The Perils of Undue Structural Reliance on "Lag Screws": *A Case Study*

By Lonnie Haughton, MCP, LEED AP

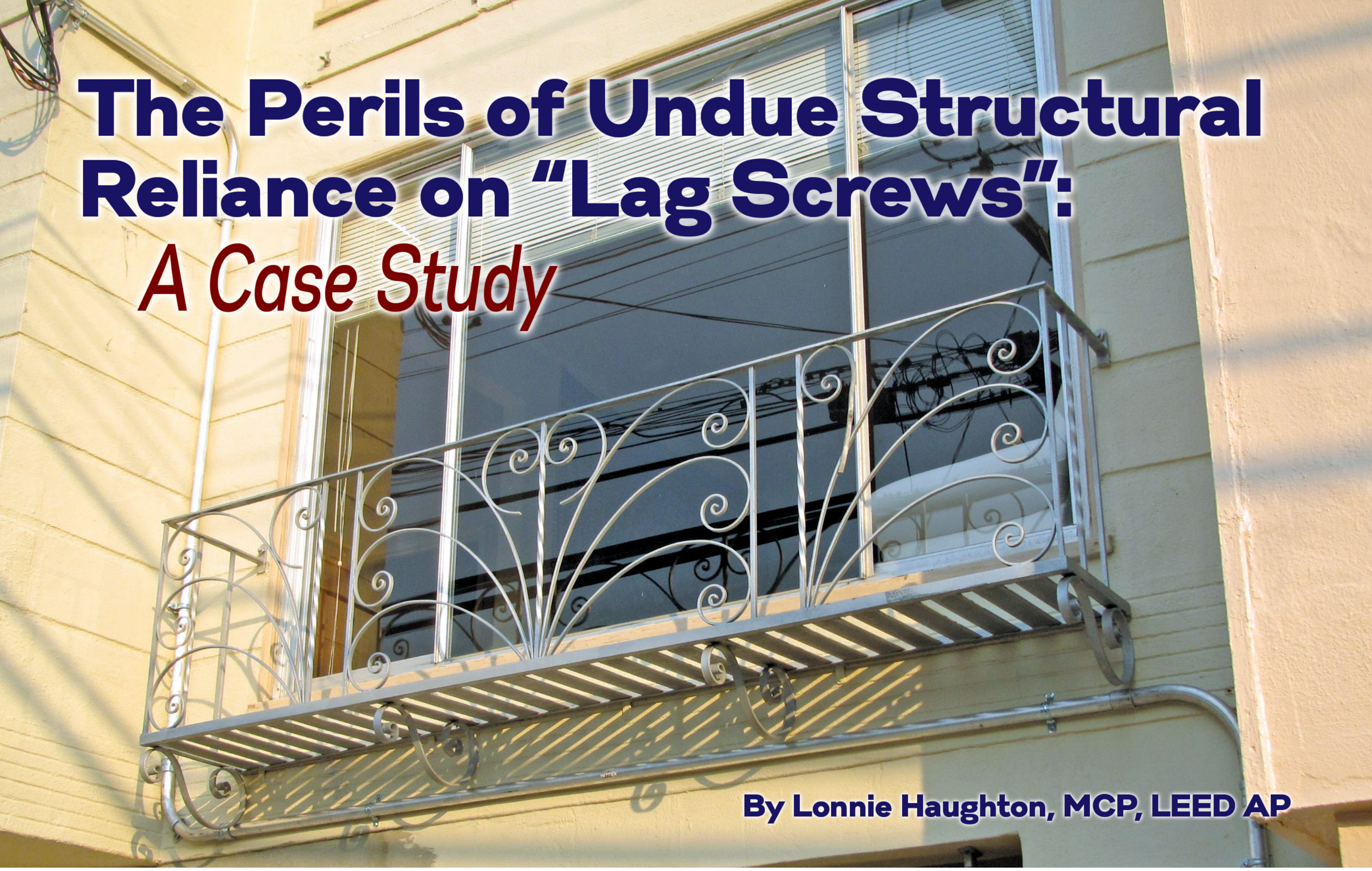

Figure 1. Wrought iron balcony attached to a three-story apartment building in San Francisco, Calif.

The terms "lag screw" and "lag bolt" often are used interchangeably in construction and maritime fields. For example, guidance from the U.S. Department of Housing and Urban Development[1] states, "Lag screws (often called lag bolts) function as bolts in joints where the main member is too thick to be economically penetrated by regular bolts." However, such imprecise terminology can be irritating for those who assert that a bolt (that is, a fastener with a machine-threaded end that can accept a nut) should never be considered a screw, which instead has helical ridges (external screw threads that taper to a point) that engage with the comparable internal threading created when these threads are rotated into a wood framing member.

In short, a bolt is a structural fastener that is assembled and tightened by rotating a nut onto machine threads, whereas a screw is installed by rotating the head of the fastener. Because lag screws are neither secured with nuts nor attached by rotating each fastener, the common term "lag bolt" can be highly misleading.

Similarly, hanger screws, to the bane of some professionals, commonly can be called "hanger bolts," even though they have helical ridges at both ends. At one end are coarse threads (for screwing into wood), and at the other end are finer machine threads, which—similar to traditional through bolts—accommodate nuts and supporting washers. Despite such differences, hanger screws still make up a distinct subset of the lag screw family.

A key advantage of using lag screws is convenience.[2] Load-resisting connections to wood framing members can be achieved without requiring access to both ends of a fastener. However, compared with the long-term performance of through bolts, the structural integrity of this attachment can be more readily degraded over time by the effects of rainwater intrusion, wood decay, overloading, and wood shrinkage.

Furthermore, it is difficult for later building inspectors to verify that the contractor followed code-prescribed installation procedures. Lastly, as demonstrated by the following case study, lag screws are, in many instances, "used in connections where very little redundancy exists, and as such, an individual fastener failure can readily lead to global failure."[3]

INVESTIGATION – BALCONY COLLAPSE DUE TO SUDDEN LAG SCREW WITHDRAWAL

This case study examines the ornamental wrought iron balcony (**Fig. 1**) collapse at a circa-1948 two-unit, three-story apartment building in San Francisco, Calif. This balcony was installed in 1960 and was first made accessible to the building's occupants and their guests via aluminum-framed horizontal sliding windows installed in 1972. The two operable sashes slide open toward a fixed center lite to provide openings that are 24 in. (610 mm) wide and 74 in. (1880 mm) high.

Figure 2 shows where the upper balcony was located, and **Fig. 3** provides a view of that balcony's remnants after it collapsed. Four partygoers were occupying the upper balcony when it suddenly failed at midnight. While two guests managed to safely leap back through the openings, two others were seriously injured during the fall. As would be expected, the ensuing personal injury litigation process encom-

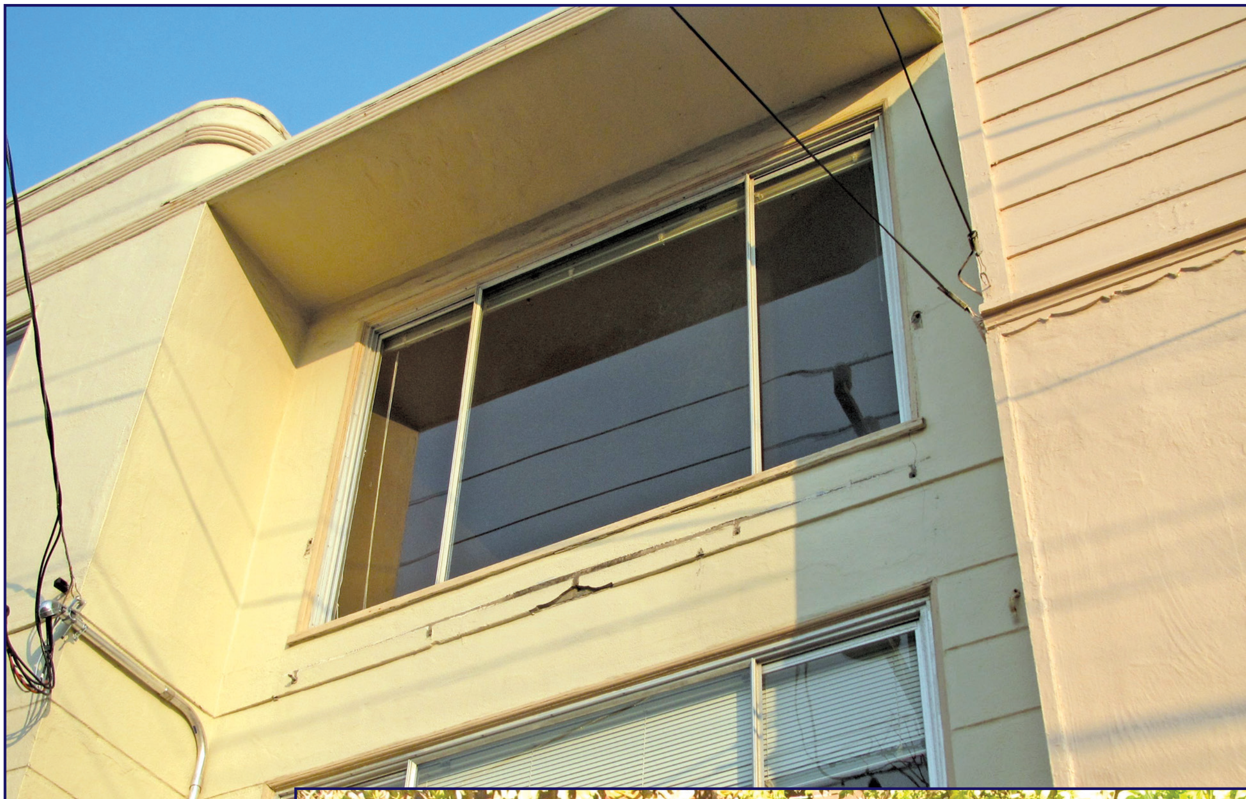

Figure 2. Window at the upper apartment after the wrought iron balcony collapsed. The collapsed balcony was identical to the one shown in Fig. 1.

Figure 3. After its sudden collapse, the failed balcony was stored in the backyard for expert inspection.

passed a wide range of expert-led analyses and disputes, including:

- Were the two balconies originally intended for solely "decorative" purposes (perhaps for flower boxes)? Or might they have been attached to this apartment building in a manner that afforded the minimum "live load" capacity for human occupancy, as prescribed by the controlling 1956 San Francisco Building Code?
- Had the circa-1972 retrofitted windows (which had replaced original wood-framed windows) promoted subsequent unsafe human usage of nonoccupiable ornamental balconies? Most of the residential buildings in this particular San Francisco district date to the post-World War II construction boom. To appeal to military veterans who had been stationed in Europe, developers often installed narrow ornamental balconies (wrought iron and wood) that were not intended for human occupancy. However, over the ensuing decades, many of these decorative elements have been occupied by unwary homeowners.
- Should the long-term property manager have known that tenants were using the narrow balconies for various lifestyle purposes?
- Should the tenants (and their guests) be expected to have sufficient knowledge to recognize that these small (14.75-ft^2 [1.37-m^2]) balconies might not be safe for human occupancy?

The purpose of this case study is not to relitigate the merits of competing expert opinions in this now-settled litigation. Instead, the goal for this article is to delve into long-term safety risks potentially associated with the use

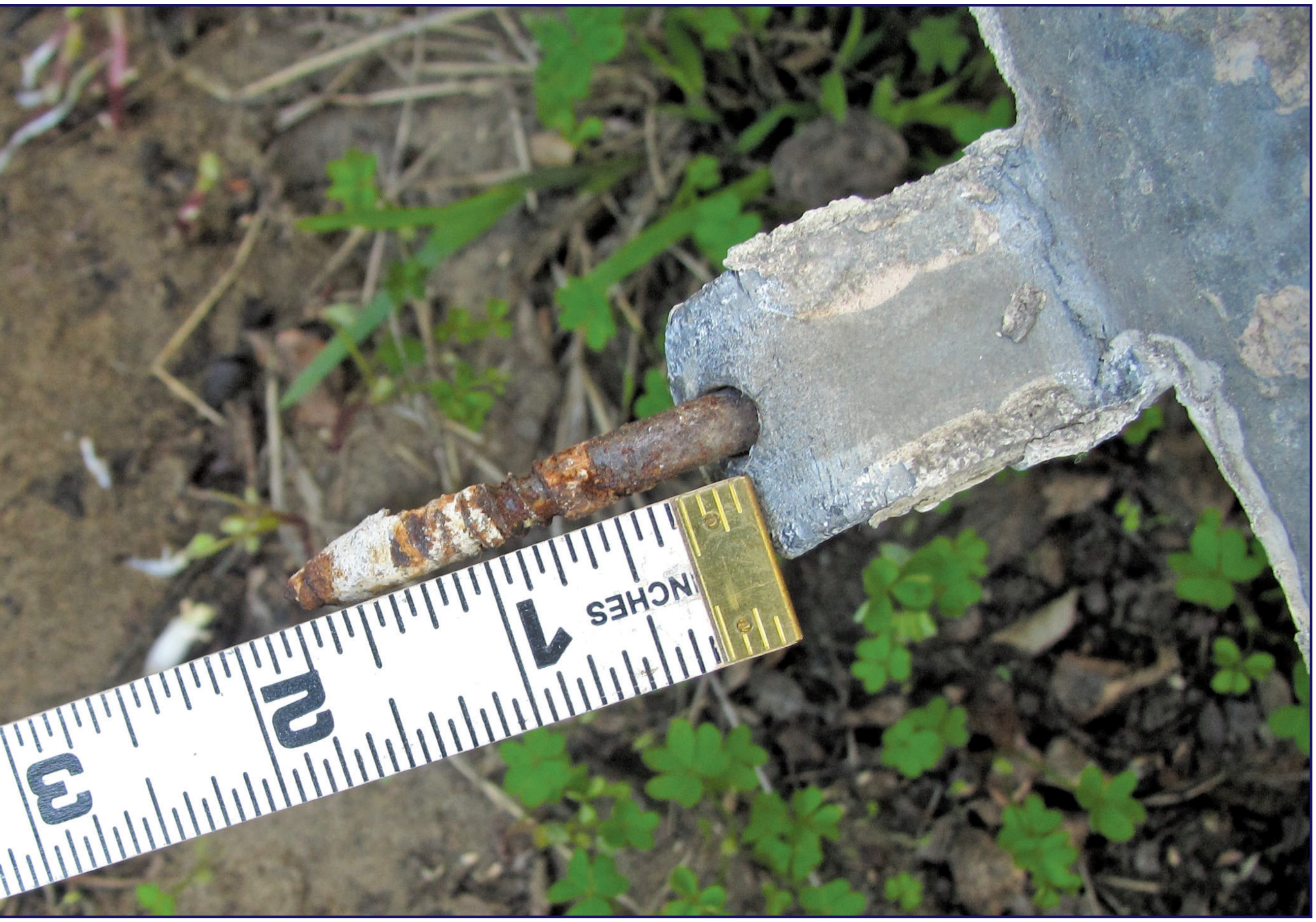

Figure 4. The bottom edge of the failed balcony was secured to the stucco-clad wall with five wood screws. Note: 1 in. = 25.4 mm.

of lag and hanger screws to "hang" such decorative or human-occupiable Juliet balconies—so named for their supposed similarities to the famous (but apocryphal[4]) balcony from William Shakespeare's play, *Romeo and Juliet*.

FORENSIC ANALYSIS

Our inspection found that these wrought iron balconies had been attached to the stucco-clad wall with (a) five wood screws (**Fig. 4**) at the bottom with overall lengths of 2 in. (50 mm), and (b) two ½-in.-diameter, 4-in.-long (13-mm-diameter, 100-mm-long) (overall length) hanger screws at each upper corner (**Fig. 5** and **6**). Note that even though the nominal dimensions of a 4-in.-long lag screw and 4-in.-long hanger screw are the same, the hanger screw (see **Fig. 5** and **7**) provides significantly shorter net penetration into a structural member because of the positioning of the machine-threaded nuts.

The combined thickness of the stucco cladding assembly—including the ¼-in. (6-mm) decorative layer of plaster cement seen in **Figure 8**, and its underlying diagonal wood board sheathing—was approximately 1.75 in. (44 mm). As a result, only the two hanger screws were structurally engaged with the wood (Douglas fir) framing. Approximately 1.5 in. (38 mm) of the 4-in.-long hanger screws was exposed (see Fig. 5), which indicates that approximately 1 in. (25 mm) of the tapering ends of the hanger screws penetrated into the wood framing.

For the following reasons, we concluded that repeated human loading (since 1972) of these decorative balconies had gradually compromised the physical engagement of the upper leftmost fasteners for both Juliet balconies, thereby intermittently exposing these critical connections to windblown rainwater infiltration:

- Our inspection confirmed that a progressive collapse (defined as "the spread of an initial local failure from element to element resulting, eventually, in the collapse of an entire structure or a disproportionate large part of it"[5]) had commenced at the top left corner of the upper balcony (viewed from the exterior).
- Various deposition testimonies suggested that the most common route of tenant access onto these balconies had been over the invitingly low, 7-in. (178-mm) threshold (**Fig. 9**), at the right side (viewed from the interior) of these windows.
- The hanger screw at the left corner (as viewed from the exterior) of the still-attached lower balcony exhibited clear evidence of axial (overturning) overloading and withdrawal (Fig. 5).

We posited that the unexpected absence of severe wood decay within these two holes reflected

- the relatively limited amounts of windblown rainwater that could migrate into these outwardly downward-sloping (see Fig. 5) and somewhat weather-sheltered holes;
- the ameliorating effects of solar heating of this highly sun-exposed wall; and/or
- the "moderately" decay-resistant properties of Douglas fir timber.[6]

Water molecules are commonly described as being "sticky": the two slightly positively charged hydrogen atoms are attracted to any available oxygen atoms (which are slightly negatively charged), including the open oxygen atoms at the surface of bare steel fasteners. This hydrogen-oxygen bond (surface tension) between water molecules and iron-based materials is the first step in the complex process of corrosive degradation known as rust oxidation. At this building, intermittent films of windblown moisture would have bonded via surface

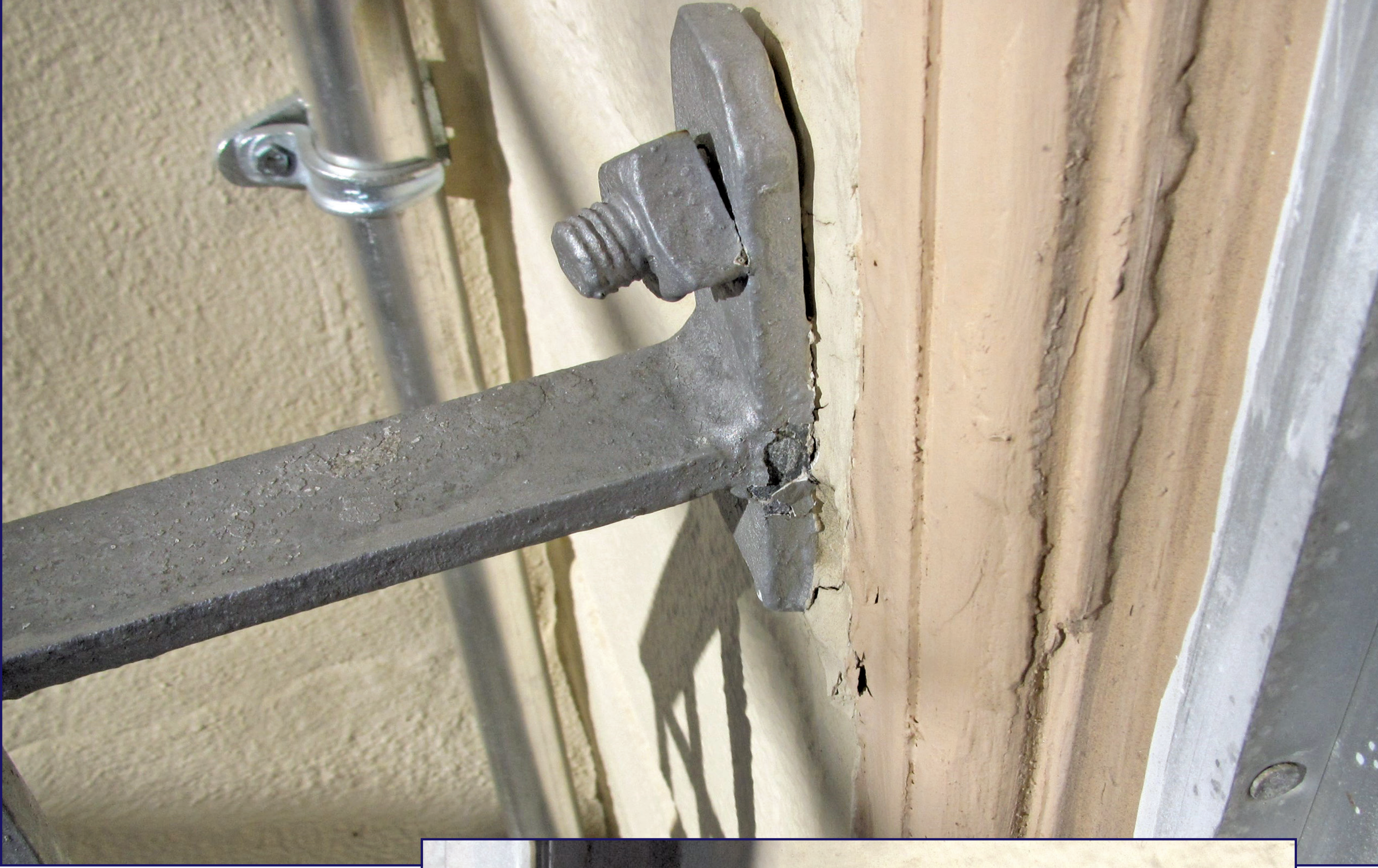

Figure 5. The lower balcony was attached at the upper corners with 4-in.-long, ½-in.-diameter hanger screws. This fastener exhibits evidence of an axial prying action and withdrawal, as compared with the opposite hanger screw shown in Fig. 6. Note: 1 in. = 25.4 mm.

Figure 6. This hanger screw at the opposite end of the lower balcony from the screw in Fig. 5 did not exhibit evidence of axial (overturning) overloading and withdrawal comparable to that shown in Fig. 5.

tension to the steel threads of the hanger screws for multiple decades, with the ensuing rust oxidation slowly degrading the screws' axial load-bearing capabilities. This worsening degradation made these downward-sloping fasteners even more susceptible (particularly when wetted) to the pull-out forces of human loading of these Juliet balconies.

Finally, we noted that even though the helical threading at the partially failing hanger screw (see Fig. 5 and 7) at the lower balcony was more severely deteriorated than the failed screw (Fig. 8) from the upper balcony, it was this top balcony that, due to human loading related to this party, suddenly collapsed. This indicates that the lower Juliet balcony was also at high risk for sudden collapse if subjected to human loading.

HISTORICAL CODES REVIEW—UNIFORM LIVE LOAD AND THE USE OF LAG SCREWS

As noted, the two balconies were installed in 1960. Our research confirmed that from 1956 through 1975, successive editions of the San Francisco Building Code (SFBC) (a) prohibited reliance on lag screws to resist axial (overturning) forces related to human occupancy, instead requiring the use of through

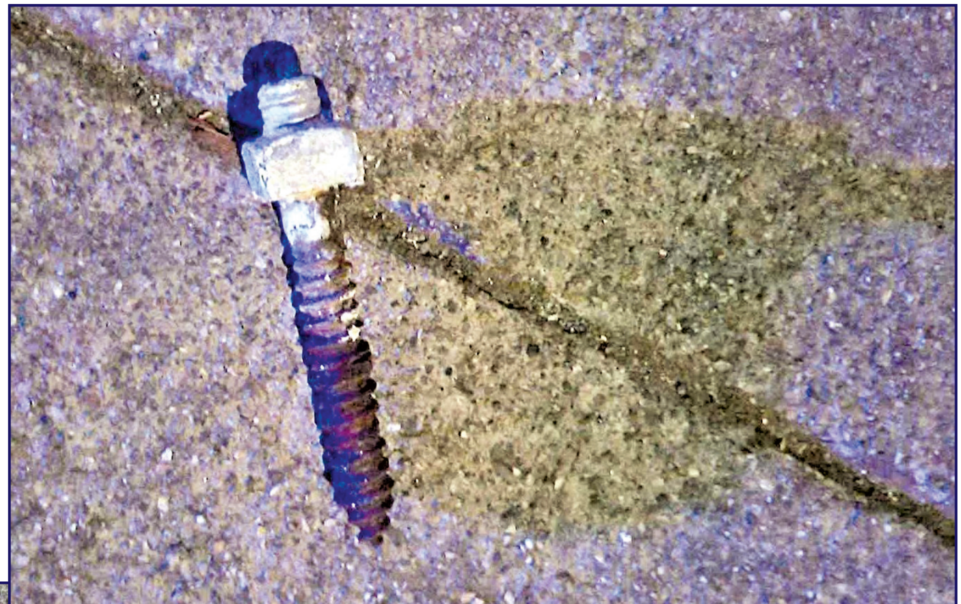

Figure 7. San Francisco Police Department photograph of a failed hanger screw from the night of the balcony collapse.

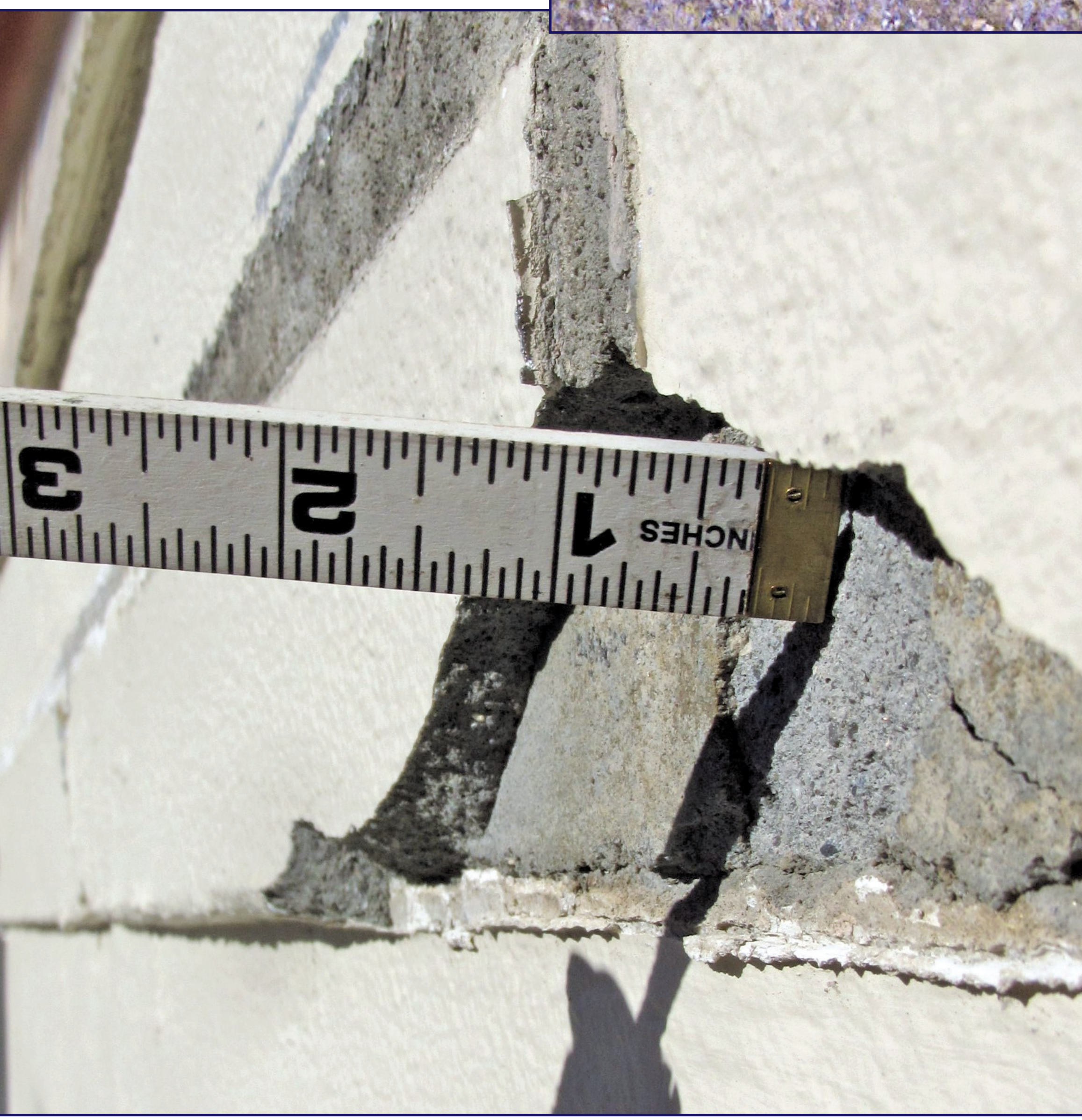

Figure 8. Damage from the failed wood screw shown in Fig. 4 to the ¼-in.-thick layer of decorative plaster cement applied for aesthetic relief atop an underlying ¾-in.-thick stucco cladding assembly. Note: 1 in. = 25.4 mm.

bolts; and (b) required occupiable balconies to provide 75 lb/ft^2 (3.6 kPa) of uniform live-load support. In short, if these 14.75-ft^2 (1.37-m^2) balconies had been intended for human occupancy, each should have supported approximately 1100 lb (500 kg).

By the mid-1970s, certain California state agencies were nearing completion of their decades-long political battle to use the model *Uniform Building Code* (UBC) to take control of San Francisco's long-independent "home rule" code-writing processes.[7] The UBC had long prescribed a lesser minimum of 40 lb/ft^2 (1.9 kPa) uniform live load for occupiable residential balconies, even if they were secured only with lag screws. Still, despite acceding on this uniform live-load issue, the 1975 and 1984 editions of the SFBC continued to discourage the use of lag screws for such axial loading purposes, stating: "Lag screws or lag bolts may be used in withdrawal only by prior written approval by the Superintendent with special inspection as a requirement."

Since 1988, all editions of the statewide California Building Code (CBC) have approved the use of lag screws for resistance to axial loading. The 1988 and 1991 editions of the CBC continued to prescribe a 40 lb/ft^2 (1.9 kPa) minimum uniform live load for residential balconies. However, beginning with the 1994 CBC (as part of the early process of the eventual melding of the regional UBC, *Standard Building Code*, and *National Building Code* into a single model *International Building Code* [IBC]), successive editions of the CBC and the new nationwide model IBC have prescribed a minimum 60 lb/ft^2 (2.9 kPa) uniform live load for residential balconies.

Additionally, most modern code agencies across North America broadly accept engineer-prescribed uses of lag screws for resistance to axial loading at exterior balconies, although there are local exceptions—for example, the City of Phoenix, Ariz.,[8] has specific requirements related to concerns about excessive wood shrinkage caused by Arizona's hot climate.

Figure 9. The invitingly low (7 in.) interior threshold height for the operable sashes at these circa-1972 horizontal sliding aluminum windows encouraged tenant access to the two balconies. Note: 1 in. = 25.4 mm.

JULIET BALCONIES AND LAG SCREWS—DISCUSSION

Safe human usage of narrow balconies such as the ones installed in the San Francisco apartment building warrants close attention from designing architects and engineers. The American Society of Civil Engineers emphasize this point in ASCE/SEI 7-16, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*,[5] stating in Section C4.3 that "balconies and decks are recognized as often having distinctly different loading patterns than most interior rooms...As always, the designer should be aware of potential unusual loading patterns in the structure that are not covered by these minimum standards."

As exemplified by this case study in which four partygoers occupied a Juliet balcony measuring only 14.75 ft^2 (1.37 m^2), a key design factor for such theoretically occupiable projections is whether the building code's minimum live load provisions are sufficient for potential future usages by tenants. Specifically, even if minimum axial withdrawal resistance requirements can technically be achieved with the use of only two lag screws, an extra degree of engineered redundancy may be warranted to

Figure 10. The hanger screw removed from upper left corner (see Fig. 5) of the lower balcony had severely corroded threads. Photo: Thomas H. Lutge, SE (http://www.quakestructural.com).

minimize the risk of progressive collapse if these structural bonds weaken over time. Section 1.4 of ASCE 7-05, *Minimum Design Loads for Buildings and Other Structures*,[9] states:

> Buildings and other structures shall be designed to sustain local damage with the structural system as a whole remaining stable and not being damaged to an extent disproportionate to the original local damage. This shall be achieved through an arrangement of the structural elements that provides stability to the entire structural system by transferring loads from any locally damaged region to adjacent regions capable of resisting those loads without collapse.

Further, even when the convenience of using lag screws outweighs the increased degree of long-term safety afforded by through bolts, special inspection of their installation may be warranted (for example, as required by the City of Phoenix, Ariz.[8]).

Decisions about such issues should be guided by the goal of promoting and maintaining life safety over the service life of the building. Although code-prescribed minimums are important, ASCE 7[5] emphasizes that they should never "replace the sound judgment of a competent professional, having knowledge and experience in the appropriate field(s) of practice, nor to substitute for the standard of care required of such professionals."

Lastly, construction professionals and property managers who inspect older buildings should be aware that severely injurious or fatal falls (due to guardrail deficiencies or structural collapse) have occurred nationwide at non-live-load-resistive decorative Juliet balconies that were only accessible through window openings. For example, in 2017, a man refinishing floors in a Harrisburg, Pa., apartment building died from a fall after he leaned on a Juliet balcony rail and it collapsed. The building had been inspected in 2015, but the inspector regarded the balcony as a decorative feature and did not evaluate whether it could withstand a human load.[10] The Harrisburg tragedy and the case discussed in this paper demonstrate why it is critical to pay particular attention during inspections to human-occupiable small decks and balconies that might originally have been constructed for ornamental purposes only.

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DOE Announces New Energy Codes to Start Virtual National Energy Code Conference


Photo by Chris Montgomery on Unsplash

On July 21, Energy Secretary Jennifer Granholm announced a series of new building energy codes at the beginning of the two-day virtual National Energy Code Conference. She also stated that the U.S. Department of Energy (DOE) would be creating partnerships to support adoption of the new codes at the local level.

According to DOE, the latest energy code determinations, which estimate energy savings based on adoption of ANSI/ASHRAE/IES Standard 90.1-2019, *Energy Standard for Buildings, Except Low-Rise Residential Buildings*, are projected to save up to 4.7% on-site energy, 4.3% source energy, 4.2% greenhouse gas emissions, and 4.3% in energy costs. In an energy savings analysis accompanying the determinations, the department outlined the specific proposed changes, which include more high-efficiency lighting, increased wall and ceiling insulation, and improved efficacy for mechanical ventilation fans.

Other topics discussed during the first day of the conference included:

- Emerging State & Local Goals: From Zero Energy to Electrification to Decarbonization
- All for Nothing: Energy Codes, Above-Code Programs and Zero Energy
- Workforce Development: Opportunities for Building Codes and Compliance Programs

Day two of the conference focused on:

- The Role of Building Codes in Shaping Equity and Environmental Justice
- Building Performance Standards—The Pathway to Zero-Carbon Buildings: Setting Goals and Metrics, Compliance and Implementation

IIBEC monitors DOE programs and outreach efforts to advance their new energy codes and take action to advance the interests of consultants. IIBEC's Codes and Standards Committee meets bi-monthly to discuss potential changes or implications of U.S. energy codes. In addition, IIBEC's Senior Director of Technical Services, Emily Lorenz, represents IIBEC members as a member of the code committee developing the commercial provisions of the 2024 edition of the *International Energy Conservation Code* and is a consulting member of the envelope subcommittee of ASHRAE 90.1.