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RATING CURTAIN WALLS ON PERFORMANCE

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Need of a Water-tightness Performance Rating System

The major performance functions for a curtain wall system include structural safety, thermal insulation, sound insulation, and water-tightness performance. Except the water-tightness performance, all other performance functions can generally be predicted and designed based on rational analyses or laboratory tests.

It is well known in the curtain wall industry that the water-tightness performance is the most difficult parameter to evaluate due to the following experienced facts.

1. Frequently reported by testing laboratory's manager that 90 to 95 percent of test mock-up failed the first water test.
2. It can be logically recognized that the workmanship on a mock-up is better than that on the real building.
3. The reported percentage of incidents of water leakage problem within the first year of curtain wall enclosure is known to be very low.
4. Remedial work is allowed to fix the water leakage until the mock-up passed the test.
5. The water leakage problem on a real building often occurs in a rain storm condition with much less intensity than that was used on the successful mock-up test in both the amount of water and the pressure differential.
6. Once the water leakage problem has been detected on a building, it will become a multiple recurrence problem within a year if no successful remedial work is executed.

The following logical conclusions can be drawn from the above six experienced facts.

C1 : The test condition is much more severe than the water leakage condition experienced in a real building.

C2 : Passing a test can not be used as a measure of water-tightness performance of the real building.

C3 : Passing a water test at a higher differential air pressure is not an indication of better water-tightness performance on the real building.

C4 : The real issue is the aging effect on the water-tightness performance of the curtain wall system and the inaccurate simulation of the nature in the laboratory.

Based on the above logical conclusions, the state of the art laboratory testing methods and procedures offer very little clue to tell a good curtain wall system from a bad one. A practical and reliable rating system is urgently needed to promote the progress of technology.

Problems of State-of-the Art Water-tightness Performance Test Methods

1. Simulation of the Natural Rain
    a. Intensity of Rain Water on the Wall Surface : Typically a fixed amount of water per unit area of the mock-up wall surface is sprayed onto the wall surface from a fixed distance from the wall surface by a grid of multiple nozzles spaced at a fixed distance between them. The amount of water, the nozzle distance from the wall, the nozzle spacing, and the type of nozzle vary from country to country. However, they are the unified test set-up within a country regardless of the size of the building and the weather variations within the country. Therefore, the true simulation of the natural rain for a particular building at a particular location is highly questionable. In addition, comparing the observed amount of water running on the wall surface of a mock-up to that on the wall surface of a highrise building, one can easily reach the following two conclusions. First, in a heavy rain with mild wind condition, the two conditions are about equal. Second, in a heavy rain with high wind condition, the amount of water running on the wall surface of a highrise building is much less than that on a test wall. For a single defense system such as a wet seal system, the test performance is not sensitive to the amount of water on the test wall surface. For an advanced modern system such as a pressure equalized system, excessive water on the test wall surface might restrict or disable the pressure equalization mechanism and/or cause the overflow of the drainage mechanism. Therefore, the true simulation of the amount of water running

on the wall surface of a real building must be evaluated as a function of the positive wind pressure on the test wall.

b. Method of Providing Water on the Wall Surface of Test Mock-up : Each spraying nozzle is perpendicular to the wall surface with a cone-shaped spraying pattern. Even though this mode of providing water on the wall surface can not be found in the natural rain, the earlier generations of curtain wall system are not sensitive to the water spaying pattern. However, the more advanced modern curtain wall systems such as Open Joint Unitized System and Airloop System are often sensitive to the water spraying pattern. For example, the spraying water is stationarily directed upwardly on the upper portion of the spraying cone, if the placement of the nozzle fits a particular orientation, this steady stream of water may be shooting at the open space designed for air entry with some tolerance for incidental water entry. The tolerance for incidental water entry would surely be exceeded by the steady entry of the spraying water causing the overflow of the internal drainage capability. Therefore, a more realistic method of delivering the water onto the test wall surface must be developed for testing the more advanced modern curtain wall systems.

2. Simulation of the Natural Wind

a. Intensity of Differential Air Pressure : Without remedial work after the first occurrence of water leakage problem, most of the reported water leakage conditions recur in a relatively mild rain storm situation. From the above discussions on the need of a rating system, it can be logically concluded that the reason for the first occurrence of water leakage is due to the degradation of the water sealing property of the system rather than the water-tightness resistance to the intensity of the differential air pressure. For example, for a wet seal system, if the caulking application is perfect, the system may be able to sustain a differential air pressure of 3000 Pa in the water test without leakage. However, the perfect seal may become imperfect after one year of service due to sealant stress fatigue caused by various structural movements and water leakage will occur at a very mild rainstorm situation. Therefore, the current concept of resisting water leakage at a higher differential air pressure is an absolute measure of water-tightness performance is highly questionable.

b. Method of Providing Differential Air Pressure on the Mock-up : To this writer's knowledge, there are four different methods of creating the differential air pressure on a mock-up. The first method is known as static pressure method using a vacuum chamber and is commonly used in USA. In this method, a sealed chamber is built on the interior side of the test wall and a negative differential air pressure is created in the chamber by extracting the air from the chamber. The second method is known as dynamic pressure method in association with the vacuum chamber method and is commonly used in USA. In this method, a positive differential air pressure on the test wall is created by real wind generated by a big fan normally powered by an airplane propellant engine or a car engine. The third method is known as static pressure method using a pressure chamber and is commonly used in countries outside USA. In this method, a sealed chamber is built in front of the outside wall surface and a positive differential air pressure is created inside the chamber by blowing air into the chamber. The fourth method is known as dynamic pressure method in association with the pressure chamber method and is commonly used in countries outside USA. In this method, the cyclic positive pressure inside the chamber is caused to fluctuate between a maximum and a minimum with a predetermined cycle period by controlling the air supply into the chamber. Again, the earlier generations of curtain wall system are not sensitive to the method of providing the differential air pressure. However, the more advanced modern curtain wall systems, such as Open Joint Unitized System and Airloop System, are more sensitive to the mode of providing the differential air pressure. For example, water ingress along a seam due to the capillary action is much easier by a steady vacuum force (equivalent to pulling an object on a friction floor) from inside than by a steady positive force from outside (equivalent to pushing an object on a friction floor). Since water leakage problem is always associated with a positive wind pressure, the positive pressure chamber method should be considered as the more accurate simulation of the natural wind pressure. Another example is the effect on the pressure equalization mechanism in an open joint system. The true nature of wind is dynamic and the pressure is caused by the impact of the air mass. The impacting air mass must rebound from the wall surface and go around the building. There is a time lag between the wind pressure on the wall surface and the pressure equalization in the wall cavity. This time lag would prevent water leakage due to continuous water ingress in an open joint system. Therefore, the dynamic pressure method should be considered as the more accurate simulation of the wind pressure. Furthermore, in the natural wind condition, the rebounding air mass would move the water around on the wall surface and carry away part of the water on the wall surface. This behavior should have some impact on the performance of an open joint system but is not simulated by the fourth method. Therefore, the second method should be considered as the most accurate simulation of the natural wind.

3. Simulation of the Effects of Long Term Cyclic Structural Movements
    a. Effects of Thermal Movements : The anticipated thermal load on the components of a curtain wall system at a specific geographic location and the thermal movement of each component material can normally be predicted with high degree of confidence. The significance of the sealant line thermal stress induced by the thermal load depends on the curtain wall system design. For an open joint design, the sealant line thermal stress is typically insignificant. For a restrained joint design, repeated long term thermal cycles could cause sealant line failure due to stress fatigue. The state-of-the-art mock-up testing procedure does not take into account the effect of thermal movement.
    b. Effects of Wind Load in the Direction Perpendicular to the Wall Surface : The sealant line stress due to wind load is caused by the perimeter restraint

on the facing material against the membrane type of deformation. This type of effect is difficult to predict by theoretical analysis and is simulated in most of the mock-up testing procedures in many countries.

c. Effects of Story Drift due to Wind Load or Seismic Load : For most curtain wall systems, the story drift would tend to change the shape of the facing material due to the tilting of mullions which are fixed to the floor slab edge. Most of the facing materials are relatively rigid against in-plane shear distortion caused by the story drift and the curtain wall component to give is the perimeter sealant line on the facing material. Therefore, sealant line dislocation and/or sealant line failures are commonly caused by the story drift of the building. The effect of story drift is simulated in most of the mock-up testing procedures in many countries.

d. Effects of Inter-Floor Deflection due to Floor Live Load : Since the curtain wall supporting mullions are secured to the edge of the floor slab, except the dead loaded mullion design, an inter-floor deflection would cause the curtain wall joints to move, some to increase the joint gap and some to reduce the joint gap. The most common method of simulating the effect of inter-floor deflection is to conduct the water test at the nutral position after performing three deflection cycles in dry condition. Since the inter-floor deflection could occur during a rainstorm, water-tightness performance test should be conducted at the maximum inter-floor deflection condition. This test condition has not been specified in most test protocol worldwide.

4. Simulation of Aging Effects on Sealant Material Properties

   There is no practical direct method of simulating the aging effect on a test mock-up. The effects of structural movements are normally considered as the indirect measure of the aging effect.

5. Simulation of Rainstorm Duration

   The standard water test duration most commonly used in USA is 15 minutes. In other country such as China, the standard water test involves a maximum of five steps of step-wise increasing pressure with 10 minutes duration at each pressure step (i.e. maximum test duration of 50 minutes).

Recommended Testing Procedures for Performance Rating System

1. Method of Simulating Wind Effects

   To simulate the wind effects including the dynamic nature and the air mass rebounding behavior for accurate water-tightness performance evaluation for all curtain wall system, the following alternative wind simulating methods are recommended.

   a. Adopt the second test method (dynamic) by using a fan powered by an airplane propellant engine or car engine to create the wind effect on the exterior wall surface of a mock-up in association with an interior vacuum chamber.
   b. Modify the fourth test method (dynamic) by adding some fans inside the pressure chamber during the water test to create the air mass rebounding behavior.

2. Simulation and Selection of Wind and Rain Intensity

   There are two considerations for long term water-tightness performance. The first is the performance after enduring the maximum design loads such as 50-year recurrence interval wind force and seismic load. The second is the performance after enduring 1-year recurrence interval wind force and seismic force repeatedly over several years. The water leakage problem is an annual concern rather than a concern of once in 50 years. Therefore, the annual weather condition should be considered for conducting the water test. The following concept parameters are recommended.

   a. Use the following three grades of test pressure for the rating system.
      Gade A : 1500 Pa
      Grade B : 750 Pa
      Grade C : 500 Pa
   b. Use rows of perforated pipes to deliver uniformly distributed streams of water downwardly onto the test wall surface at an angle of approximately 45 degrees to the vertical.

c. Use the following amount of water to be delivered to the test wall surface.
For Grade A test: 2 liters per minutes per square meter of test wall surface.
For Grade B test: 3 liters per minutes per square meter of test wall surface.
For Grade C test: 4 liters per minutes per square meter of test wall surface.

3. Duration for Water Test

Considering the typical duration of serious combination of rain and wind, it is recommended to use 30 minutes as the standard duration for water test.

4. Selection of Test Parameters for Structural Movements

The first consideration is that the wall should not leak after experiencing the maximum structural design displacements due to wind, seismic, and live loads. Therefore, the maximum structural design load tests should be conducted before conducting the first water test. The second consideration is that the wall should not leak after experiencing the daily structural movements for a complete annual cycle. This would require to conduct the structural tests for many cycles at a much less load intensity. Due to the fact that the story drift cycles can be conducted at a relatively rapid speed and the effect on the degradation of the sealing integrity are expected to be more severe, it is recommended to use the cyclic story drift tests exclusively for this simulation due to time and cost considerations.

5. Recommended Test Procedures Constituting One Cycle of Tests

In order to obtain the performance data in addition to the water test, the first cycle of tests should include the following steps.

a. Air Infiltration Test
b. Wind Load Tests at the Maximum Positive and Negative Design Intensity.
c. Three cycles of story drift at the maximum design story drift or L/100 where L is the story height.
d. Water test in accordance with Items 1 to 3 above.

The second cycle and beyond should include the following steps.

a. Twenty cycles of story drift at 50% of the maximum design story drift or L/200 where L is the story height.
b. Water test in accordance with Items 1 to 3 above.

6. Performance Rating Based on Sustained Number of Cycles of Tests

The complete test procedures should include the following steps.

Step 1 : Conduct Cycle1 test. If no water leakage occurs, proceed to Step 2.

Step 2 : Conduct Cycle 2 test. If no water leakage occurs, proceed to Step 3.

Step 3 : Repeat Step 2 and counting the number of Cycles up to a maximum of 10 Cycles or until water leakage is observed.

The recommended performance rating notation is illustrated by the following example. A rating of A-C3 means Grade A test sustaining 3 cycles of tests without water leakage.

7. Standard Mock-up Size, Panel and Support Arrangements

   A performance rating system is for comparing the performances among various curtain wall systems. Therefore, in addition to the test method, the test mock-up structure must also be standardized. The following standard features on the test mock-up are recommended.

   a. Use three spaced apart horizontal supporting beams for securing the curtain wall mullions to simulate a two story high structure. The center-to-center dimension between two mullion securing points shall be 4 meters creating a two equal span structure at 4 meters each span. The total wall height shall be 8 meters plus the bottom and the top extensions required by the curtain wall system to be tested. The intermediate beam shall be the movable beam for the story drift test.
   b. Use the following sequential panel arrangement on each bay between two mullions starting from the bottom going upwardly: one spandrel panel, one vision panel, two spandrel panels, one vision panel, and one spandrel panel at the top. The nominal height of each vision panel shall be 1.6 m and the nominal height of each spandrel panel shall be designed to cover the entire wall height.
   c. Use five mullions spaced at 1.5 m on centers to create four equal bays.
   d. The typical top and bottom details of the curtain wall system shall be used on the mock-up.
   e. If curable caulking is used for any critical seal, the caulking must be completely cured before commencing the test.

8. Additional Rating for Inter-Floor Deflection

   Due to the fact that the maximum inter-floor deflection could occur and stay stationarily during the entire duration of a rainstorm, the water-tightness performance should be evaluated at the deflected floor condition. This is an in-service issue rather than a durability issue. Therefore, the following separate conceptual rating system is recommended.

   a. Use a small mock-up with one horizontal panel joint, one vertical panel joint, and two mullion segments spliced together. The bottom mullion segment is attached to a horizontal beam which can move downwardly to simulate the inter-floor deflection. The arrangement should cause the horizontal panel joint to enlarge.
   b. Use the pressure chamber method to conduct the water test with the following two steps.

      Step 1 : Water test with zero beam deflection. It must pass this test before going to Step 2 below.

      Step 2 : Water test with a beam deflection to be rated.

      The recommended rating notation after passing Step 2 test is illustrated as follows. A rating of B-D10mm means the system passes the water test with a Grade B load at an inter-floor deflection of 10mm.

Conclusions

Due to the rapidly increasing concern about the liability caused by the water leakage problem and the advances in curtain wall technology in recent years, it is urgently needed in the industry to have reliable and practical curtain wall test method and procedures to develop a performance rating system. To this end, the test method and procedures must be revised to more accurately simulate the effects of rainstorm on a modern curtain wall system as well as to take into account the measurement of performance durability. The recommendations presented herein can only represent a start of this effort in the conceptual stage. A much bigger effort throughout the industry is needed to finalize all details. Encouraging the use of a better technology is the common goal of the insurance industry and the curtain wall industry to lessen the liability issue. This goal can only be accomplished by a sensible performance rating system. It is hoped that the building owners group, the general contractors group, and the insurance industry would form a task group to take the lead in this effort since they will be benefited significantly by reducing the liability exposure caused by the water leakage problem.