The Telecommunications Industry Foundation is pleased to announce publication of the following TIF White Paper:

Mount Analysis: Recommended Best Practices

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CHAPTER I
INTRODUCTION

As the telecommunications industry continues to support existing equipment and the deployment of new technology including 5G hardware, the quantity, size, and weight of equipment on towers and mounts continues to increase. These loading increases combined with the ANSI/TIA-222 standard development and revisions have ***increased*** the focus on mount analysis as a requirement when there is a changed condition due to loading increases. During the development process of ANSI/TIA-222-H *Structural Standard for Antenna Supporting Structures and Antennas*, it was recognized there was a lack of industry resources guiding engineers on level of rigor, best practices, and other considerations that should go into mount analysis and modification design. The Ad-Hoc committee developing what would become Chapter 16, focused on defining the minimum requirements for analysis parameters. Industry is encouraged to join the work of TIA's Engineering Committee TR-14 to advance the standard for the benefit of the industry (http://standards.tiaonline.org/standards/tia-engineering-committee-application).

A mounts White Paper Committee (**"WPC"**) was created with volunteers from across the industry. These included manufacturers, carriers (end users), engineers, and contractors. This team was able to quantify disparity in the industry and identify key analysis concerns and differences. To resolve these issues, the engagement of the end user is required to support the engineer in their communication with the contractors in the field. As we as an industry continue to support the deployment, maintenance, and recovery of telecommunications infrastructure, it is critical for the industry to continue to improve its design, installation, and maintenance standards according to codes, standards, and best practices as well as root cause analysis of failures. It must be understood that there is limited topical research on mounting systems and many questions are still only answerable by theory, or through observation during the maintenance, and condition assessment, and a limited but growing pool of testing data from mount manufacturers.

This TIF White Paper (**"White Paper"**) is intended to educate and promote the sharing of information and best practices among all stakeholders involved in the deployment, modification, and maintenance of mounts. This White Paper is not intended to modify a standard or act as a standard. It is intended to offer guidance and foster discussion on the most impactful analysis considerations, identify areas for further research, and provide transparency on the work performed to date as a reviewable resource. This includes a discussion about serviceability of the equipment on the mount (theoretical performance failure or code non-compliance) versus structural failure of the mount (physical failure). The end user needs to be able to quantify the serviceability requirements for the mount. This information must be shared with the engineers, contractors and manufacturers, as well as providing it in a manner that allows an end user to have confidence that their infrastructure will perform as intended. Complexity is increasing with the roll-out of 5G and other advancements as well as utilization of new antenna locations in the buildout of denser communications networks.

CHAPTER II
STANDARD BACKGROUND

Mount analysis parameters embedded in ANSI/TIA-222-G "Structural Standard for Antenna Supporting Structures and Antennas" aligned with existing tower analysis parameters with one explicit paragraph in

Section 2.6.9 addressing appurtenance design. As the industry evolved from 2G to 3G, 4G and 5G, the mounts, originally designed with reserve capacity, had this capacity consumed by antenna placement, antenna size and even radio equipment. This change in loading led to some mounts that physically failed and had serviceability issues, causing the industry to no longer take for granted that mounts had excess capacity, and that the ANSI/TIA-222 standards requirements for analysis should be followed without additional analysis. It was very quickly recognized that there was no real common means to certify the loading designs and intents. The industry applied varied interpretations of everything from geometry precision, member inclusion, connection fixity, and wind load factors (such as shielding and dynamic response) that were viewed as explicit and settled in tower analyses. Similarly, load application in mount analyses varied greatly amongst engineers and manufacturers. Wind loads were often limited to normal and transverse (90 degree) load combinations, with maintenance loads being applied inconsistently or even omitted entirely.

As the industry evolved, mount analyses were increasingly recognized as critical. A combined push from carriers (end users), manufacturers, and contractors led to development of a mount specific standard. The development focused on proactively setting standards to provide transparency in parameters used and installation guidelines to ensure mounts were able to achieve their theoretical design capacities, as well as ensure performance expectations were clear when procuring a new mount. The resulting standard, TIA-5053 - *Mounting System Classification*, was published in October of 2017, provides a consistent approach to defining mount capacity based on standard loading. While this document clearly defines the design loads and installation guidelines for each mount, there is very limited discussion of analysis approach or best practices underlying the consistency in nomenclature to streamline the procurement processes. This has led to a constant concern in the industry that two engineers can generate a mount analysis of an identical mount and produce significantly different results.

It became evident early in the development of ANSI/TIA-222-H that carriers (End Users) would adopt the explicit requirement for mount analyses, and increased emphasis was placed on developing mount specific parameters in the ANSI/TIA-222 standard. Most of the analysis parameters were explicitly specified in Chapter 16 – *Appurtenance Mounting Systems*, creating a baseline for analysis, while still leaving open questions regarding best practices, effective assumptions, and utilization requirements. There was an effort by consultants and carriers (end users) to better define typical mount analysis approaches and this white paper was developed to aid in the defining of best practices for mount analysis and modification design.

CHAPTER III
INITIAL CONCERNS GUIDING WHITE PAPER DEVELOPMENT

Some of the major concerns expressed in the development of this white paper:

(1) What is the appropriate balance of mount analysis rigor versus simplifying assumptions without adding unnecessary complexity, engineering timelines and expense, and increased material costs and detailing requirements?

2) Are the complexities (or simplifications) in the mount analysis approach driving excessive analysis failure rates, or are they necessary to model expected mount behavior?

3) Do mount analysis approaches reflect the real-world application and installation of the mounts?

Mounts are a surprisingly complicated hybrid between frame bending action and truss axial forces, whereas towers are accurately simplified to truss (diagonals) or frame (legs) behavior. Analyzing mounts consistently as frames can lead to an overly stiff model, utilizing non-structural elements (i.e. mount pipes or grating support angles) in the load path. Alternatively, analyses considering mounts as entirely truss elements may be unstable without adequate tower fixity and tie-backs; this gray area requires frequent engineering judgement to apply the appropriate amount of stiffness without destabilizing the model or violating basic structural analysis principles. It is recognized that to leave this solely to engineering judgement without further guidance leads to inconsistency and confusion amongst stakeholders at all levels. This inconsistency can drive up costs and cause unnecessary delays in the deployment of the network equipment.

When evaluating the items presented in this paper a consistent theme emerged; in an ideal loading application, many of these complexities are not required. Mounts have been designed and installed for the last 25+ years for a variety of loading (for example, 2G through 4G); whereas, application of widespread mount analysis is relatively new to the industry. Next generation equipment including antennas that may be larger, in both area and weight, have exacerbated critical design components that were non-issues at the time of install, but are unable to cope with ***modern loading demands***. Many of this paper's recommendations may not be critical for a well-designed, detailed, properly installed mount sold today, and can potentially be less of a concern for future mounts utilized in the industry, provided the end users maintain their data, as well as enhance their procurement processes to ensure quality application, metals, and installation.

Lastly, there are the dual concerns that the mount analysis failure rate far exceeds the rate of failure experienced in the field, and the initial shock of many mount analyses failing at excessive usages (>150%). The high frequency of failure may be a function of many first-time mount analyses just now being performed on legacy mounts designed to a significantly lower loading standard and in many cases were not installed (or reviewed by a qualified stakeholder at close out) to achieve design intent. The frequency of theoretical failures would appear lower and less severe if mount analyses were performed at each evolution from 2G to 5G loading (ANSI/TIA-222 previous revisions, updating to ANSI/TIA-222-H). Additionally, the increase in mount analyses performed over the past few years has led to a decrease in the frequency and magnitude of theoretical failure. Today, it is more common for theoretical failure to apply to current load changes rather than resolving as-is overstresses.

CHAPTER IV
BRIEF DISCUSSION OF DEGREE OF FAILURE

For stakeholders that have concerns when a mount analysis is received with a high theoretical failure usage, it is important to understand that high failing usages can be more of a function of model instability than gross overutilization. Failure magnitude does not necessarily correlate to relative modification cost or complexity. Instead, the burden on the engineer is to identify the key drivers of overstresses – is it the mount in its entirety, is it one member of a mount, is it a single inadequate connection? Current installation practices, especially antenna vertical offsets, deviate from design intent and often exacerbate weak(er) points in the mount load path. Even when a mount is analyzed in accordance with the recommendations from the WPC, many existing mounts may still result in analysis failures due to inadequate load paths to the tower and inadequate fixity or detailing at member-to-member connections.

In an effort to streamline discussion of mount concerns, the WPC will focus on providing clarification on the spectrum of mount failure, as discussed below. While we have provided some common examples in each category, this is not intended to be exhaustive, and it is possible that items may bridge between two categories.

Serviceability – The mount structure may pass from an analysis basis, but it may have movement impacting the ability of it to perform as intended. Parameters of serviceability shall be communicated from the end user to the engineer. Common examples would include potential rotation impacting desired azimuth (no/ineffective tie backs or T-Arms) or rotation impacting the desired tilt of the panel (single point for antenna connections on low profile platforms and T-arms). This type of issue is a nonstructural issue that can be addressed to support the intended performance of the structure or maintenance/installation activities.

Impacting – An issue that must be corrected as soon as can be effectively planned for the structure, equipment safety, or system to continue to perform as designed. This type of issue could be identified by multiple stakeholders – the engineer notifying the contractor after reviewing close outs, mapping or maintenance crews noticing mount deficiencies and notifying the end user (carriers), or this could be conveyed by the contractor to the structure owner. It is everyone's responsibility to monitor for impacting concerns and escalate to the structure owner or end user, as appropriate. These issues may include improperly located tie backs at either the mount or tower, improper hardware installation, or incorrectly installed reinforcing members.

Critical – Immediate action is required; while the mount has not fallen, it is in a failure state that could lead to separation from the underlying structure or significant member damage under a serviceability or higher wind event. This issue shall be addressed in the most expedient manner and actively managed to resolution while ensuring a safe work environment. These issues could include the top brackets of the antenna mount have broken loose from the underlying structure, platforms exhibiting vertical slip on a monopole, or visible and significant damage to the mounting structure.

Catastrophic – Mount has failed completely and has either fallen or is at immediate risk of falling independent of serviceability or higher wind event. The identifying party, based on their competency, should temporarily secure the mount while ensuring a safe work environment. It is recommended that when a catastrophic event occurs that a qualified engineer is consulted as well as the mount manufacturer, if known. This allows understanding if there are similar issues across other mounts if the issue exists elsewhere.

Generally, mount analysis failures can be classified as serviceability or impacting failures. Serviceability modifications often include added support rails or tie backs to avoid rotation concerns. Impacting modifications often add an additional connection to the tower to alleviate identified weak points in the existing load path. Structural modifications addressing these failures are designed to avoid the mount condition escalating to a critical or catastrophic failure in a design wind or ice event. Often, the same off-the-shelf modification kit can be used to bring a mount into code compliance whether the calculated failure usage is relatively high or low. Many times, the analysis overstress will not lead to catastrophic failure of a mount, but rather to a serviceability or impacting issue with the installed mount. It is important that the end user work with the engineer to address these issues for the good of the industry and the end user.

CHAPTER V
WHITE PAPER DEVELOPMENT PROCESS

The first step in developing this white paper was to understand the current industry non-standardized approach for mount analysis. This WPC reached out to several mount manufacturers who graciously provided mount design documents for current (4G Macro) designs that were in production at the time and designed to handle loading beyond the baseline loading that was considered for this exercise. The WPC selected (4) unique mounts (2 platforms and 2 sector frames) to try and capture the spectrum of material shapes, internal connections, and overall mount geometry. Multiple engineering firms analyzed each of the 4 mounts and provided a full analysis report and mount model to the WPC for review.

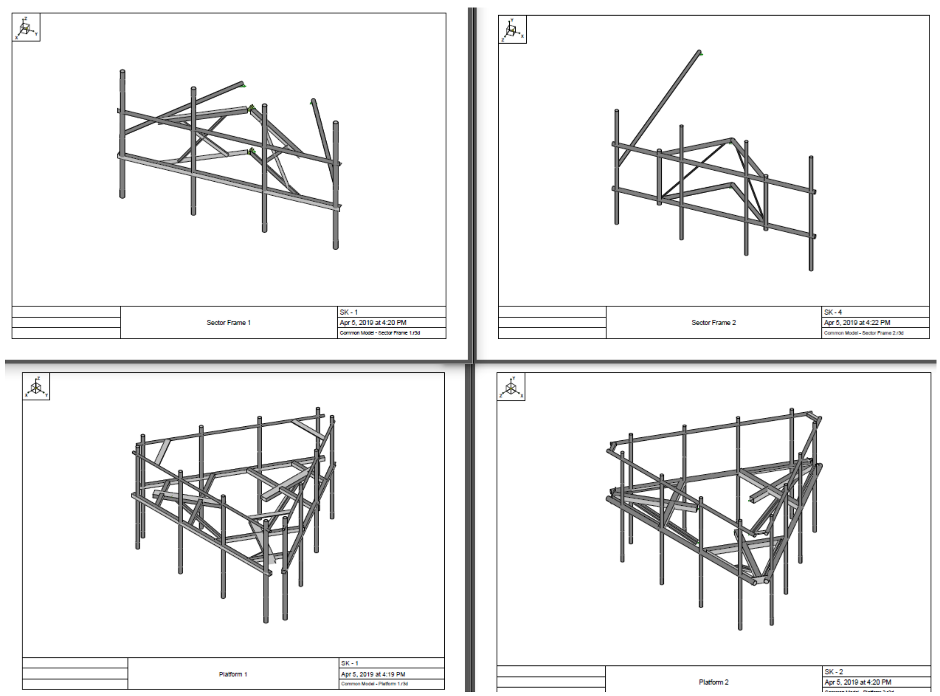

Figure 2- Mount Submissions

Upon initial review of the mount analysis results from the different engineering firms, it was apparent that there was a wide variation in mount usage in the models provided, as demonstrated in Figure 3 below. This shows the difference in mount usage for each model/firm along the horizontal axis and the difference in resultant reaction at the tower interface along the vertical axis. There were aspects of the mount modeling that were generally consistent in the models submitted by the firms, such as the number of mount pipes, overall mount geometry, and member sizes. However, after further investigation by the WPC it was determined that it was the details in how the mount was modeled and analyzed that were controlling the discrepancies in analysis results between the engineering firms.

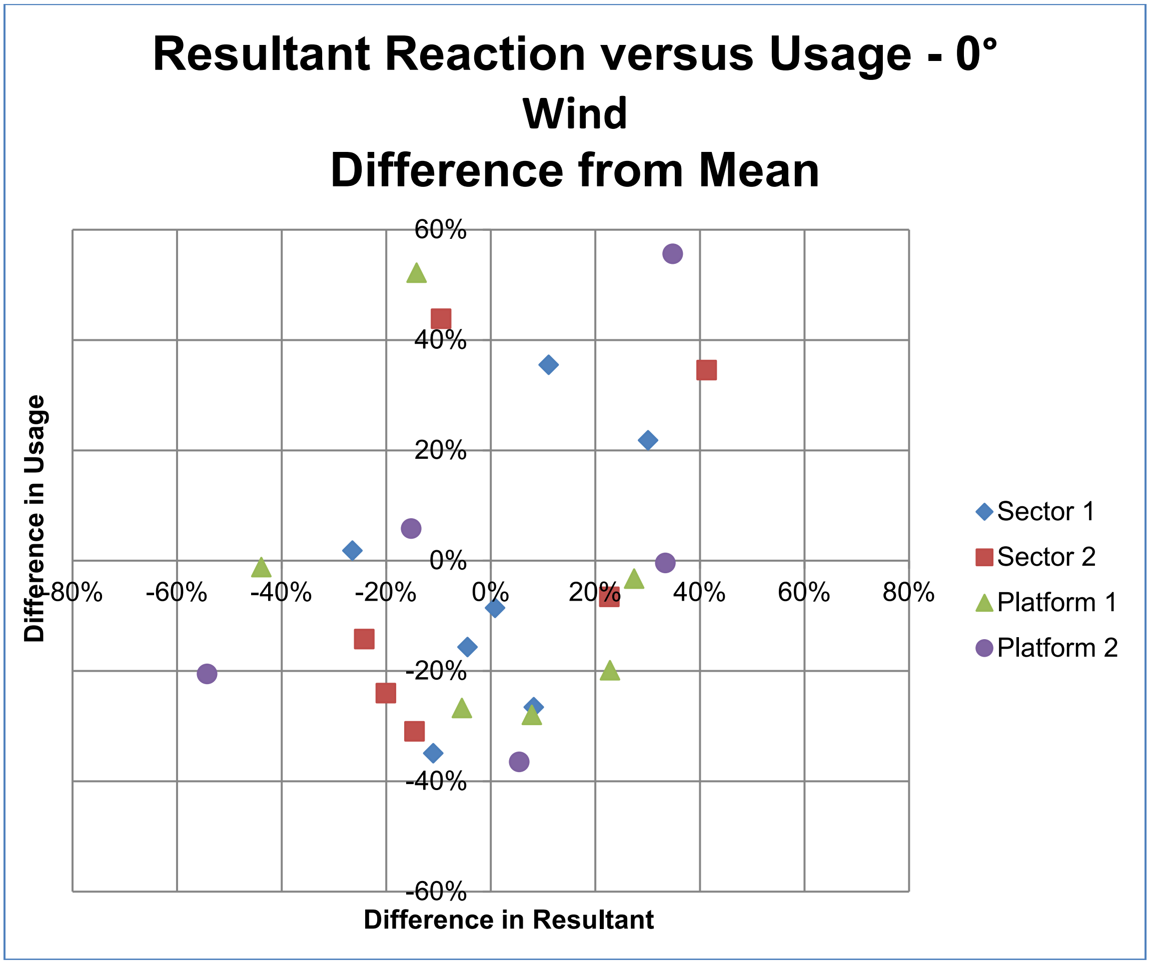

Figure 3- Resultant Reaction (at Tower Connection) Versus Usage

To understand the existence and magnitude of these discrepancies, the WPC identified a list of specific criteria to evaluate and compare each mount model against. For the sector frames, the WPC determined that there are 35 different criteria points, and for platforms there are 29 different criteria points that are involved in the creation of a mount model. When considering this extensive number of criteria and engineering decision points that go into the creation of each mount model, there are more than 1e+40 (duodecillion) different combinations of criteria possible for sector frames and more than 8e+30 (nonillion) for platforms. It should be noted that while a large quantity of criteria points also exist in traditional tower model creation, there is no industry-specific analysis program that minimizes and regulates the manual user input for mount model creation. Since there has been no consensus on best practices for mount modeling to this point, along with the large amount of manual input that goes into the creation of each mount model, it can be easily understood why mount analysis results between firms vary so greatly. On either end of the spectrum, these variances can contribute to either cost over-runs (from unnecessary modifications) or potential safety and reliability issues of these mounts (from overlooked details and unreasonable engineering assumptions).

Sector Frame Criteria Evaluation

Mount Model Parameters	Common Model Approach	Percentage of Firms Matching Common Model Approach
General Loading		
Wind loads applied at 30-degree increments	Y	94%
Discrete basic load cases vs. factoring load combinations	Factored Load Combinations	44%
Ultimate vs Nominal Wind Speed	U	67%
Man load considered	Y, 500 lb[1]	25%
Man load windspeed	30 mph[2]	31%
MLL application (pressure, point load, distributed)	Point Load	78%
Application of Loading		
Antenna point load split to two points on mount pipe	Y	88%
Antenna point loads laterally offset from centroid of mount pipe	N	88%
Antenna point load location matches provided figure	Y	69%
Radio point loads vertically offset from centroid of mount pipe to match figure	Y	94%
Radio point loads laterally offset from centroid of mount pipe to match figure	N	69%
Radio point load matches orientation provided in figure	Y	75%
Ice weight applied as distributed member loads (as opposed to self-weight factor)	Y	81%
Face members loaded (wind and ice)	Y	94%
Supporting members loaded (wind and ice)	Y	94%
Model Geometry		
Mount pipe to face horizontal connections include eccentricity (Rigid End Offset)	N	63%
Member to member connections include eccentricity	N	63%
Tieback bracket connections include eccentricity	N	81%
Location of tieback connection(s) at tower matches provided face width	N[3]	56%
Model Members		
Evaluated connection plates	N[4]	56%
Evaluated connection brackets	N	75%
Plates meshed	N	88%
Members hinged (versus fixed)	Y[5]	75%
Partial fixity assigned to connection of mount pipes to frame	N	63%
Releases assigned to connection of offset V-frame to face horizontals	N	81%
Tieback connection to frame member assigned release	Y	81%
Partial fixity assigned based on local axis (versus all bending moments released)	N	63%
Rigid links utilized to assign fixity	N	38%
Effective length (K) factors modified for members	N	63%
Unbraced length modified for members	Y	63%
Mount-Tower Connection		
Connection plates/bracket evaluated	N	63%
Zero global fixity assigned to mounting frame-tower connection	N	56%
Partial global fixity assigned to mounting frame-tower connection	N[5]	56%
Zero global fixity assigned to tieback-tower connection	N	63%
Partial global fixity assigned to tieback-tower connection	N[5]	56%

1. Ranged from 0 lb to 500 lb
2. Ranged from 0 mph - 60 mph
3. Perpendicular to face
4. Platform did check end plates but not any others, but for sector mounts most of the industry does not check it and it will be assessed by the groups. Manufacturers at the time confirmed plate was not designed
5. Fully pinned

Platform Criteria Evaluation

Mount Model Parameters	Common Model Approach	Percentage of Firms Matching Common Model Approach
General Loading		
Wind loads applied at 30-degree increments	Y	100%
Discrete basic load cases vs. factoring load combinations	Factored Load Combinations	57%
Man load considered	Y, 500 lb[1]	57%
Man load windspeed	30 mph[2]	43%
MLL application (pressure, point load, distributed)	Point Load	50%
Application of Loading		
Antenna point load split to two points on mount pipe	Y	86%
Antenna point loads laterally offset from centroid of mount pipe	N	79%
Antenna point load location matches provided figure	Y	93%
Radio point loads vertically offset from centroid of mount pipe to match figure	Y	71%
Radio point loads laterally offset from centroid of mount pipe to match figure	N	57%
Radio point load matches orientation provided in figure	Y	71%
Ice weight applied as distributed member loads (as opposed to self-weight factor)	Y	86%
Face members loaded (wind and ice)	Y	86%
Supporting members loaded (wind and ice) (back face of platform)	Y	93%
Model Geometry		
Mount pipe to face horizontal connections include eccentricity (Rigid End Offset)	Y	57%
Member to member connections include eccentricity	N	64%
Connection at tower matches provided monopole diameter	Y	71%
Model Members		
Evaluated connection plates	Y[3]	100%
Plates modeled as members instead of rigids	Y[3]	100%
Plates meshed	N	93%
Partial fixity assigned to connection of mount pipes to horizontal members	N	64%
Releases assigned to connection of internal members/plates to face horizontal	Y	71%
Releases assigned to support rail corner connections	Y	57%
Releases assigned to under platform kicker members	Y	93%
Rigid links utilized to assign fixity	N	50%
Effective length (K) factors modified for members	N	93%
Unbraced length modified for members	N	57%
Mount-Tower Connection		
Collar connection evaluated	N	79%

1. Ranged from 0 lb to 500 lb. One firm also used 40 psf
2. Ranged from 0 mph - 60 mph
3. Only applies to platform 2

During the evaluation of the mount model criteria, the WPC determined the most common approach to each of the criteria assessed and derived a “common model” for each of the four mounts. These mount models were viewed as the consensus models for the group and demonstrated the current industry standard for mount modeling practices at the time.

Based on the differences in analysis practice and approach discovered while determining the current/baseline industry standard, the participating engineers organized into seven working groups, each focusing on a different aspect of mount analysis. The primary concerns included application of loading, member eccentricities, modeling of connecting components, mount to tower connections, mount and tower interaction, fatigue, and mount modifications. Each workgroup investigated the impact of varied analysis approaches against the common mount models provided from the WPC and provided recommendations to better define best practices.

The WPC, working with each of the workgroup chairs, has developed initial recommendations based on the work to date. These recommendations provide best practices for engineers involved in mount analysis. These recommendations are presented briefly; the WPC will be releasing additional papers in the future to dig deeper into the issues, technical approach, and stakeholder specific advice resulting from each recommendation.

CHAPTER VI

CONCLUSION 1: REAL WORLD APPLICATION OF LOAD DRIVES ANALYSIS COMPLEXITY

When reviewing the investigations from each chapter, a consistent theme emerged. Many of these recommendations do not have a meaningful impact on analysis results until the mount model/analysis is updated to match a typical real-world panel installation. There is a clear divergence in the industry where the mount manufacturing, ratings, and baseline analyses assume symmetrical and vertically centered panel loading. There is a conflicting bias among carriers and owners to match leased centerline elevation rights without regard to appurtenance attachment height in relation to the mount centerline. Finally, the end user and stakeholders involved in the construction phase have installation practices in place that drive the elevation of appurtenances upward from the mount centerline (primarily for ease of equipment access, required cable bend radii, and shielding demands). This is especially evident on legacy mounts as panels have evolved from 4 ft 2G panels to 8 ft 4G panels and the centerlines creep upward. The net result is the most common installation in the field will have a significant vertical offset (defined as 'e' in TIA-5053) between the mount centerline elevation and appurtenance centerline elevation. As the vertical centerline offset increases, the ability to simplify the mount model decreases, and turns small modeling differences during analysis/design into critically controlling elements in the installed condition. This eccentricity has direct and significant impacts on mount pipe usages, appropriate evaluations of fixity in the model, connecting plate usages, torsion on face horizontal members, and effectiveness of tie-back locations. This theme will continue to be addressed throughout the following sections.

Application of Point Loads at Attachment Point(s) instead of Centroids

Historically, mount rating specifications (TIA-5053, October 2017) rate mounts based on single point loads applied on the mount pipes for wind load and gravity. ANSI/TIA-222-H offers some clarity that the "loads from appurtenances shall be applied at the centroid of the appurtenance and transferred to the supporting pipe at attachment locations," which suggests splitting the single load to two separate point loads at the antenna bracket locations. Splitting the point loads does not alter the global loading and generally has a limited effect on the frame and face horizontals, but it can affect mount pipe usages and increase the usage on the top horizontal, especially for open section members.

Connecting Plates need to be Modeled

Bent steel plates are commonly used in mount construction to connect members to one another, as well as to connect the mount to the tower. The most common approach observed in the industry is for the engineer to omit these plates in the model and to model one member directly connecting to another or add a small rigid link. While a simplified analysis approach may be appropriate under symmetric and centered loading, the real-world installation practices (vertical eccentricity) introduce significant bending across the weakest axis of these connections.

Figure 4 – Mount Connection to Tower with Bent Steel Plate

Figure 5 shows an example of a typical plate connection commonly observed in platform mount construction. The illustration on the right shows a common simplified analysis approach, omitting the plate from the mount model. It is clear the actual load path is entirely through the vertical plate member and this plate member is significantly less stiff than the two members that it is connecting. If the main face horizontal has a significant amount of torsion, this load would act as a torsional load on the flat plate. Additionally, lateral forces on the main force horizontal would act as a bending moment about the weak axis of the plate.

If the flat plate element is omitted from the model, the torsional loads in the pipe face horizontal will be transmitted directly into the tube platform decking member, both of which have a significantly higher torsional capacity than the flat plate member and U-bolt that is physically transferring the load in this example. When the flat plate element is included in the model, it becomes very evident this member is the controlling component in the load path in both strength and stiffness. This presents itself in the field by face pipe horizontals that have rotated after a severe wind event. These flat plate connecting elements should not be omitted from evaluation especially under eccentric loading or legacy mounts with less robust connecting plates (3/16" instead of 3/8").

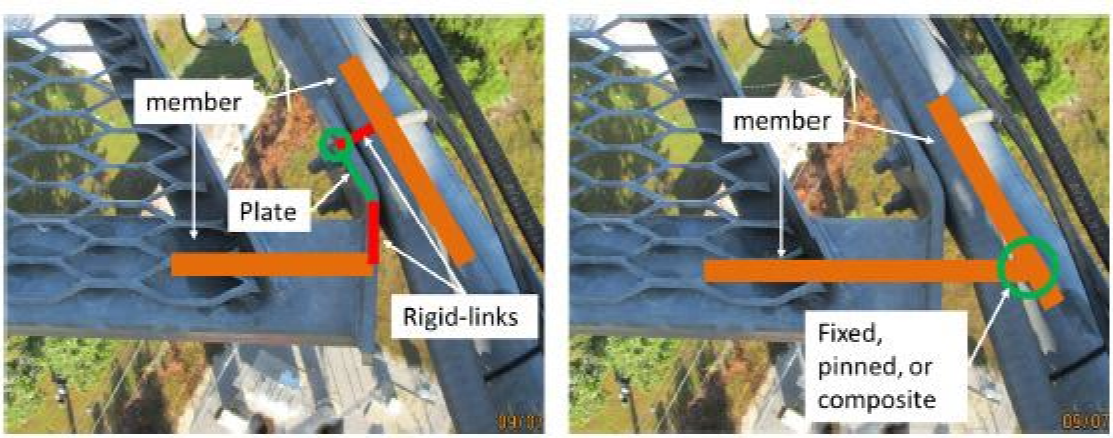

Figure 5 – Typical Plate Connection on Platform; Rigid Links vs. Simplified Approach

CHAPTER VII
CONCLUSION 2: BOLT FIXITY (OR LACK THEREOF) REQUIRES MODELING COMPLEXITY

One of the most challenging aspects of mount analysis is that there is no clear definition of frame action versus truss action and fixed connections versus pinned connections. The regular geometry and redundant load paths in tower design allow for a simplified analysis, whereas many mounts lack alternate load paths which leads to ambiguity when evaluating connections. The stability of many mounts relies on some degree of fixity via friction or prying from their connections. However, the resistance provided via friction or prying is not readily definable because the torque used to install the bolt is unknown, and limited guidance is provided in legacy manufacturer installation documentation. In these cases, the engineer is forced to make assumptions and blur traditional engineering connection theory to align connection fixity to expected mount behavior.

Direct Bolted Connections

Mounts made of primarily angle members offer both the clearest conflict of engineering rules and expected behavior. For example, Figure 6 below shows an angle-to-angle single bolt connection of the V-frame to the face angle and a mount pipe connected with a U-bolt. When examining the V-frame connection, traditional engineering principles suggest pinned along all principal axes. While this is the simplest approach, it often requires generating frame action elsewhere in the mount (often via the mount pipes) to maintain model stability. Instead, applying partial fixity increases the complexity of modeling these connections and allows for greater deviation in results based on engineering judgement, but is more accurate as it would concentrate the load path through framing elements instead of relying on mount pipes (which are better viewed as appurtenances than structural members) to generate adequate frame action.

Mount Pipe Connections

Mount pipe connections, while relatively minor, can drive some of the largest impacts in overall model behavior and usages. There are two main connection types: single U-bolt connections (Connection 1) and crossover plate with multiple U-bolts (Connection 2), as demonstrated in Figure 6. While Connection Type 2 can be considered fixed and able to transfer moment, Connection Type 1 is generally treated as a pinned connection allowing rotation about the z axis (and likely the x axis). Alternative or unique u-bolt configurations may be considered differently with documented engineering testing and/or rigorous analysis.

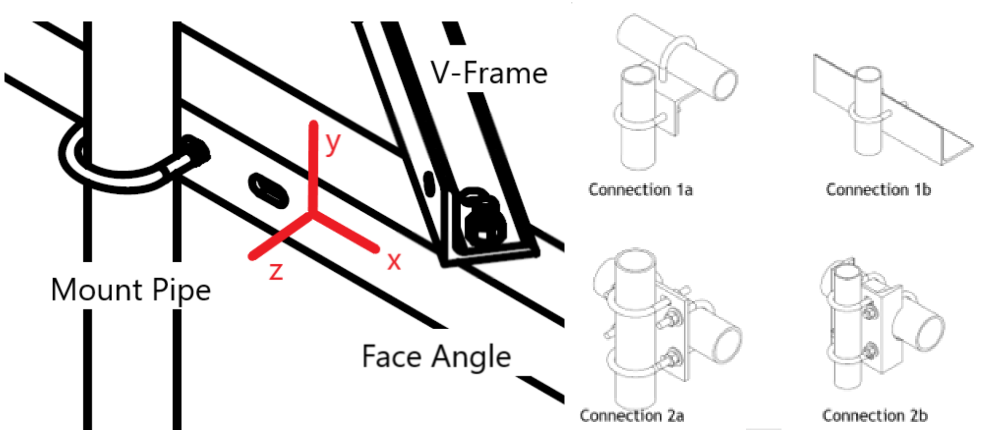

Figure 6 – Mount Pipe connections - Connections

CHAPTER VIII
CONCLUSION 3: BENEFITS OF MODELING MEMBER TO MEMBER

One of the largest differences in the various vendor models was the practice of modeling node to node versus including a rigid link to account for the differences in member centroids. The simplified approach holds that the inch or two difference between member centroids is not significant, the members are connected and acting through a common line of action, and the complexity introduces unnecessary complication. In contrast, the intent of including member eccentricities is three-fold: the engineer can use these offsets to further refine fixity, accounts for potential member torsion, and improves best practices for modeling intersecting elements.

Rigid links allow for greatest flexibility when assigning fixity

The first objective – refining fixity – must be used in crossing members and can be used to further stiffen the model. The common models generated in this report are a great point of reference – Sector Frame 1 is a predominately angle frame with x-bracing in the V frame. The most common approach was to model these braces in plane with the offset frame, which either creates a joint in the middle of these X braces or forces them to act independently. Instead, the engineer should provide a lateral offset for at least one of the diagonals and then connect the midpoints with a rigid link that can act as a connecting bolt and release the moment about this joint.

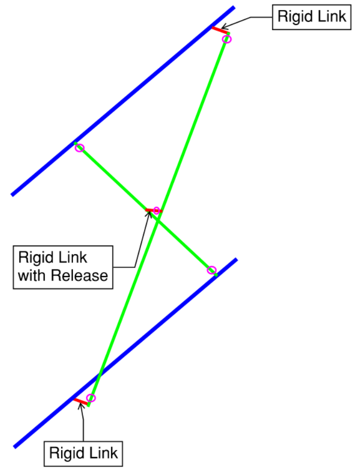

Figure 7 – Lateral offset for one of the diagonals; Connection of midpoint with rigid link

Refining fixity can also assist the engineer in generating more frame action from a mount that may be suffering from modeling instability. The common approach to Sector Frame 1 had the offset angles framed directly into the face horizontals with all bending moments released. When the mount pipes were framed into the face horizontals fully fixed, the model is relatively stable; when you free the mount pipes in accordance with Conclusion 2, the model relies heavily on the X braces to maintain shape and may become unstable. Instead, the engineer could utilize rigid links to release the moment about the axis of the bolt while leaving other axes fixed to include prying moments. The use of prying moments falls firmly in the grey area of engineering judgement, where theoretically prying or weak torsional behavior of framing angles makes a 'fixed' deflected shape more consistent with expected behavior than a pinned connection. Adding fixity can have both positive and negative contributions to mount usages and can make a significant improvement in the model matching expected physical behaviors especially on an older mount with limited load paths or limited V-frame bracing.

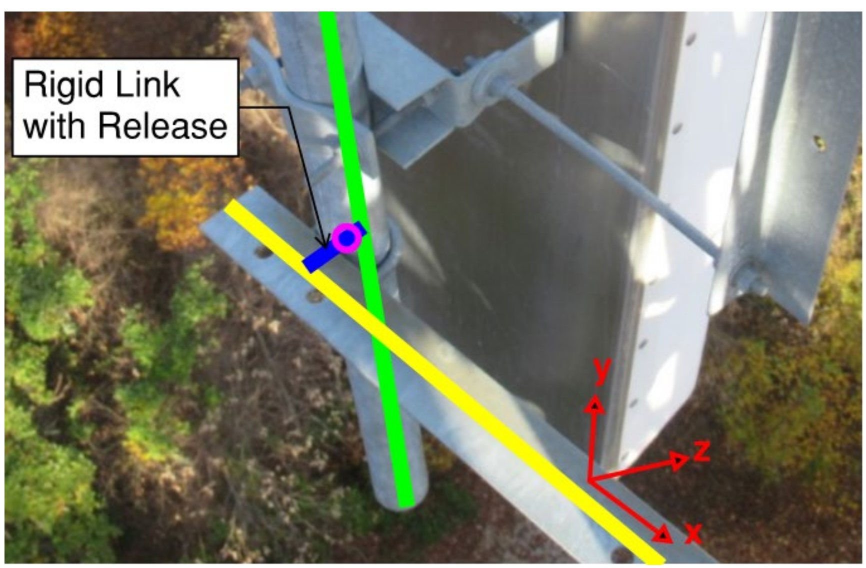

Figure 8 – Rigid Link connection between Face Horizontal and Mount Pipe

Accounting for Torsion on Open Section Members

The second application of a rigid link is to properly account for potential member torsion, especially on open section members. Returning to Sector Frame 1, the common model has all members framing into each other when the angles are stacked upon each other. For a L3x3x3/16" this can create a 1.6" offset between the centroids; the introduced torsional demand can be readily exceeded by axial loading from a framing member. This is even more problematic with tie-backs connecting to face horizontals, often with a universal joint-style connection or other eccentric connection that allows for rotation in multiple axes. The engineers evaluating this behavior recommended the eccentricities be modeled for these connections for L3X3 and above or with centroids differences over 1.5", as the torsional impact can be controlling.

Individual Nodes versus Working Points

When multiple mount bracing members connect into the same member in the same general location, it was found that there is little to no change in stress in the bracing members when modeled as a single point versus their own individual connection points. However, where multiple members connect into a framing member, the force concentrations in the framing member can have significant impact on analysis results. It is recommended that the members be modeled to have their own individual connection points instead of sharing a common node when there is a larger spacing between working points.

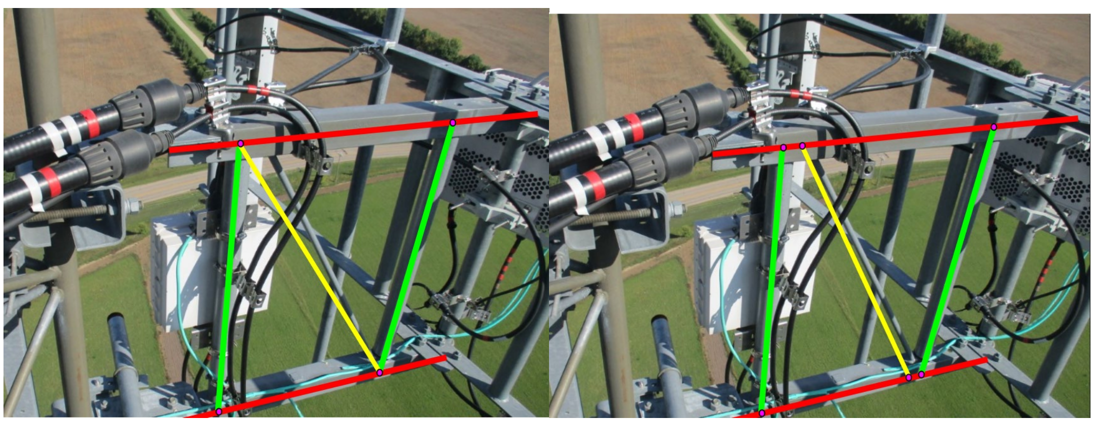

Figure 9 – Bracing Members when modeled as Single Point Vs. Own Individual Points

Modeling eccentricities of vertically stacked members (connection between a standoff member and a front horizontal) will have minimal effects on the overall usage of the mount. However, when the eccentricity exceeds 1.5 inches, the effects become significant enough that the best practice would be to include these eccentricities in the analysis model.

CHAPTER IX
ADDITIONAL TOPICS INVESTIGATED

While all work groups brought valuable new research and approaches to common mount concerns, the investigative results of many sections led to more questions than answers. Outcomes from some of these work groups and areas for further research they identified are described below.

Modeling of Connecting Components

A mount structure is composed of multiple sub-structures, which are comprised of numerous individual components, each with their own inherent capacity and boundary conditions. The engineering practice of how these components are modeled and analyzed can significantly affect the outcome of the overall mount analysis.

It is prudent engineering practice to ensure that the design strength of the connecting components always *meets or exceeds* the design strength of the main members. However, many mounts installed in the field do not demonstrate this methodology. When possible, the analysis results should be based on either design data or a rigorous analysis of the connections, rather than on assumptions of connection strength.

However, while these components need to be considered, the complexity of these connections require advanced modeling. This makes the due diligence of modeling these connections restrictive for many reasons including, but not limited to, standard mount analysis scope, conservative deflection results as compared to live testing, and the high level of input and engineering judgement which makes it impossible to achieve consistent results across multiple engineers.

While most modern mounts include a standard capacity, the real-world installation practices often differ significantly from the theoretical rating. To facilitate site-specific analysis on newly manufactured mounts, the recommendation is that mount manufacturers move toward providing design capacity on proprietary weldments and other components that would require advanced modeling.

Mount to Tower Connections

<u>Monopole Connections</u>
Mounts installed on monopole structures typically utilize a cantilevered standoff member welded to an end plate that is bolted to a collar weldment. Assessment of the weldment collar's ability to transfer the load from the standoff member to the pole shaft can be difficult as many manufacturers utilize proprietary shapes and design the collars using Finite Element Analysis (FEA) software. Analyzing the weldments using conventional simplified methods produce varying results that may diverge from the true behavior. In addition, proper installation of the collars is essential to ensure the weldment collars assemblies have sufficient frictional resistance to the applied loads on the mounting system. Ultimately, the greatest ability to understand the capacities of these connections lies with each manufacturer. Ideally, the manufacturers should develop a standard rating guideline including design strength, serviceability, and underlying structure impacts. All manufacturers would then be able to evaluate each of their collars to these criteria and publish the results for considerations.

<u>Latticed Tower Connections</u>
Typical self-support and guyed tower mount-tower connections have an array of load transfer interfaces from the primary standoff members and tie-back connections. Proper modeling and consideration of working points can be critical to an accurate analysis of the connection capacity. Almost all mount-tower connections are connected to the tower using pre-tensioned rods or bolts. The amount of pre-tension in the bolts is dependent upon how they were installed and tightened; however, most installation guidelines provided by manufacturers do not specify pre-tension requirements or bolt tightening directions. Additional installation requirements and post-installation inspections would provide better information for analysis of newly installed mounts. The best practice in scenarios with unclear installation conditions is to not rely on the frictional resistance from those pre-tensioned loads by providing alternative solutions for load resolution into the supporting structure. This is especially important for connections on open

section tower legs (smaller L shaped guyed tower legs), as the moment resistance of the leg is easily overwhelmed by a fixed mount connection.

When analyzing a mount to tower connection, it is important that the load path be traced all the way back to the tower leg. Furthermore, mount manufacturers and engineers both, must consider the type of underlying structure that the mount is attached to when determining the location of the point of rotation in the model. For open section tower legs for instance, the point of rotation in the mount will need to be considered as fixed. Engineers must be careful to analyze the impact of moment on open section legs, as they have shown to have minimal moment resistance. Alternative load paths must be established in these cases.

If moment resistance on a pipe or solid leg is required for mount stability, we recommend analyzing the connection as if it had been installed in accordance with AISC snug-tight installation guidelines (RCSC 8.1).

Mount-Tower Interaction

The current standard in the industry is to produce two standalone deliverables that are intended to provide a complete load path analysis for a typical tower structure; a tower analysis and a mount analysis. The typical scope of a mount analysis starts at the point of connection between the antennas and the mount pipes and follows through the mount to the point where it is connected to the tower. At this point, an appropriate boundary condition is applied to simulate the mount's support at the tower interaction and the mount analysis is ended. For a typical tower analysis, the tower structure is modeled and loads from antennas, mounts, coax and other appurtenances are calculated and applied directly to the tower model. In this analysis process, there is a single point that is being overlooked; the interaction between the mount and the tower.

One of the concerns for mount connections to monopoles are the local stresses applied to monopoles by collar weldment connections. As heavier loaded mounts become the norm there have been occurrences of the monopole face plastically deforming at the collar connection point. Sector frames typically have truss style geometry creating a moment couple which applies loads to the tower legs in the form of a vertical and horizontal load at two connection points. Some mounts use a single point of attachment which applies a localized moment in addition to the vertical and horizontal loads. All these forces from the mount create localized stresses in the tower legs that are not captured in a typical tower analysis. This can be an issue for certain types of tower legs and connections. In the same manner that local stresses can be introduced into the legs of a tower by mount connections, local bending stresses can be created when tie-backs are attached to the tower.

While several areas of concern were identified here, it's premature to provide any initial recommendations. As such, further discussion on this topic is required before additional guidance can be provided.

Mount Modifications

When designing optimal solutions, engineers must weigh the cost, quality, and time required to design and install a reinforcement solution. They must be aware of whether the solution is constructible and if installation will require the end user to go off-air. Although the possible solutions also include an outright replacement, the recommendation is to reinforce existing mounts wherever possible. Design engineers should identify the quickest and simplest solution, using off-the-shelf manufacturer kits prior to the consideration of custom solutions. When evaluating solutions, reducing reinforcement construction time may outweigh the cost of the additional material.

CHAPTER X
CONCLUSION

The best practices presented in this paper, if adopted widely, will increase the level of consistency in mount analysis results between engineering vendors and drive us further toward a common industry standard for all aspects of mount engineering.

While there are several aspects of mount analysis that were determined to be necessary and critical to ensure structural integrity of the mount, engineers are limited in the information that they can utilize to provide an accurate mount analysis and require additional support from the mount manufacturers. For instance, the effort required to model proprietary connections has been investigated and it is not feasible. There is also a wide variation in the analysis results of these connections obtained between engineers due to the required modeling complexity and ambiguity. Since mount manufacturers are equipped with more robust design tools and physical testing data, recommendation is the manufacturers provide additional design criteria, including design capacity of proprietary connections, as well as detailed installation guidelines and documentation requirements for contractors. The data made available now may be based on different testing conditions by the manufacturers, but it is far superior to the level of variability seen amongst engineering firms. Providing this information would also be beneficial to the manufacturers as it would allow the opportunity to have their mounts analyzed as initially intended per their design expectations and not through conservative engineering practices based on assumptions made in calculations due to lack of alternative data.

This paper is the result of a significant effort amongst many individuals, yet only a few of the critical items investigated are ready to present for consideration. While this paper acts as a platform to drive the industry towards consistency for mount engineering, there is a lot of additional research, testing, and discussion warranted for this topic. The source data and recommendations can be made available for review and discussion upon request.

The WPC will continue to work with the workgroup chairs to develop best practices for how mounts are being utilized, maintained, analyzed, and modified. As this understanding develops, the WPC will work to publish additional white papers to share this knowledge with others. The WPC earnestly seeks feedback on the information released to date as well as encourages others in the industry to share their experience and knowledge for the good of all in the industry. A reader should treat this paper as informative but it is not a substitute for your own due diligence, experience, and application to the unique situations encountered in real world deployments.

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- Michelle Kang

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FEEDBACK:

TIF wants your feedback! If you have any questions concerning this TIF White Paper, have suggestions on how to enhance or expand upon this TIF White Paper, or would simply like to share how this TIF White Paper has impacted you, please visit our website TIF Feedback and leave a note for our Board of Directors.

[1] The authors and editors of this TIF White Paper consented to the promotion of their participation and the use of their name and information with respect to the publication, marketing, and promotion of this TIF White Paper. No royalties or other compensation will be paid to these individuals in connection with this TIF White Paper and TIF has not received any compensation or donation for the publication hereof.