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TELECOMMUNICATIONS INDUSTRY FOUNDATION

The Telecommunications Industry Foundation (TIF) is pleased to announce publication of the following TIF White Paper.

Building-Mounted Structures in the Telecommunications Industry

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Introduction

Our global society is growing more connected, digitalized, and information-obsessed, with the escalation expected to continue. Accordingly, anticipated and emerging applications such as self-guided vehicles and eHealth will add to the list of services that will be critically dependent on wireless connectivity. These societal changes, in turn, are driving the evolution of the telecommunications industry. 5G is the most recent reflection of this trend. Even as 5G matures, experts are already planning for what's next.

As development of these emergent technologies expands, so does the need for additional wireless infrastructure. However, it may be challenging for End Users (tower owners, wireless carriers, government entities like 911 services, broadcasters, etc.) to find suitable locations for macro wireless facilities. This is particularly acute in urban and metropolitan areas where land is developed, but due to denser population, there is a higher demand for bandwidth. This has led wireless infrastructure developers such as End Users to deploy wireless facilities on top of or attached to alternative structures such as buildings and other non-telecommunication primary use structures.

Mounting telecommunications facilities on buildings presents unique challenges to all stakeholders in our industry. The purpose of this white paper is to raise awareness and improve consistency to the best practices for structural analysis and design considerations with building-mounted structures.

There are several considerations that affect the structural integrity of a building-mounted telecommunications facility including the materials used, design/analysis methods, installation quality, completion of a Post-Installation or Post-Modification Inspection, and completion of maintenance and condition assessments.

The **objectives of this paper** are to:

- Identify and define different types of building-mounted telecommunications facilities
- Clarify code application based on intended use of the structure
- Report initial testing of coefficient of friction values
- Discuss potential failure modes and remediation considerations
- Identify typical failures from installation fault
- Highlight the importance of completing a Post-Installation/Post-Modification Inspection

Definitions

<u>Non-penetrating ballast mount:</u> A mounting system that resists sliding and overturning entirely from the weight of its structural members, appurtenances, and mounting pipes, and is supplemented by adding weight to the attached mounting trays with ballast. Types of non-penetrating mounts include ballasted rectangular sleds and tripod mounts.

<u>Penetrating/anchored mount:</u> A mounting system positively attached to the underlying structure via weld, mechanical or adhesive anchor. Its stability is derived through load transfer from anchored connections to the roof framing system or other building components.

<u>Wall mount:</u> A mounting system attached directly to components making up the walls of the parent building, rooftop penthouse or parapet of the building. Its stability is derived through load transfer from anchored connections, dependent on the wall composition, to the wall system or other building

components. Examples may include a threaded rod and backing plate assembly, lag screws, and post-installed mechanical or adhesive anchors.

Equipment platform: A non-penetrating or penetrating structure that supports larger telecommunication equipment such as, but not limited to, equipment cabinets and generators.

Roof-mounted tower: A penetrating or non-penetrating telecommunications lattice tower or pole structure connected to the building.

Background and Code Applicability

Engineers must follow the applicable codes and standards along with reasonable requirements imposed by the authority having jurisdiction (AHJ) while designing and analyzing any telecommunications facilities supported by alternative infrastructure such as buildings. Implemented codes and standards create a minimum foundation for (a) the design and installation of building structures, (b) additional structures installed/supported on the building and (c) the entire building system and its intended use. Minimum requirements are a means to protect community health, safety, and welfare.

Engineers evaluating building-mounted telecommunication facilities must be able to review and apply standards for two different industry sectors: the structure's intended use and telecommunications facility.

The NSPE (National Society of Professional Engineers) Code of Ethics requires the following:

1. Engineers shall perform services only in the areas of their competence.
2. Engineers shall undertake assignments only when qualified by education or experience in the specific technical fields involved.
3. Engineers shall not affix their signatures to any plans or documents dealing with subject matter in which they lack competence.

Code applicability for both the telecommunications mount and underlying building structure (the original structure's intended use) should be determined based on the intended use of each individual structure – the telecommunications facility and the building. For example, consider a non-penetrating ballast mount supporting a telecommunications facility on a building roof. Since the primary intended use of the ballast mount structure is an antenna supporting structure ANSI/TIA-222 "Structural Standard for Antenna Supporting Structures, Antennas and Small Wind Turbine Support Structures" would be the applicable design and analysis standard Since the building was designed using ASCE/SEI 7 standard and still maintains its design intent, it would still be analyzed to ASCE/SEI 7 standard to confirm it can support the loads of the non-penetrating ballast mount.

Building-mounted equipment platforms would be analyzed under the provisions of ASCE/SEI 7 standard based on their intended use. Should the equipment platform have a wireless facility attached to it, the wireless facility would be evaluated under the provisions of ANSI/TIA-222. Similarly, a telecommunications tower located on top of a building would be analyzed to ANSI/TIA-222. For additional information on the topic of Intended Use, refer to the TIF White Paper Intended Use of Structures with an Emphasis on Small Cell: 2023 Update.

The engineer of record (EOR) determines the applicability of one design standard over another upon review of the referenced documentation and the intended use of each structure involved. The key to an

EOR's accurate analysis for building-mounted telecommunication facilities is to include, identify, and sufficiently accurately communicate the controlling loading scenarios.

Types of Mounts

Non-Penetrating Mounts

Non-penetrating mounts shall be evaluated for three failure limit states: overturning, sliding, and roof overstress. Non-penetrating mounts must be evaluated considering the mounting system's structural capacity.

Overturning means that portion of the mount starts to lose contact or lift from the supporting surface and either continues to pivot to the opposite side of the tray or there is a reduction of frictional resistance, allowing the mount to slide after one side of the tray starts to lift.

Sliding means the mount moves horizontally with no measurable upward movement. The TIF Rooftop Sled Mount Testing results indicates that overturning occurs when the load elevation was 60" or higher (which is the typical installation case for a wireless facility). However, due to variability in loads and installation parameters, sliding calculations should be performed for all installations. Roof overstress occurs when the overall gravity load exceeds the allowable roof pressure as determined by the engineer of record for the building structure.

Sliding – Friction Factors

Friction plays a significant role in determining the overall sliding capacity of the non-penetrating mount. When a lateral force is applied to the non-penetrating mount, the resistive force of the sliding friction acts in the opposite direction, parallel to the roof surface. Therefore, it is critical to use appropriate static friction when installing a non-penetrating roof mounted wireless facility.

The existing roof surface material and its condition is an important consideration when choosing the appropriate amount of friction. Ultimately, it is the EOR who is responsible for approving the coefficient of friction used in the mounting structure analyses and/or design. Based on the TIF Friction Coefficient Testing for Rooftop Ballast Mounts , the average coefficient of friction for dull galvanized steel on a rubber mat was 0.73. The EOR must exercise discretion when selecting an appropriate coefficient of friction value.

Common Retrofit Designs for Non-Penetrating Mounts

When analyzing non-penetrating mounts and common retrofits in to remedy a calculated overstress, there are four common failure modes:

1. **Overturning.** Typical modifications to prevent overturning include adding weight (via ballast) to the mount and/or adding base tray extensions. The mount's center of gravity will determine if additional weight is needed in the front and/or rear tray(s). Careful consideration should be taken to ensure that ballast will not cause an overstress on the roof. Alternate methods should be considered to alleviate overstress conditions (refer to the upcoming TIF Variability whitepaper). The EOR should discuss with the RF engineer if the centerline should be reduced.

2. **Sliding.** Typical modifications to prevent sliding include utilizing a reasonable coefficient of

friction and checking the application of the installed condition. Using rubber mats is the most common approach to increase the coefficient of friction. EORs may want to consider using rubber mats specifically made to increase the static coefficient of friction values should sliding significantly control ballast requirements. Other methods to increase resistance against sliding may include the installation of positively secured guy wires or the application of an adhesive compound to the interface between mount framing members/ rubber mat and rubber mat to roof deck. Be sure to consider possible roof and roof membrane damage. Although not a retrofit, consider replacing the entire mounting system with a newer style mount with primary round members.

3. **Roof Overstress.** Typical modifications include increasing the surface area of the mount base or relocating the non-penetrating mount over a load bearing and/or gravity carrying structural element of the supporting building. If the building drawings are not available, ASCE/SEI 7 standard provides guidance for minimum uniformly distributed live loads per occupancy for analysis purposes (see ASCE/SEI 7 standard Table 4.3-1I). The EOR determines the allowable roof pressure for the building structure. Due to unknown loading limitations, the mount EOR must consider the capacity of the existing roof to reduce the necessity of roof framing modifications. The mount EOR and rooftop structure EOR must communicate when proposing increases in weight prior to completion of the mount modification.

4. **Mount Overstress.** Typical modifications to address overstress and best practices for modification will be detailed in an upcoming TIF variability white paper. Topics focus on rigidity, extensions, steel replacement, and mount replacement.

Additionally, the EOR should take into consideration available lease space in the vicinity of the mount when designing the solution, as communicated by the End User.

Penetrating/Anchored Mounts

While the International Building Code, ASCE/SEI 7, and ANSI/TIA-222 do not require positive attachment of roof-mounted equipment to the underlying structure, it may be required by the AHJ or customer-driven requirements that deviate from this.

When using positive attachments to connect a wireless facility to the underlying building structure, these connections must provide adequate lateral, vertical and/or moment resistance at the positive connection points.

Positive connections can be mechanical such as wedge anchors, bolts, lag screws or other mechanical fasteners as well as be adhesive type anchors such as epoxy or other injectable adhesives. Positive connections can also be welded to an underlying steel structure. The type of positive connection used in a design is dependent on the material of the underlying structure and the EOR designing positive attachments should have knowledge of the underlying structure and positive connection being specified.

Adhesive type connections shall be evaluated per the manufacturer specifications.

Special attention should be given to the impact that penetrating connections have on the existing roof membrane and materials.

Wall Mounts

The required calculations to assure adequacy depend on the specific make and material of the existing building wall. As such, it is imperative that the EOR have a strong working knowledge of the materials and structure composition to ensure the solution does not deteriorate or compromise the building envelope. Additionally, to accurately assess the impact, the EOR must consider the additional gravity and lateral loading acting on the existing wall of the parent structure.

For the EOR to recommend installation points, this depends on the wall composition. It is strongly recommended to attach directly to the existing main structural members. Other accepted installation practices include utilizing wood blocking or steel backing to engage multiple studs and properly installing adhesive or mechanical anchors per manufacturer specification to assure effective embedment against breakout failures. It is best practice to avoid placing the wireless facility supporting structure on a non-structural component such as steel and fiber reinforced polymer screening or other architectural building components, though may be acceptable for loads of a low magnitude such as small cell installations.

Below are two common failure modes for existing wall mounted structures and common remedies:

1. **Stability**: failure occurs when the mounting structure connection to the building wall is deemed flexible and partially restrained. Typical modification includes adding a stabilizer or tie-back as an additional point of attachment to resist lateral loading.

2. **Connections**: existing slip-critical connection or attachment to the building wall is deemed inadequate. Typical modifications include installing additional connections to reduce the reaction loads onto the existing connection.

Other Considerations for Building-Mounted Telecommunications Structures

Preferred Installation and Positioning

The location of building-mounted telecommunications structures is critically important and needs to be evaluated by a professional engineer based on the anticipated loads.

It is recommended to place building-mounted telecommunications facilities near main elements of the supporting structure such as columns, girders, and walls. These load-bearing locations allow optimization of the structural framing to decrease load to secondary framing members. A best practice is to avoid placing building-mounted telecommunications facilities at or near the mid-span of the supporting structural members.

In cases where the EOR of the telecommunications structure (based on engineering knowledge and experience) and supporting structure are different, it is important for the EOR of the telecommunications structure to convey the forces that the telecommunications structure is imparting on the supporting structure. This allows for specialization of the engineering disciplines based on the intended use of the structure, the End Users' processes, or AHJ needs. It is critical for engineers to communicate and work together.

Wind Speed Up Effect

Given the limitations of applicability in ANSI/TIA-222-I Section 2.6.7, a K_s factor >1.0 applies only to isolated and unobstructed buildings with a minimum height of 50 feet or that are 50 feet higher than adjacent similar buildings in a 90-degree quadrant. The K_s is 1.0 for appurtenances or antenna mount structures installed on building walls (with the potential exception of installations on building penthouse walls). This is where it is critical to have an EOR with experience in the telecommunications industry and standards in analyzing the telecommunications portion of the structural system.

Typical Failure Modes and Proper Installation

The most common source of failure for building-mounted telecommunications structures is due to improper installation. Improper installation, or Installation Fault, as it is commonly termed is defined as deviations from the design documents (i.e. construction drawings, manufacturer specifications, structural modifications, etc.) that were not approved by the EOR to confirm code-compliance. Some common installation faults based on typical mount types are:

1) Non-Penetrating Mounts
    a. Insufficient/improperly installed ballast
    b. Installation was not constructed in accordance with the drawings
    c. Originally designed mounts are substituted/updated in-field by contractor with no engineering input
    d. Not installing site-specific requirements/updates to mount framing system
    e. Unapproved removal of ballast after appurtenance loading modifications
2) Wall mounted Frames/Stand-offs
    a. Improvised connections to the supporting structure
    b. Installation was not constructed in accordance with the drawings
    c. Incorrect parts used for installation
    d. Not installing site-specific requirements/updates to mount framing system

Figure 1 and 2 in Appendix B are examples of non-penetrating mounts which failed due to overturning because they were installed using improper ballast quantities. The images show little to no ballast blocks present. Figure 3 is an example of ballast blocks improperly installed to the mount. Figure 4 reflects failure due to improper installation as the main vertical member was not fully seated in the sleeve and then secured.

Of particular concern is the number of assumptions being made in the analysis and design of building-mounted telecommunications structures which are unverified or are inaccurate based on local/regional experience. For example, if the EOR assumed the roof was a concrete slab when in fact it is a gypsum roof, there is significantly less capacity available and would require a re-design. Every effort should be made to reduce the number of assumptions made and when necessary, verified in the field. EORs are encouraged to collaborate with the combining engineer in charge of the supporting structure analysis (where applicable) to reduce the assumptions of the structure's local capacity. Penetrative investigation during the design phase is often required and the necessity should be communicated with the End User.

Additionally, there are cases where the available building design documents were misinterpreted by the EOR on where they were directing the placement of telecommunications structures/equipment over non-load-bearing members. This highlights another instance where it is beneficial for the EOR to have experience in traditional building design when designing a building-mounted telecommunications facility.

Installation fault can be identified by completion of a Post Installation Inspection (PII) and a Post Modification Inspection (PMI). A PII is completed after the initial construction phases and a PMI is completed on any subsequent changes to the structure whether structural in nature or merely appurtenance modifications. ANSI/TIA-222 Annex N provides additional requirements for the completion of a PII and Annex O discusses the guidelines for structure modifications. Please refer to the Planning Advisory Notice entitled Post Installation Inspection and Post-Modification Inspection for additional details on these practices and the benefits they provide to all invested parties.

Finally, some calculated mount overstresses are not related to structural integrity but may potentially impact network performance. An example is where a building-mounted telecommunications facility undergoes an extreme weather event, and the mount supporting the antennas rotate laterally. Another example is where a non-penetrating mount uplifts and shifts and causes network performance issues.

In each example, the structural integrity of the mount may not have been impacted, but the End User may experience some network degradation and the landlord may experience maintenance issues. These issues are typically remedied through minor maintenance solutions. It is important for the EOR to discuss these concerns with the End User and understand how they would like to address issues that are strictly limited to potential network performance impacts. Additionally, it is crucial to confirm the accuracy of calculated failure modes.

Maintenance Practices

Post Installation Inspection (PII) and Post Modification Inspection (PMI) are critical in ensuring completion of proper installation in accordance with the EOR and Manufacturer's design intent. Proper closeout through this process documents and validates that the site has been installed based on the EOR's design intent and can decrease the potential of maintenance concerns or potential damage to the building over time.

For purposes of rooftop installation, PII should comply with ANSI/TIA-222-I Annex N where applicable for building-mounted structures. A PMI should be performed along with a changed condition in accordance with ANSI/TIA-222-I Section 15.3. B. For structures in coastal regions or corrosive environments, periodic maintenance and condition assessment should be conducted in accordance with the guidance provided in ANSI/TIA-222-I Chapter 14. Please refer to the Planning Advisory Notice entitled Maintenance & Condition Assessment Programs for additional considerations for maintenance & condition assessments.

A PMI for building mounted structures shall include but is not limited to the below applicable sections of ANSI/TIA-222-I Annex J.

- J.1 A) Structure Condition
- J.1 B) Finish
- J.1 E) Appurtenances such as Mounts, Antennas, and Lines
- J.1 L) Structure Modifications

Additional requirements of the PMI may be specified by the EOR based on varying site-specific conditions.

Summary

While telecommunications facilities mounted on buildings present a challenge because of the intersection between two different industries, following the principle of intended use can make a structural engineer's decision-making pathway clearer on code applicability. The ANSI/TIA-222 standard provides guidance on appurtenance mounted structures while ASCE/SEI 7 provides guidance on building structures and components. Engineering judgement shall be use to determine which design standards to follow based on the intended use of the structure.

During the design/analysis process of the building-mounted telecommunications facility, the EOR should be considering the economic implications to the End User based on the analysis approach and design recommendations provided. Locating the mount directly over main building members, utilizing non-penetrating solutions where possible, designing within lease space boundaries, and identifying and providing solutions for proper installation are all items that the EOR should consider as a professional consultant on these projects. Additionally, the EOR should be communicating structural failures versus potential network performance impacts to the End User and working with them to form a solution that is in alignment with their network goals. When a non-penetrating mount solution is to add more weight to the frame to resist overturning or sliding, significant consideration should be given to resulting impacts to the supporting structure.

Lastly, while the primary focus here is on the telecommunications facility's analysis and design considerations, the EOR who has been contracted to perform engineering services either on the telecommunications structure and/or the building structure must be a faithful agent to the client. As such, the EOR should evaluate the complexity of the job and their experience prior to committing and shall consult with subject matter experts where appropriate.

Appendix A

Photos of Building-Mounted Telecommunications Facilities

a. Wall Mounts

Figure A.a.1: Wall mount installed on outside of building

Figure A.a.2: Wall mount installed on the penthouse wall of a building

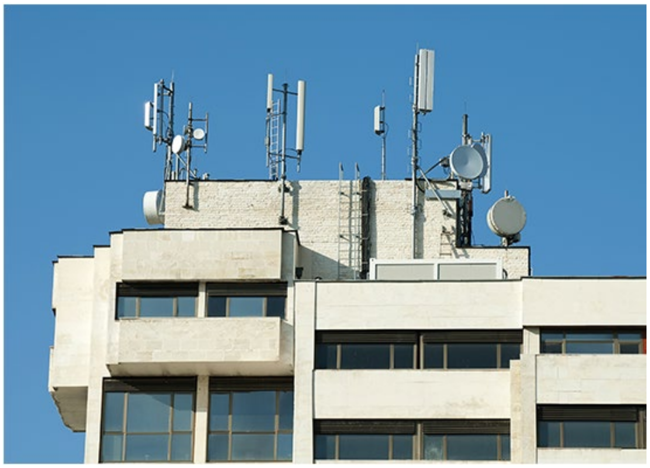
Figure A.a.3: Different types of wall mounts installed on the penthouse wall of a building


Figure A.a.4: Pipe wall mount installed on parapet wall of a building


Figure A.a.5: Pipe wall mount installed on the wall of a building

b. Rooftop Mount (Penetrating and Non-Penetrating)

Figure A.b.1: Custom penetrating mount supporting radio and dish equipment

Figure A.b.2: Custom penetrating triangular frame

Figure A.b.3: Custom penetrating triangular frame with tripod mount

Figure A.b.4: Custom penetrating rooftop mount installed on penthouse roof

Figure A.b.5: Non-Penetrating ballasted sled mount

Figure A.b.6: Non-Penetrating ballasted tripod mount


FigureA.b.7: Non-Penetrating ballasted triangular mount

c. Equipment Platform

Figure A.c.1: Custom equipment platform

Figure A.c.2: Penetrating mount installed on equipment platform

d. Towers

Figure A.d.1: Small Latice Tower ballasted on corner of a building roof

Figure A.d.2: Small Latice Tower ballasted on corner of a building roof


Figure A.d.3: Small Monopole Tower installed on a building roof

Appendix B

Examples of Faulty Installations Leading to Failure of Building-Mounted Telecommunications Facilities

Figure B.1: Rooftop sled-mount frame overturned as a result of not having enough CMU blocks

Figure B.2: Rooftop satellite Dish overturned as a result of not having enough CMU blocks and blocks not properly placed.
(Refence: FEMA 543 Risk Management Series: Design Guide for Improving Critical Facility Safety from Flooding and High Winds (January 2007))

Figure B.3: Rooftop tripod mount fell off the roof as a result of not having enough CMU blocks or proper ancorage

Figure B.4: Parapet Panel antenna mount failure due to improper anchorage

Figure B.5: Collapse of roof mounted antenna tower including progressive peeling of the roof membrane (Refence: FEMA 543 Risk Management Series: Design Guide for Improving Critical Facility Safety from Flooding and High Winds (January 2007))