BUILDING PERFORMANCE: HURRICANE INIKI IN HAWAII

OBSERVATIONS, RECOMMENDATIONS, AND TECHNICAL GUIDANCE

Learning from failure...

...building on success

Teaming To Reduce Future Damages

FEDERAL EMERGENCY MANAGEMENT AGENCY
FEDERAL INSURANCE ADMINISTRATION

IN COOPERATION WITH
THE STATE OF HAWAII OFFICE OF CIVIL DEFENSE
AND KAUAI COUNTY

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EXECUTIVE SUMMARY

On September 22, 1992, at the request of the Mayor of Kauai County, the Federal Coordinating Officer for the Iniki disaster tasked the Federal Emergency Management Agency's (FEMA's) Federal Insurance Administration (FIA) to assemble a team of experts to assess the performance of buildings. Since the 1970s, FIA has gained valuable experience through an ongoing assessment program that focuses on the performance of buildings that have incurred flood damage. In addition, FIA's National Flood Insurance Program establishes regulations for the reconstruction of substantially damaged buildings in floodplains, regardless of the cause of the damage.

For the Iniki disaster, the team assembled by FIA included FEMA Headquarters and Regional staff, representatives of the State of Hawaii Office of Civil Defense and Kauai County, and Registered Professional Engineers and Architects from both Kauai and Oahu (see Appendix A for complete list). The team was tasked with surveying the performance of primarily residential structures under wind and water forces generated during Hurricane Iniki. The goal of this effort is to provide guidance and offer recommendations for reducing damage from future hurricanes. This goal is best met through learning from both failures and successes of building performance.

During the field assessment, the team investigated primary structural systems, i.e., systems in a building that resist lateral and vertical forces. For all buildings, the performance of exterior architectural systems, such as roofing, windows, and doors was analyzed. The analysis also included the effects of windborne and waterborne debris and the quality of construction and materials. The majority of building types observed were one- and two-story, wood-frame, single-family and multi-family residential structures. However, pre-engineered steel commercial and industrial buildings, as well as resort hotels and condominiums constructed of reinforced concrete and masonry, were also examined.

WIND FORCES

Noteworthy examples of adequately engineered and constructed buildings were observed in Kauai County. Almost without exception, successful performance resulted from clearly defined and continuous "load transfer paths" from the roof to the foundation. A well-designed load transfer path depends primarily on the proper type, sizing, and attachment of connections between the critical components of a building (for example, between the roof and walls and between the walls and foundation). Where connections, such as hurricane clips and metal straps on wood-frame structures, were adequately sized and correctly applied, buildings performed relatively well.

Incomplete design and construction for load transfer and improper connections, especially between the roof and walls, were found to be the most important factors causing structural failure of buildings due to uplift wind forces. Consistently, a building's structural integrity was compromised through the action of uplift forces on insufficiently designed and connected roof and wall systems. Loss of roof cladding (e.g, shingles), roof sheathing (e.g., plywood), and other building attachments provided a source of airborne projectiles which contributed to the overall damage. In many instances, loss of glazing (e.g., glass doors and windows), either from direct wind pressure or from debris impact, resulted in a breach of the building envelope, subsequent internal pressures, and progressive structural failure.

Much of the damage to structures caused by wind forces resulted from incomplete design, reliance on outdated methods of workmanship, and/or misapplication of various building materials. Many of these problems can be addressed by training and education programs that promote prudent building design and construction practices throughout Kauai County. This is especially true for buildings in bluff and oceanfront areas exposed to accelerated wind forces.

FLOOD FORCES

In coastal floodplains and Coastal High Hazard Areas, the obvious primary cause of building failure was direct wave impact (hydrodynamic forces) on buildings whose lowest floors had been constructed directly on the ground surface. Low-lying, oceanfront buildings, situated somewhat landward of the shoreline and having lowest floors elevated above the flood hazard, fared much better than ground-level buildings immediately adjacent to the shoreline. Waterborne debris such as lava boulders and debris from damaged non-elevated buildings increased damage to adjacent buildings.

RECOMMENDATIONS

Recommendations presented in this report can be summarized as follows :

- Provide adequate means and methods to ensure the structural integrity of a building by constructing properly engineered buildings which consider the continuous load transfer path of a structure from roof to foundation. To ensure the integrity of the structure's load transfer path, metal fasteners ("hurricane clips") and straps must be adequately sized and properly installed.

- Design all architectural elements to resist the same wind forces as the primary structural systems.

- Construct and properly engineer buildings such that they protect, or contain adequately designed, glasswork in exposed areas; adhere to nailing and attachment requirements for roof sheathing, roof cladding, and windows and doors; and provide routine maintenance of building components, including repair and replacement of damaged elements.

- In areas subject to flooding, elevate buildings above predicted flood heights on properly designed and constructed foundations. Minimize the

sources of future debris by appropriately designing and locating site improvements such as stone walls.

- Provide a program of training and continuous education to code enforcement officials, plan reviewers, inspectors, supervisors, and others who are charged with implementing the recommendations noted above. Provide companion training and education programs for homeowners, building contractors, and design professionals in the proper construction techniques for mitigation of wind and flood hazards.

- Trade associations, labor associations, etc., should provide continuing education programs for updating their members concerning revisions to Building Codes under which they are performing their trades.

This report includes detailed engineering discussions of building failure modes and successful building performance. It also provides detailed recommendations for enhancing building performance under hurricane and flood conditions.