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PROGRESS REPORT ON FIRES FOLLOWING THE NORTHRIDGE EARTHQUAKE

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1. INTRODUCTION

Fires following earthquakes can add substantially to the community wide destruction initiated by strong earthquakes and the associated after shocks. The loss of life and property caused by fire occurs in a different time frame than the structural and property damage caused directly by the earthquake. While most of the loss caused by shaking occurs during the time of ground movement, there is usually no fire loss during that time. Fire loss directly attributable to the earthquake begins immediately following the earthquake and can continue for days afterward. The destruction potential associated with post-earthquake fires is strongly dependent on the damages to the community lifeline systems and to the weather conditions, especially the wind speed.

The January 17, 1994, Northridge earthquake resulted in fires which challenged the resources of the fire service due to the number of fires, disruption of the water supply, and damage to fire protection systems within buildings [1]. The Los Angles City Fire Department responds to over 900 fire, medical, and other emergences on a typical day. This number increased to over 2200 on the day of the earthquake and remain at twice the normal level in the following days. The majority of the estimated 30 to 50 significant post-earthquake fires were located in the San Fernando Valley and were confined to the building of fire origin either by separation or by fire department action. Fortunately there was no loss of life from fire. A principal cause of the fires involved natural gas leaks. A small number of fires were caused by hazardous chemical interactions. A small number of wildland fires occurred that were attributed to earthquake related causes, most likely arcing in overhead power lines. Since the wind was light and the vegetation was not excessively dry, these fires were easily extinguished.

Fires in most of the buildings were confined to the building of fire origin due to a combination of factors including light winds, building construction, building separation, and the actions of the fire department. Experience and predictions of the impact of fire following earthquake indicate that at wind speeds above 9 m/s (20 mi/hr) the fire spread and associated loss increase dramatically [2].

Building-to-building fire spread was limited to three manufactured housing developments (mobile home parks). Figure 1 shows the typical spacing between units in one of these developments. Figure 2 shows an area of the development destroyed by fire. The Building and Fire Research Laboratory staff investigated these areas in detail during the week following the earthquake. Particular attention was paid to areas where the building to building spread of fire was prevented.

Observations made at one of the manufactured housing developments after the fires indicates the method of unit-to-unit fire spread was primarily through windows. Once a unit became completely involved in fire, the thermal radiation was sufficient to cause either the breakage of windows in an adjacent unit or ignite combustibles within the unit directly through window openings. The fire department reported low water pressure in the area, which combined with multiple independent fires and limited resources hindered fire fighting operations. The fire spread was stopped either by separation such as roads and open areas or by fire department operations.

A unique aspect of the construction of these manufactured units played a role in limiting the spread and assisting fire department actions. As the units burned from the inside, the carport roofs collapsed from the building side, coming to rest on the outside supporting columns. In this way the carport roofs formed fire breaks as shown in figure 3. Although these roofs would not necessarily have survived the fire by themselves, they reduced the fire exposure on adjacent units and thus enhanced the resistance to community wide fire spread.

This investigation showed the importance of flame spread between building based on ignition of interiors through windows. Research was initiated at BFRL to quantify the effectiveness of different window systems and selected resident self-help strategies in resisting penetration of fire into building interiors through glazed and protected window openings. Preliminary results from this study are presented below.

2. FIRE RESISTANCE MEASUREMENTS OF WINDOW GLAZING SYSTEMS

In theory, fire penetration of a structure could occur as a result of radiant transmission through the window glazing, but glazing materials of practical interest are virtually opaque in the infrared wavelengths associated with natural fires, so this mode of fire penetration is not believed to be significant. Alternatively, the incident heat flux from an external fire can heat the glazing, causing thermally-induced stresses in the glazing, particularly at the frame where the glazing is shielded from the incident heat flux. When these stresses exceed the strength of the glazing material, the material breaks, typically with bifurcating cracks propagating from the shielded edge of the glazing material. Breaking of the window glazing material is suspected to be one of the principal failure mechanism associated with post-earthquake fire spread between residential structures.

An experimental study has been conducted to evaluate the performance of window glazing systems and potential protective treatments under simulated exterior fire exposure conditions. In these experiments, different glazing systems and treatments have been exposed to various uniform heat fluxes from electric and gas-fire radiant panels. Both small- and large-scale experiments have been conducted. In the small-scale experiments, 23 cm wide by 33 cm high glazing materials were installed in wooden frames and exposed to a gas-fire radiant panel. In the large-scale experiments, commercially available double hung windows, nominally 60 cm wide by 90 cm high, were installed in a 1.2 m wide by 2.4 m tall wood frame wall and subjected to the heat flux from a large-scale electrically powered radiant panel. Both single-pane and double-pane window assemblies have been tested in wood, vinyl clad wood and vinyl frames.

Several potential protective treatments also have been evaluated. These treatments have included: the use of insect screens and aluminum foil on the exposed side (outside) of the windows, the use of aluminum foil and a vinyl solar film on the inside of the windows, the use of double-pane windows, and the use of special glazing materials, such as high temperature glass, in place of ordinary plate glass.

Results of the study are still being analyzed, but some preliminary observations can be made. Figure 4 shows that for heat fluxes below about 0.5 W/cm^2, single pane glazing remains intact indefinitely. Insect screens placed between the heat source and the glazing seem to increase the imposed heat load (product of the imposed heat flux and the time to breakage) required for failure by nominally about 25-30%. Such an increase is consistent with the shading factor provided by insect screens. A vinyl solar film bubbled and smoked when heated; it did not seem to offer any benefit. Aluminum foil applied to the unexposed side (inside) of the glazing also did not offer any benefit. If anything, this treatment causes earlier failure of the glass due to reflection of heat transmitted through the glass back into the glass.

Perhaps the most promising treatment for self-help by building owners and occupants is the application of aluminum foil on the outside (exposed) of a window. Glazing systems with this treatment survived indefinitely under test conditions, indicated by data points on the abscissa of the graph in figure 4. Even with the introduction of a hole in the center of the aluminum foil covering to simulate a tear, this treatment provides approximately a three- to four-fold increase in the failure time when compared to exposed glass. Other treatments that offer some benefit, albeit at greater cost, include the use of alternative glazing materials, such as high temperature glass, or glazing systems with multiple pane assemblies.

One assembly that performed particularly poorly was the vinyl-framed window. Upon heating, this window assembly lost its strength and drooped, permitting openings through the window to develop even while the glazing itself remained intact.

As a final note, in most of the experiments where the glass broke, it remained in place after breaking.

3. 1995 POST-EARTHQUAKE FIRE AND LIFELINES WORKSHOP

In addition to the on-site investigation, a post-earthquake fire and lifeline workshop was held by the Building and Fire Research Laboratory, National Institute of Standards and Technology on January 30-31, 1995, in Long Beach, California [3]. The objective of the workshop was to assess technology development and research needs and make recommendations that could reduce the number and severity of future post-earthquake fires. The workshop brought together leaders in the fire service; fire protection engineering; codes and standards; insurance; transportation; and water, gas, power distribution, and telecommunication utilities with experience in dealing with consequences of earthquakes. The workshop participants developed a list of priority project areas where further research, technology development, or information collection and dissemination would serve as a vital step in reducing the losses from future post-earthquake fires.

The research and development needs generated by the participants are separated into two broad categories; ignition and fire spread, and fire control. Under the category of ignition and fire spread all the research needs related to either the direct source of ignition or the first fuel ignited, as well as factors that contribute to fire spread. The category of fire control includes research needs related to systems and personnel whose functions include the control and extinguishment of fires. The following summarizes the findings of the panels by topic areas.

Ignition and Fire Spread

Although investigations are conducted following most major earthquakes, there remains a lack of knowledge concerning the causes of fires and how fires spread from building to building. A process for collecting and a clearinghouse for storing post-earthquake fire incident data need to be established. Further, a methodology should be developed specifically designed to evaluate the impact of actions intended to reduce the number of fires and control their spread. In order to reduce the potential for a post-earthquake conflagration, the potential pathways for building-to-building fire spread need to be identified and practical measures to control the spread need to be developed.

Failures in power and gas distribution systems have been identified as factors contributing to the initiation of fires following past earthquakes. The technical feasibility of seismically operated shutoffs and control mechanisms should be assessed along with a cost/benefit analysis for the use of these systems. Further, guidelines for their installation and use of these devices should be developed. As a part of this analysis the susceptibility of gas leaks to ignition should be examined.

The movement of manufactured housing units during past earthquakes has caused damage to utility lines which resulted in fires. The types of support and anchoring which have successfully maintained these manufactured housing units during previous earthquakes should be examined and guidelines for new and retrofit installations developed.

Fire Control

Adequate and reliable water supplies are required for both manual firefighting and automatic fire sprinkler systems. Disruptions to the primary municipal water supplies have been common in past earthquakes. Seismic design standards for water supply systems should be evaluated as well as techniques for the rapid assessment and restoration of damage to systems. Further, guidelines for coordination between fire departments and water agencies need to be developed. Since municipal water supplies are often disrupted, alternative water supply sources and distribution systems should be considered. Experience gained in using rural water supplies may be beneficial.

Water based fire protection systems such as automatic sprinklers are an important feature in the fire protection design for many buildings. A database of water based system performance during past earthquakes should be established to assist in identifying causes of past failures. The adequacy of design, installation, and maintenance practices should be evaluated and recommendations for new and retrofit systems be developed. Guidelines also are required to assess the condition of systems following an earthquake to determine if they have retained their design effectiveness.

Passive fire protection systems such as fire resistant assemblies may be damaged during an earthquake even though their condition may not be readily apparent. Guidelines for evaluating the condition of passive fire protection features need to be developed.

Lifeline systems play an important role in controlling fires and handling emergencies following an earthquake. The guidelines for the installation and retrofit of lifeline systems should be reviewed and recommendations for codes and standards developed. In addition, guidelines and procedures for the rapid restoration of lifeline systems should be examined.

Emergency service personnel are unable to respond to all emergencies following a large earthquake; therefore, it is important that the public have adequate information and training to reduce the likelihood of fires starting and take actions to control their spread. Although public information material does exist, the material should be examined based on the experience gained in recent earthquakes. Citizen volunteer response teams are being trained in some areas and the experience gained should be made widely available.

Experience has shown that following earthquakes, there is frequently inadequate communication between lifeline providers and emergency service organizations. Guidelines for cooperation should be developed based on the successful plans that exist in some communities. Further, since industrial facilities have specialized requirements to handle large emergencies, methods to evaluate their resource requirements and mutual aid plans should be developed.

Water supplies may be limited following an earthquake and control of large spreading fires may be difficult. The new water additives intended to enhance the firefighting capabilities of water should be examined as a means to assist in the control of building-to-building fire spread with limited resources.

Models presently available to predict fire growth within buildings do not generally have the capability to predict fire spread between buildings. Methods to predict accurately the spread of fires between buildings damaged by earthquakes should be developed to assist in developing post-earthquake fire protection strategies.

4. FIRE AND LIFELINE STUDIES FUNDED BY NIST

In response to the workshop recommendations, NIST funded eleven research grants to address some of the major issues with regard to fire safety and lifelines. Most of these studies are still underway, with final reports due late in 1996 or early in 1997. Those that have issued final reports are indicated with the reference. The research grant projects and objectives are:

<u>Northridge Post-earthquake Monograph on Lifelines Performance</u>
<u>Objectives</u>: to conduct a follow-up lifeline investigation of the Northridge earthquake and publish a monograph of the observations and lessons learned. The monograph includes the information collected in the initial investigation conducted immediately following the earthquake [4].

<u>Protection of building envelope from external fire sources</u>
<u>Objectives</u>: to evaluate the fire exposure conditions that cause glass to fail, examine the protection afforded by strategies that could easily be retrofitted, and address the protection of soffit vents from external fire penetration in single family homes.

<u>Fire-related aspects of the Northridge earthquake</u>
<u>Objectives</u>: to investigate and fully document fires, fire spread and fire department operations, provide analysis of this data in support of future estimation of fires following earthquakes. Summarize lessons learned and insights resulting from this earthquake, in support of loss reduction practices and mitigation of potential conflagrations and large loss fires following earthquakes.

<u>Analysis of fire sprinkler system performance in the Northridge earthquake</u>
<u>Objectives</u>: to analyze the performance of fire sprinkler systems in the Northridge earthquake in relation to the specific earthquake protection measures employed in their design and installation and develop proposed changes to the national installation standard, NFPA 13, which should improve future system performance by bringing brace fasteners up to current levels of technology.

<u>Fire hazards and mitigation measures associated with seismic damage of water-heaters and related components</u>
<u>Objectives</u>: to assess damage of nonstructural elements in buildings which may lead to fire hazards; review current codes and provisions related to seismic design of water heaters and related components; develop, through analysis and experiments, mitigation measures which can be effective in minimizing their fire hazards; and recommend specific seismic code provisions and design guidelines for this class of nonstructural components.

<u>Evaluation of passive fire protection systems following earthquakes</u>
<u>Objectives</u>: to conduct a post-earthquake safety evaluation of the passive fire prevention features of buildings and add such evaluation to the ATC-20 document, "Procedures for Post-Earthquake Safety

Evaluation Of Buildings, which in its current form lacks procedures for fire protection system evaluation.

Reliability and restoration of water supply systems following earthquakes
Objectives: to assess post-earthquake system reliability, and make recommendations to enhance post-earthquake operability of domestic water supply and/or alternate water supply systems, and enable quick restoration of service following an earthquake.

Seismic risk assessment of liquid fuel systems
Objectives: to review and integrate available methods and procedures of seismic risk assessment and loss estimation, develop a framework for risk assessment that can logically accommodate the state-of the-art results of research and development effort on the physical and functional performance of the liquid fuel transmission systems subjected to earthquakes, identify and highlight the design issues that must reflect the risk concept in the process of the development of design guides, and develop and draft an outline of design guides.

Seismic performance of liquid fuel tanks
Objectives: to document and evaluate the performance of liquid fuel tanks during past major earthquakes, particularly the Northridge earthquake, assess their performance with respect to the current design and construction practices, and develop recommendations for improving their future performance.

The assessment and mitigation of earthquake hazard to electric power
Objectives: to develop 1) guides for selection, installation, and operation of emergency power, 2) guides for seismic evaluation and design of high voltage substation, and 3) fragility curves for substation equipment.

Method to evaluate building fire protection features following earthquakes
Objectives: to develop a methodology which can be used by fire inspectors to evaluate the condition of building fire protection features following earthquakes. The methodology shall address systems such as: automatic fire sprinklers; fire standpipes; dry chemical, liquid and gaseous fire suppression systems; fire pumps; fire alarms; fire detectors; automatic door closers; emergency egress lighting; and smoke control systems.

5. CONCLUSIONS

Investigations of post-earthquake fire events have suggested that flame penetration though broken windows is a significant means of fire spread in residential communities. Measurements have shown that covering windows with readily available aluminum foil can substantially increase the resistance of window glazing to breakage under simulated radiant exposures from external fires.

Research is underway to increase the understanding of the performance of fire safety systems and lifelines systems subjected to a strong earthquake and the aftermath. Results of this research will provide guidance to national consensus standards efforts and regulatory authorities.

6. REFERENCES

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4. Northridge Earthquake Lifeline Performance and Post-Earthquake Response, Technical Council for Lifeline Earthquake Engineering, Washington, DC, August, 1996.

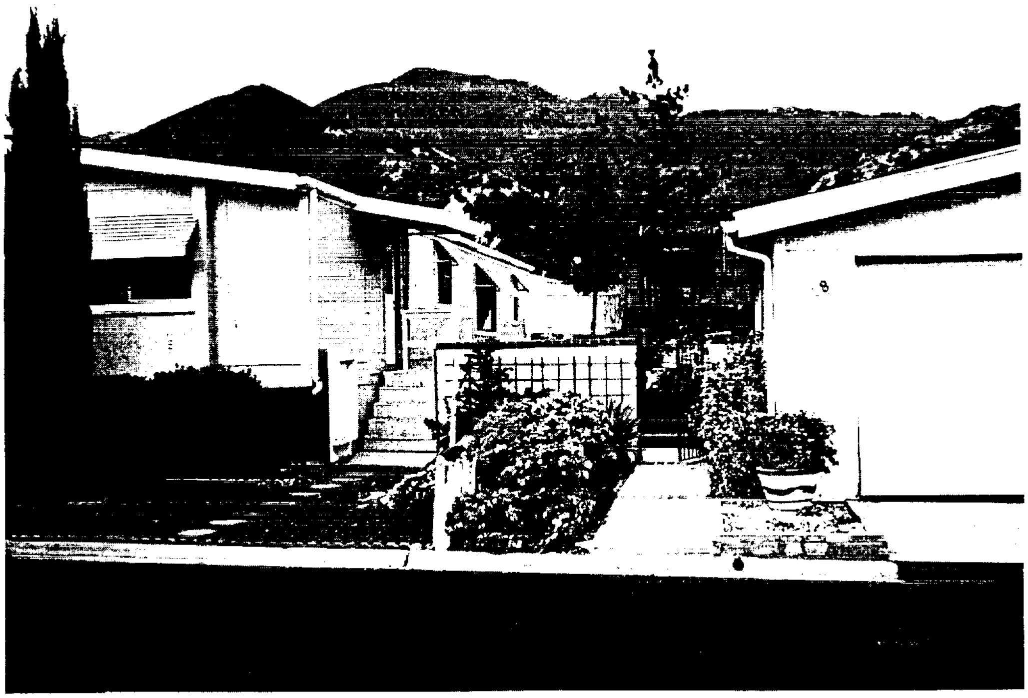

Figure 1. Typical unit spacing in a manufactured housing development.

Figure 2. Impact of a multiple unit fire in manufactured housing development.

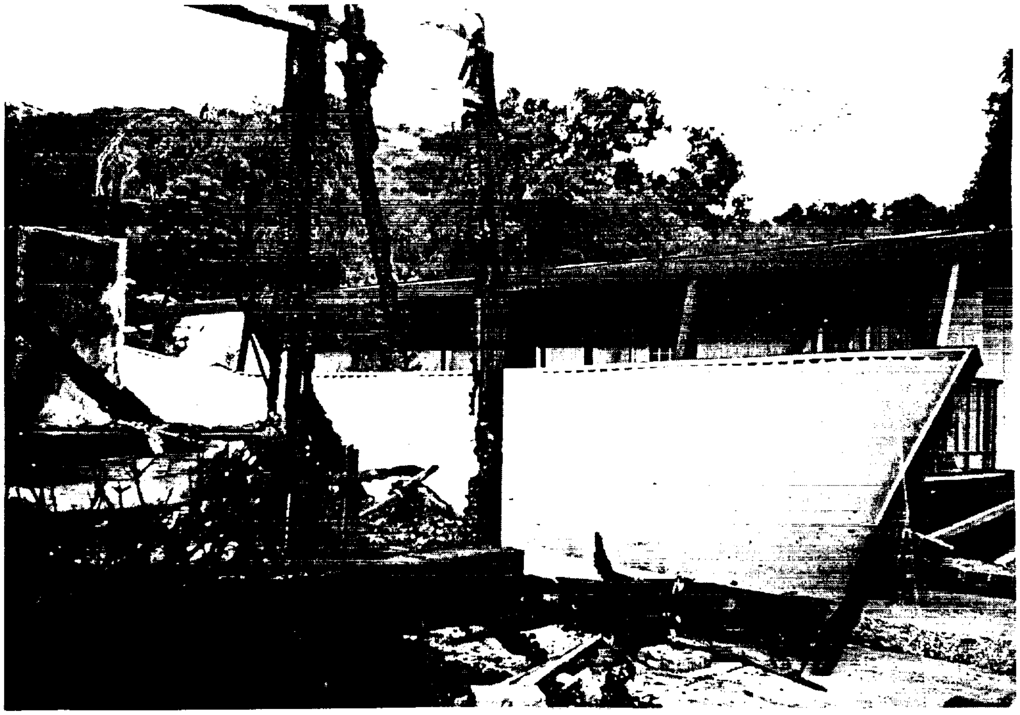

Figure 3. Collapsed roof which acted as a fire break in a manufactured housing development.

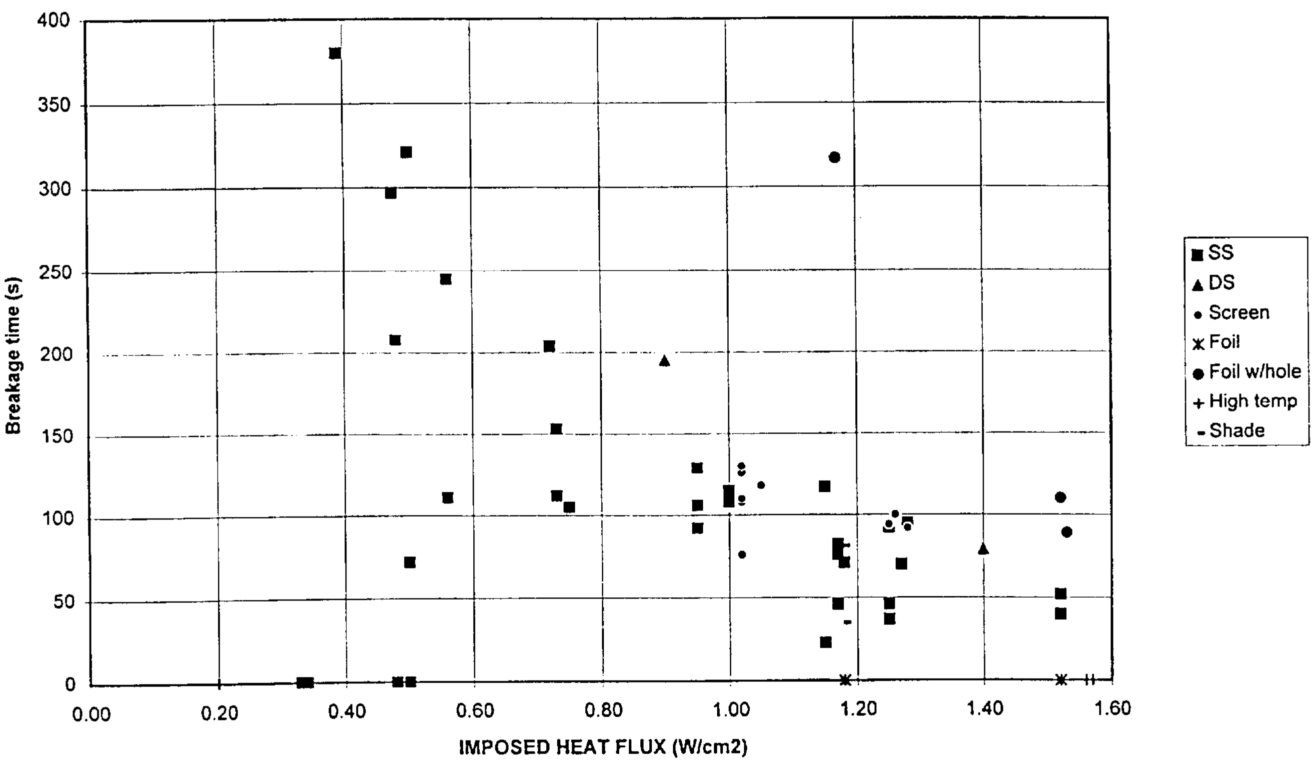

Figure 4. Data on resistance of glazing to breakage from an imposed heat flux.