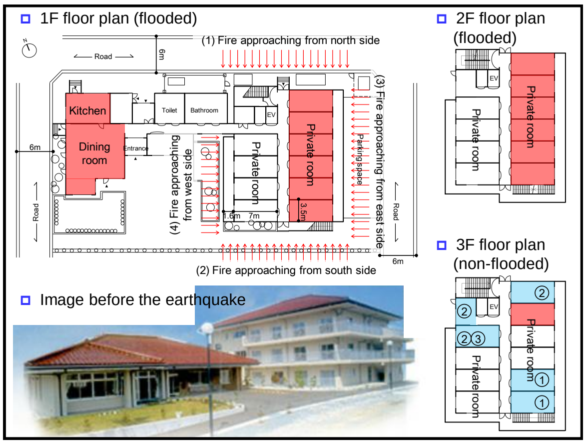

Outline of tsunami refuge building (G)

Usage (construction type)	Nursing home (RC)
Floor number (inundated)	3 (2)
No. of evacuees (attributes)	35 (over age 60 requiring no care)
Fire sighting	○
Fire catching	○ (15 rooms burned-out)

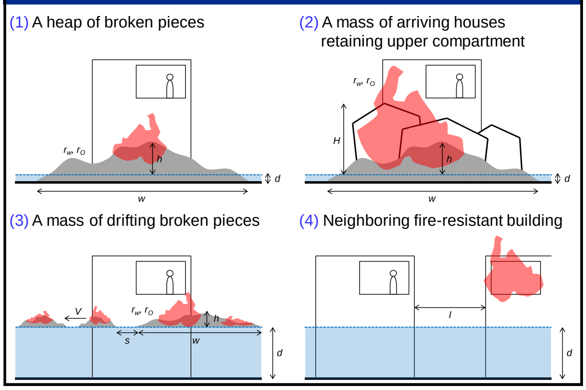



Combustible condition before fire approaching





Expected fire types (combustible condition types)



Conclusions

- Contents of this presentation
  - I presented a part of the fires in the vicinity of the tsunami refuge buildings in Kesen-numa area based on the image records and the eyewitness testimonies.
  - I obtained several fire types related to combustible conditions expected around the tsunami refuge building.
- Future issues
  - Fire experiments to estimate the burning behavior of the obtained fire types quantitatively
  - Building design enabling keeping in rooms and on the rooftop enclosed by fires (a method to evaluate the design effectiveness)

Thank you for your attention.

Statistical Modeling of Post-earthquake Ignitions

Rachel Davidson (University of Delaware)

Operation TOMODACHI: Fire Research, JAFSE and NIST Workshop
Tokyo, Japan
July 2012

Post-earthquake ignitions

Reducing ignitions is key to estimating and reducing post-earthquake fire losses.

Need to understand and better predict:
- Number of ignitions
- Geographic distribution
- Timing

Kobe earthquake

Kessenuma conflagrations (Photo Asia Air Survey)

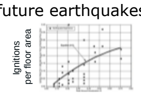
Previous work on post-eq ignitions

Accomplishments

Collected historical ignition data

Identified main ignition causes

Developed early models to estimate number of ignitions in future earthquakes



Limitations

Missing info of data collection
- Which ignitions considered?
- Which areas included (zeros?)

Large unit of study (e.g., city)

Only 1 covariate considered

Few details on
- How models were fit
- Resulting goodness-of-fit

Used least squares. Don't recognize counts as discrete.

Objectives

- Improve post-eq ignition data collection
- Improve statistical modeling to estimate number and geographic distribution of post-eq ignitions

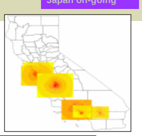
Applications

2 Present day Japan

1 Present day California

Data collection overview

- GIS database
- Unit of analysis: 1990 census tracts
- 48 variable values for each tract



Variables (num. variables)	Source(s)
Ignitions (1)	Reconnaissance reports
Ground shaking (4)	USGS Shakemap archives
Building damage (6)	HAZUS-MH MR2 output
Building area by structural type (14)	HAZUS-MH MR2 default
Building area by occupancy type (7)	HAZUS-MH MR2 default
Building age (2)	Census
Heating fuel type (5)	Census
Land area (1)	Census
Land cover type (6)	National Land Cover Data
Population (2)	Census

Data collection: Ignitions

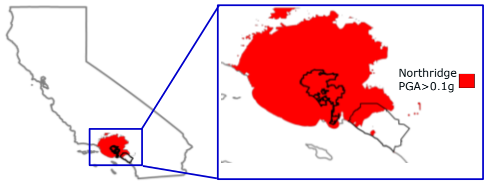
Includes ignitions that:
- Became structural fires
- Required fire department help to extinguish
- Occurred within 10 days of earthquake
- Were identified as earthquake-related
- Initial ignitions (not ignited by other buildings)

Geocoded each ignition

Earthquake	Ignitions
Coalinga (1983)	3
Morgan Hill (1984)	6
N. Palm Springs (1986)	1
Whittier Narrows (1987)	20
Loma Prieta (1989)	36
Northridge (1994)	82
Total	**148**

Data collection: Missing ignition data

2 assumptions to account for missing ignition data



Dataset A

- Includes only tracts with PGA>0 in regions with ignition data
- Likely underestimates zeros
- 3213 obs.

Dataset B

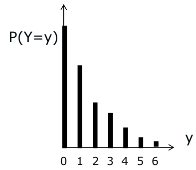
- Tracts with PGA>0 not in regions w/ignition data have zero ignitions
- Likely overestimates zeros
- 7920 obs.

Modeling Poisson Regression 1

- Want to estimate num. of ignitions in a tract *i*, Y_i
- OLS regression assumptions do not hold (e.g., Y_i~Normal)
- Since ignitions are discrete counts (0, 1, 2, …), and possible ignitions in a tract occur independently, assume

$$Y_i|x_i \sim \text{Poisson}(\mu_i)$$

$$f(y_i|\vec{x}_i) = \frac{e^{-\mu_i}\mu_i^{y_i}}{y_i!}$$



Modeling Poisson Regression 2

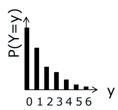
Y_i = Num. of ignitions in a tract *i*

$Y_i|x_i \sim \text{Poisson}(\mu_i)$

- In Poisson regression, estimate, μ_i, with log-linear model

$$\ln(\mu_i) = \beta_0 + \beta_1 x_{i1} + \dots + \beta_n x_n$$

- Assumes: μ_i can be computed exactly
  Counts in each cell actually have Poisson distrib.
  $E[Y_i] = Var[Y_i] = \mu_i$
- In reality, data are often overdispersed



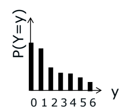
Modeling Negative Binomial Regression

- Instead assume $Y_i|x_i, \alpha \sim NB(\mu_i, \alpha)$ $\quad f(y_i|\vec{x}_i,\alpha) = \frac{\Gamma(y_i+\alpha)}{\Gamma(y_i+1)\Gamma(\alpha^{-1})}\left(\frac{\alpha^{-1}}{\alpha^{-1}+\mu}\right)^{\alpha^{-1}}\left(\frac{\mu}{\alpha^{-1}+\mu}\right)^{y_i}$

  where $\ln(\mu_i) = \beta_{i0} + \beta_{i1}x_{i1} + \dots + \beta_{in}x_{in}$
  $E[Y_i] = \mu_i$
  $Var[Y_i] = \mu_i + \alpha\mu_i^2 \qquad \alpha \geq 0$
- NB is equivalent to Poisson regression that includes Gamma-distributed error

$$\ln(\tilde{\mu}_i) = \beta_{i0} + \beta_{i1}x_{i1} + \dots + \beta_{in}x_{in} + \varepsilon_i$$

- Error ε_i describes:
  1. Effect of omitted explanatory variables
  2. Error in measurement of Y_i



- Extra variability beyond Poisson described by parameter α

Modeling: Poisson Generalized Linear Mixed Model

Instead assume $Y_i|x_i \sim \text{Poisson}(\mu_i)$

where $\ln(\mu_i) = \beta_{i0} + \beta_{i1}x_{i1} + \dots + \beta_{in}x_{in} + u_k$

$u_k \sim N(0, \sigma_u)$

u_k are iid earthquake-specific variability

(like random intercepts, one per eq)

Comparison of Model Types

Poisson regression	Simplest but often data are overdispersed
NB regression	Higher variance due to α 1 parameter to capture extra-Poisson variability
Poisson GLMM	Higher variance due to u_k for each EQ *k* *k* parameters to capture extra-Poisson variability Predicted counts overestimate a lot

Model selection

1. pseudo-R^2_{dev}
2. pseudo-R^2_{α}
3. NB overdispersion parameter α
4. Likelihood ratio tests
5. AIC
6. Avg predicted vs observed counts
7. Residual diagnostics

Recommended models

2 negative binomial models, 1 per dataset

	Dataset A	Dataset B
Instrumental intensity	√	√
% land area that is commercial, industrial, or transportation	√	√
% building area that is unreinforced masonry	√	√
People per sq. km	√	√
Total building area	√	
Area of high-intensity residential development		√
Median year built over all housing units		√

Goodness-of-fit

- R^2_{dev} (0.31, 0.34) → most variability in counts not captured
- R^2_{α} (0.86, 0.89) → most extra-Poisson variability is captured
- Most randomness in ignition counts due to inherent Poisson randomness (cannot be reduced), not uncertainty in means (can be reduced with better data/models)

Observed vs. predicted ignitions

Model	Number of ignitions: Total	0	1	2	3	4	5	6	7
Observed	148	3,086 or 7,793	110	14	2	1	0	0	0
A.P2.noeq	148	3,080	121	11	1.4	0.2	0	0	0
A.P5.eq	148	3,082	118	11	1.8	0.4	0.1	0	0
A.NB2.noeq	150	3,087	109	13	2.9	0.8	0.3	0.1	0.1
A.NB5.eq	150	3,087	109	13.0	2.8	0.9	0.3	0.1	0.1
A.MM3	356	2,931	229	39	9.6	3	1	0.4	0.1
B.P4.noeq	148	7,782	130	7.7	0.8	0.1	0	0	0
B.P6.eq	148	7,784	126	8.6	1.2	0.2	0	0	0
B.NB2.noeq	148	7,793	112	12	2.4	0.7	0.3	0.1	0.1
B.NB6.eq	150	7,793	110	12	2.8	1	0.4	0.2	0.1
B.MM3	347	7,632	245	32	7.1	2.2	0.8	0.3	0.1

Earthquake effect

Earthquake covariate is significant, possibly because:

- Missing characteristics of specific eqs or regions they affected
- How ignition data were collected

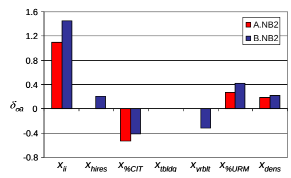
Dataset A (use only areas where ignitions collected) — Predicts more ignitions for eqs likely to be missing more zero ignition count observations

Dataset B (assume zero counts where not collected) — Predicts fewer ignitions for eqs likely to be missing more nonzero ignition count observations

Comprehensive data collection is important

Relative importance of covariates

Change covariate value x_a by 1 st.dev.
→ expected num. ignitions in tract i changes by $(100\delta_{\sigma a})$%



- *ground motion intensity, building area, pop. density* increase ignitions
- *% com/in/trans* decreases ignitions
- *%URM* could indicate building types or damage

- *Instrumental intensity* is most influential
- Then *% land that's commercial/industrial/trans.*

Applying the models for prediction

1. Estimate $\hat{\mu}_i$ for each census tract i using:

$$\ln(\hat{\mu}_i) = \hat{\beta}_{i0} + \hat{\beta}_{i1}x_{i1} + \ldots + \hat{\beta}_{in}x_{in}$$

2. Simulate many realizations of y_i, number of ignitions in tract i, using NB distribution with $\hat{\mu}_i$ and $\hat{\alpha}$:

$$f(y_i \mid \mu_i, \alpha) = \frac{\Gamma(y_i + \alpha^{-1})}{\Gamma(y_i + 1)\Gamma(\alpha^{-1})}\left(\frac{\alpha^{-1}}{\alpha^{-1} + \mu_i}\right)^{\alpha^{-1}}\left(\frac{\mu_i}{\alpha^{-1} + \mu_i}\right)^{y_i}, \quad \alpha \geq 0,\ y = 0, 1, 2, \ldots$$

Result: For a given EQ, a map showing number of ignitions in each census tract (mean with confidence interval)

Implemented in our Urban Fire Simulation model

Modeling for Japan

with Professor Charles Scawthorn and Sizheng Li

Opportunity

- ≈300 ignitions in Tōhoku EQ (vs. 148 in 6 Calif. EQs)
- 50/50 tsunami-generated vs shaking-generated

Objectives

Repeat data collection and model fitting for Japan

- More data → better models! (training/validation split)
- Resolve zero ignition problem
- Examine tsunami-generated ignitions
- Compare to California

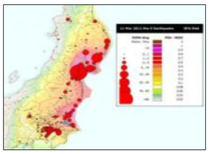
Japan data needs

Seeking ignition data

- With ignitions consistently defined
- With specific location (not num. per prefecture)
- For all regions with nonzero ground motion or inundation

And if possible

- Covariate data
- Ignition timing



Distribution of fires overlaid on PGA (SPA Risk)

Final remarks

Conclusions from California study

Data collection

- Ignition definitions
- Data collection region
- Unit of study

Modeling approach

- Treatment of discrete counts
- Many covariates
- Higher geographic resolution
- Better estimation of zero counts
- Prediction model implemented in Urban Fire Simulation model

On-going work in Japan

Acknowledgements

MCEER EARTHQUAKE ENGINEERING TO EXTREME EVENTS

(*California project*)

National Science Foundation
WHERE DISCOVERIES BEGIN

(*Japan RAPID project*)

For more information

- Davidson, R. 2009. Modeling Post-earthquake fire ignitions using generalized linear (mixed) models. *Journal of Infrastructure Systems* 15(4), 351-360.
- Davidson, R. 2008. *Generalized Linear (Mixed) Models of Post-earthquake Ignitions*. MCEER technical report, MCEER-09-0004, Buffalo, NY.

東京理科大学

Introduction of

Center for Fire Science and Technology, Tokyo University of Science

Yoshifumi Ohmiya, Dr.

Professor

Tokyo University of Science

Presentation outline

1. *Tokyo University of Science(TUS)*
   1. *History*
   2. *Organization*
2. *Center for Fire Science and Technology (CFST) ,TUS*
   1. *Achievement*
   2. *COE Program*
3. *Fire Research and Test Laboratory*
   1. *Facilities and Devices*
   2. *Experimental Research*

Tokyo University of Science

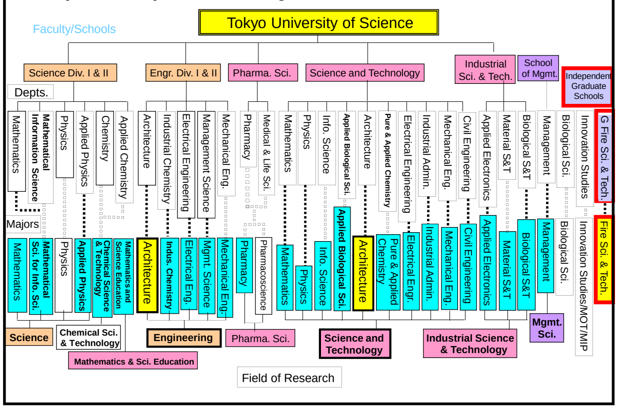
Tokyo University of Science (TUS)

:Established in 1881.

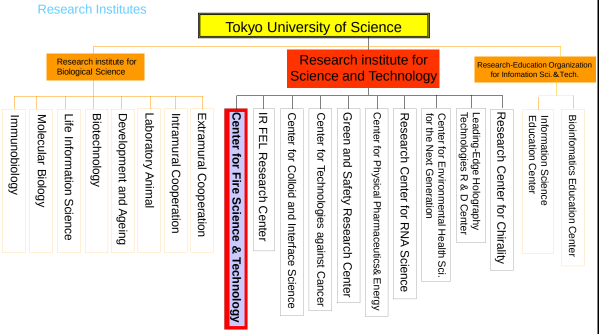
:Japan's first private educational institution in natural sciences

:The Most prestigious science-oriented university in Japan.

Tokyo University of Science – Organization Chart



Tokyo University of Science – Organization Chart



TUS's COE Program

- Center of Excellence(COE) Program supported by Japan's Government
  - *To cultivate a competitive academic environment among Japanese universities by giving targeted support to the creation of world-standard research and education bases*
- 21st Century COE Program (FY2003-2008)
  - "Center for Advanced Fire Safety Science and Technology for Buildings"
  - "Fire Research and Test Laboratory" was built in 2005.

TUS's COE Program

- Global COE Program (FY2008-2013)
  - "Center for Education and Research on Advanced Fire Safety Science and Technology in East Asia"
  - New Graduate School was established in 2010.
    - Graduate School of Global Fire Science and Technology
      - First in Japan, focused on "Fire Science and Technology"

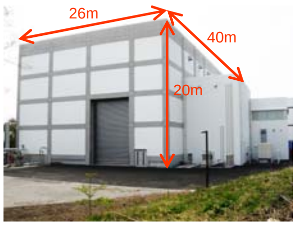
Faculty Listing
Graduate School of Global Fire Science and Technology, TUS

Name		Research Interests
M. Tsujimoto	Dean Professor	Smoke Movement, Reliability Engineering, Laws and Regulations
K. Ikeda	Professor	Building Fire Resistance Performance
M. Morita	Professor	CFD, Simulation, Suppression System
A. Sekizawa	Professor	Fire Risk Analysis, Evacuation Behavior, Urban Disaster Prevention, Firefighting and Disaster Prevention
S. Sugahara	Professor	Building Material Science, Theory of Safety and Security
Y. Ohmiya	Professor	Building Fire Safety Design, Evacuation Behavior, Smoke Control, Fire Spread
K. Kobayashi	Professor	Building Standards Law, Fire Defense Law
K. Matsuyama	Assoc. Professor	Fire/Combustion Engineering, Fluid Dynamics, Fire Suppression, Measurement Methodology
M. Mizuno	Lecturer	Evacuation Safety, Evacuation Simulation

Fire Research and Test Laboratory, CFST, TUS

Fire Research and Test Laboratory
Center for Fire Science and Technology(CFSaT)

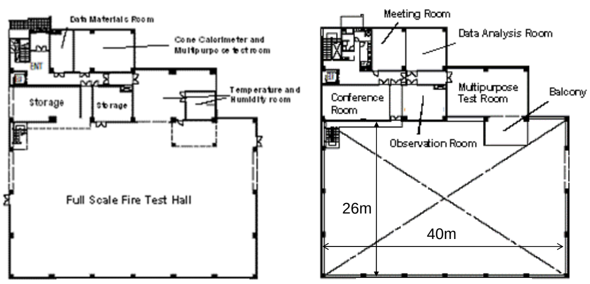
Fire Research and Test Laboratory, CFST, TUS



(East side)

Main entrance (North side)

Fire Research and Test Laboratory, CFST, TUS



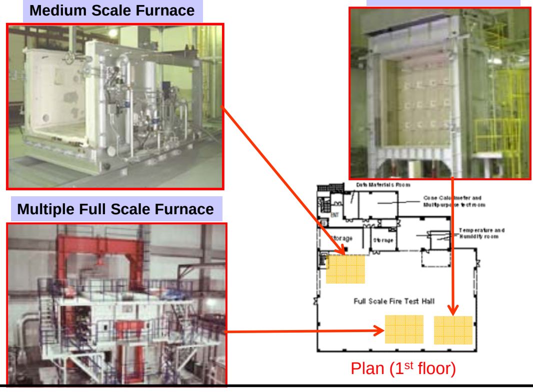
Plan (1st Floor) **Plan (2nd Floor)**

Facilities and Devices

Medium Scale Furnace

Full Scale Furnace for Wall

Multiple Full Scale Furnace



Plan (1st floor)

Facilities and Devices

Fire resistance performance of partition wall after an Earthquake

Steel Construction Building

Facilities and Devices

Fire resistance performance of partition wall after an Earthquake

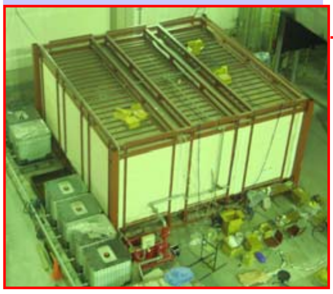

(5min)


(15min)


(40min)

Facilities and Devices

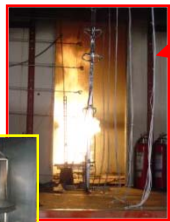
Full-Scale Compartment for Fire Experiment (with Water Pump)



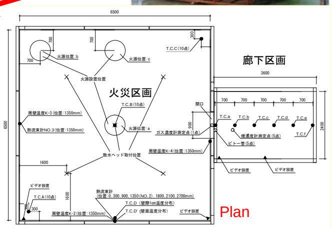
Plan (1st floor)

Facilities and Devices

Advanced Fire Safety Design Method considering effect of SP system



Fire source



Plan

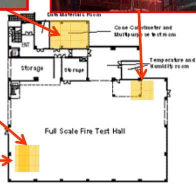
Facilities and Devices

Hood (5 m × 5 m)

Cone Calorimeter Testing Device

Room Corner Testing Unit

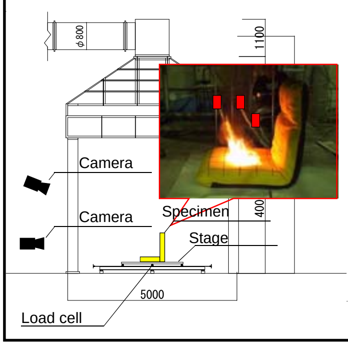
Heat Radiation Panel



Plan (1st floor)

Facilities and Devices

- Residential Fires



・Ignition point: Center of seat

Measurement
:Heat release rate
:Mass burning rate
:Temperature distribution
:Heat flux

Thank you for your attention.

Introduction of Building Research Institute

Dep. of Fire Engineering

Ichiro HAGIWARA

Brief History of BRI

- Dec. 1942 Founded as a Building Research Section
- Jul. 1948 Renamed as the Building Research Institute, Ministry of Construction.
- Apr. 1980 Moved to Tsukuba Science City from Tokyo.
- Apr. 2001 Independent Administrative Institution Building Research Institute make a start.
  At the same time, NILIM established.
  Original BRI was divided two, NILIM and New BRI.
- Present - BRI is still same status,
  not National Research Institute.
  It means that a large part of budget come from the government, but become independent and self-control/management.

Organization

- Chief Executive
  - Deputy Chief Executive
  - Executive Director for Building Research
    Research Coordinator of Building Technology
  - •Department of General Affairs
  - •Department of Research Planning and Management
  - (7 Research groups)
    1. Department of Structural Engineering
    2. Department of Environmental Engineering
    3. Department of Fire Engineering
    4. Department of Building Materials and Components
    5. Department of Production Engineering
    6. Department of Housing and Urban Planning
    7. International Institute of Seismology and Earthquake Engineering

Staff

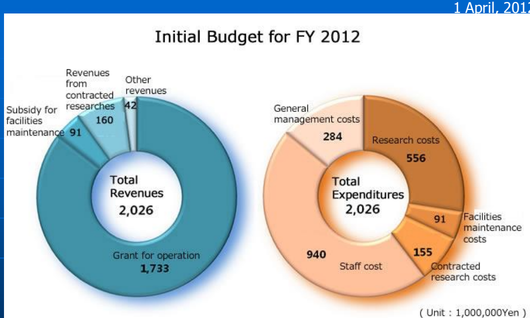
1 April, 2012

Staff :	**88**
Full time staff :	**85 (57 researchers, 31 non-researchers)**
Full time officer :	**3 (incl. 1 part-time)**

Dept. of Fire Eng 6 +1 Guest Researcher
+1 Visiting Researcher

(Ref.) 6 for fire research in NILIM

1 April, 2012



Fire Research Projects: 36 M Yen = 0.45 M USD

Ref. 1,000,000 Yen = 12 ,500 dollars

Outline of the 3rd Interim plan

- Research and Development are more concentrated for quickly achieving clear results which meet social and user needs.
- 10 Priority Research Projects are selected.
  75% of total research budget are reserved for them.
- They are classified 4 categories.
  - Sustainable development / Green innovation
  - Ensure safety and security in building and city
  - Reconstruction/redevelopment corresponding to social changes (Aged society)
  - International contribution by building and city planning technology (for developing countries)

Dept. of Fire Engineering R&D Strategy

- Fire safety design methods and engineering tools
- Advanced methods for estimating and preventing damage by fires during/after earthquakes
- Provide technical standards, test methods, references, guides and other documents for the BSL and related regulations.

For promoting fire safety design with engineering tools

Current Research Projects

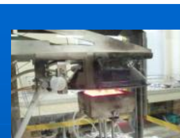
1. Wooden large / mid-rise buildings
2. Fire safety of existing non-conformed buildings
3. Evaluation test methods on interior and exterior finishing system using combustible material
4. Fire resistance of fire compartment members under loading condition

Most projects linked for revising the Building Standard Law of Japan in near future (201x)

Test Facilities

- **Full-scale Fire Test Laboratory**
- **Fire Research and Test Laboratory**
- **Fire Wind-tunnel**
- **Model Fire Experimental Field**

Fire Research and Test Laboratory Material



Cone Calorimeter

ICAL

SBI

Fire Research and Test Laboratory Structural Elements

Column Furnace

Wall Furnace

Floor Furnace

Full Scale Fire Test Laboratory

Fire Test Hall

Large Calorimeter

Measuring HRR of a Vehicle

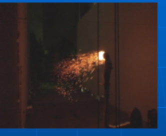
Smoke Movement in a Corridor

Evaluating fire propagation along combustible exterior facade walls

Flash-over Experiment

Fire Wind-tunnel

NIST Dragon



Firebrands falling on the bare board by assuming that tiles are removed by a big earthquake cause ignition

Firebrands coming through the gaps cause ignition penetrating the OSB board

Thank you for your attention !

Laboratory Tour

Group A: US side +

Group B: Japanese side

National Research Institute of Fire and Disaster

Fire and Disaster Management Agency, Government of Japan

Kaoru Wakatsuki, Ph.D.

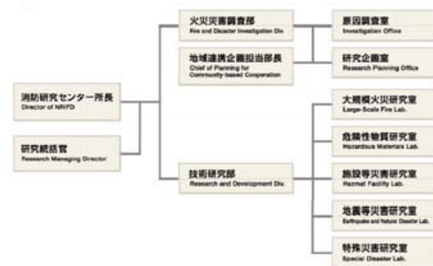
HISTORY of NRIFD

- NRIFD was inaugurated in 1948 with the aim of protecting people and their properties from disasters.
- As of April 1st, 2001, it moved to be an independent executive agency.
- As of April 1st, 2006, it became a part of the Fire and Disaster Management Agency

Mission

1. Continuous implementation of research and development into fire and disaster prevention based on the long-term vision.
2. The implementation of and support for investigations into the causes of fires and accidents involving the leakage of hazardous materials.
3. Professional support for fire-fighting activities in the event of large-scale or extraordinary disasters.
4. Establishing and maintaining cooperation with people related to science and technology in the field of fire fighting.

Organization Chart



Staffs (excluding general affairs Sec.)

Permanent Staff : 26
Seconded Staff* : 13
Part-time : 18

** experienced officers seconded from local fire departments*

Budget

'10FY : TOTAL 5.2 M$ (418M¥)
'11FY : TOTAL 4.9 M$ (388M¥)
Research expenditure 2.6 M$ (207M¥)
Administrative cost* 2.0 M$ (158M¥)
**This dose not include permanent staff costs.*
** Currency Rate 80 (JPY/USD)*

Research Facility in Mitaka Campus

Large Fire Experiment Building

Fire Extinguishing Research Building

Furniture Calorimeter

Oxygen Controlled Cone Calorimeter

Flash Fire Test Manikin

Steel-made Explosion Proof Vessel

Fire Investigation Mobile

Laboratory Tour

- Two groups (US delegates and JP delegates) will be formed.

  US delegates ---- Prof. Yamada and Dr. Hirokawa

  JP delegates ---- Mr. Tamura and Mr. Ogawa

	Japanese delegatio ←	→	US delegation
	引率田村・尾川		Yamada + Hirokawa
	↓		↓
15:20	Large fire testing site	15:20	Large fire testing site
	↓		↓
15:35	Earthquake-simulation vehicle (Dem at the fire extinguishing research site	15:35	Material strength research laboratory Nishi
	↓		↓
16:10	Thermal mannequin laboratory (Dem Wakatsuki	15:50	Thermal mannequin laboratory (Demo Wakatsuki
	↓		↓
16:30	Material strength research laboratory Nishi	16:10	Earthquake-simulation vehicle (Demo at the fire extinguishing research site
	↓		↓
	→ →	→	
			↓
		16:45	Ground floor, main building

Special Feature

- Tokyo Fire Department kindly offers their earthquake simulator vehicle.
- Those who study earthquake and fire will be subjected to drill.

Presentations Delivered by University of Michigan, CALPOLY, UL, NIST, and WPI During Optional Laboratory tour to TUS

Building Materials, Life Safety, & Security Industries

Raw Materials > > Products > > Systems > > Structures

Reaction to Fire

Building Contents
- Mattresses
- Fabrics
- Floor Coverings
- Upholstered Furniture
- Components

Building Products

Roofing
- Roofing Systems
- Roof Covering Materials

Surface Flammability
- Surface Burning
- Exterior Components

Fire Resistance
- Swing/Specialty Doors
- Hardware / Frames
- Dampers
- Wire & Cable
- Firestops & Joints
- Record Protection
- Fire Resistive Construction - Marine

Fire Suppression
- Sprinklers
- Extinguishers
- Extinguishing Systems
- Fire Main Equipment
- Foam
- Pipe & Fittings
- Pumps & Engines
- Valves

Fire Equipment Services

Inspection & testing
- Aerial devices / pumpers at plants
- In-service inspection of same at fire departments

PPE / PFD
- Garment & Component
- Glove, Boot, Helmet, Face Protection
- HazMat
- Life Safety Equipment
- Marine Rescue Equipment / Life Jackets

Fire Alarm Control & Communication Equipment
- Fire Alarm Control Panel
- Smoke Control Equipment
- Fire Suppression Equipment
- Emergency Communication Systems
- Fireman's Telephones
- Hand-held Microphones
- Audio Speakers

Initiating & Indicating Devices
- Suppression Systems Water flow devices
- Smoke Alarms / Detectors
- Heat/Flame Detectors
- CO/Gas Detectors
- Fire Horns
- Fire Strobes

Security Equipment
- Physical & Electronic
- Safes / Vaults
- Bullet-resistant Materials
- Locks / Bank Equipment
- Jaws of Life
- PASS Safety Devices
- Biometric Devices
- Access Control Systems
- Security Alarm Panels
- Microwave/PIR Sensors
- Balanced Magnetic Switches

Certificate Services
- Burglar/Fire Alarm Monitoring
- National Security System Monitoring
- Industrial Security System Monitoring

US Government
- CBRNE Detection
- Hazmat Detection
- TSWG Security Program
- NEMA-UL Partnership
- DHS Standards Development
- Secure Borders Initiative

Approximately 2,000 CCNs

National Institute of Standards and Technology (NIST)

To promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.

NIST's work enables
- Advancing manufacturing and services
- Helping ensure fair trade
- Improving public safety and security
- Improving quality of life

NIST works with
- Industry
- Academia
- Other agencies
- Government agencies
- Measurement laboratories
- Standards organizations

The NIST Laboratories

FPE at WPI

- Formal degree Program since 1979, multidisciplinary approach of fire science
- MS - 30 Credits (thesis/no thesis), PhD - 90 Credits, BS/MS (two degrees in 5 years), Corporate and Professional Education
- ADLN since 1993: Students across the US and 40 countries, 40% of enrollment
- Research on: Fire and materials, combustion and explosion protection, Firefighter safety and policy, policy and risk, bulding fire safety systems and wildland fires
- Sponsored research: NSF, NIST, DHS, NASA, USDA-FS, SFPE…
- New facilities for teaching and research in October 2012

www.wpi.edu/academics/fpe?