Fort Union National Monument
Phase Four Technical report

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Preface

A framework for identifying and monitoring site vulnerabilities and establishing sustainability indices for Vanishing Treasures Parks in the arid West

To date, there has been little coordinated attention to describe how different manifestations of changing weather conditions will affect built heritage at the material and systemic level. Only with a better understanding of damage mechanisms in terms of their severity, frequency, location, and rate of occurrence, can we begin the process of implementing remedial and preventive strategies, including the establishment of monitoring programs that can measure projected impacts to these cultural resources over real time and through new simulations and modeling. We need to bring knowledge from disaster risk management into climate change adaptation. From disaster management we know that the difference between investing in prevention and the costs of disaster impact can easily exceed a ratio of 7:1. Urgent and deep levels of mitigation alongside the need to support adaptation is now required to reduce vulnerability from current and future climate variability and extremes. Adaptation can complement mitigation in order to address the escalating changes defining future vulnerabilities to climate change. Where adaptation is not undertaken in response to a perceived risk, vulnerability will remain unchallenged. As such, we need to identify, communicate, and develop ways of thinking into everyday activities and ~~structures of~~ policymaking.

In the context of cultural heritage, risk is the potential for loss, damage or destruction of cultural resources as a result of a threat exploiting resource vulnerability. Threat causes damage or danger to a cultural resource and vulnerability is an inherent weakness or gap in our protection efforts. It is the degree to which a system is susceptible to, and unable to cope with adverse effects. In the case of climate change, vulnerability is the degree to which a system is unable to cope with the adverse effects of climate variability and weather extremes. Vulnerability is a function of the character, magnitude and rate of climate change and the variation to which a system is exposed, its specific sensitivity, and its adaptive capacity (IPCC, 2008:699). Monitoring, or the systematic process of observing, tracking, and recording data for the purpose of measuring and assessing information deemed necessary for a stated objective is the key to cultural resource management. There are many monitoring systems now in place that capture how climate is changing. They do not, however, provide information about the impacts of changing climate on built cultural resources at the park or site level. The challenge for cultural resource managers is to develop an illustrative suite of indicators, methods, and metrics at multiple scales that are essential for understanding climate impacts on various built heritage systems (e.g., materials, construction systems, conditions, settings). While measurements can be taken of individual aspects of a site or feature, such as exposure, surface erosion, or out-of-plane displacement, some indicators are explicit (i.e., measurable change), while others are more implicit and require deeper interpretation. A broad array of indicators should capture sufficient information to demonstrate change relative to climate stressors and therefore provide some insight into future weather-induced damage, and more generally a vulnerability index or threshold for specific features and sites. Because it is neither feasible nor possible to measure every phenomenon on a site, it is important to identify a resources' 'vital signs' or those aspects including condition that taken together, identify a suite of critical indicators that can provide a generally accurate and informed basis for anticipating future problems. These indicators should be significant to the problem (i.e. directly linked to degradation), measurable, and ideally display a time continuum (exist in the past and present).

Such information could be useful in the development of a coordinated monitoring strategy for any site by focusing on a representative set of measurable metrics that can be used as indicators of site vulnerability and if addressed, site sustainability. Sustainability here is a function of the vulnerability and resilience to a system or site's threats. As with natural ecosystems, built cultural resources also have the capacity to adapt and evolve in response to changes in the environment but this capacity is limited in terms of time and space as well as the intensity of the change. For example annual summer 'monsoons' will continue to differentially erode the adobe walls of Fort Union as they always have; however changes in the occurrence of these extreme weather events due to climate change will potentially stress the walls beyond their moisture threshold limits causing a new unrecoverable catastrophic type of failure due to adobe's wet strength vulnerability. The aim here is to provide a conceptual framework for defining site vulnerability and threshold limits based on site monitoring that integrates across a wide range of scales and over time.

EXECUTIVE SUMMARY

Background

In 2012, the National Park Service Vanishing Treasures (VT) program initiated a multifaceted project to identify and address the impacts and effects of climate change on built cultural heritage resources in the Intermountain Region (IMR). These resources, exhibiting traditional building techniques and materials, and different levels of exposure (e.g., ruins) were of concern. Fort Union National Monument (FOUN) and its many preserved 19th century adobe ruins, was among those sites identified to participate take part in this program because of its highly sensitive construction (adobe), its exposure as a ruin site, and its extreme environment. Sites that are maintained as ruins tend to be less resilient to changing environmental factors. The 2012 VT initiative directed efforts into three primary categories:

1. Compilation of existing data (including climate models and predictions) and literature on climate change in the Southwest and the degradation of heritage resources by a variety of climate parameters, as well as other relevant materials;
2. Identification of climate parameters that are most destructive to the built environment; and
3. Identification of climate models and projections that include the above parameters for the Intermountain Region.

Risk to Adobe Walls at FOUN

The adobe walls at FOUN are subject to a few climate related risks: intense precipitation (monsoons), snow, and wind. Its two principle vulnerabilities are related to its material (adobe) and its structural status as an unprotected (i.e., non-sheltered) ruin. This combination of primary vulnerabilities in material and structural sensitivity in a setting of extreme weather, and especially precipitation events, made it an ideal candidate to explore the nuances of vulnerability related to other factors such as wall construction and wall height to width to thickness ratio. During preliminary phases of work at FOUN, there was a common misconception that the cause of catastrophic failure of adobe walls at the site could be directly traced back to one, perhaps two, factors, such as basal erosion or heavy rain events. While many of these hypotheses were indeed valid, they did not tell the whole story, nor could they, because much like the walls themselves, their failure modes are prohibitively complex.

The culminating work produced by the CAC at FOUN during Phases I – IV has focused specifically on the Third Fort complex. Completed in 1851, this is the last and most intact of the three forts at FOUN. The ruins of the Third Fort comprise the majority of standing architecture on the site and consequently are most at risk to damage from climate related weathering. Approximately 5,000 linear feet of adobe ruins define the Third Fort with an estimated 50,000 square feet of surface area (based on an average wall height of 5'-0").

Preserved and maintained as a ruin, FOUN continues a remedial preventive program of encapsulating the adobe ruins with amended sacrificial adobe mud shelter coats. This process is initially effective but can obscure evidence of serious structural failure below the superficial layer. The nuance of the structural and environmental performance of these walls requires a systems-based approach that incorporates both observational evidence alongside a fundamental understanding of their construction, maintenance/repair history, material-specific deterioration mechanisms, and so forth. In this way, walls can be prioritized for strategic maintenance and repair. The resources otherwise expended on walls identified as stable, without need for immediate attention in a given season, can be redirected toward more intensive and comprehensive documentation and intervention for identified at-risk cases.

This report will detail the successful implementation of a feasible, self-sustaining, and evidence-based monitoring and risk-prioritization protocol for the preservation and management of the Third Fort adobe walls.

Past Work: Phases I-III

The work discussed in the body of this report is a direct evolution of efforts made during the previous three phases of work conducted between 2015 and 2017. A detailed accounting of previous work can be found in the earlier technical reports for each phase.

Phase IV Scope of Work

Introduction

The fourth and final phase focuses on implementing a comprehensive program of vulnerability monitoring and risk assessment for the adobe ruins at FOUN. The pilot Rapid Assessment Survey (RAS) program developed for the Mechanics' Corral (HS36) in fulfillment of the Phase II-III scope, is refined and expanded here to include the 32 adobe structures, 275 freestanding wall segments, and 403 individual wall sectors (see glossary) of the Third Fort. Additionally, to validate the prioritized results of the RAS an independent geometric structural analysis was performed based solely on the profilometry survey data also collected.

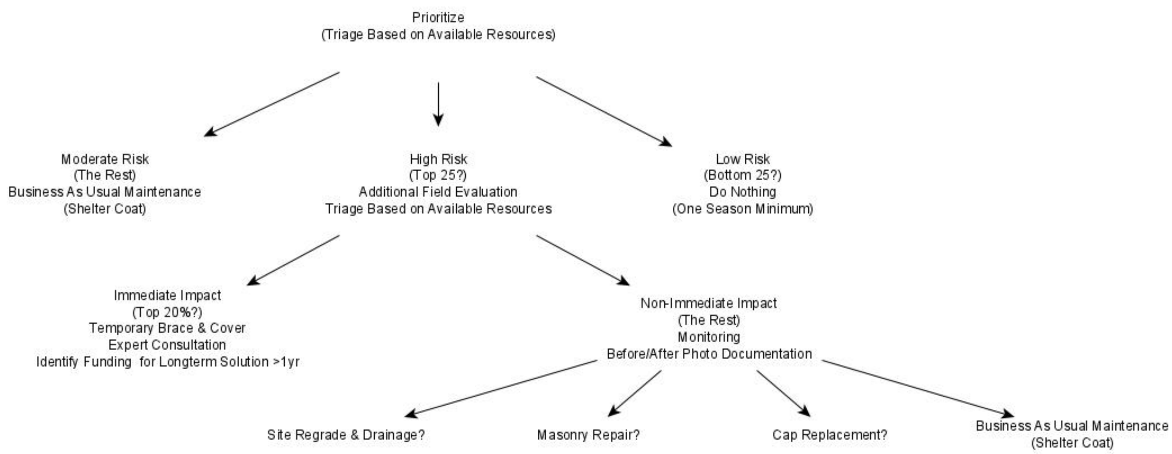


Figure 1- Illustrates the elements of the Integrated Vulnerability Assessment Methodology detailed in this report and their recommended implementation sequencing. No one element stands alone nor should be implemented as such; each has been developed to aid, clarify, or otherwise supplement another to provide a robust, evidence-based, field-validated, risk assessment methodology.

Objectives

While the effects of a changing climate can be understood and experienced in different ways, for climate-sensitive earthen sites such as FOUN, one of the most tangible is a shorter seasonal maintenance period due to earlier monsoons and an earlier freeze, which is vital to the preservation maintenance of the site. The primary objective of Phase IV therefore is to prioritize the necessary remedial and cyclical preservation work for the adobe walls based on a scale of risk (as defined and elaborated on in the Glossary of Terminology). This prioritization allows for the near-term scheduling and organization of resource-efficient cyclical maintenance, which involves the application of sacrificial, amended adobe shelter coats to the walls of the entire FOUN site (or as many as is feasible in a season). Additionally, such a program can be used in the long-term to evaluate the performance of these interventions over time. Sustainable solutions are 'smart' solutions as they conserve and redirect staff time and fiscal resources and usually result in improved resource integrity. It is important to note that wall significance, architectural or otherwise, was not included in this assessment phase. This is a value which must be addressed in the future to help guide prioritization of monitoring and preservation treatment.

THE INTEGRATED VULNERABILITY ASSESSMENT METHODOLOGY

The Integrated Vulnerability Assessment Methodology is the culmination of four phases of work conducted by the Center for Architectural Conservation. This methodology, developed and implemented at the Third Fort at FOUN, is comprised of three components:

- The rapid assessment survey (RAS),
- The profilometry methodology for validating and expanding RAS findings
- Passive RFID embedded monitoring .

These three parallel data sets provide the foundation for an integrated approach that leverages the benefits of both qualitative and quantitative techniques. Each dataset complements and reinforces the other, compensating for weaknesses that would otherwise arise from the implementation of any method in isolation - as is often the failure with most contemporary vulnerability assessment protocols that emphasize either quantitative or qualitative tactics.

Rapid Assessment Survey

The Rapid Assessment Survey (RAS) is the foundation of this methodology. It establishes the framework for completing a seasonal site-wide assessment, the results of which substantiate year-to-year maintenance, stabilization, and monitoring decisions. The primary objective of the RAS is to prioritize wall sectors based on a matrix of observed wall conditions and aspects that define vulnerability factors unique to FOUN. It does not, however, replace or supersede the appropriate application of expert judgment to actualize its findings.

The value and validity of the RAS is derived from consistent implementation each year. It provides a structured observational approach. And it replaces the various manifestations of informal annual 'survey' that have been implemented over the years, from the early Hartzler forms to the annual site 'walk-around' by the stabilization crew.

Wall Profilometry

Wall surface profilometry was identified as valuable information for both the characterization of a wall's geometrics as well as the understanding of its differential surface deterioration and loss. In addition to its height, perhaps the most fundamental piece of information needed to quickly assess the overall vulnerability of any freestanding wall segment is a record of its cross-section. Profile information is critical to the maintenance and preservation of the walls at FOUN as forms in the landscape, while the surface deterioration typologies gathered from the analysis can be beneficial to understanding surface erosion and the influence of specific geometries to gradual weathering of adobe ruins across the region.

Passive RFID embedded monitoring

Radio identification (RFID) technology was explored as an alternative method to address the same embedded monitoring objectives of classifying and locating failures of both the shelter coat and capping system. RFID technology leverages the understanding of the primary failure mode and the advantages of a passive and sacrificial embedded moisture detection technology. As a result, only the data necessary to evaluate the integrity of the primary water shedding elements of the adobe wall are collected, and only when necessary by the preservation staff during the seasonal survey.

Wall Segment Prioritization

		Condition	0 - 5	Code	
Surface	Elevation 1 N E	Wall Surface loss (top 1/3)		SL	
		Wall Surface loss (middle 1/3)		SL	
		Wall Surface loss (bottom 1/3)		SL	
		Sill Deterioration (below opening to foundation)		WS	
		Elevation 1 Subtotal		x100	a
	Elevation 2 S W	Wall Surface loss (top 1/3)		SL	
		Wall Surface loss (middle 1/3)		SL	
		Wall Surface loss (bottom 1/3)		SL	
		Sill Deterioration (below opening to foundation)		WS	
		Elevation 2 Subtotal		x100	b
	Coat 1	Cracking		CC	
		Loss (exposed masonry)		CL	
		(corresponds to elevation 1 surface) **Shelter Coat 1 Subtotal**		x10	c
	Coat 2	Cracking		CC	
		Loss (exposed masonry)		CL	
		(corresponds to elevation 2 surface) **Shelter Coat 2 Subtotal**		x10	d
	Coat 3 N E	Cracking		CC	
		Loss (exposed masonry)		CL	
		(wall segment edge condition, if applicable) **Shelter Coat 3 Subtotal**		x10	e
	Coat 4 S W	Cracking		CC	
		Loss (exposed masonry)		CL	
		(wall segment edge condition, if applicable) **Shelter Coat 4 Subtotal**		x10	f
Wall Sector	Masonry	Cap Deterioration (Breach = 5)		CP	
		Structural Cracking		SC	
		Cracking at Wall Junction		CJ	
		Out of Plane		OP	
		Lintel Deterioration		LD	
		Height			
		Wall Segment Subtotal		x1000	g

Notes:	Key: Primary ① Secondary ③ Secondary ④ Primary ②

Date	Wall Sector ID	Summary	
	HS-	g	
		a	b
		c	d
		e	f

Figure 2- The final design of the RAS form, implemented during the summer of 2019 for the entire Third Fort Site of FOUN. A logarithmic weighting scale is applied to the RAS categories to acknowledge inherent hierarchy among the vulnerabilities considered. These are highlighted in red.

RAPID ASSESSMENT SURVEY (RAS)

Overview

Most past field surveys at FOUN were developed and implemented in association with preservation work. Only the 1995 Survey was designed to better understand patterns and trends of conditions to assist in proactive management. Unfortunately, due to imprecise parameters, poor recording methodology, and lack of continued park support, little could be discerned from this effort. Key objectives of the new RAS were:

- Clarity of phenomena to be observed and recorded
- Ease of execution
- Reproducibility regardless of the individuals conducting the survey

In this way the entire site can be surveyed each year in advance of the work season and cumulative observations (spanning multiple seasons) can be used to prioritize work based on comparative vulnerabilities across all walls.

Design

Much of what sets apart this survey from those which preceded it is an underlying understanding of how adobe walls at FOUN behave as a system. The design of the survey is evidence-based and is validated to the conditions actually present. The direct result of this process is the Illustrated Conditions Glossary supplement to the RAS (see Appendix B).

The RAS centers on a distinction between intrinsic and extrinsic factors that determine a wall's vulnerability. Intrinsic factors are physical in nature and relate to the composition and construction of an adobe wall itself. This is what is generally referred to as "geometrics", examples of which include adobe coursing, wythes, wall length, width, and height, openings, lintels, etc. At FOUN these intrinsic factors are often difficult, if not impossible, to identify given the long-standing practice of shelter-coating, which conceals construction information as well as past deterioration. For ruin structures this is even more complex as the 'as built' condition, now lost, may have affected the earlier performance of the wall, resulting in the differential conditions seen today, weathering aside. The portions of the survey dedicated to these factors aim to identify, to varying degrees, deterioration or failure of the underlying fabric and structure of the wall. The risk posed by the presence of any one, or combination, of these factors, is therefore inherent to any particular wall segment and will determine wall response to 'extrinsic' factors. A prioritized list of wall sectors captures the risk related to intrinsic factors; however, such a tabular evaluation can never incorporate extrinsic geospatial factors.

Extrinsic factors are those affecting the performance and behavior of an adobe wall beyond the boundaries of the wall itself. Extrinsic factors, which act upon a wall without any influence from the wall itself, include environmental exposure, architectural and geophysical context, and the performance of ongoing preservation and maintenance strategies. Unlike intrinsic factors, greater agency is provided to influence, alter, or otherwise eliminate extrinsic elements. A prime example of this is deterioration of a shelter coat due to weathering, which is not only a function of shelter coat performance but environmental exposure (prevailing weather patterns) and architectural context (aerodynamic and solar shading from adjacent wall segments).

The observed conditions recorded during the RAS do not ascribe causality to intrinsic or extrinsic factors since most observed conditions are the synergistic result of combined factors. Each element of the RAS builds on this and uses it to establish a hierarchy of vulnerability related to both the geometrics and mechanics of an adobe wall. Specifically, the field survey form, in its final iteration (Figure 2), is comprised of three sub-sections incorporating the full spectrum of observations:

- Wall elevation loss (categories A & B);
- Surface shelter coat condition (categories C-F)
- Overall physical characterization of the wall, as a whole (category G).

These categories provide the information needed for site managers to analyze risk, threat, and wall sensitivity, determine overall wall vulnerability, and develop prioritized preservation plans. The RAS format also allows the preservation crew to use the results to inform seasonal work. Where necessary, more detailed survey forms can be employed utilizing graphic formats and quantification for cost estimating and treatment evaluations over time.

(For a more detailed description of the survey design and evolution refer to Phase III technical report)

Implementation

During Phases II and III, the RAS was evaluated in situ for both feasibility as well as fidelity; however, early versions failed to achieve acceptable results. Key to the final result was involving the FOUN preservation personnel in the design and field-testing process. Initially, this was done only to streamline the transition from the existing NPS survey; however, the preservation personnel feedback was used to finalize a form that takes approximately five to six minutes per wall sector to complete. Furthermore, as the preservation crew was involved in the design, the transition of the system over to a self-sustaining park methodology has a greater chance of success in the long run.

Benefits outweigh the costs. To complete the RAS in the field, little training is needed and can be accomplished without the need for additional equipment. The training took a few hours in a conference room setting, to explain the Illustrated Conditions Glossary and paper form, and an hour in the field to illustrate real walls and conditions to the examples provided. And the cost to print and subsequently scan the completed forms is negligible. The disadvantage is the need to digitize the results for analysis at the site scale. It is easy to look at several pages of surveys of a particular wall segment and produce a mental image of its performance over

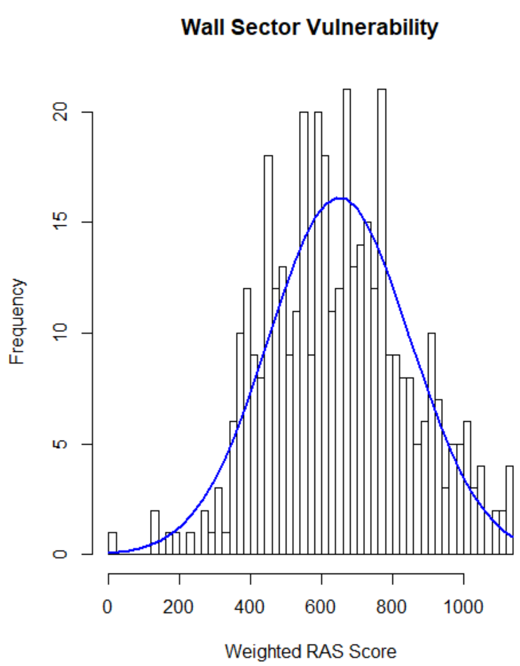


Figure 3- A histogram depicting the normal distribution of RAS scores for the 2019 Third Fort Survey.

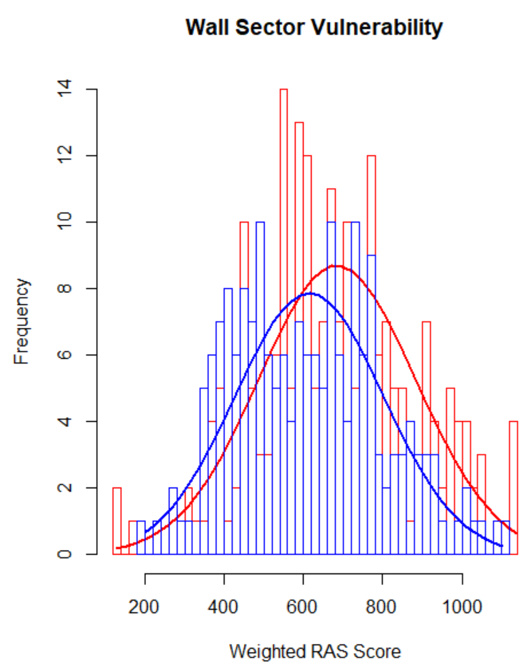


Figure 4- A comparison of normal distributions among RAS scores from north-south (red) and east-west (blue) facing wall sectors indicating that the form is not categorically biased.

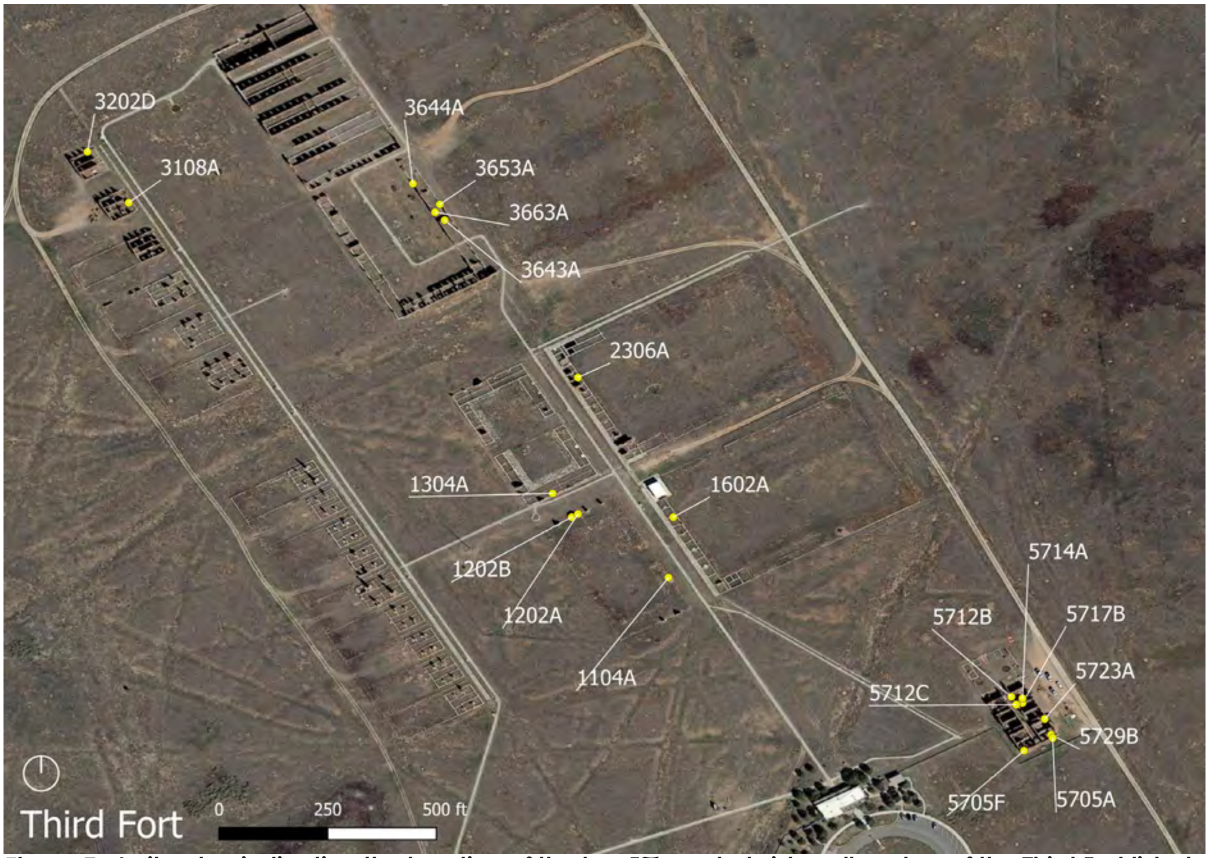


Figure 5- A site plan indicating the location of the top 5% most at-risk wall sectors of the Third Fort listed in the table below.

the years; however, it is difficult to build that same picture of how that particular wall fits into the rest of the standing walls of the Third Fort Site. This geospatial aspect requires digitally formatted data for use in programs such as Excel, GIS, or CAD, but is not ultimately considered necessary as part of the methodology proposed.

The obvious question arises: then why not implement a digital system? Phase IV work began concurrent with a digital overhaul of the park with much-needed upgrades to administrative and infrastructural systems, including plans to provide Wi-Fi to the grounds and support buildings. With this overhaul, FOUN administration discussed plans to introduce digital tablets for use in the field. As appealing as a digital format may be, we recom-

SECTOR	RANK	SCORE	BUILDING
3663A	1	1139	Mechanics' Corral
5705F	2	1134	Hospital
5723A	3	1133	Hospital
5717B	4	1128	Hospital
3108A	5	1119	Commissary's Office
5712C	6	1101	Hospital
1304A	7	1093	Company Quarters 13
5729B	8	1081	Hospital
1204B	9	1059	Company Quarters 12
1602A	10	1048	Laundresses' Quarters 16
5712B	11	1046	Hospital
3202D	12	1044	Clerks' Quarters
3643A	13	1035	Mechanics' Corral
5705A	14	1032	Hospital
3653A	15	1024	Mechanics' Corral
2306A	16	1015	Laundresses' Quarters 23
1204A	17	1008	Company Quarters 12
3644A	18	1004	Mechanics' Corral
5714A	19	1003	Hospital

Figure 6- Prioritized list of the top 5% most at-risk wall sectors of the Third Fort. Sectors are color-coded by building group.

mend that the methodology proceed as designed to evaluate its usefulness in the long term and to determine if a digital system is necessary at all. The paper forms are archival and can be integrated with a digital infrastructure to visualize the results. Any failure or obsolescence of a digital collection system would render the entire methodology inoperable. That being said, a digital system might promote the accessibility of the collected data to other, similar parks or research groups.

The categories of the RAS form were designed with an inherent risk hierarchy. These weights are visualized on the physical form by the shaded tab located to the right of each category; the darker shade indicating a heavier weight (Figure 2).

- Category "G" pertains to physical geometrics and is the single-most significant metric. It is weighted the most because input from VT structural engineers suggests these factors are most related to the overall risk to a wall.
- Categories "A" and "B" pertain to elevation characteristics, including loss of cross-section, and can indicate possible avenues for catastrophic failure, but do not stand on their own; more information is needed.
- Categories "C" through "F" pertain to surface conditions and the exposure characteristics that can be discerned from them. These categories do not suggest risk of imminent and abrupt structural or catastrophic failure, but point damage from slow, predicted erosional loss.

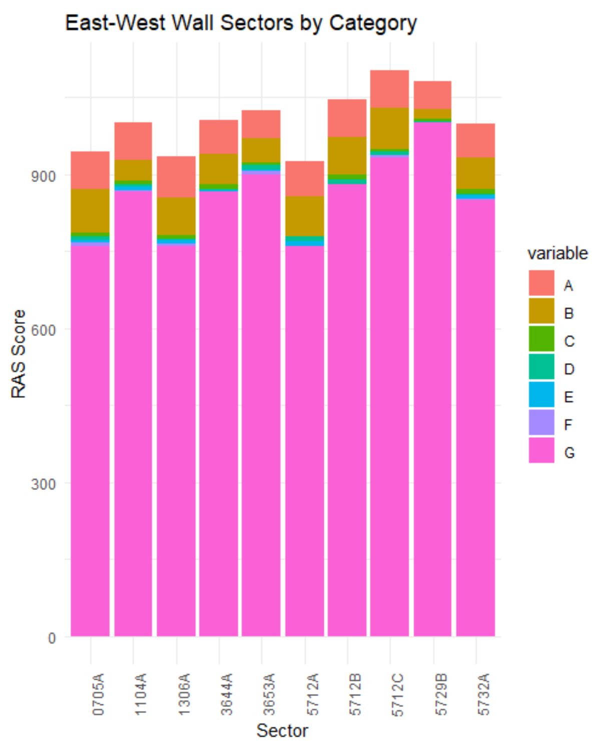


Figure 7- RAS Category breakdown for the top 10 most at-risk, east-west facing wall sectors of the Third Fort.

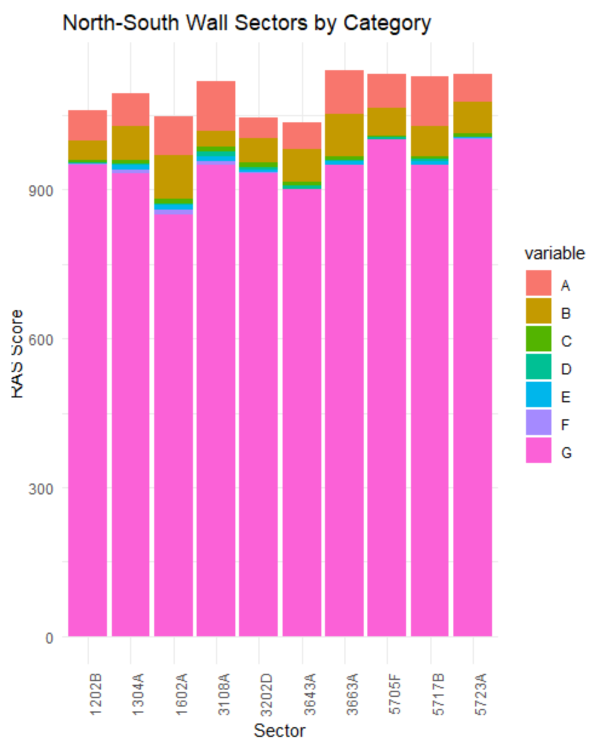


Figure 8- RAS Category breakdown for the top 10 most at-risk, north-south facing wall sectors of the Third Fort.

Results

While the primary objective of the RAS is risk-prioritization based on inherent vulnerabilities, the results should be evaluated in two different and complementary ways, since vulnerability manifests both intrinsically and extrinsically. And these are at the wall sector level and at the wall sector grouping level. Both evaluation methods are significant, and it is recommended that both be considered when implementing the integrated vulnerability assessment methodology.

Figure 9- High risk, high density risk scenarios in the Hospital (HS-57) in the lower right and left corners of the building.

Figure 10- Low to moderate risk, high density wall sectors in the Commissary's Office (HS-31). Wall sector 3108A is one of the top 5% most at-risk wall sectors in the Third Fort.

Figure 11- High risk, low density wall sectors in one of the Officers' Quarters (HS-07). These wall sectors can be seen in Photo 7, to the right.

Figure 12- The sole free-standing adobe wall sectors of Officers' Quarters HS-07.

During the survey process, missing architectural elements (for which specific survey categories applied) were given an "NA" denoting that the element was missing and did not apply. ("NA" is distinct from "0" which indicates that the element is present but is considered a minor or negligible vulnerability to the wall sector.) As a result, wall sectors that did not contain openings or wall edges would naturally score lower than wall sectors that did. For example, a freestanding wall sector without any junctions to adjacent walls can only score a maximum of 25 points instead of 30. The collected survey data, therefore had to be further processed (normalization) to generate the prioritized list of wall sectors by considering scores for each category out of points possible for that category once non-applicable elements were removed.

Normalized and weighted, the results of the RAS follow a normal distribution (Figure 3) overall as well as when separated into north-south and east-west facing wall sectors (Figure 4). This suggests that the RAS form is robust and does not bias any one particular vulnerability category. Furthermore, the RAS confirms many of the observations made by the CAC team and FOUN preservation crew during the survey process regarding the most at-risk wall sectors. The top five-percent most at-risk walls (which represents twenty wall sectors) are spread out across the Third Fort, but are mainly concentrated in the Hospital (HS-57) and Mechanics Corral (HS-36) (Figures 5 & 6). A principal contributing factor to this localization is the presence of above-average height walls in these two buildings. Height is a component of category “G,” which receives the heaviest weight factor due to the unanimity regarding its impact on overall wall vulnerability.

North-south facing wall sectors are generally at higher risk than east-west facing wall sectors (Figures 7 & 8), most likely due to increased moisture differential present across a wall with that orientation. Southern elevations, when exposed to wind-driven rain and basal snow drifts, will dry much more regularly and rapidly than northern elevations with comparable moisture deposition, since north elevations receiving little drying effect from solar gain (and often none for tall walls which cast long shadows to the north). This is exacerbated by aerodynamic and solar shading from adjacent walls (described in detail in earlier phase technical reports). It is important to note, however, that not only do north-south walls score higher overall, the contribution of category “G” is consistently elevated (above 900), suggesting that north-south facing wall sectors are structurally more vulnerable, while east-west facing wall sectors are more susceptible to exposure-related vulnerability.

A critical aspect not possible to characterize at the wall sector scale through quantitative evaluation involves the risk that walls place on each other--at the wall sector grouping level. How likely is a wall sector to fail? If it fails, what surrounding area—or “effective risk zone” (see glossary)— is impacted? And what other wall sectors are in that affected area? This aspect is characterized in one of four risk scenarios that are a function of individual RAS score, wall height and wall density.

- High-risk/low-density
- High-risk/high-density
- Moderate-risk/high-density
- Moderate-risk/low-density

The most catastrophic of the four risk scenarios is high-risk/high-density where a significant portion of standing walls exhibit moderate to severe risk, are at or near full height, and are surrounded by similar walls in close proximity. This scenario is best found in the southwest and southeast corners of the Hospital (HS-57), where most of the original walls are intact and full height. Given the layout of the building in plan, these walls are placed within close proximity to one another, where each wall is in the effective risk zone of its neighbor. In Figure 9, the effective risk zones extend significantly beyond the immediate locations of individual wall sectors (indicated by areas of red). It is in these two locations where there are clusters of tall, high-risk walls that are in proximity of one another (indicated by dots of red).

The next most threatening scenario is moderate risk/high density which emphasizes the compounding effect of risk and spatial density. In Figure 10 we see that wall sector 3108A (called out) is one of the top five percent most at-risk walls; however, two highlighted risk zones on the west side of the building are comprised of a high density of tall walls of much lower-risk. While 3108A is a high-risk wall, it is not a full height wall and is isolated from surrounding walls.

High-risk/low-density, is prevalent across the Third Fort and exemplified by 3108A in Figure 10. These wall sectors are a risk to themselves only, but by no means are they less significant. This condition is associated with tall, free-standing wall sectors, typically attached to fired masonry architectural elements like fireplaces and fireboxes which provide structural support. While not an immediate danger to other wall sectors, these examples emphasize the last critical consideration of the Integrated Vulnerability Assessment methodology that is difficult to capture quantitatively: architectural or visual integrity. While not a vulnerability, and thus difficult to factor into the quantitative assessment of risk, visual integrity is the critical aspect to interpretation on a site like FOUN. Consequently, free-standing adobe ruins that are often characterized by this risk scenario (Figure 11), are in many cases the least visual architectural elements of the building to which they once belonged (Figure 12) and thus are exposed to a different interpretation of risk than discussed above.

Additionally, the categories of the RAS form were designed in such a way that the results could be viewed as a composite or individually, revealing potential underlying correlations. This is demonstrated in Appendix D for the Mechanics' Corral, where each of the result categories are displayed individually, compared to the composite score. It is recommended that during the analysis of RAS data this approach be taken. As has been discussed above, given the unique and uncertain nature of vulnerability and risk analysis, absolutes should be avoided, and the findings should be viewed from several relevant perspectives to learn as much as possible about the underlying nature of the system.

WALL PROFILOMETRY

Overview

An early comparative study was made between four data acquisition methods that provide wall profile information on a site as large and complex as FOUN:

- Laser scanning
- Terrestrial LiDAR
- Digital photogrammetry
- Analog profilometry

The wall profilometry tool developed and implemented by the CAC, effectively validates the RAS results providing just the right amount of data and resolution at the exact location needed in a cost-effective way requiring limited technical knowledge. While a portion of the RAS (category G) is dedicated to geometrics, several field-tests during Phases II-III proved that it can be difficult to differentiate wall lean from loss when evaluating the 'attitude' of a wall. A corresponding pair of wall profiles can quickly and efficiently provide height to width ratios, weight distribution, and eccentricity. Combined with deductions made about exposure, active and latent deterioration, and movement we can begin to synthesize all the predetermined vulnerability factors into a collective snapshot of a wall's risk.

Additionally, the results of the profilometry survey can be used to validate the RAS by prioritizing walls solely on their attitudinal or geometric configuration (reduced cross-section, leaning, etc.). This process will be discussed with greater detail later in this report.

Figure 13- CAC team members carrying out wall profile survey during the summer of 2019. Within this wall segment, the most visibly compromised location was chosen for the profile, where there is a noticeable shift in planarity between the two window openings.

Objectives and Methodology:

- To evaluate the efficacy of the methodology in the field and at scale
- To attempt to identify possible surface deterioration typologies
- To use the data collected to validate the findings of the RAS prioritization.
- To create a prioritized list of most at risk values to collapse

Design

The profile gauge utilized during the summer 2019 survey has been lengthened from 8'-0" to approximately 12' from earlier designs. The hinges between wooden segments have been replaced with lap joints to ensure stability. A circular bubble rod level has been added to replace the mast level which will reduce both the potential for error and the time in the field to complete one profile.

The profile gauge was designed to be compact and portable. The wooden components have lap joints which can be fastened with bolts into a secure single member. The pins are also fully removable, and threaded keys at each point permit locking in place when in use. Fabrication and assembly details can be found in Appendix E, and a detailed profile survey protocol using the profile gauge can be found in Appendix F.

Implementation

Results of the wall 2019 profilometry survey of the Mechanics' Corral, grouped by orientation.

Figure 14- East-facing wall sectors.

Figure 15- West-facing wall sectors.

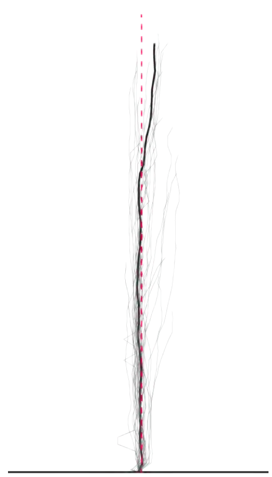


Figure 16- North-facing wall sectors.

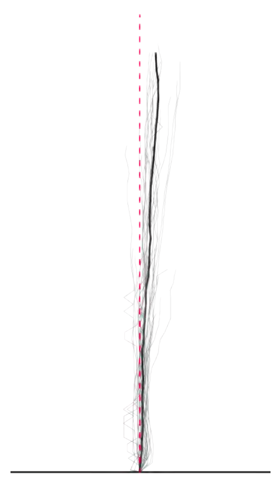


Figure 17- South-facing wall sectors..

During the summer of 2019 both the RAS and the wall profilometry tool were field-tested on the Mechanics Corral (HS-36), evaluating their intended performance in situ and in tandem. For both systems, a digital plan base drawing was required to first establish the division of wall segments and sectors (See Glossary). The CAC team initially used the HABS base drawing and wall sector division map to identify profile locations.

As the primary objective of the wall profilometry data is to quantitatively validate the qualitative findings of the RAS, it was critical to simplify the resultant data. To do this, the CAC team selected worst-case scenario locations within a wall sector to record a profile (Figure 13). While the recorded data is quantitative in nature, only expert judgment could be used to select the location: areas of relative extreme eccentricity (e.g., leaning, inflection points in a segment, and bending) or diminished cross-section (e.g., visible basal erosion, wasting, and coving) were of highest significance.

The profilometry assessment is entirely analog in nature and is essentially a large profile comb (see appendix E). Collected data was digitized and analyzed using Microsoft Excel (or similar software). Some work is needed to pre-process the recorded data, primarily to ensure that profiles are comparable, and all begin at the same datum point (the top of the stone foundation). Once in digital tabular format, a script can be used to import the delimited file into AutoCAD, producing a line drawing of the corresponding profile. It should be noted, that while having a visual representation of a profile is helpful, it is not ultimately necessary as part of the proposed methodology, and is only being used here for purposes of demonstration in this report.

63 wall profile pairs of the Mechanics' Corral were created, and the data was evaluated from two perspectives: surface topology and cross-section.

Results of the wall 2019 profilometry survey of the Mechanics' Corral, grouped by contextual condition.

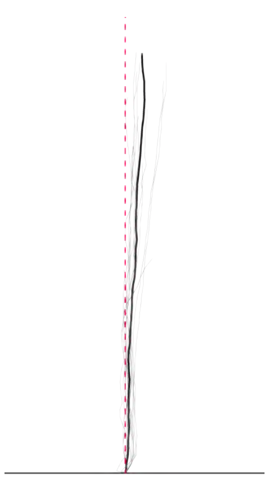


Figure 18- Historically exposed.

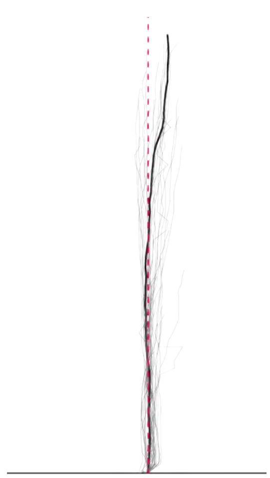


Figure 19- Historically unexposed.

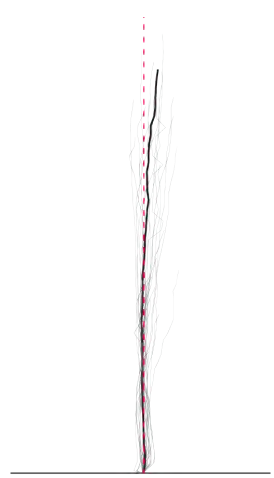


Figure 20- Presently protected.

Figure 21- Presently unprotected.

Results

Data, filtered by wall face orientation (Figure 14 - Figure 17) reveal subtle deterioration patterns related to environmental exposure such as solar gain, and prevailing storms (wind, rain, snow, debris, etc.).

A general wasting, or coving trend, biases the middle and upper thirds of west facing wall sectors (Figure 15). This phenomenon, related to differential weathering of soil-cement wall caps, causes water to gradually erode the wall surface directly below it. Depending on the condition on the obverse wall face, and the characteristics of the cross-section, extreme cases can generate top-heavy eccentric loading leading to collapse of the upper portions of a wall. (See Conditions Glossary, Appendix B).

East facing walls (Figure 14) display a wider range of loss severity, possibly caused by differential influence of environmental factors such as early morning, low angle, solar gain during winter months, exacerbating freeze-thaw conditions.

South (Figure 17) and east (Figure 14) facing wall sectors display greater variation of surface typologies compared to their composite averages. This would suggest that there are additional contributing variables to wall surface deterioration beyond orientation. The recorded profilometry data was also evaluated through a second lens to begin to account for micro-cli-

Figure 22- A photo of wall sector 3629-A illustrating the distinctive coving deterioration pattern in the top third of the elevation. Wall sector 3629-A is east facing, historically exposed, and presently unprotected.

matic and contextual factors affecting the wall sectors.

The wall sector profiles were classified into four additional evaluation categories (Figures 18-21), using current and historic environmental exposure and architectural protection . Qualitatively, we can see that there is limited variation or anomalies within each category indicating a robust classification. The resulting data confirm that East-facing walls of the Mechanics' Corral were, and still are, exposed to environmental conditions such as prevailing storm patterns, dominant winds across the plains to the east, and direct early-morning solar gain. Interior walls of the Mechanics' Corral, however, have been (and many still are) protected by adjacent or adjoining walls, presenting a different solar exposure pattern, as well as different wind profile due to aerodynamic shading. Thus, within the predominant environment of a single architectural block, determined largely by the primary climate and weather patterns of the site and region, there are a number of unique environmental micro-climates which drive the behavior of a particular wall sector(s).

For historically exposed walls, a generalized erosion pattern exists in the upper third of the wall sector where wind velocities would be greatest (Figure 18). Many historically unexposed wall sectors, however, have become exposed, explaining the similarity between the two categories (Figure 19, Figure 21). In both categories, the surface displays localized loss in the uppermost portion of the top third of the wall which would be directly below the wall cap. This 'coving' pattern suggests that soil-amended caps perform as designed yet cause differential erosion patterns directly below them. This can lead to dangerous top-heavy upper wall sections.

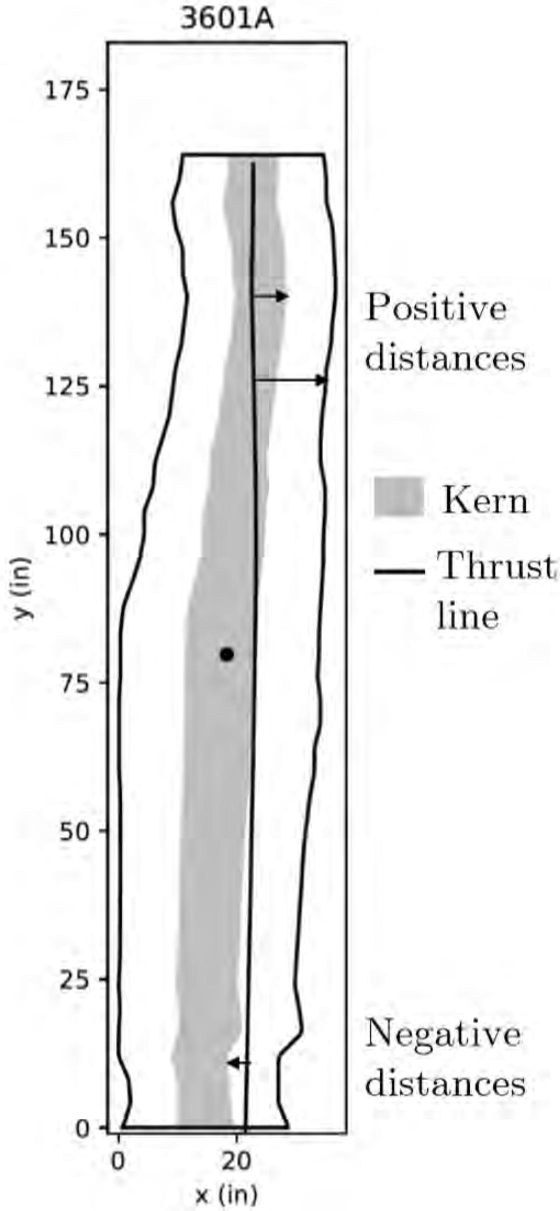


Figure 23- This diagram illustrates the geometric components of a sample wall section, derived from a pair of wall profiles, used to perform geometric structural analysis. The kern is defined as a zone around the centroid (black dot) of the section within which an eccentric force (black arrows) will not cause tension on the section. (Analysis by W. Reinhart and R. Napolitano, See Appendix G)

Additionally, to validate the results of the RAS prioritization efforts, an independent structural analysis of the profile data collected during the summer of 2019 was performed by a party not involved with the ongoing RAS efforts (to isolate biases). The 2019 profile data set is limited to the walls of the Mechanics' Corral as it was the pre-established pilot area from Phases I - III. The individual profile analysis for each sector of the Mechanics' Corral can be found in Appendix H.

The premise behind the independent validation is primarily to evaluate if the same prioritization of wall sectors provided by the RAS results could be achieved from a purely geometric perspective. Prioritization in this way would involve utilizing only the cross-section geometrics (center of gravity, kern, etc.) of a wall sector. The foundation for this analysis is the calculation of the "kern" for a cross-section (see glossary). The full explanation of these terms and the processes used in this analysis can be found in the independent structural report in Appendix G. In short, the digitized tabular format of the wall profiles provides for an efficient and rapid implementation of basic, yet accurate and telling, structural calculations.

Ultimately, of the four wall sectors which ranked among the top 5% most-at risk walls of the entire Third Fort, the independent structural analysis of the profilometry data correlated with the

Figure 24- This figure depicts the Mechanics' Corral and the results of the wall profilometry structural analysis. Of the top 5% most at-risk walls across the entire Third Fort, four are located in the Mechanics' Corral and are highlighted with leaders. The "inches to kern" metric used for this illustration is an indication of how out of plane a wall section is, and the details of this term and the methodology used to calculate it can be found in Appendix G.

RAS results. Unfortunately, wall sector 3663A was not profiled due to its prohibitive geometry and could not be correlated. Wall sectors 3644A, 3653A, and 3643A all exhibited three or more "inches to kern," a metric which indicates that areas within the cross-section may be subject to dangerous tensile stresses. It should be noted that the structural calculations were performed under "dead load" conditions only, meaning no outside forces were imparted, such as wind; the forces acknowledged were imparted only by the weight of the wall cross-section itself. It should also be noted that to prioritize these wall sectors using the profilometry data alone, the worst case scenarios were used (meaning the highest "inches-to-kern" value for the entire height of the cross-section).

It is clear that there are, in fact, other examples within the Mechanics' Corral which were deemed more at-risk, from a geometric perspective (denoted by red dots in the graphic below). This observation emphasizes the inconclusiveness of either approach. The RAS method, as a pseudo-qualitative technique, is not capable of the quantitative structural analysis made possible with the availability of the wall profilometry data. This being said, the purely geometric wall profilometry analysis cannot provide the depth of risk evaluation made possible by the documentation of several unique vulnerability factors present for each sector. As will be elaborated on in the recommendations section of this report, these two methods are complementary. Each enhances the knowledge gained from the other.

EMBEDDED MONITORING

Overview

The primary objective of the embedded monitoring system was to integrate seamlessly with ongoing maintenance operations. The proposed system uses on-demand data acquisition, replacing an active data logging system that requires external power, the resources necessary to maintain the system, and commitment to process and evaluate the recorded data. The sensing elements are:

- Small, thin
- Low-cost
- Sacrificial
- Minimally invasive
- Need only the power provided to it wirelessly by the handheld RFID reader
- Intended to remain in the wall for the lifetime of the wall
- Requires no wires, cases, stands, or additional infrastructure

During the reading process, information about the moisture content of the material surrounding the RFID tag can be calculated. Because the readings are made indirectly (wirelessly), this method avoids many of the issues related to approaches requiring direct contact between

Figure 25- The pilot data-logging system in the "weather-proof" enclosure after several seasons of continuous use and exposure. Despite efforts to weather seal the enclosure, standing water and condensation were still observed causing much of the system to malfunction.

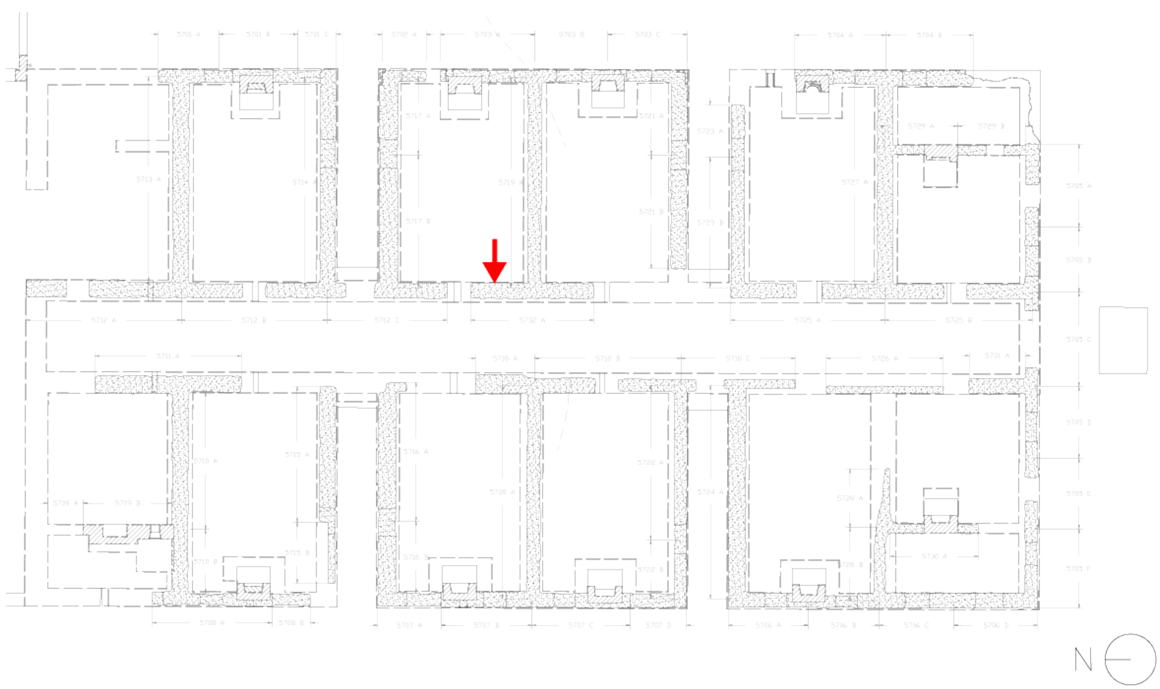


Figure 26- The red arrow indicates the location of wall sector 5732A of the Hospital (HS-57) and the location of the pilot embedded passive RFID moisture tags installed during the summer of 2019.

Figure 27- 10 passive RFID tags were installed on the east face of wall sector 5732A. The tags were spaced 12" apart, beginning from the top of the stone foundation. This, and other walls of the hospital, were re-coated later in the summer of 2019.

Figure 28- To install the passive RFID moisture tags non-conductive nylon drywall anchors (3/8" diameter) were used to attach the pre-laminated tags to the adobe substrate. This method was applied with minimal damage to the fabric while also ensuring positive affixation and the durability of the tags over many future shelter coat campaigns.

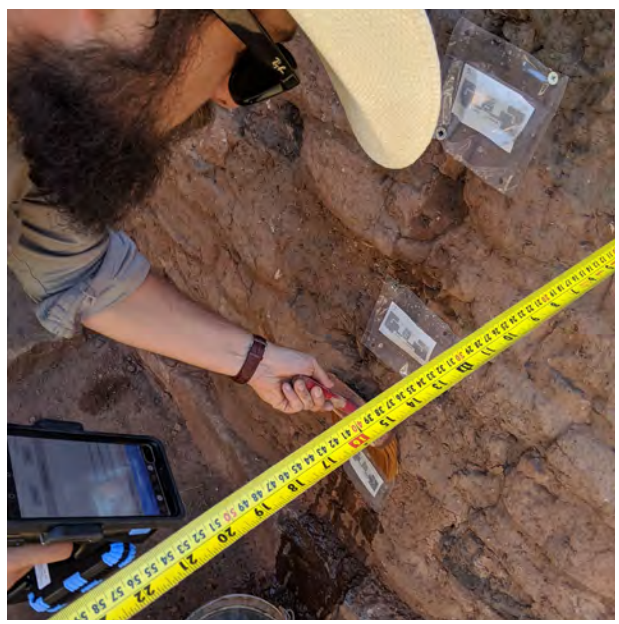


Figure 29- In Situ wetting test of the un-sheltered RFID tags installed at the Hospital. This was done to ensure that the tags were functioning properly before the new shelter coat was applied. Once embedded, members of the CAC team returned to perform a second test, the results of which are in the table below. The handheld RFID reader is visible on the bottom left.

the probe and the material. An effective monitoring network integrates with ongoing maintenance with as few logistical interruptions as possible. The need to remove shelter coats, embed costly sensors, re-apply shelter coats, and then reverse the process in the future when the sensors fail, etc. was simply not feasible.

Design

Active embedded moisture and temperature monitoring, a deterministic approach which requires a data dragnet for post-processing, was discontinued during the final phase of work at FOUN due to a range of factors:

- The size of the site
- The number of wall sectors
- The complexity of micro-climates in and around the standing ruins
- The cost and quasi- destructive nature of directly embedded sensors

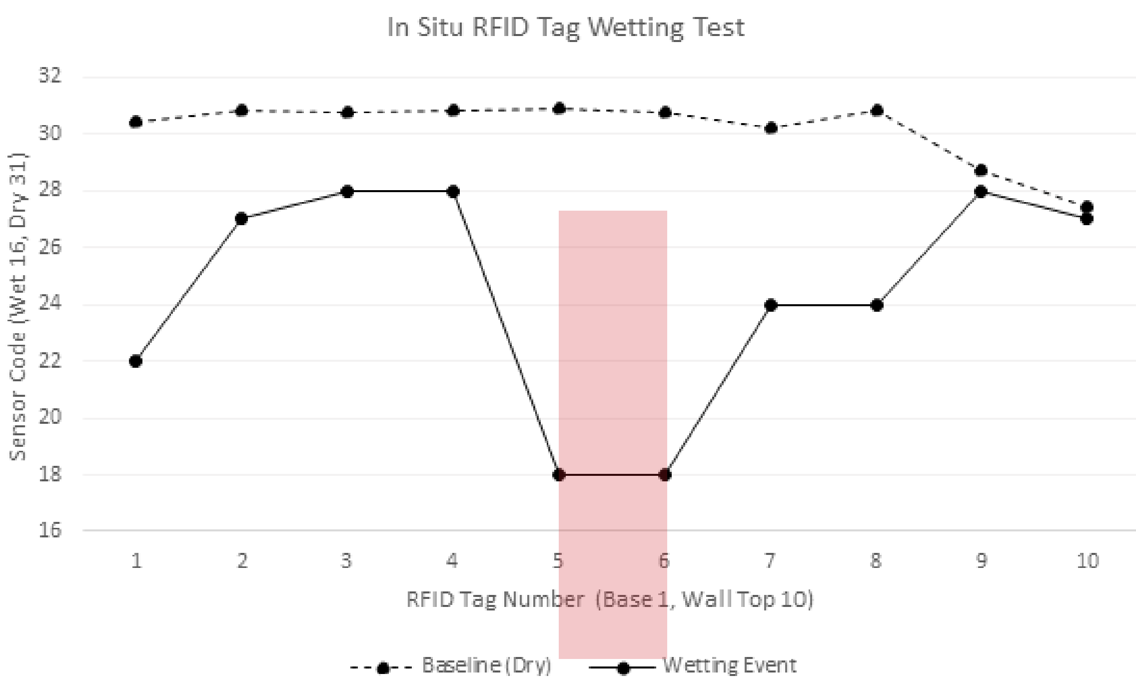


Figure 30- Preliminary results of the embedded RFID moisture monitoring network installed in the hospital, after the new shelter coat had been applied. Tag 1 is at the base of the wall, 11 at the top. The area highlighted in red indicates the tags to which water was applied. This parallels a noticeable reduction in the tag reading (corresponding to increased moisture) compared to the dry, baseline test.

The system as designed, focused specifically on the wall cap as the single most vulnerable and critical aspect of the standing adobe walls. The tags are not capable of quantifying moisture content but can detect its presence. From this data, when paired with the strategic location of the tag (e.g., under a wall cap), conclusions can be made regarding the fitness of that system (e.g., failed wall cap).

While tags beneath the shelter coat are helpful in identifying areas where liquid moisture has penetrated, the results may be misleading as these areas of a wall are intended to be saturated. Since the shelters are only partially amended with Rhoplex E-330 and therefore only slightly more moisture resistant, moisture detected simply validates that the shelter coats are functioning as intended. In the future, tags should be embedded below new wall top caps, which are slated for replacement. Moisture detected at these locations, possibly below a moisture barrier coping layer, would indicate a failure in the capping system and subsequent elevated risk associated with catastrophic failure from liquid moisture saturating the walls from the inside out.

The full, in-depth design specifications of the RFID system are found in Appendix J.

Implementation

During the summer of 2019, the CAC took advantage of an opportunity to embed RFID tags when the shelter coat of a wall of the Hospital (HS-57) had been removed to allow for repair . In addition, wall construction and previous treatments were documented before the shelter coat was reapplied over the tags. Ten tags were installed on the east face of wall sector 5732A directly to the adobe masonry substrate (Figures 26 & 27). From the top of the stone foundation, the tags were spaced evenly approximately 12" apart. The tags were affixed to the adobe substrate using nylon drywall anchors to avoid using metal of any kind that would interfere with the reception capability of the tag antenna (Figure 28).

Prior to the application of the amended shelter coat, the tags were tested to ensure they were functioning properly (Figure 29) and once the coat had been reapplied the embedded tags were tested again. It was necessary to first establish a dry, embedded baseline against which to compare subsequent readings, the "dry baseline" referring to the non-saturated, steady-state condition of the shelter coat at equilibrium moisture content or EMC (see glossary).

The success of the RFID system was evaluated from two perspectives, implementation feasibility and technical efficacy. The preliminary results gathered from the pilot in situ implementation indicate that the technique was successful overall as an alternative to active embedded monitoring techniques and the results of the embedded system used during phases II and III suggest that this level of resolution was not necessary to begin with.

Results

The preliminary results gathered from the pilot in situ implementation of the passive embedded RFID moisture monitoring network indicate that the technique was successful overall as an alternative to active embedded monitoring techniques at FOUN. Success was evaluated from two perspectives: implementation feasibility and technical efficacy.

It must be emphasized that the RFID system is not a monitoring tool as much as it is a diagnostic one, and that it supplements, rather than replaces other, more robust scientific monitoring techniques. Only when paired with a fundamental understanding of the wall failure mechanisms unique to Fort Union can such a tool be used. By identifying the wall cap as the single most vulnerable and critical aspect of the adobe wall system at FOUN, the CAC team was able to design a monitoring system which focused specifically on this aspect. The result is a system that is efficient in its design, with respect to both infrastructure and data collected. Only a single variable is recorded, presence of moisture; when paired with the strategic location of the tag (e.g., under a wall cap) conclusions can be made to the fitness of that system (e.g., failed wall cap). The tags are not capable of quantifying moisture content, as an industry standard resistance moisture meter might be capable of doing, only identifying its presence; however, results of monitoring efforts during phases II and III suggested that, in fact, this level of resolution was not necessary at FOUN.

Several in situ wetting tests were performed both before and after the tags had been encapsulated in a new amended shelter coat layer. Once the coat had been reapplied by the FOUN preservation crew, members of the CAC team returned to evaluate the tags' embedded performance. It was necessary to first establish a dry, embedded baseline against which to compare subsequent readings against. It is important to note that the baseline "dry" condition in this application refers to the non-saturated, yet steady-state condition of the shelter coat at equilibrium moisture content (EMC, see glossary) in that environment. Results from the embedded test indicate that the RFID network performed as intended and was able to accurately and repeatedly detect a surface wetting event (Figure 30).

Recommendations

Before recommending a critical path to intervention, the prioritized list of wall sectors from the RAS must be divided into action categories (low, medium, and high risk) based upon available resources. These terms are ambiguous by design, and the actual apportionment will vary from year to year. The intent is to replace the current strategy of generalized maintenance and ad-hoc stabilization which effectively treats all wall sectors as equal except for the very visible worst cases where intervention is deemed necessary.

All walls are not the same and should not be treated as such. Low-risk wall sectors that exhibit no active deterioration or exposure-related weathering, of which there are many, do not need to be shelter-coated that season, for instance. The resources (time, money, materials, and manpower) saved can be applied to those most at risk wall sectors. To the remainder is applied the 'business as usual' maintenance strategy of shelter-coating.

For the most at-risk walls identified, an additional level of field-evaluation is recommended to:
1. Validate the findings of the survey on-site by a team of three or more people, representing site personnel knowledgeable in maintenance, repair, and stabilization;
2. Apply the wall profilometry methodology to verify surface loss and wall lean characteristics; and,
3. Identify the immediacy of the risk present based on the condition of the wall sector as well as those adjacent to it.

Evidence-Based Conservation Recommendations

Depending on the amount of resources available, hopefully reallocated from the postponing of standard maintenance on low-risk walls on the site, a consensus agreement by the team must be made as to which of these most at-risk wall sectors face imminent risk of catastrophic failure. These walls receive immediate temporary bracing and covering (to prevent ingress of rain or wind-driven moisture). Additionally, the results of the RAS and field-evaluation (including wall profilometry and cross-sectional data for structural analysis) can be used to request consultation by field experts, such as engineers, environmental diagnostic consultants, and adobe wall repair specialists, to develop permanent, targeted interventions.

For those wall sectors which do not represent an immediate risk of collapse, and are thus stable enough for repair, targeted stabilization is recommended. This begins with before-and-after photo documentation using a standardized procedure (such as the CAC photo-kits developed and implemented during Phases I and II). This is to establish a baseline photo record of the wall sector's surface and subsurface conditions. In many cases, the specific construction details or location and characterization of specific past repairs are not known and are critical to its stabilization.

Next, implied in this step is the full removal of shelter coat. Not only does this reveal the original masonry below for documentation and repair, but it allows the opportunity to reapply the shelter to a nominal and uniform thickness. In most cases around the Third Fort, the amended shelter coat system currently on the walls exceeds well beyond recommended thickness <

1/2". This can be observed during or following heavy rain events where the shelter coat on the undersides of protruding wall surface features will fail in tension and slough off due to the increased thickness and weight. This method is referred to as a 'perfect barrier,' one that is durable, sacrificial, and effective until it is compromised. An excessively thick shelter coat that has been breached, allowing liquid moisture to penetrate directly and deeply into the adobe masonry, impedes the ability of a wall to naturally dry to the ambient environment. As moisture drains to the base of the wall, adobes there can become saturated and lose their compressive strength, leading to catastrophic failure.

It is recommended that as part of the stabilization process the existing wall caps be evaluated and replaced as needed. These caps, designed by Bob Hartzler, have exceeded their intended operation lifespan and many have begun to exhibit signs of severe deterioration or total loss. This may mean simply installing new caps to the same specification. A loss or breach of a cap has been identified by the CAC team as the most critical vulnerability to a wall sector resulting in water penetration and partial or total collapse, and emphasis on this element must be prioritized. Moving forward, the CAC recommends that the design specification for the shelter coats and wall caps be established by in situ testing.

Lastly, the replacement of shelter coats and wall caps creates the opportunity to integrate passive embedded monitoring to ensure the performance and integrity of these elements over time. As discussed, sacrificial, low-cost, and passive moisture monitoring RFID technology can be used to locate breaches in the wall cap system without the need to install wiring, maintain data-loggers, or process considerable quantitative data.

This new monitoring strategy no longer required the on-site weather station or time-lapse photography system; thus, these elements were removed at the closeout of Phase III. The CAC team, however, did recommend that a networked variant be installed to replace it, one that will connect to the site's new wireless system. The value of standardized micro-climate data at FOUN extends beyond the site itself and can be used to validate regional level climate models used by the Vanishing Treasures Program. This on-the-ground validation step is critical to bridging the gap between regional-level climate-response strategies on site-specific responses to climate-triggered events.

The most at-risk wall sectors are the result of overwhelmingly structural or geometrical concerns. It is intended for the most at-risk walls to receive additional evaluation by field experts and immediate, aggressive stabilization. In this way, in subsequent years of survey, these wall sectors will ultimately move to the bottom of the priority list (otherwise indicating failures in the preservation strategy). Eventually, it is the hope that the relative contribution of category "G" will decrease. It should be noted that, from a structural perspective, the stone foundations were not considered, as the scope of work focused exclusively on the adobe elements; additional, evaluation of the stone foundations, where necessary (such as in the Hospital HS-57), should be carried out to provide an even more comprehensive analysis.

Conclusions

This methodology will allow for the specific identification between different modes of deterioration based on their symptoms as well as their degree and frequency of treatability. Certain treatments, such as the application of shelter coats to reduce surface erosion of the original adobe walls, are preventive in nature, of low impact, and cyclical in application. This mode of treatment does not address other conditions such as deformation or leaning, which require more invasive, remedial interventions that should have greater performance longevity. A "sustainable conservation and management plan for climate-sensitive cultural resources, such as those constructed of earthen materials and maintained as ruins, clearly identifies the type and rate of deterioration, where it occurs, and what interventions are necessary to reduce and/or remove the causes of damage.

Data gathered from the RAS of the Third Fort, particularly with respect to contextual 'aspect' factors such as orientation, exposure, and wall geometry, provide for constructing and validating performance (i.e., deterioration) scenarios that suggest certain combinations of both intrinsic and extrinsic factors, where combined, have an exacerbating effect on both active and inactive deterioration conditions and therefore overall performance. This is the essence of understanding risk and threat and their effect on site vulnerability. The protocol framework provided in this final report can lay the foundation for NPS to develop a long-lived Site Preservation and Management Plan that can respond to the coming needs related to a changing climate and diminishing fiscal reserves.

GLOSSARY

Active monitoring – A monitoring system that requires on-board or external power to provide functionality to both the sensing and data-logging or recording elements.

Effective Risk Zone – The area surrounding a target wall that is influenced by the density of adjacent at-risk walls. This is a function of risk (chance of collapse) and height of adjacent walls.

Equilibrium Moisture Content (EMC) – The equilibrium moisture content is the point at which a hygroscopic material, exposed in part or in full to the air, neither gains nor loses moisture from its environment and has achieved a steady state moisture content.

Kern - The zone around the centroid of a cross-section within which an eccentric force, caused by wind loads or even severely out-of-plane sections, will not induce tension forces any where else in the cross-section.

Passive monitoring –A monitoring system in which only the data-logging or recording element (in the cast of the RFID system, the handheld RFID reader) requires on-board or external power to function. The sensing element does not require external power or interaction to function.

Resilience— The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions. UNISDR, Terminology on Disaster Risk Reduction (Geneva: United Nations International Strategy for Disaster Risk Reduction, 2009), 24.

Risk – The potential for loss, damage or destruction of an asset as a result of a threat exploiting a vulnerability. It is the intersection of assets, threats, and vulnerabilities.

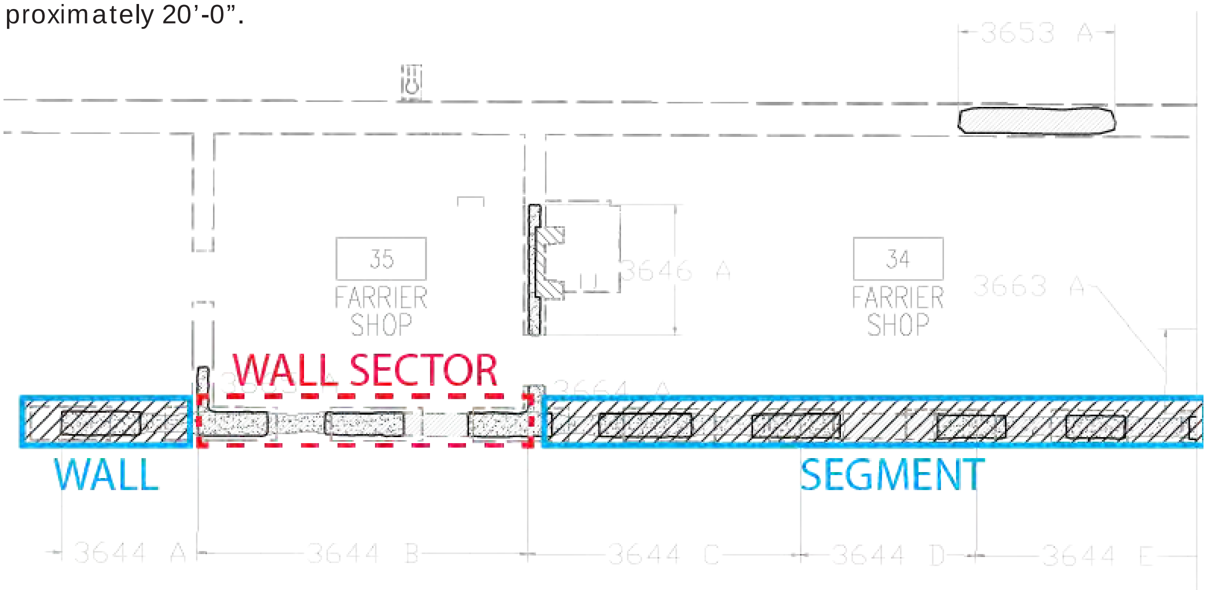
Risk Assessment— A technique used by cultural resource managers to determine the magnitude of risk to a specific resource and analyzes each and all risks affecting it (Waller 1995; Demas 2002).

Threat – That which causes damage or danger to the resource.

Vulnerability— A weakness in our protection efforts. It is the degree to which a system is susceptible to, and unable to cope with adverse effects of climate change, including climate variability and extremes. (IPCC, 2019:699)

Wall Segment – Continuous lengths of a standing adobe ruin greater than 12” in height measured from the top of the existing stone foundation. See diagram below.

Wall Sector – A subdivision of a wall segment for purposes of facilitating the rapid assessment survey (RAS) and ensuring comparability among survey results. In place of rigid quantitative metrics, a series of qualitative architectural rules were established. Visible architectural features, such as wall junctions and openings are used to establish the division. Divisions are never made through structural or load-transferring elements, such as lintels or braces. Where no such elements exist, the length is divided into equal parts where no single subdivision exceeds approximately 20’-0”.



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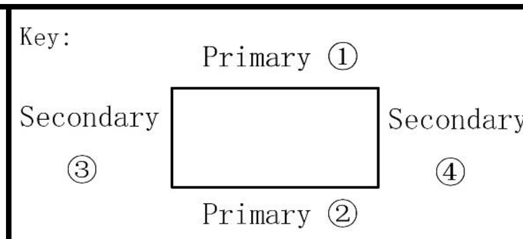
Appendix - A Blank RAS Survey Form

Wall Sector Rapid Assessment Survey

		Condition	0 - 5	Code	
Surface	Elevation 1 N E	Wall Surface loss (top 1/3)		SL	
		Wall Surface loss (middle 1/3)		SL	
		Wall Surface loss (bottom 1/3)		SL	
		Sill Deterioration (below opening to foundation)		WS	
		Elevation 1 Subtotal			a
	Elevation 2 S W	Wall Surface loss (top 1/3)		SL	
		Wall Surface loss (middle 1/3)		SL	
		Wall Surface loss (bottom 1/3)		SL	
		Sill Deterioration (below opening to foundation)		WS	
		Elevation 2 Subtotal			b
	Coat 1	Cracking		CC	
		Loss (exposed masonry)		CL	
		(corresponds to elevation 1 surface) **Shelter Coat 1 Subtotal**			c
	Coat 2	Cracking		CC	
		Loss (exposed masonry)		CL	
		(corresponds to elevation 2 surface) **Shelter Coat 2 Subtotal**			d
	Coat 3 N E	Cracking		CC	
		Loss (exposed masonry)		CL	
		(wall segment edge condition, if applicable) **Shelter Coat 3 Subtotal**			e
	Coat 4 S W	Cracking		CC	
		Loss (exposed masonry)		CL	
		(wall segment edge condition, if applicable) **Shelter Coat 4 Subtotal**			f
Wall Sector	Masonry	Cap Deterioration (Breach = 5)		CP	
		Structural Cracking		SC	
		Cracking at Wall Junction		CJ	
		Out of Plane		OP	
		Lintel Deterioration		LD	
		Height			
		Wall Segment Subtotal			g

Notes:



Date	Wall Sector ID	Summary			
	HS-	g			
		a		b	
		c		d	
		e		f	

APPENDIX - B Illustrated Glossary of Conditions

ILLUSTRATED GLOSSARY OF CONDITIONS

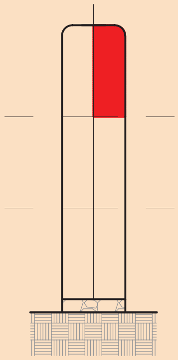
This glossary serves as a visual aid to identify the type and severity of selected conditions of the earthen walls at Fort Union National Monument. Each condition and level of deterioration is identified by diagrammatic drawings, descriptive text, and photographs. The Illustrated Glossary of Conditions is to be used in association with the Rapid Assessment Survey (RAS).







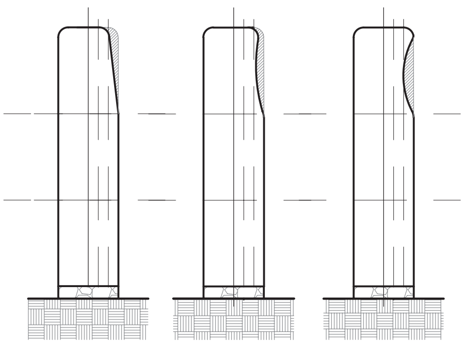




SECTION

WALL SURFACE EROSION
UPPER WALL

Loss of adobe is inferred by comparing the present vertical wall surface to the outer edge of the stone foundation. Erosion is not to be confused with shelter coat loss or an out of plane condition. Three levels of upper wall erosion have been identified. Also known as “coving” and “tapering.”

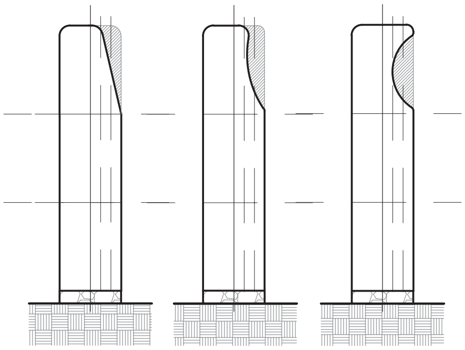


TYPE 1 TYPE 2 TYPE 3

SECTION

LEVEL 1
Roughly 1/3 of half the upper wall section is lost.

Type 1 (Tapering): thickness gradually diminishes upward.
Type 2: thickness gradually diminishes upward in the form of a shallow concavity.
Type 3 (Coving): thickness gradually diminishes in the form of a deep concavity.

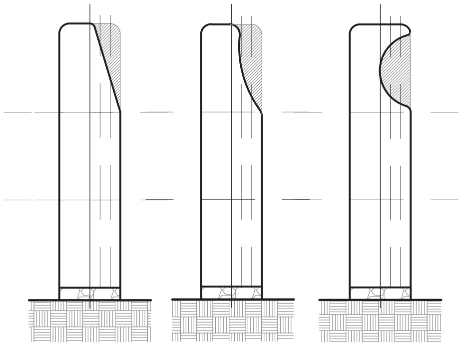


TYPE 1 TYPE 2 TYPE 3

SECTION

LEVEL 3
Roughly 2/3 of half the upper wall section is lost.

Type 1 (Tapering): thickness gradually diminishes upward.
Type 2: thickness gradually diminishes upward in the form of a shallow concavity.
Type 3 (Coving): thickness gradually diminishes in the form of a deep concavity.

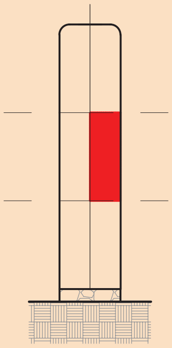


TYPE 1 TYPE 2 TYPE 3

SECTION

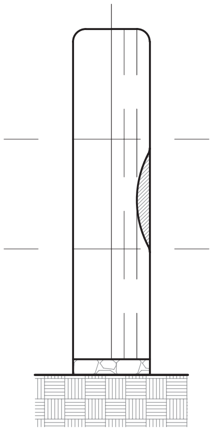
LEVEL 5
More than 2/3 of half the upper wall section is lost.

Type 1 (Tapering): thickness gradually diminishes upward.
Type 2: thickness gradually diminishes upward in the form of a shallow concavity.
Type 3 (Coving): thickness gradually diminishes in the form of a deep concavity.



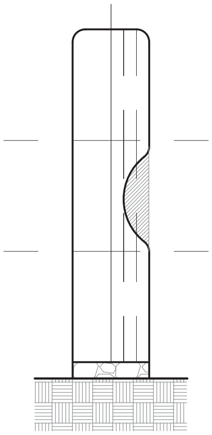
WALL SURFACE EROSION
MIDDLE WALL

Loss of adobe is inferred by comparing the present vertical wall surface to the outer edge of the stone foundation. Also known as "wasting."



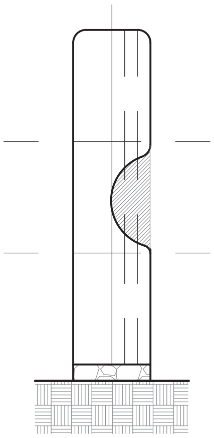
LEVEL 1

Less than 1/3 of half the mid wall section is lost.



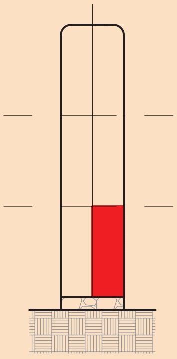
LEVEL 3

Loss of roughly one wythe, or between 1/3 and 2/3 of half of the wall section is lost.



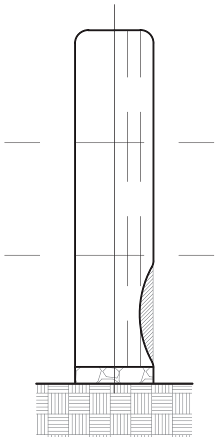
LEVEL 5

Loss of roughly two wythes or more than 2/3 of half the wall section is lost.



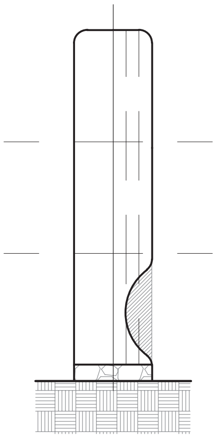
WALL SURFACE EROSION
LOWER WALL

Loss of adobe is inferred by comparing the present vertical wall surface to the outer edge of the stone foundation. Also known as "basal erosion."



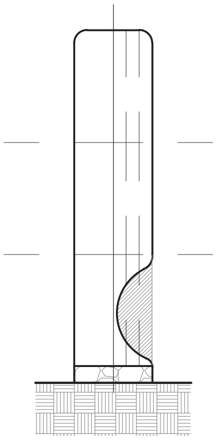
LEVEL 1

Approximately 1/3 of the lower wall face is lost, usually in the form of a concavity.



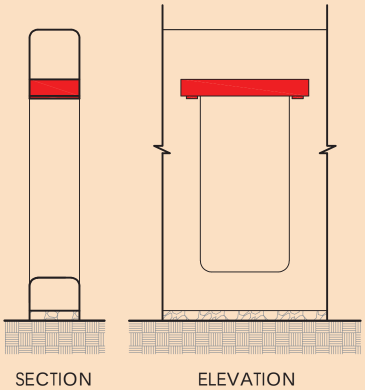
LEVEL 3

Approximately one wythe or 2/3 of the lower wall face is lost, usually in the form of a concavity.



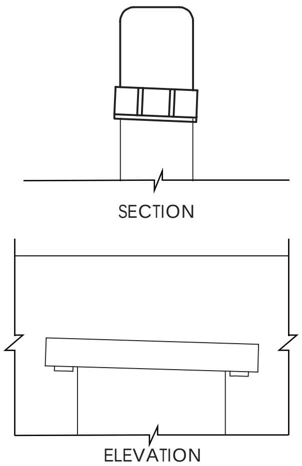
LEVEL 5

Approximately two wythes or more than 2/3 of the lower wall face is lost, usually in th form of a concavity.



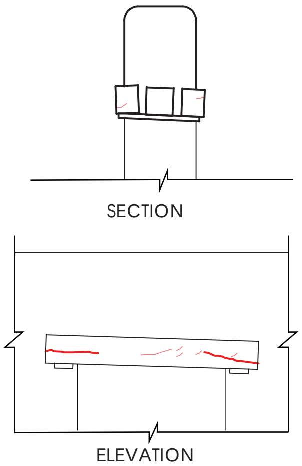
LINTEL DETERIORIORATION

Any condition that might affect the stability of the span over an opening: either a door or window. This includes: rotation, sagging, slipping, projecting, or loss of wooden elements; rot of wooden elements; or structural cracks on the adobe surrounding the lintel.



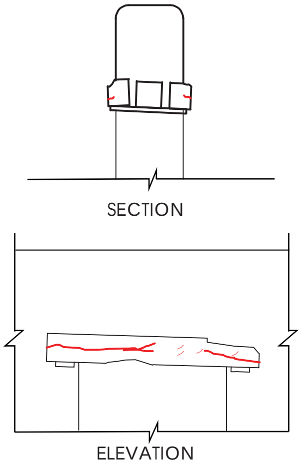
LEVEL 1

The wooden lintel components are slightly out of horizontal or vertical plane or bending; or the surrounding adobe exhibits some signs of differential loss.



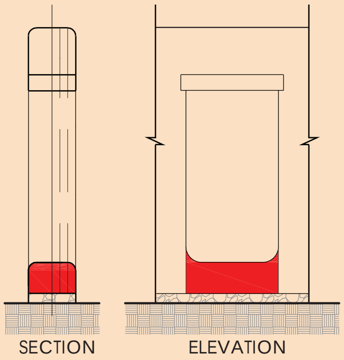
LEVEL 3

The wooden lintel components are out of plane, shows some cracking, and/or displacement. The surrounding adobe exhibits signs of structural distress and differential loss.



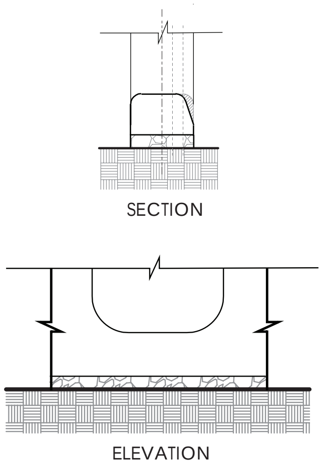
LEVEL 5

Hairline and wide cracks are visible. The structural capacity of the lintel is significantly diminished due to loss of surrounding adobe and/or wooden elements and these components are seriously in threat of collapsing.



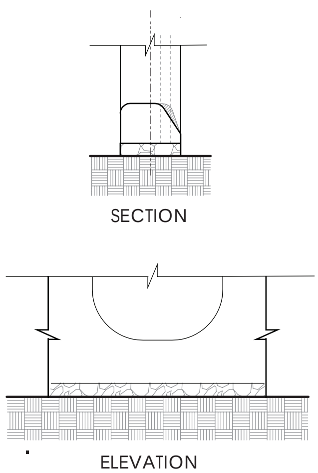
SILL DETERIORATION

The deterioration of a window sill can be inferred by the rounding of the sill, as seen in elevation, and/or the loss of sill material by comparing the present faces to the edges of the stone foundation as seen in section.



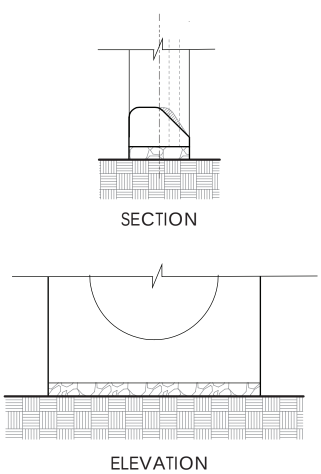
LEVEL 1

Approximately 1/3 of the sill has slightly diminished in shape, either in elevation or section. The corners are rounded, but the sill maintains a similar profile to the original squared corners.



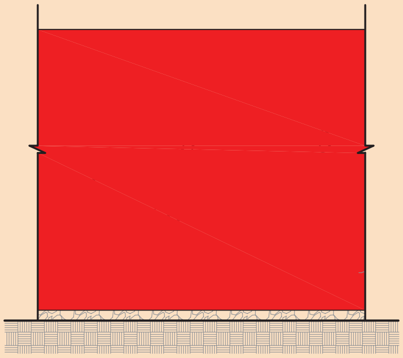
LEVEL 3

The sill has deformed to a semi-rounded shape in elevation. In section, erosion has extended to approximately two-thirds of half of the wall section.



LEVEL 5

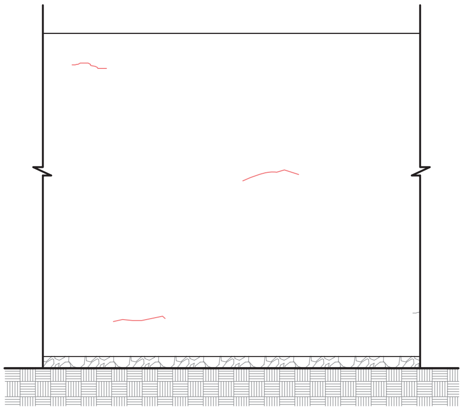
The sill has completely lost its shape in elevation and erosion has extended to half of the wall section.



ELEVATION

SHELTER COAT CRACKING

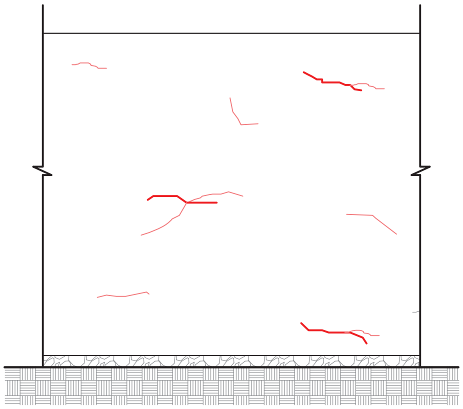
Weathering of the shelter coat in the form of hairline cracks, wide cracks, and network cracks. Extensive shelter coat cracks are often accompanied by shelter coat loss but are not to be confused with deep structural cracks.



ELEVATION

LEVEL 1

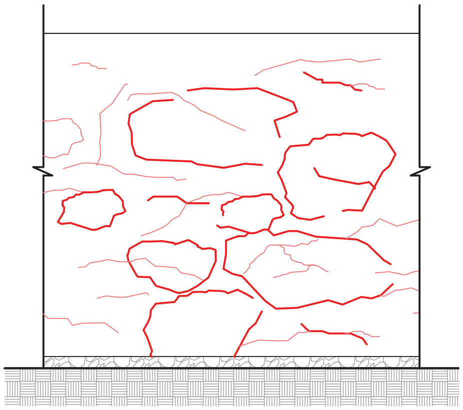
The surface of the shelter coat displays few to multiple hairline cracks. The shelter coat is still able to protect most of the adobe masonry from water intrusion.



ELEVATION

LEVEL 3

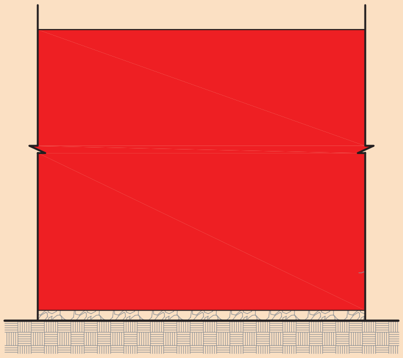
The surface of the shelter coat displays several hairline cracks and a few wide cracks. It is questionable as to whether the shelter coat is effectively protecting the adobe masonry from water intrusion.



ELEVATION

LEVEL 5

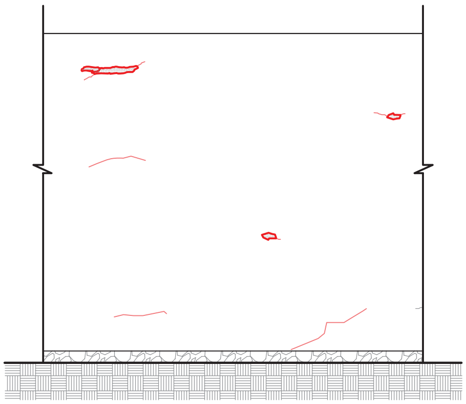
The shelter coat displays extensive cracks, both wide and hairline, mostly forming crack networks with or without associated detachment. These cracks are likely paired with shelter coat loss. The shelter coat is not effectively protecting the adobe masonry and is allowing water intrusion.



ELEVATION

SHELTER COAT LOSS

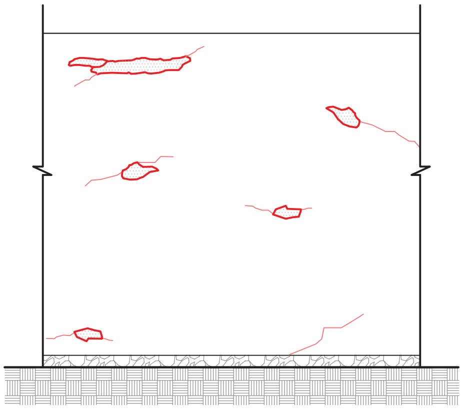
Total loss of the shelter coat which has exposed the underlying adobe allowing water to intrude into the adobe wall. In order to be considered shelter coat loss, there must at least be signs of Level 1 shelter coat cracks.



ELEVATION

LEVEL 1

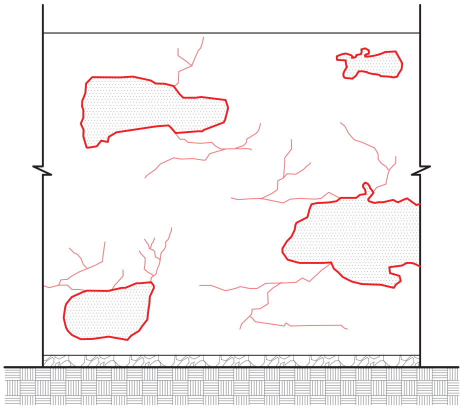
The surface of the shelter coat exhibits a few small areas of loss but is generally intact. This loss is paired with some hairline cracks.



ELEVATION

LEVEL 3

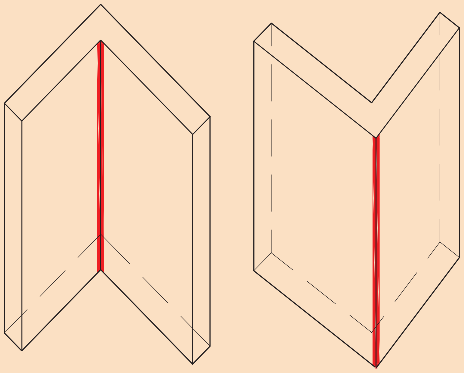
The surface of the shelter coat exhibits several moderately-sized areas of loss and is not effectively protecting the adobe wall from water intrusion.



ELEVATION

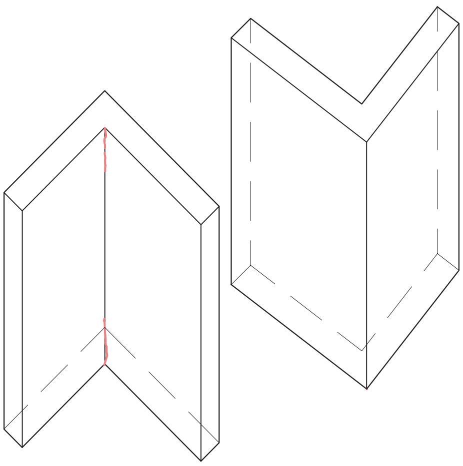
LEVEL 5

The shelter coat exhibits several extensive areas of material loss. This loss is paired with both hairline and extensive cracks forming networks that surround the shelter coat loss.



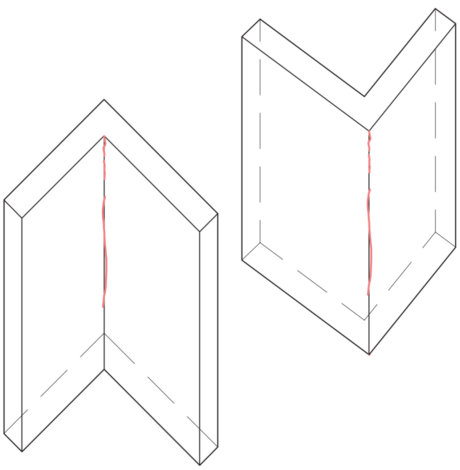
CRACKING AT WALL JUNCTION

Cracks that extend vertically near or at wall intersections in the form of hairline cracks, wide cracks, and separation. These cracks indicate the separation or independent movement of the wall units which is cause for concern.



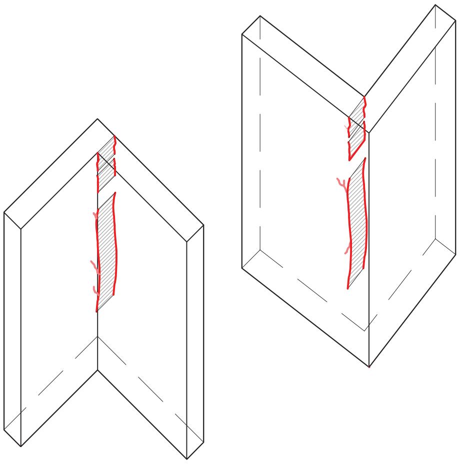
LEVEL 1

Hairline crack(s) evident on one side of the wall intersection. These cracks can be found on any height of the whole wall.



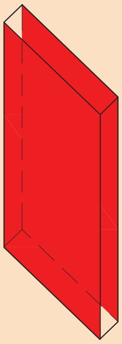
LEVEL 3

Hairline crack(s) evident on both sides of the wall intersection.



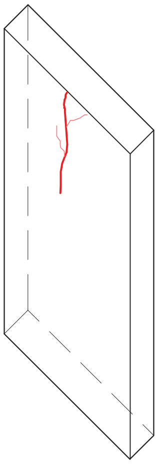
LEVEL 5

Wide cracks are evident and connect on both sides of wall intersection. This severity of a wall junction crack is usually paired with wall separation and displacement. This cracking may also be identified as a structural crack.



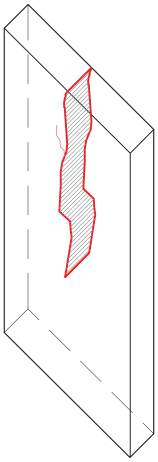
STRUCTURAL CRACKING

Major structural cracks that extend through several wythes of adobe or the whole wall unit. These structural cracks also include complete wythe separation. Structural cracks are not to be confused with shelter coat cracks or loss.



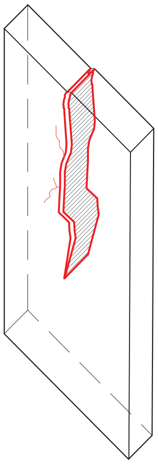
LEVEL 1

A long crack (vertical, horizontal, or diagonal) is apparent on one face of a wall.



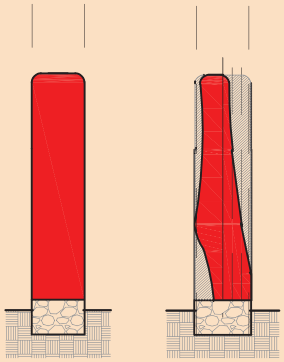
LEVEL 3

A long crack (vertical, horizontal, or diagonal) is apparent on both sides of wall. It may be surrounded by hairline cracks.



LEVEL 5

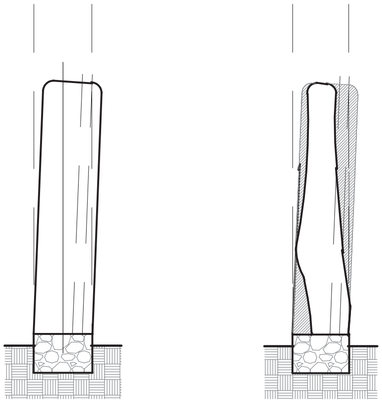
One or more deep, long cracks (vertical, horizontal, or diagonal) accompanied by apparent hairline cracks. The wall likely shows displacement. Structural cracks are likely to follow adobe wythes.



SECTION DIAGRAMS

OUT OF PLANE

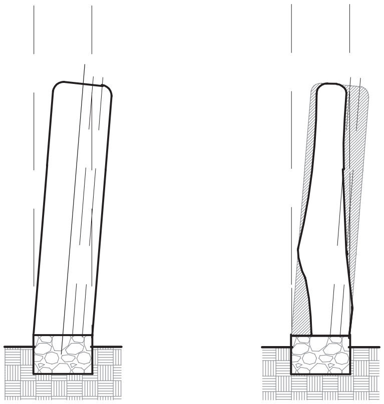
Wall centers that exhibit lean are considered to be out of plane or racking. Lean is differentiated from surface loss which refers to loss of material rather than the actual displacement of the wall. Leaning walls are inferred by comparing the present wall segment face to the location of the outer edge of the stone foundation.



SECTION

LEVEL 1

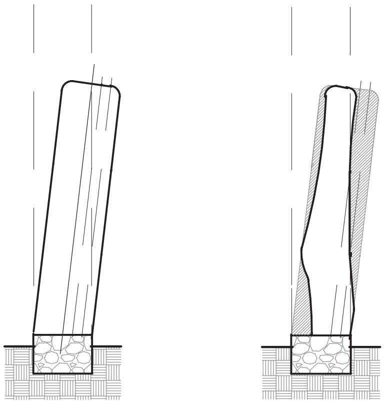
Wall segment demonstrates slight lean and does not align with stone foundation. A brace might be in place to prevent further movement.



SECTION

LEVEL 3

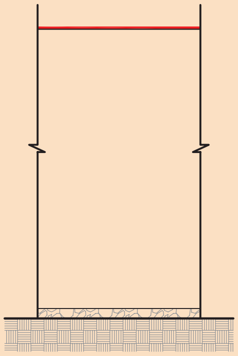
Wall unit, braced or unbraced, is leaning out of plane. If an imaginary original wall profile was drawn, the second third of the half of the wall would align with the edges of the stone foundation.



SECTION

LEVEL 5

Wall unit, braced or unbraced, is out of plane and requires immediate structural repairs. If an imaginary original wall profile was drawn, the center line of the wall would align with the edges of the stone foundation.


ELEVATION

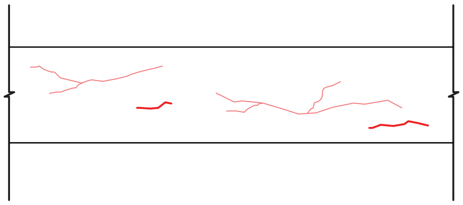
CAP DETERIORATION

The surface of the wall top is open either due to cracking or loss. This mode of deterioration leaves the interior of the wall susceptible to water intrusion which can then travel through the entire wall system especially at wythe interfaces.


TOP VIEW

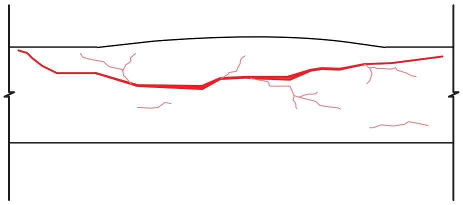
LEVEL 1

The surface of the shelter coat has many hairline cracks.


TOP VIEW

LEVEL 3

The surface of the shelter coat has several hairline cracks and a few wide cracks. Small patches of shelter coat loss might be present.


TOP VIEW

LEVEL 5

The shelter coat exhibits extensive hairline and wide cracks. These cracks are likely paired with shelter coat loss and dispacement.

APPENDIX - C Rapid Assessment Survey (RAS) Protocol

1. Using the **Illustrated Conditions Glossary** for reference, complete the RAS for the wall sectors of the Third Fort.
2. Once collected, the data needs to be **normalized** and **weighted** to establish an accurate hierarchy among the vulnerability categories.
3. **Normalization**: Sub-scores for each category of the RAS form need to be divided by the total *possible* number of points for that category. For example, a wall sector *without* a sill would have a maximum number of possible points for category A or B of 15 instead of 20.

4. **Weighting:** The subcategories of the RAS form (A-G) are assigned unique weighting categories to signify their priority among one another. Category G is the highest and is a factor of 1000 (move the decimal 3 spaces to the left); Categories A and B are weighted by a factor of 100 (move the decimal 2 spaces to the left); finally Categories C-F are weighted by a factor of 10 (move the decimal 1 space to the left). This will prevent decimal values.

	Condition	0 - 5	Code
Elevation 1 N E	Wall Surface loss (top 1/3)	3	SL
	Wall Surface loss (middle 1/3)	4	SL
	Wall Surface loss (bottom 1/3)	2	SL
	Sill Deterioration (below opening to foundation)	NA	WS
	Elevation 1 Subtotal	9 ÷ 15 = 0.6	a

5. Once normalized and weighted, the sub-scores are added and the final score is recorded in Excel. A new column can be used for each subsequent year of recorded total values. Using the sort-by tool in Excel, the scores for each wall sector can be arranged and given a priority ranking.

	Condition	0 - 5	Code
Elevation 1 N E	Wall Surface loss (top 1/3)	3	SL
	Wall Surface loss (middle 1/3)	4	SL
	Wall Surface loss (bottom 1/3)	2	SL
	Sill Deterioration (below opening to foundation)	NA	WS
	Elevation 1 Subtotal	9 ÷ 15 = 0.6 x 100 = 60	a

APPENDIX - D Mechanics' Corral RAS Results

Figure 31- Composite, normalized and weighted RAS scores for the Mechanics' Corral (HS-36).

Figure 32- Normalized and weighted RAS scores for categories A & B of the Mechanics' Corral (HS-36).

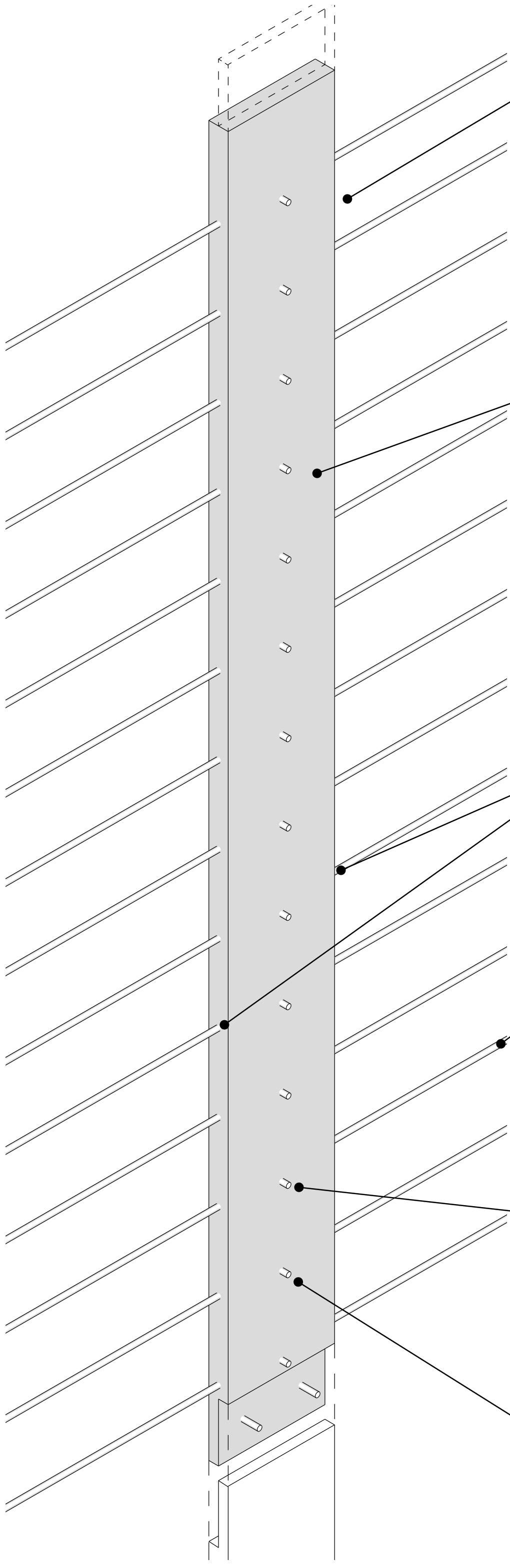
Figure 33- Normalized and weighted RAS scores for categories C - F of the Mechanics' Corral (HS-36).

Figure 34- Normalized and weighted RAS scores for category G of the Mechanics' Corral (HS-36).

Figure 35- Composite results of the RAS plotted using wall sector height as a radius of 'risk impact.'

Figure 36- Results of structural analysis of wall profilometry data in "inches to kern", a measure of structural instability based on the geometry of the cross-section alone.

APPENDIX E - Wall Profilometry Assembly Instructions



Composed of a **Top Section** (Shown), **Middle section** (lap joints at the top and bottom) and a **Bottom section** (lap joint at the top, at bottom drill a 5/16”x3” hole at center of the engrain. Hammer in place a 6-8” ground set pin).

Typical Section
5/4”x6” board in 60” sections with 3“ lap joints fastened using tie plates on both sides. Coordinate lap joints with pin locations to ensure there are no pins passing thru a lap joint. Screw Simpson Strong-Tie TP 1-13/16“x 5” 20-gauge galvanized tie plates over lap joint. Coordinate tie plate fastener locations with Pin locations.

Pin Holes
Drill 3/8” holes at 4” on center typical. Coordinate center alignment of pin holes with tapping insert and pin screw locations.

Pins
Using Everbilt 48” reflective rods (model number 31474). Cut rods to 24” length and insert one in each pin hole along the length of each section.

Tapping insert
Countersink stainless steel tapping insert for hardwood Mcmaster-Carr 1/4“-20 thread size (product number: 95807a300) perpendicular on center alignment with pin holes

Pin screws
Use prime-line 1/4”-20x1” zinc plated steel no shoulder thumbscrews. Tighten to fix pin locations in field.

APPENDIX F - Wall Profilometry Survey Protocol

1. Create a labeled form with which to record field measurements, for ease and organization.
2. Attach the bubble level to provide accurate readings.
3. Strategically set pins in the profile gauge in such a way that will optimize data collection for each individual profile.
4. Set up the ladder next to the data point to be measured so that one person may hold and operate the upper section of the profile gauge.
5. Use the ground peg (located at the bottom of the profile gauge) to plant the device securely in the ground at the marker-designated point being measured.
6. Check that the bottom-most pin of the profile gauge clears the top of the foundation.
7. Measure the height (H) (distance from the stone foundation to the bottom most pin) and depth (D) (distance of the adobe wall from the foundation at the bottom most pin). These measurements allow for the rest of the data points to be located in relation to the adobe wall, ultimately creating an accurate profile (to convert the profile shape measurements (PS) into the processed profile shape measurements (PPS)).
8. Once these measurements are recorded, double check the position of the profile gauge; this includes re-reading the levels and a visual assessment.
9. Set and lock the pins by gently pushing them through the drilled hole and eyelet until it touches the adobe wall being profile, and lock into place by tightening the threaded key to stabilize the gauge.
10. Gently remove the profile gauge from its position against the adobe wall, and place it on the ground for measurements.
11. Record the profile shape measurement, the distance from each pin tip to its base on the profile gauge.
12. Once complete, disengaged the pins and move on to the next wall profile.

Appendix G - Independent Structural Evaluation of 2019 Wall Profilometry Survey Data [Report]

Third Party Vulnerability Assessment for Fort Union National Monument in New Mexico

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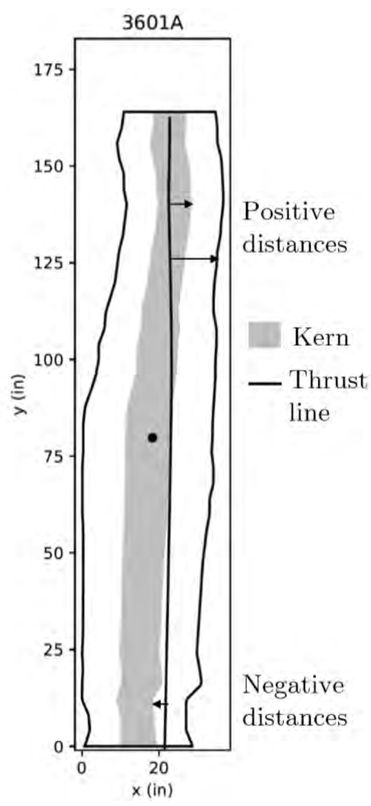
Department of Architectural Engineering Pennsylvania State University

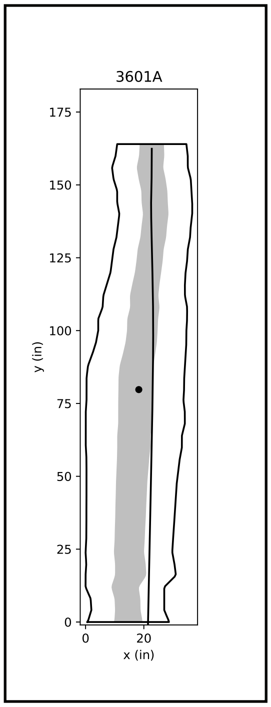
Scope of work A rapid assessment protocol has been designed and implemented by Evan Oskierko-Jeznacki and Frank Matero of the University of Pennsylvania to evaluate the vulnerability of adobe ruins in the southwest. The project started at Fort Union National Monument in New Mexico and is now the case study park for several other climate-sensitive sites in the American southwest. In addition to a numeric survey, they also recorded wall profiles of select at-risk walls using a large profile gauge. A ranking system which listed the profiles hierarchically from a structural vulnerability perspective based solely on their geometrics was requested; it was stated that the primary interest was in determining the kern. This graphical analysis was provided by the authors as an independent third-party so as to validate the prioritized list the survey provided.

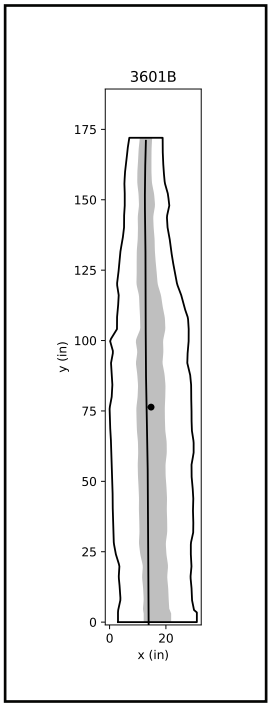
Results Attached to this report are images of each of the profiles with the middle third of the wall highlighted as a grey patch and the graphical thrust line depicted as a black line. Based on conversations with Evan Oskierko-Jeznacki, only dead weight was analyzed for this work; other factors such as wind loading were not accounted for. A density of 1700kg/m3 was assumed for the material. Additionally a .csv file is provided which gives the wall id (as given in the autocad file), the smallest (or worst) distance to the outside of the wall, the smallest distance to the outside of the wall at the base, the smallest (or worst) distance to the kern (grey highlighted area), as well as the smallest distance to the kern at the base. All distances are given in inches where positive indicates that the thrust line stays either inside the kern or the mass of the wall and negative indicates that the thrust line exits either the kern or the mass of the wall (Figure 1). The columns of the .csv can be sorted to show which walls are presently the most vulnerable.

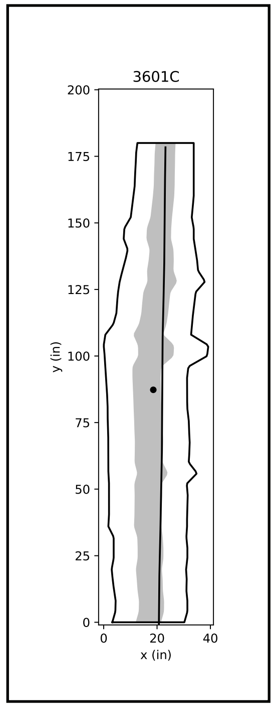


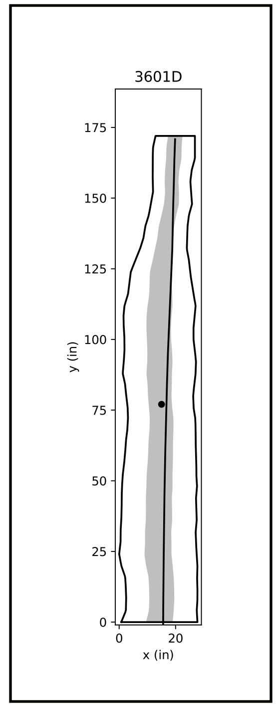
Disclaimer *This is not an offer of engineering services. Mutual Limit on Liability: Neither party will be liable for damages suffered by the other party that are remote or speculative, or that could not have reasonably been foreseen on entry into this agreement. Maximum Liability: There is no liability for Rebecca Napolitano and Pennsylvania State University's liability under this agreement.*

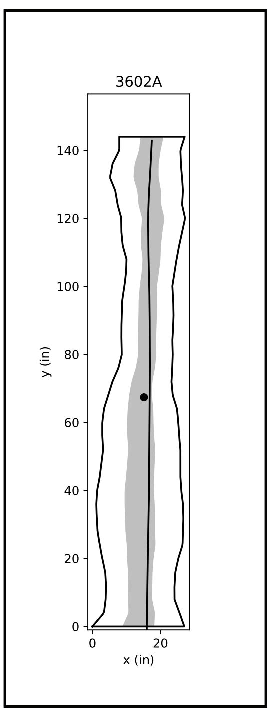
Appendix H - Independent Structural Evaluation of 2019 Wall Profilometry Survey Data [Results]

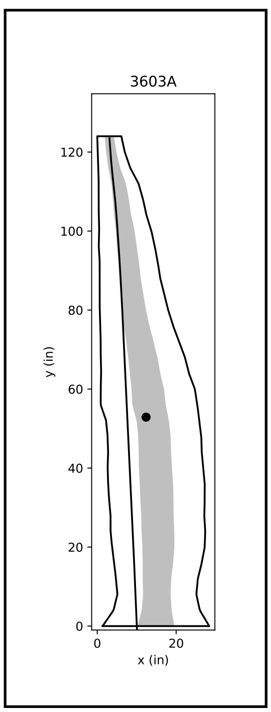


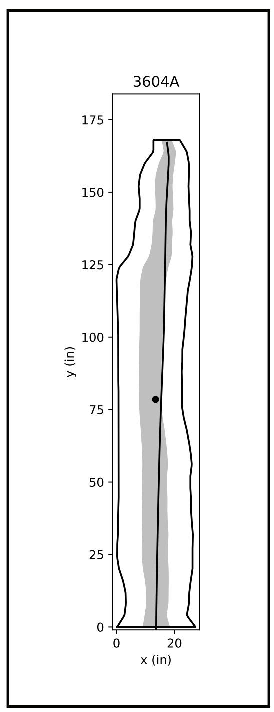


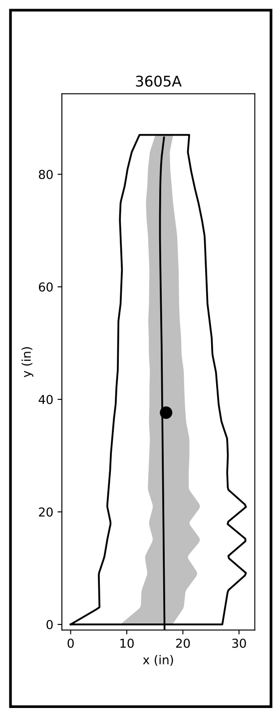


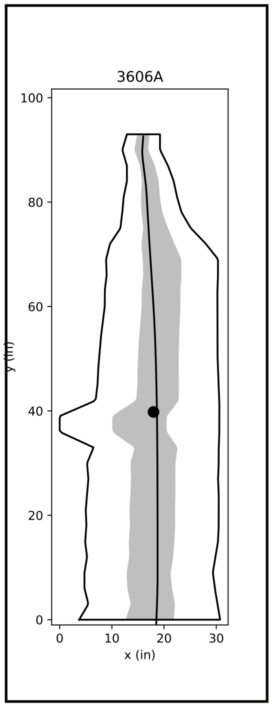








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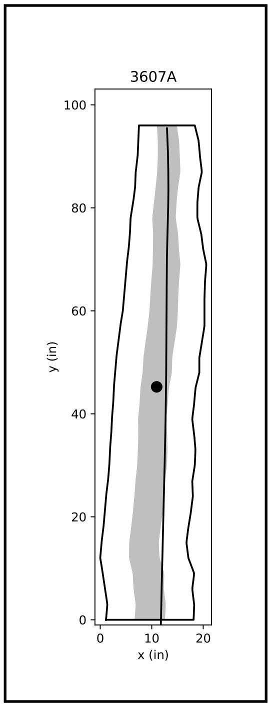
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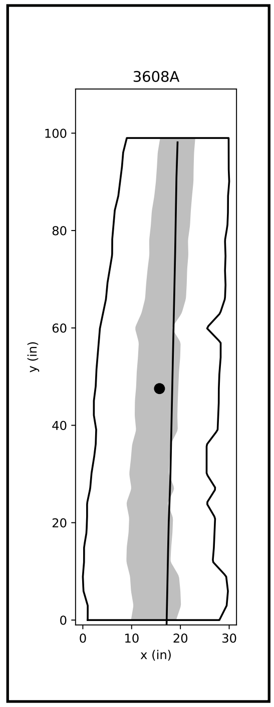
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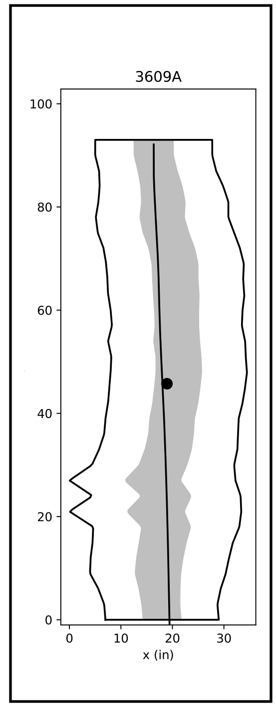
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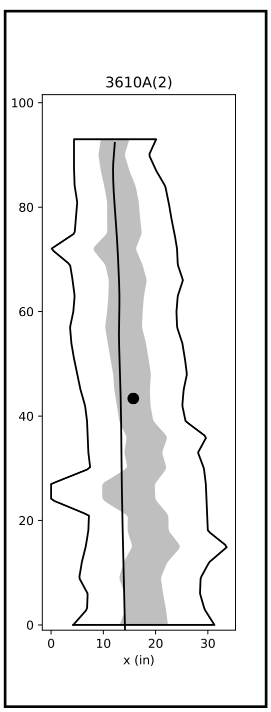
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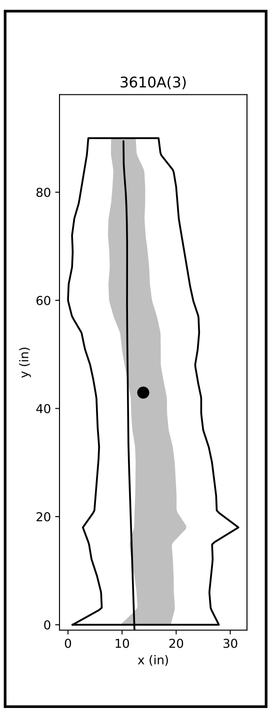
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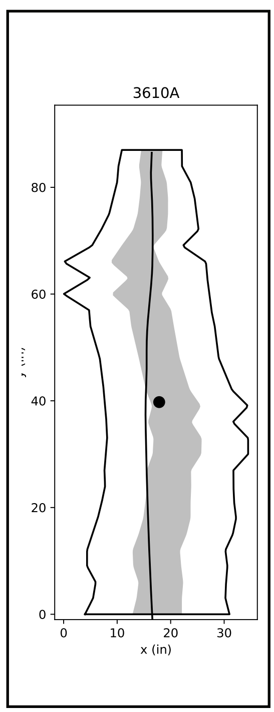
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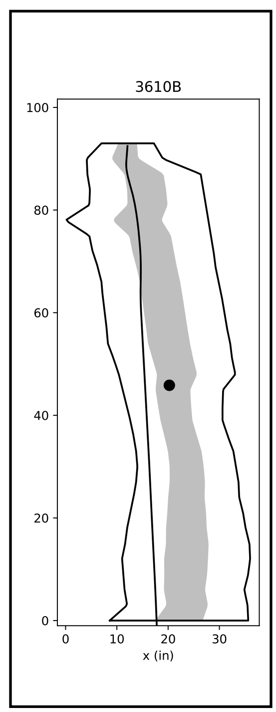
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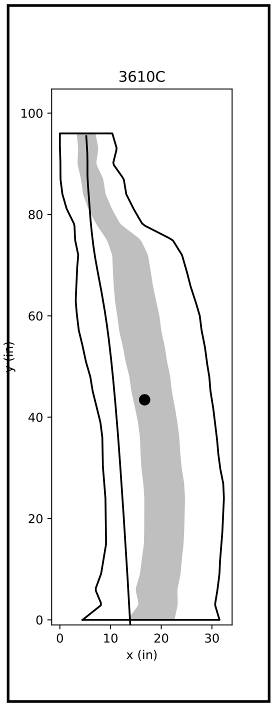
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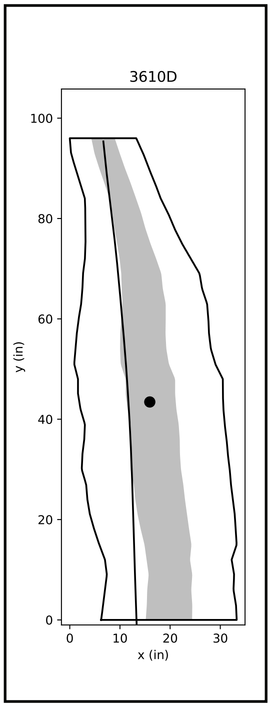
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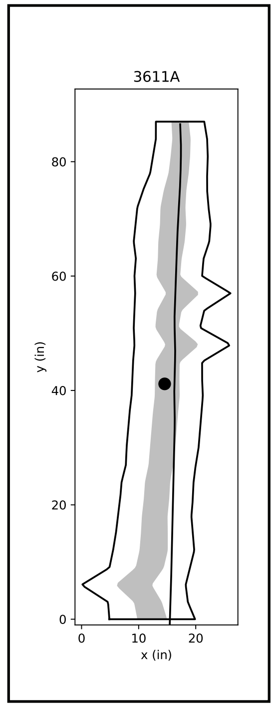
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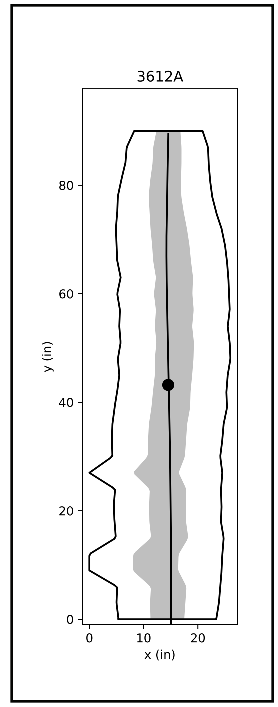
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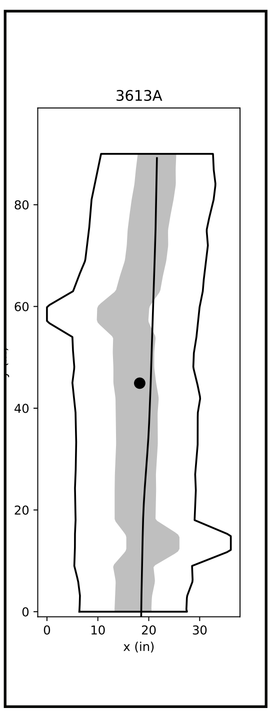
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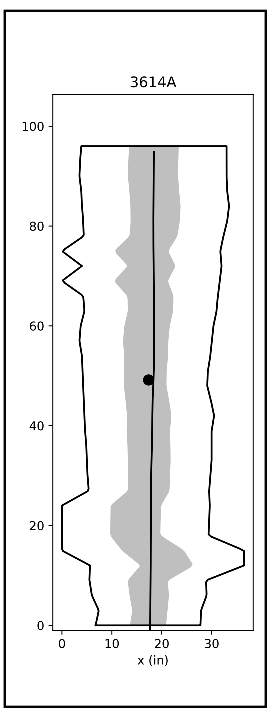
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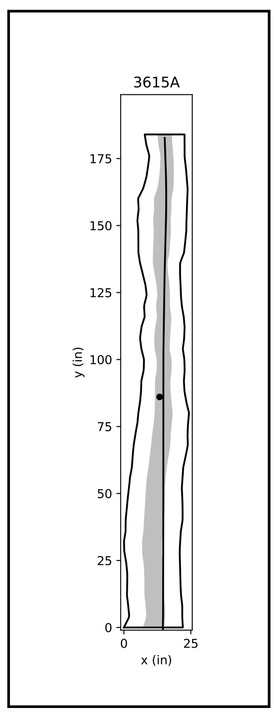
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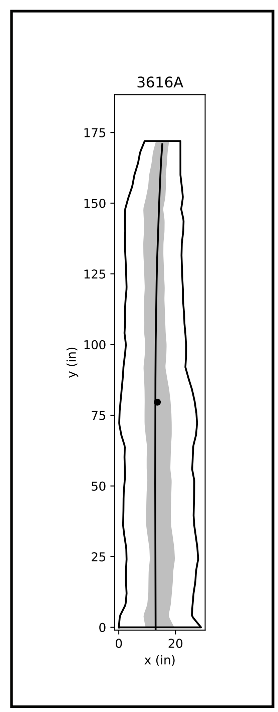
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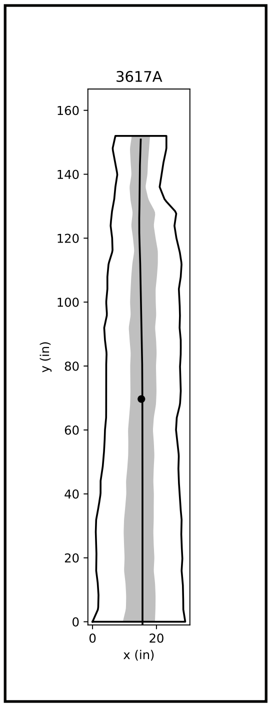
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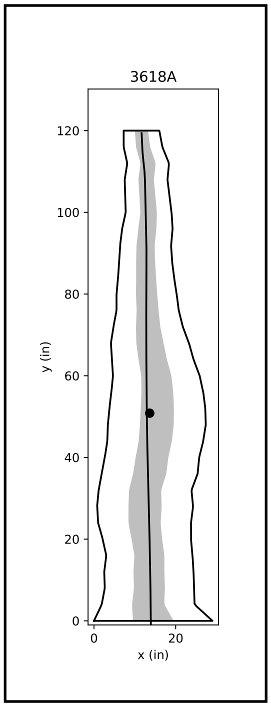
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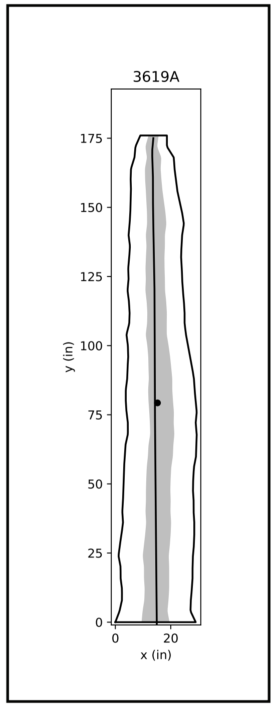
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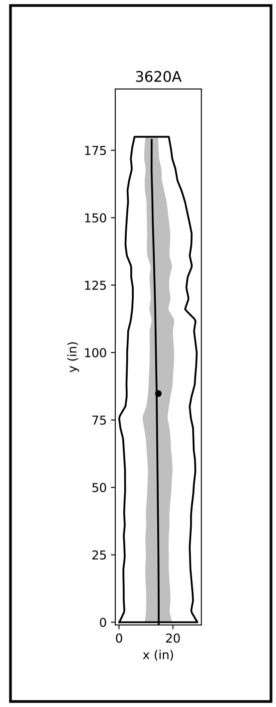
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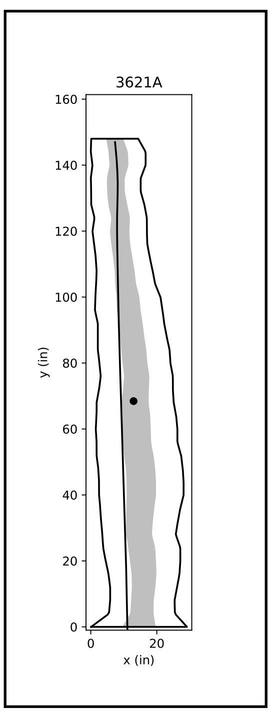
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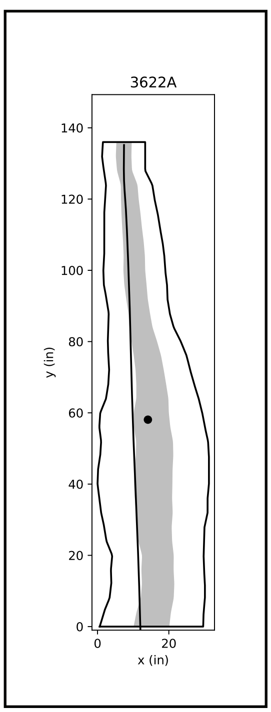
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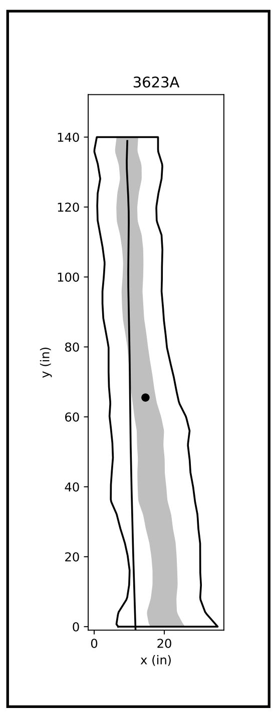
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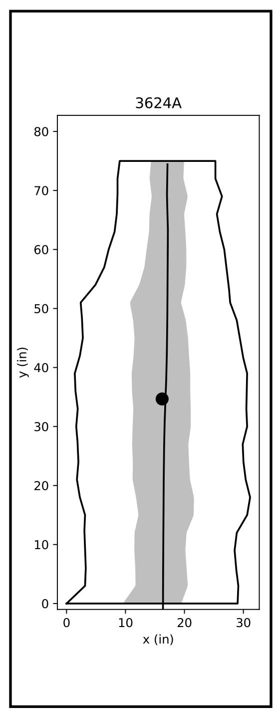
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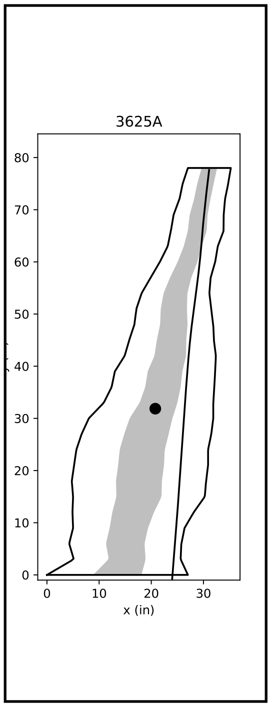
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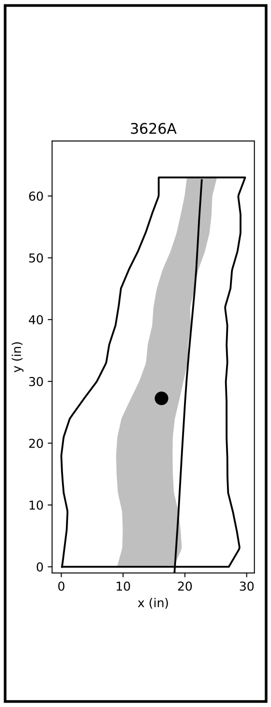
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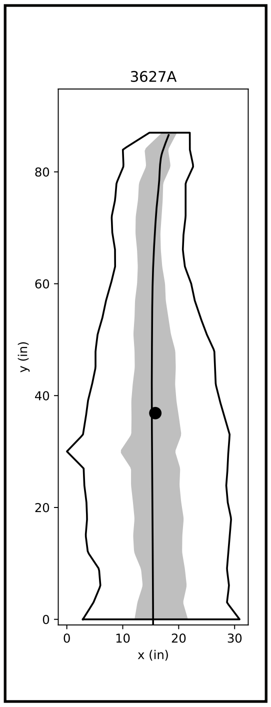
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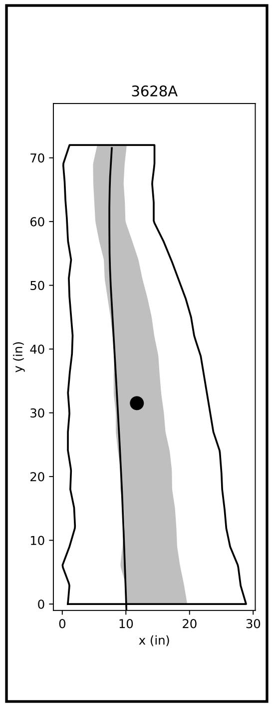
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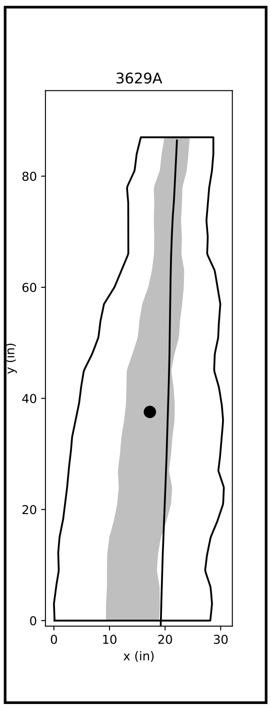
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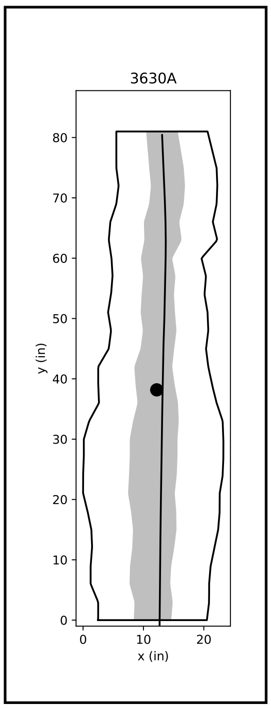
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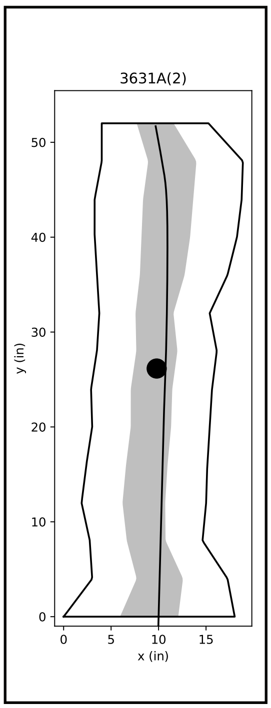
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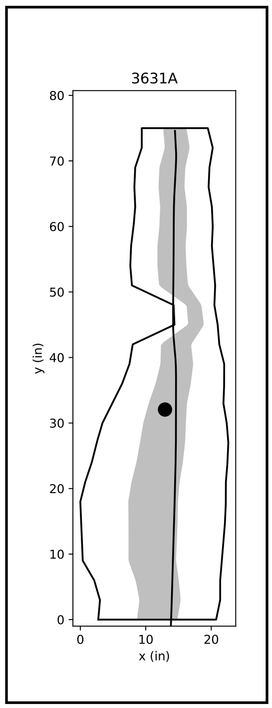
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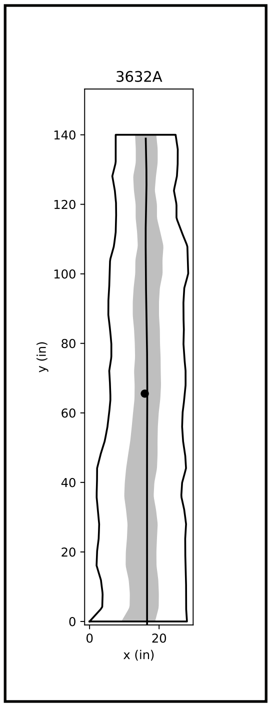
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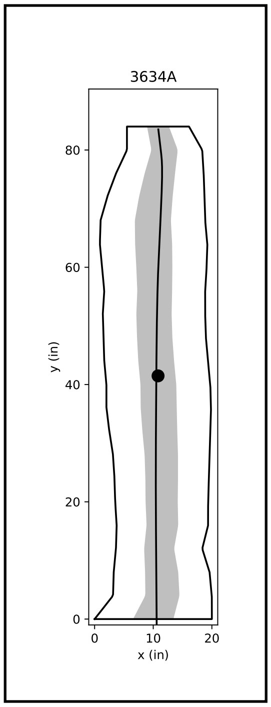
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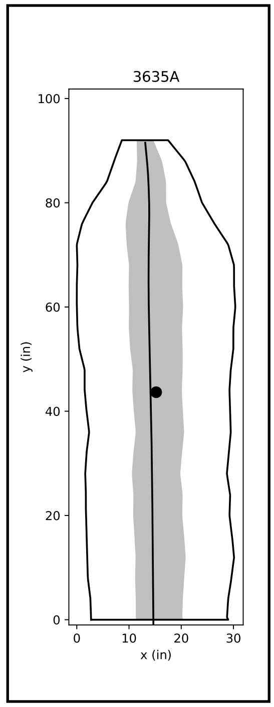
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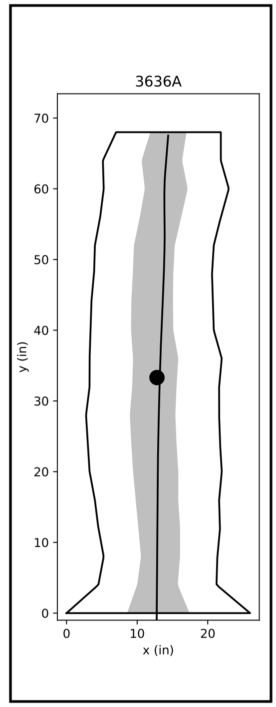
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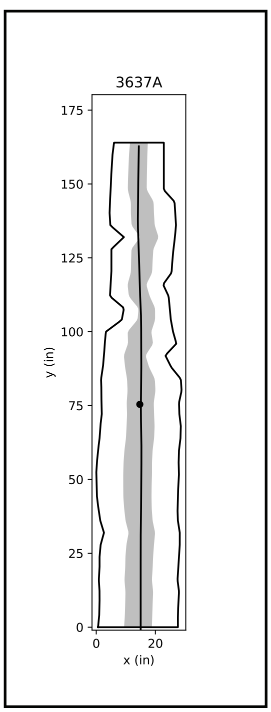
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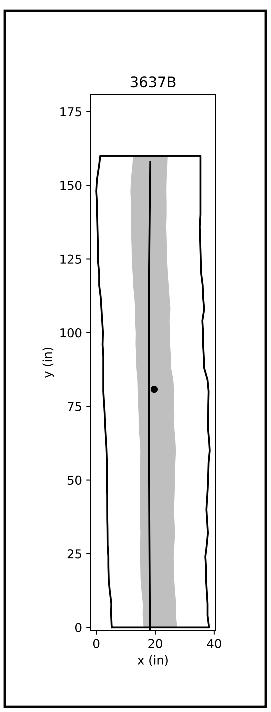
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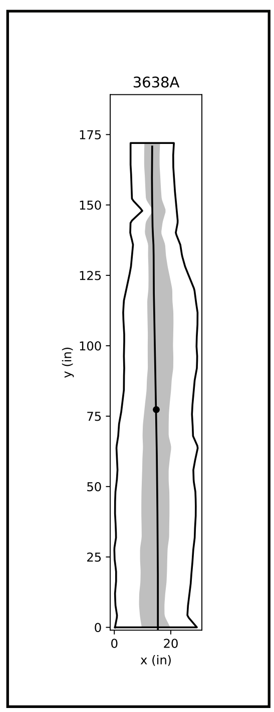
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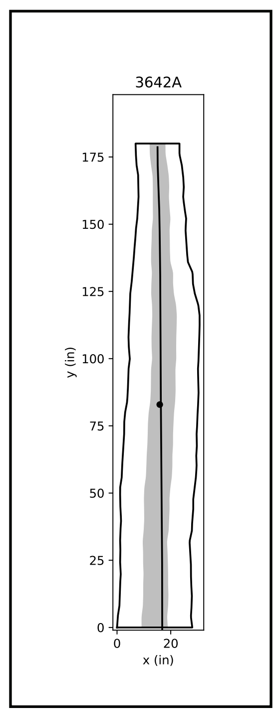
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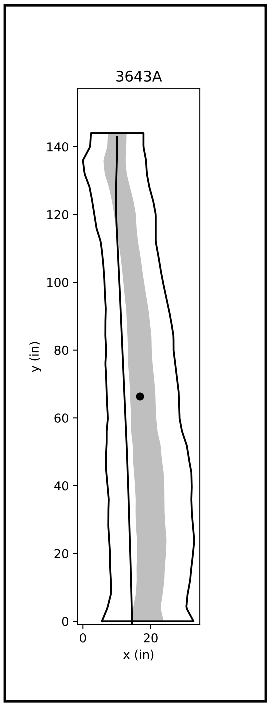
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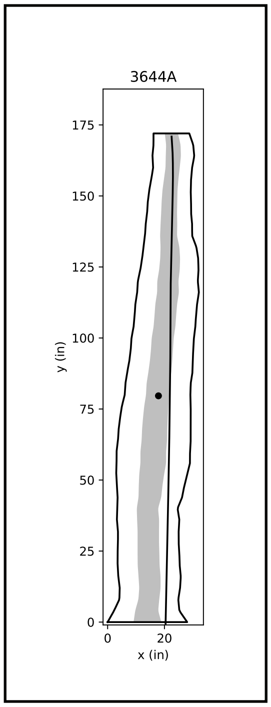
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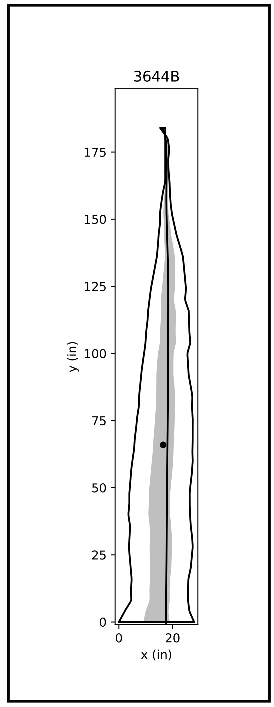
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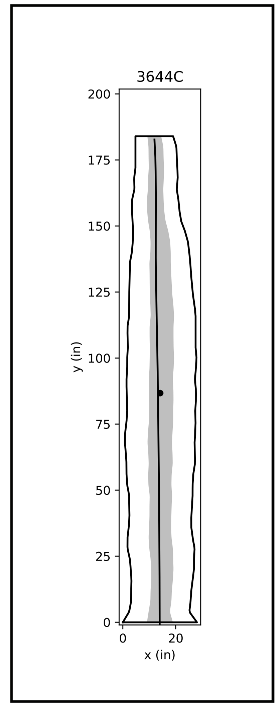
x (in)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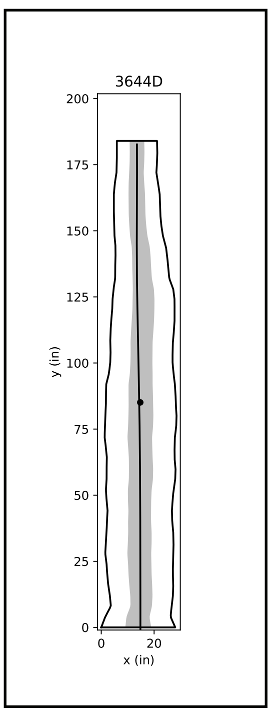
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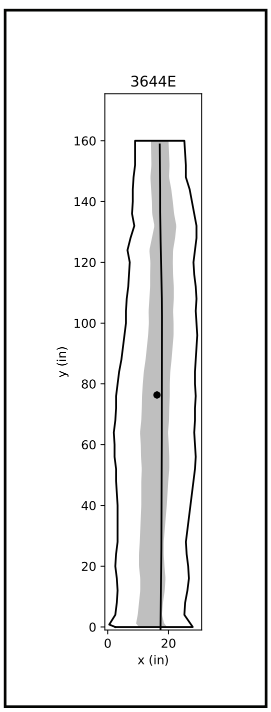
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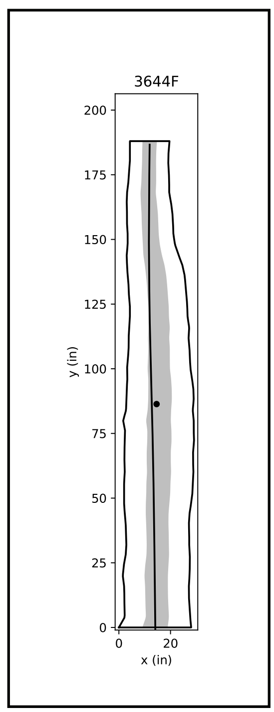
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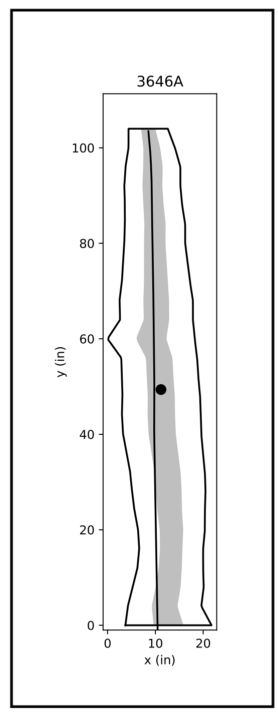
x (in)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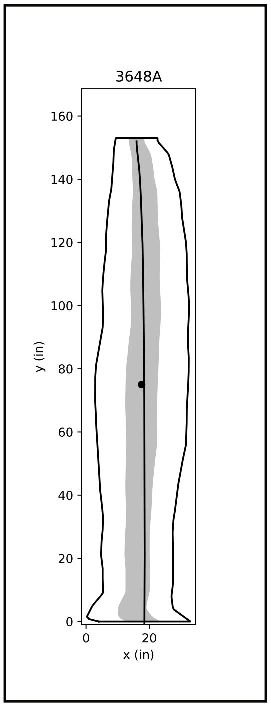
x (in)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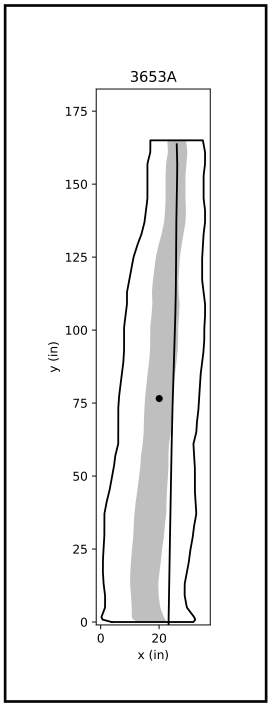
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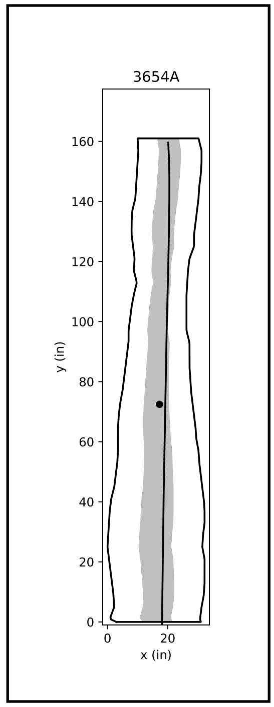
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x (in)
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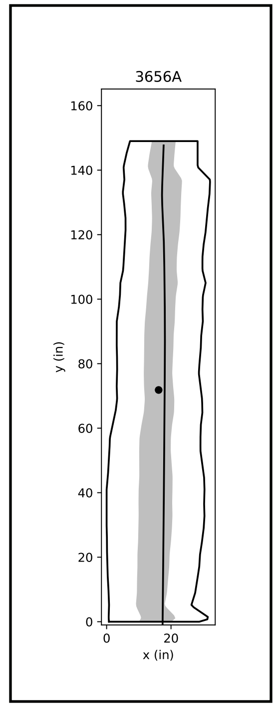
20
40
60
80
100
120
140
160


3656A
y (in)
x (in)
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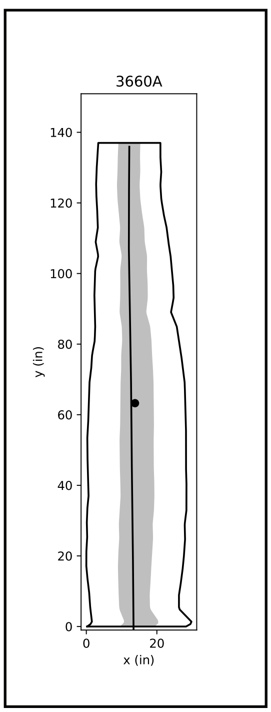
20
40
60
80
100
120
140
160


3660A
y (in)
x (in)
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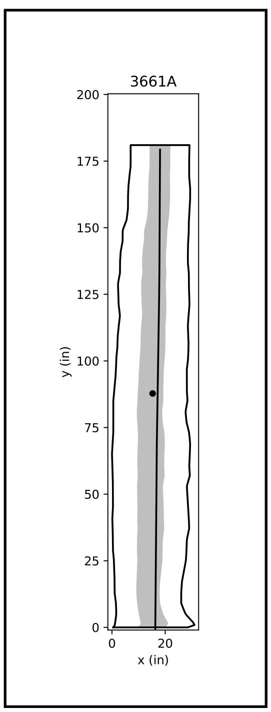
40
60
80
100
120
140


3661A
y (in)
x (in)
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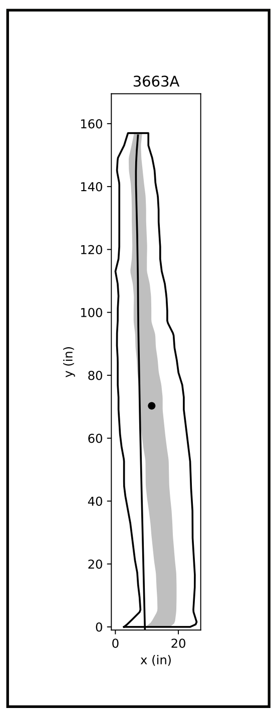
20
25
50
75
100
125
150
175
200


3663A
y (in)
x (in)
0
20
40
60
80
100
120
140
160

Appendix I - Third Fort RAS Wall Sector Results

SECID	A	B	C	D	E	F	G	H	Total	SECRANK	SEGID	Kern (in)	Kern @ base
0101A	53.3	13.3	1	0	0	1	320	20	388.7	369	101	NA	NA
0201A	73.3	25	1	2	0	1	480	32	582.3	251	201	NA	NA
0201B	33.3	60	6	1	1	1	560	37	662.3	191	201	NA	NA
0202A	60	60	3	2	2	1	360	35	488	313	202	NA	NA
0202B	33.3	46.7	2	1	2	1	280	25	366	382	202	NA	NA
0203A	46.7	40	4	2	2	0	360	30	454.7	334	203	NA	NA
0204A	73.3	53.3	3	0	0	0	360	31	489.7	312	204	NA	NA
0301A	60	6.7	4	0	5	3	120	25	198.7	399	301	NA	NA
0302A	26.7	26.7	2	2	0	2	240	20	299.3	395	302	NA	NA
0303A	60	13.3	1	0	1	0	350	20	425.3	349	303	NA	NA
0401A	46.7	13.3	2	2	0	0	240	19	304	394	401	NA	NA
0402A	66.7	33.3	1	3	0	2	360	30	466	324	402	NA	NA
0403A	53.3	40	1	1	0	2	280	25	377.3	375	403	NA	NA
0404A	46.7	53.3	0	1	1	3	320	28	425	350	404	NA	NA
0405A	33.3	40	1	1	4	1	150	21	230.3	398	405	NA	NA
0406A	40	53.3	1	0	3	4	250	27	351.3	388	406	NA	NA
0501A	13.3	13.3	1	3	1	0	280	16	311.7	392	501	NA	NA
0502A	33.3	66.7	0	0	0	0	320	23	420	354	502	NA	NA
0503A	46.7	40	2	2	3	1	440	32	534.7	285	503	NA	NA
0504A	30	45	1	0	1	0	320	25	397	364	504	NA	NA
0505A	15	15	3	2	0	3	320	22	358	386	505	NA	NA
0601A	55	40	6	1	7	0	480	45	589	243	601	NA	NA
0601B	0	45	0	2	7	5	600	38	659	193	601	NA	NA
0602A	60	0	4	0	2	0	520	28	586	246	602	NA	NA
0603A	33.3	46.7	7	6	8	7	440	51	548	271	603	NA	NA
0604A	66.7	40	6	6	0	4	600	47	722.7	143	604	NA	NA
0605A	53.3	46.7	8	0	3	1	480	39	592	240	605	NA	NA
0701A	53.3	20	6	4	6	1	280	35	370.3	379	701	NA	NA
0702A	60	66.7	10	6	8	6	600	64	756.7	122	702	NA	NA
0703A	53.3	46.7	5	4	6	2	400	42	517	295	703	NA	NA
0704A	40	40	2	4	4	0	280	29	370	380	704	NA	NA
0705A	73.3	86.7	6	7	6	6	760	68	945	33	705	NA	NA
0801A	40	26.7	7	2	5	4	360	37	444.7	344	801	NA	NA
0802A	60	33.3	3	7	0	5	560	43	668.3	184	802	NA	NA
0803A	80	100	3	2	0	3	550	46	738	130	803	NA	NA
0804A	33.3	46.7	4	2	2	6	320	34	414	358	804	NA	NA
0901A	40	40	4	3	5	2	400	36	494	309	901	NA	NA
0902A	66.7	46.7	8	3	0	4	400	42	528.3	291	902	NA	NA

0903A	73.3	40	7	4	7	2	360	46	493.3	310	903	NA	NA
0904A	60	53.3	2	3	3	0	480	37	601.3	229	904	NA	NA
1101A	66.7	40	7	2	9	4	800	58	928.7	37	1101	NA	NA
1102A	40	26.7	2	1	1	0	300	20	370.7	378	1102	NA	NA
1103A	93.3	60	6	8	8	2	800	55	977.3	28	1103	NA	NA
1104A	73.3	40	6	5	7	3	866.7	51	1001	20	1104	NA	NA
1201A	53.3	33.3	8	1	10	4	640	52	749.7	123	1201	NA	NA
1202A	86.7	66.7	4	2	9	0	840	59	1008.3	17	1202	NA	NA
1202B	60	40	5	2	0	2	950	43	1059	9	1202	NA	NA
1203A	73.3	40	6	3	4	2	680	47	808.3	84	1203	NA	NA
1205A	66.7	53.3	6	2	7	2	840	56	977	29	1205	NA	NA
1301A	100	0	10	0	10	5	520	53	645	202	1301	NA	NA
1302A	100	60	8	3	10	10	650	68	841	70	1302	NA	NA
1303A	53.3	26.7	8	5	10	3	550	49	656	196	1303	NA	NA
1304A	66.7	66.7	7	3	10	7	933.3	61	1093.7	7	1304	NA	NA
1305A	80	53.3	8	1	10	5	750	59	907.3	47	1305	NA	NA
1306A	80	73.3	7	3	7	4	760	63	934.3	36	1306	NA	NA
1307A	66.7	53.3	1	3	5	3	600	45	732	136	1307	NA	NA
1308A	80	26.7	6	4	5	0	800	51	921.7	40	1308	NA	NA
1309A	73.3	13.3	5	0	7	0	680	42	778.7	100	1309	NA	NA
1401A	73.3	46.7	6	2	2	0	360	37	490	311	1401	NA	NA
1402A	73.3	73.3	2	2	6	0	300	38	456.7	332	1402	NA	NA
1403A	53.3	53.3	5	2	2	3	760	47	878.7	58	1403	NA	NA
1404A	53.3	73.3	5	2	6	1	840	54	980.7	26	1404	NA	NA
1405A	53.3	60	5	2	0	4	520	41	644.3	203	1405	NA	NA
1501A	60	73.3	8	9	3	6	600	58	759.3	120	1501	NA	NA
1601A	66.7	66.7	3	4	6	6	680	56	832.3	75	1601	NA	NA
1602A	80	86.7	10	2	10	10	850	74	1048.7	10	1602	NA	NA
1603A	80	80	7	3	9	9	520	53	708	156	1603	NA	NA
1604A	73.3	53.3	6	2	0	6	520	46	660.7	192	1604	NA	NA
1605A	80	40	10	4	0	10	640	58	784	95	1605	NA	NA
1607A	60	46.7	7	2	3	2	640	46	760.7	116	1607	NA	NA
2201A	60	46.7	4	3	7	8	560	48	688.7	165	2201	NA	NA
2202A	66.7	46.7	5	6	4	2	440	45	570.3	259	2202	NA	NA
2203A	33.3	20	2	2	3	4	320	27	384.3	374	2203	NA	NA
2204A	66.7	66.7	6	4	7	0	760	56	910.3	44	2204	NA	NA
2204B	73.3	60	8	3	0	3	600	49	747.3	125	2204	NA	NA
2205A	60	53.3	7	3	3	0	640	46	766.3	112	2205	NA	NA
2301A	26.7	46.7	1	2	5	1	680	37	762.3	115	2301	NA	NA
2302A	66.7	0	7	0	7	2	400	36	482.7	314	2302	NA	NA
2303A	46.7	53.3	7	2	0	2	560	40	671	181	2303	NA	NA
2304A	70	0	9	1	2	0	640	35	722	144	2304	NA	NA
2305A	70	33.3	5	2	10	0	560	43	680.3	171	2305	NA	NA
2306A	60	33.3	6	6	8	2	900	54	1015.3	16	2306	NA	NA
2307A	80	46.7	7	2	8	4	680	57	827.7	77	2307	NA	NA

2308A	73.3	53.3	9	3	0	2	640	49	780.7	96	2308	NA	NA
2313A	73.3	30	5	2	6	2	333.3	34	451.7	337	2313	NA	NA
2701A	53.3	26.7	5	2	2	5	400	36	494	309	2701	NA	NA
2702A	26.7	46.7	2	1	7	4	320	33	407.3	360	2702	NA	NA
2703A	66.7	40	8	2	6	2	480	46	604.7	225	2703	NA	NA
2704A	53.3	33.3	9	2	7	1	440	43	545.7	276	2704	NA	NA
2705A	66.7	26.7	9	2	4	0	640	45	748.3	124	2705	NA	NA
2706A	33.3	53.3	7	3	2	0	800	45	898.7	53	2706	NA	NA
2706A*	66.7	20	3	3	4	0	680	40	776.7	103	2706	NA	NA
2707A	60	40	5	2	7	0	550	45	664	189	2707	NA	NA
2707B	46.7	40	4	2	6	1	320	34	419.7	355	2707	NA	NA
2708A	60	40	6	2	4	3	520	43	635	207	2708	NA	NA
2709A	53.3	20	10	2	4	9	520	49	618.3	217	2709	NA	NA
2710A	46.7	53.3	8	5	5	3	480	48	601	231	2710	NA	NA
2711A	46.7	15	5	2	0	4	320	29	392.7	366	2711	NA	NA
2712A	46.7	46.7	6	2	0	7	480	41	588.3	244	2712	NA	NA
2713A	53.3	46.7	7	2	0	1	440	36	550	268	2713	NA	NA
2714A	40	40	4	3	7	0	320	34	414	358	2714	NA	NA
2716A	40	40	6	2	4	0	360	33	452	336	2716	NA	NA
2717A	53.3	33.3	6	2	0	3	520	37	617.7	219	2717	NA	NA
2718A	40	13.3	6	2	0	0	480	28	541.3	281	2718	NA	NA
2719A	30	30	4	3	9	6	400	36	482	315	2719	NA	NA
2801A	66.7	60	7	9	7	4	300	52	453.7	335	2801	NA	NA
2802A	60	55	7	2	5	0	400	47	529	290	2802	NA	NA
2804A	70	45	5	1	6	4	440	50	571	257	2804	NA	NA
2804B	65	25	7	4	6	2	440	48	549	270	2804	NA	NA
2805A	60	25	8	4	8	2	440	47	547	272	2805	NA	NA
2806A	53.3	33.3	8	3	0	7	400	41	504.7	301	2806	NA	NA
2807A	53.3	46.7	7	5	0	2	560	43	674	176	2807	NA	NA
2808A	60	26.7	2	1	8	1	600	40	698.7	162	2808	NA	NA
2809A	46.7	33.3	7	2	0	2	520	36	611	224	2809	NA	NA
2810A	73.3	33.3	7	2	0	4	440	40	559.7	264	2810	NA	NA
2811A	26.7	20	6	2	6	3	360	33	423.7	352	2811	NA	NA
2901A	73.3	60	3	2	8	2	520	48	668.3	185	2901	NA	NA
2902A	20	26.7	4	2	2	0	280	22	334.7	391	2902	NA	NA
2903A	73.3	26.7	6	2	6	5	560	48	679	172	2903	NA	NA
2904A	40	73.3	7	3	8	0	440	46	571.3	255	2904	NA	NA
2906A	66.7	53.3	9	1	9	0	640	53	779	99	2906	NA	NA
2907A	60	46.7	6	2	2	2	550	39	668.7	183	2907	NA	NA
2908A	86.7	40	7	2	1	2	400	39	538.7	283	2908	NA	NA
2909A	80	0	6	3	3	2	500	36	594	238	2909	NA	NA
2910A	86.7	66.7	8	2	4	2	300	45	469.3	321	2910	NA	NA
2911A	66.7	73.3	4	1	7	1	520	47	673	179	2911	NA	NA

2913A	46.7	33.3	1	1	2	1	280	24	365	383	2913	NA	NA
3001A	46.7	53.3	6	3	3	0	633.3	46	745.3	129	3001	NA	NA
3001B	66.7	40	7	2	0	1	800	50	916.7	42	3001	NA	NA
3001C	55	60	4	4	0	4	633.3	54	760.3	117	3001	NA	NA
3002A	70	30	8	1	8	3	440	51	560	263	3002	NA	NA
3002B	60	65	5	3	4	3	550	51	690	164	3002	NA	NA
3002C	60	50	7	2	4	4	440	50	567	261	3002	NA	NA
3002D	55	25	6	5	0	3	760	49	854	66	3002	NA	NA
3003A	33.3	20	0	2	5	3	200	23	263.3	397	3003	NA	NA
3004A	40	46.7	5	1	1	3	350	30	446.7	341	3004	NA	NA
3005A	93.3	0	0	0	3	4	320	29	420.3	353	3005	NA	NA
3006A	60	55	4	4	0	0	466.7	45	589.7	242	3006	NA	NA
3006B	10	55	0	5	1	1	640	36	712	149	3006	NA	NA
3007A	60	40	0	1	3	1	280	27	385	373	3007	NA	NA
3008A	93.3	80	10	0	0	2	750	53	935.3	35	3008	NA	NA
3008B	100	93.3	10	9	5	4	700	78	921.3	41	3008	NA	NA
3008B*	93.3	80	10	2	4	0	800	62	989.3	25	3008	NA	NA
3009A	93.3	80	10	7	0	0	666.7	63	857	65	3009	NA	NA
3009A*	86.7	53.3	10	6	0	0	400	47	556	265	3009	NA	NA
3009B	86.7	66.7	9	8	0	0	733.3	62	903.7	50	3009	NA	NA
3009B*	53.3	66.7	8	8	2	0	640	52	778	102	3009	NA	NA
3101A	66.7	20	8	3	0	0	633.3	43	731	137	3101	NA	NA
3101B	66.7	26.7	7	1	0	0	733.3	44	834.7	72	3101	NA	NA
3101C	45	35	2	4	0	1	566.7	40	653.7	197	3101	NA	NA
3102A	45	40	6	2	3	2	560	44	658	194	3102	NA	NA
3102B	55	45	6	2	8	2	600	50	718	145	3102	NA	NA
3102C	45	40	5	2	5	0	800	49	897	54	3102	NA	NA
3102D	50	35	5	2	6	1	600	43	699	161	3102	NA	NA
3103A	40	33.3	4	4	3	3	300	31	387.3	370	3103	NA	NA
3104A	60	50	7	2	3	0	520	47	642	204	3104	NA	NA
3104B	50	40	3	5	0	3	350	36	451	338	3104	NA	NA
3104C	45	35	6	0	0	5	366.7	38	457.7	331	3104	NA	NA
3104D	53.3	26.7	7	4	2	4	650	42	747	127	3104	NA	NA
3105A	40	50	5	5	0	3	480	36	583	249	3105	NA	NA
3106A	46.7	40	2	2	4	0	520	34	614.7	221	3106	NA	NA
3107A	100	100	10	8	6	6	600	75	830	76	3107	NA	NA
3108A	100	33.3	10	9	9	8	950	75	1119.3	5	3108	NA	NA
3109A	60	60	6	4	0	0	633.3	47	763.3	114	3109	NA	NA
3109B	60	40	5	4	4	0	720	46	833	74	3109	NA	NA
3110A	46.7	33.3	5	2	0	0	800	39	887	55	3110	NA	NA
3110B	33.3	20	7	3	0	0	433.3	31	496.7	306	3110	NA	NA
3201B?	60	26.7	5	2	7	0	550	38	650.7	198	3201	NA	NA

3201C	53.3	46.7	3	2	0	2	640	38	747	127	3201	NA	NA
3201D	40	46.7	7	2	0	0	480	34	575.7	254	3201	NA	NA
3202B	60	45	7	2	5	4	866.7	52	989.7	24	3202	NA	NA
3202C	60	45	7	3	6	2	866.7	52	989.7	24	3202	NA	NA
3202D	40	50	9	5	5	2	933.3	53	1044.3	12	3202	NA	NA
3202E	20	25	3	5	0	5	120	25	178	400	3202	NA	NA
3203A	46.7	33.3	7	8	3	6	400	44	504	302	3203	NA	NA
3205A	53.3	33.3	8	4	8	3	600	51	709.7	154	3205	NA	NA
3205B	80	46.7	10	6	8	0	450	52	600.7	233	3205	NA	NA
3207A	86.7	40	10	3	0	0	766.7	55	906.3	48	3207	NA	NA
3601A	65	75	6	7	0	4	800	69	957	32	3601	-3.6	-2.2
3601B	45	80	3	6	0	0	600	52	734	135	3601	1.5	1.5
3601C	75	35	5	3	0	0	500	45	618	218	3601	-0.9	0.6
3601D	60	35	5	4	6	0	800	58	910	46	3601	-0.4	3.2
3602A	80	50	5	7	7	4	640	65	793	93	3602	0.5	2
3603A	40	66.7	2	4	2	2	700	40	816.7	80	3603	-2.7	-0.4
3604A	60	53.3	4	3	2	3	560	43	685.3	167	3604	-0.7	4.4
3605A	53.3	53.3	5	4	2	0	666.7	47	784.3	94	3605	1.3	1.4
3606A	33.3	40	4	1	3	3	360	31	444.3	345	3606	0.6	3.2
3607A	40	26.7	2	3	0	6	560	35	637.7	206	3607	-0.9	0.7
3608A	0	46.7	1	3	0	0	360	20	410.7	359	3608	-0.5	1.9
3609A	80	60	5	4	0	0	400	42	549	270	3609	0.9	2.2
3610A	46.7	40	6	6	0	2	500	42	600.7	233	3610	-1.5	3.5
3610B	60	60	6	4	0	0	666.7	48	796.7	90	3610	-4.1	-0.1
3610C	60	53.3	3	3	0	0	700	44	819.3	79	3610	-4.4	0.2
3610D	46.7	40	3	3	0	0	500	34	592.7	239	3610	-2.8	-2
3611A	66.7	60	7	7	0	0	533.3	49	674	176	3611	-3.4	-0.7
3612A	40	46.7	4	5	0	0	400	34	495.7	307	3612	1.2	2.3
3613A	66.7	40	7	6	0	0	433.3	42	553	267	3613	-0.9	1.9
3614A	53.3	53.3	4	5	0	0	400	37	515.7	297	3614	1.8	3.1
3615A	53.3	66.7	4	6	3	0	400	43	533	287	3615	-0.8	0.1
3616A	20	40	2	3	3	4	850	38	922	39	3616	1.3	3.4
3617A	33.3	26.7	5	4	4	4	550	37	627	213	3617	1.6	3.6
3618A	66.7	66.7	4	2	5	4	500	45	648.3	200	3618	0.7	4.3
3619A	60	53.3	4	2	6	4	600	42	729.3	139	3619	1.4	4.3
3619A?	13.3	46.7	1	3	4	3	533.3	28	604.3	226	3619	0	0
3620A	53.3	46.7	2	1	5	3	600	38	711	151	3620	1.1	4.6
3621A	73.3	46.7	6	2	5	2	640	49	775	105	3621	-1.8	1.1
3622A	66.7	73.3	6	2	4	2	680	52	834	73	3622	-1.5	1.6
3623A	66.7	53.3	5	1	4	1	680	46	811	83	3623	-5.5	-4.3
3624A	53.3	40	2	3	0	1	360	29	459.3	328	3624	2.2	3.1
3625A	80	60	8	2	3	0	520	47	673	179	3625	-6	-6

3626A	73.3	46.7	6	2	0	4	550	41	682	170	3626	-1.7	-0.2
3627A	73.3	86.7	2	5	0	1	500	42	668	187	3627	0.7	3.2
3628A	60	66.7	3	2	0	4	533.3	36	669	182	3628	-0.3	-0.2
3629A	60	46.7	2	4	5	2	640	45	759.7	119	3629	-1.1	-0.4
3630A	53.3	46.7	3	3	0	4	800	45	910	46	3630	1	1.8
3631A	53.3	53.3	3	3	1	0	520	36	633.7	210	3631	-2.4	0.9
3632A	33.3	40	2	4	3	1	520	34	603.3	227	3632	1.8	2.2
3633A	60	33.3	5	2	0	0	720	39	820.3	78	3633	0	0
3634A*	33.3	20	4	1	2	0	400	25	460.3	327	3634	1.5	2.8
3635A	60	20	5	4	4	3	450	37	546	275	3635	1.5	3.2
3636A	40	40	1	1	4	0	300	24	386	372	3636	1.3	4
3637A	55	70	8	3	0	2	633.3	57	771.3	108	3637	-0.6	3.6
3637B	20	40	3	2	3	0	66.7	18	134.7	401	3637	2	2
3638A	40	60	8	5	3	0	360	40	476	318	3638	-0.3	3.9
3639A	40	20	4	2	8	1	800	43	875	60	3639	0	0
3642A	60	35	7	5	4	0	520	48	631	211	3642	1.6	1.8
3642B	45	30	4	3	0	3	650	38	735	134	3642	0	0
3643A	53.3	66.7	7	8	0	0	900	51	1035	13	3643	-2.3	-0.1
3644A	65	60	8	3	2	0	866.7	64	1004.7	18	3644	-3.6	-1.9
3644B	55	45	8	4	0	0	800	56	912	43	3644	-0.3	1.1
3644C	60	35	6	3	0	0	633.3	47	737.3	131	3644	1.7	4.5
3644D	66.7	40	6	4	0	0	640	42	756.7	122	3644	1.4	3.8
3644E	46.7	40	6	3	0	0	633.3	43	729	140	3644	0.2	1.6
3644F	55	20	7	1	0	2	600	40	685	168	3644	0.2	4.6
3646A	26.7	26.7	3	3	3	4	520	34	586.3	245	3646	-0.9	0.7
3648A	46.7	40	7	7	4	3	750	49	857.7	64	3648	0.4	4
3649A	40	35	4	2	4	4	480	39	569	260	3649	-4	-1.2
3650A	46.7	40	3	3	3	3	500	35	598.7	235	3650	0.2	3.2
3651A	46.7	80	5	10	9	2	360	54	512.7	298	3651	0.5	2.9
3652A	66.7	33.3	6	6	8	0	320	43	440	346	3652	1.9	3.3
3653A	53.3	46.7	5	9	4	6	900	57	1024	15	3653	1.3	3.8
3654A	80	45	6	4	4	0	666.7	59	805.7	86	3654	-4.3	-1
3654B	55	50	4	2	4	3	360	43	478	317	3654	NA	NA
3655A	46.7	26.7	5	4	5	2	360	36	449.3	339	3655	NA	NA
3660A	65	35	4	3	9	4	400	50	520	294	3660	NA	NA
3661A	55	26.7	5	3	7	0	350	37	446.7	340	3661	NA	NA
3663A	86.7	86.7	7	3	6	0	950	61	1139.3	1	3663	NA	NA
3901A	60	73.3	2	4	2	0	760	47	901.3	51	3901	NA	NA
3901B	60	40	4	3	0	0	560	36	667	188	3901	NA	NA
3902A	65	40	4	5	0	0	733.3	50	847.3	68	3902	NA	NA
3902B	60	45	5	3	0	1	700	51	814	81	3902	NA	NA
3902C	60	60	6	5	2	1	750	53	884	56	3902	NA	NA

3905A	70	55	5	7	3	1	800	57	941	34	3905	NA	NA
3905B	45	55	4	7	2	1	600	46	714	148	3905	NA	NA
3905C	50	65	4	5	3	2	666.7	47	795.7	91	3905	NA	NA
3906A	66.7	26.7	2	4	2	5	200	32	306.3	393	3906	NA	NA
3907A	26.7	46.7	6	5	3	4	450	38	541.3	281	3907	NA	NA
3908A	45	60	6	5	4	3	600	51	723	142	3908	NA	NA
3909A	46.7	33.3	0	0	0	0	466.7	19	546.7	273	3909	NA	NA
3910A	46.7	60	4	4	2	2	680	45	798.7	89	3910	NA	NA
3911A	20	5	2	0	0	0	360	15	387	371	3911	NA	NA
4001B	45	40	5	4	2	4	600	47	700	159	4001	NA	NA
4001C	45	55	5	3	1	3	700	46	812	82	4001	NA	NA
4001D	55	30	5	3	3	3	680	48	779	99	4001	NA	NA
4001E	60	65	4	3	1	2	600	50	735	134	4001	NA	NA
4002A	50	30	2	3	3	3	500	42	591	241	4002	NA	NA
4002B	40	66.7	5	2	0	1	520	37	634.7	208	4002	NA	NA
4003A	35	60	4	5	0	1	440	40	545	277	4003	NA	NA
4003B	65	60	4	5	4	0	640	54	778	102	4003	NA	NA
4004A	46.7	66.7	0	4	2	1	450	33	570.3	259	4004	NA	NA
4004B	55	40	3	3	3	1	360	38	465	325	4004	NA	NA
4005A	60	26.7	2	2	0	3	280	27	373.7	377	4005	NA	NA
4006A	26.7	13.3	3	2	0	0	400	21	445	343	4006	NA	NA
4101A	85	55	5	4	0	0	566.7	54	715.7	146	4101	NA	NA
4101B	60	45	6	0	0	0	560	41	671	181	4101	NA	NA
4101C	55	35	6	6	0	0	700	51	802	87	4101	NA	NA
4101D	53.3	33.3	7	2	6	0	600	46	701.7	158	4101	NA	NA
4101E	35	60	7	7	0	0	400	41	509	299	4101	NA	NA
4101F	75	40	8	7	0	5	640	59	775	105	4101	NA	NA
4101G	50	45	6	3	2	0	520	43	626	214	4101	NA	NA
4104A	75	30	0	5	0	0	600	44	710	153	4104	NA	NA
4104B	55	45	5	0	0	0	480	37	585	247	4104	NA	NA
4104C	75	50	0	5	0	0	466.7	44	596.7	236	4104	NA	NA
4104D	33.3	46.7	4	5	0	0	300	30	389	368	4104	NA	NA
4104E	65	35	0	0	0	0	400	32	500	304	4104	NA	NA
4104F	60	60	0	7	4	0	480	47	611	224	4104	NA	NA
4104G	46.7	50	6	6	6	0	466.7	42	581.3	253	4104	NA	NA
4105A	60	25	6	4	0	0	440	38	535	284	4105	NA	NA
4105B	70	45	8	4	0	0	600	53	727	141	4105	NA	NA
4106A	26.7	26.7	5	3	0	5	400	31	466.3	323	4106	NA	NA
4107A	40	46.7	3	6	4	0	600	41	699.7	160	4107	NA	NA
4108A	40	20	6	2	0	3	360	29	431	348	4108	NA	NA
4109A	26.7	26.7	2	2	5	0	520	30	582.3	251	4109	NA	NA
4201A	60	80	1	1	1	5	250	34	398	363	4201	NA	NA
4202A	40	40	1	6	1	3	300	29	391	367	4202	NA	NA

4203A	86.7	53.3	0	7	3	5	400	44	555	266	4203	NA	NA
4204A	65	45	5	3	6	0	300	45	424	351	4204	NA	NA
4204B	55	45	5	5	0	4	560	48	674	176	4204	NA	NA
4204C	50	45	6	6	0	0	566.7	48	673.7	177	4204	NA	NA
4204D	46.7	26.7	6	4	8	0	433.3	42	524.7	292	4204	NA	NA
4205A	65	55	6	10	7	0	560	61	703	157	4205	NA	NA
4205B	60	53.3	7	9	0	2	400	50	531.3	288	4205	NA	NA
4206A	80	50	7	4	0	0	400	49	541	282	4206	NA	NA
4206B	55	45	6	4	0	0	600	45	710	153	4206	NA	NA
4206C	50	60	9	4	0	0	533.3	51	656.3	195	4206	NA	NA
4206D	40	40	5	3	0	0	366.7	35	454.7	334	4206	NA	NA
4206E	65	40	7	4	2	0	520	47	638	205	4206	NA	NA
4207A	0	40	3	3	1	1	80	16	128	402	4207	NA	NA
4208A	46.7	60	2	6	0	2	480	38	596.7	237	4208	NA	NA
4209A	40	26.7	2	5	0	2	400	29	475.7	319	4209	NA	NA
4210A	26.7	33.3	2	0	2	0	433.3	26	497.3	305	4210	NA	NA
4211A	40	53.3	6	3	9	0	600	47	711.3	150	4211	NA	NA
4301A	46.7	40	4	5	4	2	360	37	461.7	326	4301	NA	NA
4301B	45	40	2	7	1	1	533.3	44	629.3	212	4301	NA	NA
4301C	40	46.7	5	2	1	1	350	29	445.7	342	4301	NA	NA
4301D	40	46.7	5	1	2	0	450	30	544.7	278	4301	NA	NA
4302A	80	40	7	5	0	0	640	34	772	107	4302	NA	NA
4302B	80	40	6	5	0	0	640	33	771	109	4302	NA	NA
4302C	60	40	6	0	0	5	320	24	431	348	4302	NA	NA
4303A	60	60	9	2	9	0	666.7	64	806.7	85	4303	NA	NA
4303B	65	55	9	0	0	1	533.3	50	663.3	190	4303	NA	NA
4303C	50	65	7	3	4	2	633.3	58	764.3	113	4303	NA	NA
4303D	53.3	40	10	2	5	3	533.3	50	646.7	201	4303	NA	NA
4303E	60	60	5	5	5	2	600	50	737	132	4303	NA	NA
4303F	66.7	73.3	4	2	0	0	400	37	546	275	4303	NA	NA
4304A	60	60	5	5	0	4	640	48	774	106	4304	NA	NA
4305A	46.7	40	8	5	10	4	520	53	633.7	210	4305	NA	NA
4306A	46.7	33.3	0	4	0	0	320	24	404	361	4306	NA	NA
4306B	46.7	26.7	2	6	0	0	320	27	401.3	362	4306	NA	NA
4306C	40	33.3	2	7	0	0	280	27	362.3	384	4306	NA	NA
5701A	6.7	20	8	2	2	0	240	22	278.7	396	5701	NA	NA
5701B	80	53.3	6	3	6	0	500	45	648.3	199	5701	NA	NA
5701C	80	55	6	8	0	0	560	55	709	155	5701	NA	NA
5702A	40	60	6	3	0	10	350	41	469	322	5702	NA	NA
5703A	100	100	10	10	10	10	520	93	760	118	5703	NA	NA
5703B	40	50	6	3	0	0	800	47	899	52	5703	NA	NA
5703C	45	45	6	3	0	0	680	44	779	99	5703	NA	NA
5704A	25	5	0	0	8	0	440	25	478	317	5704	NA	NA
5704B	80	40	1	5	0	3	720	51	849	67	5704	NA	NA

5705A	40	66.7	0	1	5	0	920	47	1032.7	14	5705	NA	NA
5705B	45	45	0	1	0	0	480	31	571	257	5705	NA	NA
5705C	60	40	0	0	0	0	520	30	620	216	5705	NA	NA
5705D	30	45	0	0	0	0	600	30	675	173	5705	NA	NA
5705E	46.7	50	0	0	0	0	250	22	346.7	389	5705	NA	NA
5705F	70	55	3	6	0	0	1000	59	1134	2	5705	NA	NA
5706A	40	35	2	2	0	0	720	37	799	88	5706	NA	NA
5706B	60	40	5	3	0	0	560	42	668	187	5706	NA	NA
5706C	30	40	3	1	0	0	800	38	874	61	5706	NA	NA
5706D	45	55	6	2	0	0	750	43	858	63	5706	NA	NA
5707A	35	10	5	6	4	4	550	39	614	222	5707	NA	NA
5707B	60	50	6	2	4	0	480	46	602	228	5707	NA	NA
5707C	65	85	9	9	0	4	450	61	622	215	5707	NA	NA
5707D	75	35	4	2	0	0	400	36	516	296	5707	NA	NA
5708A	60	40	5	0	8	3	280	43	396	365	5708	NA	NA
5710A	66.7	40	8	4	0	0	650	41	768.7	110	5710	NA	NA
5710B	53.3	60	5	4	9	0	450	44	581.3	253	5710	NA	NA
5711A	60	53.3	7	2	5	2	600	45	729.3	139	5711	NA	NA
5712A	66.7	80	0	8	10	0	760	54	924.7	38	5712	NA	NA
5712B	73.3	73.3	10	10	0	0	880	64	1046.7	11	5712	NA	NA
5712C	73.3	80	5	5	0	5	933.3	66	1101.7	6	5712	NA	NA
5713A	73.3	53.3	2	10	0	0	700	40	838.7	71	5713	NA	NA
5714A	55	30	8	5	5	0	900	53	1003	19	5714	NA	NA
5715A	40	55	5	2	7	1	733.3	45	843.3	69	5715	NA	NA
5715B	35	25	4	5	2	2	450	34	523	293	5715	NA	NA
5716A	60	45	6	6	5	6	666.7	54	794.7	92	5716	NA	NA
5716B	60	35	7	4	6	3	500	49	615	220	5716	NA	NA
5717A	85	80	8	3	0	5	700	63	881	57	5717	NA	NA
5717B	100	60	5	6	7	0	950	66	1128	4	5717	NA	NA
5718A	53.3	46.7	6	3	5	0	450	38	564	262	5718	NA	NA
5718B	46.7	33.3	4	3	0	0	600	34	687	166	5718	NA	NA
5718C	40	46.7	4	1	0	0	250	23	341.7	390	5718	NA	NA
5719A	100	53.3	10	6	0	0	800	55	969.3	30	5719	NA	NA
5720A	66.7	53.3	9	4	0	0	400	39	533	287	5720	NA	NA
5721A	80	40	8	2	0	2	550	47	682	170	5721	NA	NA
5721B	53.3	100	9	5	5	5	800	59	977.3	27	5721	NA	NA
5722A	50	40	5	2	0	4	500	39	601	231	5722	NA	NA
5722B	50	25	4	0	5	0	500	34	584	248	5722	NA	NA
5723A	55	65	6	0	4	3	1000	52	1133	3	5723	NA	NA
5723B	26.7	60	5	4	5	0	900	45	1000.7	21	5723	NA	NA
5724A	66.7	40	4	6	0	0	650	39	766.7	111	5724	NA	NA
5725A	60	46.7	7	3	0	0	760	45	876.7	59	5725	NA	NA
5725B	20	53.3	3	3	0	0	280	24	359.3	385	5725	NA	NA

5726A	6.7	33.3	0	1	0	0	333.3	12	374.3	376	5726	NA	NA
5727A	53.3	0	6	0	4	2	840	41	905.3	49	5727	NA	NA
5728A	100	86.7	6	4	6	0	760	63	962.7	31	5728	NA	NA
5728B	60	40	7	7	0	0	600	41	714	148	5728	NA	NA
5729A	60	53.3	5	4	0	0	750	41	872.3	62	5729	NA	NA
5729B	53.3	20	5	3	0	0	1000	43	1081.3	8	5729	NA	NA
5730A	40	40	2	6	0	4	600	36	692	163	5730	NA	NA
5731A	53.3	46.7	0	0	0	0	400	23	500	304	5731	NA	NA
5732A	66.7	60	10	3	7	2	850	58	998.7	22	5732	NA	NA
5735A	46.7	40	8	1	0	3	360	34	458.7	330	5735	NA	NA
5740A	40	53.3	5	3	7	0	400	39	508.3	300	5740	NA	NA
5740B	86.7	80	8	5	0	7	560	59	746.7	128	5740	NA	NA

APPENDIX J - Embedded RFID Moisture Monitoring System Specifications

RFID Reader

Manufacturer: Convergence Systems Limited
Model Number: CS108
Notes: Requires CS108 Java/ CS108 C# Application for Android or iOS phone (with bluetooth)
Contact: Rod Saunders, 808.205.0321

RFID Tags

Manufacturer: SmarTrac Technology Group, Inc.
Model Number: Dogbone RFMicron Magnus S-2 Wet Inlay
Vendor: www.atlasrfidstore.com
Contact: Bill Barr, Product Management, 206.305.1226

Application Note AN006
Sensor And Temperature Measurements

1 Introduction

Sensor tags based on Magnus®-S produce a Sensor Code which gives information about the sensor tag's environment. In addition, Magnus®-S3 chips can generate a Temperature Code indicating the chip temperature. To maximize the precision of sensor and temperature measurements, the user should understand and account for effects related to the reader transmission frequency, the amount of power received by the sensor tag, averaging, and command timing. This note describes best practices for maximizing the accuracy of measurements with Magnus®-S.

2 Sensor Code Measurements

2.1 Channel Frequency Effects

Legal regulations governing ISO 18000-6C communication forbid readers to continuously transmit on a single frequency for an unlimited time. Instead, readers typically transmit on a set of frequency channels, periodically hopping between them in a non-sequential, random-looking order.

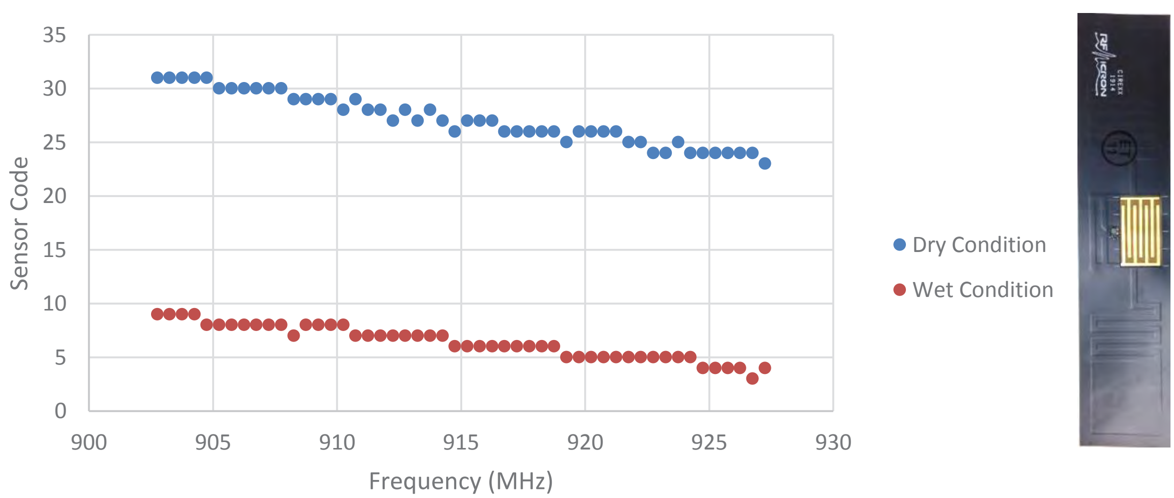


Figure 1 Sample Magnus®-S2 Sensor Codes for a moisture sensor in dry and wet conditions

The Sensor Code provided by Magnus®-S chips indicates changes in antenna impedance, which can be caused by factors the sensor tag is designed to sense, such as moisture, or the proximity of something metallic. But impedance also depends on frequency, which means that Magnus®-S can report different Sensor Codes when it is read repeatedly, as the reader changes its transmission frequency.

Typically, the Sensor Code will vary approximately linearly with frequency, and the line will shift up or down in response to a change in the sensing stimulus. For example, Figure 1 plots the measured Sensor Code as a function of frequency for a Magnus®-S2 sensor tag designed to sense moisture.

It is possible for Sensor Codes to saturate at their extreme values (0 and 31 for Magnus®-S2). It is a good idea to ignore readings at these extremes to ensure that only data within the dynamic range of the sensor are used in the measurement. Saturation is more likely for sensor tags which exhibit a Sensor Code vs. frequency plot with a large slope (Figure 2). Sensor tags designed to be placed on metal often have this feature.

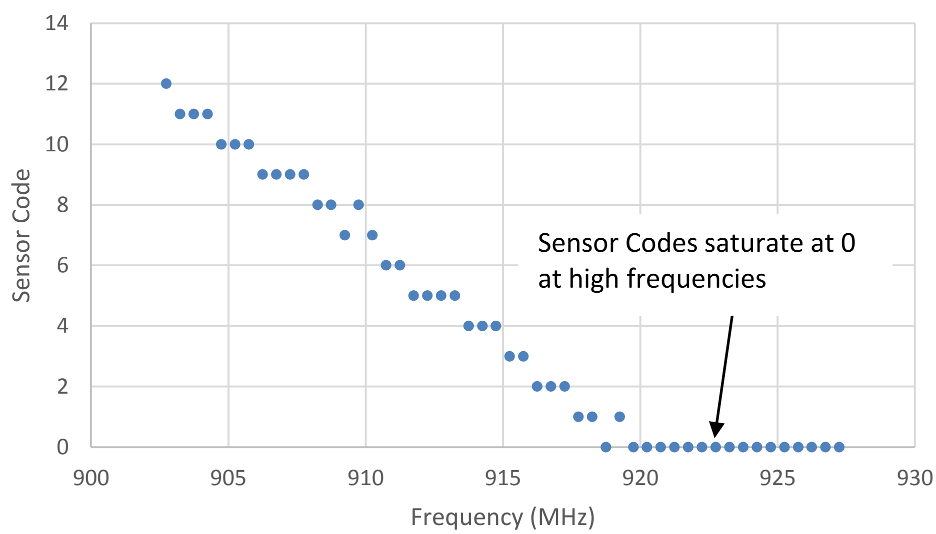


Figure 2 Example Magnus®-S2 Sensor Code results showing saturation at high frequencies

2.2 Summarizing A Set Of Sensor Code Measurements

When the Sensor Code is plotted against frequency, it is straightforward to visually recognize a change in sensor condition. However, it is often preferable to condense the data to a single number which eliminates frequency dependence and focusses entirely on the sensor environment. Combining results from different frequencies can also average out random noise and improve precision. Table 1 describes three possible approaches to dealing with frequency-dependence and reducing a series of readings to a single number.

Table 1 Techniques For Dealing With Frequency Dependence

Technique	Pros	Cons
Use Sensor Code value from one frequency only	• Simplest to implement	• Regulatory requirements prevent continuous transmission at a single frequency; compliance will limit the sample rate • Lack of averaging reduces precision.
Use the average Sensor Code value over the entire frequency band.	• Simple to implement • Averaging over frequency improves precision and reduces numerical noise	• Must collect enough data to ensure that the frequency range is adequately and evenly sampled to avoid biasing the results
Use regression analysis to fit the Sensor Codes to a line, then take the value of the line at some fixed frequency. (See Appendix for details.)	• Regression process improves precision and reduces numerical noise. • Can achieve good results even when sampling only a fraction of the frequencies in the band	• More complex to implement.

Note that different regulatory regimes have significantly different numbers of frequency channels in them. For example, in North America there are 50 frequency channels, each 500 kHz apart, between 902 and 928MHz. Under the European ETSI EN 302 208 specification, there are only 4 channels between 865 MHz and 868 MHz. So the time required – and precision gained – by reading the Sensor Code at every channel before producing a result depends significantly on regulatory requirements.

2.3 Power Distortion

When a Magnus®-S chip is receiving a low amount of power, the Sensor Code it generates is fairly independent of the precise power level. Once the received power increases beyond a certain threshold, the Sensor Code is distorted by the excess power: higher power levels produce artificially low Sensor Code values. Figure 3 shows a sample plot of the relationship between power and the Sensor Code value, averaged over frequency. (Keep in mind that power received by the sensor tag depends on many factors such as distance and antenna gain, not just reader output power.)

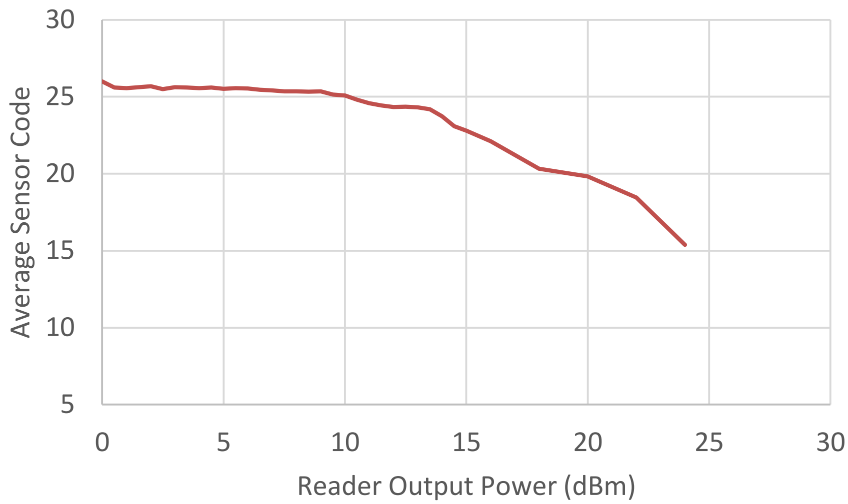


Figure 3 Sample Sensor Code vs. reader output power plot for a Magnus®-S2 sensor tag

For applications using low-gain antennas, low-power readers, large minimum separations between sensor tag and reader, or when high sensor precision is not needed, this effect may not be a concern. But in some cases, it will be desirable to ensure that the sensor tag does not receive enough power to avoid distortion. This can be achieved readily by making use of the On-Die RSSI Code.

The On-Die RSSI Code is a 5-bit value (0-31) which can be read from Magnus®-S and gives an indication of the amount of power it is receiving. Larger values correspond to higher power. If the On-Die RSSI Code is above the recommended upper threshold given in Table 2, the reader power should be reduced to avoid affecting the Sensor Code.

It is also desirable to avoid delivering very low amounts of power to Magnus®-S, mainly because this increases the chance of reading at some frequencies but not others. This is more likely to occur with readers and/or antennas which exhibit non-uniform radiated power across frequency. In some cases, very low power may also pull the Sensor Code lower, but by a maximum of only about 1 code value. If the On-Die RSSI Code is below the recommended lower threshold given in Table 2, the reader power should be increased, if possible.

Table 2 Recommended Ranges For On-Die RSSI Code When Taking Sensor Measurements

Recommended On-Die RSSI Values	Magnus®-S2	Magnus®-S3
Upper threshold (to avoid affecting Sensor Code)	21	21
Lower threshold, if achievable (to reduce the chance of missed reads)	16	13

In some applications, the power received by the sensor tag can be kept fairly constant (by fixing the placement of the sensor tag and reader and controlling interference in the transmission path). In those cases, the reader power can be preset to a level which achieves the codes in Table 2 and held constant. But often, the reader will be programmed to search automatically for a desirable power level and periodically adjust itself to account for changes in the environment that affect received power.

As noted earlier, higher On-Die RSSI Codes correspond to more received power, up to a maximum code of 31. However, if Magnus®-S is receiving very large amounts of power, the reader may fail to communicate properly with the tag. This should only occur when the reader is transmitting at or near the upper EIRP limit allowed by regulations, and only when the sensor tag is within a few feet of the reader. But for this reason, when searching for a desirable power level, the reader should start at a lower power and increase if necessary, rather than beginning at maximum power.

3 Temperature Measurements

Magnus®-S3 chips generate a 12-bit Temperature Code which can be translated into a measurement of the temperature of the chip. As with the Sensor Code, achieving accurate temperature readings requires consideration of a few factors.

3.1 Calibration

To account for manufacturing variability, Magnus®-S3 chips come with single-point calibration data pre-stored in the User memory bank, which is individually determined for each chip. By reading and applying this data, the user can translate the 12-bit Temperature Code into a temperature in degrees C. More information on the calibration data format is available in Application Note AN002.

3.2 Averaging

Unlike the Sensor Code, the Temperature Code does not depend on channel frequency. However, it does contain some inherent noise which can be reduced by averaging multiple readings. Table 3 gives the approximate number of samples that need to be averaged in order to obtain a particular confidence interval for the Temperature Code.

Table 3 Temperature Code Confidence Intervals

Temperature Code 95% Confidence Intervals	Number of Samples
+/- 3	1
+/- 2	3
+/- 1	9
+/- 0.5	35
+/- 0.25	139

Note that Table 3 refers to Temperature Code values, not actual temperatures. Temperature precision depends on multiple factors in addition to Temperature Code noise. In approximate terms, the Temperature Code will change by about 7.5 for every 1 degree C change in temperature.

3.3 Command Timing

The temperature sensor circuit is activated by a specific Gen2 UHF Select command (See Application Note AN002 for more details). After sending this Select command, the reader should emit a continuous wave for 3 ms. This will provide low-noise power for the temperature circuit and will maximize measurement accuracy. After the 3 ms of continuous wave, the commands for accessing the tag memory can be issued to retrieve the Temperature Code.

3.4 Power Distortion

As with the Sensor Code, the power received by the tag can affect the Temperature Code, so the user should always check the received power when taking readings. The amount of power the chip is receiving can be readily determined by reading the On-Chip RSSI Code (See Application Note AN002 for more information).

At very low received powers (On-Chip RSSI of 5 or lower) the Temperature Code is not reliable. At high received power levels, the Temperature Code can indicate a temperature higher than the actual value. The most accurate Temperature Code readings are available when the On-Chip RSSI Value is between 13 and 18, as indicated in Table 4.

Table 4 On-Chip RSSI Values For Temperature Measurements

Absolute Minimum	Preferred Minimum	Preferred Maximum
5	13	18

4 Notices

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