Wind-induced failures and structural modeling of large-volume buildings impacted by Hurricane Michael (2018)

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ABSTRACT: (10 pt)
This paper describes the forensic assessments and observed failure mechanisms to a collection of large-volume, low-rise buildings in Panama City, FL that failed during below-design conditions induced by Hurricane Michael (2018). The buildings represented multiple structural systems, including pre-engineered metal buildings, precast tilt-up concrete systems, and metal rack buildings, and represented a range of years of construction. Three case study buildings are studied in detail, informed by static and dynamic analysis of the structural systems through 3D, linear elastic finite element models developed from structural drawings and extensive reconnaissance data. The analysis demonstrates the critical importance of the longitudinal load path through the end bay of the windward wall in the observed collapse mechanisms.

Keywords: hurricane, industrial buildings, forensics, collapse

1. INTRODUCTION

The landfall of hurricanes producing design-level winds is a relatively uncommon occurrence in the United States, and so provides an important opportunity to evaluate structural performance at or near design limits. Hurricane Michael (2018) was one such event, making landfall on October 10, 2018 near Mexico Beach, FL with peak wind gusts estimated at just over 68 m/s (150 mph). This study specifically focuses on the performance of large-volume, low-rise buildings (LVLRB) during Hurricane Michael (2018), which is a class of buildings here loosely defined as buildings with heights less than 18 m (60 ft) above ground level, long-span structural systems, and large, mostly undivided interior volumes. Structural systems within LVLRB include pre-engineered metal building systems, precast concrete tilt-up systems, and steel braced frames.

Twenty-three buildings were assessed in total (all in locations experiencing below design-level wind speeds) using lidar, unmanned aerial systems, and high-resolution terrestrial photographs primarily using equipment from the NSF NHERI RAPID facility (Berman et al. 2020). Fifteen of the twenty-three buildings experienced partial or full collapse of the end bay, with the collapse typically propagating to successive interior bays. Damage mechanisms included buckled steel roof joists or roof purlins in the end and interior bays, removal of some steel roof decking, buckling of large rollup or panelized doors, and collapse of some columns and wall systems. Damage observed to the buildings was strongly directional in nature, with typically heavy damage on one side of the building but little to no evidence of damage on the opposite side. A few buildings suffered complete collapse. Three case study buildings are studied in detail from this dataset.

2. CASE STUDIES

The three case studies examined in more detail consist of (1) Watson's Marina, a 4000 m^2 footprint, steel rack marina building, (2) the Intermodal Distribution Center, a 14,000 m^2 footprint, tilt-up precast concrete building with steel joists and steel deck diaphragm, and (3) the Port of Panama City East Terminal, a 17,500 m^2 footprint, pre-engineered metal building. Failure mechanisms present in each are highlighted in Figure 1. 3D structural analysis models were generated for each building using the analysis software SAP2000, based on the reconnaissance data and structural drawings provided by the building owners. Nonlinear static and dynamic analyses were performed using ASCE 7 load cases and wind tunnel data from the NIST Aerodynamic Database (Ho et al. 2005). Wind loads were applied for both design conditions and best estimates of conditions during Hurricane Michael (peak wind speeds and directions adjusted for actual upwind terrain).

The analysis of these case studies suggests an end bay load path failure mechanism is at fault for many of the premature failures observed, but further exploration is needed. The study identified several possible contributing causes, including internal pressurization, failure of roof decking removing lateral support to framing members, and eccentricities in the lateral load path. The premature failures of these buildings, many of which served as critical facilities, warrants further investigation so that existing vulnerabilities can be identified and prevented in future designs.
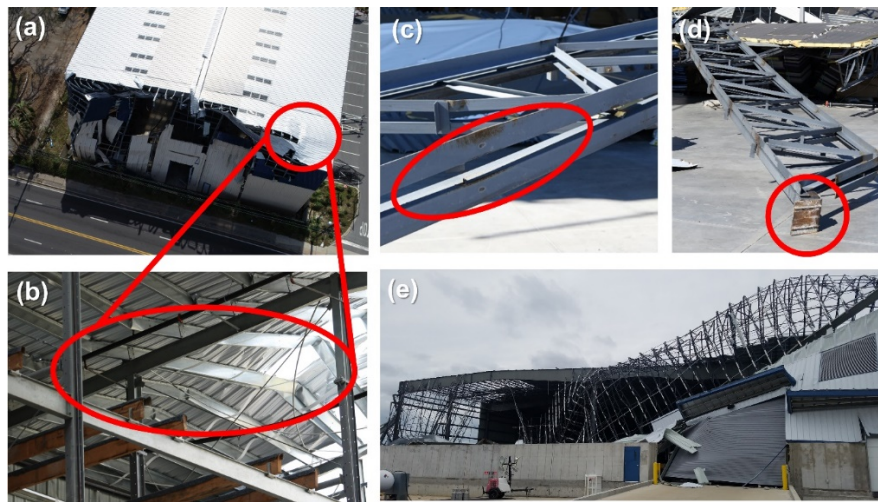
Figure 1. Specific failure mechanisms including (a), (b) purlin buckling in the end and interior bays of Watson's Marina, (c), (d) joist girder failures pullout and buckling in the Intermodal Distribution Center, and (e) end bay collapse of the Port of Panama City East Terminal.

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