ARMA WIND UPLIFT LOAD MODEL FOR ASSESSING ASPHALT SHINGLE PERFORMANCE

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RESEARCH ESTABLISHES NEW WIND UPLIFT PERFORMANCE CONSIDERATIONS FOR ASPHALT SHINGLES

The Asphalt Roofing Manufacturers Association (ARMA) recently concluded a comprehensive research program examining the wind loading of asphalt shingles. This research pertains specifically to the behavior of in-place asphalt shingles under various wind loads. The multi-year program was carried out under the direction of Dr. J.E. Cermak and Dr. J.A. Peterka, professors at Colorado State University (CSU) and principals of Cermak Peterka Petersen, Inc. (CPP), leading researchers in the field of wind engineering.

ARMA's purpose was to establish a way to determine shingle uplift pressures under various wind conditions to provide shingle manufacturers with the methodology to evaluate and improve their products. The results are not only of interest to roofing manufacturers, contractors, code officials, insurance companies, roofing specifiers and other professionals in the residential roofing industry, but also to commercial and institutional building owners and homeowners.

The research is important because it provides the roofing industry with a scientific basis to determine a realistic measure of wind performance. Past and present test methods, as confirmed again by this research, inadequately reflect real-world conditions and so present an incomplete picture of the forces at work on shingles in high winds and the resultant performance. Also, current building codes and design standards do not completely address air-permeable roof coverings; that is, roof coverings like asphalt shingles that are installed in discrete pieces and consequently do not experience the full level of imposed uplift pressure.

This research indicates a need for improved design procedures for determining the uplift pressures on shingles and proposes a cost-effective test method to measure the uplift resistance. ARMA believes this will shed new light on this important subject for engineers, designers, contractors, code officials and manufacturers and can be used to strengthen existing standards, specifications and performance.

INDUSTRY TESTS, PAST AND PRESENT

During the early years of asphalt shingle use wind resistance depended upon interlocking shingle designs. In the late 1950s, thermally-activating shingle tab adhesives were introduced on asphalt strip shingles to improve their wind resistance. These self-seal shingles enhanced asphalt shingle product performance and expanded market acceptance.

Current standard test methods of the American Society for Testing and Materials (ASTM) and Underwriter's Laboratories (UL) for wind resistance of shingles subject a small test deck of shingles that have been sealed under heated conditions to a fan-induced air stream impinging at a continuous velocity of 26.8 m/s (60 mph), for a period of two hours (ASTM D 3161 and UL 997). Although these standard test methods have served a useful purpose in the past, it is generally accepted today that they are deficient in a number of respects. These deficiencies include: the test deck does not contain any protrusions or valleys, the shingles are sealed under "ideal" conditions, and turbulence of the impinging air stream is not taken into account. Realizing that the ASTM and UL tests inadequately predict failures at extremely high winds, some code authorities have increased the test wind speed to 110 mph. The conditions of the standard test methods and the fan-induced, non-turbulent air stream are still not representative of real-world conditions and can lead to inappropriate conclusions.

Most asphalt shingles on the market today meet the requirements of the ASTM and UL wind test standards. Asphalt shingles have also shown excellent wind performance when installed properly and sealed adequately, even in hurricanes. Testing for high wind resistance of shingles simply by increasing the wind speed of present test methods only serves to magnify the limitations of the existing test and will lead to confusing results and false expectations for the whole industry. The results of ARMA's research should provide more realistic and meaningful procedures.

WIND RESEARCH PROGRAM

The objective of ARMA's wind research program was to develop an appropriate method to calculate uplift forces due to the wind acting upon shingles installed on low-rise buildings and to develop a cost-effective test method to measure the shingle's resistance to the uplift pressure. The program included several elements, as described in the following paragraphs.

WIND STUDIES

Experiments were conducted on scale-model houses and on test decks, with full-size shingles, using the Meteorological Wind Tunnel (MWT) at Colorado State University. A diagram of this wind tunnel is presented in Figure 1. This wind tunnel was designed and operated to simulate real-world wind conditions, including turbulence and gustiness, but on a small scale.

In addition, CPP personnel constructed a one-story test building at a windy location in the Rocky Mountain foothills, north of Fort Collins, CO. The purpose of the test building was to validate the results of the extensive wind tunnel experiments with real-world data. Figure 2 is a photograph of the test building. A tower was also constructed with anemometers installed at various elevations to measure wind velocities. The shingles on the building were instrumented with velocity sensors and pressure transducers to measure the wind parameters on the roof. The building was built on a turntable so it could be rotated into the desired direction with respect to the wind. The experiments, including the data collection and the building rotation, were remotely controlled automatically by a computer.

SHINGLE TAB UPLIFT TEST

The outcome of the wind experiments is a load model (equation) that can be used to calculate the uplift pressure on a shingle tab for specified wind conditions. The model was validated by real-world field evaluations on an actual building.

Another aspect of ARMA's research program is to develop a cost-effective test method to measure the uplift resistance of a shingle tab after it had been sealed under specified conditions of time and temperature. The test method, which is currently under development within ASTM, utilizes a standard tensile testing machine and a special test apparatus designed to attach to a sealed shingle tab. A photograph of the test apparatus, installed in a tensile testing machine, is presented in Figure 3. The measured load can be compared to the calculated wind uplift pressure derived from the load model and matched to the test results to assess wind performance. Further, development work is underway to improve the level of the test method lab-to-lab reproducibility. Without increased reproducibility, similarly qualified labs will obtain significantly different results when testing specimens from the same sample of material.

The wind tunnel experiments showed that the wind pressure on a shingle is developed by the wind immediately above the shingle, as depicted in Figure 4. The wind is deflected up over the leading edge of the shingle in the same way that wind is deflected up over the wing of an airplane. This produces a negative pressure, or uplift, on the top surface of the shingle. The wind flow also produces a positive pressure at the front of the shingle that feeds under the leading edge, as shown in the figure. The combination of negative pressure on the shingle top side and positive pressure on the bottom side add together to cause a net upward differential pressure acting on the shingle tab. This pressure decreases with distance back from the leading edge of the shingle. This can also be influenced by the configuration of the sealant and the extent of leakage of the wind pressure behind it.

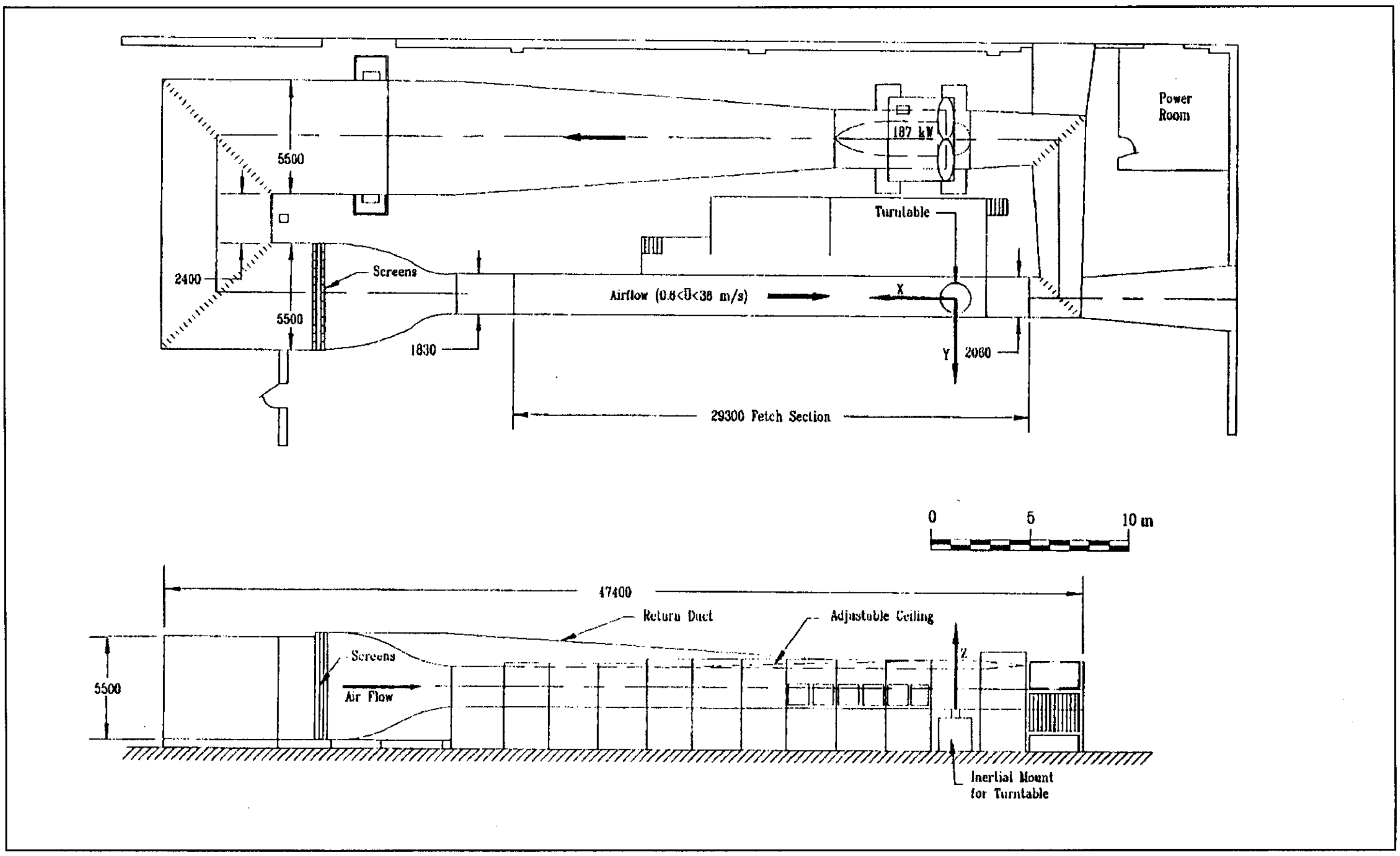

Figure 1.

This description of the physical interaction of wind with shingles, which was discovered by this research, is significantly different from the pressures calculated from procedures in building codes and other design documents which are in use today to provide the design wind loads on the entire building envelope and other components.

The pressures from the code procedures are imposed by the overall wind flow patterns that surround the building. In the case of asphalt shingle roofs, these pressures are passed through the shingles to the sheathing by the air-permeable nature of the shingles. Current building codes and other design standards do not completely address air-permeable roof coverings such as asphalt shingles.

RESEARCH RESULTS

The wind tunnel experiments at Colorado State University contained turbulence (gustiness) to simulate real-world winds, which are highly gusty. Appropriate levels of gustiness are required in a test to obtain realistic wind loads on building skin elements. The lack of appropriate turbulence is a major deficiency of the current wind test methods, as described earlier.

The Colorado State University experiments showed that the largest uplift on a shingle occurs only briefly during a windstorm, and uplift pressures during the remainder of the storm will vary at some fraction of this maximum.

In a wind storm, the maximum uplift pressure for a shingle on a house due to turbulence might be 2 to 5 times the average uplift pressure based upon the field test data of this research program.

Using the Meteorological Wind Tunnel, shingle uplift pressures were measured and converted to dimensionless coefficients for use in the load model. Data were acquired for typical 3-tab, strip shingles and for a typical laminated shingle. The uplift pressure coefficient is mainly determined by the leading edge geometry of the tab. Thus, a laminated shingle will have a different value than a 3-tab product. Another important factor is the type of sealant application. As a result, uplift pressure coefficients will differ for various shingle types and must be determined by using the wind load model.

OUTSIDE REVIEW

To have the research assessed by knowledgeable and interested persons independent of the ARMA organization, a group of outside expert reviewers was gathered at the site of the research. The reviewers toured the research facilities which provided on-site knowledge of the equipment and instrumentation. The research methodology and results were described and discussed in detail.

The peer review experts agree that the research is on target and that it will provide valuable data to help develop appropriate wind performance methodology for asphalt shingles. Additionally they indicated that the laboratory and field results are reasonable and consistent with observed shingle behavior in windstorms. The field experiments conducted are considered to validate the wind tunnel studies to the extent that recommendations should be brought forward.

Additional suggestions from the experts included:

- Field experiments to expand the data to include roof corners and the effect of roof structures such as dormers, chimneys and other protrusions.

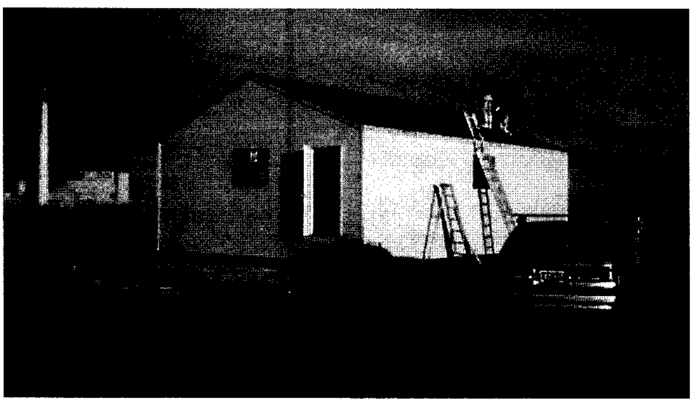

Figure 2.

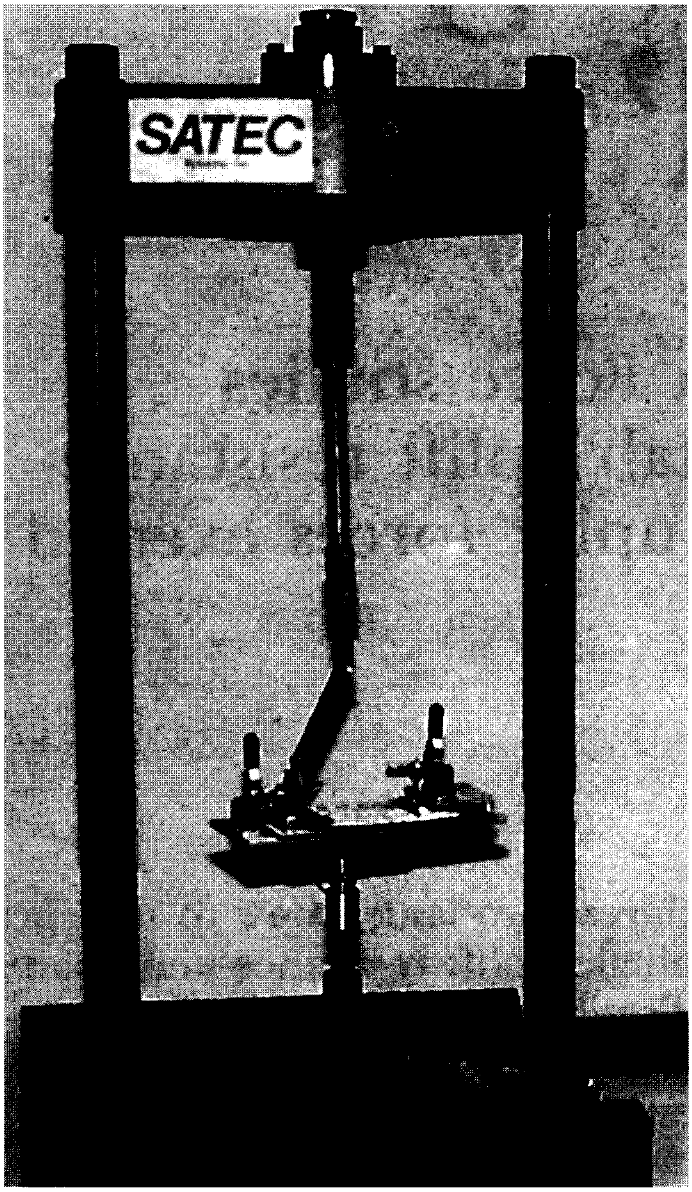

Figure 3.

- With regard to the shingle tab uplift test method, the conditions used to seal the shingle specimens for testing should be selected based upon the temperatures in the climate where the shingles are intended to be used.

SUMMARY AND FUTURE PLAN

The ARMA research program has resulted in a fundamental description of the interaction of wind with asphalt shingles and a validated load model that can be used to calculate the uplift pressure for design wind conditions. As discussed previously, a cost-effective mechanical tab uplift test method is being developed to measure the shingle tab uplift resistance.

Efforts are underway to publish the results of the research in a technical journal distributed by the American Society of Civil Engineers. The ASCE Journal will most likely publish the results sometime in 1998. Other efforts include publishing the results in other roofing industry technical publications and proceedings and trade publications.

USE OF THE WIND LOAD MODEL: AN EXAMPLE

The intent of this example is to demonstrate use of the results of ARMA's wind research and test method development, as they apply to composition shingles. For simplicity, some of the details have been omitted and several assumptions have been made.

Wind Studies: The Load Side of the Story

The outcome of the ARMA wind research is a validated model, or equation, which can be used to predict the peak uplift pressure on a shingle. This equation can be put into a form compatible with building codes so that their design wind speeds may be used. All major U.S. building codes refer to American Society of Civil Engineers Standard No. 7. In this example, the ASCE 7-93 version will be used.

Also, for this example, assume that the structure is a building in an open country environment, Exposure C, where the 50-year fastest-mile wind speed is 44.7 m/s (100 mph) (not at hurricane coast). The mean roof height of the building is to be 9.1 m (30 feet). The importance factor "I" in ASCE 7-93 is equal to 1, as it is for most buildings. Making other minor assumptions, for simplicity, that result in an error of less than 8 percent, the resultant design equation is:

$$P_{[peak]} = 0.60\ q\ (U_P / U_m)^2\ (C_p)$$

where,

$P_{[peak]}$ = largest uplift area averaged pressure on a shingle during a period of about one hour at storm maximum.

(U basic) = basic wind speed

(U_p) = the largest short duration peak wind speed measured one inch above the shingle surface.

(U_m) = the mean wind speed at eave height approaching the building at storm peak.

(C_p) = the mean uplift coefficient for the shingle referenced to the mean wind speed one inch above the shingle surface.

and,

$$q = 0.613\ K\ (U\ basic)^2 \qquad 0.00256\ K\ (U\ basic)^2$$

where,

K = the exposure factor, from ASCE 7-93, and is equal to 0.98 for a building height of 9.1 m (30 feet).

Then,

$$q = 0.613\ (0.98)\ (44.7\ m/s)^2 \qquad 0.00256\ (0.98)(100\ mph)^2$$

$$q = 1200.3\ Pa \qquad (25.08\ psf)$$

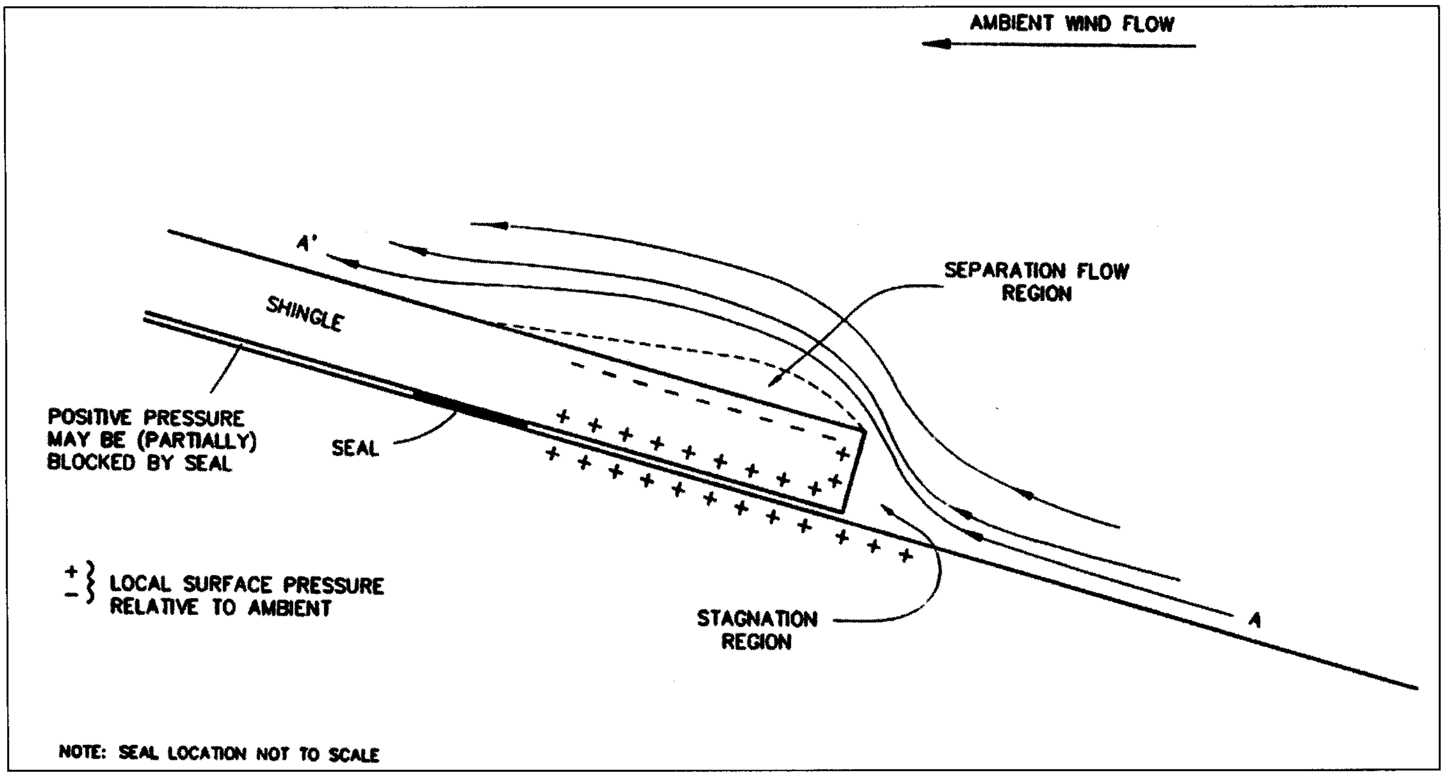

Figure 4.

The ARMA wind research program showed that,

$[U_p/U_m] = 2.5$

So,

$P_{[peak]} = 0.60\ (1200.3\ Pa)\ (2.5)^2\ (C_p)$ $\quad 0.60\ (25.08\ psf)\ (2.5)^2\ (C_p)$

$= 0.60\ (1200.3\ Pa)\ (6.25)\ (C_p)$ $\quad 0.60\ (25.08\ psf)\ (6.25)\ (C_p)$

$= 4501\ Pa\ (C_p)$ $\quad 94.1\ psf\ (C_p)$

The shingle uplift pressure coefficient, C_p, will be different for different types of shingles. In the ARMA wind research program, C_p was determined for a limited number of shingle types. For this example, the case of a typical 3-tab strip shingle will be used. It was determined that $C_p = 0.4$ from the front edge of the shingle to the seal strip and $C_p = 0.1$ behind the seal strip to the top of the cutout.

Therefore,

$P_{[peak]} = 1800\ Pa\ (37.6\ psf)$ (in front of the seal strip)

$P_{[peak]} = 450\ Pa\ (9.4\ psf)$ (behind the sealant strip)

Shingle Tab Uplift Test: The Resistance Side of the Story

The other aspect of ARMA's research program was to develop a test method to mechanically measure the uplift resistance of a shingle tab after it has been sealed under specified conditions of time and temperature. This uplift resistance (or force), with an appropriate safety factor, is needed to offset the uplift pressure due to the wind, which was calculated above.

For the shingle tab uplift test method, the specimen width is 95 mm (3.75 inches). Also, for the typical shingle considered in this example, the dimension from the shingle edge to the seal strip is 25 mm (1 inch) and from the seal strip to the top of the cutout is 102 mm (4 inches). Thus the calculated pressures, above, can be converted to a force on the shingle specimen to be tested in the tab uplift test apparatus.

$F_{[front]} = (Area_{[front]})\ (P_{[peak]})$

$= (0.95)\ (0.025)\ (1800\ Pa)$ $\quad (3.75/12)\ (1.0/12)\ (37.6\ psf)$

$= 4.36\ N\ (0.98\ lbs.)$

$F_{[behind]} = (Area_{[behind]})\ (P_{[peak]})$

$= (0.95)\ (0.102)\ (450\ Pa)$ $\quad (3.75/12)\ (4.0/12)\ (9.4\ psf)$

$= 4.36\ N\ (0.98\ lbs.)$

Therefore;

Total uplift force = 4.36 N + 4.36 N (0.98 lbs.+ 0.98 lbs.)

= 8.72 N (1.96 lbs.)

Assuming a safety factor of 2, then for this example, the force measured on the assumed shingle specimen in the Shingle Tab Uplift Test Apparatus would need to be 17.44 kg/m^2 (3.92 lbs.) in order to withstand the uplift pressure resulting from a wind of 44.7 m/s (100 mph) on the hypothetical building used in this example.

ACKNOWLEDGMENT

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