NATIONAL BUREAU OF STANDARDS REPORT

10 193

HAIL RESISTANCE TESTS OF ALUMINUM SKIN HONEYCOMB PANELS FOR THE RELOCATABLE LEWIS BUILDING, PHASE II

Report to

Commanding Officer
U. S. Navy Civil Engineering Laboratory
Port Hueneme, California

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

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NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT 4215421

April 10, 1970

NBS REPORT 10 193

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Ice spheres simulating hailstones were impacted on the surface of aluminum skin honeycomb panels in order to determine their resistance to hail. Various sizes of hailstones were projected at their terminal velocities and at velocities corresponding to wind driven hail. Damage caused by various sizes of hailstones on supported and unsupported areas of the panels are reported.

A brief discussion is given on the occurrence and intensity of hailstones and the probability of the size of hailstones when a hail day occurs.

1. INTRODUCTION

Hail resistance tests were carried out as part of the test and evaluation of the relocatable Lewis building, phase II. Structural tests on a full scale structural system of the relocatable Lewis building, phase II, were conducted in the Structural Laboratory at the National Bureau of Standards. A photograph of the building set up in the laboratory prior to the structural tests is presented in Figure 1. The building consists primarily of aluminum skin honeycomb panels having 3/4-inch cores.

The project leader of the full scale structural test, Mr. Thomas W. Recichard, requested on February 23, 1970 that hail resistance tests be conducted on typical aluminum skin honeycomb panels that are used or are proposed for use in the Lewis relocatable building. The hail impact tests were carried out in the Materials Durability and Analysis Section.

At the present time there are no standard methods of testing the hail resistance of materials nor are there standards for the evaluation of hail damage. Furthermore, there are no criteria for the

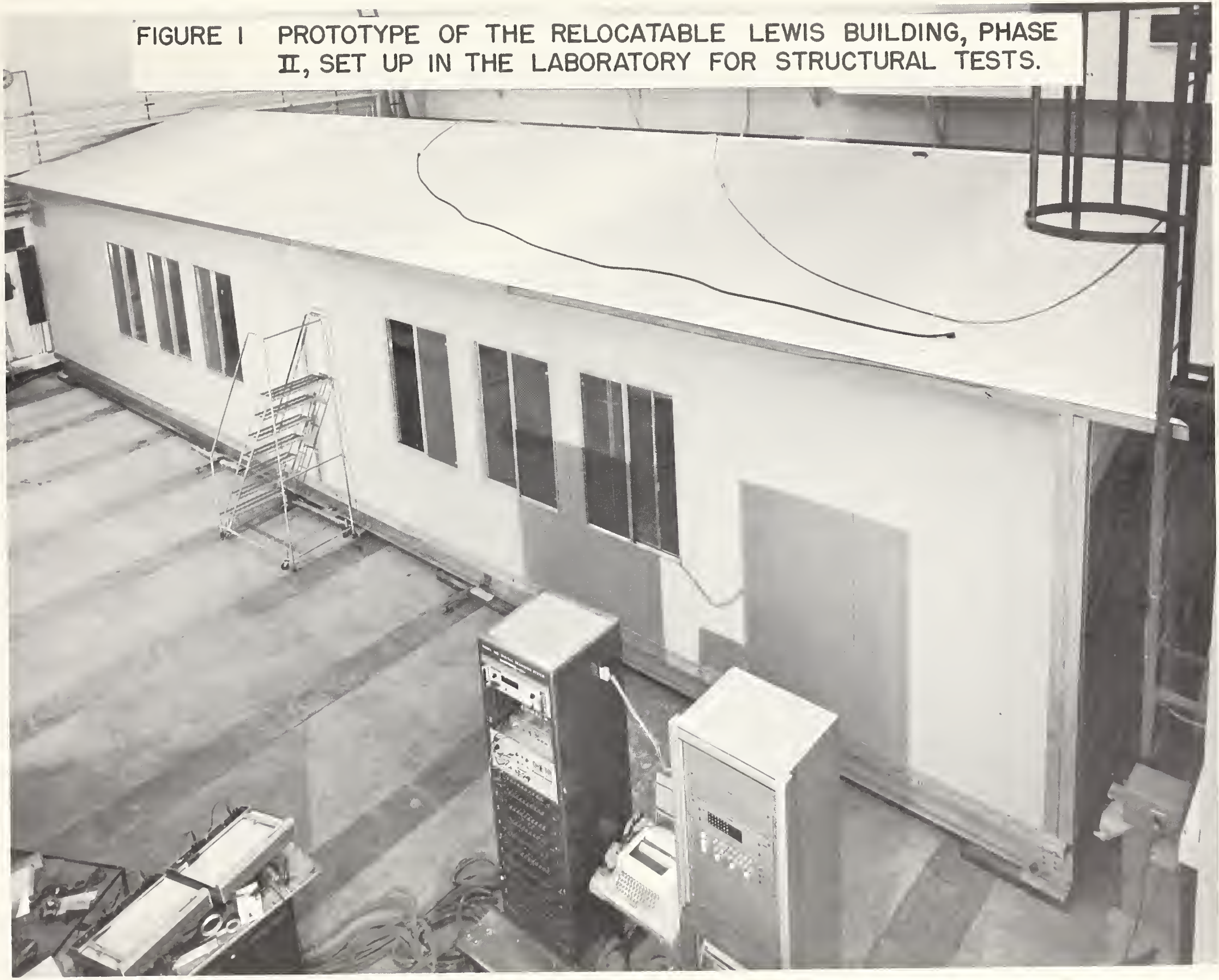

FIGURE I PROTOTYPE OF THE RELOCATABLE LEWIS BUILDING, PHASE II, SET UP IN THE LABORATORY FOR STRUCTURAL TESTS.

design of structures to resist hail. Because of the lack of standard test, evaluation, and design methods regarding hail resistance, the hail tests were planned to cover a range of sizes of ice spheres and impact energies. Although the density of hailstones is generally less than that for pure ice, ice was selected for the simulated hailstones for two reasons. First in some cases hail has been reported to have the same density as ice, thus providing more potential for structural damage, and secondly if some other material were used to simulate hailstones the damage evaluation may not correlate with that resulting from hail. Other investigators [1, 2, 3, 4]* used ice spheres in evaluating damage to structures that may be caused by hail.

2. NATURE AND FORMATION OF LARGE SIZE HAIL

Hailstorms are generally the outgrowth of thunderstorms and usually contain relatively small hailstones. However, large size hail stones, 1-inch in diameter or larger, have been reported to frequently fall in the United States and many other parts of the world. A review of the literature on hail formation [5, 6, 7, 8, 9] indicated that the mechanism of hail formation is not completely understood. However, in the United States it is generally accepted that the majority of the hailstorms result from warm moist tropical air from the Gulf area as it moves into the Middle Western States. Storms resulting in the fall of large size hail mostly occur in the States located between the Appalachian and Rocky Mountains. The surface temperatures are generally above freezing when hail occurs. Hail occurrence in Texas for example, is in the spring, early part of summer, and late fall.

The conditions needed to produce thunderstorms with sufficient intensity to develop damaging hail are (1) the air aloft is cooler than normal, (2) the air near the surface of the earth is warm and moist, (3) strong winds aloft to assist in developing vertical motion, (4) means of lifting the warm air to cause updrafts such as frontal lifting and

*Numbers in brackets indicate literature references given at the end of this report.

orographic lifting, and (5) air temperature not too warm below cloud formation so that the hail does not melt before reaching the earth. These conditions cause a rising column of air or updraft chimney that is roughly cylindrical in shape and topped by a half spherical cap. The updraft velocities in thunderstorms have exceeded 100 ft/sec and the distance these updrafts travel or the height of the storm effects the size of the hail that is discharged. This means that the longer the path length available for the growth of hailstones the larger they may grow.

The air in the upper portion of a thunderstorm is super cooled, with temperatures ranging from 0 to -40°C. The rising moist warm air is cooled below the freezing point and remains subcooled until it encounters a nucleus on which to freeze. As more water comes in contact with the ice particle it grows in size. At the higher levels of the storm cloud the very low temperatures cause rapid freezing of moisture and entrappment of air bubbles in the ice. Thus, an opaque low density layer of ice is formed. Falling of the hailstones into warmer regions results in accumulation of moisture in the form of water. When the ice particle encounters an updraft it is pushed up where it is cooled and the water freezes and forms a layer of dense clear ice. The ice particle again subcools and goes through the process of rising and falling, subcooling and freezing over and over until the updraft no longer is able to lift it. The hailstone then falls to earth at a constant velocity depending on its mass and the drag encountered. The hailstone in its cycling process of rising and falling developed alternate layers of opaque and clear ice. Hailstones with as many as 22 layers of ice have been reported [9].

It is also interesting to note that large size hailstones have been reported that have been of clear high density ice. The growth of large size hailstones can be compared to the accretion of ice on aircraft which is formed in layers. The hailstones move downward through the subcooled water drops at their terminal velocities. The updraft encountered serves primarily to increase the length of time and path

the hailstone travels through the cloud and thus to increase its collection of ice.

There are in general two types of hailstorms, the frontal storm which has been described and the orographic storm. In the latter, lifting of moist air occurs as it moves up the slopes of mountains. In the western-Midwestern States, orographic storms result from the lifting of air as it moves up the eastern slopes of the Rocky Mountains. The frontal storms occur in northern Texas and in the midwestern states extending northward. The duration of these hailstorms generally range between 1 and 15 minutes with the median length of hail duration being 5 minutes. The size of a representative hailstorm covers an area of 20 square miles.

Hail is defined as being composed of ice balls or stones ranging in diameter from that of medium size raindrops to about 5-inches in diameter. Hailstones 5-inches in diameter are theoretically the limiting size and hail this size was reported falling in Potter, Nebraska in November 1928. Hailstones of many different sizes fall at the same time. The size range was estimated to be about 3 to 1, or in most cases the largest size stone is about three times the size of the minimum stone. The large stones which are discharged by the heaviest storms are in general spherical in shape. In a study to determine the hail intensity in Northeastern Colorado and Western Nebraska in the summer of 1959 it was found that more than 75 percent of the hailstones that fell in this area approximated spheres [10]. Furthermore, the density of the hailstones were found to be 0.9 gm per cm^3.

3. HAIL OCCURENCE AND INTENSITY

Rational methods for predicting hail occurrence have been developed by Thom [11]. A method for predicting the frequency and probability of size of hail for the Midwestern States was developed by Friedman [12]. It is important to the engineer to have criteria to be able to design structures that will perform satisfactorily. Information presented by Friedman [12] will enable a more rational design of

structures in the Midwest to resist hail damage.

In the Midwestern States the occurrence of hail large enough to cause property damage is relatively rare for any given location. Some locations in this area of the United States are more likely than others to have hailstorms containing large size hail. The average number of days per year that hail storms have occurred in the Midwestern States over a period of 57 years has been reported [12]. These data were derived from U. S. Weather Bureau reports that include only the annual number of days with hail and did not mention hail size. It is noted that the Weather Bureau does not normally report hail size. The annual frequency patterns of the number of days with hail reported by Friedman [12] is shown in Figure 2.

Using several sources of data Friedman [12] also estimated the probability that hail will be of a given size on a day when hail occurs. Over 3,000 reports from the U. S. Weather Bureau monthly bulletin Storm Data covering a 17 year period (1950-1966) were tabulated and studied in order to validify the estimated probability of hail size on a hail day. Many of the damage reports for which hail was a factor, hail size was estimated. The probability of a given size of hail with regard to the annual average number of days with hail is given in Table 1. By using Figure 2, the average annual number of days with hail in the Midwestern States, and Table 1, the hail size occurrence could be estimated on a geographical basis. An example of hail size probability, areas having 4 average annual number of days with hail, the probability of hailstones exceeding 1-inch in diameter on a day with hail is about 13 out of 100.

Most of the property damage due to hail has been to roofing. A hailstorm struck Billings, Montana on July 6, 1955 and caused over 5 million dollars in property damage [13]. Damage to roofs accounted for nearly 80 percent of the building losses. The storm lasted 15 minutes and hailstones the size of baseballs (2 3/4-in. in diameter) were found embedded in the lawn of a homeowner after the storm.

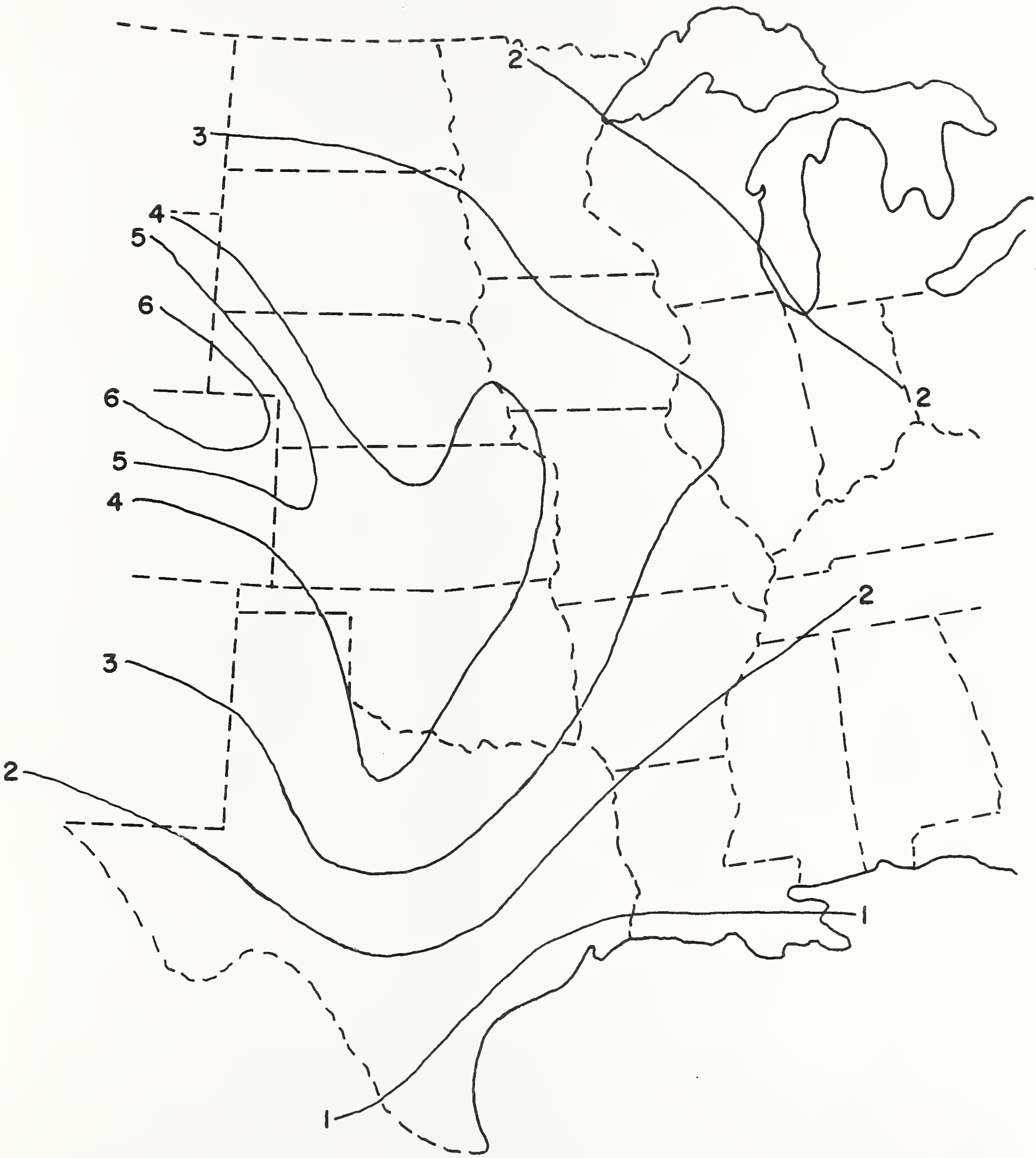

FIGURE 2. AVERAGE ANNUAL NUMBER OF DAYS WITH HAIL IN THE MIDWESTERN STATES [12]

TABLE 1. Probability of A Given Hail Size as A Function of Annual Average Days with Hail [12].

Average Annual Number of Days with Hail	PROBABILITY OF HAIL SIZE WHEN A HAIL DAY OCCURS								
	Less Than 0.5-in.	0.5-in. 1.0-in.	1.0-in 1.5-in.	1.5-in. 2.0-in.	2.0-in. 2.5-in.	2.5-in. 3.0-in.	3.0-in. 3.5-in.	3.5-in. 4.0-in.	More Than 4.0-in.	Total
2	0.613	0.284	0.035	0 031	0.016	0.005	0.002	0.002	0.002	1.000
4	0.435	0.433	0.044	0.039	0.023	0.006	0.004	0.004	0.004	1.000
6	0.254	0 580	0.053	0.047	0.030	0.008	0.008	0.004	0.007	1.000

In South Africa the more common hail storms are those where the hail size is 0.5-inches in diameter or less, damage due to this size hail by impact is negligable. Property losses from these storms results from the accumulation of hail that dams rainwater which penetrates the laps in roofing materials. The severe hailstorms in South Africa occur in the summer rainfall area and hailstones up to 3-inches in diameter have occurred over most of this area. Pretoria has experienced a number of severe hailstorms within the last forty years [1]. A hailstorm in 1958 in the Woomera area of Austrailia damaged roofs and other property. It is estimated that hail was approximately 1 1/2-inch in diameter [4]. Hailstones were also reported falling in California that had diameters up to 1 3/4-inches.

4. DESCRIPTION OF TEST SPECIMENS

The test specimens were cut from two types of full size honeycomb sandwich panels having aluminum skins and paper cores. The skins were 3105-H264 aluminum 0.024-in. in thickness that were stucco embossed and prefinished by the aluminum producer. The only difference in the two types of 3-in. thick panels were the paper cores. In one type of panel the cores were 3/4-in. and were made with No. 99 paper. The paper number indicates its weight per 3,000 ft^2. The second type of panel had 1/2-in. cores made with No. 70 paper. Both types of paper were impregnated with 11 percent phenolic resin. The adhesive used to form the cores and attach the aluminum skin to the cores was a neoprene phenolic resin, a contact adhesive applied with 25 to 30 percent solids. The solvent was evaporated out of the adhesive in a flash oven.

The full scale relocatable Lewis building, Phase II, shown in Figure 1 was fabricated with 4 X 8-ft. panels having 3/4-inch cores. Panels having 1/2-inch cores were not included in the prototype building. However, it was desirable to also determine the hail resistance of these panels since they may be used in future buildings.

Two 2 X 3-ft. test specimens were cut from both the 1/2-inch and 3/4-inch core panels. Strips of wood nominally 2 X 2-inches in cross section and 2-ft. long were attached using an adhesive along a line

3-inches from the ends of the specimens. The strips were oriented along the 2-ft. length of the specimen. By attaching strips of wood to the specimens it provided supported and unsupported areas that were impacted with simulated hailstones. Photographs of damaged specimens are shown in Figures 3 and 4.

5. TEST PROCEDURE

Simulated hailstones, ice spheres, were fired at the test specimens from a compressed air gun. The method used in these tests for shooting hailstones was a modification of the method developed by Greenfeld [2]. The test system for shooting and measuring the velocity of hailstones is shown in Figure 5. The inside diameter of the 40-inch long barrel on the gun was 3 1/16-in. Hail carriers made from 3-inch diameter polyethylene cylinders 6-inches long were used to carry the ice spheres out of the barrel of the gun. The polyethylene cylinders were cut in half longitudinally. The hemicylinders had hemispheres cut in them 2 1/4-inches from one end and were truncated at the other end at an angle of 45 degrees to a plane passing through the longitudinal axis. Therefore, various sizes of ice spheres could be fired from the same gun barrel. A different carrier for each size of ice sphere was used. The truncated portions of the carrier allowed the two hemicylinders to separate after leaving the barrel of the gun while the ice sphere continued toward the target area.

The pressure in the chamber of the gun was determined by a pressure gage. The desired velocity of the hailstone was calibrated with gun chamber pressure. However, the velocity was determined by using two 5-inch wide beams of light and a pair of photo electric cells. The beams of light were spaced 2-ft. apart with the second beam that the ice spheres passed through being 3-inches in front of the test specimen. The light source and the photo electric cells were supported on a steel frame. A digital timer powered by 100,000 cycles standard frequency recorded the time that the hailstone traveled between light beams. This time was measured with an accuracy of 1/2 percent.

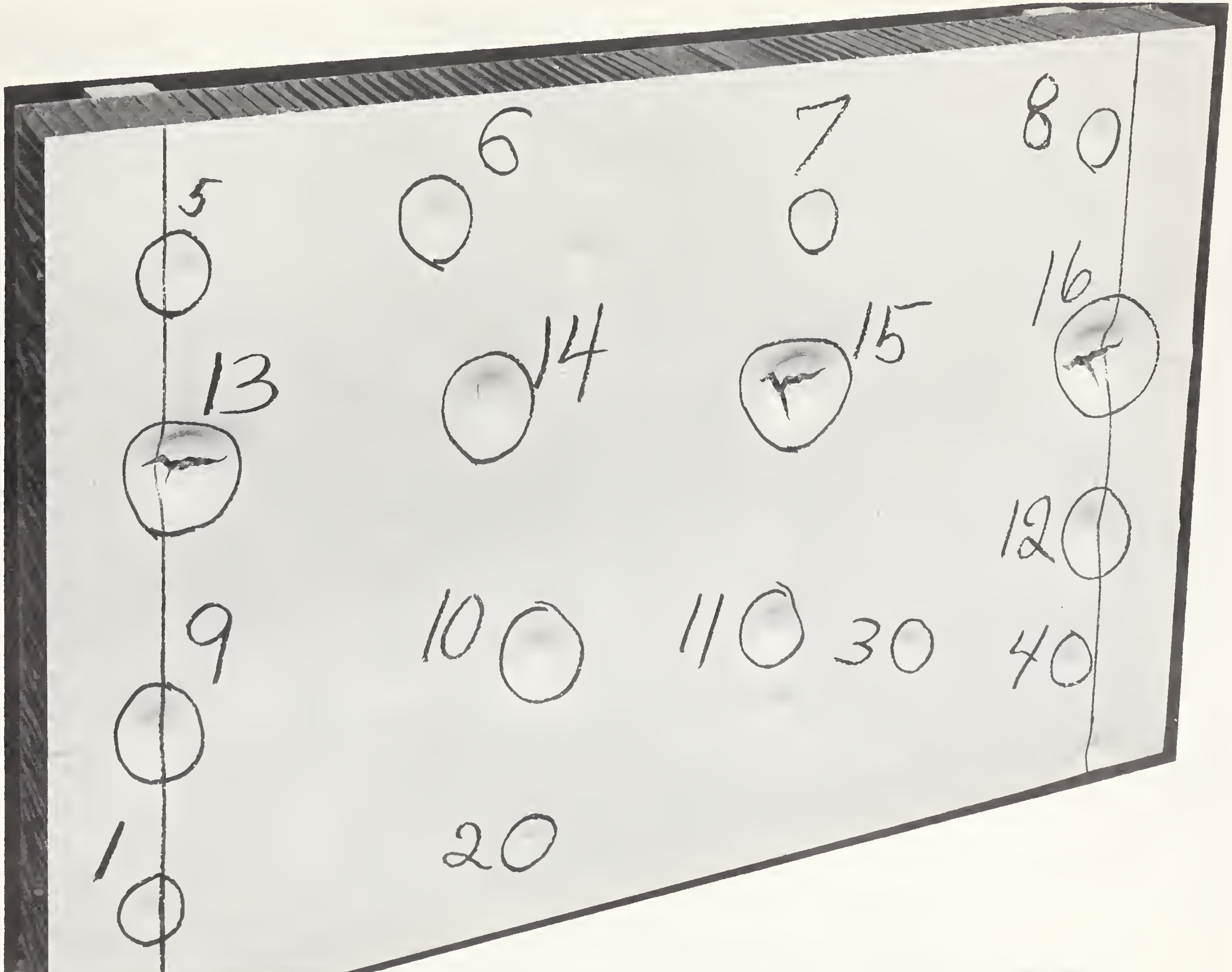

FIGURE 3 IMPACTED AREAS ON TEST SPECIMENS HAVING 1/2-in CORES.

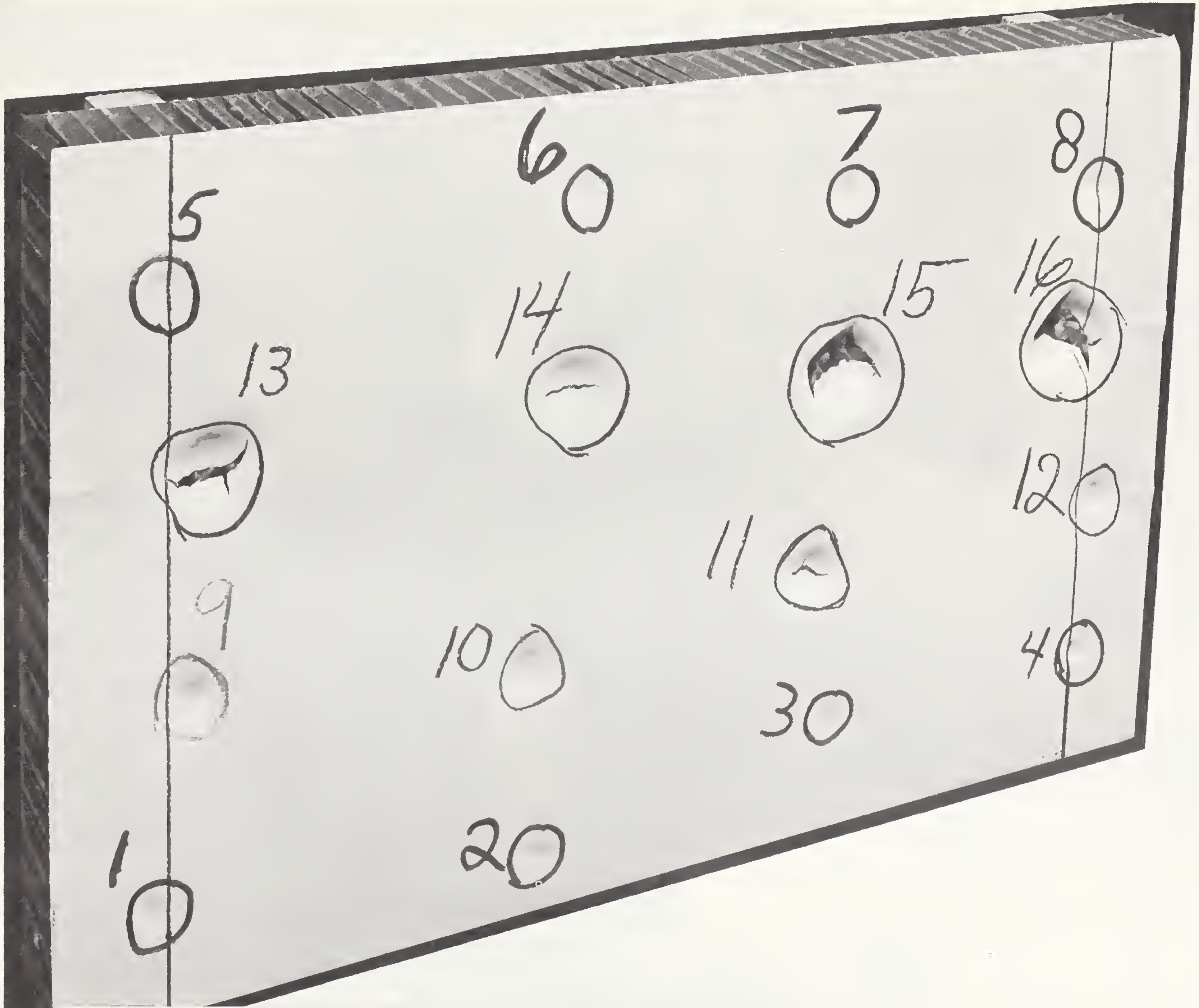

FIGURE 4 IMPACTED AREAS ON TEST SPECIMENS HAVING 3/4-in CORES.

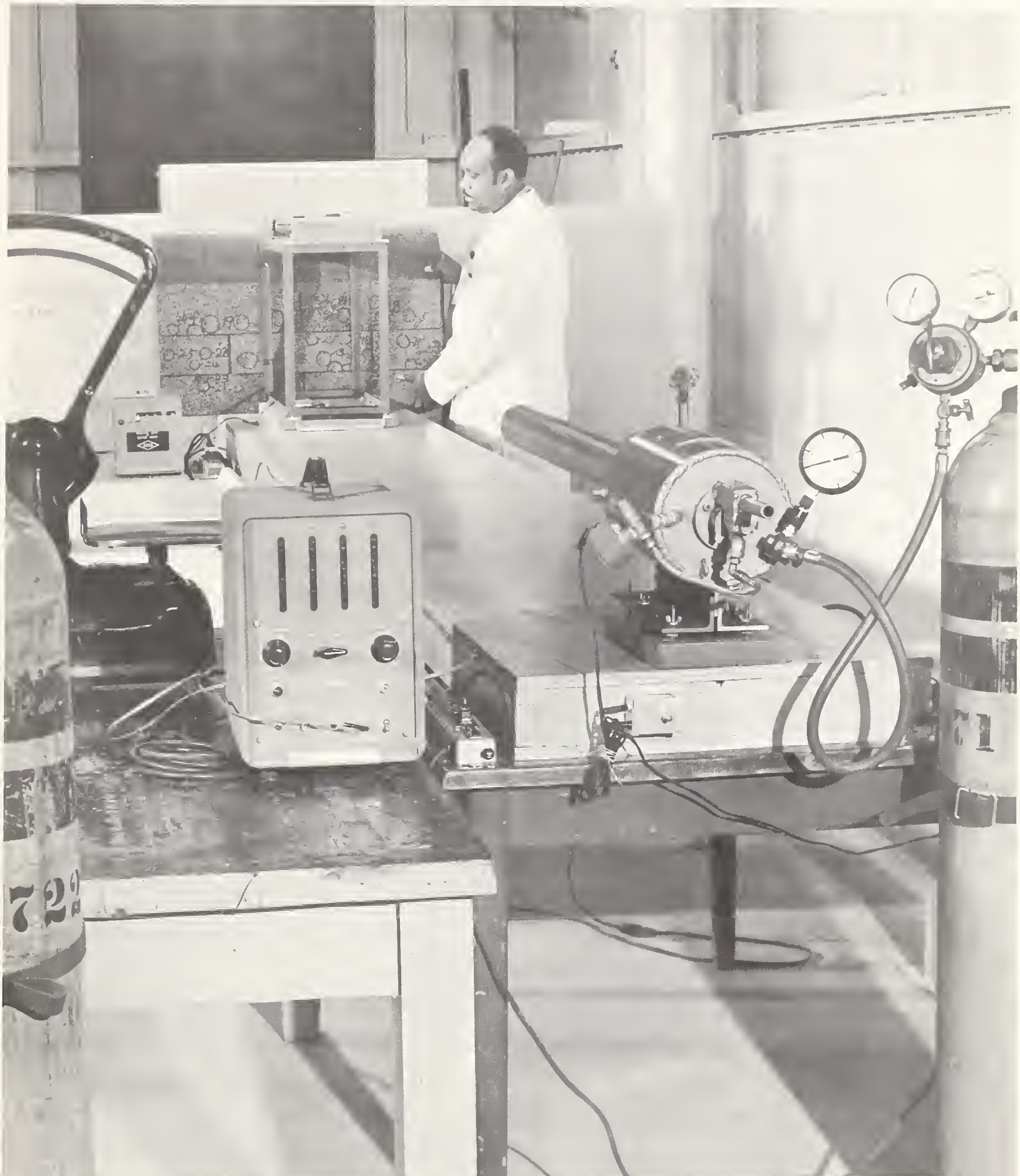

FIGURE 5 TEST SYSTEM FOR SHOOTING AND MEASURING THE VELOCITY OF HAILSTONES.

The test specimen was placed against the backstop shown in Figure 5 and held firmly in place with a C clamp. Ice spheres 1 1/4, 1 1/2, 2, and 2 1/2-inches in diameter were impacted on the specimen at velocities corresponding to the terminal velocity and a velocity which took into account a 45 mph wind acting on a free falling hailstone.

The hailstones were made in the laboratory in silicone rubber molds. They were cast in two stages in order to permit the expansion of water during freezing without causing cracking or shattering of the ice spheres. The density of the artificial hailstones was 0.9 gm/cm^3. Density of hail has been reported to range between 0.7 and 0.91 gm/cm^3, the latter value being the density of pure ice.

The ice spheres were stored in a freezer at about -19°C until ready for use. At the time of firing, an ice sphere was removed from the freezer cleaned of any burrs or projecting pieces of ice, weighed, placed in the hailstone carrier which was then slid into the barrel of the gun as far as possible. Air or nitrogen was then allowed to enter the chamber of the gun to the desired pressure and the gun was fired. The elapsed time between taking the ice sphere out of the freezer and it being fired from the gun was about 1 minute. When the carrier with the ice sphere was propelled from the gun, the air resistance forced the carrier to separate the two halves, thus allowing the hailstone to travel alone toward the target. Prior to hitting the target the ice sphere passed through two beams of light, the first starting the counter and the second stopping the counter. This enabled accurate determination of velocity and combined with the weight of the hailstone, values of kinetic energy were computed.

Test specimens were tested in duplicate with 16 shots fired at each specimen. Each of the four sizes of hailstones were fired at two different velocities at points on the specimen that were supported and unsupported.

The diameter and depth of indentation on the specimen was measured and the condition of the specimen after firing was recorded. Photograps of test specimens showing impacted areas are presented in Figures 3 and 4. The depth of the indentations were measured with a 0.001-inch micrometer dial gage that was supported on a steel frame. The stem of

the dial gage was at the center of two 1/4-inch diameter posts on the frame that were 3-inches apart. The position of the posts on the test specimen determined the plane of reference in making the depth measurements.

6. TEST RESULTS

Hailstones fall of different sizes, shapes and at different velocities depending on their mass and atmospheric conditions. Extensive studies [10] have shown that approximately over 75 percent of large size hail is spherical or nearly spherical in shape. Other experimental studies [14] have provided values of drag applicable to hail falling through the atmosphere. Coefficients of drag of ice spheres traveling through air were obtained in one investigation from observations on ice spheres towed by airplanes.

When a hailstone falls to earth, its velocity becomes a constant value when the drag forces equal it mass. Therefore, under conditions of no wind this constant velocity can be reasonably predicted. It has been pointed out that thunderstorms are generally accompanied by a strong wind. The value of wind speed varies considerably, however, reported values of range from 30 to 60 mph for the more frequently occurring winds during a hailstorm. Therefore, for the tests reported herein a value of 45 mph was taken as a representative value of the wind velocity for wind driven hail. Table 2 gives values of terminal velocity, resultant velocity (assuming a 45 mph wind), weight, and the kinetic energy for smooth ice spheres having diameters ranging from 1/2 to 4-inches. In computing these values the specific gravity of ice was taken as 0.915 gm/cm^3. The terminal velocity was computed from an equation derived by Bilham and Relf [14]. Values for the density and kinematic viscosity of the air were taken as 0.0758 lb/ft^3 and 0.000159 respectively.

Damage to property by hail generally starts with hail having a diameter between 1 and 1 1/2-inches and having kinetic energy from about 1.5 to 7.5 ft. lb. Roofing damage was defined [2] as severe or super-

TABLE 2. Values of Weight, Terminal Velocity, Resultant Velocity, and Kinetic Energy Computed for Smooth Ice Spheres.

Diameter in	Weight gm	Weight lb	Terminal Velocity ft/sec	Resultant Velocity ft/sec	Kinetic Energy 1/ ft-lb	
1/2	0.98	0.002	51	83	0.09	0.24
3/4	3.30	0.007	62	91	0.44	0.94
1	7.85	0.017	73	98	1.43	2.58
1 1/4	15.33	0.034	82	105	3.53	5.79
1 1/2	26.50	0.058	90	112	7.35	11.38
1 3/4	42.08	0.093	97	117	13.56	19.73
2	62.81	0.138	105	124	23.71	33.07
2 1/4	89.43	0.197	111	129	37.73	50.96
2 1/2	122.67	0.270	117	134	57.48	75.39
2 3/4	163.28	0.360	124	140	85.95	109.57
3	211.98	0.467	130	146	122.66	154.71
3 1/4	269.51	0.594	137	152	173.21	213.21
3 1/2	336.61	0.742	143	157	235.67	284.08
3 3/4	414.02	0.913	149	163	314.71	376.63
4	502.46	1.108	155	168	413.31	485.55

1/ First value corresponds to the terminal velocity and the second value corresponds to the resultant velocity.

TABLE 3. Diameter and Depth of Impacted areas and Properties of Hailstones causing Indentations in Test Specimens

Indentation Number	Ice Sphere Diameter in.	Average Weight of Ice Spheres gm	Average Velocity ft/sec	Kinetic Energy ft-lb	Impact Location	Panels with 1/2-in. Cores: Average Indentation Diameter in.	Panels with 1/2-in. Cores: Average Overall Indentation Diameter in.	Panels with 1/2-in. Cores: Average Depth of Indentation in.	Panels with 3/4-in. Cores: Average Indentation Diameter in.	Panels with 3/4-in. Cores: Average Overall Indentation Diameter in.	Panels with 3/4-in. Cores: Average Depth of Indentation in.
1	1 1/4	14.5	85	3.6	1/4 span	0.82	1.48	0.11	0.72	1.51	0.12
2	1 1/4	14.5	85	3.6	support	0.81	1.48	0.12	0.80	1.55	0.11
3	1 1/4	14.5	105	5.5	1/4 span	0.79	1.64	0.17	0.75	1.65	0.14
4	1 1/4	14.5	105	5.5	support	0.68	1.49	0.16	0.80	1.62	0.15
5	1 1/2	25.8	93	7.6	1/4 span	0.81	2.04	0.20	0.75	1.86	0.17
6	1 1/2	25.8	93	7.6	support	0.95	1.86	0.20	0.91	2.08	0.20
7	1 1/2	25.8	115	11.7	1/4 span	0.88	1.98	0.24	0.86	2.12	0.24
8	1 1/2	25.8	115	11.7	support	0.95	2.11	0.25	0.95	2.21	0.25
9	2	60.2	109	24.5	1/4 span	1.45	2.98	0.36 [1]	1.34	2.85	0.34
10	2	60.2	109	24.5	support	1.52	3.00	0.36	1.36	3.02	0.34
11	2	60.2	123	31.2	1/4 span	1.46	2.95	0.39 [1]	1.52	3.00	0.45 [2]
12	2	60.2	123	31.2	support	1.48	3.41	0.40	1.25	3.28	0.35 [1]
13	2 1/2	121.5	115	55.0	1/4 span	1.65	3.61	0.47 [1]	2.01	3.90	0.51 [3]
14	2 1/2	121.5	115	55.0	support	1.90	3.86	0.56 [2]	2.30	3.82	0.70 [4]
15	2 1/2	121.5	135	75.8	1/4 span	2.50	4.12	0.80 [4]	2.98	3.98	1.0 [4]
16	2 1/2	121.5	135	75.8	support	2.59	4.18	0.84 [4]	2.91	4.22	1.0 [4]

1/ Crack in indentation in one of the panels

2/ Large Y-shaped crack in indentation in one of the panels

3/ Crack in indentation of one panel and large Y-shaped crack in indentation in other panel

4/ Large Y-shaped cracks in indentations in both panels

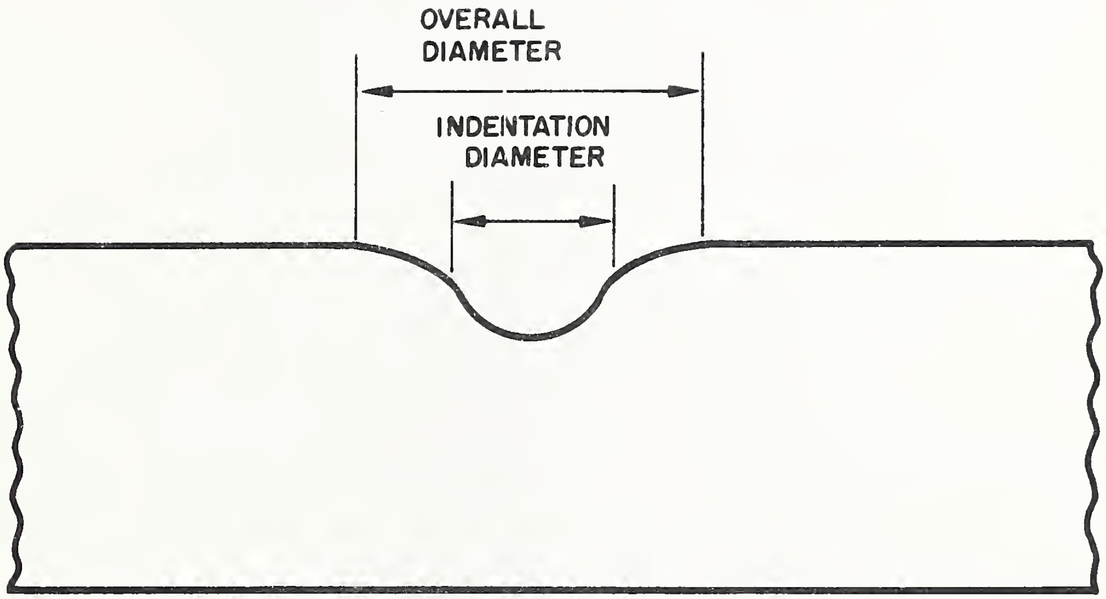

FIGURE 6 CROSS SECTION VIEW OF TYPICAL INDENTATION IN ALUMINUM SKIN HONEYCOMB PANEL TEST SPECIMENS

ficial. Severe damage leads to penetration of the structure by the elements. Some obvious indications of severe damage are cracks, punctures, tears or openings in the surface of the material protecting the structure. Superficial damage effects the appearance of the structure but does not interfere with its performance. Both types of damage lead to insurance claims; however, severe damage may result in losses far in excess of the replacement cost of the damaged area. The indentations in the test specimens are reported along with the fractures in the aluminum skin. These fractures in the material are considered as failure in this report.

The diameter and depth of the indentation in the test specimens shown in Figures 3 and 4 along with the weight, velocity, impact location, and kinetic energy of the hailstones are given in Table 3. This table also includes information on cracking in the test specimen due to impact of hailstones. The values in this table are average values for two test specimens. It is noted in Table 3 that there are two values given for the diameter of indentation. The sketch in Figure 6 depicts the typical cross section of an impacted area of the skin of the honeycomb panel. The overall diameter and indentation diameter of the impacted area are shown on the sketch.

In comparing the average indentation diameter, average overall indentation diameter, and the average depth of indentation given in Table 3 for panels having 1/2 and 3/4-inch cores, it can be seen that there was little difference in the hail resistance of the two panels. Only in the case of the indentation caused by the 2 1/2-inch diameter ice spheres was there a noticable difference in performance of the panels to resist large size hail. The panels with the 1/2-inch cores developed smaller indentations, however, damage was very extensive for both types of panels. The location of impact with regard to supported or unsupported areas on the test specimens also had no appreciable effect on the hail resistance.

Both types of panels with the 1/2 and 3/4-inch cores resisted the 1 1/2-inch diameter hailstones without developing cracks or breaks in the aluminum skin. The kinetic energy of the 1 1/2-inch diameter hailstones traveling at the resultant velocity (terminal velocity combined with a 45 mph wind) was 11.7 ft-lb. The average depths of indentations caused by the 1 1/2-inch diameter ice spheres ranged from 0.17 to 0.25 inches for the terminal and resultant velocity respectively. These indentations at both supported and unsupported areas after affect the appearance but not the performance to resist penetration of moisture or water.

Values of kinetic energy for various sizes of hailstones ranging in diameter from 1/2 to 4-inches and traveling at the terminal velocity and resultant velocity are given in Table 2. These values differ slightly from those given in Table 3 since the values in Table 2 were determined from computed velocities of smooth ice spheres. The values in Table 3 were determined from the measured velocity and weight of the hailstone. The density of the ice balls used in the test was about 0.9 gm/cm^3. In an investigation [3] to establish a quantitative method of evaluating hail damage to roofing products. The kinetic energy at impact was taken as a suitable criterion because the work required to stop a moving object is equal to its kinetic energy. The kinetic energy at impact of a hailstone which cracks or causes breaks in the roofing products was considered as a measure of hail resistance of the material..

Tests were carried out by hitting one area with a hailstone of a given size. Tests did not include multiple hits in one specific area because of the difficulty of evaluating damage.

In hail tests reported by Rigby [3] of plain corrugated aluminum roofing 0.025-inches in thickness and supported by 2 X 3-inch purlins at 2 1/2-ft. on centers on rafters at 4 1/2 ft-lb on centers the impact energy to cause failure was 56 ft-lb. This material was more severly damaged near the purlins. Once the material was punctured it was weakened considerably and subsequent shots easily extneded the damage.

7. CONCLUSIONS

1. The two types of aluminum smin honeycomb panels having 1/2 and 3/4-inch cores resisted hailstones up to 1 1/2-inches in diameter

without causing cracks or breaks in the aluminum skin. The kinetic energy of the 1 1/2-inch diameter hailstones at impact ranged from 7.6 to 11.7 ft-lb.

2. Kinetic energy is a suitable criterion for establishing a quantitative means for evaluating the hail resistance of building materials.

3. There was appreciably no difference in the hail resistance of the panels having 1/2 and 3/4-inch cores.

4. The location of the point of impact of the hailstone with regard to supported or unsupported areas on the test panels did not effect the hail resistance.

5. Data are presented [12] that gives the estimated probability of a given hail size when a hail day occurs for the Midwestern States of the U. S.

8. ACKNOWLEDGEMENT

Acknowledgement is made to Jessie C. Hairston for preparing the specimens for test, assisting in carrying out the tests and measurement of indentations.

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