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Wind performance and vulnerabilities of garage doors

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SUMMARY:
Garage doors frequently serve as a damage amplifier for residences and commercial structures subjected to high winds. The breach of garage doors during high winds can subject a structure to large internal pressures that can lead to failures of surrounding walls and roofs. This research included a series of full-scale tests on residential garage doors in simulated high-wind conditions in the full-scale wind tunnel at the Insurance Institute for Business & Home Safety (IBHS). The study examined the influence of garage door size and style and focused on the deformation of the garage doors as well as the resulting pressurization of the garage space and the net loading on the garage door. The study showed that leakage around garage doors can result in significant pressurization of the garage, even without damage or failure of the door. The study suggests that structural designers should consider treating the garage space as "partially enclosed" rather than "enclosed" when selecting internal wind pressure coefficients from ASCE 7.

Keywords: Wind Performance, Garage doors, Internal pressures.

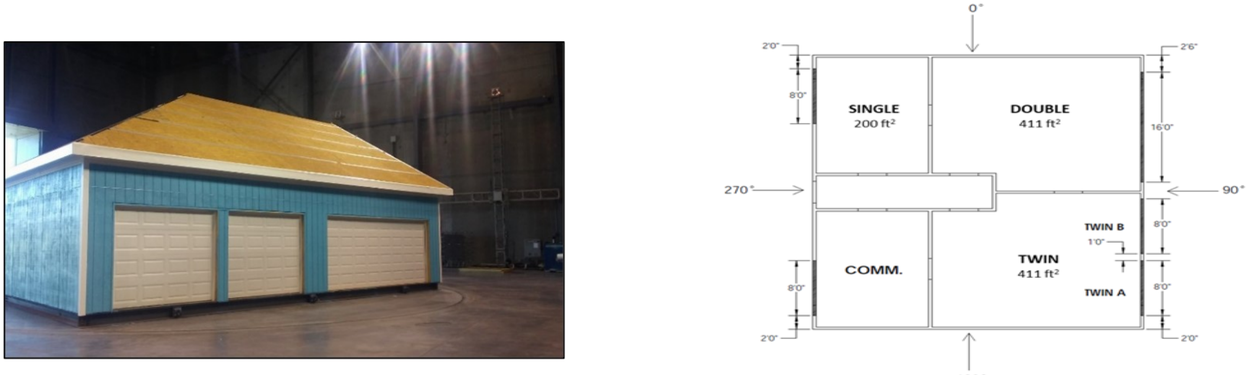
1. INTRODUCTION

Residential garage doors present a significant vulnerability to structural damage in high winds. Post-storm investigations (e.g., FEMA, 2020; Kovar et al., 2018; Morrison et al., 2014) have shown that garage doors are frequently damaged in tornadoes, hurricanes, derechos, and other high-wind events. The garage doors can be a "damage amplifier," for when they are damaged, additional structural damage can occur to the surrounding roof and walls due to internal pressurization. In cases where garage doors are breached, additional damages to nearby roofs and walls are often evident (Graettinger et al., 2014; Kovar et al., 2018; Morrison et al., 2014). Despite substantial efforts focused on weatherproofing garage doors, air still leaks air around their edges (e.g., Jaffe et al., 2019). Under increased wind pressures, garage doors can flex, allowing for even more air leakage. Post-storm investigations as well as prior full-scale wind chamber tests of commercial structures in the IBHS test chamber (Morrison and Reinhold, 2015) suggest that garage doors may experience sufficient deflection to permit over-pressurization of the garage cavity, contributing to the net loading and subsequent failure of surrounding wall and ceiling (roof) surfaces. An accurate understanding of their effect on internal pressures is therefore necessary for achieving safe and resilient structural designs. The objectives of the current investigation include measurement of leakage, deflection, net loading, and pressurization of the garage space experienced with different door sizes and ratings.

2. EXPERIMENTAL SETUP

The 30 ft x 40 ft (9.1 m x 12.2 m) garage door test house has a mean roof height of 16.2 ft (4.9 m) and a 7:12 roof pitch. As shown in Figure 1, the house consists of four separate garage cavities situated in the corners of the house. All garage doors are 7 ft (2.1 m) in height, and the width of the doors and volume of each discrete garage are provided in Figure 1b. The internal walls between garage cavities were finished as in typical residential construction. A fourth garage chamber was included in the test house for testing commercial roll-up doors for a future test campaign. Testing of the commercial doors is outside the scope of the current paper. Wind-rated doors with design pressures up to +20/–21 psf (+0.96/-1 KPa) were selected, corresponding to the range of wind-rated doors that could be used in the interior U.S. to help reduce windstorm vulnerabilities.

The wind test chamber of the IBHS Research Center was used to simulate hurricane wind gusts on the garage door test house. The flow field in the IBHS wind tunnel has undergone a detailed development and validation process; further details are provided by Morrison and Kopp (2018) and Standohar-Alfano et al. (2017). The test house was subjected to repeatable 15-minute stochastic wind-speed time histories. In total, five input time histories were employed with the following peak 3-sec gust wind speeds at mean roof height: [S1] 37 mph (17 m/s); [S2] 62 mph (28 m/s); [S3] 75 mph (33 m/s); [S4] 88 mph (39 m/s); [S5] 103 mph (46 m/s).



(a) Test house with twin-single and double doors on the "west side".

(b) Building floor plan.

Figure 1. Test house installed in IBHS test chamber and floor plan with principal wind directions

3. PRESSURIZATION OF GARAGE CAVITIES

In instances where garage doors are "open", broken, or missing (ASCE 7 "partially enclosed" condition), the resulting dominant opening in a stagnation region can cause high positive pressures in the garage volume, leading to high net pressures on surrounding walls and ceiling. Figure 2 shows the internal pressures in the double and single garage cavities measured with the doors open. This figure provides a direct comparison of the internal pressures at the lowest and highest wind speeds (S1 and S5 traces). The internal pressures are slightly larger for the single garage than for the double garage. This figure also gives a comparison of the theoretical maximum internal pressure coefficient GCpi = +0.8 for internal pressure taken in isolation, suggested by the ASCE 7 commentary (ASCE 7-98, 02, 05, 10, 16). These observations support the approximation of GCpi = +0.8 as a maximum internal pressure in general; the maximum measured values for the double garage are very similar to +0.8, while the maximum measured values for the single garage are slightly larger than +0.8.

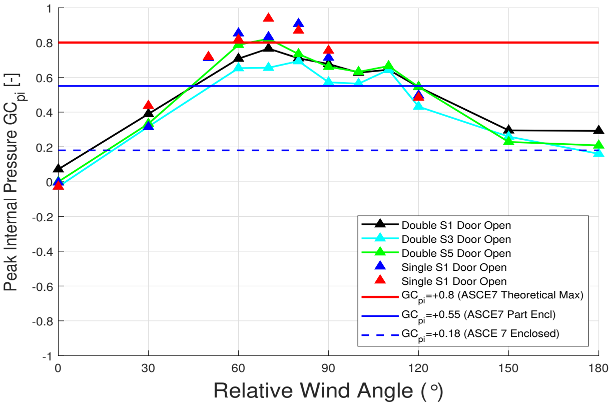


Figure 2. Peak maximum GC_{pi} in double and single garage cavities with doors open compared with ASCE 7 values.

3.1. Distributed leakage compared with external databases

In addition to the multiple configurations (different garage doors, wind speeds and wind angles), two cases- where the garage doors were covered by external walls to simulate the distributed leakage conditions, were investigated. In the first case, the internal doors separating the chambers were open and in the second case these doors were closed (see Figure 1b). Considering the internal pressures measured in the chamber of the double door, these increased to produce a maximum positive value for a wind angle of 45° (Figure 3) when the internal doors were closed. The internal pressures recorded in the double door chamber for these two cases were compared with those recorded in the NIST database (Ho et al., 2005, 2003; Oh et al., 2007). Inspecting the ASCE7 equivalent mean internal pressures (GC_{pi}) in model EE1 (80'x125'x16' with 1:12 gable roof pitch) with distributed leakage, these followed closely- in trend and value- the GC_{pi} values recorded in the double door chamber when the internal doors were closed. For the sake of comparison, the mean (ASCE7 equivalent) external pressures averaged over all the pressure taps in the model- $\sum_{i=1}^{n} GC_{pe}/n$- with n being the total number of pressure taps-was calculated. From Figure 3 it can be noted that the values of $\sum_{i=1}^{n} GC_{pe}/n$ for model EE1 fluctuate around those of the GC_{pi} of the open internal doors case in the 20°-100° range.

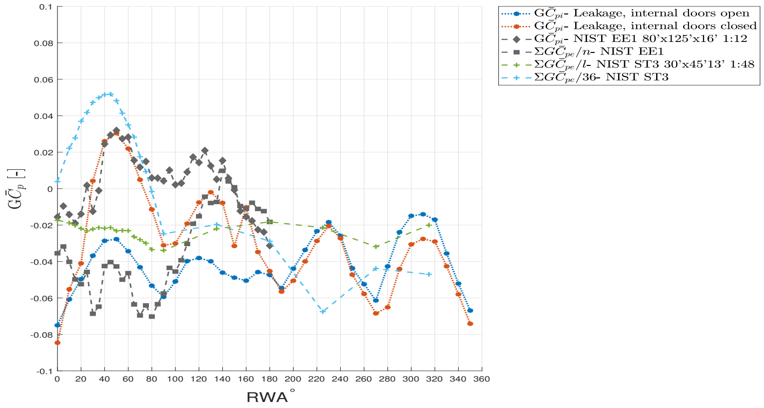


Figure 3. Internal pressures in double chamber compared with NIST database.

4. CONCLUSIONS

Based on the test data, it was found that the full-scale tests of residential garage doors of various wind ratings (strengths) show that normalized internal pressures (pressure coefficients GC_{pi}) are a function of both the wind speed and the door wind ratings. Additionally, pressure measurements show that positive internal pressures decrease as the wind rating of the garage doors increase and that the net pressures on garage doors increase as the wind rating (stiffness) increases. To guard against pressurization effects, it is recommended that walls, ceilings, and roofs in a garage should be designed using the "partially enclosed" internal pressure coefficients from ASCE 7. It can be hypothesized that this applies to other buildings such as commercial structures with large flexible doors. Internal pressures inside garages (and thus net pressures on the garage doors) are found to be sensitive to the size of the garage and door configuration (single/double/twin), especially for unrated doors. Among the unrated doors, the single doors experienced the highest net pressures. The full paper will describe these results in detail.

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