As elevator systems age, the need for modernization becomes compelling for a host of reasons, including system performance, reliability, safety, energy efficiency and aesthetics. The common solution to system-aging issues is the upgrading and replacement of various system components in lieu of complete elevator replacement. An alteration is defined by ASME A17.1-2016/CSA B44-16 as "any change to equipment, including its parts, components and/or subsystems, other than maintenance, repair or replacement." Section 8.7 of that code provides the criteria for alterations. This article focuses on the issue of system weights when performing alterations, with respect to the code, elevator operation and safety.

There is a sizable percentage of elevators in current operation with car deadweights heavier than indicated in their original installation documentation and AHJ files, and on their crosshead data plates. There are three logical reasons this might occur:

1) Deadweight incorrectly stated at engineering:
   The standard practice has been for the elevator system manufacturer to estimate the car deadweight as a function of the product sale and engineering. For many manufacturers, this process, with varying degrees of accuracy, used broad guidelines based on the type of system, rated load, car size and height, general finish selections, etc. Unless a disciplined procedure to sum up all the major and minor components of the elevator car was employed, arriving at the deadweight is merely a rough estimation process. As a result, the actual car installation deadweight for some elevators was never properly identified and could be misstated by as much as 10%.

2) Deadweight accounting for less than the complete car: For some installations, the original equipment manufacturer is not made aware of the cab interior finishes to be installed. This phenomenon is more common at the higher end of the market, where more elaborate finishes are selected, and for projects where the finishes are not supplied or installed by the elevator contractor. The project planning may leave the decisions about aesthetics to a later portion of the process, as late as when the equipment is being installed. Therefore, the engineering, system documentation and even crosshead data plate may be completed showing a car deadweight that does not include the final interior finishes, including flooring, wall panels, trim, ceiling/lighting and handrails. Many earlier installations had crosshead data plates with two entries: one with the weight of car frame, platform and safeties and a separate entry for the weight of the enclosure. On many of these, the latter entry was never completed, leaving only the former entry to misrepresent the deadweight. Another aspect of this phenomenon is where elevators are installed, inspected and permitted for construction use early in the building process.

**It is a simple calculation to verify whether the buffer load rating, or the sum of the ratings for multiple buffers, still meet the range criteria for an increase in car deadweight and the heavier, rebalanced counterweight.**

*by Richard Blaska*
for the purpose of removing the temporary construction hoist. Elevators are turned over with empty car shells so as not to damage the final expensive finishes to be installed later. The crosshead data plate car deadweight represents the actual turnover weight for construction use. As the building reaches completion, as much as 1,000 lb of interior finishes, which may not be reflected in the AHJ files or the prior completed crosshead data plate, may be added.

3) Increase in deadweight due to alteration: Where the originally installed car deadweight is accurately expressed, over time, the car interior finishes may be replaced with new, heavier finishes. New control equipment and safety features may be installed (with a net weight increase). In some jurisdictions, the work of replacing car interior finishes may be performed by non-elevator personnel. (This may introduce other code violations, in addition to the potential for excessive weight.) Upgrading may include more elaborate finishes, such as natural stone, polished steel or heavy wood, resulting in an increase in car deadweight.

The issue of changes or excessive car weight is often referred to as the “5% rule,” referring to A17.1/B44, Requirement 8.7.2.15.2 — Increase or Decrease in Deadweight of Car, which states in part:

“Where an alteration results in an increase or decrease in the deadweight of the car that is sufficient to increase or decrease the sum of the deadweight and rated load, as originally installed, by more than 5%, the installation shall conform to: (see code for sections).”

A listing of new installation and alteration code sections follows. These reference the prescriptive criteria for all major elevator system components that may be affected by system weights. To comply with 8.7.2.15.2, it is necessary to either replace the referenced components with compliant products, or perform the engineering analysis and component or system recertification as it relates to each of the sections listed. The means and methods to achieve this recertification are not expressly defined by the code and may be subject to interpretation by the AHJ. Proven engineering principles and practices and applying the code design criteria is the typical method.

A simple but possibly expensive solution is to replace the elevator component or subsystem with new products fully rated by the manufacturer for the new loading. An example of the choice to replace-with-new versus recertify-the-existing is Section 2.15 — Car Frames and Platforms. Most AHJs will accept factory-manufactured systems, such as car frames and platforms, from reputable manufacturers without formal engineering (drawings and calculations). To retain the existing car frame and platform, the AHJ may accept documentation from the OEM that the equipment was initially rated for the higher load. For example, manufacturers’ duty charts showing the maximum sheave-shaft loading for a model of drive machine or overhead sheave is usually acceptable to prove compliance for the 8.7.2.15.2 reference to Section 2.24. However, such proof may be difficult to obtain for many components, especially for older systems. In such cases, retention of the equipment would require a full structural analysis by a competent engineer. Many AHJs will require the engineering to be performed by a professional engineer licensed in the jurisdiction.

8.7.2.15.2 — Referenced Sections

2.15: Car Frames and Platforms

Many traction and winding-drum elevators from the early 20th century had car frames made of structural steel members but had platforms constructed of wood timbers and planking. The structural steel car frames are reasonably simple to calculate and recertify, but the wooden platforms require considerable work to do so. Fabrication drawings for these products are generally unavailable, so field reverse engineering is required. The timber member sizes and quantities need to be evaluated, as well as how these members are joined, connected and loaded. There may be decay or fracturing that isn’t readily visible.

Referencing back to the third common reason for car deadweight to increase, many of these early elevators were equipped with light birdcage-type cars with open grilework and minimal interior finishes, collapsible gates or no gates at all. Some of these were altered with the installation of full steel-shell cabs, interior panels, car fronts with multispeed doors and power operators. The result was often adding 600 lb or more to the deadweight — weight the original platforms were never designed to carry. There are several basement winding-drum elevators operating in San Francisco (and, likely, other older American cities) with signage restricting ridership to a maximum of four persons due to the inability of the old system to carry the overage in load caused by the added deadweight. Such signs should be a red flag to the AHJ that there is a compliance problem.

2.16: Capacity and Loading

Inclusion of this section may seem odd or inapplicable, but a few very early elevators still in operation have car inside areas that exceed 2.16.1 — Minimum Rated Load for Passenger Elevators. Compliance with 8.7.2.15.2 would require reducing the area, either by adding a false wall or installing a new cab — possibly adding more to the deadweight overage. If this problem exists, the argument for a completely new car (and other system components) becomes more compelling.

2.17: Car and Counterweight Safeties

Most electric elevators installed from the mid-20th century on included marking plates listing the maximum weight rating for the safety, per 2.17.14(c). Some original equipment manufacturers installed elevators with safeties rated marginally over the deadweight plus rated load, where an increase in deadweight will exceed the safeties’ rating. Older systems that lacked the marking plates would require documentation to prove the safeties are rated for the increased deadweight if they are to be retained. If the car frame and platform meet the criteria and can be certified, but the safeties are of a make or model that is suspect, from an obsolete manufacturer or of a very old vintage (such as many drum-type safeties), it is typically better to install new safeties. The most commonly available new safeties are bolt-on types, which will require good field measurements to marry the new sets

Continued
to the existing bolster channels. Unless the original safeties can be disassembled and removed from the car frame, in part or whole, the new safeties may add weight. Some original safeties included castings that also served as the structural connecting members between the bolster channels, stiles and/or platform. If these are to be removed, a structural solution must be engineered and certified to ensure the integrity of the car frame and platform. In many such cases, the better decision would be to replace the complete car as well as the safeties.

2.20: Suspension Means and Their Connections

The hoist rope factor of safety (FoS) calculation is very straightforward per the formula in 2.20.3 and Table 2.20.3. Additional considerations include ride quality (bouncy ride) if the FoS is taken too close to the minimum. Drive-sheave traction and rope and sheave wear will also play into the suspension-means calculations when adding to the car deadweight.

2.21: Counterweights

This can be one of the most challenging requirements and is often overlooked or incorrectly addressed. All electric elevators, including geared and gearless traction and geared winding drum, require a counterweight (two for most winding drums) to offset the weight of the elevator car and a portion of its rated load. The calculation for the weight of the counterweight is the car deadweight (balance), plus a percentage of the rated load — often referred to as the “overbalance.” Traditionally, the overbalance value for most installations was 40–42.5%. For newer systems, especially those using permanent-magnet AC gearless machines, the overbalance is commonly 45–50%. For example, a traction elevator with a rated load of 2,500 lb, deadweight of 3,500 lb and design overbalance of 42% would result in a counterweight of 4,550 lb (2,500 + 0.42 + 3,500). Therefore, adding weight to the car deadweight requires adding an equal amount to the counterweight to maintain the same overbalance.

Modern electric elevators typically include compliant steel-framed-type counterweights designed to be sufficiently robust and with enough open space to allow adding weight, as required. The most common counterweights include steel-plate filler weights. Some applications, due to spatial constraints, require the use of some or all lead fillers at a weight of 0.41 lb/in.^3 versus steel weight of 0.28 lb/in.^3. Adding filler weight to otherwise full counterweights may require replacing some steel filler plates with lead. Some manufacturers used concrete in their counterweights, either poured in pans (a messy and often imprecise process) or precast blocks. Adding weight to these counterweights may be difficult, making them candidates for replacement.

Most pre-mid-20th century traction and drum elevators were equipped with non-framed, rod-type counterweights, often referred to as sash weight counterweights. Alteration Requirement 8.7.2.22.2 allows retention of rod-type counterweights, provided they are equipped with a minimum of two suspension rods and two tie rods. Many early rod-type counterweights were equipped with only the two suspension rods and, therefore, cannot be altered, including adding weight. Also, some AHJs will note that Requirement 8.7.2.15.2 does not reference 8.7.2.22.2, but instead references Section 2.21. Note that in 2.21.1.1, frames require a structural or formed metal frame. Therefore, these AHJs contend, probably correctly, that adding weight to any rod-type counterweight does not comply with 8.7.2.15.2. Further, if an AHJ allowed retention and alteration to a rod-type counterweight, one that contained the suspension and tie rods, certified engineering would be required to prove the altered counterweight assembly meets the strength requirements, including impact loading. In such cases, and especially in seismically active areas, it would be best to replace the rod-type with a modern, compliant framed-type counterweight.

2.22: Buffers and Bumpers

Post-mid-20th century elevators should have compliant buffers with marking plates listing the load ratings. It is a simple calculation to verify whether the buffer load rating, or the sum of the ratings for multiple buffers, still meet the range criteria for an increase in car deadweight and the heavier, rebalanced counterweight. However, for most pre-mid-20th century elevators, marking plates on the buffers are rare. Many of the very early elevators had bumpers for the car, and neither bumpers nor buffers for the counterweight. For these, new buffers sized and marked for the new loading must be installed.

Alterations that require the installation of new buffers and/or new car slings and platforms often present problems with the original pit depths. Many early elevators have pit depths as shallow as 2-3 ft. Some of these have pit floors structurally deficient to withstand the buffer and safety-load reactions. The solution is deepening the pit sufficiently to meet the clearance requirements for the car and counterweight run-bys and buffer strokes. Altering the pit, including deepening, includes the requirement for a platform guard per Requirement 2.15.9, as well as to obtain the refuge space per Section 2.4. Deepening an elevator pit also requires extending the guide rails, and adding a new pit ladder, lighting, service outlet, sprinklers, etc. The design and installation of the new pit does not fall within the realm of elevator work and must be performed with proper engineering and installation.

2.23: Car and Counterweight Guide Rails

This is potentially the most problematic recertification criteria to meet, especially in seismic zones requiring compliance with the more stringent Section 8.4 — Elevator Seismic Requirements. Elevators installed prior to current seismic standards typically contained strength deficiencies regarding the size and bracketing of the guide rails. This is especially the case with the counterweight guide rails, where there was little design consideration for lateral loading. The engineering for car guide rails had always considered unbalanced loading, especially in the process of car loading and unloading. Counterweight guide rails and their building connections were designed simply to guide the counterweight mass in its vertical travel.

It is true that the counterweight guide rails never see lateral loading — until a seismic event! Pre-seismic code counterweight guide rails were almost universally the lighter-weight 8 lb/ft (ISO T89/B and Otis), though some used rails as light as 6 lb/ft (ISO T70/B). The building connection brackets for these rails were commonly simple “L” shaped 1/2-in. X 2-in. and even 3/8-in. X
1-1/2-in. bars with a single bolt or anchor. The car guide rail brackets on these older systems often utilized similar bent-bar sizes, which also lack lateral integrity in a formed hoop.

The 5% rule almost always requires correcting strength deficiencies in the guide rails. This can be true for non-seismic applications per the 2.23 criteria but is especially the case with seismic conformance to Section 8.4. There have been different applications of the code by AHJs regarding the connection between sections 8.7 and 8.4. California explicitly added a connection in its code reference language, mandating that alterations trigger seismic compliance (3000(h)(2) and 3141.2(b)) where no connection existed before. It is your author’s opinion that, whether required (triggered) by code or not, structural and seismic deficiencies in guiderail systems should be corrected, especially in seismically active regions, to ensure elevator operational integrity and to safeguard the riding public.

Note that this provision can be misinterpreted to apply only to the car guide rails. The false logic is that an increase in the car deadweight in excess of the 5% formulation would only affect the car guide rails. This would, indeed, be true if the altering party errantly failed to rebalance the counterweight. Weight added to the counterweight and its effect on the guide rails is covered by a separate 5% rule, Requirement 8.7.2.24 — Guide Rails, Supports and Fastenings. As an increase in counterweight weight and the added stress on its guide rails are proportional, a 5% increase in counterweight weight triggers this additional 5% rule.

The remediation of structural and seismic deficiencies in guide rails, as well as other load-bearing systems, generally requires competent reverse engineering of the existing system, followed by strength analysis, new loading calculations, retrofit design, component fabrication detailing and installation drawings. Increasingly, this engineering work is being outsourced to specialty consultants. Properly, many AHJs are requiring this work be certified by a professional engineer.

### 2.24: Driving Machines and Sheaves

Most occurrences of increase in car deadweight and the counterweight rebalance are not of a magnitude to present a problem with these components. However, AHJs should require proof of machine and sheave strength to meet the new loading. For typical overhead machines in compression loading, the FoS machine element to certify will be the drive-sheave shaft. For many of the older, commonly installed drive machines, design manuals can still be found that list the maximum sheave shaft loading per machine model. Some engineers have used and AHJs have accepted certifying calculations based on measurement and metallurgy of the sheave shaft. The same principle and practice apply to overhead sheaves and their mounting components. Machines mounted in tension (upthrust) have additional strength considerations to properly certify for increased loading. For some applications, new machines and sheaves are the right solution.

#### 8.7.2.9: Machinery and Sheave Beams, Supports and Foundations

Related to the previous item, this final referenced criterion listed in Requirement 8.7.2.15.2 is from the alteration section. Again, most systems were designed and installed with sufficiently robust machine/sheave beams or foundations to handle the increased system loading, per the criteria of Section 2.9. However, your author has encountered machine beams that were deficient from the code deflection criteria L/1666 for their original loading. On several occasions, your author has found where the building structure that supported the machine or sheave beams was deficient from installation. This condition is more prevalent on older, wood-framed five- and six-story structures. Note that Requirement 8.7.2.9 explicitly says “where alterations increase the original building design reactions by more than 5%...the adequacy of the affected building structure to support the loads shall be verified by a licensed professional engineer.” This certification can be an easy matter if the original building structural plans are available. Otherwise, field investigation, possibly requiring the removal of fireproofing material, is required.

### Conclusions and Recommendations

An important point often overlooked in the wording of Requirement 8.7.2.15.2 is the phrase “as originally installed.” Some jurisdictions have allowed an elevator car to be field weighed prior to the alteration work to establish the existing car deadweight. That weight is then accepted as the criteria for enforcement of 8.7.2.15.2, regarding the 5% calculation. That is clearly a misreading of the code and a practice that can, over time, compound an overweight problem. Imagine an elevator modernized every five years. At each interval, new interior finishes, fixtures and controls are installed. At each occurrence, 5% of the sum of the last empty car weight plus rated capacity is added. This would compound to an 88% increase in the car deadweight in 40 years, with obvious negative ramifications. See Table 1.

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<th>Compounding Car Deadweight</th>
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<td>year</td>
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<tr>
<td>capacity</td>
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<td>5% allowed</td>
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<td>ending deadweight</td>
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Table 1
Dan Barker, senior safety engineer, elevators, California Division of Occupational Safety and Health, Elevator Unit, has proposed a potentially better code system to avoid some of the problems with the 5% rules of 8.7.2.9, 8.7.2.15.2 and 8.7.2.24. His proposal is to establish two car deadweight values, a minimum and a maximum, each to be recorded and to have separate entries on the crosshead data plate, for each installation. Every aspect of the elevator installation, including the building structure, would be engineered to work within this value range. At installation, the counterweight would be properly loaded to the design overbalance based on the actual car deadweight. The overbalance percentage would also have an entry on the crosshead data plate, eliminating any future question as to this value. Replacing the 5% rule, this system would allow for future alterations, resulting in a decrease or increase in car deadweight, provided the new weight fell within the original range. Rebalancing the counterweight would be critical and should be verified at inspection. It is important to note that underweight car deadweights can be as great a hazard as an overweight car when considering possible loss of traction, the setting of safeties, etc. Your author endorses Barker’s proposal and encourages the code committees to consider this change to Requirement 2.16.3. In 2019, the code will also require the counterweighting percentage to be noted on a plate for future reference.

Earlier, the problem of establishing the originally installed car deadweight was mentioned. In some cases, there is no crosshead data plate, no available documentation and no recording of the deadweight in the AHJ files. The original deadweight might be extrapolated logically, assuming prior alterations are minimal and weight changes are quantifiable. Your author has seen several examples of 1920s installations in which, by all appearances, the cars are unaltered. Here, photographs should be taken to document the originality of the car and equipment. A certified dynamometer can be used to weigh the empty car. The result of subtracting the weight of any length of traveling cable or compensation can be used to make the case to the AHJ that this is the originally installed car deadweight.

All elevator modernizations that involve a change in the car deadweight should be weighed and recorded before and after the alteration work. Whether the intent is to avoid triggering any of the code’s three 5% rules by keeping the deadweight, loading and stress within the limits or to recertify for exceeding the limits, the alteration engineering should include calculating the weight of all materials to be removed and added to the car. This can include the physical weighing or calculating the weight of materials.

Various new electronic instruments, some that measure the tension in the hoist ropes to arrive at a suspended weight, have been used for the purpose of establishing the weight of cars or counterweights. Most of these devices were developed for the purpose of individual rope tensioning. It is important to recognize the functional tolerance of these devices. Some are +/-2%. A 2% variability range in accuracy should be deemed insufficient when the code criteria objective is 5%. A quality dynamometer has a certified tolerance of +/-0.2%, a tenfold advantage. Some elevator companies have chosen to only use certified dynamometers for establishing the weight of cars and counterweights.

It must be noted that many of the current elevator designs take advantage of technologies and advanced engineering with the result of car deadweights becoming lighter — in some cases very much lighter. Some of the car deadweights are less than their rated capacity. The result is a delta of 100% or more between empty and fully loaded. Many of these systems have tolerances that cannot accept any added weight.

The inevitable future alteration to replace tired cab interior finishes must be performed with great care, both regarding weight and taking care to not compromise the car structure. With some systems, the cab itself is an integral part of the car structure, which must not be altered. With the lack of robustness of these elevators compared to earlier elevator systems, much greater care must be taken regarding the accuracy of car deadweights, counterweight overbalance, compensation, etc. In some cases, even the code-allowed 5% deviation may be problematic and should be verified with the original equipment manufacturer.
To retain the existing car frame and platform, the AHJ may accept documentation from the OEM that the equipment was initially rated for the higher load.

Many elevator consultants’ modernization specifications will call for items to be installed, seemingly without considering the weight they will add to the car. Examples include car-top guard railings, oversized three-speed blowers, added doghouses, elaborate interior finishes and flooring, cladding front returns and door panels and display panels. Some installations where the cars are already overweight or where the desired equipment and finishes will result in triggering the 5% rule — but where the car slings, platforms and safeties are viable — replacing the entire cab with a new, lighter-weight aluminum cab shell may be the solution. Considering that aluminum is approximately 34% the weight of steel, several hundred pounds may be saved. Many cab manufacturers are offering this option at a reasonable cost premium.

In conclusion, the elevator car deadweight, the counterweight, the complete system weight and the building loading must be carefully considered in an elevator alteration. Altering any of these weights will affect the elevator and building reaction loads, with potentially critical ramifications. The code, with respect to the three 5% rules, must be followed. Some systems must not be altered as to their weights and loads. Existing elevator and building structural and seismic deficiencies should be corrected, even where not mandated (“grandfathered”). Proper and thorough engineering, including professional engineering where mandated and where prudent, should be performed. All original and altered conditions must be documented along with AHJ inspections and acceptances. These are all potential factors of life safety, legal responsibility, operational integrity and good elevating.

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