Structural Design and Load Testing of Façade Access Equipment

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INTRODUCTION

Façade access equipment is used on mid- and high-rise buildings to wash windows, perform maintenance, implement repairs, and replace glazing. Design of this equipment is governed by both the Occupational Safety and Health Administration (OSHA) and state and local laws, including building codes. Before façade access equipment is put into initial service, OSHA requires equipment be inspected and tested in the field to verify that it meets OSHA regulations, which include structural requirements. Although OSHA leaves responsibility for determining the specific requirements for the "test" in the hands of the engineer or architect, field tests for structural components typically consist of load tests. Load test practices and procedures vary widely in the industry (and are often technically flawed). Some engineers test only a limited portion of the components; others test to a fraction of the full design forces, often in a non-critical direction. This article is intended to describe some common misconceptions and poor engineering practices in the industry, and to help provide guidance regarding how the authors believe load testing of façade access equipment should be conducted, with due consideration to code requirements for such testing.

COMMON TYPES OF EQUIPMENT

Façade access equipment (a.k.a. exterior building maintenance equipment) comes in all shapes and sizes, from rooftop carriages that traverse the perimeter of a building, to individual davits that can be mounted at discrete points on the roof, to anchorages to which workers connect their lifelines or tie back temporary suspension equipment. *Figures 1* through *3* show typical façade access equipment. Provided below are very

Figure 1 – Large, rail-mounted rooftop carriage.

Figure 3 – Anchorage on a roof.

Figure 2 – Typical davit-supported work platform.

specific requirements for design and testing of façade access equipment, of which many engineers and architects have historically been unaware.

GOVERNING DESIGN LOADS

Design of façade access equipment can be broken down into two primary types: equipment that supports powered motors or hoists that typically support suspended platforms, and equipment that supports rope descent systems and fall arrest equipment, such as lifelines. While other elements, such as work platforms, have structural requirements, this paper focuses on the primary elements that support hoists and elements that support fall arrest equipment.

Design Loads for Elements that Support Hoists

OSHA operates under a federal mandate to regulate workplace safety and to develop minimum safety standards nationwide. OSHA requires that elements that support a hoist be able to resist at least 4.0 times the rated load of the hoist. The rated load is the safe working load that the hoist for a suspended window-washing platform is intended to lift. Equipment that is used to perform construction—including mundane activities such as painting and hanging of signs and holiday lights—is required by OSHA to be able to resist 1.5 times the stall load of the hoist, where the stall load is the maximum load that can be mechanically exerted by the hoist. OSHA permits stall loads to be as high as 3.0 times the rated load of the hoist. So where the exact stall load of the hoist is unknown or where different hoists may be used over the life of the equipment, equipment used for construction must be able to support 1.5 x 3.0 = 4.5 times the rated load of the hoist. While these load factors might appear high to engineers not particularly experienced in façade access design, these loads are dynamic and are generated by machines, which means that starting and stopping forces can be significantly larger than the weight of the suspended platform and workers. Further, if the platform snags an obstruction while ascending, the hoist can continue to increase tension in the suspension cable until it stalls, resulting in an effective factor of safety against failure of only 1.33 or 1.5 (calculated by taking the factored load and dividing by a stall load of 3 times the rated load), depending on whether the equipment was designed for building maintenance or construction purposes.

OSHA regulations are not written in conventional engineering terms, and confusion regarding the requirements is fairly common throughout the industry. Fortunately, the 2015 International Building Code (IBC) and the American Society of Civil Engineers' *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE 7-16) both define the loads in terminology that is more commonly understood and used by engineers. Wherever the 2015 IBC or ASCE 7-16 have been legally adopted, the elements that support hoists for façade access equipment must be designed for a minimum unfactored live load equal to the larger of the following:

- 2.5 times the rated load of the hoist
- 1.0 times the stall load of the hoist

These loads are provided in Section 1607.9.3 of the 2015 IBC, and ASCE 7-16 mandates similar loads. When multiplied by the typical live load factor of 1.6 (as defined in the IBC), the factored load is equal to the larger of the following:

- 4.0 times the rated load of the hoist
- 1.6 times the stall load of the hoist

Where the stall load of a hoist is unknown, it should be assumed to be 3.0 times the rated load of the hoist (i.e., the maximum allowed by OSHA), which results in an equipment design load of 1.6 x 3.0 = 4.8 times the hoist's rated load.

These loads match or slightly exceed OSHA's minimum requirements, and they eliminate the need to differentiate between building maintenance and construction loads, the boundary between which is often not clear and is defined by OSHA based on the work task being performed rather than the access equipment being used.

Design Forces for Lifeline/ Fall Arrest Anchorages

OSHA requires that lifeline/fall arrest anchorages be able to resist a minimum of 5000 pounds per attached worker in any direction that the anchorage can be used to arrest a fall. Although OSHA provides an exception that allows designers to reduce the load to the expected load times 2.0, the exception requires "supervision" by a "qualified person" during design, installation, and use. Designers who use this exception should advise the building owner of the potential costs associated with requiring supervision by a person "with extensive knowledge, training, and experience" for using the system over the life of the equipment, a requirement that may dwarf the cost of designing the anchorages without relying on the exception. The exception is not permitted to be applied to anchorages for rope descent systems, so if anchorages are used or may be used in the future to wash windows from boatswain's chairs, the full 5000-pound load should be used.

Additionally, OSHA does not clearly specify what constitutes "supervision of use," and practices vary widely in the fall protection industry. Consequently, the residual safety risks associated with potential misuse of the fall arrest anchorages and increased administrative and operational challenges for such anchorages should also be considered before using this exception to reduce fall arrest anchorage design loads.

Section 1607.9.4 of the 2015 IBC provides an analogous unfactored design live load of 3100 pounds for lifeline/fall arrest anchorages, and ASCE 7-16 has a similar provision. When multiplied by the typical live load factor of 1.6, the factored load is equal to 4960 pounds, essentially equaling OSHA's requirements. Neither the IBC nor ASCE 7-16 permits reduction of the design live load using the OSHA exception.

TESTING REGULATIONS

OSHA requires building owners to provide assurance that the exterior building maintenance equipment meets certain critical requirements, including the requirements regarding minimum capacity and design loads. OSHA further requires that such assurance be based on a "field test" prior to initial use and following any major modification, or if documentation of the initial certification is not available. Although OSHA does not define "field test," it is typically interpreted to mean an in-situ load test. Determination of the correct test setup and test load is left to the engineer responsible for the testing and certification program.

Further, OSHA has issued conflicting requirements and interpretations. OSHA requires certification for the required strength in Section 1910.66 (e.g., having a minimum capacity with a factor of safety of 4.0) and Section 1910.27 (i.e., having a minimum strength of 5000 pounds per attached person), but it also issued a poorly worded interpretation 24 years ago that illogically indicates that testing to the full load is not required by Section 1910.66.

Controversy Regarding Load Tests

Some engineers advocate for load testing to a maximum of 50 percent of the minimum required strength (a.k.a. the full factored load). However, other engineers believe that if façade access equipment is to be tested to certify compliance with a particular required strength, then the test load needs to be a minimum of 100 percent of that required strength. To determine whether a given test load or procedure is logical, well-established principles of mechanics, materials science, and statistics must be considered.

Testing to 100 Percent of the Minimum Required Strength

If load testing is performed to 100 percent of the minimum required strength and the equipment successfully holds the test loads, the tester (and the workers using the equipment) can be confident that the equipment has the minimum required strength, *quod erat demonstrandum.*[1] Successfully passing the test load includes confirming that the tested elements did not suffer damage during the test (e.g., significant yielding, fracture, etc.).

Unfortunately, not all equipment should be load tested. For equipment that must develop significant inelastic deformations to resist the minimum required loads (for example, fall arrest anchors that bend over if the anchor is ever used to arrest a falling worker), testing to 100 percent would likely result in unusable equipment, but testing to only 50 percent would be reckless, because these designs are pushing the envelope more than typical, and if significant strain hardening must occur to develop the required strength, these designs are more likely to result in premature failure. In these relatively rare cases, load testing is generally not an option, and other methods must be employed if the capacity of the equipment is to be verified.

Testing to 50 Percent of the Minimum Required Strength

Advocates for 50 percent load tests on elements that support hoists have historically tested davits and outriggers to a maximum of only 2.0 times the rated load of the supported hoists, and fall arrest anchorages to only 2500 pounds. So both test loads are half of the minimum required strength (or less than half of required strength for hoists used for construction). In addition, many proponents of this approach recommend only testing a sampling of the equipment rather than every element. Advocates of 50 percent testing falsely claim that this level of testing is standard in the industry, but we have seen testing levels vary from as little as 18 percent to slightly more than 100 percent. Advocates of 50 percent testing also occasionally claim it is necessary to cap load tests at 50 percent to avoid damaging the roofing; however, damage to roofing can happen during any load test, and artificially limiting a structural load test of life-safety equipment to avoid hypothetical damage to an architectural element that can be easily repaired constitutes negligence.

Although some industries may conduct load tests to less than the full factored loads, there is absolutely no scientific or structural engineering justification for a 50 percent cap on loads during load tests. One cannot extrapolate a 50 percent load test and properly conclude that the element being tested has a capacity of at least twice the load used in the test. Arbitrary limits on test loads ensure that critical design, fabrication, or installation defects and/or damage will not be detected. Similarly, one cannot load test a fraction of the equipment and properly conclude that the untested equipment does not have any defects or damage that would cause it to fail prematurely.

To better illustrate these points, we offer the following actual examples of the illogical, indefensible nature of 50 percent load tests.

Case A: An engineer tested a group of apparently identical fall arrest anchorages to 2500 pounds. Several of these anchorages were unable to resist the 50 percent test load. The engineer then certified that the remaining anchorages, which had only been tested with 2500 pounds, could all support 5000 pounds, despite the knowledge that apparently identical anchorages had contained significant hidden defects that precluded them from being able to resist even half of this load.

Case B: An engineer tested a group of anchorages used for fall restraint and fall arrest purposes. The engineer only loaded them to 900 pounds during the tests—a shockingly low test load—and then certified that they met the minimum strength requirement of OSHA. For several years, these anchorages were used as both fall restraint and fall arrest anchorages, and some were even used as anchorages for horizontal lifelines, which means that in the event of a fall, they could be subject to forces two or three times larger than 5000 pounds due to geometric effects of loading a cable perpendicular to its length. Subsequent review revealed that each anchorage was only connected to a 2½-in.-thick concrete slab with a single bolt, clearly inadequate to resist the full load. Had the anchorages been called to resist an actual fall arrest load, the likelihood of failure would have been unacceptably high.

Case C: An engineer certified that a group of davit bases had the required strength based on testing to only half of the required strength. Subsequent testing to higher loads revealed that several bases did not have the strength needed to carry the minimum OSHA-specified loading. The davit bases failed due to brittle fracture of welds. Had those davit bases been required to resist the full load, such as during a stall situation, the bases would have failed.

Load Test Requirements of the IBC

In jurisdictions where the 2015 IBC has been adopted, Section 1708 governs in-situ load tests. Where load tests are not specified by the relevant IBC-referenced material design standard (e.g., components constructed of wood), Section 1708.3.2 requires that the minimum load applied during the test be the factored design load. In the case of davits, outriggers, and their supports, the factored design loads are shown below, which means the minimum permissible test load is the greater of the two.

1) 4.0 times the rated load of the hoist
2) 1.6 times the stall load of the hoist (which equals 4.8 times the rated load of the hoist if the stall load is 3.0 times the rated load, or if the stall load is unknown)

For fall arrest anchorages, the factored design load, and therefore the minimum load test, is 1.6 x 3100 pounds = 4960 pounds.

Where load tests are specified by the relevant IBC-referenced material design standard (e.g., components constructed of steel or concrete), Section 1708.3.1 requires load testing to be conducted according to the provisions of that standard, as described below.

Load Test Requirements of AISC

Load test requirements for steel structures are provided in Section 5.4 of Appendix 5 of AISC 360-10, *Specification for Structural Steel Buildings,* published by the American Institute of Steel Construction (AISC). Like the IBC, the load test provisions require the factored load to be applied. As the load factor for live loads is 1.6, the net result is identical to that required by Section 1708.3.2 of the IBC.

Load Test Requirements of ACI

Load test requirements for concrete structures are provided in Section 27.4 of the *Building Code Requirements for Structural Concrete* (ACI 318-14), published by the American Concrete Institute (ACI). ACI requires that the magnitude of the load test be determined using a load factor of 1.5. In the case of davits, outriggers, and their supports, the minimum test load can be calculated as the greater of the following:

1) 1.5 x 2.5 times the rated load of the hoist = 3.75 times the rated load of the hoist
2) 1.5 times the stall load of the hoist (which equals 4.5 times the rated load of the hoist if the stall load is 3.0 times the rated load, or if the stall load is unknown)

For reinforced concrete components of fall arrest anchorages and their supports, the minimum load test can be computed by multiplying the live load factor of 1.5 times 3100 pounds, which equals 4650 pounds.

These values are within 6 percent of the test loads required by AISC and the IBC, which is a negligible difference.

Voluntary Standards

There are two voluntary (i.e., not referenced by the building code) standards that limit testing to only 50 percent of the minimum required strength: IWCA I-14.1, *Window Cleaning Safety*, and ASME A120.1, *Safety Requirements for Powered Platforms and Traveling Ladders and Gantries for Building Maintenance*. Neither standard can supersede the requirements of mandatory standards or engineers' duty to use rational engineering principles when developing a load test. Further, both have significant technical flaws, a few of which are discussed below.

IWCA I-14.1

The International Window Cleaning Association's IWCA I-14.1 standard was published only once, in 2001. Many technical errors in the standard were pointed out by the authors of this article as well as other engineers and the National Council of Structural Engineering Associations (NCSEA); however, the committee never incorporated the comments into an updated standard. After the IWCA failed to update its standard for a decade, the American National Standards Institute (ANSI) administratively withdrew the standard in 2011. Furthermore, ANSI suspended the IWCA's accreditation for cause in 2012, and again in 2016. Half a year later, ANSI took the unusual step of permanently withdrawing the IWCA's accreditation, citing "repeated serious procedural and administrative concerns...including but not limited to unreasonable restrictions on consensus body membership and failure to properly process public review comments, substantive changes and appeals." Consequently, the IWCA I-14.1 standard should not be relied upon for any technical information.

ASME A120.1

The American Society of Mechanical Engineer's A120 committee has a similar history of ignoring public comments regarding problems with its load testing provisions. The A120 and the I-14.1 committees have significant overlap in terms of membership, and both committees are dominated by individuals without engineering degrees or licenses; thus, it is not surprising that in 2010, the A120 committee proposed load testing restrictions essentially identical to those in I-14.1. Despite an exceptionally large number of public comments objecting to the proposed changes, the flawed limits on load testing were adopted into the 2014 edition. Since A120.1 is only a voluntary, advisory standard, engineers should ignore its load testing provisions, which are in direct conflict with reputable, non-voluntary standards such as 2015 IBC, AISC 360-10, and ACI 318-14.

How Proper Load Testing Is Conducted

The following examples show how proper load testing can be conducted in the field to verify that façade access equipment meets the minimum structural requirements. Such testing should be performed prior to initial use to satisfy OSHA Section 1910.27, Section 1910.66(c), after a major modification, if there is doubt regarding the capacity of the equipment due to lack of documentation regarding initial testing, or if damage or deterioration has occurred or is suspected.

Figure 4 shows a hydraulic ram pushing upwards against an inward-projecting load test apparatus beam that is connected to a davit base. Pushing upward on the beam creates a moment towards the side

Figure 4 – Load testing of a davit base.

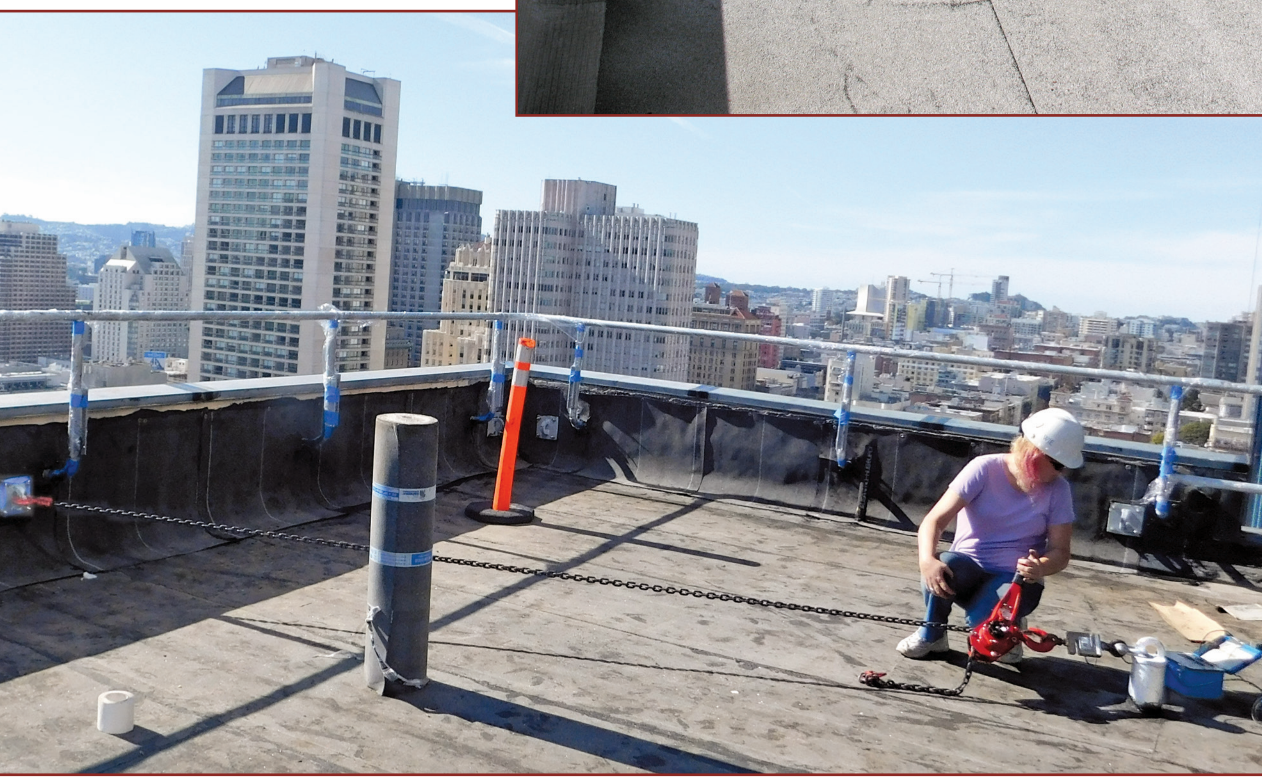

Figure 5 – Load testing of a lifeline/tieback anchorage.

of the building, simulating the overturning demand that would result from a work platform suspended over the side of the building. Deflections of the equipment were monitored during the load test to confirm that the davit bases remained undamaged under the required full-factored loads.

Figure 5 shows load testing of a lifeline/tieback anchorage. In this photo, the load is being applied toward the edge of the roof to match one of the potential directions for a fall arrest load. Since lifeline loads could come from a number of directions, this anchor was also pulled toward the edge of the building behind the engineer in the photo.

Figure 6 shows the load testing of a davit. In this case, the davits had been designed in the 1950s, long before the development of modern design standards for façade access equipment. At some point, the original 675-pound hoists had been replaced with 1000-pound hoists, a significant mismatch that calculations indicated the davits were unlikely to be able to support. Since replacement 675-pound hoists are no longer commercially available, it was necessary to verify that the davits could support the next best available choice: slightly larger 750-pound hoists. The load was applied downward at the tip of the davit, simulating the bending caused by a suspended work platform. Deflection was monitored to ensure that the davit remained elastic. Load testing of the carriage and the perimeter rails that support the davit was performed separately using a cantilever loading beam similar to that shown in *Figure 4*.

CONCLUSIONS

The 2015 IBC and ASCE 7-16 now provide design live loads for façade access equipment. When factored by the required live load factor of 1.6, the loads closely match or slightly exceed the loads required by OSHA. Due to the critical nature of this equipment, load tests are commonly performed prior to initial use, after major alterations, and whenever there is reason to believe that damage or deterioration may have reduced the capacity of the equipment. Misunderstanding regarding how to perform the load testing is common within the industry, largely due to two technically flawed voluntary standards: the IWCA I-14.1 (which has been administratively withdrawn, and which lost its ANSI accreditation) and the ASME A120.1. Both of these standards violate common sense and basic engineering principles when it comes to load testing; they also conflict with the legally required codes and standards wherever the latest versions of the IBC, ASCE 7, AISC 360, and ACI 318 are adopted. Engineers conducting or specifying load tests of façade access equipment must fully understand both fundamental engineering principles and the requirements governing such testing. Failing to understand the requirements, or basing certifications on inappropriate testing, may result in equipment users experiencing excessive risks.

For new or replacement façade access equipment, the authors recommend the following:

1) Elements that support hoists (e.g., davits, outriggers, rooftop carriages, and tiebacks and their structural supports) should be designed elastically or essentially elastically to support the loads provided in Section 1607.9.3 of the 2015 IBC when multiplied by the required live load factor of 1.6.
2) Rope descent anchorages and lifeline/fall arrest anchorages and their supports should be designed elastically or essentially

Figure 6 – Load testing of a davit mounted on a carriage.

elastically to support the loads provided in Section 1607.9.4 of the 2015 IBC when multiplied by the required live-load factor of 1.6.

3) All façade access equipment should be load tested to satisfy OSHA requirements prior to initial use. Testing should be performed according to Section 1708 of the 2015 IBC, Section 5.4 of Appendix 5 of AISC 360-10, and Section 27.4 of ACI 318-2014, using the full-factored loads required by the 2015 IBC and ASCE 7-16, in the direction that the loads will be applied. No significant deformation or failure should occur during or immediately after the test.

Design and testing of façade access equipment can be complicated; a more comprehensive discussion regarding these topics can be found in ASCE's *Façade Access Equipment: Structural Design, Evaluation, and Testing.*

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ENDNOTE

1. "That which was to be demonstrated"; also known as QED or Q.E.D.

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