AMERICAN ARCHITECTURAL

AAMA 501.4-00 (Revised 7/18/01)

Recommended Static Test Method For Evaluating Curtain Wall And Storefront Systems Subjected To Seismic And Wind Induced Interstory Drifts

AAMA 501.6-01

Recommended Dynamic Test Method For Determining The Seismic Drift Causing Glass Fallout From A Wall System

AAMA

MANUFACTURERS ASSOCIATION

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501.4-00, Recommended Static Test Method For Evaluating Curtain Wall And Storefront Systems Subjected To Seismic And Wind Induced Interstory Drifts *(Revised 7/18/01)*

1.0 SCOPE

1.1 This test method provides a means of evaluating the performance of curtain walls and storefront wall systems when subjected to specified horizontal displacements in the plane of the wall. The method is not intended to test for dynamic, torsional, or vertical movements. The relatively slow (i.e., "static") movements of this test method may not produce the same results as would be obtained in a dynamic movement test.

1.2 This test method is a complement to AAMA 501.6 – "Recommended Dynamic Test Method for Determining the Seismic Drift Causing Glass Fallout from a Wall System." AAMA 501.6 focuses primarily on determining the dynamic fallout from wall system panels that are representative of the overall wall system being evaluated. In contrast, this test method focuses primarily on changes in serviceability of wall system specimens (e.g., air and water leakage rates) as a result of statically applied, in-plane (horizontal) racking displacements. Thus, the AAMA 501.6 test method focuses primarily on the seismic ultimate limit state behavior of architectural glass in a wall system or partition, while this test method focuses primarily on the seismic serviceability limit state behavior of wall systems.

1.3 This test method is applicable to large curtain wall and storefront mock-ups consisting of supports, components and cladding.

1.4 The proper use of this test method requires an understanding of static load applications, deflection measurements, and test fixture design as required to accomplish controlled movements of the simulated structure.

1.5 This test method describes the apparatus and the procedure to be used for displacing a specimen horizontally. The displacement cycle time is not limited and is not intended to duplicate the interstory displacement rates associated with dynamic building sway and seismic events.

2.0 INTRODUCTION

As a result of recent earthquakes, interest in the design of buildings to resist seismic loads and displacements has increased. In order to design and detail curtain wall frames and their attachments to meet seismic requirements, one needs to understand how earthquake loads differ from other loads, and how seismic design is approached by contemporary designers. Design decisions, based upon this understanding, can then be made to minimize earthquake induced damage to connections, supports, glass, stone, and other cladding materials, as well as minimizing the hazards associated with falling debris during an earthquake.

Compared to other loads, such as gravity loads, earthquake loads are more difficult to predict with a high degree of certainty. Not only are the magnitude, direction, duration, and time of occurrence of an earthquake unpredictable, but the inertial forces and displacements imposed on a building structure and its subsystems and components during an earthquake are strongly dependent on the structure of the building itself. Thus, while most loads (e.g., dead, live, snow, wind) are "imposed on a building," earthquake forces and displacements are related directly to the response of a given building to the ground motions at the building site due to a given earthquake event. In the context of curtain walls and storefront wall systems, earthquake-induced interstory displacements of the primary building structure are highly important factors to consider in seismic design.

Economics also play a major role in current seismic design philosophy. To design a building to withstand the loads and movements it could experience during the worst possible earthquake without experiencing any damage would likely result in a cost-prohibitive structure. A building like this could not compete economically with a structure of similar usage located in an area expecting less seismic activity.

The result of these factors is a seismic design philosophy that differs significantly from the structural design philosophy employed to resist other load types. Conventional design requires the structure to withstand an expected load multiplied by an appropriate load factor. Instead, current seismic design philosophy relies upon the building's ductility to prevent major structural damage or collapse, while allowing certain amounts of damage as a result of different earthquakes magnitudes. Interstory drift (racking), or the relative horizontal movements between adjacent stories of a multi-story building, must also be considered. (It should be noted that these interstory drifts can be induced either by earthquake loads or by wind loads.)

3.0 DEFINITIONS

BSSC – The Building Seismic Safety Council was established in 1979 under the auspices of the National Institute of Building Sciences (NIBS) for dealing with the complex regulatory, technical, social, and economic issues involved in developing and promulgating building earthquake hazard mitigation regulatory provisions that are national in scope. Building Seismic Safety Council, 1090 Vermont Avenue, N.W., Suite 700, Washington, DC 20005.

Curtain Wall – Any exterior building wall, of any material, which carries no superimposed vertical loads, i.e., any "non load-bearing" exterior wall.

Design Earthquake – An earthquake that would produce ground motions at the site under consideration having a 90% probability of not being exceeded in 50 years. (Previously, some referred to this as the "probable earthquake.") As defined in 1997 SBC: "the earthquake at the site under consideration that produces ground motions having 90% probability of not being exceeded in 50 years." As defined in 1999 BOCA National Building Code: "the earthquake that produces ground motions at the site under consideration which has a 90% probability of not being exceeded in 50 years." As defined in 1997 UBC: "the design basis ground motion is that ground motion that has a 10% chance of being exceeded in 50 years as determined by a site specific hazard analysis or may be determined from a hazard map."

Displacement – A vector or the magnitude of a vector from the initial position to a subsequent position assumed by a body.

- **Design Displacement** – The design earthquake lateral displacements, excluding additional displacement due to actual and accidental torsion. Numerically, this is the calculated elastic deflection multiplied by an appropriate deflection amplification factor that approximates the actual inelastic displacement.

- **Total Design Displacement** – The design earthquake lateral displacement, including additional displacement due to actual and accidental torsion.

- **Total Maximum Displacement** – The maximum considered earthquake lateral displacement, including additional displacement due to actual and accidental torsion.

Drift – Generally refers to horizontal displacement. Story drift (or interstory drift) refers to lateral movement (displacement) of one level (story) of a structure with respect to the level (story) above or below due to the design lateral forces. Story drift is the calculated elastic drift that has been amplified by factors required by government regulations or codes.

Force – A push or pull action that tends to change the shape of a deformable body or the state of motion of an object.

Maximum Capable Event – The maximum intensity of earthquake ground shaking that may ever be expected at the building site within the known geological framework. In areas on NEHRP maps with an A_α (acceleration coefficient) value of 0.3 or greater, this ground shaking intensity may be taken as the level of earthquake ground motion that has a 98 percent chance of non-exceedance in 50 years, or an average return period of 2,500 years. This event has also been termed a "Maximum Credible Earthquake," and, most recently, (1997 NEHRP "*Provisions*") a "Maximum Considered Event."

NEHRP – National Earthquake Hazards Reduction Program. It was developed in response to the Earthquake Hazard Reduction Act of 1977. The principal agencies involved in the NEHRP are:

- **FEMA** – Federal Emergency Management Agency, the lead agency for overall administration of the NEHRP program.

- **NSF** – National Science Foundation, which supports academic research studying all aspects of the earthquake hazard problem.

- **NIST** – National Institute for Standards and Technology (formerly the National Bureau of Standards), which supports standardization activities, including those related to building construction.

- **USGS** – United States Geological Survey, which studies and defines earthquake hazards from the seismological and geological points of view; produces the base maps for seismic hazard.

Story Drift – See Drift

Story Height – Vertical dimension from one floor level of a structure to the next adjoining floor level.

$\Delta_{\mathbf{fallout}}$ – The drift that causes glass fallout from the curtain wall or storefront wall being considered.

4.0 HISTORICAL CONTEXT

In the past, seismic designs for cladding emphasized a force-based approach. Magnitudes of story drift were often ambiguous, but yet were most often the controlling factor. In Performance Based Seismic Engineering of Buildings released in April 1995, SEAOC (Structural Engineers Association of California) recommends that "…deformations should replace forces as the key parameter."(1)

It is anticipated that new codes will provide more guidance regarding the magnitude of seismic movements appropriate for the seismic design of building wall systems.

"It also appears that the general public was not aware that the intended performance objectives of current building codes anticipate substantial damage from strong ground motion."(2) The basic premises of the 1988 UBC seismic provisions were:

A) In minor earthquakes, structures should experience no damage.

B) In moderate earthquakes, structural elements should experience no damage, but there may be some damage to non-structural elements.

C) In major earthquakes, structural and non-structural damage may be severe, but the structure will not collapse. Designers are counting on ductility (inelastic response) and proper detailing to prevent collapse.

The 1988 UBC code recognized the probability of earthquake occurrence and severity, site conditions, importance (based on occupancy) of the structure, and type of structural system.

In 1994, BSSC (Building Seismic Safety Council) in its publication "NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures" introduced the following new terms: Design Earthquake, Maximum Capable Event, Maximum Credible Earthquake, Maximum Intensity Earthquake, Design Displacement, Total Design Displacement and Total Maximum Displacement. Definitions of these terms are included in Section 3.0.

In the "1997 NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures" (Part 2 - Commentary) four design performance levels, in terms meaningful to the building user community, are defined:

1) Operational Level, with essentially no damage to non-structural (e.g., cladding) elements;

2) Immediate Occupancy Level, with moderate damage to non-structural elements and light damage to structural elements in the primary structural system of the building;

3) Life Safety Level, with moderate damage to structural and non-structural elements; and

4) Near Collapse Level (also known as the "Hazards Reduced Level" of performance in the FEMA 273 Seismic Rehabilitation Guidelines.)

Although these levels are still somewhat conceptual, they provide at least some degree of guidance to designers.

The choice of approach, based upon the design philosophy and associated performance levels, will affect how the cladding specifications are written and, ultimately, the cost of the wall system. Similarly, other portions of the specification and the building's structural design must reflect this same design philosophy.

Minimum standards for earthquake design are given by building codes and government agencies. However, much latitude is given to the designer to determine a philosophy with respect to seismic design. This philosophy, as noted above, can be based upon function, cost, and probability of damage, and should remain consistent from preliminary design through specification and construction.

5.0 GENERAL NOTES REGARDING THE TEST METHOD

5.1 This test method establishes the procedures for evaluating, under laboratory conditions, the performance of curtain walls and storefronts when subjected to horizontal displacements intended to represent the effects of an earthquake or a significant wind event. This test method is not intended to evaluate foundation systems or main structural support elements of a building design.

5.2 This test method may be used to determine failure modes for cladding products and identify the need for changes in design approaches as they relate to horizontal displacement. The specifier should consider the cost/benefit of testing, especially for calculated interstory drifts in the primary structural system of the building less than 0.005 times the story height.

5.3 Whenever possible, the displacement testing shall be performed in the same test chamber as that used for air, water, and wind load testing. The specifier should be aware that substantial modification of the chamber and significant preparation time are normally required to prepare for and perform this displacement test.

5.4 Seismic performance requirements for operating windows and doors installed within a curtain wall or storefront wall system might differ from those required for "non-operating" components of the wall system.

5.5 The design displacements for project specific testing shall be specified in the contract documents. Unless otherwise specified, horizontal displacements employed in this test method shall be in the plane of the primary mock-up elevation. Design displacements shall be 0.010 x the greater adjacent story height, unless otherwise specified.

Specifier Note: The specifier should refer to the building engineer of record considering the applicable building code or NEHRP Table 5.2.8 or NEHRP Equation 6.1.4-1

(NEHRP, 1997) for guidance on the appropriate design displacement.

5.6 The specifier shall stipulate whether air and/or water performance tests shall be conducted subsequent to seismic displacement tests, and whether or not these tests shall have pass/fail criteria or shall be for informational purposes only. If these tests are to be performed, the specifier shall stipulate the extent of repair allowed, if any, after the displacement tests. Examples of such repairs include re-seating partially displaced glazing materials and/or trim and re-sealing of perimeter caulking. (See Section 11.0 for default pass/fail criteria for various building occupancy types.)

5.7 The accredited independent testing agency shall be responsible for a chamber design and details of the movement system.

6.0 TEST SPECIMENS

6.1 The curtain wall or storefront test specimen shall be of sufficient size and configuration to determine the performance of all typical parts of the wall system. For curtain walls or other walls constructed with prefabricated units, the specimen width shall be not less than two typical units plus the connections and supporting elements at both sides, and shall be sufficient to provide full loading on at least one typical vertical joint or framing member, or both. The height shall not be less than the full building story height or the height of the unit, whichever is greater, and shall include at least one full horizontal joint, which accommodates vertical expansion. For multistory systems, the specimen height shall not be less than two full building stories plus the height necessary to include one full horizontal joint accommodating vertical expansion.

6.2 All parts of the curtain wall or storefront test specimen shall be full size, using the same materials, type of glass, details, methods of construction, and anchorage as those used on the actual building.

6.3 The test chamber structure shall simulate the main structural supports of the actual building. However, the test chamber support structure may differ from the actual building as required to perform the required displacement. For curtain wall mock-ups, the test chamber shall be constructed so that the anchorage at the simulated floor structure at an intermediate level of the test specimen is moveable in the horizontal direction(s). For single story mock-ups, the test chamber shall be constructed so that the anchorage at the top or bottom is moveable in the horizontal direction(s).

7.0 RECOMMENDED TEST PROCEDURES

7.1 Prior to conducting the displacement tests, the test specimen shall be, at a minimum, characterized for serviceability by conducting air leakage (ASTM E283) and water penetration (ASTM E331) tests. The air leakage and water penetration tests shall be conducted at the differential pressures specified for the project. (Refer to AAMA 501-94 for guidance on selection of appropriate test pressures.)

7.2 Conduct Specified Design Displacement Test(s).

7.2.1 Test chamber elements representing the primary building structure shall be displaced to produce the specified movements. Each test shall consist of three (3) full cycles. (Herein, a cycle is defined as a full displacement in one direction, back to the originating point, full displacement in the opposite direction, and back to the originating point.) At the conclusion of the test, technicians and witnesses shall visually inspect the mock-up for evidences of failure. The Test Agency shall record all areas of visual distress, such as disengagement, metal distortion, sealant or glazing failure, or permanent deformation. If glass breakage occurs during the displacement test, the Test Agency personnel shall carefully examine the test specimen. If breakage was caused by deformation or failure of the supporting frame of the glass, or by any interaction between the glass and its supporting elements, record the findings and discontinue the test. If the cause of the breakage cannot be determined replace the glass with the original components and repeat the test one additional time.

7.2.2 Elements representing the building structure shall be displaced in a manner and method as determined by the Testing Agency and may be subject to review by the design professional. (See Figure 1 for typical test specimen configuration with moveable test chamber elements.)

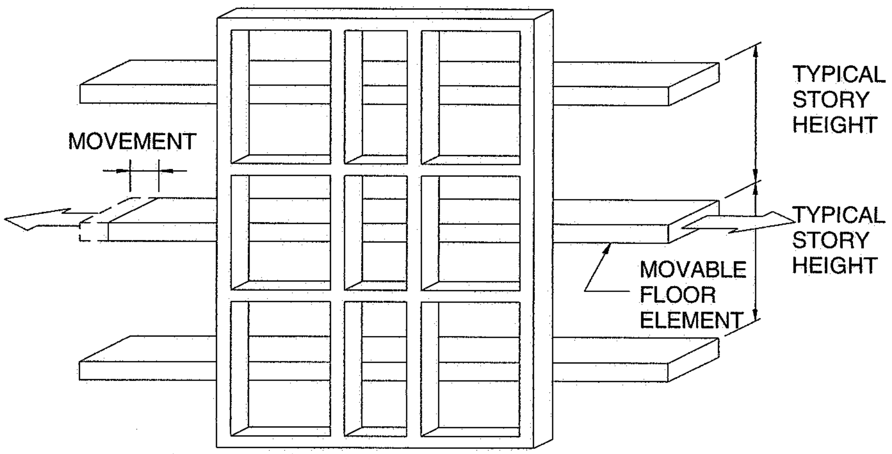

FIGURE 1
Typical Test Specimen Configuration

7.2.3 The time duration of each cycle is not prescribed, but shall be recorded for information purposes only. Changes in displacement direction(s) shall allow for movement of equipment, stops, measuring devices, etc. The Test Agency shall displace the chamber elements in a manner that does not induce sudden acceleration and deceleration.

7.2.4 Additional cycles and/or displacement direction(s) may be specified by the design professional.

7.2.5 The design displacement shall be determined by the specifier according to the predicted interstory movements of the subject building. For multi-story mock-ups, the displacement between levels may vary due to different story heights. Unless otherwise specified, the design displacement shall be 0.010 x the greater of the adjacent story heights. The displacement shall be measured at the movable floor element, not at the test specimen.

7.3 Serviceability tests for air leakage (ASTM E283) and water penetration (ASTM E331) may be conducted after the static displacement tests. The air leakage and water penetration tests should be conducted at the pressures specified for the project.

7.4 Displacement tests in addition to, and of greater magnitude than, the design displacement test may be conducted, if specified. However, consideration should be given that those additional tests could jeopardize the feasibility of performing subsequent air, water or structural tests. At the conclusion of the displacement testing, the Testing Agency shall record all areas of visual distress such as disengagement, metal distortion, sealant tearing, glass fracture, glazing failure, or permanent deformation.

7.5 Unless otherwise specified, the default test sequence shall be as follows:

- Air Leakage (ASTM E283)
- Static Water Resistance (ASTM E331)
- Dynamic Water Resistance (AAMA 501.1) (optional)
- Structural Performance @ Design Wind Pressure (ASTM E330)
- Repeat Air Leakage (ASTM E283) (optional)
- Repeat Static Water Resistance (ASTM E331) (optional)
- Seismic Movement @ Design Displacement (AAMA 501.4)
- Repeat Air Leakage (ASTM E283)
- Repeat Static Water Resistance (ASTM E331)
- Structural Performance @ 1.5 x Design Wind Pressure (ASTM E330)
- Seismic Movement @ 1.5 x Design Displacement (AAMA 501.4)

Note: To determine the drift causing glass fallout (i.e., $\Delta_{fallout}$), refer to AAMA 501.6-01.

8.0 APPARATUS

8.1 The description of the apparatus in this section is general. Any suitable apparatus arrangement approved by AAMA during the laboratory accreditation process is permitted.

8.2 The displacement(s) may be accomplished using hydraulic or pneumatic cylinders or jacks of sufficient load and stroke capacity, or mechanical devices, such as ratchet pulleys or a chain hoist.

8.3 Test chamber members that are representative of the building structure shall be designed to accomplish the specified displacement(s). This may be done through a system of sleeves, fixtures, pins, or any system capable of accomplishing the displacement(s) directed by the specifier.

8.4 The displacement measuring system shall be accurate to within 2 mm (1/16 in.).

8.5 The apparatus shall include "fail-safe stops" to prevent the test specimen from being subjected to displacements exceeding the test specifications.

9.0 SAFETY PRECAUTIONS

9.1 This test method could involve the use of hazardous materials, operations, and equipment. This document does not purport to address all appropriate safety issues associated with its use. It is the responsibility of the user of this recommended test method to establish appropriate safety precautions.

9.2 Proper precautions shall be taken to protect all test observers in the event of any failure.

10.0 TEST AGENCY

10.1 Testing shall be conducted by an independent laboratory accredited by AAMA to perform this test method.

11.0 PASS/FAIL CRITERIA

11.1 The project specifications shall state detailed pass/fail performance criteria for the curtain wall or storefront wall system. If detailed pass/fail performance criteria are not in the project specification, the criteria outlined in this test method shall be utilized.

11.2 Unless otherwise specified, a specimen subjected to the design displacement test shall be considered passing the interstory drift provisions of this test method if the applicable performance level, listed below by building occupancy type, is achieved.

11.2.1 Essential Facilities (Seismic Use Group III in NEHRP *Provisions*): Seismic Use Group III structures are those having essential facilities that are required for post-earthquake recovery, and those containing substantial quantities of hazardous substances. Essential Facilities include: (Refer to Table 1604.5 in IBC for more detail and background.)

- Fire, rescue and police stations
- Hospitals
- Designated medical facilities having emergency treatment facilities
- Designated emergency preparedness centers
- Designated emergency operation centers
- Designated emergency shelters
- Power generating stations or other utilities required as back-up facilities for Seismic Use Group III facilities
- Emergency vehicle garages and emergency aircraft hangers
- Designated communication centers
- Aviation control towers and air traffic control centers
- Structures containing sufficient quantities of toxic or explosive substances deemed to be hazardous to the public
- Water treatment facilities required to maintain water pressure for fire suppression

11.2.1.1 Seismic Performance Requirements for Curtain Walls and Storefront Wall Systems in Essential Facilities (Seismic Use Group III):
(These requirements are intended to represent the "Operational" performance level in both the NEHRP *Provisions* and in FEMA 273.)

- all functions remain unimpaired with no visible damage
- no glass breakage or glass fallout is allowed
- post design displacement performance (e.g., air infiltration, water leakage, structural performance, etc.) shall remain within specified allowable limits without adjustments or repair
- no wall components may fall off. Trim may not be visibly disengaged.

11.2.2 High Occupancy Assembly (Seismic Use Group II in NEHRP *Provisions*): Seismic Use Group II structures are those having a substantial public hazard due to occupancy or use. High Occupancy Assemblies include:

- Covered structures whose primary occupancy is public assembly with a capacity greater than 300 persons
- Educational structures through the 12th grade with a capacity greater than 250 students
- Day care centers with a capacity greater than 150 persons
- Medical facilities with 50 or more resident incapacitated patients, but not having surgery or emergency treatment facilities
- Jails and detention facilities
- All structures with occupancy greater than 5,000 persons
- Power generating stations and other public utility facilities not included in the Seismic Use Group III
- Water treatment facilities required for primary treatment and disinfection for potable water

- Waste treatment facilities required for primary treatment.

11.2.2.1 Seismic Performance Requirements for Curtain Wall and Storefront Wall Systems in High Occupancy Assembly Structures (Seismic Use Group II):
(These requirements are intended to represent the "Operational" performance level in both the NEHRP *Provisions* and in FEMA 273.)

- no glass breakage or fallout is allowed
- any damage shall be readily repairable/adjustable on site with no part replacements required
- post design displacment performance (e.g., air infiltration, water leakage, structural performance, etc.) can be attained with adjustments not requiring wall system disassembly. Visible seals or gaskets may be repaired or reset.
- no wall components may fall off. Trim may be visibly disengaged.

11.2.3 Standard Occupancy (Seismic Use Group I in NEHRP *Provisions*): Seismic Use Group I structures are those not assigned to Seismic Use Groups II or III.

11.2.3.1 Seismic Performance Requirements for Curtain Wall and Storefront Wall Systems in Standard Occupancy Structures (Seismic Use Group I):
(These requirements are intended to represent the "Immediate Occupancy" performance level in both the NEHRP *Provisions* and in FEMA 273.)

- one glass lite or up to 10% of total lites may break, but must be retained completely in the glazed opening with no glass fallout
- any damage shall be readily repairable/adjustable on site
- post design displacement performance (e.g., air infiltration, water leakage, structural performance, etc.) can be attained with minor adjustments. Broken glass may be replaced in order to conduct subsequent performance tests. Visible seals or gaskets may be repaired or reset.
- no wall components may fall off. Trim may be visibly disengaged.
- trim elements may require replacement

11.3 For all building occupancy types, a specimen subjected to the 1.5 x design displacement test shall be considered passing if all glass is retained completely in the glazed opening with no glass fallout and no wall components fall off, unless otherwise specified.

12.0 TEST REPORT

12.1 The test report shall include the name and address of the testing laboratory, location of test site, date when test was completed, and date of issuance of report.

12.1.1 Identification and description of the specimen(s) – manufacturer, source of supply, dimensions, model number, type, materials of construction, and any other pertinent information.

12.1.2 Description of locking and operating mechanisms.

12.1.3 Glass thickness, type, and method of glazing.

12.1.4 Type, materials, and locations of all anchoring systems and devices.

12.1.5 A drawing of the test chamber and the wall system test specimen mock-up indicating location of measuring devices and movement devices.

12.1.6 Complete description of test measurements and visual characterization of system and components both prior to horizontal displacement and after completion of specified displacement cycles.

12.1.7 A clear, definitive, written statement summarizing the observed performance of the wall system test specimen in relation to the seismic performance requirements for the building occupancy type of the subject building.

12.1.8 Additional observations made by testing agency personnel during testing that may aid the specifier in evaluating system performance.

12.1.9 A statement that tests were performed in accordance with the AAMA recommended test method.

13.0 REFERENCED DOCUMENTS

AAMA 501.6-01 – "Recommended Dynamic Test Method for Determining the Seismic Drift Causing Glass Fallout from a Wall System," American Architectural Manufacturers Association, Schaumburg, Illinois.

AAMA 501-94 – "Methods of Test for Exterior Walls"

ASTM E283 – "Standard Test Method for Determining the Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen"

ASTM E331 – "Standard Test Method for Water Penetration of Exterior Windows, Curtain Walls, and Doors by Uniform Static Air Pressure Difference"

"Uniform Building Code" – 1997 Edition, International Conference of Building Officials (ICBO), 5360 Workman Road, Whittier, CA 90601-2298

"Uniform Building Code" – 1988 Edition, International Conference of Building Officials (ICBO), 5360 Workman Road, Whittier, CA 90601-2298

"BOCA National Building Code" – 1999 Edition, Building Officials and Code Administrators International Inc., 4051 West Flossmore Road, Country Club Hills, IL 60478-5795

"BOCA National Building Code Commentary" – 1999 Edition

"Standard Building Code" – 1997 Edition, Southern Building Code Congress International (SBCCI), 900 Montclair Road, Birmingham, AL 35213

"International Building Code" – 2000 Edition, International Code Council, 5203 Leesburg Pike, Suite 708, Falls Church, VA 22041-3401

"NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures," 1994, BSSC (Building Seismic Safety Council) Washington, DC, Issued by Federal Emergency Management Agency as FEMA 222A

"NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures," 1997, BSSC (Building Seismic Safety Council) Washington, DC, Issued by Federal Emergency Management Agency as FEMA 302

"NEHRP Guidelines for the Seismic Rehabilitation of Buildings," 1997, BSSC (Building Seismic Safety Council) Washington, DC, Issued by Federal Emergency Management Agency as FEMA 273.

Endnotes:

(1) "Seismic Code Questioned." ENR/May 8, 1995 p. 3.

(2) Reviewing the "Seismic Provisions of the 1988 Uniform Building Code", by Philip Terry, P.E. as reported in Building Standards Magazine/March-April 1991 p. 11.

501.6-01, Recommended Dynamic Test Method For Determining The Seismic Drift Causing Glass Fallout From A Wall System

1.0 SCOPE

1.1 This method provides a means of determining the horizontal racking displacement amplitude of wall framing members that would cause fallout of representative architectural glass panels under controlled laboratory conditions.

1.2 This test method is a complement to AAMA 501.4 – "Recommended Static Test Method for Evaluating Curtain Wall and Storefront Systems Subjected to Seismic and Wind Induced Interstory Drifts." AAMA 501.4 focuses primarily on changes in serviceability of wall system specimens (e.g., air and water leakage rates) as a result of statically applied, in-plane (horizontal) racking displacements. In contrast, this test method focuses primarily on determining the dynamic fallout from wall system panels that are representative of the overall wall system being evaluated. Thus, the AAMA 501.4 test method focuses primarily on the seismic serviceability limit state behavior of wall systems, while this test method focuses on the seismic ultimate limit state behavior of architectural glass in a wall system or partition.

1.3 This test method is applicable to any type of glass panel installed in wall system framing members, including the associated glazing components (setting blocks, gaskets, fasteners, etc.).

1.4 The proper use of this test method requires an understanding of dynamic testing methods, displacement and time measurements, and the test apparatus design and controls required to accomplish the horizontal racking displacements.

1.5 This test method describes the definitions, test specimens, apparatus and procedures to be used to determine the dynamic drift that would cause glass fallout from a representative wall system or partition panel.

1.6 The values stated in SI units are to be regarded as the standard. The IP equivalents of SI units (provided in parentheses) may be approximate.

2.0 INTRODUCTION

2.1 In the design of building wall systems to resist earthquakes, where glass-to-frame contacts cannot be avoided, or where glass selected is not from glass types that are highly resistant to earthquake-induced glass fallout, NEHRP Recommended *Provisions* for Seismic Regulations for New Buildings and Other Structures (NEHRP, 2000) call for the determination of $\Delta_{fallout}$, which is defined as "the relative seismic displacement (drift) causing glass fallout from the curtain wall, storefront or partition." The word "seismic" in the $\Delta_{fallout}$ definition implies that $\Delta_{fallout}$ shall be determined on the basis of dynamic motions. The purpose of this test method is to describe a "dynamic racking crescendo test" for determining $\Delta_{fallout}$, the in-plane dynamic drift causing glass fallout from a glazed curtain wall panel, a glazed storefront panel, or a glazed partition panel. According to the 2000 NEHRP *Provisions*, dynamic racking tests are not required when sufficient clearance exists between glass edges and wall frame glazing pockets to prevent contact during seismic design displacements in the main structural system of the building.

2.2 Extensive laboratory research reported in the open literature has indicated that in-plane (horizontal) dynamic racking motions are the most relevant and practical motions to be included in laboratory determinations of $\Delta_{fallout}$ for glass components (Wright, 1989; Thurston and King, 1992; Behr *et al.*, 1995).

3.0 DEFINITIONS

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Curtain Wall
Any exterior building wall, of any material, which carries no superimposed vertical loads, i.e., any "non load-bearing" exterior wall (AAMA, 1996).

Design Earthquake
An earthquake that would produce ground motions at the site under consideration having a 90% probability of not being exceeded in 50 years. (Previously, some referred to this as the "probable earthquake.") As defined in 1997 SBC: "the earthquake at the site under consideration that produces ground motions having 90% probability of not being exceeded in 50 years." As defined in 1999 BOCA National Building Code: "the earthquake that produces ground motions at the site under consideration which has a 90% probability of not being exceeded in 50 years." As defined in 1997 UBC: "the design basis ground motion is

that ground motion that has a 10% chance of being exceeded in 50 years as determined by a site specific hazard analysis or may be determined from a hazard map."

Displacement
A vector or the magnitude of a vector from the initial position to a subsequent position assumed by a body.

- **Design Displacement** - The design earthquake lateral displacements, excluding additional displacement due to actual and accidental torsion. Numerically, this is the calculated elastic displacement multiplied by an appropriate displacement amplification factor that approximates the actual inelastic displacement.

- **Total Design Displacement** - The design earthquake lateral displacement, including additional displacement due to actual and accidental torsion.

- **Total Maximum Displacement** - The maximum considered earthquake lateral displacement, including additional displacement due to actual and accidental torsion.

Drift
Generally refers to horizontal displacement. Story drift (or interstory drift) refers to lateral movement (displacement) of one level (story) of a structure with respect to the level (story) above or below due to the design lateral forces. Story drift is the calculated elastic drift that has been amplified by factors required by various design provisions and model building codes.

Drift Index
The total lateral (horizontal) displacement (drift) that occurs over the height of the glass panel divided by the height of the glass panel, expressed as a percent or a decimal. The height is measured to the extreme edges of horizontal framing members.

Glass Panel or Glazed Panel
Any type of glazing infill panel, including, but not limited to, the following: monolithic, laminated, or insulating glass employing annealed, heat-strengthened, or tempered glass types; vision or spandrel; captured four sides or attached with structural silicone.

Maximum Capable Event
The maximum intensity of earthquake ground shaking that may ever be expected to occur at the building site within the known geological framework. In areas on NEHRP maps with an A_a (acceleration coefficient) value of 0.3 or greater, this ground shaking intensity may be taken as the level of earthquake ground motion that has a 98 percent chance of non-exceedance in 50 years, or an average return period of 2,500 years. This event has also been termed a "Maximum Credible Earthquake," and, more recently (i.e., in the 1997 NEHRP Provisions) a "Maximum Considered Event."

NEHRP
National Earthquake Hazards Reduction Program. The NEHRP was developed in response to the Earthquake Hazard Reduction Act passed by the United States Congress in 1977. The principal agencies involved in the NEHRP are:

- **FEMA** - Federal Emergency Management Agency, the lead agency for overall administration of the NEHRP.

- **NSF** - National Science Foundation, which supports basic research and applied research addressing all aspects of the earthquake hazard problem.

- **NIST** - National Institute for Standards and Technology (formerly the National Bureau of Standards), which supports standardization activities, including those related to building design and construction.

- **USGS** - United States Geological Survey, which studies and defines earthquake hazards from seismological and geological perspectives, and which produces extensive seismic hazard maps for the United States.

Story Drift
See Drift.

Story Height
Vertical distance between a designated point or component at one floor level and the same designated point or component at adjoining floor levels of a building structure.

$\Delta_{fallout}$ – The drift that causes glass fallout from the curtain wall or storefront wall being considered.

4.0 GENERAL NOTES

4.1 Curtain wall systems and storefront systems often include glazed panels with different sizes, aspect ratios, glass types, glass edge clearances, etc. Once a wall system is selected, the specifier must identify the various glass panels to include in the $\Delta_{fallout}$ test plan in order to encompass glass panel configurations within the wall system that have the highest potential for glass fallout. When uncertainty exists, the specifier shall consider additional specimen configurations in the test plan. Usually, $\Delta_{fallout}$ test specimens include those panels in the wall system having the largest glass area, the thinnest glass, the most vulnerable glass type (NEHRP 2000, Part 2 – Commentary), the most vulnerable glazing system type, the smallest glass-to-frame clearances, the smallest height-to-width ratio, and the highest drift index.

5.0 TEST SPECIMENS

5.1 Unless otherwise specified, $\Delta_{fallout}$ tests shall be conducted on test specimens that simulate closely the components of the overall wall system being evaluated. If a test specimen includes more than one glazed panel in order to simulate the boundary support conditions of the designated "test panel," then said test panel must be clearly labeled as such prior to conducting each crescendo test. Crescendo tests shall be conducted on three individual test specimens according to Section 5.3.

5.2 Mounting conditions for each test specimen panel shall replicate the support conditions for the full-size wall system assembly. Typical storefront and curtain wall test specimen mounting configurations are shown in Figure 1. For storefront and strip window systems, the test specimen shall be mounted between (like an infill wall) and anchored to the sliding steel tubes utilizing actual head and sill detail conditions. For curtain wall tests, the specimen shall be mounted to the outside faces of the top and bottom sliding steel tubes. As depicted in Figure 2, the outside edges of the glass-holding horizontal members shall align with the inside edges of the sliding steel tubes. The vertical mullions of the curtain wall system test specimen shall run beyond the outside edge of the glass-holding horizontal member by no more than 200 mm (8 in.). Figure 2 represents a typical curtain wall mullion anchor detail. The Test Agency shall employ a mullion anchor detail during crescendo testing that replicates the actual mullion support conditions of the wall system being tested. If actual, project-specific mullion anchorage details are not available, the test specimen shall be anchored as shown in Figure 2.

5.3 For wall systems comprised of individual windows or punched openings, the test specimen shall consist of three individual units. For the case of individual units, it is permissible to install all three units together in the test apparatus (assuming the actuator capacity is not exceeded at $\Delta_{fallout}$) and test them simultaneously, or install each unit in the test apparatus individually, and test them one at a time.

6.0 TEST PROCEDURES

6.1 "Crescendo tests," similar in concept and configuration to the "multiple step test" described in ATC-24 (1992), shall consist of a concatenated series of "ramp up" intervals and "constant amplitude" intervals. As depicted in Figure 3, in-plane (horizontal) racking displacement steps between constant amplitude intervals shall be 6 mm (0.25 in.). Ramp up intervals and constant amplitude intervals shall consist of four sinusoidal cycles each. Crescendo tests shall be performed at a frequency of 0.8 +0.1/-0.0 Hz for total applied racking displacements (drift amplitudes) of ±75 mm (±3 in.) or less, and 0.4 +0.1/-0.0 Hz for total applied racking displacements (drift amplitudes) greater than ±75 mm (±3 in.). The displacement measuring system shall be accurate to within ±2 mm (±1/16 in.).

6.2 Each crescendo test shall be run continuously until completion. Each crescendo test shall proceed until the first of the following conditions exists: (1) glass fallout, as defined in Section 6.3, occurs; (2) the drift index over the height of the glass panel is at least 0.10 (10%); or (3) a dynamic racking displacement of ±150 mm (±6 in.) is applied to the test specimen.

6.3 Three test specimens of each glass panel configuration in the $\Delta_{fallout}$ test plan shall be subjected to the crescendo test. The dynamic racking amplitude associated with glass fallout, $\Delta_{fallout}$, shall be measured and recorded during each crescendo test. The lowest $\Delta_{fallout}$ value measured during the three crescendo tests shall be the controlling value reported for that set of specimens. Measurement of $\Delta_{fallout}$ shall be accomplished either by synchronized videotaping of the crescendo test or by another measurement technique approved by the specifier. Glass fallout is considered to have occurred when an individual glass fragment larger than 650 mm^2 (1.0 $in.^2$) falls in any direction from the test panel glazed opening. If no glass fallout occurs by the end of the crescendo test, $\Delta_{fallout}$ for that specimen shall be reported as being "greater than" the maximum drift amplitude in mm (in.) imposed on the test specimen during the crescendo test.

6.4 Although the focus of this test method is on glass fallout, the dynamic racking amplitude associated with fallout of other wall system components shall also be noted and recorded during each crescendo test for information purposes. This information is particularly relevant if component fallout occurs before glass fallout during a given crescendo test.

6.5 Optional $\Delta_{cracking}$ Test: The dynamic racking amplitude associated with initial glass cracking, $\Delta_{cracking}$, may also be recorded as an option during each crescendo test. ($\Delta_{fallout}$ is a life safety limit state of glass panels during seismic movements, while $\Delta_{cracking}$ is a serviceability limit state of glass panels during seismic movements. Life safety considerations form the primary basis for current model building code provisions. A cracked glass panel would require replacement, so it would no longer be "serviceable." However, a cracked glass panel could also present a longer-term life safety hazard if glass fallout were to occur before a replacement glass unit is actually installed.) If $\Delta_{cracking}$ values are measured, results from all three individual crescendo tests shall be reported, but the lowest $\Delta_{cracking}$ value measured during the three crescendo tests shall be the controlling value reported for that set of specimens. If no glass cracking occurs by the end of the crescendo test, $\Delta_{cracking}$ for that specimen shall be reported as being "greater than" the maximum drift amplitude in mm (in.) imposed on the test specimen during the crescendo test.

7.0 APPARATUS

7.1 A laboratory facility that has already been developed and utilized to perform dynamic racking crescendo tests is shown in Figure 1. This test facility is described in greater detail by Behr and Belarbi (1996). A schematic diagram of the stroke control and data acquisition system for the dynamic racking test facility is shown in Figure 4. Figures 1 and 4 are not included in this test method with the intention of prescribing the apparatus to be used for conducting the $\Delta_{fallout}$ tests. In fact, some of the features in Figures 1 and 4 (e.g., load cell measurements) are beyond the basic requirements of the crescendo test described in this test method. Figures 1 and 4 are included in this document primarily for information purposes.

7.2 The test apparatus shall include a means of recording and printing a hard copy of a displacement versus time history for each crescendo test performed.

7.3 The Test Agency may use an alternative apparatus to perform the dynamic racking crescendo test described in this test method. Any suitable test apparatus approved by AAMA during the laboratory accreditation process is permitted for use in performing $\Delta_{fallout}$ or optional $\Delta_{cracking}$ tests.

8.0 SAFETY PRECAUTIONS

8.1 This test method could involve the use of potentially hazardous operations and equipment. This document does not purport to address all appropriate safety issues associated with its use. It is the responsibility of the user of this recommended test method to establish appropriate safety precautions.

8.2 Proper precautions shall be taken to protect all test observers in the event of any failure.

9.0 PRODUCT QUALIFICATION

9.1 Successful tests (i.e., no glass fallout at the required drift) of a particular wall system assembly shall qualify other assemblies of the same type that contain smaller glass panels, provided the anchorage of the glazing remains unchanged. Smaller units shall qualify, provided that both the width and height do not exceed the tested size, the edge clearances are not reduced, and the specified drift index (i.e., the drift index required for the particular project) is equal to or less than the tested unit.

9.2 Successful tests (i.e., no glass fallout at the required drift) of a particular wall system assembly containing laminated glass shall qualify other assemblies containing laminated glass, provided the interlayer is equal to or greater in thickness, the glass type, thickness, treatment and anchorage of the glazing remains unchanged, the edge clearances are not reduced, and the specified drift index is equal to or less than that required for the tested unit.

9.3 Successful tests (i.e., no glass fallout at the required drift) of a particular wall assembly shall qualify other assemblies with the same glazing type that are tinted, heat absorbing, reflective, or aesthetically modified, provided the requirements of Sections 9.1 and 9.2 are satisfied.

9.4 Successful tests (i.e., no glass fallout at the required drift) of a particular wall assembly that contains construction to improve thermal efficiency of the frame or sash shall qualify other assemblies that do not contain construction to improve thermal efficiency, provided the system otherwise remains unchanged and the requirements of Sections 9.1 and 9.2 are satisfied.

10.0 TEST REPORT

10.1 Three specimens of each glass panel configuration shall be subjected to the crescendo test. Results from all three individual crescendo tests shall be reported, but the lowest $\Delta_{fallout}$ value measured during the three crescendo tests shall be the controlling value reported as $\Delta_{fallout}$ for that set of specimens.

10.2 The displacement versus time record for each crescendo test shall be included in the test report to document the dynamic displacements actually imposed on each test specimen. The dynamic drifts associated with $\Delta_{fallout}$ (required) and $\Delta_{cracking}$ (optional) for all specimens of each test panel configuration shall be reported. Test results shall be reported in terms of both drift magnitudes in mm (in.) and drift indices expressed as either decimals or percentages.

10.3 A clear sketch (or photograph) and a written description of glass fallout (required) and glass cracking (optional) shall be included in the test report for each test specimen. In terms of seismic life safety, the lowest $\Delta_{fallout}$ value measured during the entire approved test plan shall govern the glass fallout resistance of the prototype wall system under consideration. The test report shall also make specific reference to any non-glass fallout event observed during any crescendo test, because such fallout events could also impose risks to life safety during an earthquake.

10.4 The test report shall also include:

10.4.1 The name and address of the Test Agency, location of test site, date when test was completed, and date of issuance of report.

10.4.2 Identification and description of the specimen(s): manufacturer; source of supply; dimensions; model number; type; materials of construction; and any other pertinent information.

10.4.3 Glass thickness, type, and method of glazing. Type of interlayer employed in laminated glass units. Type of gasket material and structural silicone bead size when used. Dimensions of edge bite and clearances.

10.4.4 Type, materials of construction, and locations of any anchoring systems and devices.

10.4.5 A drawing or photograph of the test facility and the wall system test specimen indicating location of measuring devices and movement devices.

10.4.6 Additional observations made by Test Agency personnel during testing that could aid the specifier in evaluating system performance.

10.4.7 A statement that tests were performed in accordance with the AAMA recommended test method.

11.0 REFERENCED DOCUMENTS

AAMA 501.4-00 – "Recommended Static Test Method for Evaluating Curtain Wall and Storefront Systems Subjected to Seismic and Wind Induced Interstory Drifts," American Architectural Manufacturers Association, Schaumburg, Illinois.

AAMA CW-DG-1-96 – "Aluminum Curtain Wall Design Guide Manual," American Architectural Manufacturers Association, Schaumburg, Illinois.

ASTM E564-95 – "Standard Practice for Static Load Test for Shear Resistance of Framed Walls for Buildings," Annual Book of ASTM Standards, American Society for Testing and Materials, Philadelphia, Pennsylvania.

ATC-24, 1992 – "Guidelines for Cyclic Testing of Components of Steel Structures," Applied Technology Council, Redwood City, California, p. 11.

Behr, R.A., Belarbi, A. and Culp, J.H., 1995, "Dynamic Racking Tests of Curtain Wall Glass Elements with In-plane and Out-of-plane Motions," Earthquake Engineering and Structural Dynamics, Vol. 24, No. 1, pp. 1-14.

Behr, R.A. and Belarbi, A., 1996, "Seismic Test Methods for Architectural Glazing Systems," Earthquake Spectra, Vol. 12, No. 1, February 1996, pp. 129-143.

"NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures", Part 1 – Provisions, 2000, BSSC (Building Seismic Safety Council), Washington, D.C., Issued by the Federal Emergency Management Agency.

"NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures", Part 2 – Commentary, 2000, BSSC (Building Seismic Safety Council), Washington, D.C., Issued by the Federal Emergency Management Agency.

Thurston, S.J. and King, A.B., 1992, "Two-Directional Cyclic Racking of Corner Curtain Wall Glazing," BRANZ Study Report No. SR44, Building Research Association of New Zealand, Judgeford, New Zealand, p. 11, p. 13.

Wright, P.D., 1989, "The Development of a Procedure and Rig for Testing the Racking Resistance of Curtain Wall Glazing," BRANZ Study Report No. SR17, Building Research Association of New Zealand, Judgeford, New Zealand, p. 7, p. 13.

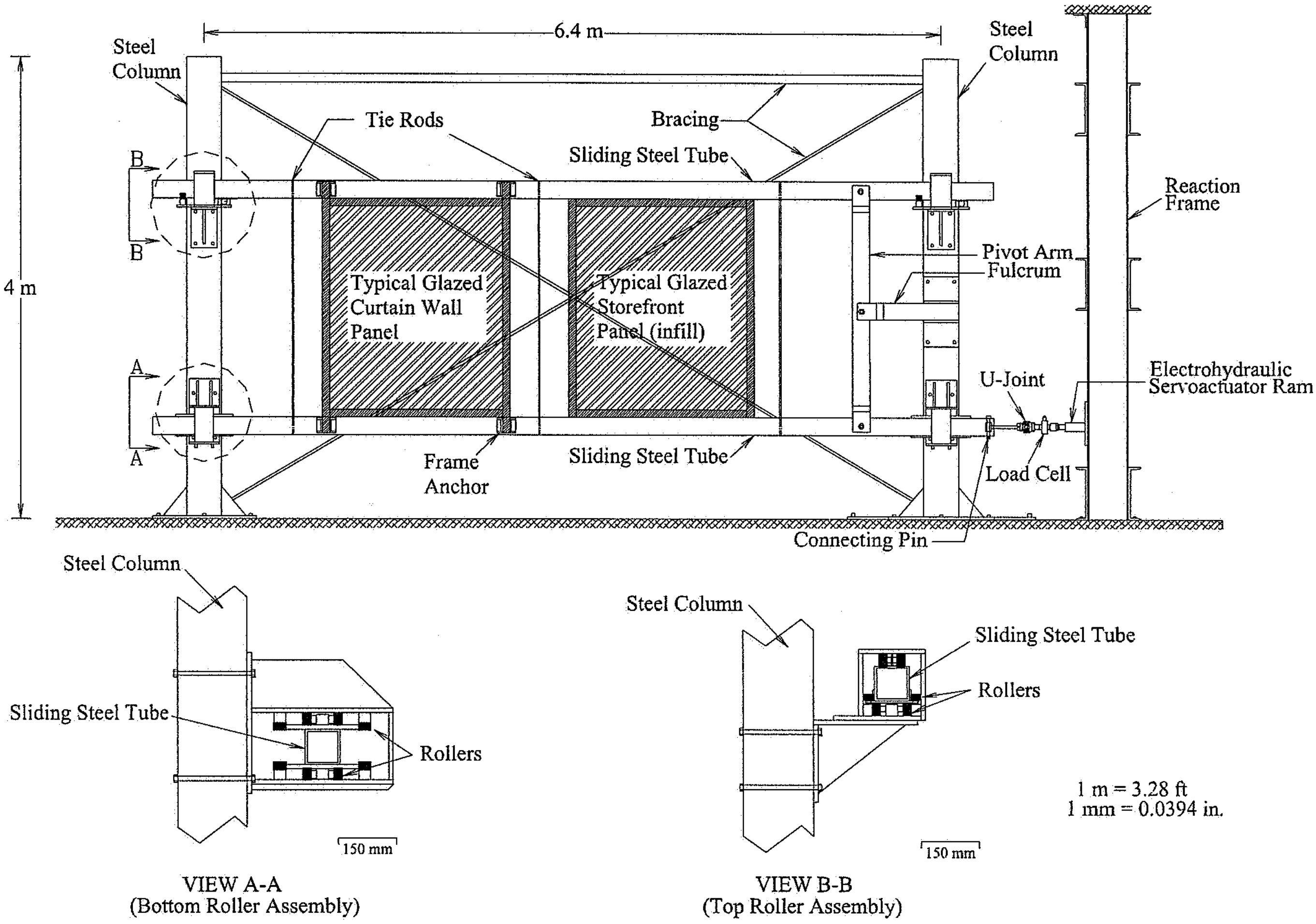


FIGURE 1
Dynamic Racking Test Facility at the Building Envelope Research Laboratory, Department of Architectural Engineering, The Pennsylvania State University, University Park, PA.

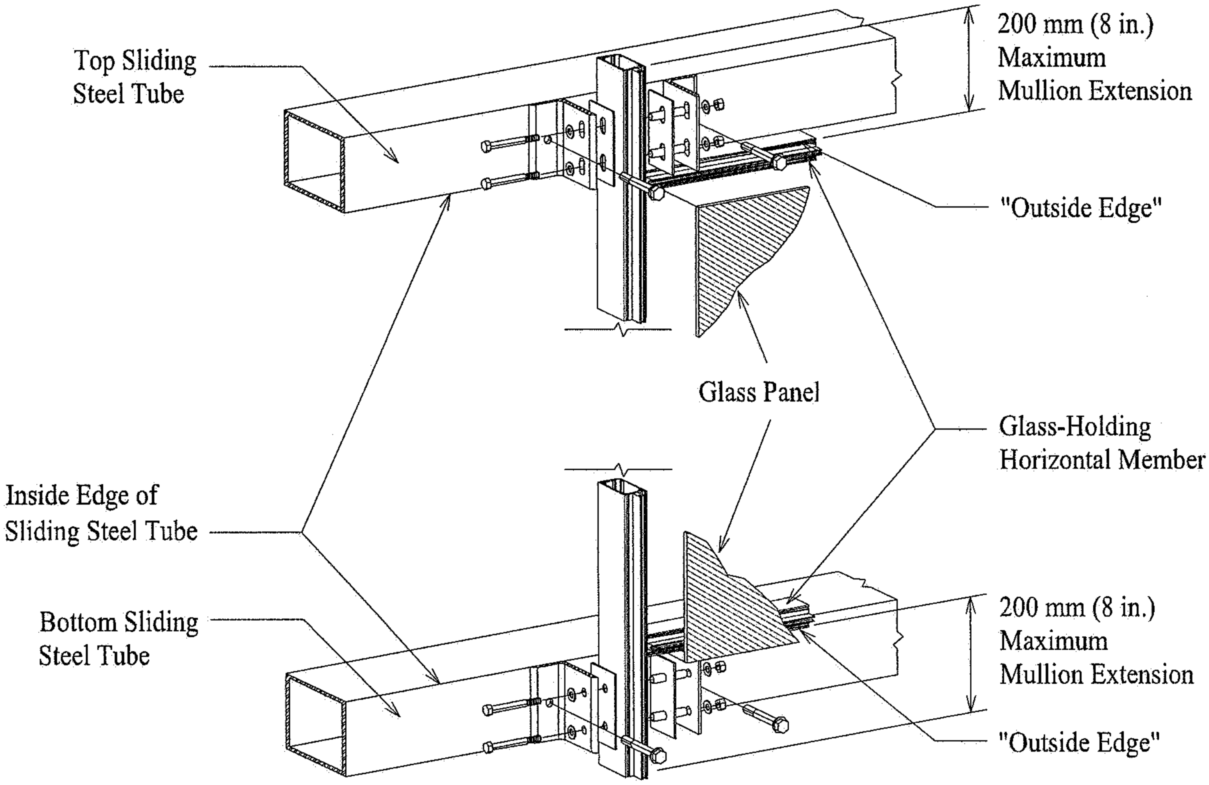
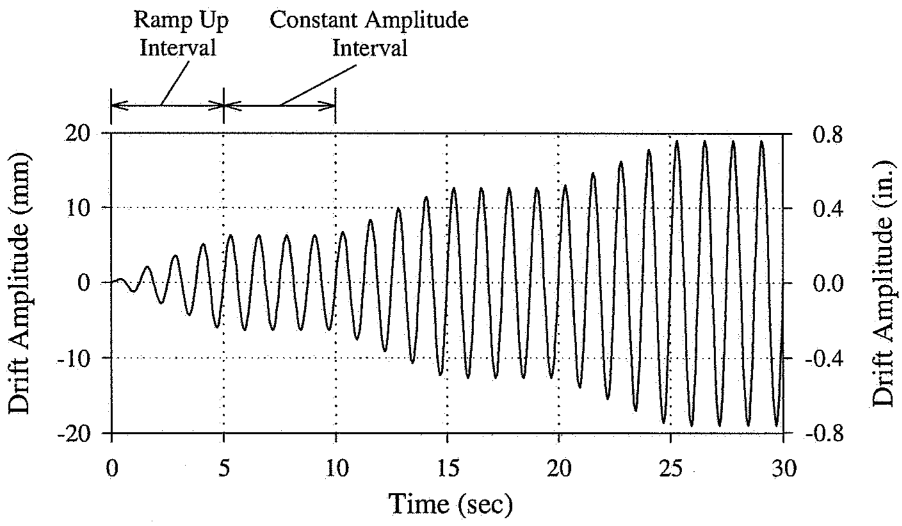
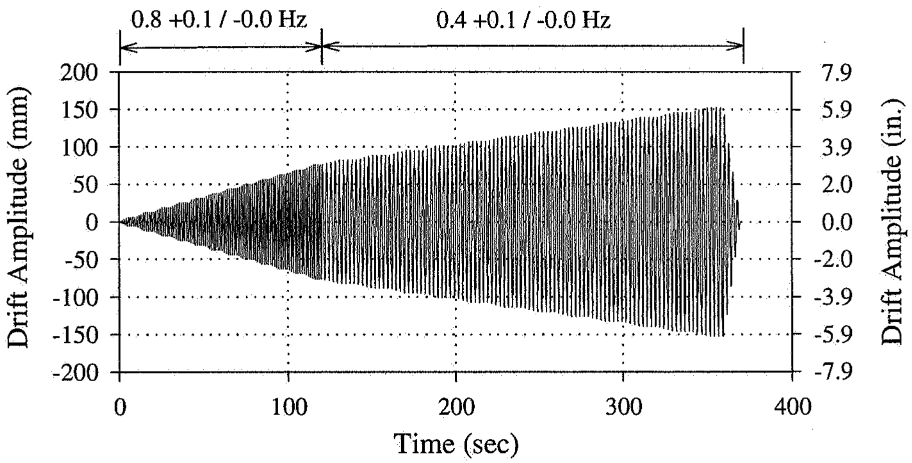


FIGURE 2
Typical Curtain Wall Mullion Anchor Detail at Top and Bottom Sliding Steel Tubes of Dynamic Racking Test Facility



(a) First 30 Seconds of Crescendo Test



(b) Full Crescendo Test

FIGURE 3
Schematic of Displacement Time History for Dynamic Crescendo Test

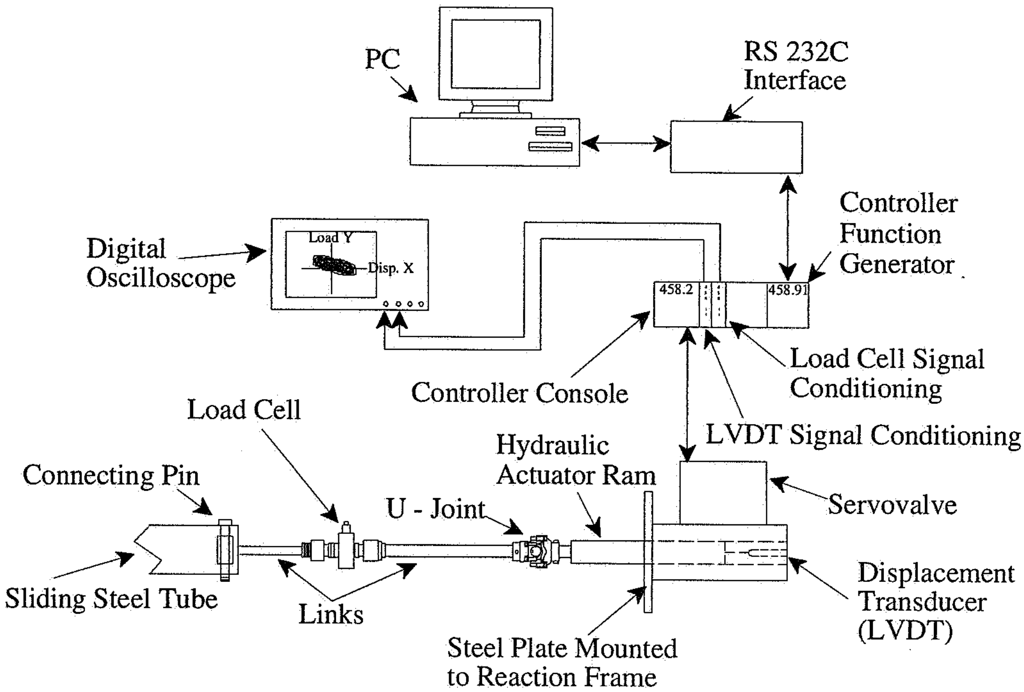


FIGURE 4
Control and Data Acquisition System for Dynamic Racking Test Facility at the Building Envelope Research Laboratory, Department of Architectural Engineering, The Pennsylvania State University, University Park, PA.

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