METAL BUILDING MANUFACTURERS ASSOCIATION

Technical Bulletin **Spring 2000**

METAL BUILDING SYSTEMS
Wind Design and Performance

by

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Introduction

This article was prompted by the IBHS publication, "Performance of Metal Buildings in High Winds" [1]. While the IBHS publication did provide illustrations of observed metal building failures in the field due to hurricanes over the last 15 years, it did not attempt to document the improvements that have been made in the codes and industry design practices after these lessons were learned. It was felt that this additional information would be useful to the insurance industry in relating expected performance of metal buildings since codes have evolved considerably with regard to wind loads.

What is a Metal Building System?

The process of designing a metal building system has changed considerably over the years, primarily due to the implementation of computer-aided design and drafting. Many people still harbor the notion that a metal building system is selected from a catalog of standard designs, based on the size of the building. In fact, all major metal building system manufacturers utilize computer tools to custom design a building by order, to specified dimensions, based on the building code in effect, the loading conditions, and material specified. Today's metal building systems can also look much different than their predecessors because of the many different architectural finishes that may be utilized to provide the look required for applications such as churches, schools, shopping centers, office buildings, etc., while still offering the cost advantages of the metal building system.

Metal building systems have evolved over the years into assemblages of structural elements that work together as a very efficient structural system. While there are many variations on the theme, the basic elements of the metal building system are constant: primary rigid frames, secondary members (wall girts and roof purlins), cladding, and bracing. Metal building system design may seem trivial at first, but experience shows that the complex interaction of these elements into a stable system is a challenging engineering task. MBMA member companies have demonstrated this expertise and are on the leading edge of systems design.

Post-disaster investigations have suggested that metal building system "look-a-likes" suffer more extensive damage than engineered systems subjected to the same extreme loading. These look-a-like metal buildings are not easily distinguished from a metal building system; however, they are not typically designed with regard to the interdependence of the structural elements *(See Photo 1)*. The individual components are usually purchased from one or more vendors and may be shipped out as a complete metal building.

Additionally, it is unlikely that the supplier(s) of these look-a-like metal buildings have been scrutinized in the same manner as a metal building system manufacturer who has become certified under the AISC-MB quality certification program that is described later in this article.

Table 1: Hurricanes

Storm	Date	Location	Windspeed[1] (mph)
ALICIA	08/18/83	Galveston, TX	90
ELENA	08/29/85	Gulfport, MS	95
GILBERT	09/11/88	Jamaica	110
HUGO	09/21/89	Charleston, SC	120
ANDREW	08/24/92	Miami, FL	140
ERIN	08/03/95	Pensacola, FL	100
OPAL	10/04/95	Pensacola, FL	95

[1] Maximum Adjusted Fastest Mile Windspeed.

Lessons From the Past

Investigations of hurricanes and other high wind events have helped us learn where improvements can be made to enhance performance. Many surveys that were conducted in the 1970's, beginning with a Texas Tech University report [2], categorized a building's performance relative to the amount of engineering attention provided. In this method, buildings were classified as fully engineered buildings, pre-engineered buildings, marginally engineered buildings, and non-engineered buildings. Taking into account how the metal building industry has evolved, a classification of buildings today should in fact remove metal buildings from the pre-engineered classification and into the fully engineered category recognizing that they are now designed for specific site and loading conditions and receive the same level of engineering attention as other fully engineered buildings.

The hurricanes that have provided the most insight into the performance of metal buildings over the past two decades are summarized in Table 1. The maximum fastest mile windspeeds noted are given for relative comparisons, even though varying estimates can be found in the

Photo 1: Hurricane Opal Observation – Engineered metal building system on left, multi-component building with wood trusses, metal cladding/roofing on right.

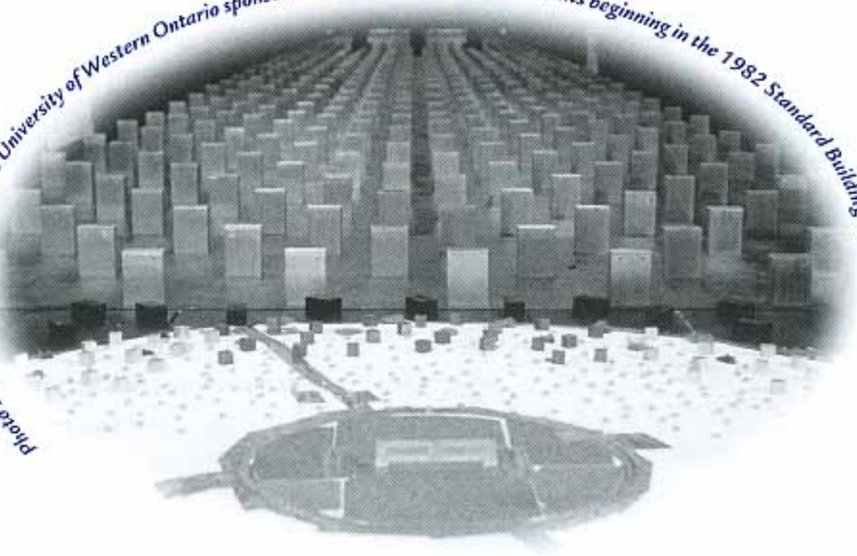


Photo 2: Wind tunnel studies at the University of Western Ontario sponsored by MBMA led to improvements beginning in the 1982 Standard Building Code.

literature for different analyses of the windspeed data. It is important to note that until the 1982 edition of the Standard Building Code [3], the pressures generated by wind loads were seriously underestimated by the building codes. The 1982 SBC incorporated the research carried out at the University of Western Ontario in the 1970's that was sponsored by MBMA and others *(See Photo 2)*. A very thorough review of the history of the design wind pressures used in the Standard Building Code is presented in the National Research Council investigation of Hurricane Elena [4]. This report states:

"In the late 1970's, an extensive study of wind pressures on low-rise buildings was conducted in a modern boundary-layer wind tunnel at the University of Western Ontario, Canada. The results of these tests formed the basis of the revisions to the Standard Building Code. First introduced as an alternative procedure in 1982, the provisions became mandatory for low-rise buildings in 1986, finally providing for a more rational treatment of wind pressures on low-rise buildings.

Unfortunately, most of the buildings affected by Hurricane Elena were built to older versions of the Standard Building Code. Notable exceptions to this were several pre-engineered metal buildings. The upgrading of the Standard Building Code took place as a result of pressure from the metal building industry, and many manufacturers took advantage of the new regulations when they became an alternative procedure in 1982."

As an example of the significant changes in the wind pressure, it was shown in the Hurricane Elena study that the design pressure using the 1986 Standard Building Code (1982 Alternate) for a fastener in the corner of the building with a tributary area of 10 square feet or less was over 2.8 times higher. Therefore, the performance of buildings in hurricanes Alicia, or possibly Elena, may not be a predictor of performance of buildings designed to today's codes *(See Photo 3)*.

Hurricane Alicia (1983)

Observations from Hurricane Alicia must also take into account that buildings would have been designed without the current knowledge of wind loading effects. However, some lessons were learned from the observations made. In the proceedings of the conference [5] that focused on this storm, it was noted:

"There were several thousand pre-engineered metal buildings in the area impacted by the hurricane. The great majority suffered no damage. Among those that did, there seemed to be a repeating pattern. The failures observed by the author fell into three distinct categories, in order of their frequency:

1) Roof damage caused by overhead door failures.

2) Roof and wall damage in buildings which had some open bays (See Photo 4).

3) Damage due to interface between metal buildings and masonry walls."

The observations regarding large doors will be discussed in a later section since this was a common observation in several wind events. Buildings with open bays were subsequently addressed through research and included in the 1986 MBMA Low-Rise Buildings Systems Manual.

The interface of masonry with the steel frame has been an area where improvement has been achieved over the years. Although any masonry that is used in conjunction with a metal building system is not designed by the metal building designer, the deflection of the steel frame must be compatible with the attached masonry. The coordination of the elements of the building not provided by the metal building manufacturer was addressed in a recently published article [6]. Also, on this topic, the National Concrete Masonry Association published a guide [7] that addresses the important considerations when designing a masonry wall that will be incorporated into a metal building system.

Hurricane Elena (1985)

As discussed previously, Hurricane Elena struck as the transition was being made in designing buildings to take into account the knowledge learned from wind tunnel studies of low rise buildings. The National Research Council investigation of Hurricane Elena [4] provided the best analysis of the performance of metal buildings in this storm.

Photo 3: Hurricane Elena Observation – Large cross-section of metal buildings and metal roofs designed to various codes due to their apparent age. Newer buildings show little or no damage.

This study concluded that the tens of thousands of metal buildings constructed over the past two decades in the areas affected by Elena provided a unique opportunity to assess the adequacy and extent of enforcement of the building codes of record for this type of construction. The review of damage from Elena versus Frederic and Camille indicated that for the most part a significant improvement in performance of pre-engineered metal buildings. They cited two factors that appeared to be primarily responsible:

1) The revisions to the Standard Building Code based on the design procedures developed by the metal building industry.

2) The almost uniform acceptance of the UL 580 specification for roof uplift testing. The increasing customer demand for roofs meeting the UL specification resulted in a reduction of hurricane damage for engineered metal buildings.

In general, school buildings performed very poorly in Alicia, but this study reported that "many metal multipurpose school buildings sustained little, if any, damage. Also, the performance of pre-engineered churches was satisfactory." One motel that was a metal building system was reported to have suffered only damage to the attached signage and was returned to service immediately after restoration of electrical power, which was atypical for other motel structures.

It was pointed out that a number of metal buildings performed in a less than satisfactory manner but that it was not clear how many buildings were designed to the new alternate wind loads adopted in 1982 since it was still permissible to use the existing wind load provisions. The observed damage was grouped into the following categories, in order of their frequency of occurrence:

1) **overhead door failures**
2) **canopy failures**
3) **damage to steel/masonry facade interface**
4) **omission of bracing by contractor**
5) **improper anchorage of columns**
6) **strut purlin failures**

Only overhead door failures and damage to steel/masonry facade interface has continued to persist to any extent in subsequent storms. The other observations from Elena have not proved to be a recurring problem possibly due to more buildings being designed to the improved wind codes and/or improvements in the design standards. The omission of bracing by the erector or the removal of bracing by the building occupant is a problem that occurs more frequently than is acceptable. MBMA is supporting efforts for erection certification programs for metal building contractors to help elevate construction quality.

Hurricane Gilbert (1988)

A survey [8] was made of the performance of low-rise industrial buildings in Jamaica that were in the path of Hurricane Gilbert that struck on September 11, 1988. A number of recently constructed metal buildings were evaluated that had been designed to the MBMA standards for wind loading (same provisions that became mandatory in the 1986 Standard Building Code and were adopted as part of the Caribbean Uniform Building Code). The analysis of the windspeed data and the requirements of the Caribbean Uniform Building Code and Jamaican Building Code showed that Gilbert very closely represented the 3 second gust design windstorm of 125 mph, or 100 mph fastest mile. This report concluded that "the group of metal buildings studied in this paper represented an unusual opportunity; they constituted a group of buildings of identical design and construction standard in different surroundings in different parts of the island. All saw winds near the maximum intensity at sites that were in open exposures to the wind. All of the recently completed buildings were completely undamaged except for one or two minor instances of missile damage." The report also concluded that "two buildings still under construction were damaged; in one case only the bare frames were erected without installation of the bracing; in another the roofing was still unattached. One older building roughly ten years old and built to an earlier wind loading specification suffered local buckling of the roofing along a strip adjacent to the gable end; more recent MBMA specifications address this question, requiring higher pressures in this region."

Photo 4: Hurricane Alicia Observation – Roof and wall damage to building with some open bays.

This was probably the first good documentation that the wind loading standards that resulted from the work sponsored by MBMA did in fact produce buildings that withstood the impact of a design level hurricane with very minimal damage.

Hurricane Hugo
(1989)

Hurricane Hugo struck on September 21-22, 1989 and was the most severe hurricane to hit Charleston, South Carolina in 30 years. It offered a good opportunity to make an assessment of how metal building systems performed that were designed to more recent wind load requirements. In particular, several industrial parks that contained over 100 metal building systems just north of the Charleston Airport provided a database of buildings to analyze [9] that were easily correlated to the actual wind load based on the anemometer data from the airport. The average age of these buildings, particularly in Pepperdam Industrial Park was just six years when Hugo struck.

This survey did find some wind damage to trim parts and overhead doors in metal building systems, but concluded that:

"...the more than 100 metal building systems in Pepperdam and adjacent areas that showed no structural damage from the hurricane indicates that recent and current building codes, standards and design methods reflects more adequate and truer wind loads and more reliable structures than those of the past. This is contrasted by earlier vintage of nearly all types of damaged low-rise buildings, most evident in the corners and edges or roofs and walls where more recent practices have called for greater design loads."

"In other areas, there was some damage of metal building systems that were designed to meet earlier standards. There are some metal building system look-a-likes that employ parts of the same general appearance, but are not designed according to proper standards. These buildings can show signs of damage and can appear as metal building systems, even to the trained eye."

Hurricane Andrew
(1992)

By all accounts, Hurricane Andrew was a severe storm where substantial damage could be expected, but more damage occurred to all types of construction than was acceptable, thus producing many questions. Interestingly, Hurricane Andrew's main blow struck two of the three counties in Florida that had their own building code, instead of adopting the Standard Building Code. Dade and Broward Counties had long thought that their building codes were more stringent and would provide greater protection from hurricanes.

However, looking at the basic design windspeed is not sufficient in comparing the provisions for determining the wind pressures on various building components. The South Florida Building Code did not include the latest knowledge of higher corner effects and higher loads on fasteners with smaller tributary areas as did the Southern Building Code. Using the appropriate design windspeeds from each code, the Southern Building Code would have required more than twice the uplift on corner fasteners than the South Florida Building Code provisions that were in effect. Also, the belief that the code enforcement in South Florida was fairly strong was quickly eroded after the investigation of Andrew began. This was the major impetus in the Insurance Services Office development of the Building Code Effectiveness Grading Schedule.

A report [10] that was based on the detailed investigation of 14 buildings with metal roof systems provided some useful information. Several failures of standing seam roofs were a result of the clips pulling out from the seams in which they are crimped. It has been argued that the UL580 uplift test, while effective for through-fastened metal roofs, may not properly take into account the effect of the large deformations in the panel of a standing seam roof system because it uses a test specimen that is too small (10 ft. x 10 ft.). The investigator recommended that to enhance metal roof system performance that "uplift load capacity be based on the ASTM E1592 test method." In fact, this has been the direction of the industry over the last few years. ASTM E1592 provides a test that reduces the boundary condition effects and provides a better indication of the structural capacity of standing seam roofs *(See Photo 5).*

Just recently, the AISI Specification for the Design of Cold-Formed Steel Structural Members [11] adopted a supplement that will be issued in 2000 that includes a requirement that the uplift capacity of standing seam roof panel systems must be established by test in accordance with ASTM E1592 and the results evaluated in accordance with new AISI Specification provisions.

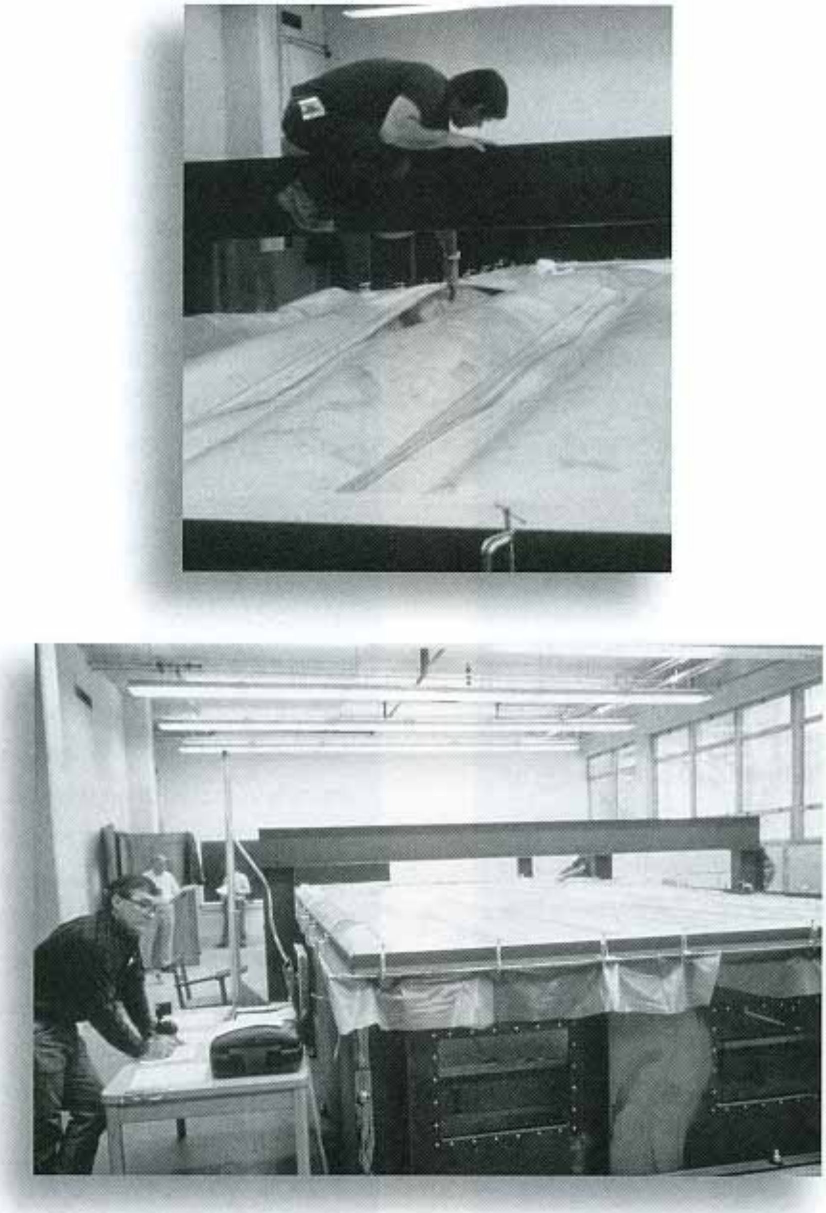


Photo 5: ASTM E1592 test of a standing seam roof to determine uplift capacity.

MBMA, along with AISI and the Metal Construction Association is sponsoring research at Mississippi State University to determine if ASTM E1592, which is a uniform static pressure test, can be better correlated to the dynamic, non-uniform nature of true wind forces acting on a metal roof system. This research program is utilizing a grid of 34 electromagnets to match measured wind tunnel pressure data in the corner of a roof. In fact, the initial data has been selected to represent the pressures that a typical roof would have experienced in Hurricane Andrew. This is the first time that both the time varying and spatial varying phenomena of wind is being replicated in a laboratory uplift test.

Many investigations of commercial/industrial building performance in Andrew referred to problems with large doors. These may relate to the door itself, whether consideration was given to the appropriate design pressure to use for the door, or if the structural framing design provided the required strength and stiffness to properly support the door. The following observations can be found in the referenced reports:

"In the commercial structures the collapse of overhead doors exposed the structures to interior hurricane pressures which were apparently not considered in their design [12]."

"Metal roll-up doors failed, usually due to positive wind pressure on the windward

side. Failure of supports at the top occurred in most cases, sometimes associated with failure of the side tracks or the door itself. In some cases, failure of roll-up doors triggered more catastrophic structural failures due to opening of the facility to internal wind pressure. Sturdier roll-up doors are required as well as greater attention to the attachment of the doors to the building structure [13]."

"One of the more common failures observed in metal building systems was that the overhead doors and windows were 'blown-in'. Once the doors were lost, the building system experienced internal pressures for which the system was not designed. Many metal building systems lost their outer sheeting when the internal pressures increased, and the panels were pulled over the fastening screws [14]."

"Many of the failures in commercial low rise buildings during Andrew can be directly related to internal pressurization from improperly designed doors and windows. In low rise steel buildings this pattern was epidemic. The loss of large access doors led to unanticipated internal loads which stripped the buildings of the roofing and siding. In extreme cases, the collapse of the structural frame can be traced to loss of lateral support from the cladding elements. The same problem plagued other construction types as well. Tilt-up concrete wall panels were often blown out by internal pressure from a failed windward door. Prestressed concrete double tee roof panels were cracked or blown off by the same internal pressure problem [15]."

Suggested improvements in the design process affecting large doors are addressed later in this article.

Hurricanes Erin & Opal

(1995)

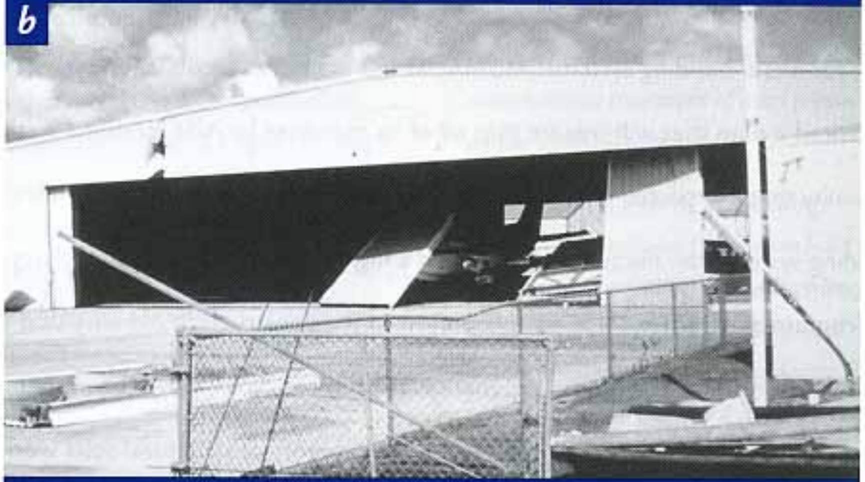
Surveys of Hurricanes Erin and Opal were conducted by SBC Staff and reported in Southern Building [16,17]. Although these hurricanes were low in magnitude, they were investigated because "a low magnitude hurricane presents a real world field test of materials and systems that are expected to perform well in hurricanes of higher magnitudes. Observations of damage from low magnitude hurricanes gives those associated with building construction a chance to spot potential problem areas and take corrective action before a hurricane of moderate or strong magnitude exploits these weaknesses and causes major damage."

The reports noted that for all construction, the most frequently observed and most serious problem was loss or damage to roof coverings. "The damage caused by Erin should be a cause for alarm because roof coverings that should have performed well at 100 mph exhibited serious problems in winds that were in many cases well below this level." With regard to metal building systems, the report notes that "metal roofs appeared to perform quite well on pre-engineered metal buildings." "However, on most other applications, [metal roof] performance was highly varied, ranging from good to poor." This is supportive of the earlier statements regarding the systems approach to engineering a metal roof system as opposed to less rigorous component assembled metal roofs. The report concluded, "no serious problems were noted to pre-engineered metal buildings."

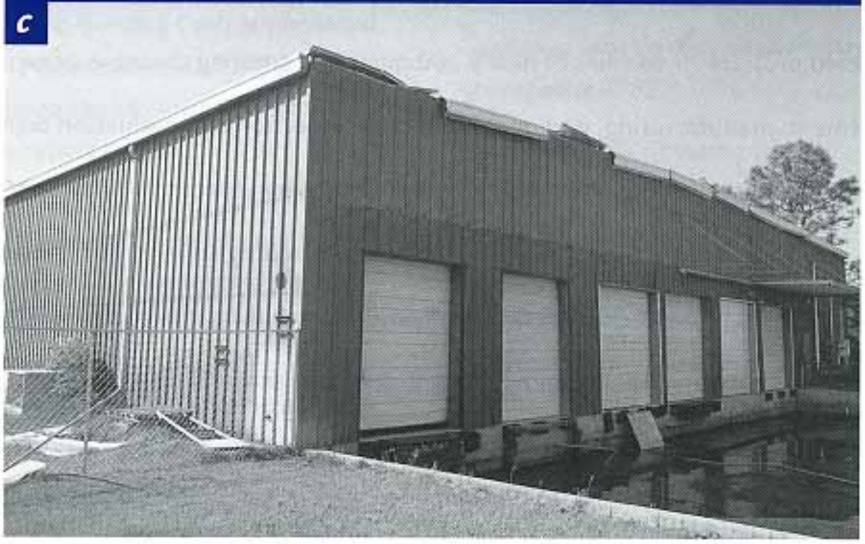
As in Erin, the Opal survey found that "no serious problems were noted with pre-engineered metal buildings." However, the same varied performance was noted in metal roof coverings as was observed in Erin, but the investigators "got the impression that overall performance of metal roofing in Opal was quite better than in Erin."

It is clear from both Erin and Opal that the consistency of performance of metal roofing in general needs improvement. It was noted in both investigations that the metal roofing systems that were engineered as part of metal building systems performed well and could be used as a standard of good performance. In fact, MBMA has just published a Metal Roofing Systems Design Manual that could help to elevate the design and construction standards currently used by others utilizing metal roofs. The metal roofing systems manufacturers who became members of MBMA in 1998 are leading this effort. MBMA has also recently developed and has begun to administer a certification program for metal roofing manufacturers that will enhance metal roofing design and fabrication.

Photo 6: Observed damage to overhead doors a) Hurricane Alicia b) Hurricane Elena c) Hurricane Opal



Note that the building designed to more recent code in Opal only suffered damage to canopy and edge flashing.



Garage Doors

A common observation in many of the hurricane investigations was that large doors blew in and may have caused increased internal pressure that resulted in roof and wall failures *(See Photo 6)*. Large doors are not supplied by the metal building manufacturer, but are either selected by the builder or design professional for the project. This creates the potential for miscommunication or the selection of an incompatible door that does not have the same strength as the rest of the building envelope. Most metal building manufacturers stipulate in their letter of certification that they have assumed in their building design that the doors will support the same wind loads that the door jambs and support structure have been designed for. Some manufacturers have gone further and require a signed letter back from the responsible party for the doors in the order confirmation that stipulates that the proper doors have been selected that are compatible with the design assumption that the building is enclosed.

The door industry has also stepped up their efforts to improve performance of buildings in high winds [18-23]. The Door & Access Systems Manufacturers Association (DASMA) has available, and is also developing, a number of resources to clarify and educate those connected with the building industry on the relationship between wind loads and large doors such as garage doors and rolling doors. These resources are intended to aid in the process of effectively specifying these types of doors for buildings.

AISC Certification

To further ensure reliability, MBMA was the moving force behind an independent certification program administered by the American Institute of Steel Construction (AISC) for metal building systems. MBMA, whose members account for over 90% of the metal building systems market, has implemented a plan that will require that all of its members be AISC certified by the year 2000. This is a major endorsement of the quality that is expected of MBMA members and inherent in the AISC Certification program. The program ensures that a metal building system manufacturer has achieved a high level of competency in all aspects of design and fabrication. The purpose of the program as stated by AISC is to "confirm to the construction industry that a Certified structural steel fabricating plant has the personnel, organization, experience, procedures, knowledge, equipment, capability and commitment to produce fabricated steel of the required quality for a given category of structural steel work."

The certification program examines policies and procedures at each of the manufacturer's facilities, and the application of those policies and procedures to randomly selected projects. It consists of nearly 200 questions covering the areas of general management, engineering and drafting, procurement, manufacturing, and quality control. Inspection and evaluation teams from an independent auditing firm annually observe and evaluate the manufacturer in almost every aspect of operation to verify compliance with the detailed certification standards established by AISC, which has been setting steel construction standards and writing specifications for more than 75 years. As a result of all of these measures, architects, design professionals, building code officials and the insurance industry can be assured that certified metal building systems manufacturers are capable of meeting the industry's highest standards for product and design integrity.

Summary

Involvement in technical activities toward improving the performance of metal building systems has been a hallmark of MBMA over the years. MBMA has helped advance the industry by taking the lead in sponsoring millions of dollars of research conducted by many eminent investigators at prestigious universities. This research has elevated the state-of-the-art in such areas as wind loads on low-rise buildings, tapered member analysis and design, bolted end-plate connections, and cold-formed steel design. Many of these research efforts were a direct result of field observations such as those presented in this article.

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