10-31-1993

Attachment systems for curtain wall construction and maintenance requirements

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ABSTRACT

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Peter S. Donaghy

Curtain Wall construction has become a familiar and widely used method for enclosing structures. Since the 1950's this type of enclosure has become increasingly the most popular choice of Designers and Builders. During this period of development, however, acceptable and uniform building standards have not evolved to create adequate quality control.

This thesis investigates some of the design requirements of Curtain Walls, in particular the attachment system, and the maintenance costs that are directly related to the attachment system and the consequences of such failures.

ATTACHMENT SYSTEMS FOR CURTAIN WALL CONSTRUCTION AND MAINTENANCE REQUIREMENTS

by
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A Thesis
Submitted to The Faculty of
New Jersey Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Civil Engineering

Department of Civil and Environmental Engineering
October 1993

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APPROVAL PAGE

Attachment Systems for Curtain Wall Construction
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This thesis is dedicated to
Tass Campbell, soon to be Mrs. Donaghy

ACKNOWLEDGMENT

The author wishes to express his sincere gratitude to his supervisor Professor Edward Dauenheimer for his help throughout the preparation of this thesis.

Special thanks to Roland MacDowell for his willingness to provide technical input and pass on valuable experience. Thanks also to John Marcantonio and Gordon Smith for their help.

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INTRODUCTION

1.1 Defining a Curtain Wall

The strict definition of curtain wall construction is that of a building which incorporates exterior non-load bearing walls. That is, a curtain wall is a wall that divides space, is controllable and supports nothing but itself. William Lescazede defined the new wall as "an exterior wall which is non-load bearing and is supported at each floor by the structural framework of the building", in his report to the Porcelain Enamel Institute, (1). Therefore, in some instances, traditional building materials such as brick and block may constitute a curtain wall. That is if this masonry wall is non-load bearing.

In the early 1900's, the use of structural steel determined that buildings could now be built higher than previously thought possible. In addition to this, the advent of electric power and elevators meant these tall buildings could be serviced and accessible to people. In 1952, the Lever House Building was built on Park Avenue in New York City. This light weight metal and glass enclosure attached to the structural steel frame, was to become the most prominent and most easily recognizable curtain wall construction type (see figure 1.1).

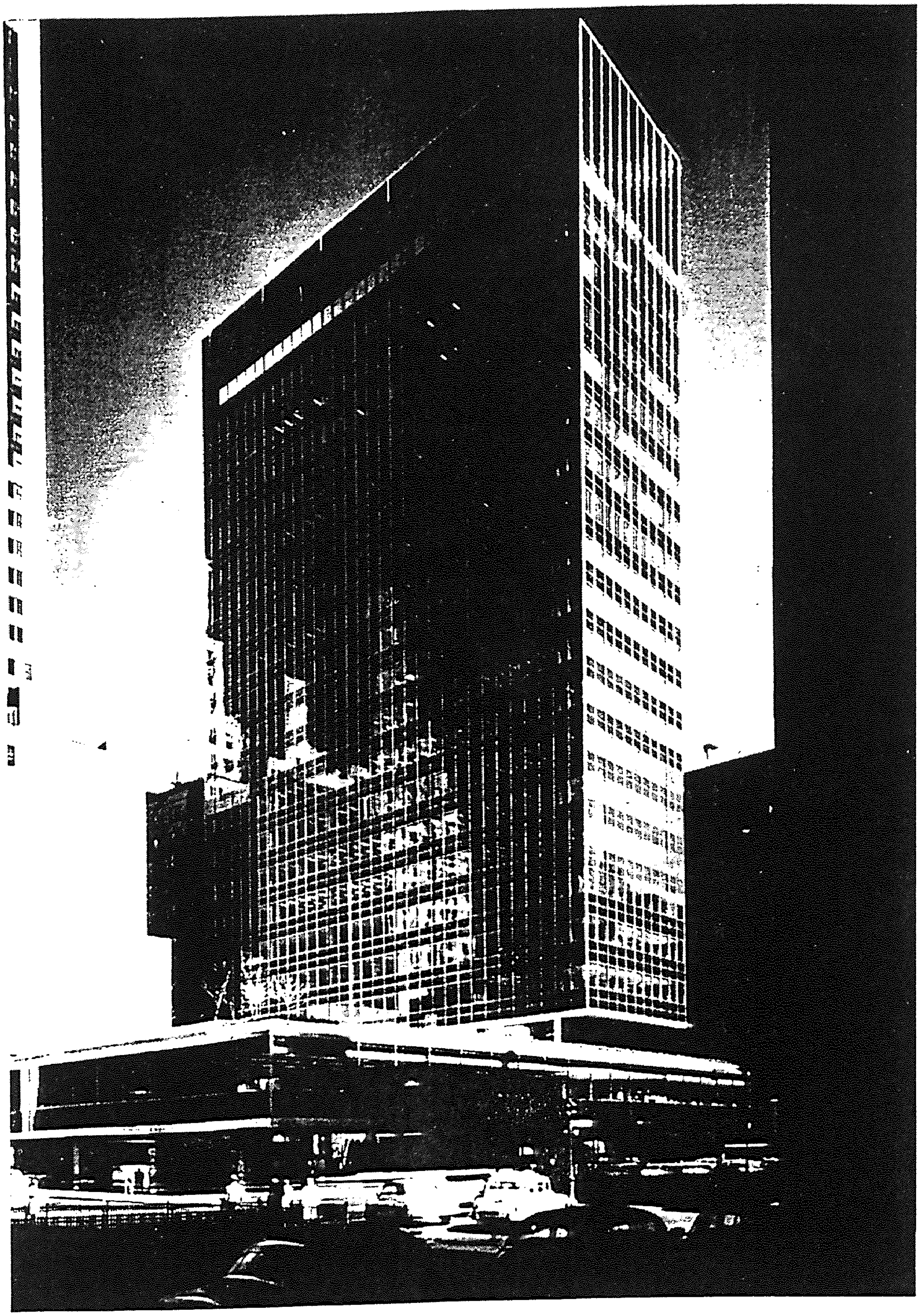


Figure 1.1 Lever House

It should be noted that many brick veneer walls and stone clad buildings, seen commonly in New York City, are also curtain wall type construction. It is possible that some analogies can be drawn between these types of structure (see figure 1.2 and 1.3). The cavity wall construction consists of a block back up separated from the brick veneer by a cavity. The block back up bears directly on the concrete floor slab and the brick veneer is supported by steel relieving angles which are bolted and/or welded to the structural steel spandrel beam. In some instances, the relieving angle may be attached directly to the concrete by means of inserts or anchors (discussed in Chapter 4). Figure 1.3 outlines the special attachment system that is required above openings. In this case, the relieving angle is attached to the structure using bolted angles which are "hung" from the structural steel.

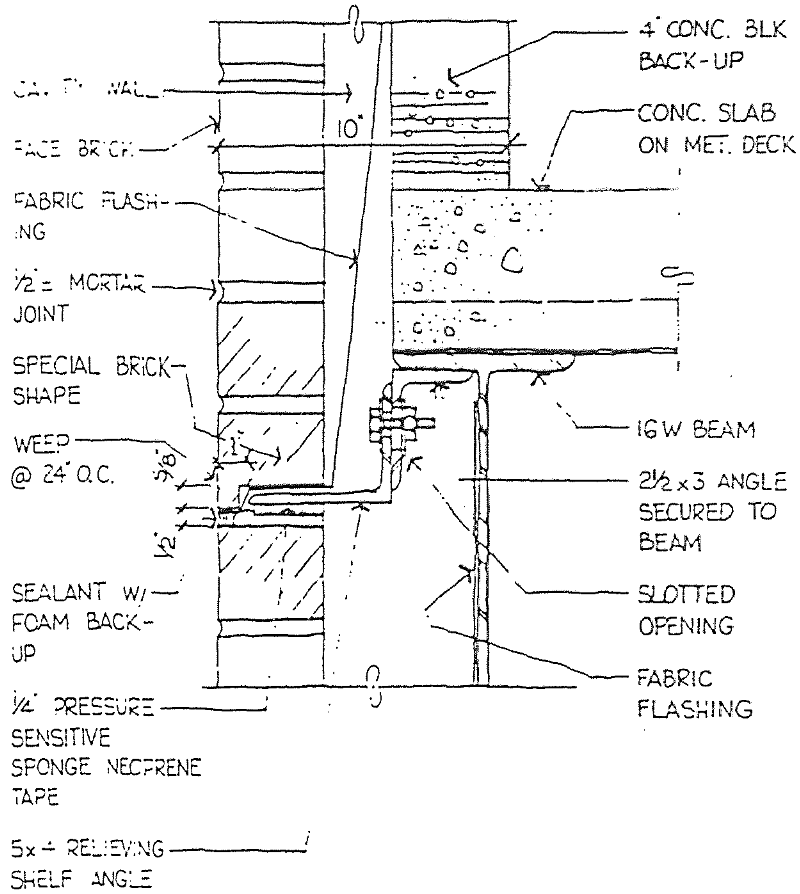


Figure 1.2 Brick Relieving Angle (3)

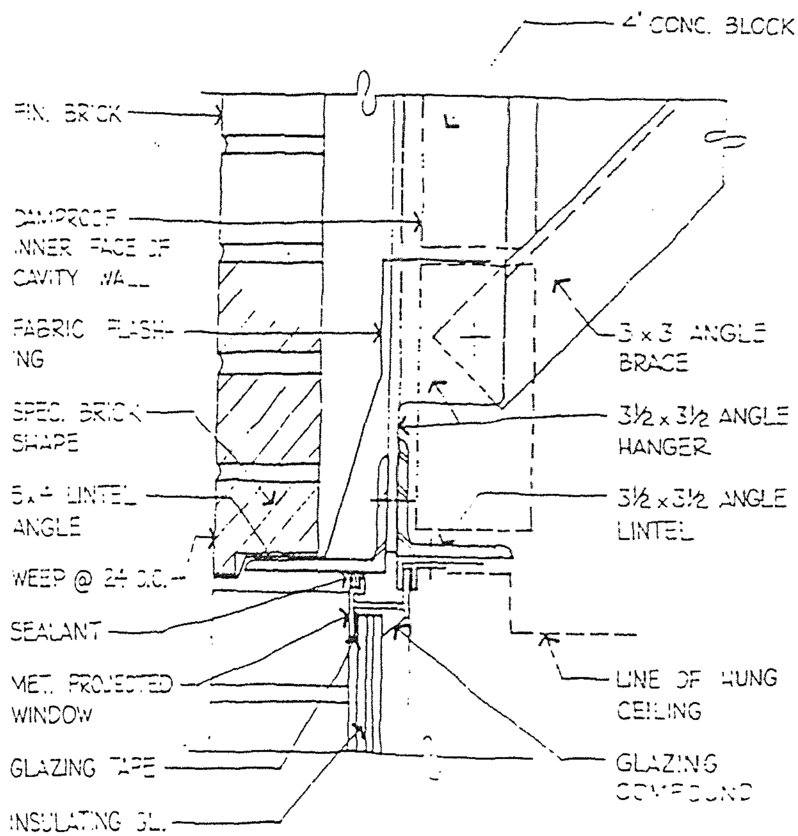


Figure 1.3 Relieving Angle at Window (3)

1.2 Development

Curtain wall construction has existed for centuries. Greek's and Romans used post and lintel construction filled in with masonry or concrete.

The 19th Century saw the first use of an iron frame as a structure and glass as a building material. The use of these materials was perfected in the Crystal Palace in 1851. In essence, Joseph Paxton, architect of the Crystal Palace, invented the putty method for installing glass (2). This determined that glass walls need not incorporate thick heavy frames. Crystal Palace was the first building to make use of prefabricated parts and a light framework made possible by the use of the a curtain wall.

An article in Illustrated London News, 5th of April, 1945, contained an interesting review by Edwin Chadwick of the Prototype House erected at the Paris Exhibition of 1867. Commenting on the design by Architect M.S. Ferrand, Mr. Chadwich states "The thickness of the double wall is 5", which, of course, would be insufficient for bearing purposes. But the wall is held together and the bearing power is obtained, on what I have termed the Crystal Palace Principle, by iron columns, beams and cross tees. Mr. Ferrand claims for this construction the advantages of walls which are thin, and which therefore saves space, and yet are warmer, resists changes of temperature, and are better known conductors of sound than the common brick or stone bearing walls, and at a lower cost..."(2). This review contains all the design advantages of the modern curtain wall.

In the next fifty years, many systems were developed to produce a light weight, prefabricated and less expensive building. Prefabricated elements were designed using all types of materials. In Great Britain, in the late 1920's, metal clad houses appeared more and more frequently. In the 1930's, there was a general return to load bearing construction. This was because traditional materials became plentiful and vast unemployment determined that the provision of work was more important than developing fast and inexpensive housing. However, during and after World War II, this economic environment reversed. Large numbers of experimental houses were designed and prototypes built. Technology developed during this period and the earlier 20's and 30's was used as a basis of the curtain wall development in the 1950's.

A research program was started in North America in 1946. The system was developed into one unit to complete a complex function of the wall (1). Two years later, the first panel, "entirely prefinished" was produced.

1.3 The Present

Today, architects have a large range of materials and building systems at their disposal. Precast concrete, stamped metal panels, vacuum form plastics and other light-weight materials are all available in virtually any shape and size. The modern curtain wall relies upon the combination of glass panels held in place by vertical and horizontal metal extrusions that span their supports between slab. There are however, many curtain wall buildings that are not easily recognized.

The Lever House Building (see figure 1.1), previously mentioned in Section 1.1, represents the beginning of the light weight curtain wall building in New York City. Since the 1950's, many similar buildings have been constructed in New York. However, prior to the 1950's, building practice determined that shelf angles for a brick veneer wall were not required at every floor. Indeed, some buildings in New York City have recently been found with twenty foot sections of shelf angles installed intermittently throughout the facade. It was not until the late 1950's that this practice changed to require continuous shelf angles at every floor. It seems that despite more efficient design and construction techniques, builders were slow to replace age-old construction practices. It is clear now that the masonry veneer serves no structural purpose. Therefore, to prevent masonry at lower levels from being crushed by the self-weight of the masonry veneer wall, shelf angles should be at each floor in order to carry the self-weight of the veneer from floor to floor. The owners of 425 Park Avenue, New York City are at present faced with the prospect of spending three to four million dollars to install shelf angles at each floor. This is a direct result of the masonry veneer wall being built to pre-1950 standards. In addition to the lack of shelf angles at every floor continuously, building standards did not require adequate brick ties to secure the veneer wall to the back up.

1.4 Maintenance Problems

On July 1, 1992, during approximately fifty mile per hour winds, two extruded aluminum panels (12'x4') became detached from the 57th floor of a building in mid-town Manhattan. These were attached to the structure by means of angle clips and were bolted with ferrous metal anchors (see figure 1.4). During this occurrence, there were no injuries and no damage to surrounding buildings.

This particular building had recently been inspected by a licensed engineer to detect any deterioration which could cause danger to the public (New York City Law requires that all buildings above six-stories be periodically inspected at least every five years - Local Law 10 of 1980).

It must be pointed out that the location of these panels did not require inspection in strict accordance with Local Law 10. However, since the cause of attachment failure was found to be weathering of the fastening system, how could a qualified inspector reasonably detect such deterioration by means of a hands on inspection? This leads us to the prospect, that attachment failure in curtain wall buildings would not be detected in the course of regular inspections.

Several years ago, the New York City newspaper reported that segments of brick were falling into the street of

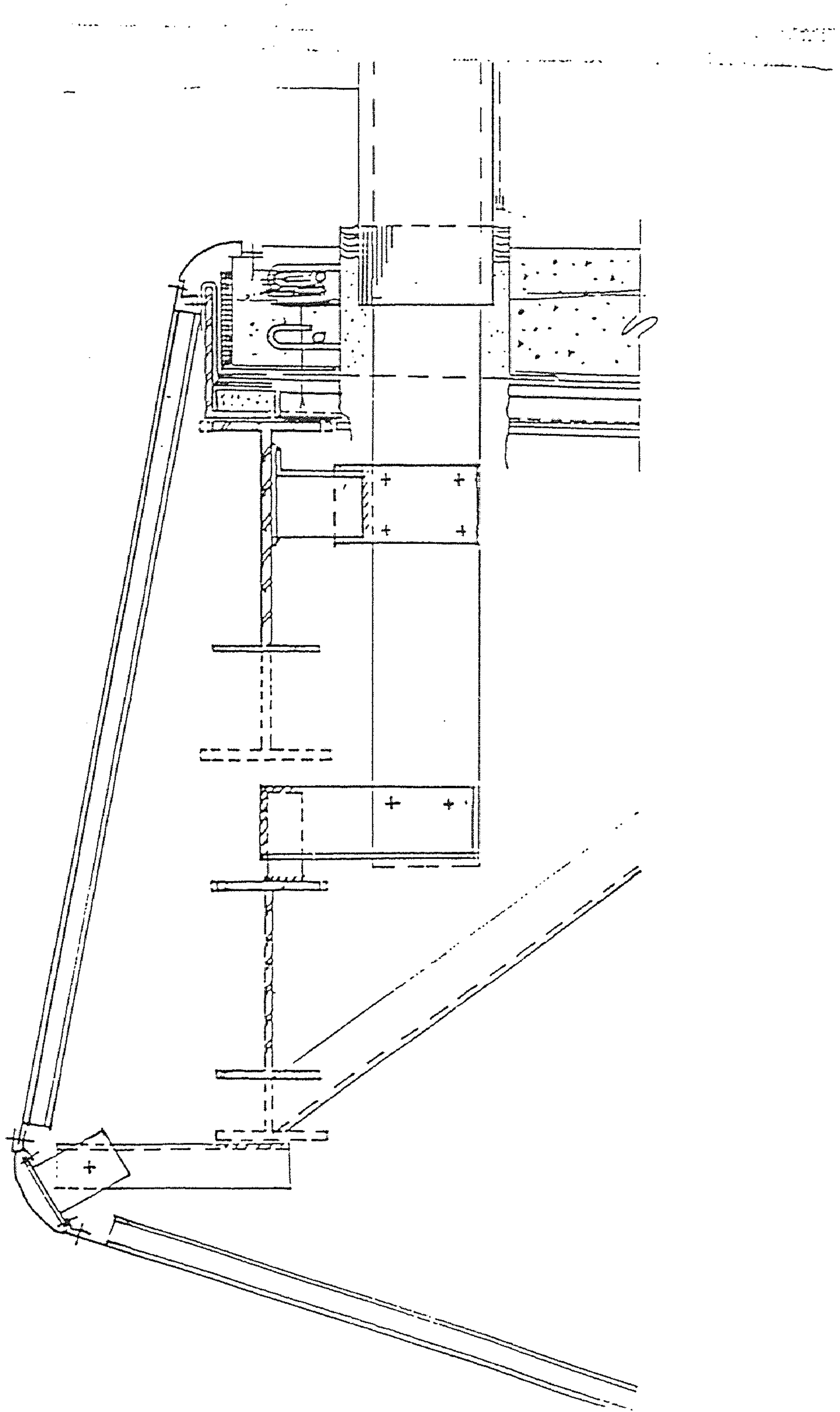


Figure 1.4 Attachment System for Extruded Aluminum Panels

Manhattan. Apparently, these bricks seemed to shoot explosively from the face of certain buildings (3). The design of this building incorporated shelf angles which were designed to carry the exterior face brick from floor to floor. The joint below the angle was filled with mortar and debris which had hardened, thus the shelf angle no longer transferred weight to the spandrel beam, but transferred the weight to the brick below causing bricks to be forced from the face of the building.

The aforementioned incidents would seem to indicate that both masonry curtain walls and "traditional"light weight metal curtain walls can be prone to failure. Given that many curtain wall buildings in New York are over 30 years old, this Thesis proposes that the City will see an increasing need to address curtain wall failure and/or maintenance. The 1970's witnessed a large increase in brick failure at spandrels and columns. A complete industry has developed with many contractors specializing in "waterproofing work". This work includes removing bulging brick, treating exposed steel rebuilding brick to include flashing and drainage and installation of flexible compression relief at the angles .

A major problem associated with light weight metal curtain wall refurbishment is the lack of tell-tale signs. Unlike masonry veneer walls, many curtain walls will show no signs of possible attachment failure.

It is clear that curtain walls have their share of maintenance problems. In 1988, curtain wall problems became the most common owner complaint, surging ahead of the traditional roofing problem complaint (9).

CHAPTER 2

DESIGN OF CURTAIN WALLS

2.1 Function of a Curtain Wall

Curtain walls are designed to meet basic functional requirements (see figure 2.1).

1. Separate exterior from interior.
2. Provide selective filter (windows and doors).
3. Make Building weatherproof and windproof.

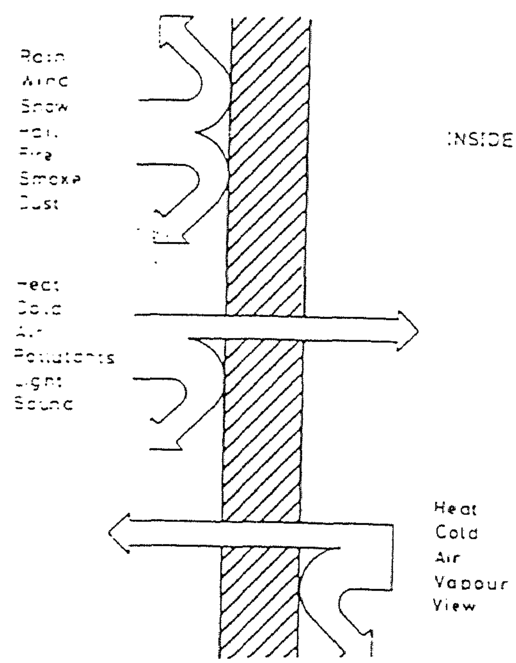


Figure 2.1 Functional Requirements of a Curtain Wall (3)

In addition to these functional requirements, a curtain wall must also meet the following design criteria:

1. Wind loading
2. Movement
3. Moisture Control
4. Thermal and Sound Insulation
5. Attachment

2.2 Wind Loading

All buildings must be designed to withstand wind-loading. In New York City, this wind loading can be as much as 80 to 100 miles per hour. In other parts of the country, the wind speed may be as high as 200 miles per hour. The American standards ANSI A-58.1/1982 is entitled "minimum design wind loads...buildings and structures." This standard details the design requirements for wind loads (see figure 2.2) (7). Depending on how tall the building is, facade design loads increase. However, these facade loads do not account for the wind tunnel effect occurring in built up areas. The standards requires design loading that is constant from floor to floor. At a certain elevation above grade, the design load requirement is increased. However, wind tunnel tests show that pressure distribution on the facade of a multi-story building is by no means linear (see figures 2.2 and 2.3). (4) This variation is caused by the effect of surrounding buildings and turbulence

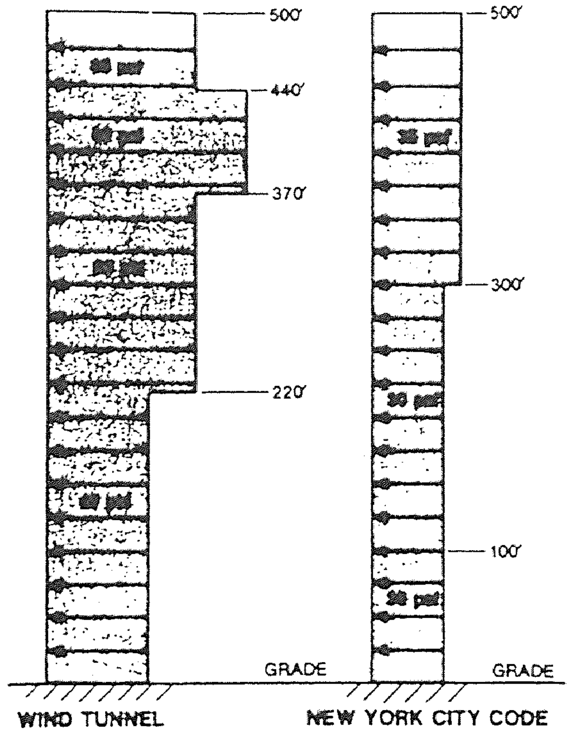


Figure 2.2 ANSI Design Standards (ENR Magazine) (7)

Around the building as wind passes by it. For instance; the pressure at the leeward corner of a building may be as much as 73 pounds per square foot. Other areas may be subject to less than 37 pounds per square foot.

Depending on the curtain wall type, design must account for the possibility of negative pressure occurring particularity at higher elevations.

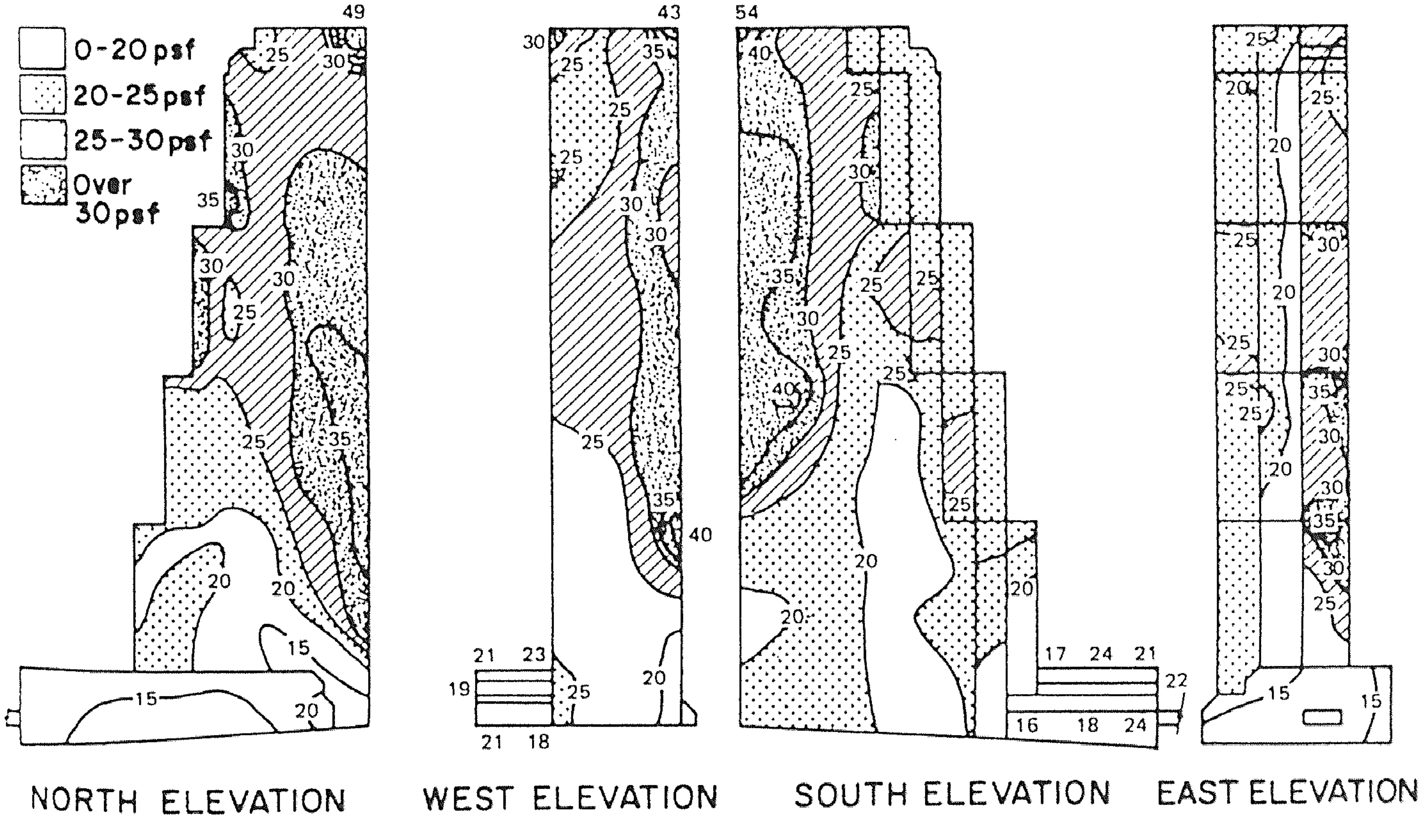


Figure 6-17 Contours illustrate test results showing that wind pressure on the facade of this building varies widely. *(ENR.)*

Figure 2.3 Wind Pressure on Scale Model (7)

In Houston Texas, the uniform building code requires that buildings must be designed to withstand 90 mile per hour winds. In the last few years, many hurricanes in this area have exceeded these designed velocities. Panels have been known to separate from the building curtain wall, leading to further separations as the adjacent panels will then peel away. Recently, the Airport Moto Enterprises of Texas hired Quest Engineering Development Company - Humble, Texas to design a retrofit to prevent panel separation. (10) This incorporated resecuring all panels to the structure and tightening all joints against water and air infiltration. Horizontal structural elements were fastened through the panel to the structure using 3-1/2" self tightening screws. This expensive retrofit was primarily commissioned to prevent wind damage.

In an average year, hurricanes and tornadoes caused five billion dollars in property damage and more that three hundred deaths in the United States. This is far more costly than other natural disasters including earthquakes and floods.

2.3 Movement

Curtain walls systems are designed to withstand structure movement. This can be caused by the following:

1. Thermal expansion and contraction
2. Deformations and movements in the building structure (creep, elastic deformations, settlements).

For example, building columns will sway causing stress on the curtain walls panels and/or attachments (see figure 2.4). This problem may be alleviated by the design of connections to allow movement. That is, the joint on the perimeter of the panel, must have some capacity to enlarge or contract. Typically in construction, this would lead to the design of a caulked detail. However, for reasons discussed later, this may not necessarily be the best solution for a curtain wall system.

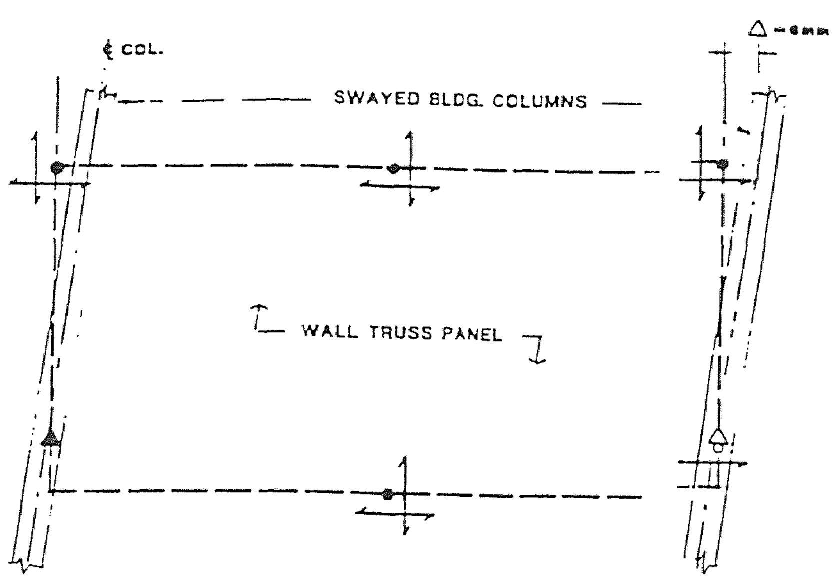


Figure 2.4 Panel Movement (4)

2.4 Moisture Control

Metal and glass are not impermeable to moisture, but have a low heat retention capacity leading to possible condensation within the wall. Therefore, a vapor barrier is required, usually attached to the room side of the wall. Impervious materials should be utilized and insulated in order to keep temperatures higher than the dewpoint of the incoming air. At the same time, water vapor must be allowed to escape to the outside. Failing this, provisions should be made for any water condensation within the wall to drain away from the wall, via weeps

2.5 Thermal and Sound Insulation

Thermal and condensation resistance of the wall will help minimize heat loss in the cold weather or heat gain in hot weather. High performance glass, thermal breaks, and insulating surfaces are recommended for this purpose. At the same time, insulation and laminated glass may be used in order to increase the mass of the wall and reduce the transmission of sound.

2.6 Attachment Detail

Attachment of a curtain wall systems is one of the most important design factors and must have the following characteristics.

Adjustment:
On site assembly of curtain wall systems are designed to allow for three way adjustment. That is, attachment brackets must allow for on site adjustment in three directions (see figure 2.5).

Strength:
Attachment brackets, connecting bolts, and anchors are designed to withstand full design loads. In particular, care must be taken when choosing the materials to be used.

Durability:
All components of the attachment system must be resistant to corrosion. Not only must weathering be taken into account, but also bimetallic corrosion. That is the electrolytic action between two dissimilar metals.

The design and installation of panel attachment is discussed in more detail in Chapter 4.

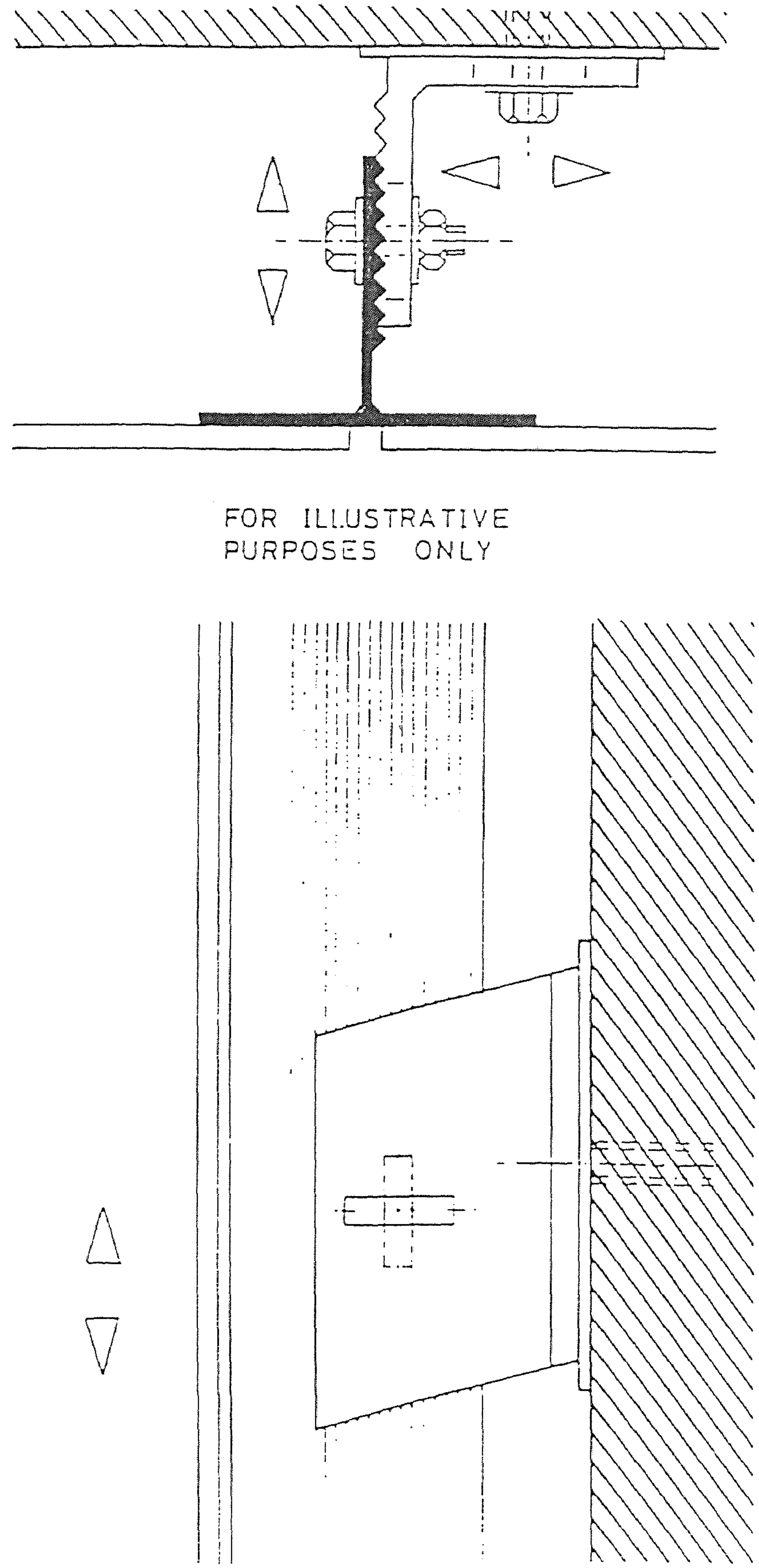


Figure 2.5 Adjustment of Attachment System (3)

2.7 Controlling Water Infiltration

There are three methods by which a curtain wall will prevent water infiltration

1. Prevent all infiltration through the outermost curtain wall skin.

2. Design of an in-wall drainage system.

3. Shield the curtain wall with overhanging roofs and setbacks.

The single outer skin barrier system is subject to many design problems. Joint design is in this case critical and subject to failure. Even the most carefully designed system incorporating joint sealants can fail. Additionally, cracking and porosity will occur. Therefore, the second method of controlling water infiltration is by far the best method.

Care must be taken in design to accommodate the three dimensional reality of joints and attachments (9). Water can move laterally behind walls which causes problems. Vertical and horizontal joints are also an important design consideration, but not always considered.

CHAPTER 3

TESTING

3.1 Introduction

Performance testing is a tool used to predict the performance of curtain wall systems in place. They are also used to check compliance with recognized standards. However, the limitations to each of these test must be understood, therefore each test must be judged individually in accordance with the simulated condition and its relation to the real conditions. Limitations of such tests include the following:

1. Workmanship
2. Site conditions
3. Alignment of the building structure.
4. Quality of the building material.
5. Effect of time

It is clear that performance testing is closely related to an understanding of the overall design and detailing of the building of the curtain wall.

The test sample used in any testing should be as close a reproduction of the installed curtain wall as possible. This includes details such as windows, doors and copings. The size of the sample should also be adequate,at least one story high and as many as three modules wide (5).

The attachment detail should also match the worst loading condition. That is the attachment brackets must be installed at the extreme of their adjustment capability.

Given the above requirements, it is clear that testing can and should be a relatively expensive procedure that must be carefully considered and planned.

Therefore, it is beneficial to test each sample in as many ways as possible before determining its performance.

The suggested sequence of tests (5) for the same test sample is the following:

1. Air infiltration
2. Water penetration
3. Wind loading
4. Fatigue
5. Impact resistance

3.2 Air Infiltration

Air infiltration tests are carried out using static weather testing apparatus. In this test, constant and steady pressure is applied to the curtain wall surface by wind force. Natural wind force is simulated using propellers or blowers (assumption, pressure is uniformly distributed over the test area). Simple calculations determine that a certain wind velocity will provide a certain pressure. As a base line, 25 miles per hour is used. (6)

Air infiltration is measured in cubic feet per minute. The required wind velocity is applied to the exterior face of the sample and the infiltrated air is gathered on the inside face of the sample. The air is allowed to pass a small orifice, calibrated in order to determine the value of air passing through. The total volume of air in CFM is then computed to find the CFM per lineal foot around the perimeter of the test sample.

3.3 Water Penetration

Water penetration tests can be carried out in a static pressure chamber as detailed in Section 3.2, however these tests have important limitation for the most part. This test does not simulate the conditions at a curtain wall and does not experience water that is forced into the vertical and horizontal joints. Additionally, sample curtain wall assemblies rarely have a pressure differential between exterior and interior which of course, is the actual condition that the test is intended to simulate (see figure 3.2).

An alternative to this method is the dynamic testing method. In this test an attempt is made to duplicate the variable wind pressures on a curtain wall building. Pressure generated by wind forces on a building are not completely determinable. That is, the effect of wind force on the building is a function of the building's height and shape, surrounding structures, and surrounding terrain. In addition to this, stresses caused by varying wind forces are an important factor to be considered. This factor is taken into account when using the Marvin Formula (6).

This formula states that $P = 0.004V^2$

P is pressure in pounds per square foot

V is the velocity in miles per hour.

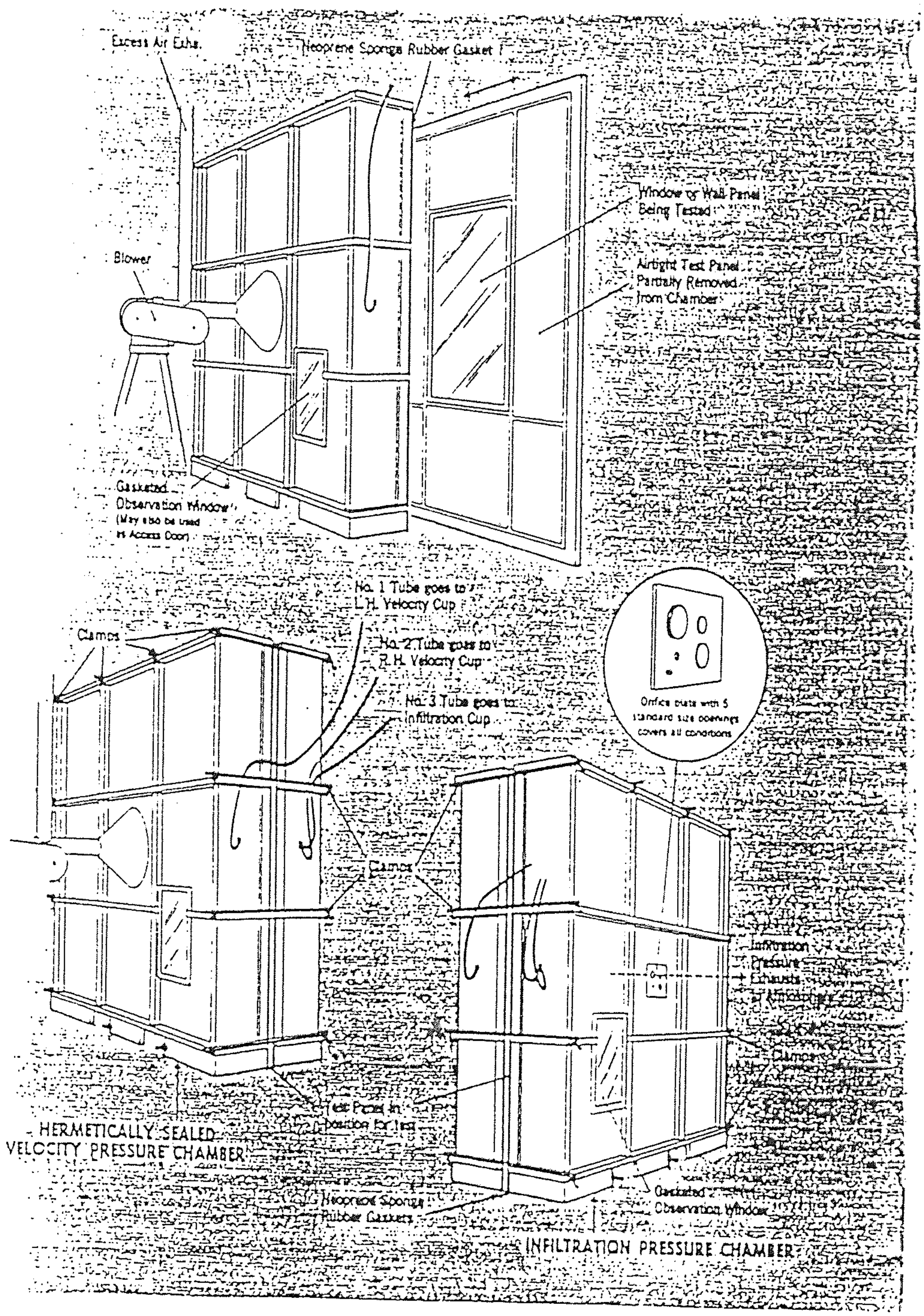


Figure 3.2 Water Penetration test (6)

That is, a wind speed of 25 miles per hour will produce a pressure of 2.5 pounds per square foot and 100 mile per hour produces a pressure of 40 pounds per square foot.

In this dynamic test, wind is simulated by the use of a large wind generator (or fan). These are positioned on the outside face of the sample curtain wall (see figure 3.3). Rainfall in simulated by introducing a water stream into the wind stream generated by the fans. This water will be forced horizontally until it strikes the curtain wall surface. At other locations, mainly above and each side of the test sample, more water is introduced into the test.

Water penetrating the sample curtain wall is measured in gallons per minute and can be adjusted to inches per hour for varying wind pressures. At this time, other tests may be carried out. Gauges attached to the rear of the test sample can be used to measure the water, while static tubes can record the pressure at the face of the sample. In reality, turbulence is present in a layer of air built up close to the structure. That is, the approach velocity of a steady wind will decrease as it approaches the face of a building causing increased pressure to the same face.

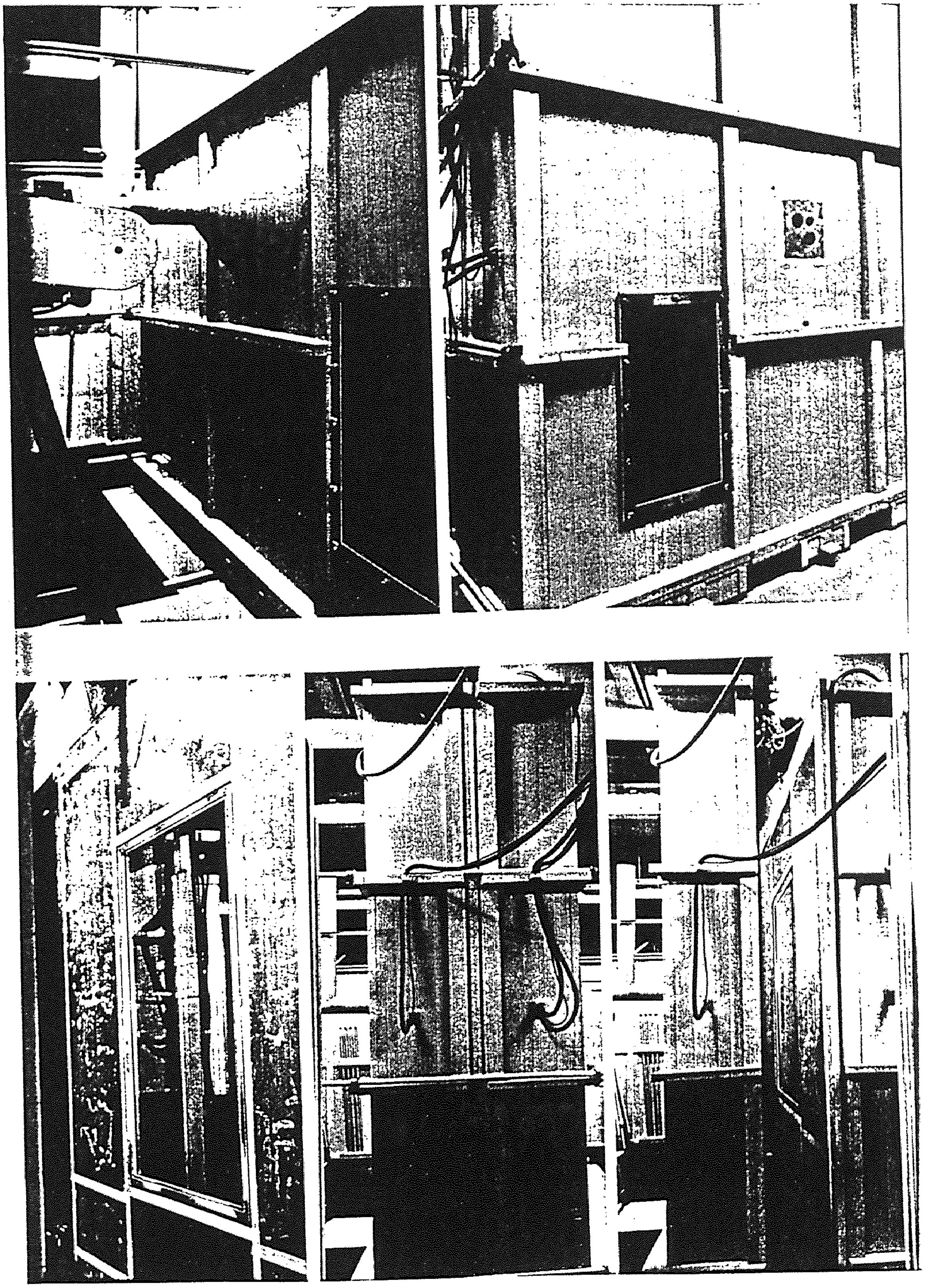
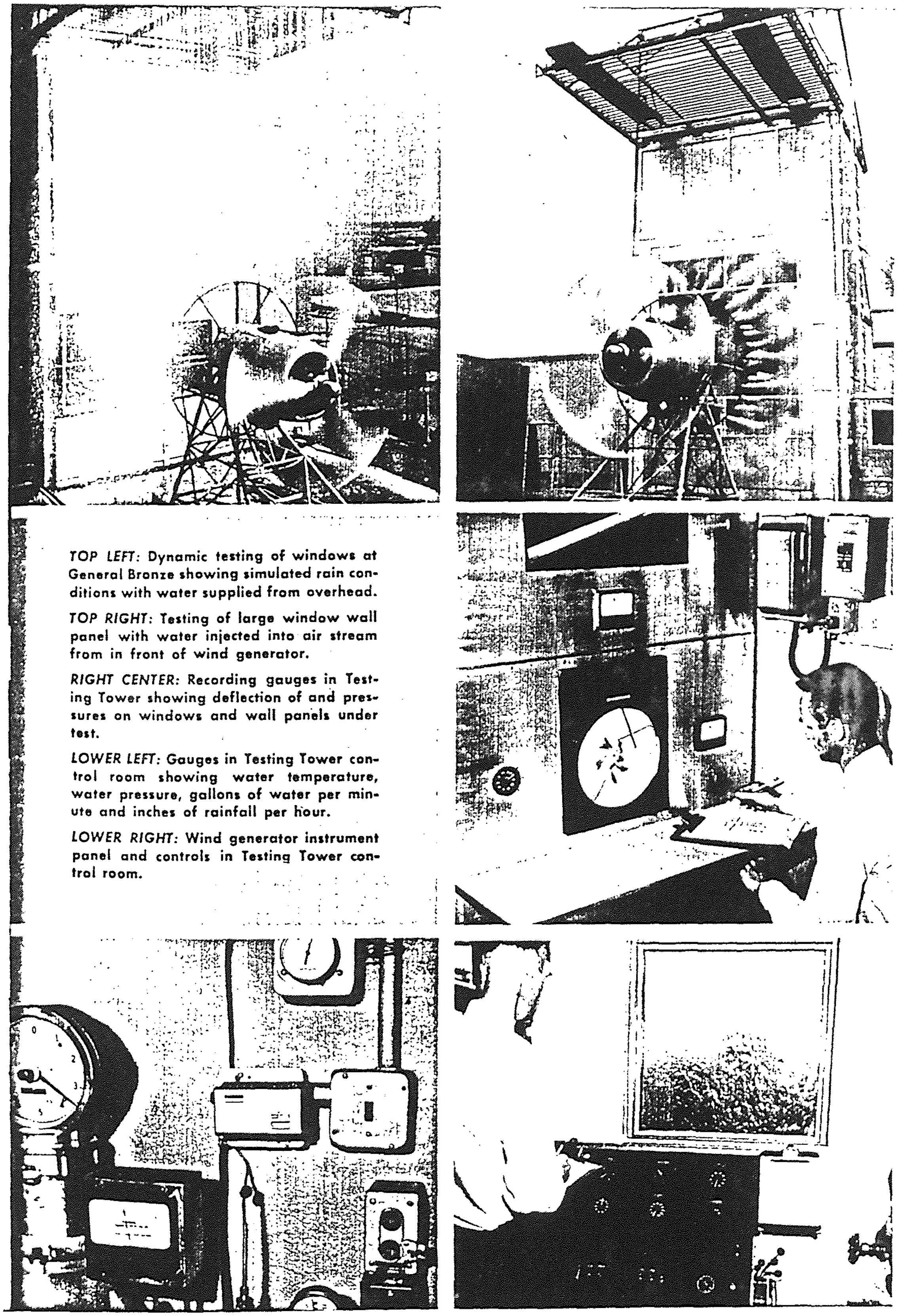


Figure 3.3 Dynamic Testing (6)



TOP LEFT: Dynamic testing of windows at General Bronze showing simulated rain conditions with water supplied from overhead.

TOP RIGHT: Testing of large window wall panel with water injected into air stream from in front of wind generator.

RIGHT CENTER: Recording gauges in Testing Tower showing deflection of and pressures on windows and wall panels under test.

LOWER LEFT: Gauges in Testing Tower control room showing water temperature, water pressure, gallons of water per minute and inches of rainfall per hour.

LOWER RIGHT: Wind generator instrument panel and controls in Testing Tower control room.

Figure 3.4 Dynamic Test Equipment (6)

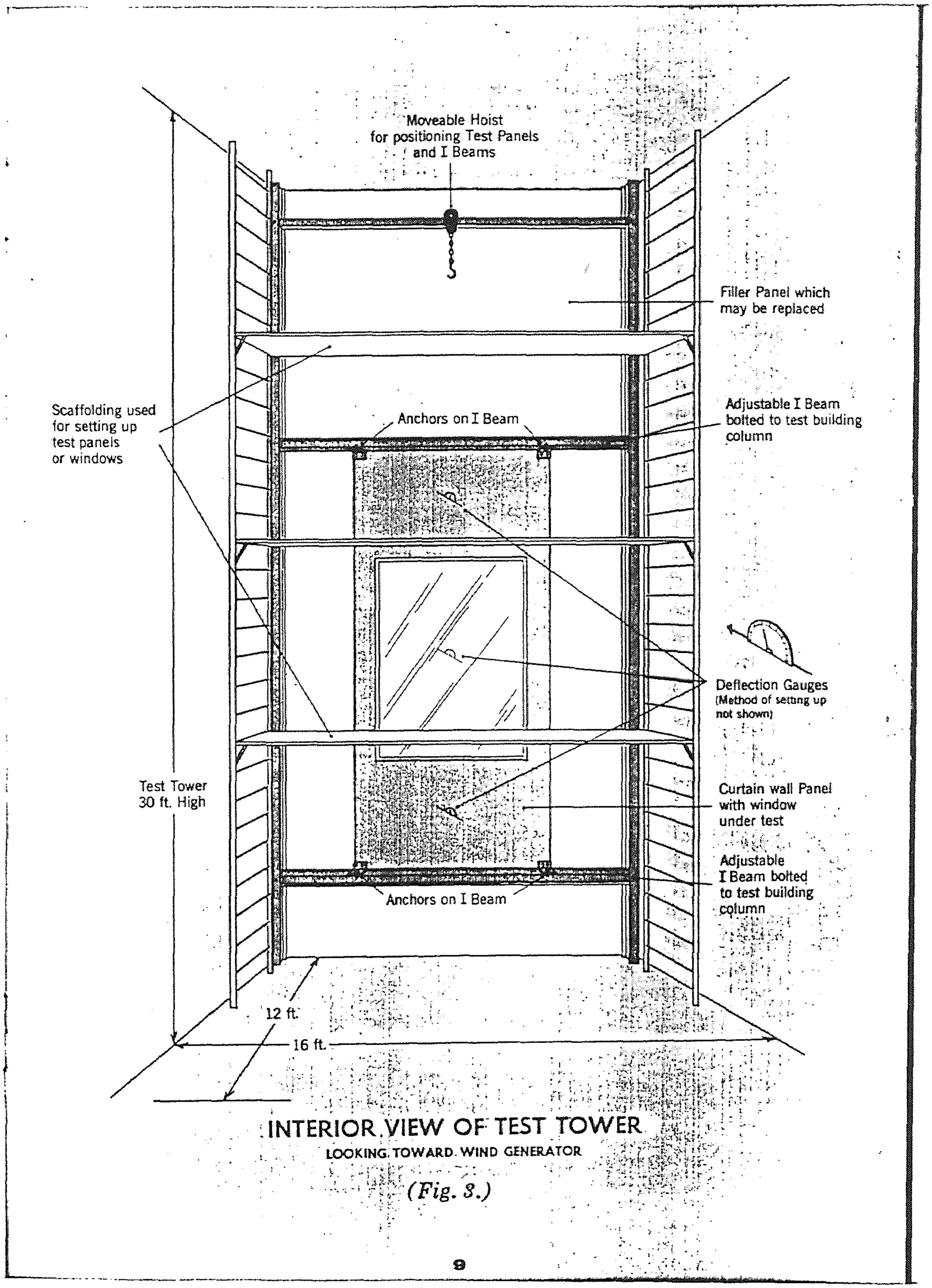


Figure 3.5 Interior View Dynamic Test (6)

CHAPTER 4

ATTACHMENT

4.1 Introduction

One of the most important design factors involved in curtain wall construction is the attachment to the structure of the building. Early curtain walls involved supporting masonry walls either directly on spandrel beams ,lintels or shelf angles attached to the beam, (see figure 1.2). The contemporary wall requires a different approach. The building structure does not necessarily have perfect alignment. Also, tall buildings sway due to wind loading. Another design requirement for curtain wall attachment, is the relatively large expansion and contraction of modern materials compared to traditional masonry walls. Therefore, the design of curtain wall attachments must take into account many conditions and requirements. Usually designers make use of spandrel beams in order to support curtain walls at each floor.

4.2 Design Requirements

The attachment should be strong enough to resist gravity and wind forces that it will be subject to. They should also be corrosion resistant in order to retain their strength over long periods. In addition to this, this attachment must be flexible. That is three dimensional adjustment must be available in order to compensate for building tolerances accumulated during erection of the primary structure.

The design of the attachment detail must also allow for the movement of the building structure and the expansion and contraction of the curtain wall itself.

The attachment detail should be easily installed if possible. These attachments should be installed from the interior of the building, eliminating the requirement for scaffolding on the outside of the building.

The fireproofing requirements of the spandrel beams will also effect the attachment detail. The attachment detail should be easily disassembled in order to facilitate maintenance and/or replacement of the units. Last and certainly not least, the attachment detail should be economically feasible.

4.3 Metal Inserts

Slotted metal inserts are often specified as the attachment for curtain wall units. This is most often used for reinforced concrete frame buildings. (see figure 4.1) Metal inserts are cast into the concrete spandrel beams. These are designed to receive 1/4" to 3/4" bolts. In addition to this, these inserts are designed to allow flexibility during installation, that is building tolerances are allowed for.

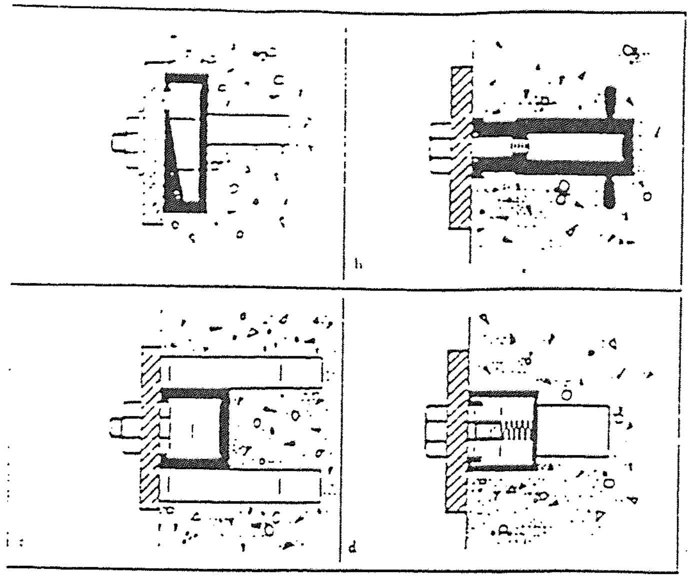


Figure 4.1 Metal Inserts

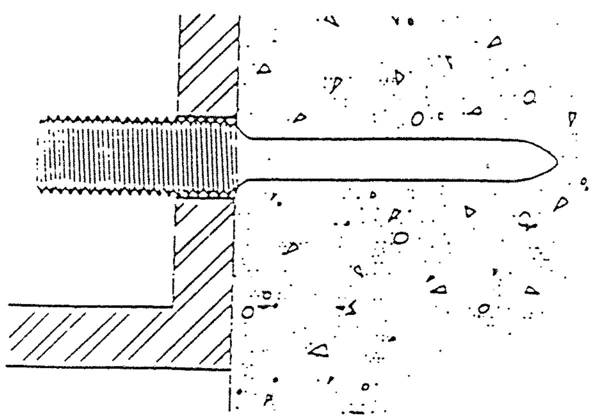


Figure 4.2 Powder Actuared Detail

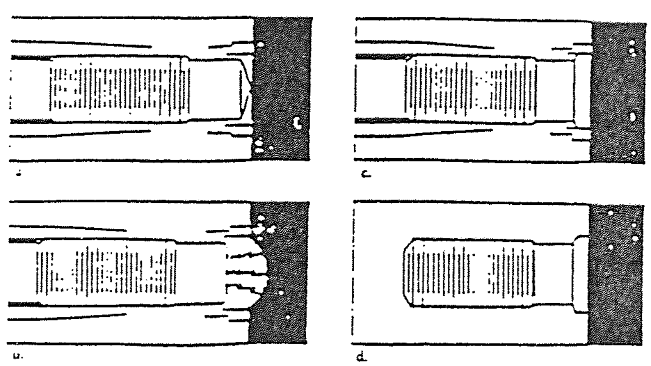


Figure 4.3 Stud Welding Attachment

4.4 Powder Actuated Fasteners

These fasteners are driven into steel or concrete with special power guns. (see figure 4.2) The exposed portion of this fastener may be internally or externally threaded allowing attachment directly to this fastener.

4.5 Stud Welding

This is usually used to attach studs to the steel frame. Special equipment is used in order to press the stud against the steel. An electric arc is created between the end of the stud and the steel, melting the tip of the stud, thereby, welding the stud to the steel.(see figure 4.3) These studs provide strong attachment to the structure, however, they cannot be easily moved or adjusted.

4.6 Bolting

In some instances Structural Steel is used in order to secure the Curtain Wall. Angles are bolted either directly to the Structural Steel or by means of a steel framework (see figure 1.4). In this instance a combination of welded and bolted connections are used.

CHAPTER 5

CORROSION OF METALS

5.1 Introduction

Corrosion of metals is a huge problem for Engineers. Each year millions of dollars are spent either preventing or rectifing corrosion of metals.

5.2 Galvanic Corrosion

Galvanic action occurs between dissimilar metals or between materials that can carry an electric current. The galvanic series lists metals in order of least noble to most noble.

Zinc	<u>Least Noble</u>
Aluminum 1100	
Catamium Aluminum 2024/T4	
Steel, iron, cast iron	
Cromium Iron	
Ni/Resist	
Type 304, 316 Stainless Steel	
Lead, tin	
Nickel	
Hastelloy "B"	
Bronzes, copper	
Silver solder	
Nickel (passive)	
Chromium Iron	
Type 304, 316 Stainless Steel	
Silver	
Graphite gold, platinum	<u>Most Noble</u>

The farther apart two metals are on the list, the greater the deterioration of the Least Noble Metal.

5.3 Pitting

Other types of corrosion are pitting and concentration cell corrosion. Pitting occurs when bubbles of gas are deposited on the metal surface. Oxygen deficiency under this area sets up an Anodic area causing pitting.

5.4 Corrosive Environments

Corrosion occours in three environments; the atmosphere, under water, and in the soil. Therefore, it is in the atmosphere with the presence of moisture that most deterioration occurs. Oxygen must be present to combine with the hydrogen released by the metal. This further determines the need for adequate protection and/or drainage within a curtain wall to prevent deterioration of the attachment system.

CHAPTER 6

CASE HISTORIES

6.1 National Air and Space Museum

Construction for the National Air and Space Museum in Washington, DC was started in 1974 (see figure 6.1). Leakage began soon afterwards and has been a constant problem. It was found that failure occurred at the skylight corners. These skylights were tested using mockups. During testing, it was found that water penetrated the corner of the skylights. However, workers applied enough sealant at these corners to prevent leakage and therefore the mockups passed the test. A gutter system weaved through the five hundred skylights also failed. This was due to long-term deterioration of the materials used. It was impossible for short-term testing to expose this deterioration. (9)

In this case, the correct procedure was followed. However, between design and construction, the inherent problems were not identified and solved prior to construction. Non representative mockup and improper design lead to a curtain wall building with many problems. In addition to this, inadequate review of shop drawings did not intercept this design flaw.

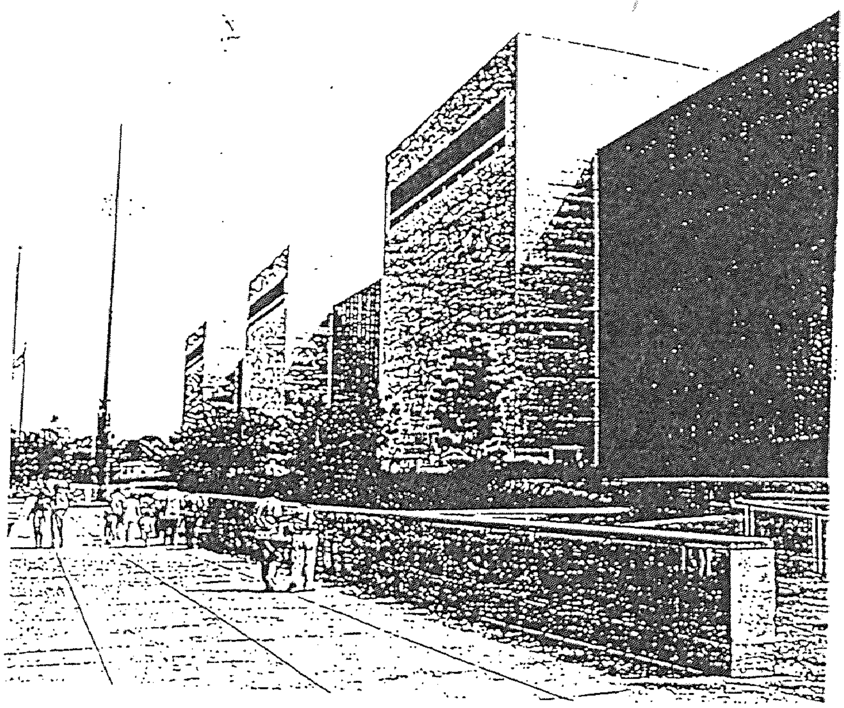


Figure 6.1 National Air and Space Museum

6.2 Tempered Glass Failure

A tall office building in Phoenix, Arizona includes 1900 panes of spandrel glass .

Tempered glass is commonly used in spandrel areas because of the heat that builds up behind the spandrel. Tempered glass has higher mechanical and thermal endurance.

One hundred and sixty panes of shattered glass have already been replaced in the 12-story building in Phoenix. It is proposed that the remaining 1900 panes of glass will have to be replaced. The City of Phoenix officials could find no deficiencies in the tower construction or design. However, it was found that the tempered glass has higher than normal levels of impurities, particularly nickel sulfide and carbon sulfide. This determines that the tempered glass is more vulnerable to stresses created by the impurities (11).

Indeed, it was found that tempered glass had been cited in previous cases of spandrel glass failure. A 43-story building in Chicago, 30 North LaSalle Street, recorded dozens of broken panels. Similiarily, 1818 Market Street in Philadelphia recorded 26 spandrel panels broken or cracked. In each case, tempered glass, 1/4" thick and were identified as the cause of failure.

6.3 Sheraton Hotel and Convention Center (10)

The Airport Hotel Enterprises, Texas commissioned Quest Engineering Development Company to design a retrofit system for the Sheraton Hotel and Convention Center. In this case, wind damage in Houston had caused the designed wind loading requirements to be increased. It was decided to reattach the curtain wall through the panels to the structure behind (see figure 6.2).

Specially fabricated extruded aluminum beams were attached to the concrete columns using 10-1/4" studs which were installed through the existing panels. This effectively resecured the panels to the structure. In addition to this, "L" clips were attached to the interior floor slab and subsequently attached to the stud system which formed the frame work for the curtain wall.

In order to reach the interior side of the stud wall, carpets had to be removed in the hotel rooms and dry wall sections had to be removed and subsequently patched. During construction in 1986, all the joints were resealed to prevent water infiltration. This retrofit was caused by the changing standards, however, we can see that the attachment of the curtain wall to the structure was deemed to be an important part of the design. A lot of money was spent in order to attach the curtain wall in a double system.

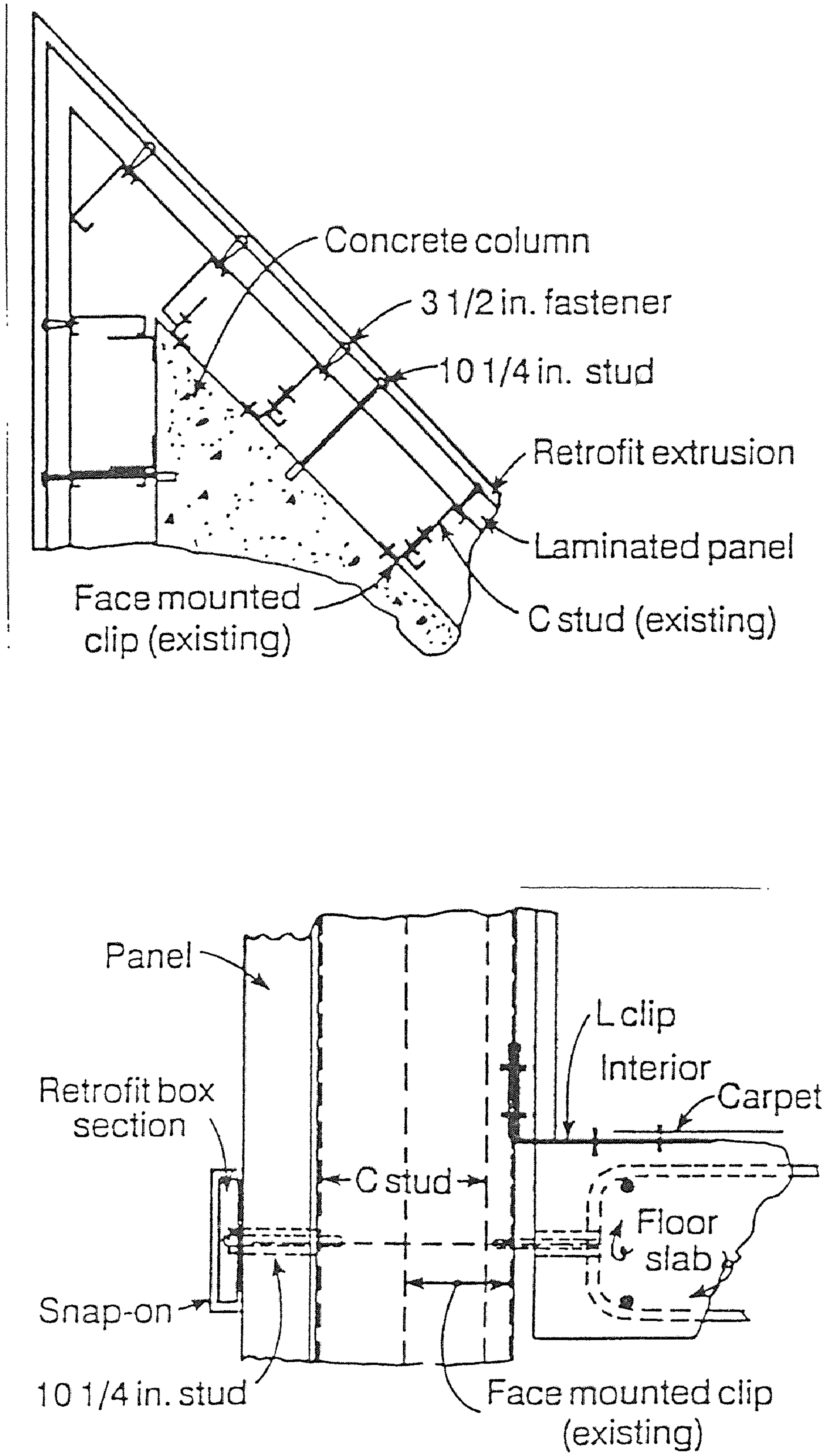


Figure 6.2 Retrofit System (10)

6.4 3DI Tower, Houston

Built in 1978, Houston 3DI tower was a centerpiece attraction advertized in brochures (12). By November 1992, Harvey Construction Company is embroiled in legal action relating to severely delaminating panels. The curtain wall was designed and built by Cupples Products, St. Louis.

A repair plan is currently under consideration. This plan involves constructing a new skin around the existing one. It is estimated that this would cost $4.6 million dollars.

Harvey Construction claims that the edges of panels were not sealed causing moisture to penetrate the outer skin.

Galvanic action between dissimilar metals then lead to serious deterioration of, the attachment system.

The question now remains whether improper installation, design or both lead to this failure.

6.5 Pan Am Building, Manhattan

Section 1.4 details the failure of Aluminum panels atop the Pan Am building in Manhattan, (see figure 1.4). A caulked joint at the top of the panel failed and subsequently caused the failure of the whole system. Water infiltrated behind the panels and caused galvanic action between the steel screws and the aluminum panel. It was found that many of the spacers installed at the angle were completely deteriorated.

A Stud Weld system was designed to re-attach the top of the panel to the structural steel, (see figure 6.3). These were drilled directly through the panel and welded to the structural steel behind. The success of this system can be measured by the fact that New York has endured two 100 miles per hour storms in the latter part of 1992.(Note; these panels failed during 50 mph winds). However, inspection and repair will be extremely difficult and expensive at some future date.

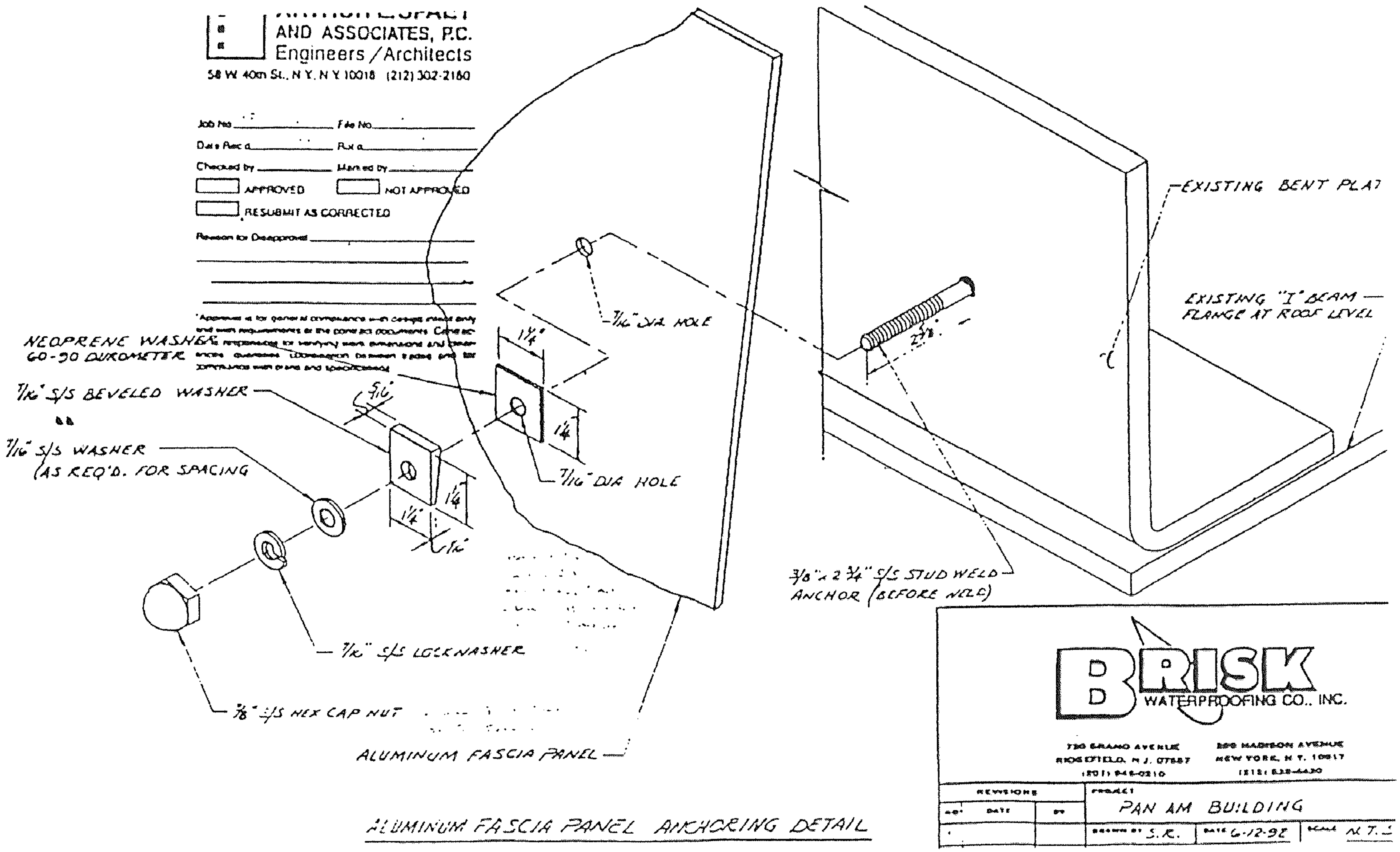


Figure 6.3 Stud Welding attachment

CHAPTER 7

ECONOMICS OF CURTAIN WALLS

7.1 Introduction

Cost analysis relating to Curtain Walls versus other building enclosures is very difficult to compile. There are many factors involved which can cloud any information gathering process. These will be discussed in more detail later.

In 1982 the Department of Environment, Property Services Agency, attempted to describe the cost appraisal of three building types,(16). The following categories were designated as the main expenditure groups;

1. construction cost
2. maintenance, repairs and improvements to the building facade.
3. maintenance, repairs and improvements to mechanical and electric service.
4. interior decorations.
5. exterior decorations.
6. running costs, eg.fuel etc.
7. cleaning
8. overheads and management

Coincidently, the Building Owners and Managers Association (BOMA) produce a yearly "Experience and Exchange Report",(17). Within this report expense categories are presented thus:

1. cleaning
2. repair and maintenance
3. utilities
4. administration
5. fixed Expenses
6. leasing Expenses

There are obviously some similarities between these reports. Not surprising since both reports are intended for owners and managers. The BOMA report is intended to give a "snap shot" picture of average expenses for one particular year.The PSA report was intended to provide an estimate of expenses over the design life of three types of buildings. This thesis will attempt to interpolate between these reports and evaluate the cost of enclosure repairs and maintenance.

7.2 Basic Data

For the purposes of this Thesis, the following Building characteristics will be used;

	Building A	Building B
Type	Traditional(masonry)	Curtain Wall
Design Life	60 Years	40 Years
Initial Cost	$68.40/sf	$62.70/sf
Size	200,000 sf	200,000 sf
Rate of Interest	10%	10%
Maintenance Costs	$27,000(+670/year)	$40,000 (+1000/year)
Residual Value	Land Only	Land Only
Replacement Cost	Nil (for comparison)	$30.00/sf

Figure 7.1 and 7.2 represent the analysis of the above data. In addition to this ,the Means Building Construction Cost Data Manual was used to input relevant data.

Building A is assumed to be a traditionally built structure and B a modern Curtain Wall type structure both having approximately 200,000 square feet of office space. The Means catalogue was used to determine a construction cost of approximately $63.00 per square foot for the Curtain Wall building. The Traditional Structure is assumed to have a construction cost that is 10% higher.

The BOMA report indicates an average running cost of $13.50 /sf per year. Of which, .22c/sf is attributed to structural and roof maintenance. The PSA report indicates a much higher maintenance cost for the traditional building though this escalates at a much lower rate.

The design life of the Curtain Wall is assumed to be 40 years and the new enclosure cost is estimated at $30.00/sf.

Total expenditure over five years is assumed to be relatively constant throughout the life of the buildings. This can be explained by the large number of categories involved in calculating this cost and the small variations from year to year. Exterior maintenance/renovation is not necessarily a large cost item in terms of total expenditure.

7.3 Conclusions

The data used in this report is approximate and at best should be used only to indicate trends. However, the author believes that some important conclusions can be drawn from the data.

Figure 7.1 indicates that despite initial higher maintenance costs , the traditional building will cost less to maintain at some stage during the lifetime (approx. 30 yrs). If the owner elects to reclad the Curtain Wall (a 6 million dollar proposal in our case) maintenance costs will return to their initial value.

Figure 7.2 details an overall view of the building expenditure. Although the pattern of expenditure is very different, the present value of total investment is very similar. One of the reasons for this is that costs incurred after 20 years are relatively small when discounted back to present day value.

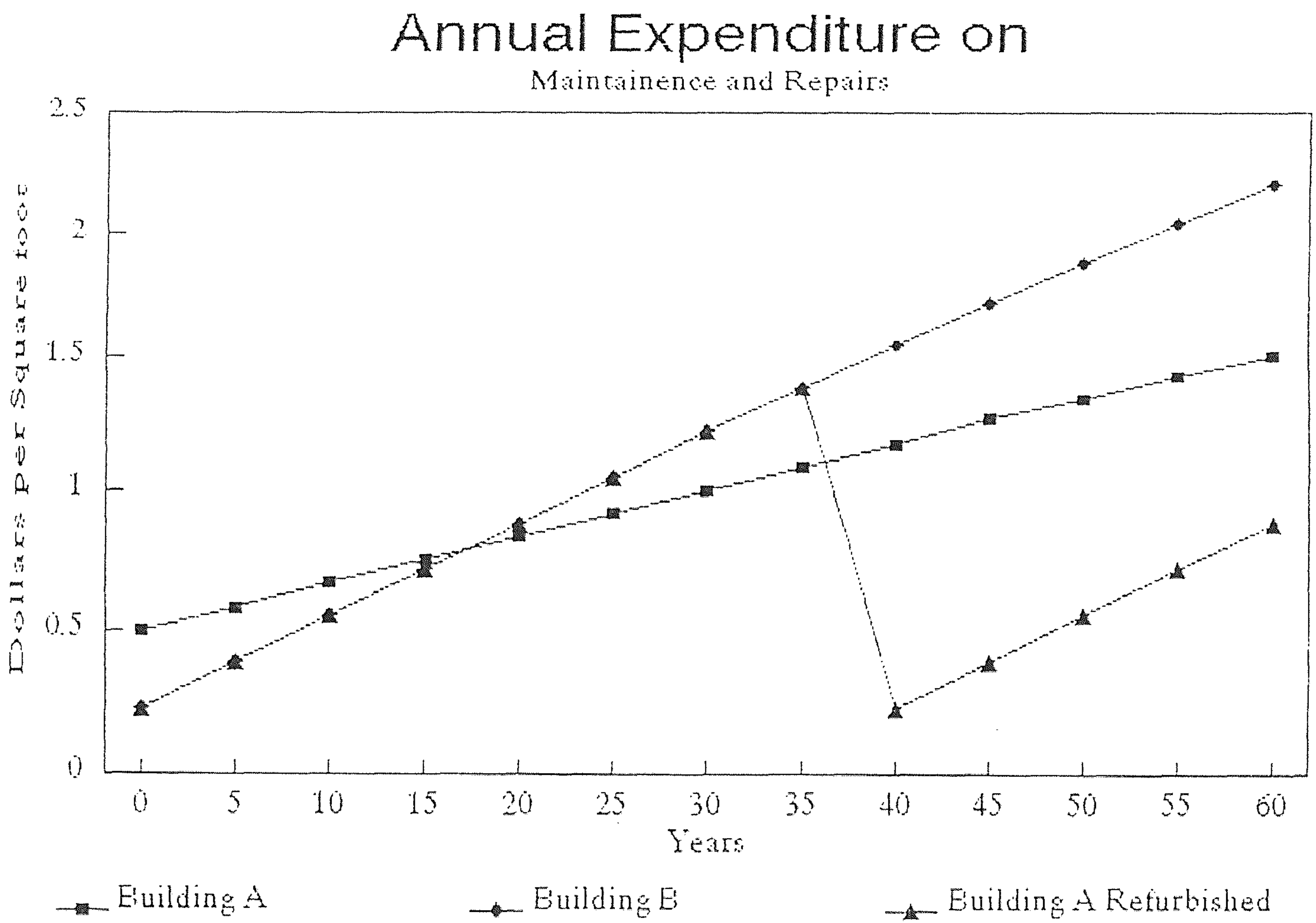
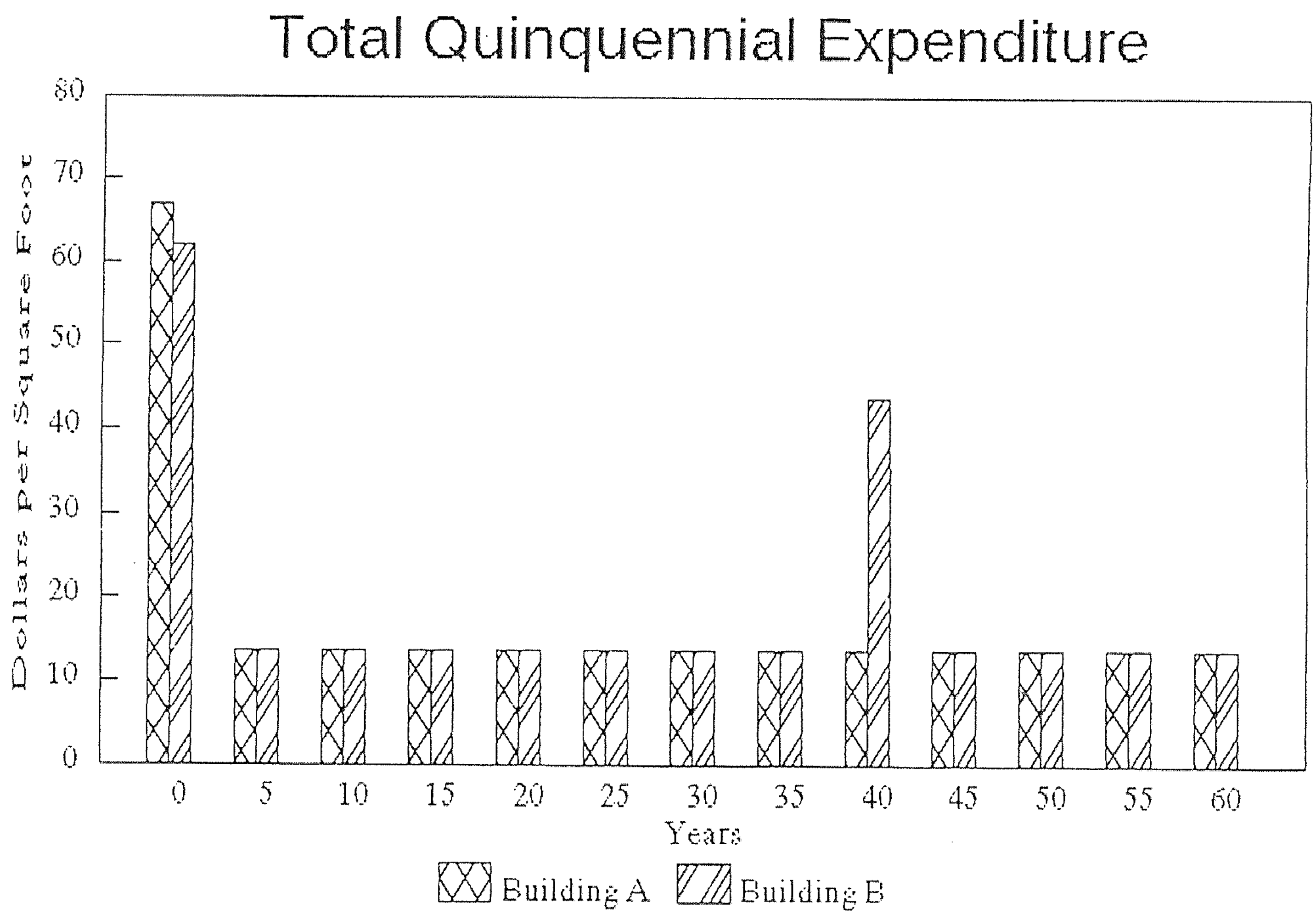


Figure 7.1 Annual Expenditure on Maintenence and Repairs



Building A Total Spent $528
Building B Total Spent $535

Figure 7.2 Total Quiquennial Expenditure

CHAPTER 8

CONCLUSIONS

Despite the economy associated with curtain wall design (versus traditional methods), curtain walls are not standard "off the shelf items". That is, the design, fabrication and installation must be carefully monitored in order to prevent problems. Therefore, despite the changes in methods and materials the application of these ingredients must adhere to basic rules.

In 1938, an article in Engineering News Record outlined "how to build leaky walls with good materials" (13). Many of the practices mentioned bear remarkable similarity to problems detailed in Chapter 6. The construction industry seems quick to advance but slow to learn.

Perhaps, some blame for failing to learn by our mistakes is the unfortunate practice of "Gagging" parties involved in a dispute. Indeed, many settlements include clauses that prevent the details of the case from becoming public knowledge. For example, the exact cause of glass cladding failure at Boston's Hancock Building is still subject for much debate. Taywood Engineering in London and Testwell Craig Berger, Inc. from New York have recently started to perform on site testing on existing curtain wall buildings. The Building Research Establishment studied 41 failed curtain walls and determined that inadequate waterproofing was the most common cause of failure (14).

Another potential cause of problems that have surfaced and have yet to surface is the adoption of value engineering. In one case, $7,000.00 was saved using plastic flashing as apposed to traditional metal flashing. This cost the owner one million dollars, ten years later.

Attempts are made to standardize curtain wall construction. In Great Britain, the Center for Window and Cladding Technology will shortly publish new standards. This standard will likely provide the basis for a new European standard. It will include performance, installation and testing methods.

Notwithstanding the aforementioned problems, it is possible that the next ten years will see a steep increase in curtain wall corrective work. This is not necessarily due solely to inadequate design or quality control, but rather to an increased number of buildings reaching their design life. Outer skin cladding will, I think, become a more common in the 1990's. Roland Macdowell (affectionately known as "Mac") of Brisk Waterproofing has spent over thirty years at the forefront of Restoration work in North America. Recently he stated in a memo "Given the unseen,insidious but inexorable deterioration of the concealed fastening devices as a result of metal fatigue, bi-metal corrosion and/or the oxidation of ferrous metal, there is very little doubt in my mind that we will see a substantial increase in Curtain Wall failures in the next 10 to 20 Years." During the preparation of this report the writer has come to accept the opinion stated above.

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