

2019

A Framework for Risk Analysis and Vulnerability Assessment of the Rubble Masonry at Tuzigoot National Monument

Dorcas Corchado Colón

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A Framework for Risk Analysis and Vulnerability Assessment of the Rubble Masonry at Tuzigoot National Monument

Abstract

Located on the summit of a sandstone and limestone ridge overlooking the Verde River in Clarkdale, Arizona lies a cluster of two to three story masonry Native American ruins known as Tuzigoot National Monument. This thesis focused on Group III, which contains the first pueblo rooms built on the site, still containing historical stabilization material. Despite partial collapse, burial and excavation, these walls have endured. Since excavation in 1933, Tuzigoot has been continuously stabilized reflecting changing attitudes in materials and methods. In light of past and current preservation management, this thesis studied the construction and performance of the rubble wall masonry at Tuzigoot National Monument in order to develop a risk and vulnerability analysis of the walls. It resulted in the development of a Historic Preservation Guide that included a phased methodology consisting of a comprehensive development and preservation history, the development of a rapid assessment survey to identify wall vulnerability and priority, and a detailed comprehensive condition assessment for the most at-risk walls to identify monitoring and/or remedial interventions.

Keywords

masonry deterioration, rapid assessment survey, conditions assessment, deterioration, ruins

Disciplines

Historic Preservation and Conservation

Comments

Suggested Citation:

Corchado Colón, Dorcas (2019). *A Framework for Risk Analysis and Vulnerability Assessment of the Rubble Masonry at Tuzigoot National Monument* (Masters Thesis). University of Pennsylvania, Philadelphia, PA.

A FRAMEWORK FOR RISK ANALYSIS AND VULNERABILITY ASSESSMENT
OF THE RUBBLE MASONRY WALLS AT TUZIGOOT NATIONAL
MONUMENT

Dorcas Estelle Corchado Colón

A THESIS

in

Historic Preservation

Presented to the Faculties of the University of Pennsylvania in
Partial Fulfillment of the Requirements of the Degree of

MASTER OF SCIENCE IN HISTORIC PRESERVATION

2019

Advisor and Program Chair
Frank G. Matero
Professor

Acknowledgements

First, I would like to thank Frank G. Matero, my thesis advisor, for introducing me to the American Southwest, for suggesting such a wonderful topic, and for the opportunity to work with such an outstanding ruin, Tuzigoot National Monument. His guidance and encouragement during this process was invaluable.

I would also like to thank the U.S. National Park Service, and the Tuzigoot National Monument staff, for all of their help in acquiring archival materials and taking their time to share their current stabilization methodologies.

I am very grateful of Sara Stratte, for her ongoing support and assistance during my site visit performing the RAS, the Conditions Assessment and photo documentation the site.

I would also like to thank my classmates, the HPSV Class of 2019, in particular Emelyn Nájera for her endless moral support, during all stages of this thesis.

Lastly, I want to thank my family, which no matter the distance has been able to support me through these two years.

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1.0 Introduction

Located on the summit of a sandstone and limestone ridge overlooking the Verde River in Clarkdale, Arizona lies a cluster of two to three story masonry Native American ruins known as Tuzigoot National Monument. The name “Tuzigoot” is derived from the Tonto Apache phrase for the crooked waters of the Verde River that surrounded and provided agricultural land to the site.¹

The builders took full advantage of the natural topography of the site, which allowed strategic views of the surrounding lands, protecting them from native invasions.² The Tuzigoot buildings are characterized by the staggered pyramid-like emplacement of the pueblo onto the ascending topography of the site. Archaeological excavation suggests that the development of the pueblo occurred from the top of the ridge, downward towards the east and south.³ The independent development of room clusters reflects the phased expansion of the pueblo that coincided with cultural shifts represented by the groups that occupied the site.⁴ Like most ancestral mesa-top pueblos in the region, these are of rubble wall construction built using the available local stone and soil mortar.

Despite partial collapse, burial and excavation, these walls have endured. Since excavation in 1933, Tuzigoot has been continuously stabilized over time reflecting changing preservation attitudes in materials and methods. In recent years the Monument’s approach

¹ Louis Caywood and Edward Spicer, *Tuzigoot, The Excavation and Repair of a Ruin on the Verde River Near Clarkdale Arizona* (Arizona: National Park Service, 1935), 13.

² Gelentler, Mark, *A History of American Architecture: Buildings in their Cultural and Technological Context* (Hanover and London: University Press of New England, 1999), 28-29.

³ Caywood and Spicer, *Tuzigoot*, 18-22.

⁴ *Ibid.*

to stabilization has shifted to embrace a more uniform appearance by repointing entire elevations where work is needed. Current mortar repointing formulations are consistent and based on empirical observations of performance in the field.⁵

During excavation in the 1930's the park divided the ruins into six different groups I-VI.⁶ This study focuses on Group III, located at the highest elevation of the ridge; it contains the first pueblo rooms built on the site, and includes the only rooms still containing historical stabilization material. In light of past and current preservation management, this thesis aims to study the construction and performance of the rubble wall masonry at Tuzigoot National Monument in order to develop a risk and vulnerability analysis of the standing walls. This research is part of a current Cooperative Ecosystem Unit (CESU) project to examine and develop a risk and vulnerability framework at several cultural parks in the Southern Arizona (SOAR) region. By identifying specific vulnerabilities across a range of archaeological sites within SOAR, it is hoped that park managers can learn and share how best to plan and manage for the effects of climate change and other stresses. Condition assessment records wall materials (stone and mortar), construction methods, and past treatments as well as environmental context. It is the intention that this study allows the park to better address cyclical preservation needs based on a better understanding of wall performance over time.

This thesis will also result in the development of a Historic Preservation Guide that includes a phased methodology consisting of a comprehensive development and

⁵ Current maintenance and stabilization approach and procedures, and mortar formulations were conveyed through interviews and meetings with Tuzigoot National Monument personnel.

⁶ Caywood and Spicer, *Tuzigoot*, 15.

preservation history, the development of a rapid assessment survey that can be used by the park for future cyclical evaluation to identify wall vulnerability and priority based on wall condition, integrity and significance, and a detailed comprehensive condition assessment for the most at-risk walls to identify monitoring and/or remedial interventions.

1.1 Scope of Work

In order to develop a comprehensive understanding and assessment of the walls at Tuzigoot, five (5) stages of investigation were completed: (1)technical research on masonry wall statics and performance, (2)archival research on the history of excavation and stabilization at Tuzigoot, (3)on-site data collection and conditions recording on selected walls (4) evaluation of results, and (5)future monitoring and conservation recommendations.

(1)The technical research stage supported the development of the conceptual background for this study: **A Framework for Risk Analysis and Vulnerability Assessment of the Rubble Masonry at Tuzigoot National Monument**. It explored the technical literature on types of rubble-masonry construction and typical deterioration mechanisms, focusing on the masonry's physical and mechanical properties and performance for each type of construction. The thorough understanding of the individual elements that configure the wall to complete a system, the external elements that affect or interrupt it, and how they all interact, were crucial to develop a framework for the on-site survey and vulnerability study of the walls at Tuzigoot.

(2) The archival research focused on gathering excavation, stabilization (conservation) and maintenance records to develop a comprehensive chronology and history of Group III of the Tuzigoot ruins. The creation of a chronology of excavation and

stabilization as well as noting wall failure over time provided information that influenced and informed assessment of both deterioration as well as treatment performance, which comprised an important part of this assessment. In addition, previous conditions and maintenance recording methods were studied to evaluate their effectiveness in documenting conditions and stabilization for future reference.

(3)The on-site data collection and conditions recording consisted of two main documentation events. First, a rapid assessment survey (RAS) was undertaken to determine the most vulnerable walls by recording the existing conditions and evaluating the type and severity of each condition observed on wall units. In situ condition assessments were preceded and informed by technical and archival research prior to the site visit. In every case the focus was on wall construction and condition, rather than wall elevation alone. The premise guiding this assessment was that in order to understand the overall condition and performance of the masonry walls at Tuzigoot, a structural systems-approach is necessary first before looking at the individual conditions of individual wall elevations and rooms. The objective of the RAS was to quantify the deterioration level of each wall segment to determine which were the most vulnerable at-risk walls. Ideally, this survey will potentially help resource managers prioritize monitoring and stabilization based on wall integrity and condition. The RAS was followed as needed by a detailed graphic survey and assessment of the most vulnerable walls, based on the results of the highest-scoring wall of the RAS. The objective of the comprehensive condition assessment is to determine patterns of deterioration based on the combination of collected field data, and archival evidence of important historic events. The conditions were traced over ortho-rectified photography of

the wall elevations, locating specific conditions along with past maintenance and stabilization information of the walls.

(4) All of the data collected on site was processed in the form of graphic diagrams and an appropriate wall pathology was interpreted. In order to determine the wall pathologies, these graphic analyses were supplemented with the information learned from the technical rubble wall performance research. A full understanding of the walls at Tuzigoot, their construction, their stabilization and maintenance history, and their performance and deterioration aided the interpretation and development of the in-depth, site-specific diagrams that show the actual construction and performance of the rubble masonry walls. Diagrams include all elements that are external and intrinsic to the wall that could be and are contributing to its deterioration. This includes moisture flow paths, points of moisture accumulation and processes of deterioration that were depicted based on a combination of the data collected from the RAS, and the comprehensive conditions assessment. The graphic interpretations helped explain the sources of deterioration within the wall systems, the current conditions, and inform short & long-term weather related remedial and preventive conservation for future treatments and maintenance.

(5)The last part consists of treatment, recording and monitoring recommendations. Recommendations will be grounded from the results and findings from the previous assessment and analysis of the walls.

2.0 Background

Prior to evaluating the conditions found on site, background information concerning rubble masonry construction, its deterioration, and site-specific information will be discussed in four (4) different sub-sections: (1.1) Technical Rubble Masonry Construction, (1.2) Construction, Maintenance, and Stabilization Chronology⁷, (1.3) Rubble Masonry Construction at Tuzigoot and current wall typologies in Group III, and (1.4) the Environmental Conditions at Tuzigoot. Site-specific data and an integrated examination of the rubble-masonry-system will aid wall diagnostics and its corresponding pathologies.

2.1 Technical Research: Rubble Masonry

A general understanding of the common types of rubble masonry construction, their mechanics and how external deterioration mechanisms affect performance set a baseline understanding that informs the operation and deterioration factors of any rubble masonry system. This section discusses the shared properties common to all rubble masonry construction. It begins by examining the components, properties, and functions within the wall system and continues with an exploration of rubble masonry mechanics that expands on load distribution analysis and anticipates how different conditions affect the stability of the system. It is vital to contextualize this information and interpret how material relationships occur within the masonry construction at Tuzigoot. This section will conclude by describing the case of the walls at Tuzigoot and understanding these processes within the existing wall typologies found on site.

⁷The Construction, Maintenance and Stabilization chronology section will also expand on the forms that have been used historically to record the maintenance and stabilization events.

Rubble Masonry Components

Rubble masonry walls can be constructed dry (without mortar) or laid with any type of bedding mortar. Even the simplest walls are complex systems employing stones selected and placed according to size and shape, coursing patterns, and wythe bonding and the presence or absence of subsurface foundations. Wet laid walls are compound systems consisting of two materials: stone and mortar.⁸ Usually, the biggest stones are placed first at the base and the remaining spaces between them are filled with smaller stones and mortar to increase surface contact.⁹ Although these two classes of materials have their own properties and functions they are interchangeably dependent on each other in the total performance of the walls.¹⁰ This is why their interactions as well as their isolated behavior must be examined.¹¹ Given the wide diversity of materials and the complexity of rubble masonry construction, this section will elaborate on the materials and typologies similar to those observed at Tuzigoot.

Typical rubble masonry construction uses natural stones, either surface harvested boulders or extracted from bed and ledge-rock, typically of non-uniform shapes and sizes found in proximity of the site.¹² The connective component, the mortar, is a simple or complex binder (clay, lime, gypsum, cements) mixed with water and aggregates.^{13,14} Both the

⁸ L. Dispasquale, L. Rovero and F. Fratini, “Ancient Stone Masonry Constructions” in *Nonconventional and Vernacular Construction Materials*, (Cambridge: Woodhead Publishing, 2016), 303.

⁹ Ibid, 317.

¹⁰ Anna Anzani, Guiliana Cardani, Paola Condoleo, Elsa Garavaglia, Antonella Sais, Cristina Tedech, Claudia Tiraboschi, Maria Rosa Valluzzi “Understanding of historical masonry for conservation approaches: the contribution of Prof. Luigia Binda to research advancement,” *Materials and Structures* 51, no. 6 (2018): 2.

¹¹ Ibid.

¹² Dispasquale, Rovero and Fratini, *Ancient Stone Masonry Constructions*, 317.

¹³ Ibid, 310.

¹⁴ Water and clay-soil are mixed to create the required consistency for the paste. Aggregates found from river beds are added to compensate and reduce the shrinkage and strengthen the product.

masonry units and the mortar components will depend on geographical locations and the geological formations found near each site. These ultimately define the masonry system and its properties.¹⁵

In general, stones and mortars have a brittle mechanical behavior, meaning that the material breaks under stress values that are very low under tension and higher under compression.^{16,17} How the loads are distributed throughout the wall system will depend on the stone, the mortar and the combined masonry configuration.¹⁸

Due to the low resistance of both mortar and stone to tensional loads²², it becomes vital for the performance of the wall that the loads within the system are distributed in a uniform manner.²³ If on the contrary, the loads are concentrated and not uniformly distributed, overloads will surpass the tensional capacity causing stresses in punctual locations of the stone and mortar, resulting in irreversible deformation and collapse.²⁴ Depending on the load and the amount of stress exerted upon the materials, areas with a concentration of stress will fail causing microcracks²⁵, cracks²⁶, or fractures²⁷, in advance of

¹⁵ Dispasquale, Rovero and Fratini, *Ancient Stone Masonry Constructions*, 310.

¹⁶ Giorgio Torraca, *Porous Building Materials: Materials Science for Architectural Conservation*, (Rome, ICCROM, 1982), 19.

¹⁷ Giorgio Torraca, *Lectures on Materials Science for Architectural Conservation*, (Los Angeles, The Getty Conservation Institute, 2009), 12.

¹⁸ L. Binda, A. Fontana and L. Anti, *Load Transfers in Multiple Leaf Masonry Walls*, p. 1488.

²² Brittle materials are not resistant to tensional loads or loads that transmit loads in an axial or horizontal manner. On the contrary stones and mortars have a good compression load transmission or the vertical transmission of loads.

²³ Dispasquale, Rovero and Fratini, *Ancient Stone Masonry Constructions*, 315.

²⁴ Giorgio Torraca, *Porous Building*, 21.

²⁵ Cracks that appear in the microstructure of the stone.

²⁶ The surface linear split of a material without breaking into individual pieces.

²⁷ Fracture is the breaking of a hard material.

the under-stressed areas. This effect can cause accelerated deterioration and lead to consequential failure of the complete wall system.^{28,29}

These two elements, stone and mortar, are constantly interacting and provide support to each other. The mortar bonds the stones together and provides permanent and transient load dispersion amongst the system.³⁰ Stones are the stiff (and brittle) elements that make the wall durable and structurally capable of supporting compressive loads.³¹ The load resistance (in tension and compression) and the stability of masonry constructions vary among systems because they rely on the shape and resistance of the stones used, the stone arrangement, and the stone: mortar ratio.³² In order to ensure structural stability the mortar should have enough flexibility and bond to withstand the permanent and transient loads.³³ Where mortar does not have these properties, it results in cracking, loss, and planar instability of the wall system, eventually leading to partial or full collapse.

Stone Morphology and Distribution

The wall performance will depend not only on the geo-chemical characteristics of the local rock, but also on the dimensions of the stones and their arrangement in the wall.³⁴

‘Undressed’ or ‘rough’ imply a lack of consistency and variability in size and shape which

²⁸ Giorgio Torraca, *Porous Building*, 21.

²⁹ Ibid, 24.

³⁰ Dispasquale, Rovero and Fratini, *Ancient Stone Masonry Constructions*, 315.

³¹ Ibid, 317.

³² Ibid, 324.

³³ Caspar Groot, “RILEM TC 203-RHM: Repair Mortars for Historic Masonry, Performance Requirements for Renders and Plasters” in *Materials and Structures*. (Delft: University of Technology, Faculty of Civil Engineering and Geosciences, 2012), 1278.

³⁴ Dispasquale, Rovero and Fratini, *Ancient Stone Masonry Constructions*, 315-16

define the term ‘random rubble’.³⁵ Typically the best performance can be expected where the majority of the wall consists of medium to large regular-shaped stone blocks with even bearing surface and a homogeneous load distribution.³⁶ Systems that have random rubble masonry require more mortar between stones in order to provide a surface that ensures balance and a stable assembly of the wall.³⁷ The mortar should produce sufficient bearing surface that compensates for the remaining gaps, that have resulted from the combination of different sizes and irregular shapes of stones that cause imbalance in the system.³⁸ Failure to do so will result in concentrated over-loads, causing stress and resulting in cracking, collapse and an exponential deterioration of the system.

Bonding Courses

There are two sub-types of random rubble masonry defined by coursing or the horizontal organization of stones. (1)‘Coursed random rubble masonry’ is organized in equal courses of stone of uniform height. (2)‘Uncoursed Random Rubble Masonry’(Figure 2) is randomly arranged of different heights of rubble stone.³⁹ Where masonry is coursed (Figure 1) the mechanical performance is better due to the even horizontal distribution of loads through the system.⁴⁰ The same concept is true for the load path where stones are aligned in wall faces; the path will be vertically direct and no interruptions will compromise the structure. Contrary to coursed rubble masonry, in walls where stones are irregular and there

³⁵ Ibid, 317.

³⁶ Ibid.

³⁷ Ibid.

³⁸ Ibid,324.

³⁹ Ibid, 317.

⁴⁰ Ibid.

is no coursing, the loads are imbalanced causing localized differential load distribution (Figure 2). In these cases the load paths will follow the shape of the stones and concentrate in specific concentrations creating stress in punctual locations. In un-coursed 'random rubble masonry' the load distribution will highly depend on the mortar between the stones to dissipate stress.⁴¹ While the type and amount of mortar plays a large role in the structural performance of the system, the way that the stones interlock, both in the coursing of elevation(s) and across the thickness of the wall (the wythes) will also impact the total wall performance. In the case of walls built with small of stones that do not overlap, the mortar should be able to provide balance by transferring the loads in the transverse direction.⁴²

The arrangement of stones in the perpendicular direction, where the connection occurs across the thickness of the wall (two opposite wythes), will aid the transverse interlock and secure the wall to prevent vertical separation. This is not always the case and different types of masonry constructions will behave differently.

⁴¹ Ibid.

⁴² Ibid, 315.

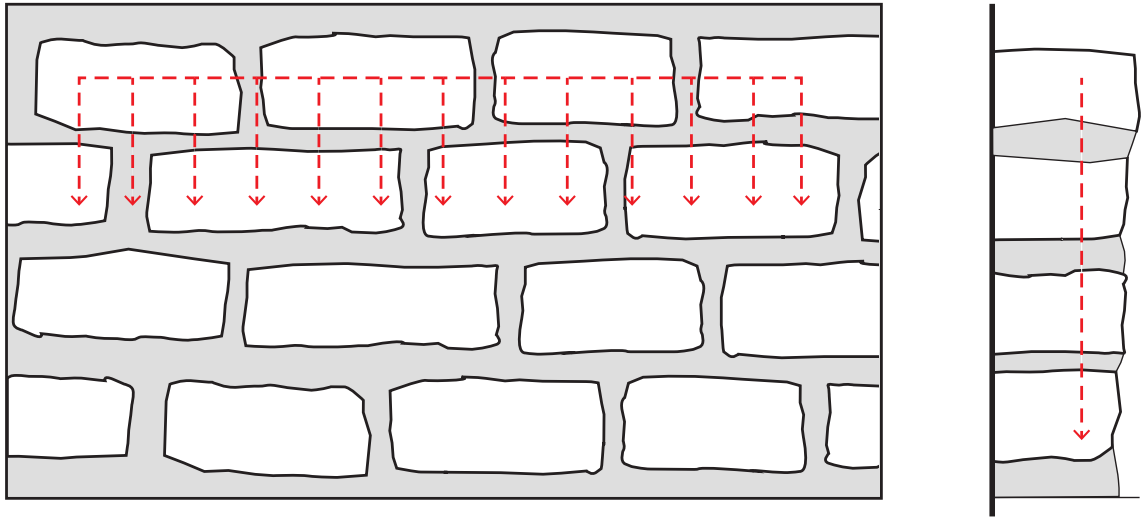


Figure 1 / 'Coursed random rubble masonry' which is organized in equal courses of stone of uniform height. In elevation the red dashed lines show the uniform horizontal load distribution of coursed rubble masonry. In section, the aligned stones allow the loads to have a direct vertical path.

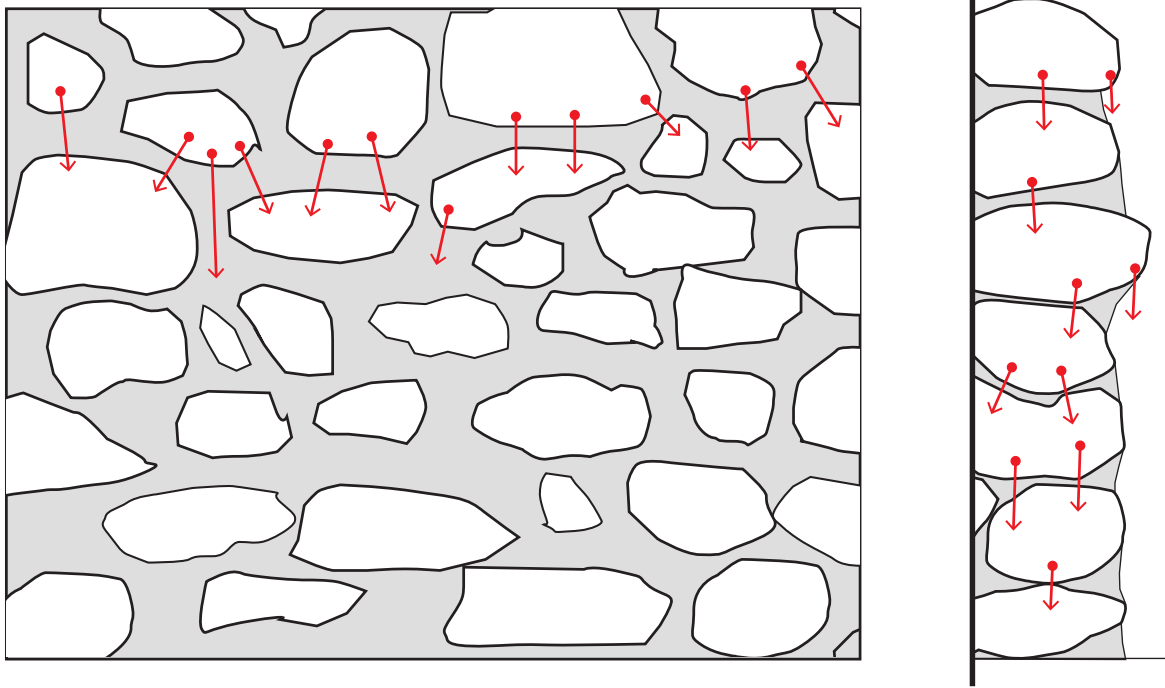


Figure 2 / 'Uncoursed Random Rubble Masonry' is randomly arranged of different heights of rubble stone. In walls where stones are amorphous and there is no coursing, the loads are imbalanced causing localized differential load distribution as shown in the diagram

Types of Uncoursed Random Rubble Masonry

Uncoursed random rubble masonry walls can be further subdivided into five different types that are defined based on the number of wythes and the way they interlock: (1) single-wythe(Figure 3a), (2) two well-interlocked wythes(Figure 3b), (3) two partially-interlocked wythes(Figure 3c), (4) two non-interlocked wythes(Figure 3d), and (5) three or more multiple wythes (Figure 3e). The structural stability of each type of wall is dependent of the load distributions and stone relationships across their wythes. The distribution of loads will depend on the geometry of each wythe, how the elements connect, if they connect, and the mechanical and geometrical properties of the stones.⁴³ Consequently, deterioration and structural failure will vary depending on how the loads are distributed.

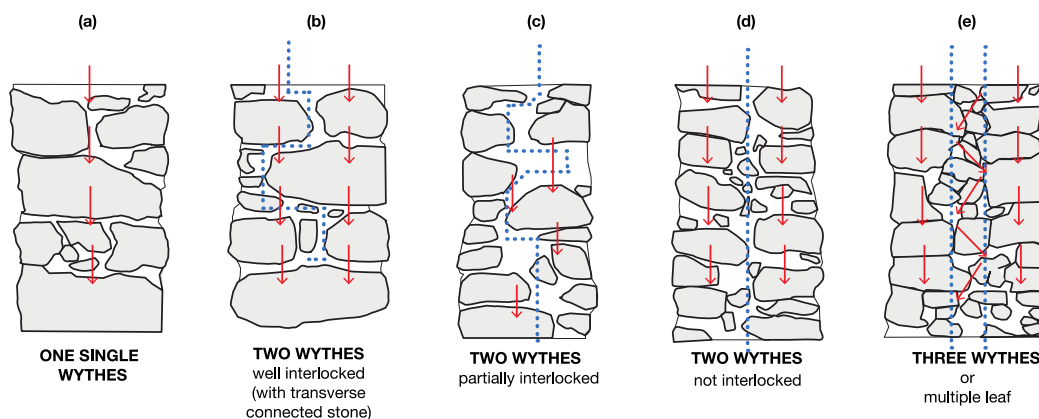


Figure 3 / Cross-section diagrams of the types of random rubble walls showing the stone interlock relationship(red) and the typical load path (blue), where the mortar is the weaker of the two components.

(1) Single-wythe (Figure 3a) refers to those walls where construction consists of a single course of superimposed stones, where either the same stone unit is visible from both

⁴³ Binda, Fontana, Anti, *Load Transfers in Multiple Leaf Masonry Walls*, 1488.

sides of the wall (through wall) or the course is not continuous throughout the wythe. In this type of wall, since the stones are erected over each other, the load continuously runs vertically through the stones and the mortar. Where the rubble masonry has suffered loss of mortar, discontinuities in the load path may cause localized differential load distribution that can stress the stones and result in failure of the wall system.

The double-wythe wall is sub-divided into three sub-categories: (2) well-interlocked (Figure 3B), where stones are interlocked with each other in a zig-zag way so that each wythe supports and connects to the other wythes; (3) partially-interlocked (Figure 3C), where the stones occasionally overlap with other stones from the opposing wythe; and (4) not-interlocked (Figure 3D), where wythes act as two walls stacked next to each other without cross wall stone-interlocking connections and usually a rubble core. Well-interlocked double wythe walls are the most structurally sound. The overlap of stones in this type of wall creates a stable interlock where each stone supports the other. This aids in the symmetrical distribution of loads that safeguards the connection of the two wythes. Similarly, the partially-interlocked double wythe wall distributes the loads from side to side, but it is not as consistent and tightly interlocked. This type is more susceptible to structural damage if mortar is lost. In the double wythe non-interlocked wall, there is no stone connecting the two wythes. This system behaves similar to two single-wythe walls, where the load paths of the two wythes are independent to each other.

Similar to double-wythe non-interlocked walls, (5) multiple-wythe type walls (Figure 3E) are composed of two exterior walls that are not connected, but are separated by another material, usually earthen or rubble fill, in between them.⁴⁴

Rubble Masonry Deterioration

Due to the variety of materials and types of construction in rubble masonry construction, deterioration may occur in different ways; it can be specific to a material (i.e. the stone itself), or it can extend to the whole wall system. This section will discuss external agents that affect the component materials which in turn can causing irreversible damage to the system. In porous materials, such as most stones used in masonry construction, microstructural stressing from moisture, frost, and thermal expansion, can cause specific damage that will initiate physical decay processes. Other exterior macro forces such as wind and invasive vegetation differential fill, and traffic loads can cause a more general damage to the system. This section will introduce both intrinsic and extrinsic stresses and will expand on the deterioration agents to explain different processes of deterioration and the conditions necessary for their occurrence.

Intrinsic Stresses

Stresses that are intrinsic to the masonry system depend on the unit materials, their morphology, and type of construction previously discussed.

⁴⁴ Ibid, 1490.

In porous materials, such as stone and mortar, water from many different sources will enter the system by absorption through the pores or existing cracks.⁴⁵ Water that enters the system and rises upward against gravity through the pore system from contact with wet soil is called rising damp. Water can also enter the system through direct contact with precipitation as falling damp. This latter construction can be especially problematic where water is held in reserve as snow and sits as caps on wall tops until it melts.

Once the water enters the masonry system, decay processes begin. First, the smaller pores inside the stones fill to capacity. This alone can result in weaker strengths making the stone more susceptible to damage. In the case where temperatures drop below freezing temperatures, the water-filled pores will begin to freeze and the resulting internal disruptive pressure can cause cracking, flaking and general disintegration.⁴⁶

Extrinsic Stresses

Some loads, such as the load of the accumulated stone itself are inherent to the wall system. These loads are permanent and will travel through the wall according to the wall construction as stated in the previous section. Extrinsic loads are those exerted from outside the system into it. Loads from differential fill, wind, and traffic loads are extrinsic to the wall system, and can easily disrupt the masonry according to the origin and direction of the load, the wall construction, and its condition.

⁴⁵ Torraca, *Lectures on Materials*, 82.

⁴⁶ *Ibid*, 32.

Differential Fill

The structural stability of walls is dependent on the load distributions across their wythes. The distribution of loads will depend on the geometry of each wythe and how the elements connect, if they connect. Consequently, deterioration will vary depending on the load distribution.

Undifferential and differential soil fill levels around walls result in different dead (permanent) loads and wall stresses that cause the walls to collapse or deform. In above grade single-standing walls with no fill, the walls do not have differential lateral loads exerted upon them. This maintains the wall in balance. In grounds with differential fill levels, larger amounts of loading from the fill force the wall towards the side of the wall that has no resistance. Differential fill can also hold and transmit moisture causing greater damage. This imbalance produces instability, deformation and eventual collapse (Figure 4 & Figure 5).

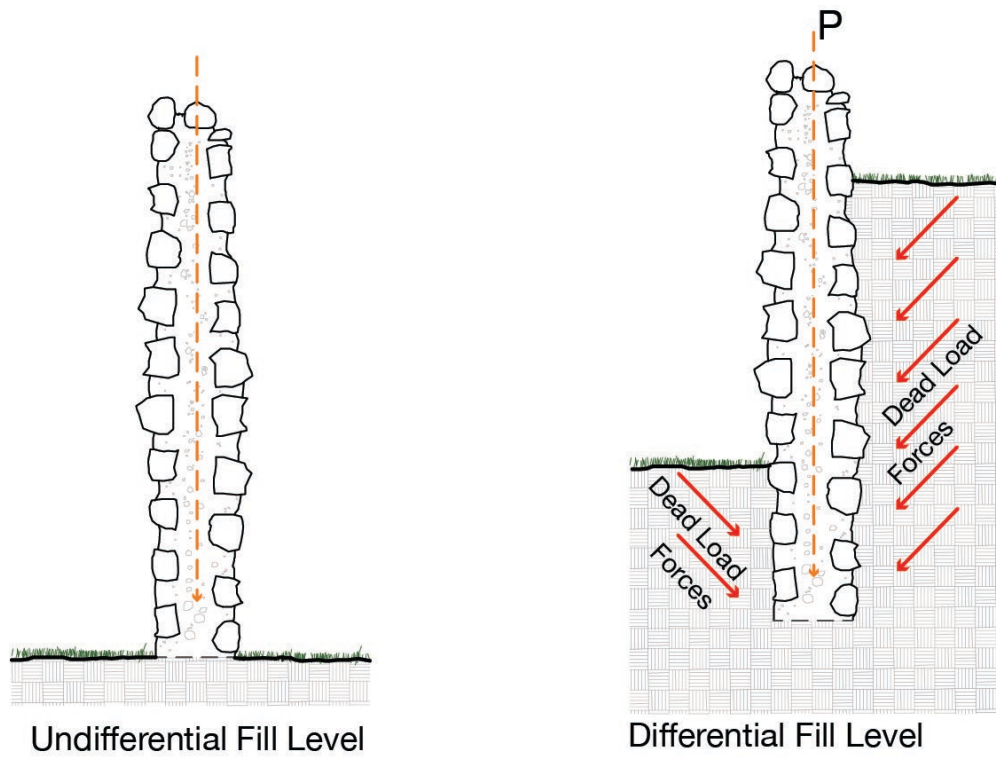


Figure 4 / Load distribution in undifferential fill and differential fill levels. While undifferential fill levels do not exert additional loads to the wall and keep it balanced, in cases where there is differential fill the wall experiences additional loads on one side, causing imbalance in the system.

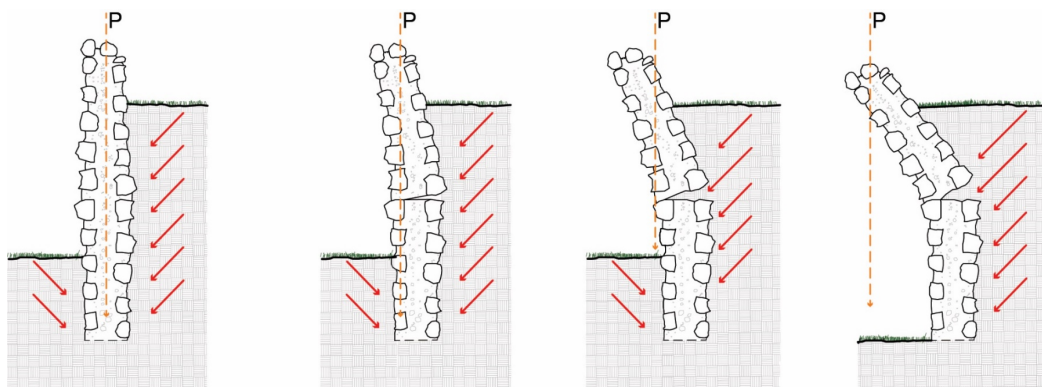


Figure 5 / Process of possible deformation and collapse caused by loads acting on a wall with differential fill.

Changes in External Loads

As previously discussed, rubble masonry is composed of non-uniform stones. Loads that are not planned for in the design or construction of a wall may disrupt the system, causing cracking differential movement.

Rubble Masonry Deterioration

Agents of deterioration of rubble masonry are similar to any masonry wall and include direct as well as indirect environmental factors. Direct environmental factors such as precipitation, wind and sun radiation, are those that affect the wall and are also related to indirect environmental factors. Indirect environmental factors are those such as water runoff, or surface splash, that are caused from direct deterioration, in this case water from precipitation and accumulation.

Precipitation moisture is one of the biggest causes of deterioration in historic structures.⁴⁷ Rain itself can find multiple entryways into the masonry wall system; it can enter through any opening in the wall caps, through water runoff, water splashing in the wall surface, or even by capillarity.

In the case where water intrusion occurs through openings or cracks in the wall caps, water can enter the interior of the wall unseen, causing irreparable damage to the interior structure. As water enters and travels downward through the core of the wall, it can remove and transport the fine material to the bottom, leaving large voids in the upper sections of

⁴⁷ Torraca, *Porous Building Materials*, 29.

the interior of the wall.⁴⁸ These voids allow the larger materials to detach and redistribute within the wall, and also fall to the base, causing internal pressure and the wythes to separate..⁴⁹ Eventually this can result in bulging, leaning, and collapse.⁵⁰

Water from precipitation can also enter the system when in contact with damp soil. Moisture will travel vertically and horizontally through the pores by capillarity and saturate the materials. As the moisture rises in different materials, different rates of expansion and contraction can occur as they saturate and dry, causing movement. Depending on the composition of the materials and their properties, it can result in expansion, displacement or erosion of the materials. This process can also cause efflorescence due to the crystallization of dissolved salts from the stones, mortar or soil.⁵¹

Water accumulation can also attract biological agents, which can have some impact in the deterioration of the materials.⁵² In some cases roots may increase the deterioration of masonry. Additionally, vegetation close to the structures is an indicator of a high concentration of moisture.⁵³

⁴⁸ D.M. Lilley and A.V. March, *Problems in Rubble-Filled Ransom Masonry Wall* in Transactions on the Build Environment, vol.26, (Newcastle: WIT Press, 1997), 420.

⁴⁹ Ibid.

⁵⁰ Ibid.

⁵¹ Torraca, *Porous Building Materials*, 85.

⁵² T. Stambolov and JR Ivan Asperen de Boer, *The deterioration and Conservation of Porous Building Materials in Monuments, A Review of Literature*, (Rome: DAPCO s.r.l., 1976), 27.

⁵³ Ibid.

Wind

With the help of wind pressure, rain can penetrate the system by forcing the water into the wall surface and absorbing it.⁵⁴ Depending on the direction of the wind one side of the wall may absorb more water than the other causing differential movement on both sides of the wall. Wind can also cause material erosion. The loss of mortar or stone surface can interrupt the load distribution causing stresses in punctual locations.

Animal Burrowing

In order for animals to dig their dwellings they remove and loosen exterior and interior wall material, specifically mortar. As previously discussed, mortar provides a surface to distribute the concentrated loads caused by the irregular shape of the stones. The lack of bonding surface not only allows for the wall to suffer intrusion of water, but also to fail to distribute the loads, causing localized concentrated stresses making the system prone to cracking, instability, and failure. Depending on how deep the burrowing is in the wall, movement and loss of stones can promote collapse.

Processes of Deterioration

The process of deterioration for above grade and below grade rubble masonry construction varies depending on the construction, their loads and how they interact. For instance, above grade structures are exposed, and unprotected from rain, snow, wind and

⁵⁴ Stambolov and Asperen de Boer, *The deterioration and Conservation of Porous Building Materials in Monuments*,18.

sun, while subterranean structures experience deterioration from the same sources, but differently.

Above grade structures consist of free-standing walls that connect and enclose an area and are shielded, to provide protection. Their deterioration is caused by agents mentioned above. When debris accumulates and plants begin to colonize the area conditions of decay can begin. Roof materials decay and eventually begin to fail. Mortar and masonry on the walls continue to erode until eventually stability is lost and major collapse occurs. The structure is buried within its own debris, and will erode until completely buried.

As water continues to be absorbed, accumulated and distributed through the masonry differentially, depending in the collapse. Walls begin to bulge in response to differential dead loads. Without the roof protection, eventually the structure is buried by its own and foreign (e.g. aeolian) debris.

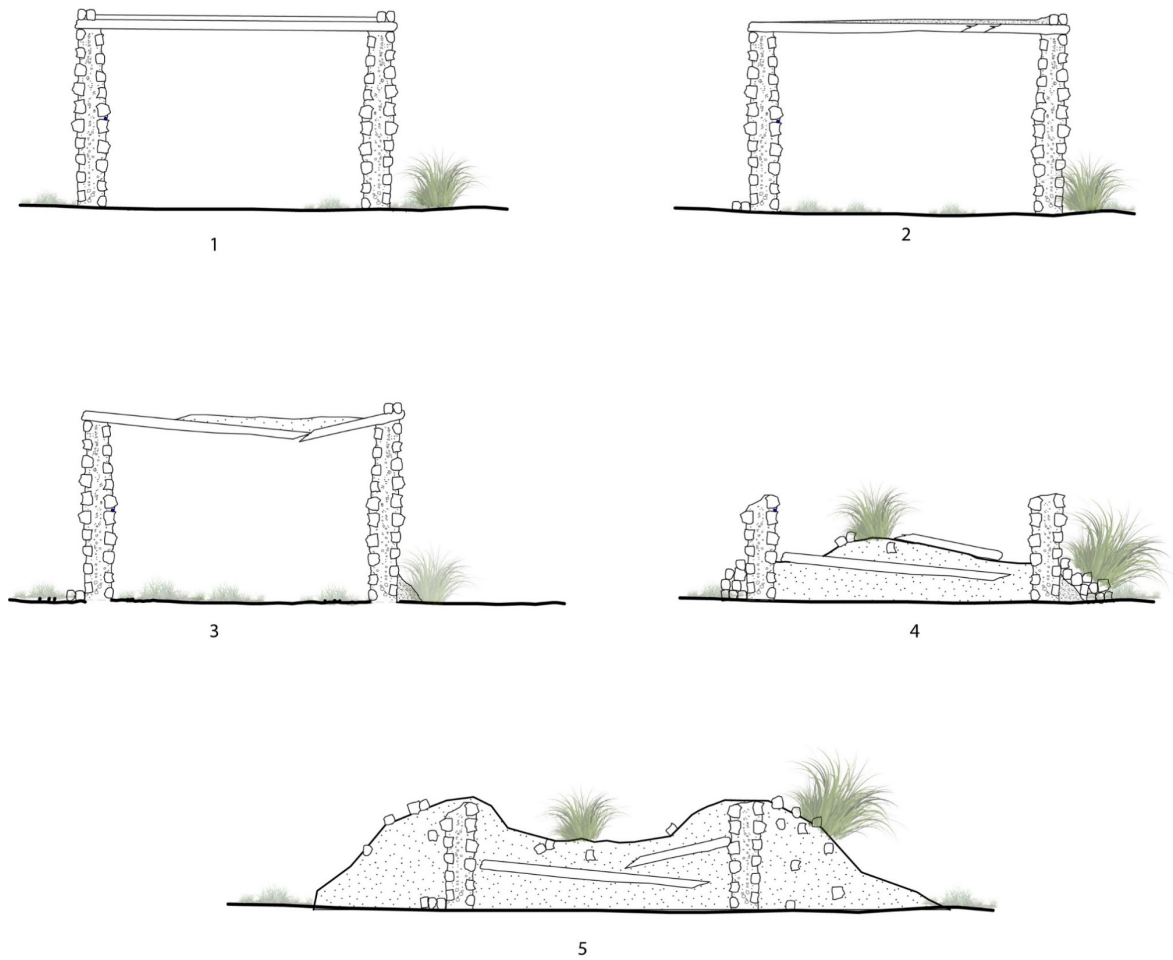


Figure 6 / Process of deterioration of above grade structures.

2.2 Site Construction, Maintenance and Stabilization Chronology

Tuzigoot as we see it today is the product of different periods of construction and abandonment, excavation, and preservation.⁵⁵ Although the specific stages of development of the pueblo are not definite, Caywood and Spicer, who excavated the pueblo in 1934-35, identified the superimposition of rooms, contrasting materials, room features, and

⁵⁵ Caywood and Spicer, 17

architectural elements.⁵⁶ According to existing research, the rubble masonry walls at Tuzigoot represent three periods of site occupation: (1) The First Period from 1000 to 1200 A.D., (2) The Second Period dated between 1200 and end of 1300 A.D. and the (3) Third Period from 1300 to 1420. Although Tuzigoot itself was occupied prior to 1000 A.D., only these three periods will be discussed on this study, as they are the periods that pertain to the use of rubble masonry walls on the site.

First Period (1000-1100 A.D.)

The first rubble masonry rooms at Tuzigoot were built between A.D. 1000-1100 (Figure 7) in the form of a small pueblo of approximately eight rooms (II-1, II-2, II-5, III-7, III-8, III-9, III-12, III-18). Rooms III-7, III-8 and III-9 were constructed using rounded cobbles, and rough blocks of sandstone and limestone, and did not show any evidence of support posts.⁵⁷ Room V-30, to the south east of the ridge, and underneath room V-31, was also identified as an earlier room. In contrast to the other rooms, this room used interior support posts in roof construction and had a circular, clay lined fire installation.⁵⁸

Sometime between 1000 and 1200, rooms III-1, III-7, III-8, and III-9 were abandoned in favor of the east slope of the ridge. The abandoned rooms fell into disrepair and were gradually buried under refuse accumulation.⁵⁹

⁵⁶ Ibid, 17-19.

⁵⁷ Ibid, 19.

⁵⁸ Ibid.

⁵⁹ Caywood and Spicer, *Tuzigoot*, 39.

Second Period (1200 to end of 1300 A.D.)

In the early 1200s, with the Sinagua intrusion, eight or more additional rooms were built (Figure 8) at the top of the ridge (III-2, III-3, III-4, III-5, III-6, III-11, III-10, III-13), and partially covered the rooms that were previously abandoned (III-7, III-8, III-9).^{60,61} Stones from the walls of the abandoned rooms were reused to build the walls of the new rooms.⁶² After these were built an accelerated growth of the pueblo continued to expand towards the east (Group I) and south (Group V, north section) slope of the ridge.⁶³

Third Period (1300-1420 A.D.)

The third period of development was stimulated by the great drought of 1276 that continued up to 1299.⁶⁴ The lack of resources in other settlements induced a large wave of immigration of other native groups to establish new settlements in Tuzigoot. This period (Figure 9) was characterized by an accelerated expansion that was conceived in the form of disconnected clusters of rooms of whole groups or families along the south (Group V), east (Group VI) and north (Group VI) slopes of the ridge.⁶⁵

The Sinagua continued to live and prosper here until the 1400s when the pueblo was suddenly abandoned perhaps to join the Pueblo communities of the North.⁶⁶

⁶⁰ Ibid, 19-20;39.

⁶¹ Dennis D. Neilson, *A Brief History of the Reconstruction and Stabilization of Tuzigoot National Monument*, (Tuzigoot National Monument, National Park Service, 1980), 13.

⁶² Caywood and Spicer, *Tuzigoot*, 19.

⁶³ Ibid.

⁶⁴ Dennis D. Neilson, *A Brief History*, 11.

⁶⁵ Louis R. Caywood and Edward H. Spicer, *Tuzigoot*, 19.

⁶⁶ Aron Mason, *The Administrative History of Tuzigoot National Monument*, (Tuzigoot National Monument:National Park Service, 1999), 2.

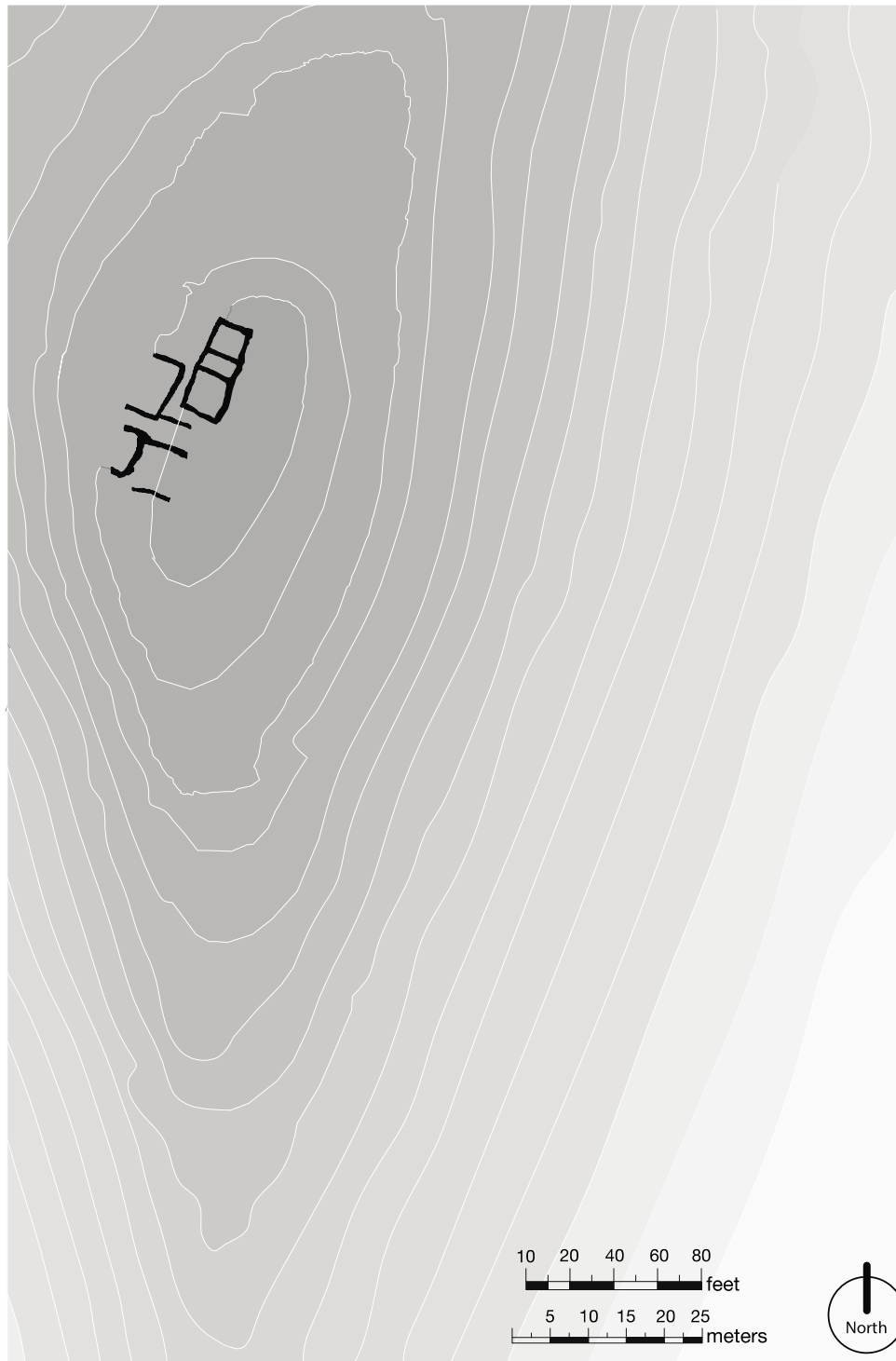


Figure 7 | Map of Tuzigoot's first masonry rooms. Drawing is depicted as excavated, and information was extracted from the Caywood and Spicer 1933-34 Excavation and Stabilization Report.

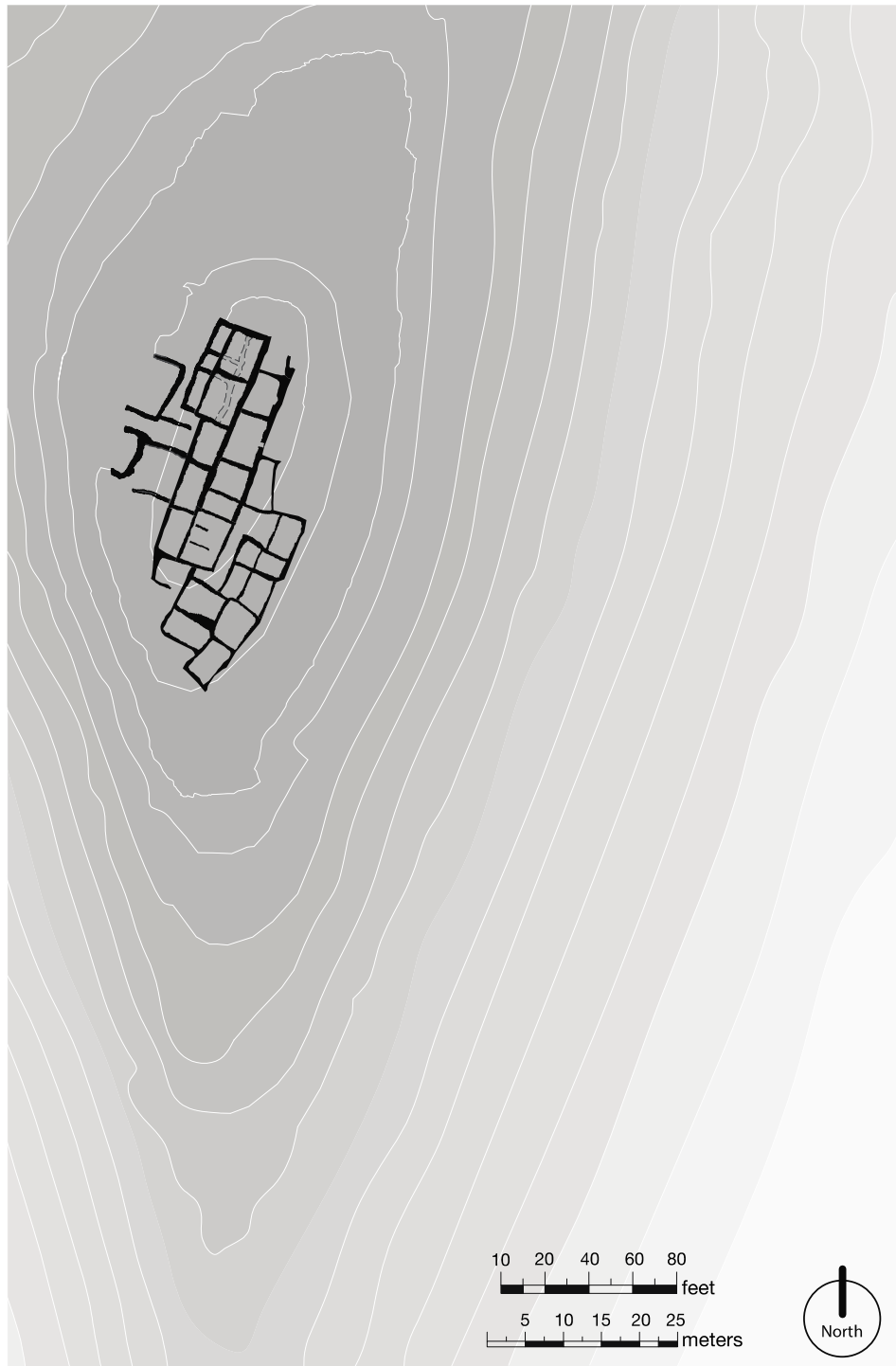


Figure 8 / Map of Tuzigoot growth in 1200 with the Sinaguan expansion. Drawing is depicted as excavated, and information was extracted from the Caywood and Spicer 1933-34 Excavation and Stabilization Report.

500 Years of Disrepair

For five-hundred years Tuzigoot was abandoned and consequentially became buried. During these years the site continuously switched ownership up until excavation. In 1583 Antonio de Espejo led a Spanish expedition that arrived to the surrounding area, where the Spanish exploited Yavapai people for mineral exploitation.⁶⁷ This continued until 1783, and by 1850 the U.S. government began to exercise power in the area.⁶⁸ By 1883 an area that included Tuzigoot became part of United Verde Valley Copper Company (UVCC), eventually becoming one of the most profitable and lucrative copper mining companies in the world.⁶⁹ But with the Great Depression, sales began to decrease and by 1932 the UVCC closed their operations.⁷⁰ The same year Franklin D. Roosevelt was elected president and by 1933 his public works projects were implemented, including the Civil Works Administration (CWA).⁷¹ One of the projects that was incorporated as part of the program to excavate, study and investigate Native American archaeological ruins was Tuzigoot, located on the property of the UVCC.⁷² In 1933 UVCC approved the excavation, and in 1934 archaeologist Louis Caywood and Edward Spicer served as the excavation supervisors.⁷³ During the excavation Tuzigoot was not yet part of the National Park Service, but stabilization and conservation efforts were employed. Soon after excavation Frank Pinkley, the Superintendent of the Southwestern Monuments of the National Park Service took an

⁶⁷ Aaron L. Mason, *The Administrative History of Tuzigoot National Monument*, 3.

⁶⁸ *Ibid.*, 4.

⁶⁹ *Ibid.*, 5.

⁷⁰ *Ibid.*, 7.

⁷¹ *Ibid.*, 9.

⁷² *Ibid.*, 10-11.

⁷³ *Ibid.*, 17.

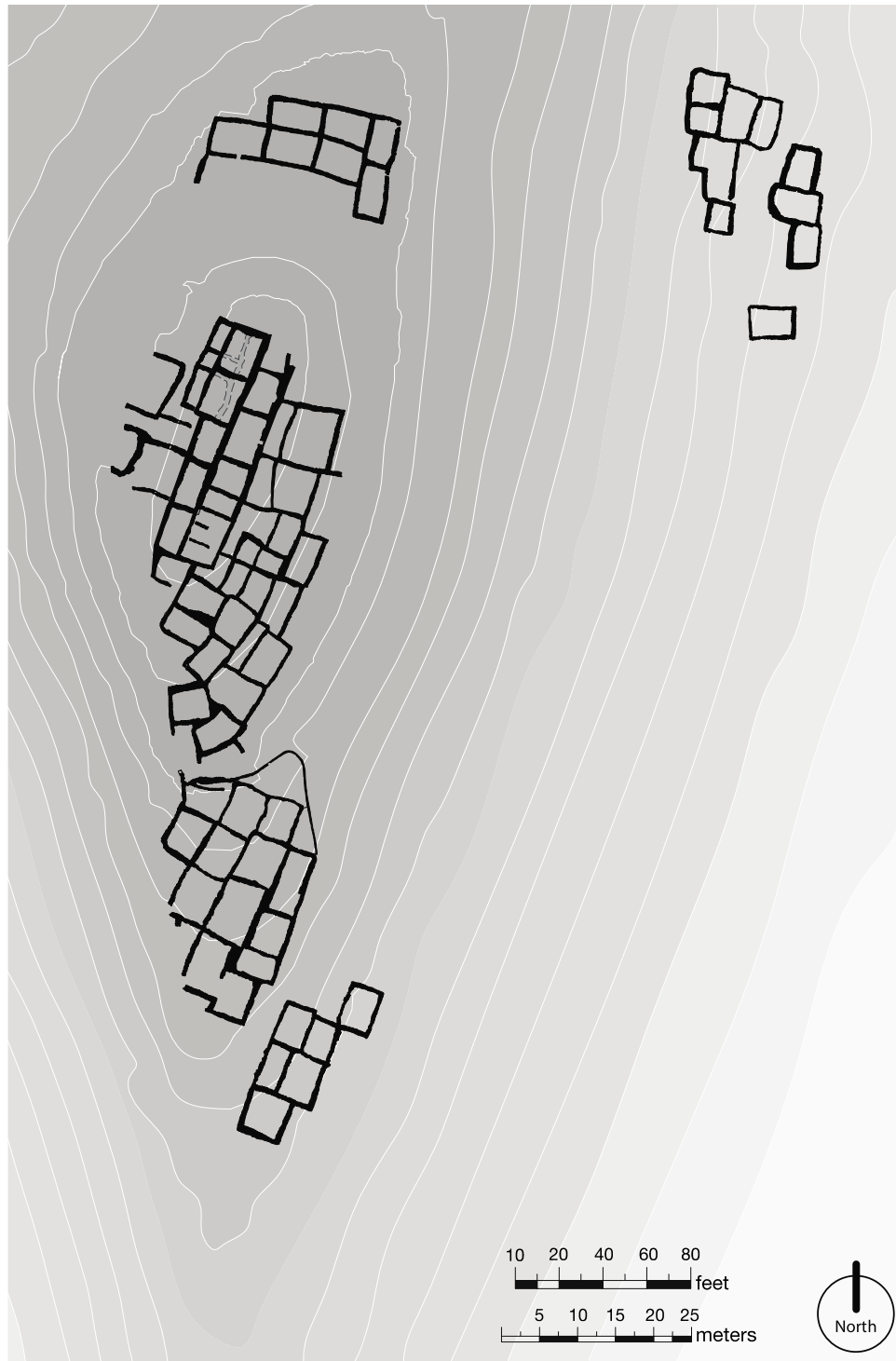


Figure 9 / Map of Tuzigoot growth in the Third Period. Drawing is depicted as excavated, and information was extracted from the Caywood and Spicer 1933-34 Excavation and Stabilization Report.

interest in Tuzigoot and suggested annexing the site to the Montezuma Castle National Monument, which was only 20 miles away.⁷⁴ Although Pinkley announced the approval from the Secretary of Interior with the best intentions, some legal and ownership transference issues prevented the establishment of Tuzigoot as a National Monument.⁷⁵ After some changes in the law the issue was resolved when, on July 27, 1939 President Roosevelt signed the proclamation that established Tuzigoot as a National Monument.⁷⁶ Tuzigoot is a National Monument of the YUMA/TUZI/WUPA Program of the Southern Arizona Office (SOAR) of the National Park Service.

Maintenance and Stabilization Chronology

The walls at Tuzigoot have been continuously stabilized by archaeologists and park personnel since excavation resulting in a range of different approaches of materials and methods. Past historic stabilization has been implemented piecemeal as needed, and not with a uniform whole-wall, or whole-room approach. In recent years the park has shifted its approach to embrace a more uniform appearance by repointing entire elevations by room. Current mortar repointing formulations are consistent and based on empirical observations of performance in the field.⁷⁷

Most of the park has now been stabilized using this approach; Group III is the last remaining group with historic stabilization material, and only some of the walls visually

⁷⁴ Ibid, 21.

⁷⁵ Ibid.

⁷⁶ Ibid, 24.

⁷⁷ Current maintenance and stabilization approach and procedures, and mortar formulations were conveyed through interviews and meetings with Tuzigoot National Monument personnel.

accessible to the visitors have been uniformly repointed following the present method. The areas that have not yet been repointed, have multiple mortar types from different stabilization campaigns with varying visual and performance properties. Walls have a variety of conditions such as burrowing holes, stone detachment, vegetation and mortar erosion, among others that expose the interior of the wall to the elements and compromise the stability of the wall. Understanding wall behavior overtime, and the complexity that derives from both the original wall construction and the combination of later repairs defines and explains current conditions and predicts future failure of the walls. While there are gaps in time when stabilization and conditions were not recorded, this section will attempt to understand and evaluate the historic evolution of wall assessment and stabilization performed in Group III in order to identify the campaigns, materials and previous wall failure.

Since excavation in 1933-34, Tuzigoot has been continuously maintained and stabilized reflecting shifting attitudes in materials, documentation, and methods of preservation. The methods for recording the existing conditions, preservation methods and the result of the work completed has changed based on previous experiences and to the extent of the activities commissioned by the National Park Service. Some campaigns have been much more effective in recording the work and conditions than others. Seven documents were used to assess previous and current stabilization procedures and work performed on the Group III walls: (1) Caywood and Spicer's 1935 excavation report, (2) Richert's 1953 Stabilization Report, (3) Shiner's 1962 Stabilization Report (Incomplete), (4) Voll's 1964 Maintenance Stabilization, (4) Mayer & Waggoner's 1968 Stabilization Report (5) Chamber's Drainage Project Report, (5) Triple "XXX" forms, and (6) 1998 Vanishing

Treasures forms, and (7) Current Pre-stabilization, Post-stabilization Forms, and Condition Assessment Wall Forms. The following sections give the reader a summarized chronology of the stabilization and repair work performed during each event and can be referred to using the wall and room identification map (Figure 10). For a more comprehensive wall-by-wall, room-by-room chronology refer to Appendix A.

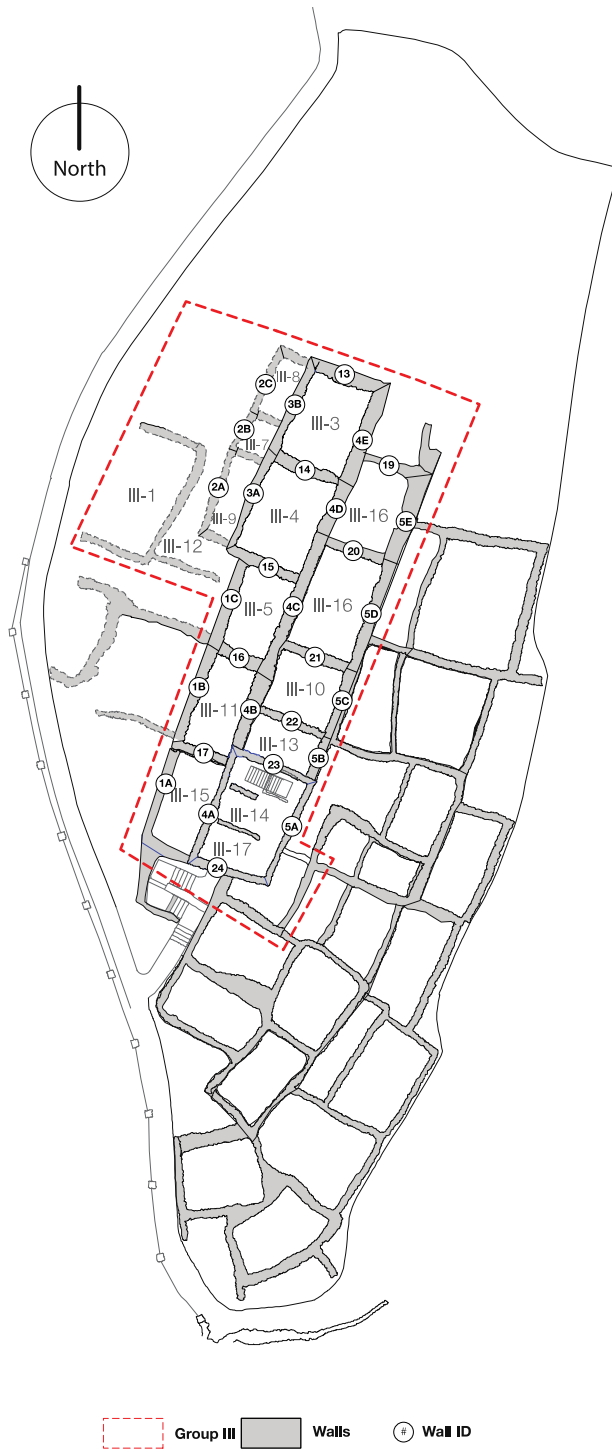


Figure 10 / Map of current walls under study with room ID, and the new Wall ID created for this study.

Excavation (1934-35)

The first document that describes Tuzigoot's architecture, its history, and methods of construction was Caywood and Spicer's 1935 excavation report. In this document the conditions and preservation procedures were recorded in the form of a narrative that consists of brief descriptions of the existing conditions at the time of excavation, original native constructive methods and materials examined by the archaeologists, observed deterioration, and the stabilization work performed during this campaign. The work completed is very broadly described, which left information gaps about the reconstruction and stabilization work completed. Diagrams and before and after photographs of the work performed supplement these accounts. Given the nature of this document as an excavation report, and not a study that records or assesses the conditions of the walls prior to repair work, the format does not allow for easy translation for future on-site evaluations of the pueblo walls. Nevertheless, it provided some before and after photographs, and later reports describe the work completed. Once converted into a room-by-room record of the walls, it became useful for future evaluations and diagnosis.

The first attempt to stabilize the ruins was conducted by the archaeologists Caywood and Spicer after excavation. The only existing record of the work performed on Group III during this stabilization campaign was extracted from later records produced by Roland Richert that recorded past stabilization events. Refer to (Figure 10) for this section. Richert recorded the capping and repointing of all the walls in rooms III-18, III-11 and III-9, and the capping of the walls in rooms III-8 and III-7.⁷⁸ Additionally the ceiling parapet, and a

⁷⁸Richert, *Stabilization Report*, 64-69.

rooftop rectangular hatchway of room III-14, the citadel room, was restored in the north-east corner of the roof.⁷⁹ Although it is unclear who directed the project, after excavation, CWA funds were used to create a new visitor path (Figure 11) that allowed the public to access the Citadel room at the top of the pueblo.⁸⁰ This path was built using flat flagstone limestone caps (Figure 12 and 13) on top of the center wall of the pueblo between rooms III-3, III-2, III-4, III-6, III-5, III-10, III-11, III-13, and III-11, and the North wall of Room III-3 (wall segment 13A).⁸¹

Jack Cotter (1941-42;1947)

Another stabilization project was undertaken by Jack Cotter in 1941-42 and 1947, custodian of Tuzigoot at the time. No records created by Cotter exist but later 1953 forms from Roland Richert's Report also recorded previous repairs, including Cotter's stabilization work. This stabilization campaign was interrupted for a period of 5 years due to WWII; the first phase being from 1941-42, and the second phase in 1947.⁸² Minor repairs were completed during these events: pointing and capping on all walls of room III-18, all the walls in room III-7 were pointed (walls 7A, 8A, 2B and 3B), in room III-8 the north (6A) and east (3B) walls were pointed, the north wall of room III-11 (wall 16A) was pointed, "minor repairs at east end" of the south wall in room III-3 (wall 14A), and the south wall in room III-11

⁷⁹ Ibid.

⁸⁰ Ibid, 38.

⁸¹ Ibid, 45;47;59.

⁸² Bailey and Kleinman, *Tuzigoot Pueblo Stabilization History (Ongoing): Tuzigoot National Monument*, 2008. (Tuzigoot National Monument: National Park Service, 2008), 12.

(17A) was pinned. All walls in room III-9 were badly eroded and undercut requiring all to be repaired.⁸³

A combination of the lack of maintenance between 1942 and 1947 as a result of WWII and an abnormal rainfall event, left supporting walls to decay and fall into a state of disrepair that forced the regional superintendent to intervene.⁸⁴ That year stabilization focused on repairing the damage caused by the previous rainfall event.⁸⁵ A section of the east wall in room III-9 (wall 3A) was rebuilt and patched after its collapse caused by weather and rodent damage.⁸⁶ In the same room, the stones on the south wall (wall 9A) were reset in cement and pointed with soil cement.⁸⁷ On the west wall (wall 2A) the foundation was re-laid in soil cement and all holes were patched with soil cement.⁸⁸ All walls in room III-7 (walls 7A, 3B, 8A, and 2B), that had been previously pointed in the 1941-42 events, were repointed.⁸⁹ In room III-3 all walls were patched as needed, and in room III-4 minor pointing was completed in all walls.⁹⁰

⁸³ Richert, *Stabilization Report*, 45;51;53;56;59.

⁸⁴ Ashley Bailey and Joshua Kleinman, *Tuzigoot Pueblo*, 12.

⁸⁵ Ibid.

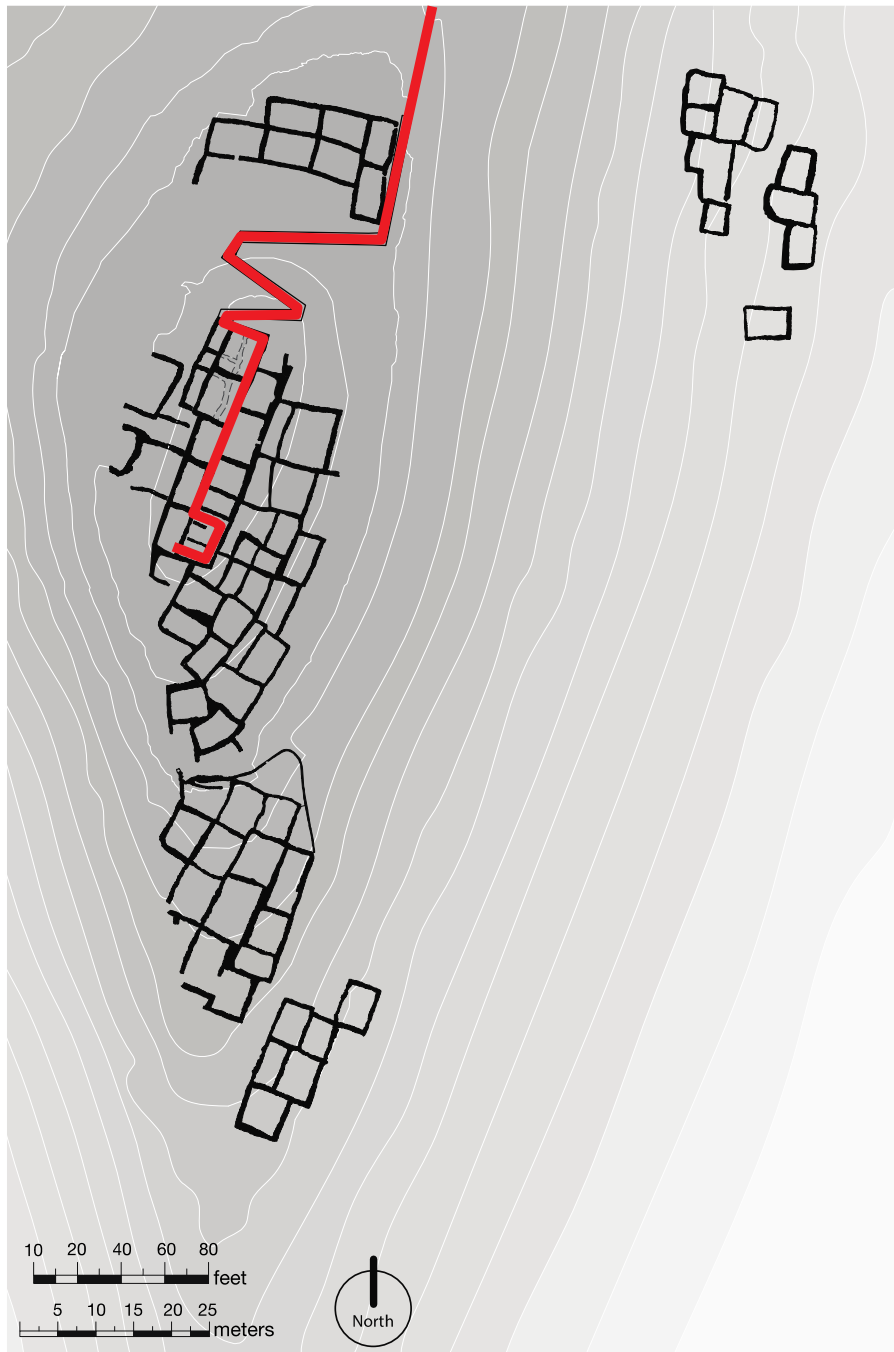
⁸⁶ Neilson, 1980, p.16

⁸⁷ Richert, *Stabilization Report*, 55.

⁸⁸ Ibid.

⁸⁹ Ibid, 51.

⁹⁰ Richert, *Stabilization Report*, 45.



Excavated with visitor flagstone path on wall tops

Figure 11 / Map showing 1934-35 excavated walls with the historic visitors path route highlighted in red.
 Source: Richert, 1953 Stabilization Report, 1935, p.45



Figure 12 / View of Group III of Tuzigoot from north showing the historic visitor's trail built after Caywood and Spicer's excavation and stabilization. Source: 1942 Cotter's photograph collection from the digital archives of Tuzigoot National Monument



Figure 13 / Photograph showing the limestone flagstone detail of the historic visitor's trail on wall caps. Source: 1942 Jack Cotter's photograph collection from the digital archives of Tuzigoot National Monument.

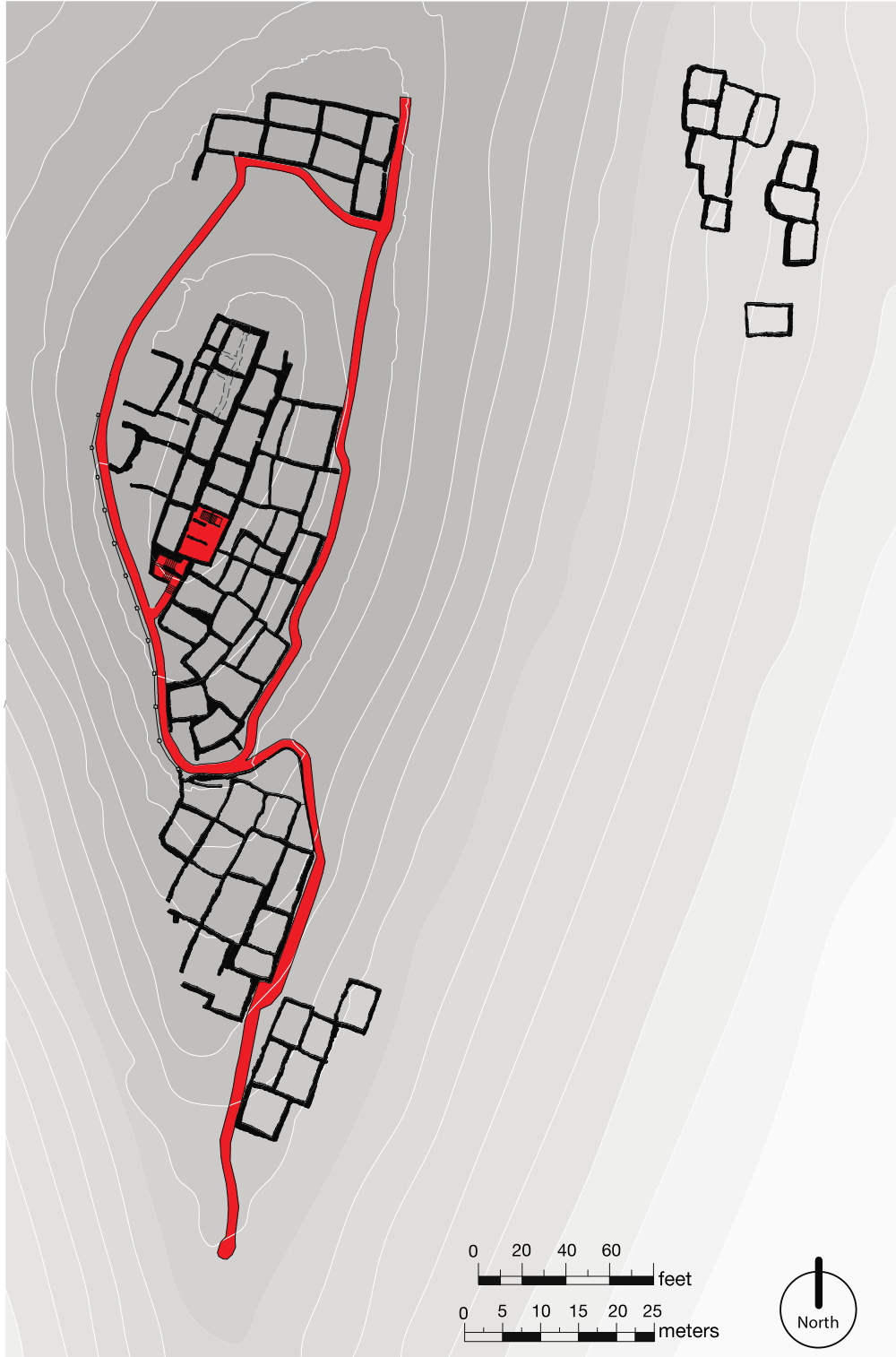
1952 Trailwork

The only remaining records for this campaign are documented in Richert's stabilization forms. In 1952 a new visitors, trail loop was built (Figure 14). Instead of walking on the wall caps, the new path traveled around the east and west sides of the ruins on grade, and allowed access to the Citadel room (III-14) through a new opening on the south wall of the room.⁹¹ This project completed two (2) major tasks: (1) the construction of the new trail (2) and the redesign and construction of the visitor access to room III-14.⁹² The new visitor's trail, still used today, was built around the main cluster of rooms in the pueblo (groups II, III, I and the north section of V), and led to the south wall of room III-14.

A section of this wall was opened to allow visitor access (Figure 15) and the existing wall was strengthened with metal reinforcement. In addition, the roof hatch located at the northeast corner of the roof was enlarged to an opening of 3'-10" wide and 10'-3" long and the previous rung-type ladder was replaced by a stairway with handrails.

⁹¹ Ibid, 65.

⁹² Ibid, 45;51;53;59;56;65.



*Figure 14 | Map showing 1934-35 excavated walls with new Bitumul visitors path route highlighted in red.
Source: Richert, 1953 Stabilization Report, 1935.*



Figure 15 | Photograph of the 1952 opening in the south wall of Room III-14. Photograph from Roland Richert's Stabilization Report, page 66.

The next four stabilization and maintenance events, *Richert's 1953 Stabilization Report*, *Shiner's 1962 Stabilization Report (Incomplete)*, and *Mayer and Waggoner's 1968 Stabilization*, were documented in the form of reports where the archaeologists recorded their findings and work using the *Southwestern National Monuments Permanent Record Sheets*, a form that was common to Southwestern National Monuments. It was created ca.1937, and was used by Tuzigoot National Monument at least until Mayer and Waggoner's 1968 Stabilization Report. These *Southwestern National Monuments Permanent Record Sheets* were originally intended to provide a quick history of the stabilization of each room, wall or architectural element that provided information regarding the original condition, previous preservation events, including the methods and materials previously used, and the work performed that year.⁹³ It consisted of a modifiable form that could be adjusted to a wide variety of parks, and had the advantage of recording accumulative stabilization data of each unit, easily extracted from the daily field notes.⁹⁴

⁹³ Richert, Roland Von S., and Vivian, R. Gordon. *Ruins Stabilization in the Southwestern United States*. (Washington: U.S. Department of Interior,1974), 85.

⁹⁴ *Ibid.*

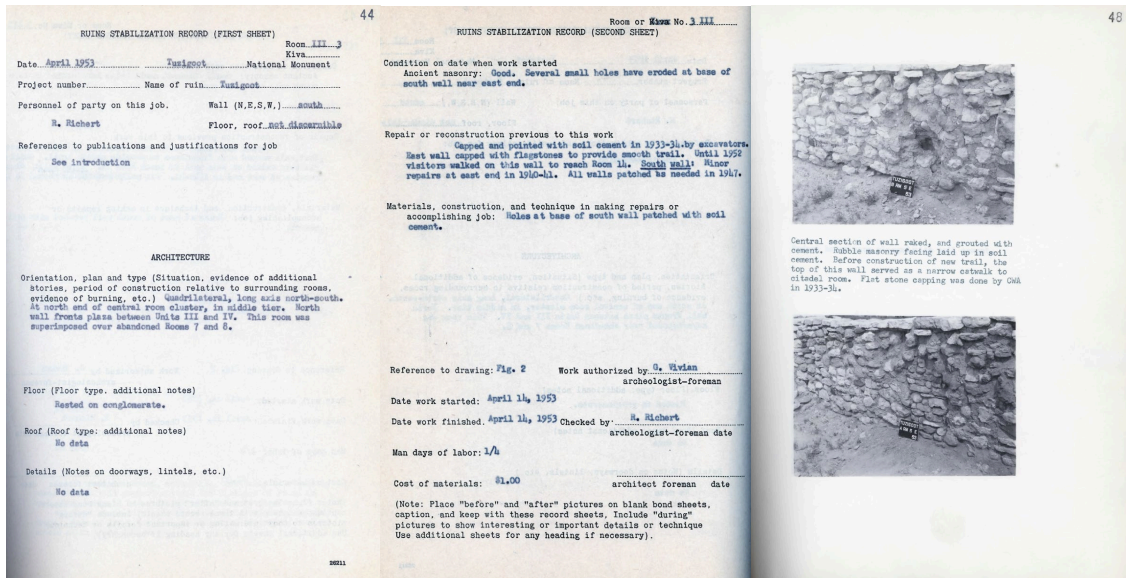


Figure 16a

Figure 16b

Figure 16c

Figure 16a, 16b & 16c / Example form of the Southwestern National Monuments Permanent Record Sheets used by Roland Richert in his 1953 Report. Sheet order from left to right.

Each stabilization record consisted of two pages followed by detail and context photos that recorded the conditions prior to, and after work was completed. In the case of Tuzigoot's form it collects the information room-by-room; one form records previous interventions and current work completed on the wall elevations that pertain to that room. The first sheet (Figure 16a) was reserved for general information about the National Monument, unit location, room ID, wall(s) recorded (north, south, east, west), and space for references to publications and justification for job. A second section identified architectural background information such as location, description, and materials and descriptions of roof, floor and other architectural elements such as doors, lintels, etc.. The second sheet (Figure 16b) recorded the conditions of the ruin prior to commencing work, historic repairs, and work performed in this phase. If the information provided in the first sheet was shared with

similar units, then only one first sheet could be used to include a group of units.⁹⁵ A separate page (Figure 16c) with photographs of before and after work were added for each *First Sheet* group of units. This form was the most successful thus far to record stabilization and maintenance, and to gather data as different campaigns were completed but it relied on observational assessment of the wall, and not on an evaluation of the wall masonry as a system to diagnose the overall pathology. Nevertheless, the fact that the identical form was used for different stabilization campaigns makes the data comparable over time.

Roland Richert (1953)

In 1953 Roland Richert, archaeologist, was commissioned to execute comprehensive work on the ruins.⁹⁶ In his notes, Richert noted three leading conditions: (1) “Sloughing” and stone collapse on the central wall of Group III, perhaps caused by visitor traffic on the wall caps, (2) mortar erosion, and (3) damage caused by rodents.⁹⁷

The walls affected by the historic visitor path were weak, and “...in imminent danger of collapse”⁹⁸ or had already begun to loose stones. In some of these walls, such as the east wall of room III-5 (wall segment 4C), the north wall of room III-8 (wall segment 6A) and the east wall of room III-11 (wall segment 4B), the central hearth of the wall was cleared out, grouted with cement masonry and laid up in soil cement.⁹⁹

⁹⁵ Richert, Roland Von S., and Vivian, R. Gordon. *Ruins Stabilization in the Southwestern United States*. (Washington: U.S. Department of Interior, 1974), 85.

⁹⁶ Neilson, 1980, 18.

⁹⁷ Richert, *Stabilization Report*.

⁹⁸ *Ibid*, 47.

⁹⁹ *Ibid*, 47;59; 75.

Erosion was mostly found on south and west wall faces, but few instances were still extant in the north and east elevations.¹⁰⁰ In some cases where basal erosion was evident the walls were patched with soil-cement. In more severe cases of basal erosion, the foundation was relayed in soil-cement and the holes were patched with matching soil cement; other extremely severe cases were completely rebuilt. Where stone collapse was caused by erosion or animal burrowing, the stones were reset on the walls using soil-cement. Similar to erosion repairs, burrowing holes were fixed by grouting, filling and/or patching with matching soil cement. Detailed description of repairs wall by wall can be found in Appendix A.

Joel L. Shiner(1961)

In 1961, after eight years, Joel Shiner was contracted to perform stabilization and maintenance repair of damage resulting from erosion, rodent activity and visitor use.¹⁰¹ For Group III, this translated to recapping of the center wall of the group (wall segments 4B, 4C, 4D, 4E, 13A, and 6A).¹⁰² This work comprised of removing the flagstones located on the edges of the caps that were originally used to create the historic visitors walkway.¹⁰³ This was executed by recapping the walls with large stones to disrupt the previous flat profile.¹⁰⁴ More detailed information can be found in Appendix A.

¹⁰⁰ All this information was extracted and summarized from the stabilization forms in Roland Richert's Stabilization Report.

¹⁰¹ Joel Shiner, *Stabilization of Tuzigoot Ruin*, (Globe: Ruin Stabilization Unit, National Park Service, 1962), 2.

¹⁰² *Ibid.*, 30-33.

¹⁰³ *Ibid.*

¹⁰⁴ *Ibid.*

Charles B. Voll (1964)

In 1964 Voll was commissioned to do some stabilization and maintenance work, but no records exist of such work.

Mayer and Waggoner (1968)

The 1968 events completed in Group III by Mayer and Waggoner mainly focused on repair of wall bases and wall caps, that had degraded due to two and one-half feet (2'-6") of snow accumulation from the previous winter.¹⁰⁵ All walls were capped with the exception of those that had already been recapped in the 1961 stabilization.¹⁰⁶ The wall bases were all excavated and evaluated for deterioration due to capillary moisture.¹⁰⁷ Depending on the conditions found, grouting and tinted cement patching were performed and sandstone was replaced with "indurated limestone".¹⁰⁸ A major stabilization event took place in all walls of room III-14, where walls were grouted with tinted cement and mud.¹⁰⁹ In the upper sections of the walls the mortar was painted with tinted cement over a green cement grout.¹¹⁰ Upright poles were also added to the cross south wall and all holes were sealed.¹¹¹ The north wall was capped and a hole that was causing leakage in the west wall was repaired.¹¹²

¹⁰⁵ Martin T. Mayer and William M. Waggoner, *Stabilization Report 1968:Tuzigoot Ruin, Tuzigoot National Monument*, (Arizona: Ruins Stabilization Unit, Southwest archaeological Center,1968), 1.

¹⁰⁶ Ibid, 48-54.

¹⁰⁷ Ibid, 2.

¹⁰⁸ Ibid, 51;59.

¹⁰⁹ Ibid.

¹¹⁰ Ibid.

¹¹¹ Ibid.

¹¹² Ibid.

Tuzigoot National Monument Park Personnel (1968-1994)

The period between Mayer and Waggoner's 1968 and 1994, maintenance and stabilization work were conducted by park personnel and no records of conditions assessments or work completed exist. The only evidence found is general descriptions of work needed at the park, in the form of memos and "XXX Forms", and the Chamber's Report of the *Drainage Project of 1983*. This report records the work performed and does not have a room-specific assessment of the walls or room conditions, and it mainly focuses on the work completed.

The "Triple XXX Form" (Figure 17) does not record specific work completed on rooms or walls, rather it generally describes the work needed, and it records the proposed action (e.g. "Replace missing historic fabric"), and describes the indicated effects (e.g. "A few areas need minor repointing and a few loose stones need to be reset. A weak soil cement mortar matching the original stabilization mortar in texture and color will be used").

By 1983 the park, in the interest of attending moisture problems on the monument's wall, proceeded with the completion of a large drainage project that had been planned since 1975.

XXX FORM
ASSESSMENT OF ACTIONS HAVING AN EFFECT ON CULTURAL RESOURCES
(Attach continuation sheets as necessary)

This form is required for all actions that have the potential to affect historic properties.

A. **Originating Office** VR: _____

1. Park: Tuzigoot National Monument

2. Description of proposed action:
 Implementing action included in plan under PMOA
 Other PMOA Action Preservation Maintenance
 Action not under PMOA.

3. Explain why the action is needed: Routine cyclic maintenance, to replace eroded mortar and to reset loose stones.

4. Cultural resources affected by proposed action (name and LCS number, if applicable): Tuzigoot Ruin (88-1), LCS #01348

5. The proposed action will (check as many as apply):

- Destroy historic fabric.
- Remove historic fabric.
- Replace historic fabric in kind.
- Replace missing historic fabric.
- Add nonhistoric elements to a historic structure.
- Remove nonhistoric elements from a historic structure.
- Alter historic terrain, groundcover, or vegetation.
- Introduce nonhistoric elements (visible, audible, or atmospheric) into a historic setting or environment.
- Reintroduce historic elements in a historic setting or environment.
- Remove historic elements from a historic environment.
- Remove nonhistoric elements from a historic environment.
- Disturb, destroy, impair, or render inaccessible archeological (surface or subsurface) resources.
- Possibly disturb presently unidentified archeological resources or historic fabric.
- Incur gradual deterioration of historic fabric, terrain, or setting.
- Other (Describe briefly):

Describe the indicated effect(s) concisely: A few areas need minor repointing and a few loose stones need to be reset. A weak soil cement mortar matching the original stabilization mortar in texture and color will be used.

6. Identify supporting approved plan(s), comment and/or action thereon by Advisory Council on Historic Preservation, dates of ACHP action and NPS approval, and section(s) of the plan(s) pertaining to the action. If none, so state:

NCRMP - 4/75
Revised - 7/81
Revised - 11/81

7. Identify relevant NPS management policies and guidelines:
 NPS-28, Chapt. 2, Page 11
 Standards for Historic Preservation Projects, Part 2, page 20

8. Describe any measures planned to minimize or lessen the loss or impairment of historic fabric, setting, integrity, or data:
All work will be done by NPS personnel who have had previous training and experience from the WACC preservation supervisor, George J. Chambers.

9. Identify supporting study data and date(s) of preparation (attach if feasible):

10. Prepared by: Glen E. Henderson Title: Superintendent

11. Signature of Park Superintendent: Glen E. Henderson Date: 1/3/84

B. **Regional Cultural Resources Staff Review and Certification**

1. The foregoing assessment is adequate; the proposed action is consistent with all applicable NPS management policies, standards, and guidelines reviewed and concurred in by the Advisory Council; and the proposal incorporates all feasible measures to minimize adverse effects to cultural resources.

2. The proposed action is authorized by a planning document or program reviewed and concurred in by the Advisory Council.

(Negative certifications must be justified on attachments.)	Yes	No	N/A		
1	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

[] Energy Consultation Held 1

Regional Energy Coordinator Date 1

2

Additional requirements of the proposed action:

C. **Regional Director Approval of Proposed Action Including Additional Requirements**

[] The proposed action, including any additional requirements stated above, meets all conditions in B.1 and 2.

1/3/84
Date John Williams
Regional Director

D. **WASO Record**

Assessment received and noted: Associate Director, Cultural Resources Management Date

Figure 17/ Example of Triple XXX Form from 1982 to replace missing historic fabric. It describes the work to be done: "a few areas need minor repointing and a few loose stones need to be reset. A weak soil mortar matching the original stabilization mortar in texture and color will be used." Note that it does not indicate where the work is being done. Source: Glenn E. Henderson. Triple XXX Form. January 3, 1984.


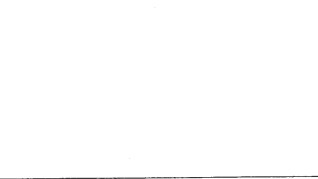
This project did not focus on recording the conditions of the walls or where the work was completed. The report only generally describes the conditions observed on the wall, the solutions proposed by the engineers for each condition and the description of work completed. No narrative or site plan indicate the location of the work that was completed.

It was not until 1994, twenty-six years later that Vanishing Treasures introduced a new recording form called the Work Condition Assessment Form (Figure 18). This form recorded the repairs performed in each of the rooms, recording all the walls (north, south, east, west). Very different from the *Southwestern National Monuments Permanent Record Sheets*, this instead has four sections on each page, each one dedicated to each of the wall faces for that room.

VANISHING TREASURES 200
RM # _____


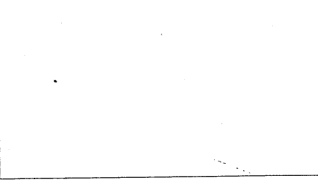
FINAL- Work Condition Assessment Form

1. Provide "after" photo documentation - N,S,E,W walls. (Check box)
2. Illustrate wall repair done. Provide wall elevation sketch with arrows.

North Wall	South Wall
	

Total s.f. of replaced rock: _____
Total l.f. of Basal repair: _____
Total s.f. of repointing: _____
Linear feet of Wall Cap _____

Total s.f. of replaced rock: _____
Total l.f. of Basal repair: _____
Total s.f. of repointing: _____
Linear feet of Wall Cap _____

East Wall	West Wall
	

Total s.f. of replaced rock: _____
Total l.f. of Basal repair: _____
Total s.f. of repointing: _____
Linear feet of Wall Cap _____

Total s.f. of replaced rock: _____
Total l.f. of Basal repair: _____
Total s.f. of repointing: _____
Linear feet of Wall Cap _____

Additional Notes:

Date work completed: _____ Author: _____

Figure 18 | Sample of a 1994 Vanishing Treasures Form used at Tuzigoot National Monument

Each wall area has space for a small sketch that illustrates the repair performed, and space to input quantifiable information such as square footage of replaced rock, basal repair, repointing and wall cap replaced. This way of documentation was not to record the conditions as found, but rather to record the work completed. The data collected during this period was not available in the archives.

Current Stabilization

Today the park's approach is different to historical documentation methods.¹¹³ Repairs and maintenance work are completed in most months of the year, usually excluding the months that reach freezing temperatures, December and January. A wall elevation is identified by visual observation and comparison is made to the other walls being assessed. Based on the worst looking wall, the team repairs all the wall elevations in that entire room. Before beginning work, the team prepares their Conditions Assessment Wall Form, takes photos of the wall, and annotates conditions observed.

The first page of the Conditions Assessment Wall Form (Figure 19a) records the initial conditions on each of the wall faces. It is based on a scale of 0-3 (0 = no impact, 1= low, 2= moderate, and 3 = severe) Value definitions are based on how long it will take the wall to fail; the higher the number, the more severe the threat. It evaluates seventeen (17) conditions and their location on each wall: cap, mid-wall, and base. Conditions like wall (1)collapse, (2)leaning, (3)bulging, (4)differential fill, and (5)drainage impacts are identified only on the overall condition of the wall. Other conditions, such as (6)surface erosion, (7) friability, and (8) efflorescence are assessed only on the stones and mortar joints. The conditions that impact the wall, as well as stone and mortar joints are (9)animal activity, (10)insect activity, (11) cracking, (12) detachment, (13) water dampness, (14) biological

¹¹³ Current maintenance and stabilization approach and procedures were conveyed through interviews and meetings with Tuzigoot National Monument personnel.

(10)insect activity, (11) cracking, (12) detachment, (13) water dampness, (14) biological growth, (15) visitor impact, (16) vandalism and (17) other.

Condition Assessment Wall Form
Tuzigoot National Monument

DATE:	12/17/11
TUZI Site #:	06A-01
ASM #:	AZ.N:04:001
LCS ID #:	001348
Structure Name:	TUZI pueblo ruins
Room #:	V-23
Wall ID #:	231-1
Wall Face:	Interior / Exterior
Wall Name/Description:	
Examined by:	N. Cuch

Impacts

Type of Impact	Location of Impact						
	Wall	Stones	Mortar Joints	Adobe	Cap	Mid	Base
Wall collapse	0						
Loosening segments	0						
Chipping segments	0						
Differential fill	0						
Drainage impacts	0						
Animal activity	0						
Insect activity	0	0	0				
Cracking	0	0	0				
Detachment	0	0	0				
Surface erosion	0	0	0				
Water dampness	0	0	0				
Friability	0	0	0				
Efflorescence	0	0	0				
Biological growth	0	0	0				
Visitor impact	0	0	0				
Vandalism	0	0	0				
Other (describe)							
TOTALS	0	0	0				
TOTAL SCORE	0	0	0				

Figure A52: Condition Assessment Form for Room V-23, south interior wall, page 1. Examined by: N. Cuch on 12/07/2011.

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Figure 19a

Condition Assessment Wall Form
Tuzigoot National Monument

Treatment Recommendations

Plan a Check V in all boxes that apply

Treatment Type	Location of Impact			Treatment Urgency			
	Cap	Mid	Base	Immediate (ASAP)	High (1-2 Years)	Medium (3-5 Years)	Low (6+ years)
Repoint							
Seal							
Apply Seal							
Fill Cracks							
Install Control							
Remove Control							
Vegetative Control							
Modify Fill/Seal							
Remove Chalk							
Other (describe)							

Summary Condition: WALL HAS BEEN RESTABILIZED BUT MOST OF STABILIZATION HAS ERODED AWAY EXPOSING OLD HISTORIC MORTAR. ALSO CAPS AREA WAS RESTABILIZED AND MOST MORTAR HAS ERODED AWAY. LITTLE BIT OF FRIABILITY IS OCCURRING ON CAP STONES.

Summary Treatment Needs: REPOINT AREAS WHERE MORTAR HAS WASHED AWAY. MAY NEED TO CHIP OUT OLD MORTAR BEFORE REPOINTING OVER. ALSO, CAPSTONES NEED REPOINTING AND MAY NEED TO BE REPLACED. MIGHT WANT TO MONITOR CRACK AT SOUTHWEST CORNER FOR CRACKING AT BASE AREA.

Figure A52.1: Condition Assessment Form for Room V-23, south interior wall, page 2. Examined by: N. Cuch on 12/07/2011.

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Figure 19b

Figure 19 / Example of Current Conditions Assessment Form

The second page (Figure 19b) records the location and urgency of the recommended treatments based on the first page's conditions. The first section has ten (10) treatment types all to be located on the cap, mid or base of wall and given an urgency rating: ASAP, High (1-2 years), Medium (3-5 years), and Low (6>years). The second section has space for a written, more comprehensive description of the conditions found on the wall and the needed treatments or recommended monitoring, specifically pointing to the conditions previously

recorded. The recorded photos with noted conditions with their exact locations are added to this form.

PRE-STABILIZATION FIELDWORK FORM
(One Sheet per Wall)

DATE: _____ CREW MEMBERS: _____
TOTAL HOURS WORKED: _____

PHOTO DOCUMENTATION
DATE: _____
SITE LOCATION / PROJECT: _____
PHOTOGRAPHER(S): _____
CAMERAS USED: _____
AREAS PHOTOGRAPHED: _____

ANNOTATIONS
AREAS DOCUMENTED: _____

CREW MEMBERS: _____

SOIL PROCUREMENT
ESTIMATED AMOUNT NEEDED BY WALL: _____
SOIL SITE LOCATION (COMPANY NAME & UTM): _____

SOIL TYPE & MUNSELL COLOR: _____
AMOUNT PURCHASED: _____
PRE-STAB. COLOR MATCH TEST:
LOCATIONS: _____

UNAMENDED MORTAR MIXTURE: _____

MORTAR CAKES:
HOW MANY: _____
MUNSELL COLOR RESULTS: _____

LOCATION (IF LEFT WITHIN SITE): _____

SAFETY
JHA SAFETY BRIEFING: YES / NO _____ DATE: _____
RESPIRATORS / PARTICULATE MASKS NEEDED: YES / NO _____
MSDS FORMS ON RECORD FOR MATERIALS USED: YES / NO _____
DESCRIBE: _____

SAFETY EQUIPMENT USED: _____

ADDITIONAL EQUIPMENT / MATERIALS USED

NOTES

Page 1

Page 2

Figure 20 / Example of current Pre-stabilization Form

Next is the *Pre-stabilization Form* (Figure 20) and the *Post-Stabilization Form* for each of the walls in that room. The objective of both of these forms’ is to record the amounts of materials used for administrative accounting. They also record information about the crew members and hours worked, photo documentation information, annotations on areas documented, any estimation or actual material and screening needed, and any safety precautionary forms needed.

Wall elevations with the worst condition are selected by means of field observation conducted by the park archaeologist. As opposed to historic maintenance and stabilization

procedures, the current approach aims to leave a more uniform appearance by repointing entire elevations of entire rooms. This approach is not only visually preferable to the public, but the wall can now perform as a system instead of multiple microsystems dictated by the contrasting properties of different mortars on different wall planes. Although this is a good way to approach the problem, it still focuses on one face of the wall and does not approach the problem of the wall as a system. By addressing only one side of the wall, contrasting elevation behavior may accelerate the rate of deterioration of the walls. Although the park's current stabilization does attempt to complete a uniform solution for the walls at Tuzigoot, it still needs to approach the problem recognizing the walls as systems.

2.3 Climate Data

After discussing the agents of deterioration and how temperature and moisture affect the materials and the mechanics of the rubble masonry system it is important to summarize the climatic conditions of Clarkdale Arizona, where Tuzigoot National Monument is located.¹¹⁴ This background information will become useful for the next section where a focused attention will be given to the walls at Tuzigoot.

According to the Köppen Climate Classification Map¹¹⁵, Tuzigoot has a 'Hot-Summer Mediterranean Climate' (Csa). Csa Mediterranean Climates usually have moderate

¹¹⁴ The data source for this section is based on statistical analysis of historical hourly reports and model reconstructions of recorded weather in Clarkdale, Arizona from January 1, 1980 to December 31, 2016.

¹¹⁵ Köppen Climate Classification is a vegetation based climate classification system developed by a botanist-climatologist in the 1900. The factors used to classify the climate types are sunshine wind and precipitation.

temperatures and variable, rainy weather. Summers are hot and dry, due to the domination of the subtropical high-pressure systems.

Temperature

The average yearly temperatures in Clarkdale typically range from 36°F to 96°F, rarely below 28° or above 103°F. From the end of November to the beginning of March temperatures can vary from 36°F to 64°F. December and January are the coldest months. The hottest months are from June to mid-September with temperatures ranging from a low of 61°F in beginning of May to a high of 96°in the beginning of July.

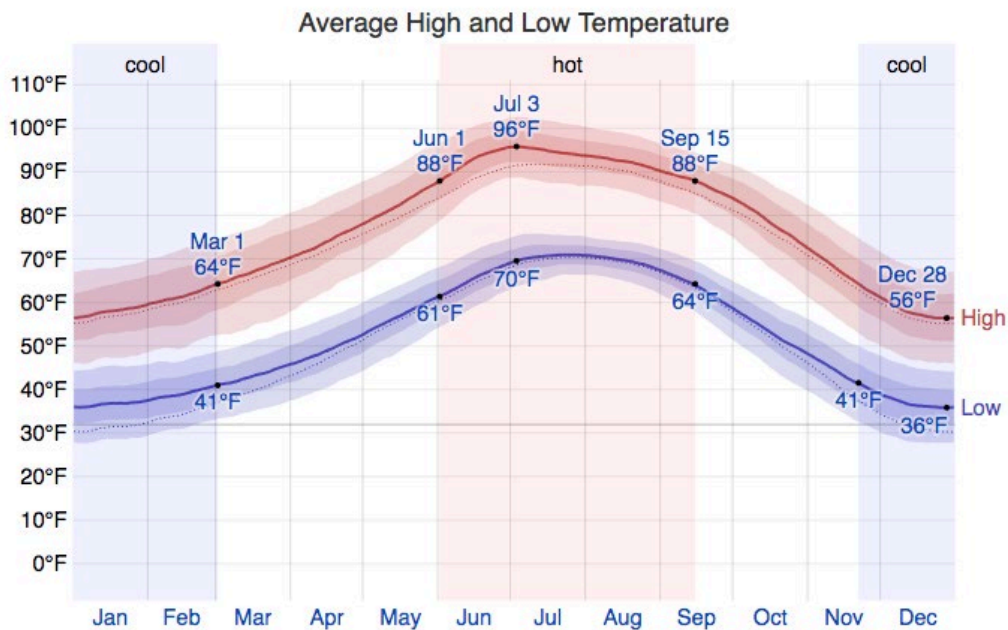


Figure 21 /In this graph the daily average high (red line) and low (blue line) temperature, with 25th to 75th and 10th and 90th percentile bands. The thin dotted lines are the corresponding average perceived temperatures. Source: <https://weatherspark.com/v/2471/Average-Weather-in-Clarkdale-Arizona-United-States-Year-Round>

Sunlight (Hours of Light)

The hours of sunlight vary throughout the course of the year ranging from almost 10 hours to 14.5 hours. The shortest day in December 21 is expected to have 9 hours, 49 minutes of sunlight. The longest day, June 21, will be 14 hours with 30 minutes of daylight.¹¹⁶

Precipitation

Clarkdale precipitation varies throughout the year, but it generally does not have a lot of rain.¹¹⁷ The wet season, during the summer, lasts from July 7 to September 22, with an average precipitation of 2.0 inches.¹¹⁸ The dry season is from April 26 to June 25, with an average accumulation of 0.2 inches.¹¹⁹ The average snowfall is two inches, but this year, two weeks prior to our visit Tuzigoot received 10 inches of snow.

Wind

The wind in Clarkdale blows from different directions, east, south and west, during different seasons (Figure 22). During the winter (from October to February) it is most likely that wind blows from the east at speeds ranging from 2.5 mph to 11 mph. During spring, summer and fall the wind mainly blows from the south with higher speeds ranging from 3.8mph to 14.3mph. But during a small window of time in July the wind changes direction

¹¹⁶ "Sunlight", Average Weather in Clarkdale, Weather Spark, unknown modified date.

¹¹⁷ "Precipitation", Average Weather in Clarkdale, Weather Spark, unknown modified date.

¹¹⁸ Ibid.

¹¹⁹ Ibid.

and blows from the west and lowers its speed to a range from 2mph to 9mph (Figure 22 & 23).

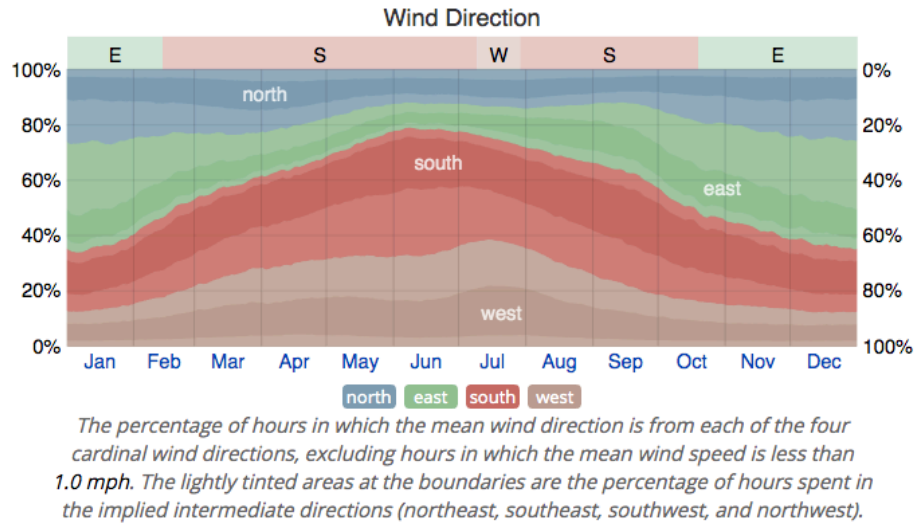


Figure 22 | Source: <https://weatherspark.com/y/2471/Average-Weather-in-Clarkdale-Arizona-United-States-Year-Round>

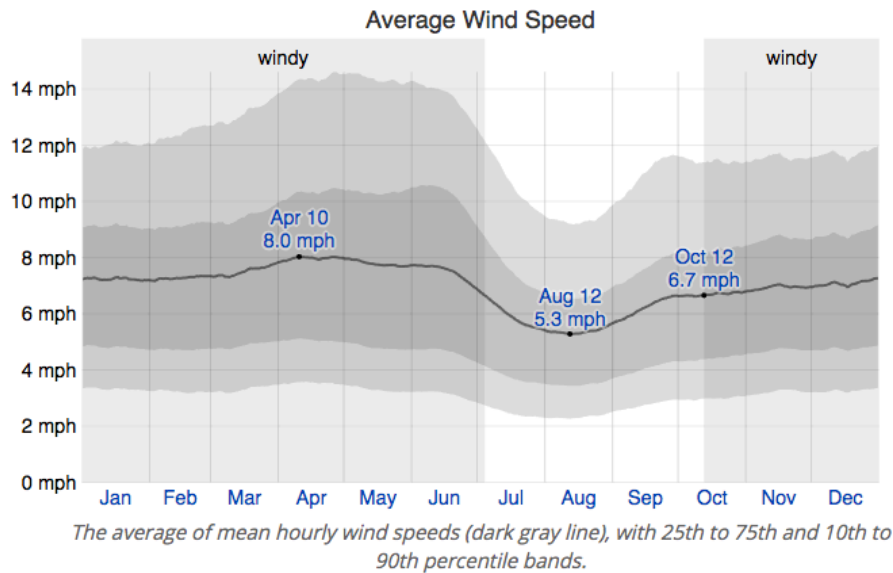


Figure 23 | Source: <https://weatherspark.com/y/2471/Average-Weather-in-Clarkdale-Arizona-United-States-Year-Round>

2.4 Walls at Tuzigoot National Monument

After discussing how rubble masonry systems perform and their processes of deterioration, a focused discussion about the walls at Tuzigoot, specifically Group III, will guide the rationale for the development of a Rapid Assessment Survey (RAS). Discerning the varying materials used in different stabilization campaigns and understanding how all of the components of the walls' elements interact with each other provided a better interpretation of the current conditions found on site.

This section is supported with findings recorded from the 1934-35 excavation report, the comprehensive stabilization chronology, and observations from the site visit completed in March 2019. It begins by discussing the original wall construction at Tuzigoot and reviews historic stabilization and maintenance changes that might have changed the wall behavior and deterioration over time. It discusses different scenarios to which the walls at Tuzigoot are subjected due to the site's topography, the general wall conditions and the current fill levels of the rooms. And finally, by referencing the previous section about rubble masonry performance, it culminates by anticipating wall failure in the different wall scenarios previously discussed.

Original wall Construction

Like most pre-contact Native American masonry construction, the walls at Tuzigoot were built using available local stone and soil for mortar on and near the site.¹²⁰ The geological maps suggest that the Tuzigoot pueblo currently sits on top of a ridge composed

¹²⁰ Caywood and Spicer, *Tuzigoot*, 23.

of “unconsolidated to weakly consolidated sand and gravel in river channels and sand, silt, and clay on floodplains”¹²¹. The archaeological reports suggest that it was composed of a conglomerate of river boulders of basalt, red sandstone, and some hard limestone in a matrix of a limey materials.¹²²

In the case of Tuzigoot, the walls of the first rooms, developed at the top of the ridge (all in Group III) following the topography of the site, were built using a great deal of the rounded basalt river cobbles acquired from the grounds of the ridge where the walls were erected.¹²³ Other stones used for the later masonry were also collected from the Verde Lake; these were unevenly broken and came from the outcropped ledges of the ridge. Consequently, the stones used for constructions of the walls at Tuzigoot were of different lithotypes, shapes, and sizes, causing imbalance and compromising the stability of the wall.¹²⁴ Additionally, Caywood and Spicer, referred to the stones used for the constructions of the walls as weak and “of poor quality”.¹²⁵

The rubble masonry at Tuzigoot was erected by superimposing stones on top of each other and applying thick layers of mortar between stones. The original mortar was prepared with a river-silt found in the proximity of the site.¹²⁶ The organization of stones was random and stones were placed without creating any coursing.¹²⁷ Although in later walls the remaining

¹²¹ “State Geologic Map Compilation, Arizona Geological Survey, DI-8 Geologic Map of Arizona, Digital Spatial data for the Geologic Map of Arizona[Map]. “ArcGIS”. 2002 <<http://arcg.is/1mCrOf>> (Accessed Feb. 17,2019).

¹²² Caywood and Spicer, *Tuzigoot*, 23.

¹²³ *Ibid*, 24.

¹²⁴ *Ibid*.

¹²⁵ *Ibid*.

¹²⁶ *Ibid*.

¹²⁷ *Ibid*.

spaces between large stones were filled with small irregular stones to counteract for their irregularities and reduce the proportion of earth mortar, this was not the case for the walls in Group III. These walls were built using large pieces of stone and the remaining spaces were filled with mortar (Figure 24). At the time of excavation, the archaeologists suggested that mortar took up to fifty-percent (50%) or more of the volume of the walls.¹²⁸

The walls were of a compound construction with an earthen core with small mixed rubble in between two outer wythes.¹²⁹ Although according to the excavation report foundations for these walls were completed using very large boulders of limestones or sandstone that would extend across the whole wall width¹³⁰, during the March 2019 visit this only occurred in counted occasions, and it is possible that most of the walls were founded directly on bedrock.

¹²⁸ Ibid.

¹²⁹ Ibid.

¹³⁰ Ibid.



Figure 24 / *Detail photo of wall as excavated. Source: Spicer and Caywood, 1933-34*

In addition, it is important to clarify that in Group III in particular there were three phases of development, the second of which was characterized by the superimposition of three of the first built rooms that were previously abandoned (See Figure 24). It is believed that at the time of building the new walls, the walls of the earlier rooms had collapsed and only 2'-8" of wall height remained.¹³⁴ As depicted in the 1934 map, the walls were not perfectly aligned with the wall underneath.

¹³⁴ Ibid.

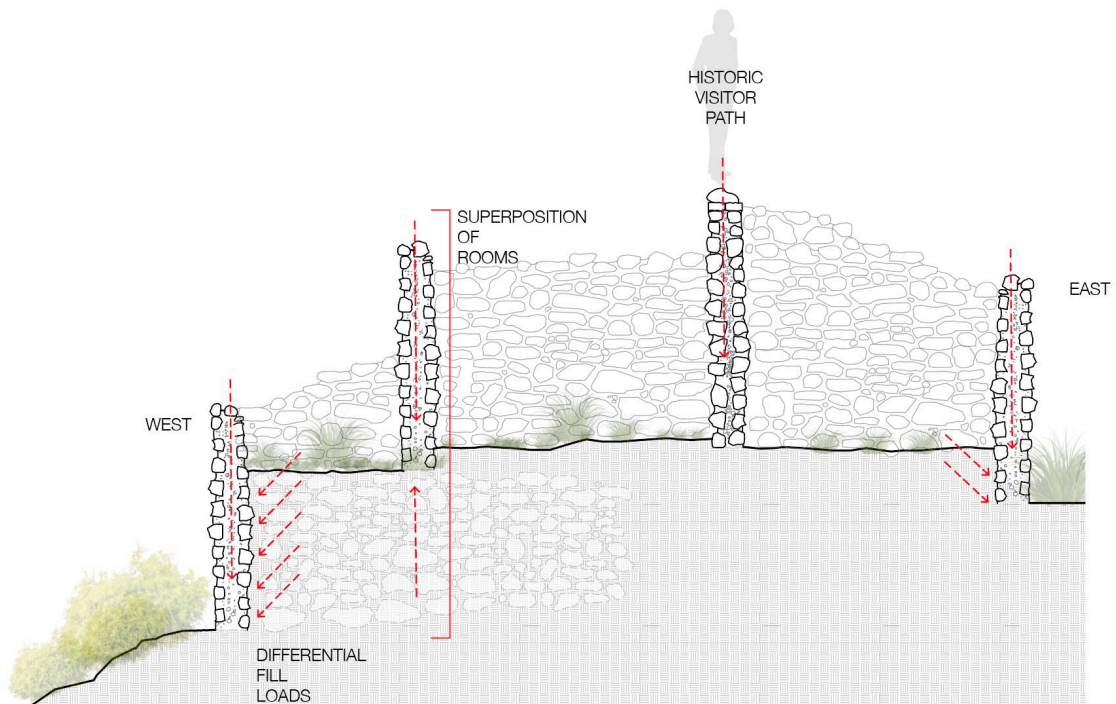


Figure 25 / *Diagram showing the current differential fill and room superposition.*

In summary, the original rubble masonry at Tuzigoot was not a structurally robust system. First, as previously discussed in the technical section, both the rounded shape of the stones and their random positioning contributes to a nonuniform distribution of loads causing localized stress concentrations resulting in failure in the form of cracking, and material loss and a short life. Second, the disconnection between wythes and between intersecting walls also makes the walls prone to vertical separation, displacement, and collapse. And third, the surrounding conditions of the walls such as differential fill and the super positioning of the walls might be slowly contributing to the structural failure of some of the walls at Tuzigoot.

Wall System Alterations

After excavation the ruins underwent several repair and stabilization campaigns that modified the original mortars by attempting to make them stronger, more durable, and requiring less maintenance.

Despite the fact that the original intent was to repair damage, the addition of soil-cements and concrete has contributed to some differential deterioration of the wall systems, where some of the sections of the walls have completely eroded (Figure 26). This not only begins to contribute to load distribution issues where no mortar is supporting and transporting loads, but rather is creating conditions for new types of structural deterioration to emerge. Furthermore, as material is lost on the wall faces and the caps of the walls, the interior of the system is becoming more vulnerable to the intrusion of deterioration agents previously discussed causing further disruptions of the wall system.

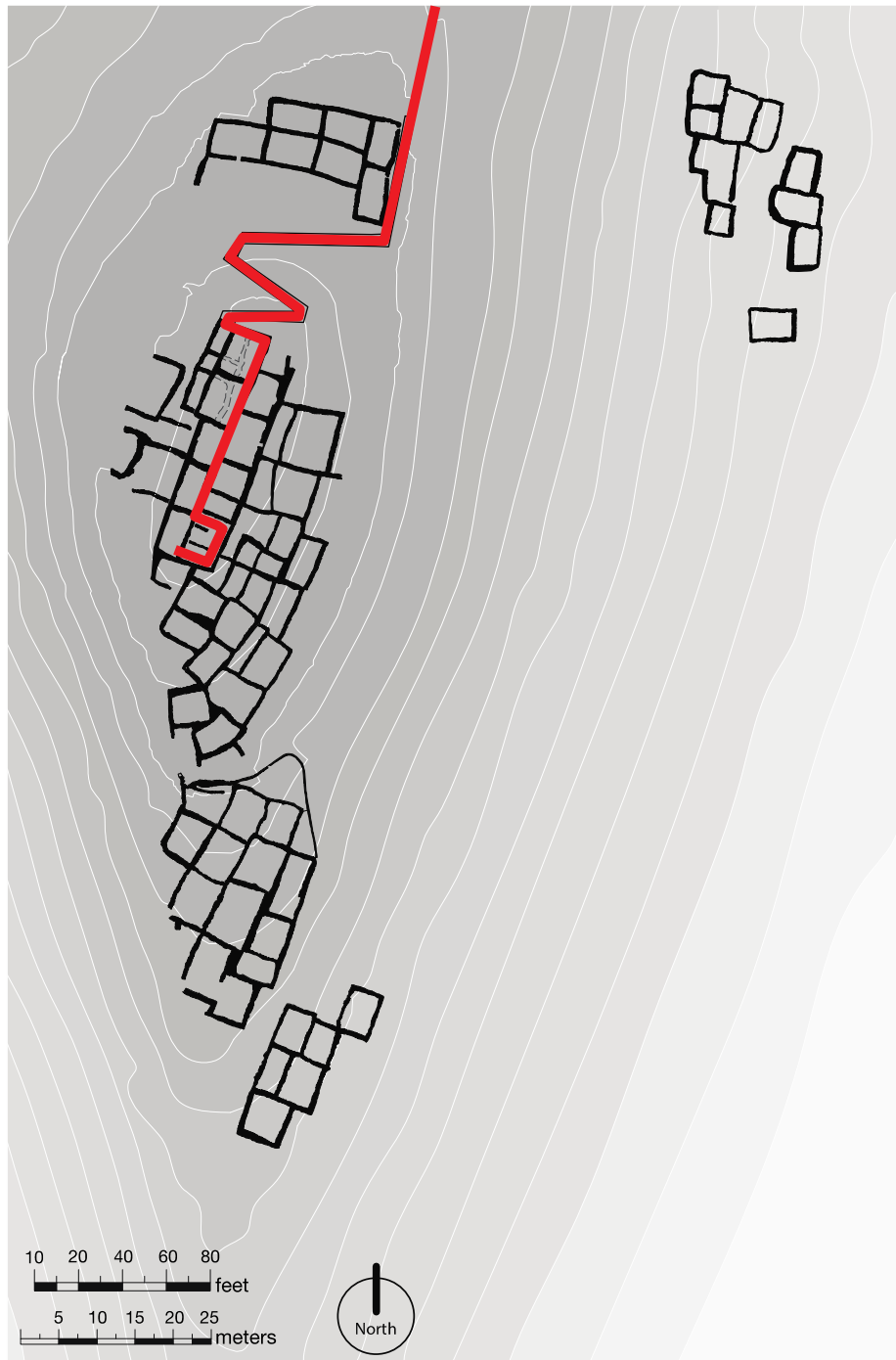
During our site visit, seven different type of mortars were visually identified, including the current mortar mix used. Although the scope of this study did not include the characterization of the different mortars, it seemed important to note that they all had different textures, colors, and levels of weathering.



Figure 26 / Example of a wall at Tuzigoot with different mortar conditions.

Another important condition identified was related to the current stabilization approach. Currently the park performs full elevation repointing. Although this method, approaches the stabilization in a more uniform manner it still does not consider the wall as a three-dimensional system.

A notable historical change that is important to highlight in this section is the wall caps that historically served as a visitor path. Immediately after excavation, in 1935 the wall caps of the center wall that leads to the Citadel room (Figure 13 and Figure 27) were modified to a smooth flat surface using limestone flagstones. This path was continuously used by visitors for 17 years, until 1952 when the new bitumen trail was built. Historic stabilization reports recorded damage and repairs completed specifically to these walls, due to the live loads induced by pedestrian traffic.



Excavated with visitor flagstone path on wall tops

Figure 27 / Map showing 1934-35 excavated walls with the historic visitors path route highlighted in red.
 Source: Richert, 1953 Stabilization Report, 1935, p.45

3.0 Methodology

After completing Tuzigoot's excavation and preservation chronology, a risk and vulnerability assessment was developed including three components: (1) a rapid assessment survey (RAS) that identified the most at-risk walls through field survey, (2) a comprehensive graphic conditions assessment of the highest scoring walls, and (3) an analysis of the decay mechanisms using vulnerability diagrams that show the various scenarios of deterioration through a combination of mechanisms.

In preparation for the site visit, each wall or wall segment was given a unique identification number (Figure 28). Additionally, in order to have equivalent data among walls, the long north-south oriented walls were divided into segments of similar sizes. All walls were identified with a number; the wall segments from long north-south walls were identified by a number followed by a letter (A,B,C,D, etc.). The letters indicate separate wall segments pertaining to the same wall. The irregular uncoordinated construction of the walls made it challenging to divide the wall segments. In situations where walls did not align, decisions were made based on the conditions and deterioration patterns observed in-situ.

Although the scope of work aimed to record all the walls in Group III, due to lack of time, some walls were not recorded. These walls are identified in all of the drawings and illustrations as "no data".

Wall ID

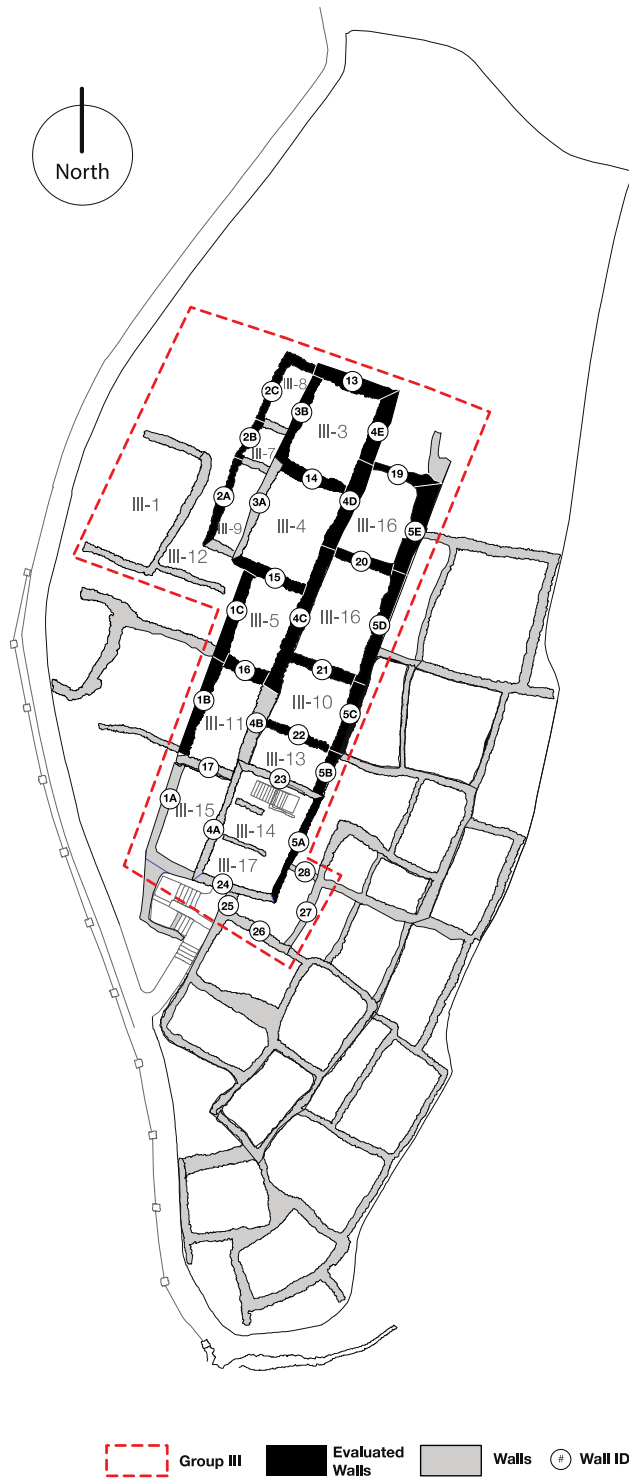


Figure 28 / Map of Group III showing wall segment division from the RAS completed in March 2019.

3.1 Rapid Assessment Survey (RAS)

Background

Prior to arriving at the site, a preliminary RAS form was developed. It was informed by three main inputs: the typical behavior and deterioration of uncoursed random rubble masonry, a comprehensive chronology of site stabilization and maintenance, and the Wall Level Condition Assessment form currently used by the park to assess walls prior to stabilization. All of these documents contributed to an understanding of typical forms of deterioration found on the wall in Group III. In every case the focus was on the entire wall segment construction, rather than wall elevation alone. The premise guiding this assessment was that in order to understand the overall condition and performance of the masonry walls at Tuzigoot, a structural systems-approach is necessary before looking at the individual conditions of individual wall elevations and rooms. The objective of the RAS was to assess overall wall condition to determine which were the most vulnerable at-risk walls. The RAS was followed as needed by a detailed graphic survey and assessment of the most vulnerable walls, determined by the results of the highest-scoring walls of the RAS.

Once on site, the preliminary forms were tested and modified according to the conditions observed and to complete a faster evaluation. The rapid assessment survey recorded the existing conditions pertaining to structural performance of the wall segment and then assigned a cumulative value of severity for each of the walls in Group III. All elevations of the assessed walls were photographed for future reference.

The final used form (Figure 29) recorded four main sets of information for each wall segment in the following order: (I) Wall ID, (II) context and (III) conditions. The form also

had a (IV) map of the walls where the wall segment was circled. The (I) Wall ID, and (II) context sections were created to record qualitative information. The wall identification section recorded the date of survey, the person who examined the wall, the group of rooms (in this case Group III), room number(s), and wall ID. The context section documented surrounding conditions that could influence deterioration, such as if drainages were in fact removing water and any differential soil fill associated with the wall. Differential fill was recorded by noting which side of the wall had a higher floor level.

RAPID ASSESSMENT SURVEY FORM for the Rubble Masonry Walls at Tuzigoot National Monument, Arizona Center for Architectural Conservation The Stuart Weitzman School of Design, University of Pennsylvania				
I. Wall ID	DATE:	GROUP ID	III	
	EXAMINED BY:	WALL Segment		
	PHOTO ID:	ADJACENT ROOMS		
III. Context	Drainage keeping water out?	Y	N	N/A
	Differential Fill (+/-)	N / E		
		S / W		
IV. CONDITIONS	Wall Segment	CONDITION	Score (0-5)	
			WALL SEGMENT	
		Cap Deterioration (cracks, loss)		
		Masonry Loss		
		Structural Crack		
		Structural Crack at Wall Junction		
		Animal Burrowing/Vegetation		
		Bulging		
		Out of plane		
		Collapse		
	WALL SEGMENT TOTAL			
V. COMMENTS / NOTES				

Figure 29 / Modified RAS Form

(III) The conditions section quantified data concerning the level of deterioration of each condition. This survey form took into consideration the conditions defining overall structural stability for the entire segment. Seven conditions were assessed for each wall segment: (1) cap deterioration, (2) masonry loss (3) structural crack, (4) structural crack at wall junction (5) animal burrowing and vegetation, (6) bulging, and (7) out of plane. This section measured the degree of vulnerability by using a 0-5 scoring-based system that recorded the apparent level of conditions. (1) *Wall cap deterioration* referred to material loss or cracking that was susceptible to damage from moisture intrusion and plant growth, and given a score from 1-5. (2) *Masonry loss* was given a score larger than 0 if partial or complete localized loss of stone and mortar was visible. (3) *Structural crack* refers to fractures within the stone, mortar or both, not to be confused with shelter coat loss or cracking. (4) *Structural cracks at wall junction* could be identified as cracks that extend vertically (in the form of cracks, wide cracks, and splitting) near or at wall intersections. These cracks indicate the separation or independent movement of the wall units which is cause for concern in masonry construction. (5) *Animal Burrowing* refers the opening on the wall used by animals for shelter, and *vegetation* includes the growth of higher plants in walls or surrounding grade. The loss of mortar by animal burrowing can cause uneven distribution of loads and expose the core to the elements. The growth of plants also indicates concentrated moisture accumulation. (6) *Bulging* is the outward deformation of a wall, and should not be confused with (7) *wall out of plane*. A wall that is out of plane is a wall that exhibits more than 5° lean perpendicular from wall to base or ground. Leaning walls were inferred by comparing the present wall top to the location of the base.

Every wall condition and level of deterioration was identified, described, and depicted in a visual glossary (Appendix B) that accompanies this assessment; it supplements the survey by identifying and clarifying the conditions found on site and setting a scoring standard for the different levels of severity. In future assessments using this form, the glossary will aid and allow for the data to be comparable.

Once the data was collected, it was processed in a spreadsheet and scores were tabulated. The scores were then translated into graphic representations of the data that assigned values to walls in their location on the site. After locating the data on a site plan, it became easier to understand relationships between the conditions, and context data. Based on the collected data, questions regarding individual conditions, location, and wall scorings grounded the analysis and interpretation.

Data & Analysis

When analyzing the wall scores some questions were used to guide the analysis. By comparing and contrasting the results acquired from this assessment we started to reveal patterns and relationships that informed relationships between the structural conditions observed.

Differential fill was depicted in the site plan (Figure 30) to show the relationships between the ground height on both sides of the walls. This diagram was used to compare and contrast conditions that might be affected by differential fill.

Differential Fill Diagram

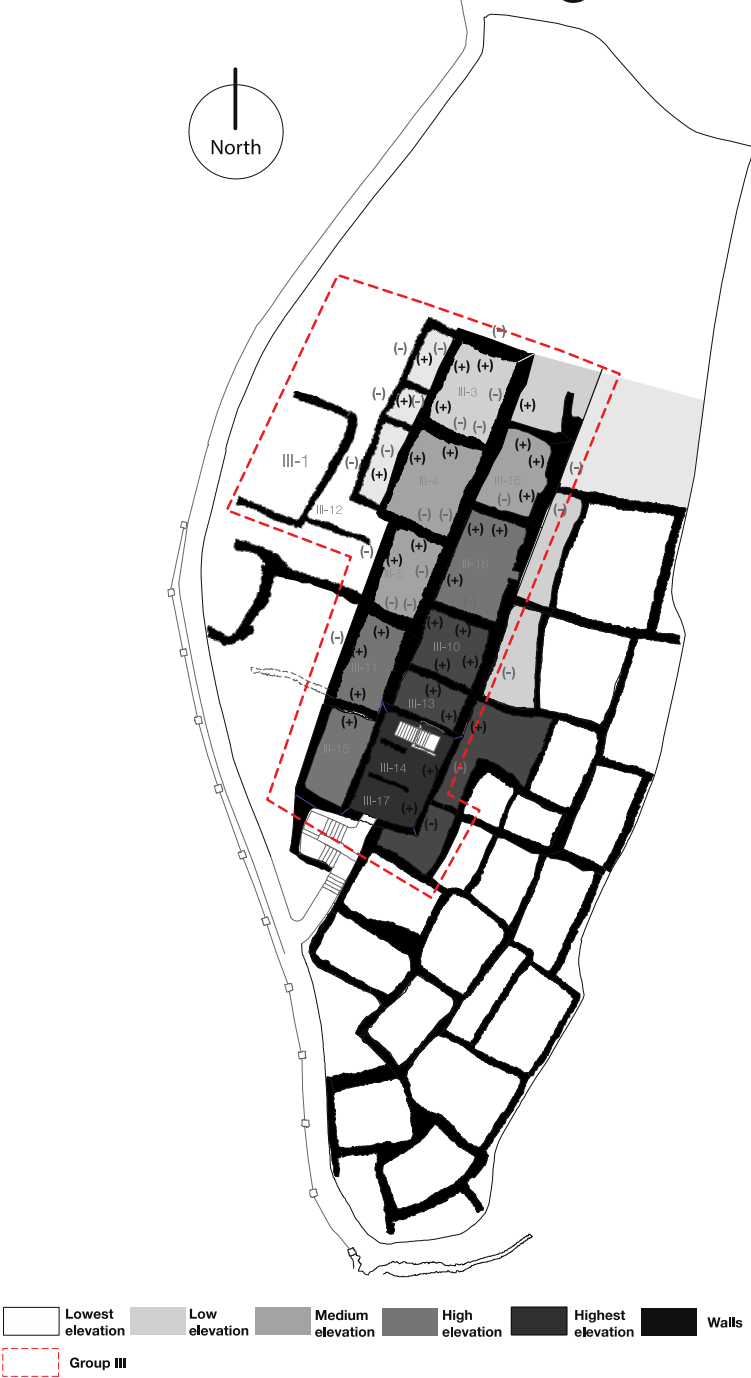


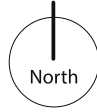
Figure 30 / Differential Fill diagram

In general, wall cap deterioration, bulging and animal burrowing were the most recurrent conditions found on site, where more than 80% of the evaluated walls had some level of each condition. Cap Deterioration (Figure 31) occurred in 96% of the walls and 48% of the evaluated walls had a high level of deterioration of 4 or 5. This condition was observed in both, north-south and east-west oriented walls. This confirms that wall orientation does not influence cap deterioration of walls. The only wall that did not show any signs of cap deterioration was one that is accessible to the public and is regularly maintained.

Bulging (Figure 32) was observed in 87% of the assessed walls, but only 18% were given high scores of 4 or 5. It is possible that this condition is influenced by wall orientation. Of the 22 wall segments evaluated, the only segments that did not show evidence of bulging were east-west oriented walls. It is possible that long north-south oriented walls are more vulnerable to this type of deformation because they are continuous walls that have other walls abutted that might be exerting some lateral loading, and forcing the masonry to bulge between points of fixity. It is acknowledged that some bulging may have occurred before and during abandonment, during reburial, and immediately after excavation. Animal burrowing and vegetation (Figure 33) was recurrent in 96% of the walls, but only 22% of the walls had a high score of level 4 or 5. Similar to cap deterioration, no relation to the wall orientation is apparent. This condition occurs mainly in walls located more distant to the areas accessible to the visitors.

Wall Caps

(Since 1962-64)



96%
of walls have some degree
of cap deterioration

48%
high level of
deterioration

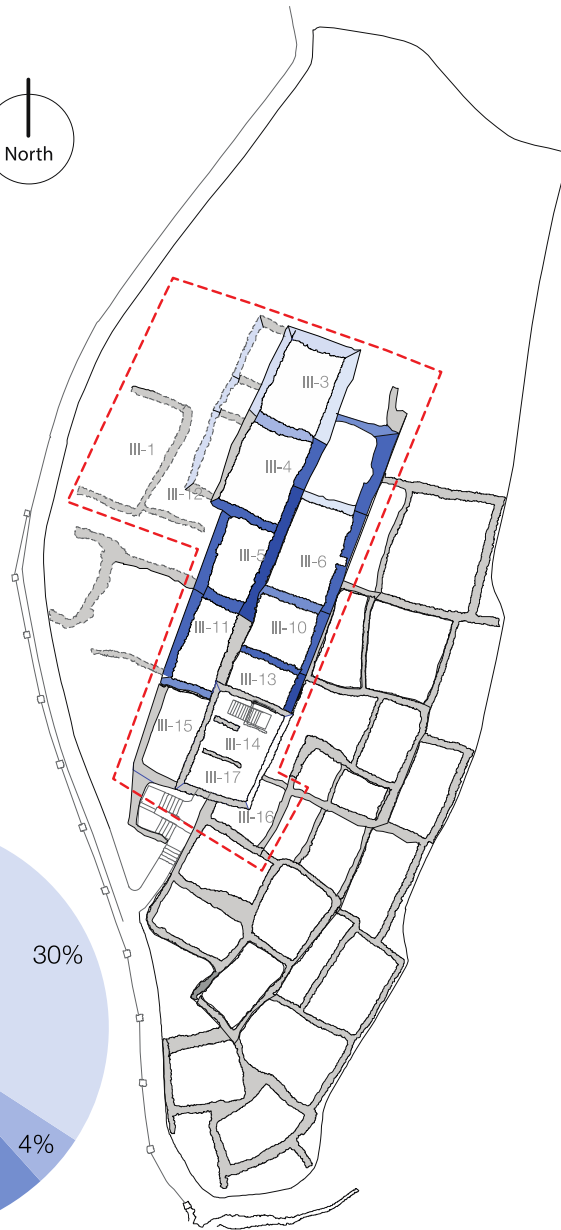
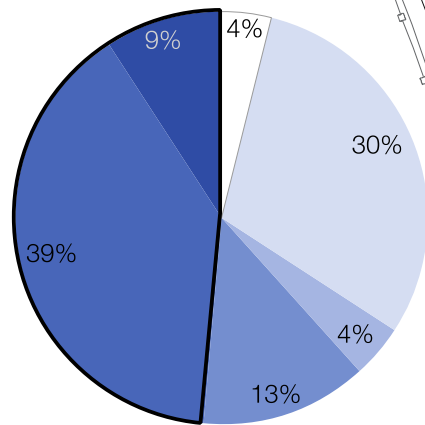


Figure 31/ Wall Cap deterioration Diagram

Bulging

87%
of walls have some
degree of bulging

18%
high level of
deterioration

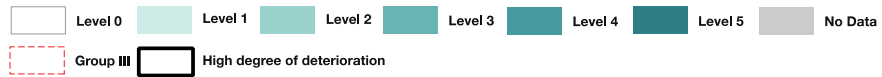
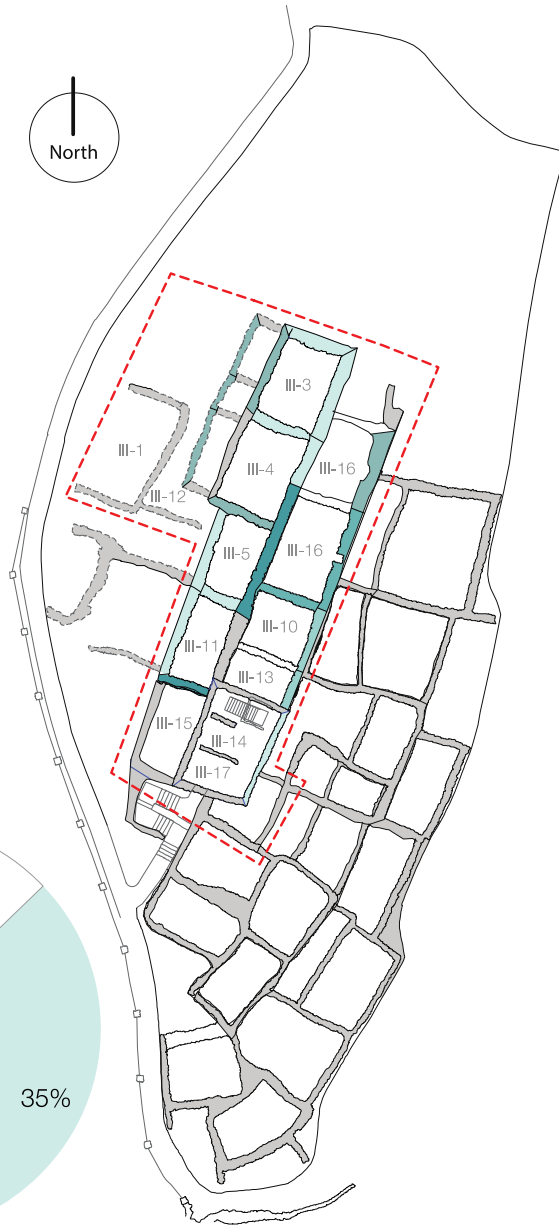
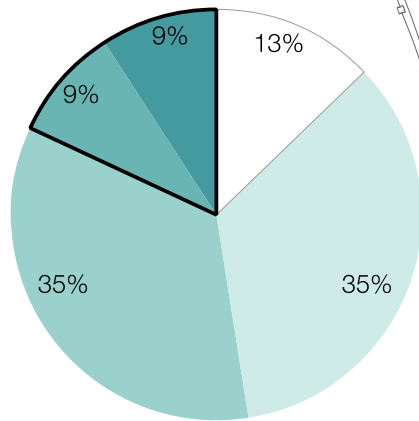


Figure 32 / Bulging Diagram

Animal Burrowing / Vegetation

96%
of walls have some
degree of animal
burrowing or vegetation

22%
High level of
deterioration

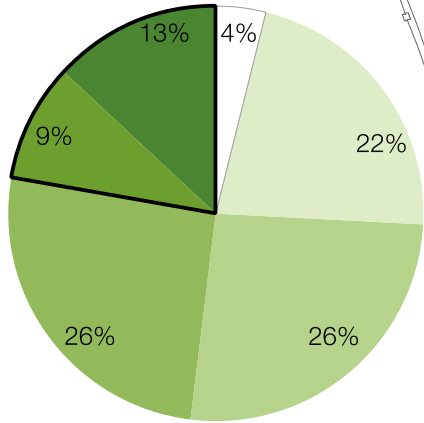


Figure 33 / Animal Burrowing and Vegetation

Out of plane, structural crack and structural cracks at wall junctions had an intermediate recurrence. Out of plane (Figure 34) was only observed in 48% of the walls, with 96% of the walls scoring low levels (level 1 and level 2) for this condition. The only wall that scored a level 5 was the interior division wall of the rooms that superimposed earlier construction. In this case the superimposed wall is not perfectly aligned with the buried wall underneath causing the upper wall to be unsupported and lean out of plane. Neither wall orientation nor location were found to influence structural cracking (Figure 35) or structural cracking at wall junction (Figure 36).

The least repeated condition among the walls was masonry loss; where only 30% of the walls had this condition. Most of the walls that had this condition scored a low level of loss with the exception of the highest scoring wall, which scored a level 5 for masonry loss.

Out of Plane

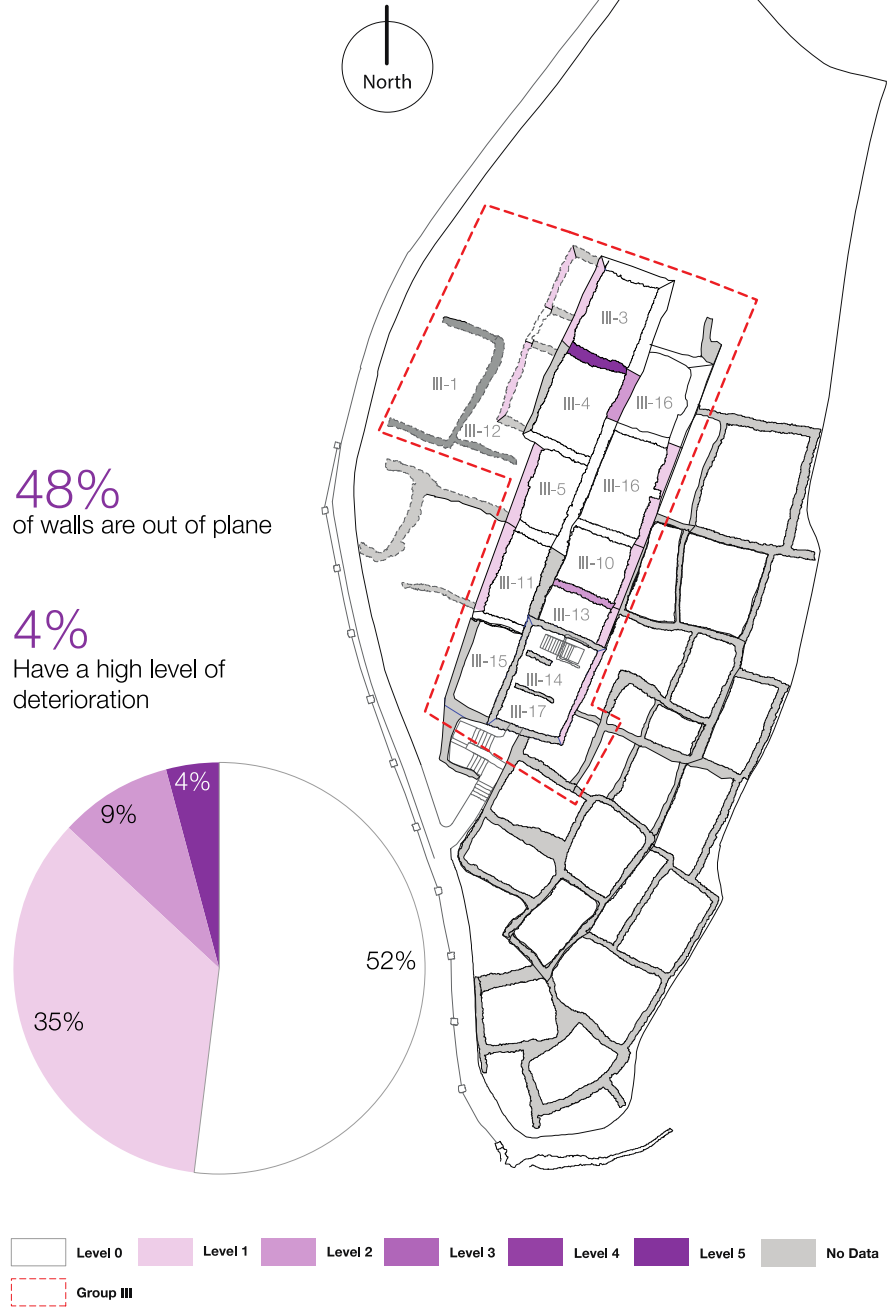


Figure 34 | Out of Plane Diagram

Structural Crack

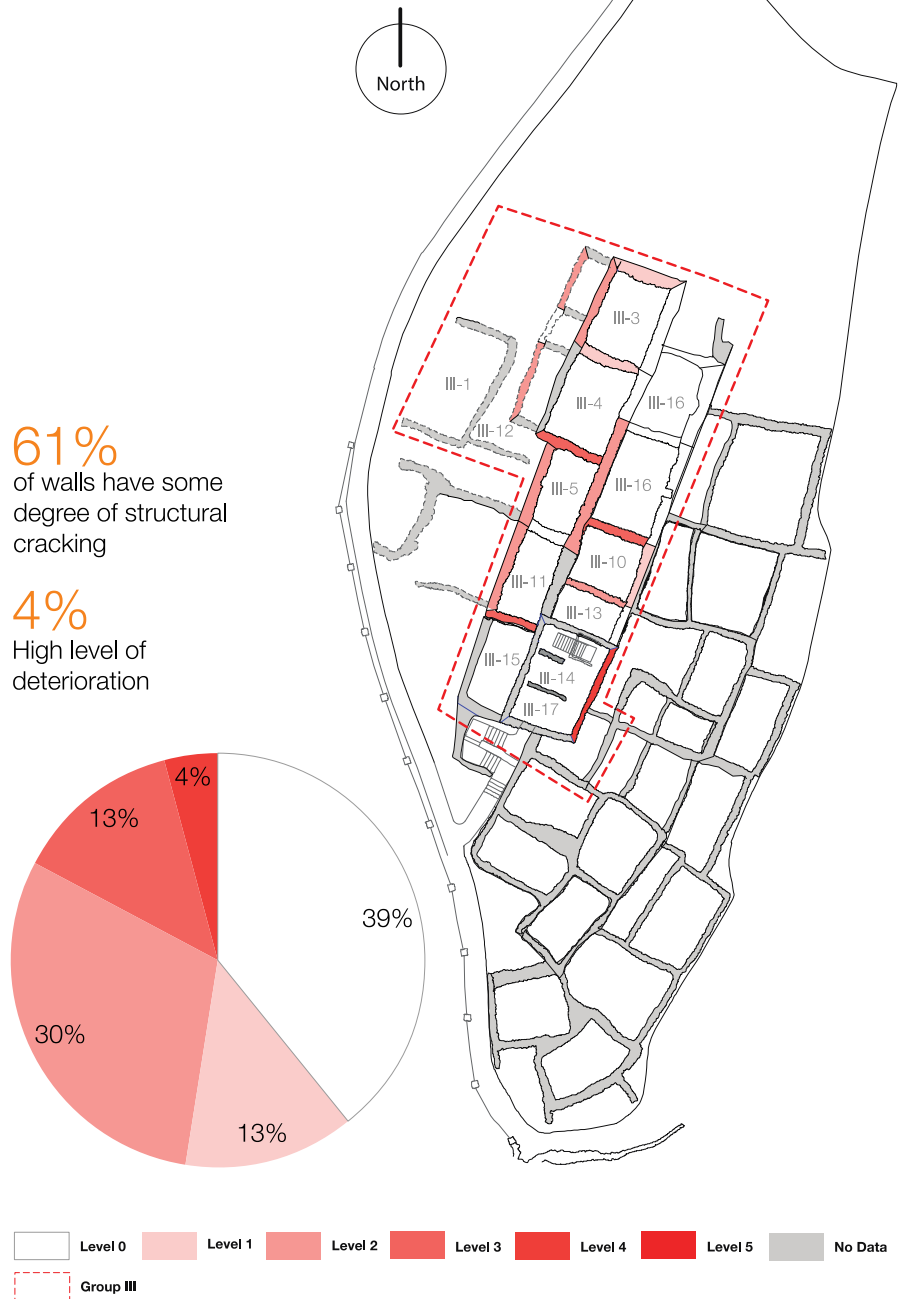
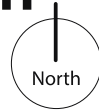


Figure 35 / Structural Cracks Diagram

Structural Crack at Wall Junction



57%
of walls have some
degree of structural
cracks at wall junction

4%
High level of
deterioration

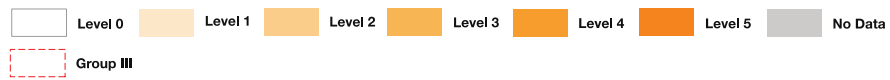
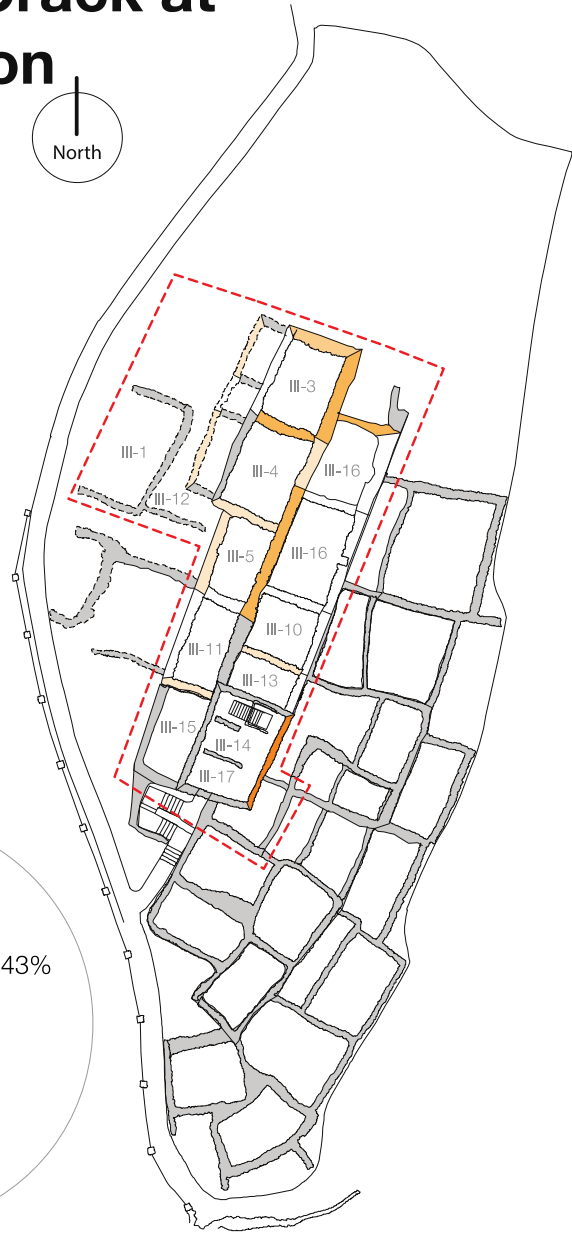
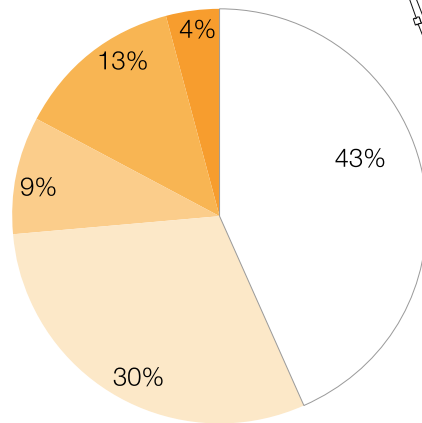


Figure 36 / Structural Cracks at Wall Junction

A matrix that highlighted the highest scoring conditions (Figure 37) on each wall was able to portray one important relationship. Two walls segments, 4C and 5D were found to have the highest scoring on cap deterioration, animal burrowing and bulging. A curious fact is that these are both north-south oriented walls, standing adjacent to each other. It is possible that water intrusion into the wall core, due to animal burrowing and cap deterioration has caused bulging. The rubble masonry at Tuzigoot is characterized by walls that have two wythes and are not interlocked. If water enters the core this would exert disruptive pressure from material displacement as well as expansion and contraction of the soil components, and cause dislodgement of outer wythes.

Wall ID	Cap Deterioration (cracks/Loss)	Structural Crack	Structural Crack at Wall junction	Animal Burrowing/Vegetation	Bulging	Out of Plane	Stone Loss
1B	4	2	0	1	1	1	0
1C	4	2	1	3	1	1	0
2A	1	2	1	2	2	1	2
2B	1	0	1	2	2	0	0
2C	1	2	0	2	2	1	1
3B	1	2	0	2	2	1	0
4C	5	2	2	3	4	0	0
4D	4	0	1	1	1	2	0
4E	1	0	3	3	1	0	1
5A	0	4	4	0	1	0	0
5B	5	0	0	1	2	1	1
5C	4	1	0	5	2	1	2
5D	4	0	0	5	3	1	0
5E	4	0	0	2	2	0	0
13A	1	1	3	3	1	0	0
14A	2	1	3	2	1	5	0
15A	4	3	1	4	2	0	0
16A	4	0	0	1	1	0	0
17A	3	3	1	1	4	0	0
19A	3	0	2	4	0	0	0
20A	1	0	0	5	0	0	0
21A	3	3	0	3	3	0	0
22A	4	2	1	3	0	2	2

Figure 37 / Matrix that highlights the highest scoring conditions on all walls by category. Wall 4C and 5D have high scoring on cap deterioration, animal burrowing and vegetation, and bulging.

Assigning the most serious risk to those walls that display bulging and cracking and are out of plane, walls 4C, 5D, 14A, 17A and 21A were identified for further examination. Wall segment 4C was then studied further to identify the relationships among various other conditions and context.

3.2 Comprehensive Conditions Assessment

The comprehensive conditions assessment employs detailed graphic illustration of the field recorded conditions over an ortho-rectified photograph that is annotated, noting past conditions and treatments, as well as associated ‘aspects’ such as exposure and orientation that could help inform the conditions observed.

The objective of the comprehensive condition assessment was to identify patterns of deterioration based on the combination of collected field data, and archival evidence of important past events. A summarized chronology of the maintenance and stabilization performed on Wall 4C was created to help explain the possible origin of certain conditions observed on the wall.

Wall 4C

Wall 4C is a north-south oriented wall located in the center of Group III. It was built during the second period of construction, between 1200 A.D. and the end of the 13th century.

¹³⁵ It is possible that some of the masonry used to build this wall was recycled from earlier

¹³⁵ Louis R. Caywood and Edward H. Spicer, *Tuzigoot* (Berkeley: National Park Service Publishers, 1935), 19-20; 39.

rooms from the first period of construction that were previously abandoned.¹³⁶ In 1953, Richert noted in his report that this wall was “the widest in the ruin. Probably it supported beams for ceilings of rooms on each side, hence it was made stronger and more massive.”¹³⁷ Like the rest of the pueblo ruins, this wall segment, due to the sudden abandonment of the pueblo in 1420 fell into a long 500-year period of disrepair.¹³⁸ The rooms were filled with refuse until excavation in 1934-35.



Figure 38 / Photo taken from north looking at Room III-5. Note the flat profile wall caps on the left wall (wall segment 4C). Source: 1942 Jack Cotter's photograph collection from the digital archives of Tuzigoot National Monument.

¹³⁶ Caywood and Spicer, *Tuzigoot*, 19.

¹³⁷ Richert, *Stabilization Report*, 47.

¹³⁸ Aaron Mason, *The Administrative History of Tuzigoot National Monument*, (Tuzigoot National Monument:National Park Service, 1999), 2.

After excavation this wall segment was part of a historic visitor trail that was built using a flat flagstone limestone cap on top of the center wall of the pueblo (Figure 38)¹³⁹ It was submitted to pedestrian traffic loads for 28 years, causing noted damage to the masonry, until 1962 when Shiner replaced the wall caps.¹⁴⁰ In 1944-45 an abnormal rainfall event that caused some damage to the ruins was reported in the area, but due to WWII the wall did not receive any maintenance or stabilization until 1947 when minor repointing was completed.¹⁴¹ During that period of abandonment the walls were exposed and vulnerable to deterioration where material loss had occurred.¹⁴² The combination of both, previous weakening caused by live loading from visitor traffic, and the vulnerability of the wall to the weather, could have caused irreparable damage that was only redressed by the 1947 repointing campaign.¹⁴³

In 1953 Richert completed extensive repair in a section of the west elevation that involved clearing the masonry and grouting the core voids with cement and pointing the facing with soil cement. His work was documented with before and after photos shown in Figure 39 and Figure 40.

¹³⁹ Ibid, 45;47;59.

¹⁴⁰ Richert, *Stabilization Report*, 47.

¹⁴¹ Richert, *Stabilization Report*, 47.

¹⁴² Richert, *Stabilization Report*, 47.

¹⁴³ Richert, *Stabilization Report*, 47.



Figure 39 / Photos of damage found in wall segment 4C (east wall of room III-5) prior to stabilization completed by Richert in 1953. Source: Richert, Roland. *Stabilization Report Tuzigoot National Monument. (Arizona: Southwestern National Monuments Ruins Stabilization Unit Globe, 1953), 48.*



Figure 40 / Photo of wall 4C (east wall of room III-5) after stabilization completed by Richert in 1953. The work completed involved clearing the wall out, grouting it with cement, and masonry facing was pointed with soil cement.



Figure 42 / Flat profile of wall caps prior to Shiner's work. Source: Shiner's 1962 Report, 33.



Figure 41 / New wall caps completed by Shiner. Source: Shiner's 1962 Report, 33.

In 1961-62 the visitor trail was redirected, and wall caps were replaced by big rounded stones (Figure 42 & Figure 41) by Joel Shiner in order to remove the flat profile of the caps.¹⁴⁴ Although today some of the historic flagstone still remains, during his work many flagstones located on the edges of the wall top were removed, particularly those that extended out wider than the wall that provided a drip edge for the wall top.¹⁴⁵ In order to remove the flat profile the walls were capped with randomly set larger stones¹⁴⁶ Some areas below the flat top were patched where necessary.¹⁴⁷

Four years later, in 1968 the wall was described to be in “excellent condition” in Mayer and Waggoner’s report. Although records for stabilization between 1968 to 1994 do not exist, judging from the condition of the wall, it is possible that this wall has not received any maintenance or stabilization work since 1962.

¹⁴⁴ Shiner, *Stabilization Report*, 30-33.

¹⁴⁵ *Ibid*, 30-33.

¹⁴⁶ *Ibid*, 30-33.

¹⁴⁷ *Ibid*, 30-33.

Condition Assessment (See Figure 43 & Figure 44)

In general, the west elevation is in a more advanced state of deterioration than the east elevation of wall segment 4C. The west side exhibits two instances of extreme bulging. Basal erosion is present in the majority of the wall and structural cracking surrounds the areas with bulging. The east elevation only displays some structural cracking, but animal burrowing and vegetation conditions are recurrent conditions in this side. Although no cracks are visible on the caps, the wall was given a high score due to the pronounced level of erosion and some masonry loss, revealing a core clay material, possibly dating from historic 1930's excavation repairs.

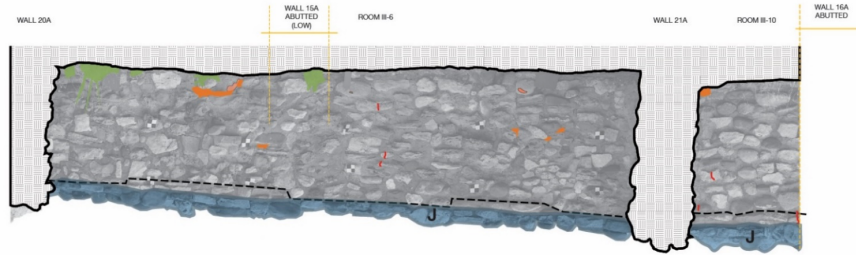
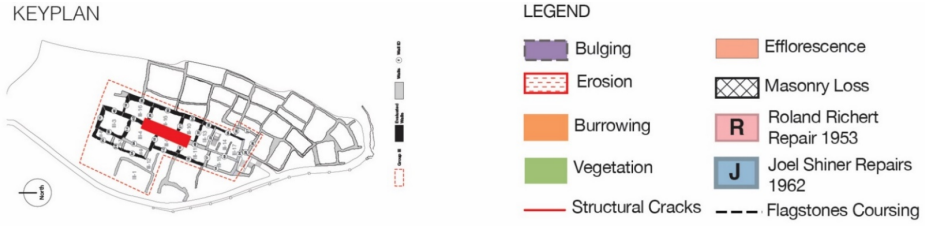
In addition, the tops of this wall were used as the historic visitor's path for 28 years. Already in the 1940's damage was occurring in the base and in the mortars. Perhaps the load from the visitor's traffic on the wall tops caused some movement and stone displacement that disrupted the load distribution.

Both instances where bulging is evident are located on the west elevation of the wall where perpendicular walls abut on the opposite side. Structural cracks occur in areas where the wall is bulging or in areas surrounding it, but never in the space where a wall is abutted. According to excavation records, the abutted walls are not interlocked to this wall. The cracking in the masonry shows there is or has been movement in the masonry, disrupting the original load path and causing structural cracking. A more comprehensive assessment of the walls abutted to this wall segment, would aid in determining the pathologies of these walls and why are they pushing and causing damage to wall 4C.

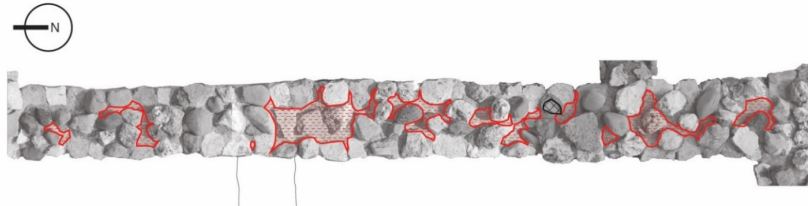
Interesting enough, the only structural cracks visible in the east side of the wall are located towards the relative center of the segment. When comparing the location of those cracks with the other side of the wall (west), structural cracks are also visible. This also reinforces the hypothesis that the abutted walls are causing displacement and deformation of the wall. The two abutted walls (20A and 21) are pushing west exerting opposing forces to wall pressures in wall 4C causing the wall to be in tension, thus deforming the wall, and cracking in the zone of highest stress, the center of the wall (Figure 45).

Wall segment 4C has a slight differential fill (Figure 30), with a higher ground elevation on the east side than that of the west side. This is particularly true in zones where basal erosion and some masonry has collapsed in the west elevation. These two conditions, basal erosion and collapse, are visible in historic photographs since the 1940's in Cotter's 1942 photo Records (Figure 38) and Richert's 1953 Stabilization Report (Figure 39). It is highly possible that moisture accumulated on the ground of the east rooms (III-16 and III-10) has caused deterioration by capillarity and freeze thaw.

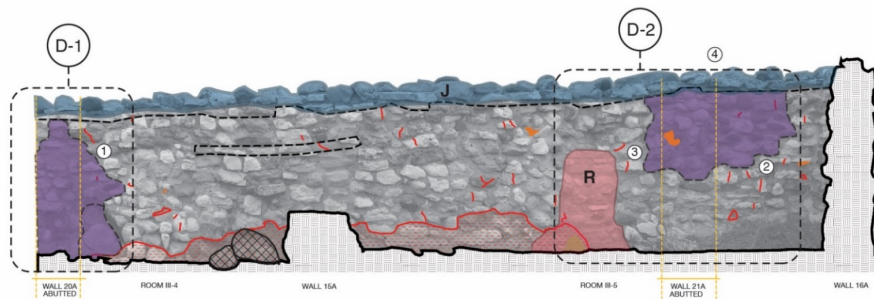
It is possible that moisture accumulated in the higher ground of Rooms III-10 and III-16 (to the east) have caused damage to the base of the other side of the wall. Although Tuzigoot does not get high amounts of precipitation, during the rainy season (summer) it gets an average of two (2) inches annually. During the winter the average is also two (2) inches, but this year prior to arriving at the site to complete the assessment, there was a 10-inch accumulation of snow during February. During the winter the wind mainly blows from east to west, pushing the moisture from snow into the east side of the wall.



EAST ELEVATION OF WALL 4C

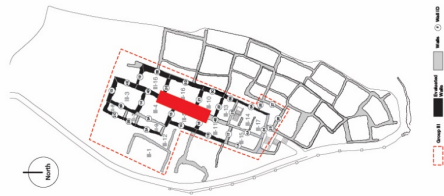


WALL CAP











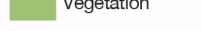
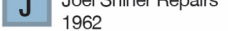
WEST ELEVATION OF WALL 4C

Figure 43/ Comprehensive Condition Assessment of wall 4C completed on top of Ortho-rectified Photography. The west elevation displays an advanced level of bulging, basal erosion, and structural cracking. Some stone loss, where basal erosion has occurred. Refer to Figure 17 (next page) for details (D-1 & D2) and notes (1,2,3,4). For larger drawings refer to Appendix X.



Keyplan

LEGEND

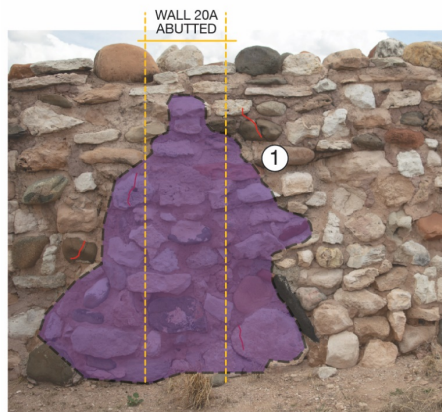
 Bulging	 Efflorescence
 Erosion	 Masonry Loss
 Burrowing	 Roland Richert Repair 1953
 Vegetation	 Joel Shiner Repairs 1962
 Structural Cracks	 Flagstones Coursing

NOTES:

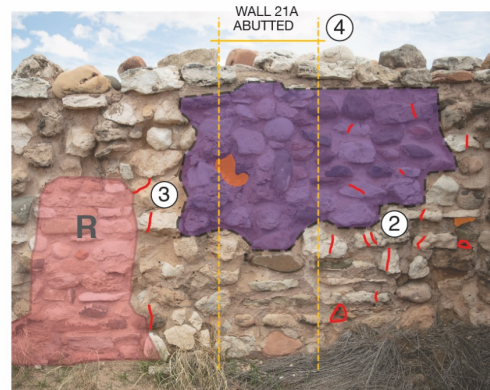
1. **Structural cracks** surrounding the northmost **bulging** on west wall support the fact that loads, probably from wall abutted behind is causing displacement.
2. Appearance of **structural cracks** surrounding the bulge, only in adjacent areas to abutted wall.
3. **Structural cracks** are visible between bulge, abutted wall and Richert's cement grouting repair.
4. Mortar on Shiner's **caps** have eroded to the point where a more clay-ish, silt-like material is visible. Caps might be susceptible to water intrusion.



Wall was grouted with cement and finished with soil cement tinted mortar.



D-1 Detail Photo of Northmost Bulging West Wall



D-2 Detail Photo of Southmost Bulging West Wall

Figure 44 / Detail and historic photos referred to Conditions Assessment annotations.

During the summer the wind blows from the south. These conditions are likely to change as Climate Change causes more intense, albeit fewer periods of precipitation.

Animal burrowing is visible in both sides of the wall, with predominance on the east elevation. This wall is characterized by having larger burrowing holes than other walls in Group III. Although the loss of mortar and core material due to burrowing can cause cracking due to lack of uniform distribution of loads, the evident cracks do not respond to a cracking pattern that relates to the locations of the burrowing holes. Vegetation is usually indicative of high moisture content and lack of maintenance. In this wall vegetation is prominent in the east elevation and its location correlates with basal erosion occurring in the west elevation. In this case vegetation is just more evidence that water is in fact accumulating on the east ground, causing damage to the base of the wall.

In summary, there are two main forces affecting the lateral loads from adjacent walls. The first is displacement and movement of the wall segment, due to lateral loads exerted by the abutted walls (Figure 45). This is evident in both the form of structural cracking and bulging. The bulging is the result of the loads exerted by the abutted walls. The cracking visible surrounding or where bulging occurs, evidences the origin of the loads. The cracks in the center of both sides of the wall show that these two loads are causing displacement and or distortion. The vertical cracks visible in stones of both sides of the wall are indicative of stress caused by the deformation of the wall. It is important to understand the reason for these walls to exert loads to this wall. A more comprehensive assessment of the abutted walls may inform the origin.

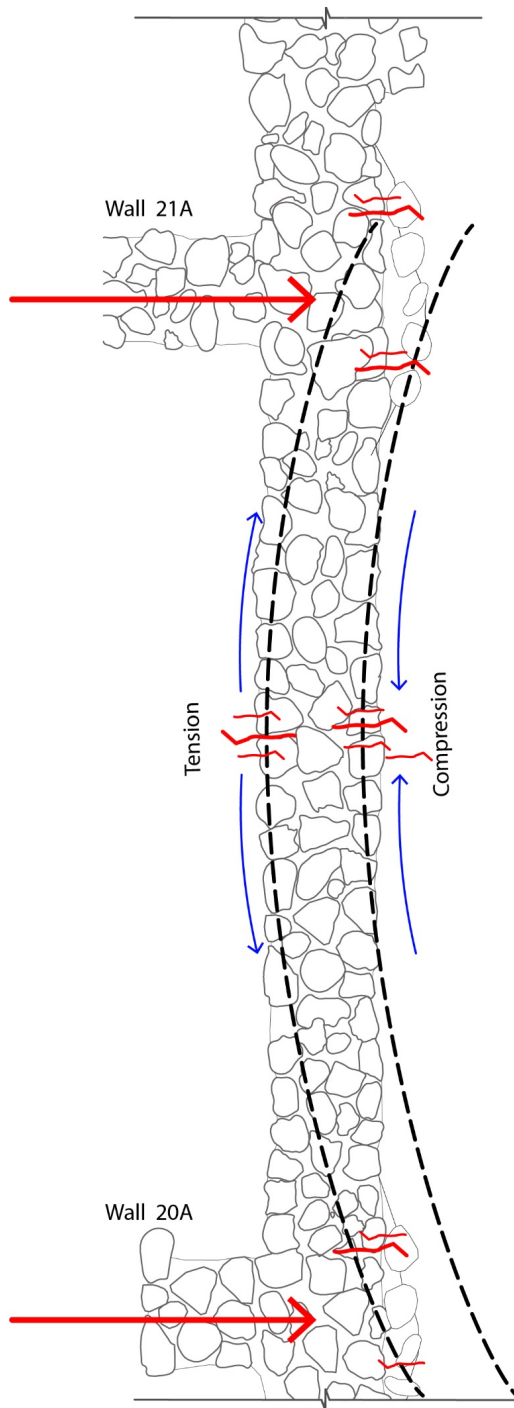


Figure 45 /Diagram of 4C with abutted walls (20A & 21A). It shows how loads (red arrows) from abutted walls are being exerted and cracks (red lines) appear due to tensional and compressive loads resulting from the wall deformation.

The second is the intrusion of moisture from two different sources (Figure 46). Moisture is entering the system through the caps and the wall base. If moisture is in fact entering from the caps, the interior earth and rubble core material might be dislodged and traveling down with the water, compromising the interior strength and exerting pressure on the wall faces. This damage may also be exacerbated by the expansion and contraction of the clays in the fill. However, the source for the moisture intruding the system from the base of the wall is accumulated precipitation (rain or snow) entering the system by capillary absorption. The higher ground on one side of the wall is accumulating water differentially that is absorbed by the wall causing damage from freeze-thaw, thermal expansion, and erosion. Due to the location of this wall segment and the surrounding wall locations the west elevation of the wall segment does not get much direct sunlight to dry the moisture absorbed fast enough. The sun rises from the east, around the south and as it sets towards the west side its elevation lowers, allowing for the east-west walls located on the south end of the segment, to provide shade while the sun sets. When the sun reaches the west, the south and west walls provide a period of the time of shade, preventing the sun from drying the base of the west elevation.

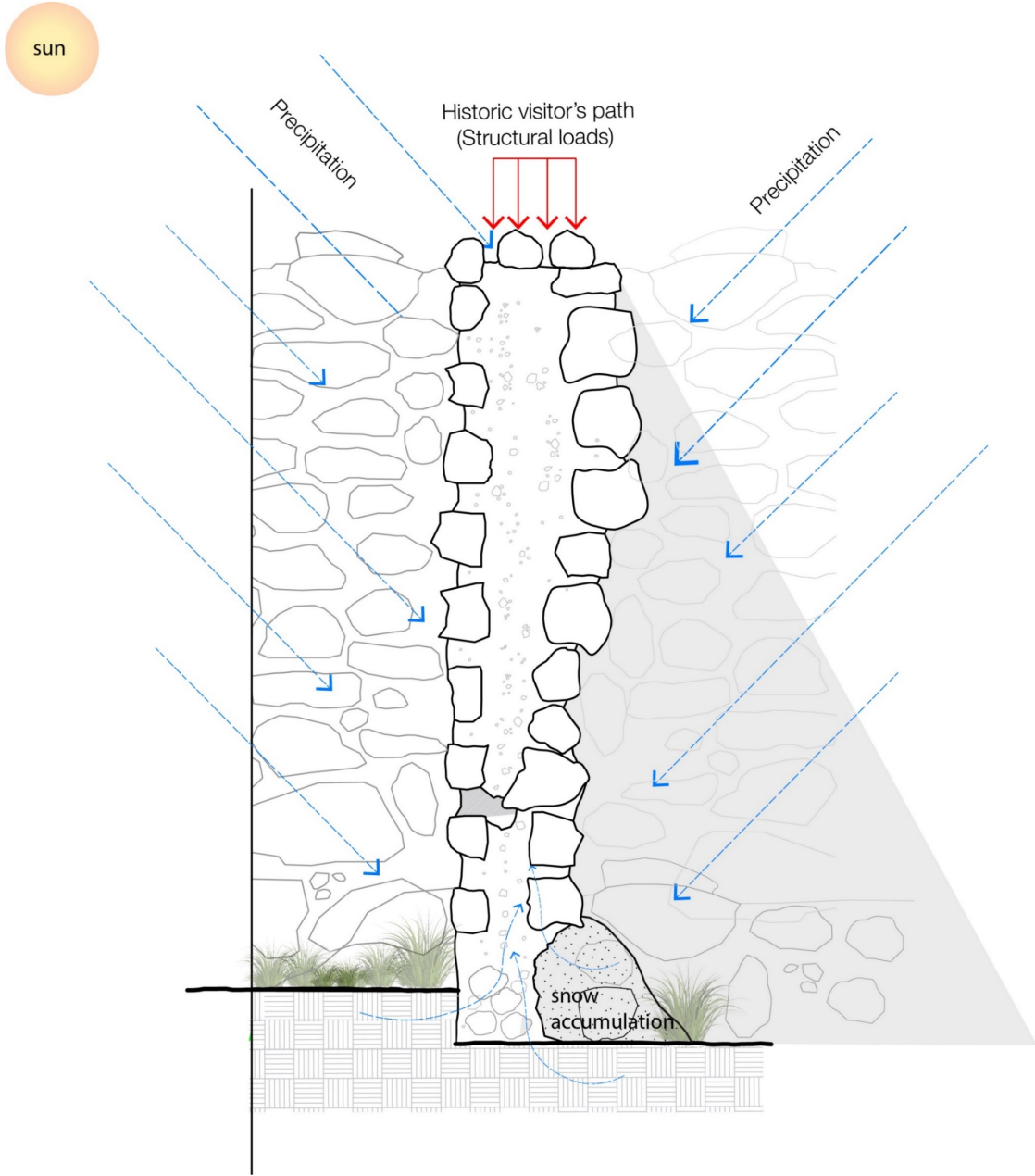


Figure 46 | Diagrammatic section of wall 4C showing precipitation, water intrusion, absorption and erosion of wall base.

4.0 Recommendations

Recommendations are made based on the wall behavior observed during the site visit and the assessment. Some of the observations made are related to the current and historic maintenance approach; other observations were learned in the process of evaluating the structures. Further long-term monitoring and assessment can inform this study's findings to expand conservation recommendations.

Unlike many other similar sites, the region's climate allows for maintenance to be completed most of the year, except December and January, when the temperatures reach freezing levels. Once the "work season" begins, the park archaeologist decides by visual inspection which walls appear to be in the worst condition. All elevations of a given room are then repaired. The existing mortars are first removed and then the entire wall is repointed with the new mortar mix, to achieve a uniform appearance.

First, a more systematic approach to wall selection would be more favorable for identifying the walls in need of preservation. The RAS performed during this summer did not only identify the most recurrent conditions, but also identified the most at-risk walls; it also set a baseline to record more frequently as a form of monitoring. The use of this system quantifies the conditions of the walls that can be cross-referenced yearly to identify where additional damage has occurred, helping the park understand which conditions and walls are in and active state of deterioration. By understanding periodical changes on the walls (stabilized and not stabilized) will provide the park with information that can identify sources of deterioration, and other patterns that cannot be recorded by a single assessment of the wall.

In addition, the approach that the park embraces may completely replace the pointing of one elevation rather than the entire wall itself (both walls faces and the top). In most cases, lost or eroded mortar on the other elevation of the wall will allow moisture to enter the system and begin to damage the interior core of the wall differentially. Leaving the two elevations with contrasting conditions may cause the wall as a system to be imbalanced, resulting in moisture movement, displacement, and causing further deterioration. It is recommended that stabilization work be completed on both elevations of the wall and the caps, in order to approach the problem in a more structural way.

During this phase of the project a comprehensive chronology of construction and stabilization of Group III, a Rapid Assessment Survey (RAS), and a Comprehensive Condition Assessment of the most at-risk walls were completed. Unfortunately, due to lack of time at the park the RAS was not completed for all the walls in Group III. It is recommended that prior to commencing any stabilization work that RAS evaluation for all walls is completed.

It is also recommended that a more comprehensive assessment be completed for the identified out of plane and bulging walls. The conditions and observations resulting from this assessment can reveal patterns that inform the cause of these conditions. Although one example of a wall with bulging was already assessed, it would be interesting to see if the patterns repeat, or if in the contrary, the same conditions are being caused by different agents.

The combination of all of the conditions found on the comprehensive assessment of wall 4C are detrimental to the wall system. While the eroded base is lacking support for the upper stones, failing in distributing the vertical loads, the abutted walls are causing the wall

to deform, further compromising the stability of the wall. Grading the ground on the east rooms would help redirect water so that it doesn't accumulate, and it will help mitigate the damage caused by moisture intrusion. This wall is need of urgent stabilization, but before any work is completed monitoring and additional investigations should be made in this and other segments of this wall and abutted walls. Moisture content and cracks should be monitored on both sides of the wall in order to determine if the diagnosis of the wall is correct and still active.

In addition, other segments should be verified and assessed for conditions similar to this wall segment. Only with additional investigation will the origin of the problem be discovered, and informed repairs can be made. This will help the wall to endure for posterity.

5.0 Conclusion

After completing this assessment several closing statements can be made. It is critical to have a clear understanding of the chronology of construction, excavation, and stabilization, in order to make an informed diagnosis of overall wall condition and performance. Understanding the mechanics of rubble masonry and the site conditions aided in the interpretation of the RAS and the comprehensive condition assessment. The RAS not only helped identify which were the most at-risk walls, but it also aided in finding patterns such as which were the most recurrent conditions on the wall. The highest scoring wall, wall 4C, resulted in having a high score in bulging, cap deterioration, and animal burrowing and vegetation. Although this wall was a good model for understanding the reoccurring

conditions, it is recommended that the wall be monitored (cracks and moisture) to clarify and have confirmation of the wall pathologies.

In any assessment prior to stabilization all background information should be collected. Historic stabilization events, climatic events, periods of disrepair, and previous use of the structure will inform the wall diagnostics. In order to design a functional rapid assessment survey for any site, the wall mechanics, previous conditions, and current conditions should be known. In some cases, conditions occur in certain areas of the wall, and this might be important to note for each case. Only by integrating this knowledge will the evaluation be effective in determining the most vulnerable walls.

Prior to commencing the comprehensive assessment of the most vulnerable, at-risk walls, a comprehensive chronology of the stabilization work should be completed. This will identify recurrent conditions and trends and determine some of the wall diagnostics. Understanding if certain conditions have been present for long periods of time or appear after certain changes have been made to the wall will usually inform the origin of some of the conditions. After depicting all the conditions on top of a photograph or drawing, all patterns visible on all wall elevations and caps should be analyzed to interpret wall conditions.

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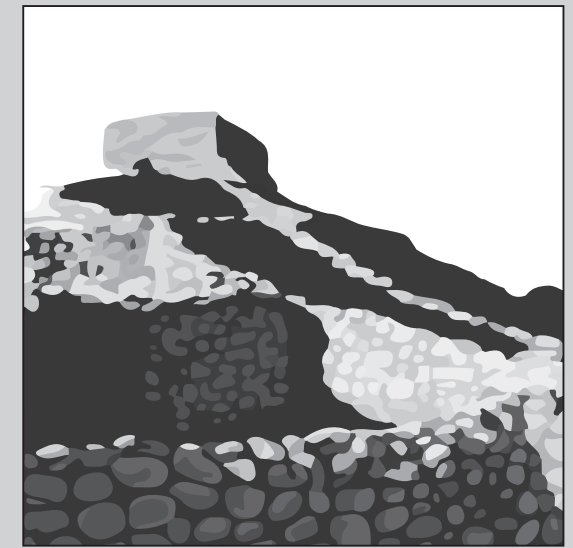
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Appendix A

Comprehensive Stabilization and Maintenance Chronology (Group III)



TUZIGOOT NATIONAL MONUMENT
25 Tuzigoot Rd, Clarkdale, AZ 86324

THE CENTER FOR ARCHITECTURAL CONSERVATION
Graduate Program in historic Preservation
The Stuart Weitzman School of Design
University of Pennsylvania

A THESIS ON:
A FRAMEWORK FOR RISK AND VULNERABILITY
ASSESSMENT OF THE RUBBLE MASONRY OF TUZIGOOT
NATIONAL MONUMENT

Dorcas Corchado, Student Researcher
Frank Matero, Thesis Advisor

**COMPREHENSIVE
CHRONOLOGY OF
STABILIZATION**

SOURCES: Rapid Assessment Survey - March 2019.

DRAWN BY: Dorcas Corchado

DATE: 05/17/19

APPENDIX-A

Wall ID		Stabilization History (by campaigns)											
ROOM	WALL	Wall Segment ID (2019)	Caywood & Spicer (1934-35)	1941-42	1947	1952 Trail work	Roland Richert (1953)	Joel L. Shiner (1961)	Voll (1964)	Mayer & Waggoner (1968)	Chambers Drainage Project (1983)	Park Service (Triple XXX forms)	Vanishing Treasures (1998)
All					Decay of supporting walls. All roofs were taken down, orders of the regional superintendent		Commissioned to do extensive stabilization work on the Tuzigoot Ruins. (Neilson, 1980, p. 18)						
III-1	North									Walls were capped and bases were excavated to check for deterioration due to capillary spread of moisture. 2. Crumbling sandstone was replaces with enduring limestone. 3. Grouting and patching was performed as needed. 4. All work set in tinted cement.			
	East												
	South												
	West	4E	1. Capped with sandstone flagstones to provide smooth trail.							1. Trail flagstones which were on the edges were removed. 2. Wall was capped and occasional larger Rocks were set randomly to breakup the flat profile. 3. Few small patches were necessary just beneath the flat top in the area that had been rebuilt for the walkway.			
III-2	North									Walls were capped and bases were excavated to check for deterioration due to capillary spread of moisture. 2. Crumbling sandstone was replaces with enduring limestone. 3. Grouting and patching was performed as needed. 4. All work set in tinted cement.			
	East												
	South												
	West	4D, 4E	1. Capped with sandstone flagstones to provide smooth trail.							1. Trail flagstones which were on the edges were removed. 2. Wall was capped and occasional larger Rocks were set randomly to breakup the flat profile. 3. Few small patches were necessary just beneath the flat top in the area that had been rebuilt for the walkway.			
III-3	North									Walls were capped and bases were excavated to check for deterioration due to capillary spread of moisture. 2. Crumbling sandstone was replaces with enduring limestone. 3. Grouting and patching was performed as needed. 4. All work set in tinted cement.			
	East	4E	1. Capped with flagstones to provide smooth trail. 2. Until 1952 visitors walked on this wall's cap to reach room 14.							1. Trail flagstones which were on the edges were removed. 2. Wall was capped and occasional larger Rocks were set randomly to breakup the flat profile. 3. Few small patches were necessary just beneath the flat top in the area that had been rebuilt for the walkway.			
	South			1. Minor repairs at east end in.	All walls patched as needed in.			Covered holes at base of south walls patched with soil cement.		Walls were capped and bases were excavated to check for deterioration due to capillary spread of moisture. 2. Crumbling sandstone was replaces with enduring limestone. 3. Grouting and patching was performed as needed. 4. All work set in tinted cement.			
	West												
III-4	North				1. Minor pointing at all walls.					Walls were capped and bases were excavated to check for deterioration due to capillary spread of moisture. 2. Crumbling sandstone was replaces with enduring limestone. 3. Grouting and patching was performed as needed. 4. All work set in tinted cement.			
	East	4C	1. Capped with flagstones to provide smooth trail. 2. Until 1952 visitors walked on this wall's cap to reach room 14.					1. "Traffic undoubtedly weakened this wall and it is in imminent danger of collapse." 2. Central section of east wall cleared out, grouted with cement masonry, laid up in soil cement.		1. Trail flagstones which were on the edges were removed. 2. Wall was capped and occasional larger Rocks were set randomly to breakup the flat profile. 3. Few small patches were necessary just beneath the flat top in the area that had been rebuilt for the walkway.			
	South West	1C						1. Undercut and porous sections plugged with masonry in soil cement		Walls were capped and bases were excavated to check for deterioration due to capillary spread of moisture. 2. Crumbling sandstone was replaces with enduring limestone. 3. Grouting and patching was performed as needed. 4. All work set in tinted cement.			
III-5	North												
	East												
	South												
	West												
III-6	North									Walls were capped and bases were excavated to check for deterioration due to capillary spread of moisture. 2. Crumbling sandstone was replaces with enduring limestone. 3. Grouting and patching was performed as needed. 4. All work set in tinted cement.			
	East												
	South												
III-6	West	4C	1. Capped with flagstones to provide smooth trail. 2. Until 1952 visitors walked on this wall's cap to reach room 14.							1. Trail flagstones which were on the edges were removed. 2. Wall was capped and occasional larger Rocks were set randomly to breakup the flat profile. 3. Few small patches were necessary just beneath the flat top in the area that had been rebuilt for the walkway.			

Appendix B

Glossary of Conditions (Rapid Assessment Survey)

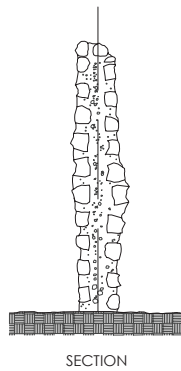
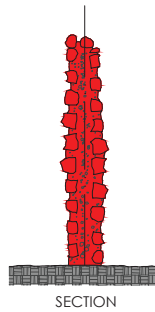
ILLUSTRATED GLOSSARY OF CONDITIONS

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



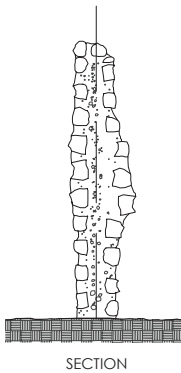
BULGING

Localized outward deformation of a wall. Not to be confused with "Out of Plane".



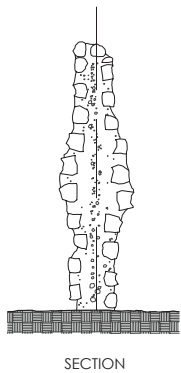
LEVEL 1

Slight outward swelling of the wall.



LEVEL 3

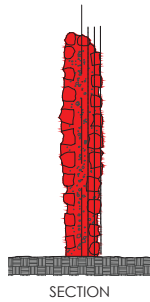
Pronounced outward swelling of the wall.



LEVEL 5

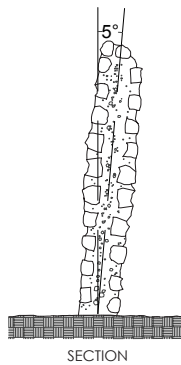
Pronounced or slight outward swelling of the wall on both sides of the wall.





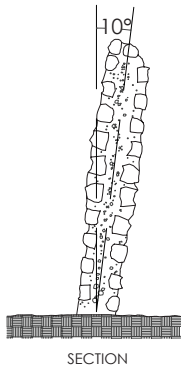
OUT OF PLANE

Walls that exhibit lean more than 5° from perpendicular wall to base or ground are considered to be out of plane. Lean is differentiated from bulging and masonry loss. Leaning walls are inferred by aligning the present wall top to the base.



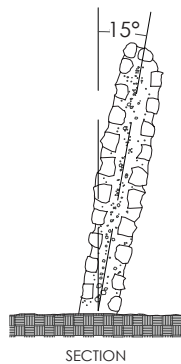
LEVEL 1

Walls that display a slight lean along any portion of the elevation and not greater than 5°.



LEVEL 3

Walls that display a moderate lean along any portion of the elevation and between an angle of 5° to 10°.



LEVEL 5

Walls that display a severe lean along any portion of the elevation and an angle greater than 10°.



STRUCTURAL CRACKS



Structural cracks are fractures within stone or mortar or both. Structural cracks also include complete wythe separation. Structural cracks are not to be confused with shelter coat cracks or loss.



LEVEL 1

Single or multiple intermittent cracks (vertical, horizontal, or diagonal) on one face of a wall.



LEVEL 3

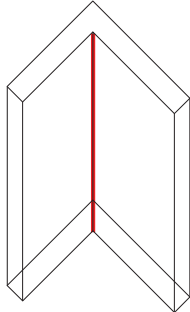
Single or multiple cracks (vertical, horizontal, or diagonal) on both sides of wall.



LEVEL 5

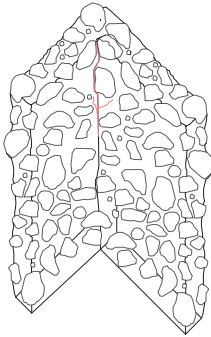
Single or multiple deep or continuous cracks (vertical, horizontal, or diagonal) accompanied by apparent hairline cracks on one or both wall faces. The wall may also show displacement (Bulging or out of plane lean) and wythe separation.





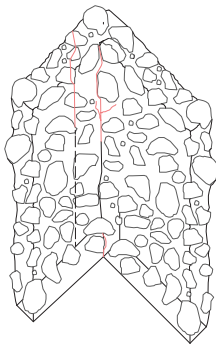
STRUCTURAL CRACKS AT WALL JUNCTION

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 wall units often associated with no/poor wall bonding.



LEVEL 1

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



LEVEL 3

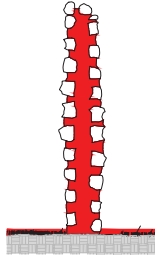
Hairline crack(s) evident on both sides of the wall intersection.



LEVEL 5

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



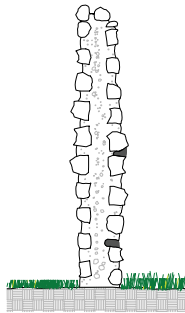


SECTION

ANIMAL BURROWING & VEGETATION

Animal Burrowing: Tunneling within and at the base of the wall used by animals for shelter.

Vegetation: Growth of higher plants at surrounding grade and within cracks and open joints in the wall.

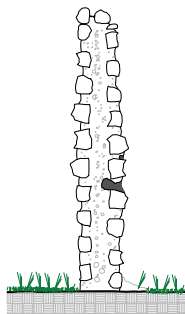


SECTION

LEVEL 1

Burrowing: Minor breaches.

Vegetation: Only grasses are present adjacent or close to the wall.

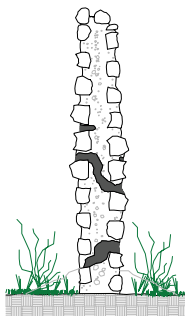


SECTION

LEVEL 3

Burrowing: Larger breaches, specially at grade causing instability. Pulverized wall material can usually be found in association.

Vegetation: Grasses and herbaceous plants have grown adjacent or close to the walls.



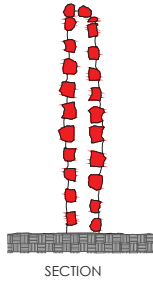
SECTION

LEVEL 5

Burrowing: More than three large breaches are visible and the wall core is exposed.

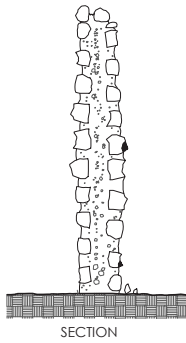
Vegetation: Grasses and herbaceous plants dominate the ground surrounding the wall.





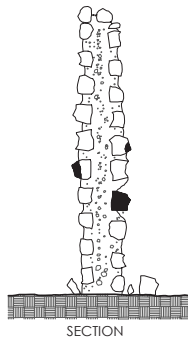
MASONRY LOSS

Partial or complete localized loss of stone and mortar.



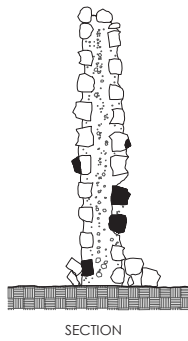
LEVEL 1

Localized minor loss of stone and mortar.



LEVEL 3

Moderate localized loss of stone and mortar accompanied by incipient detachment.



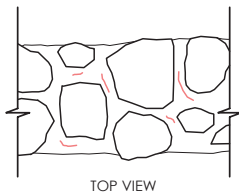
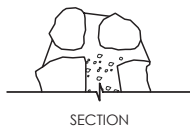
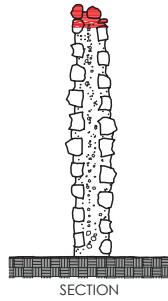
LEVEL 5

Major localized loss of stone and mortar accompanied by incipient detachment.



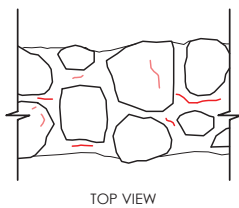
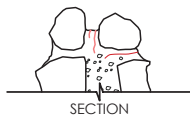
CAP DETERIORATION

The wall cap has been compromised by cracking or loss leaving the wall interior and veneer susceptible to damage from moisture intrusion.



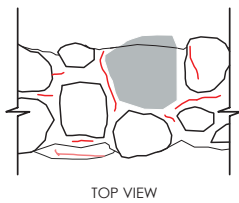
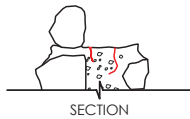
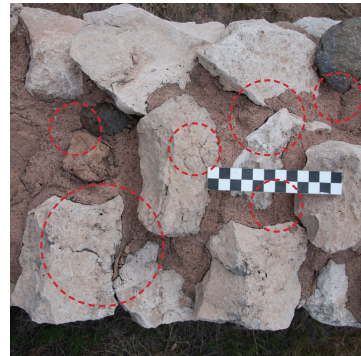
LEVEL 1

Few hairline cracks visible, possibly mortar shrinkage/expansion cracks. Wall caps retain integrity and stones are still stable.



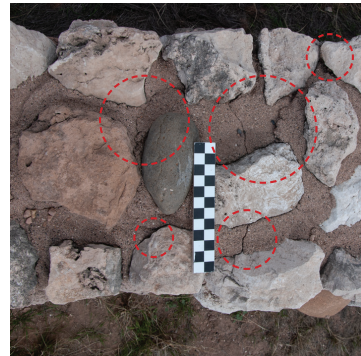
LEVEL 3

Some mortar erosion has occurred, and cracks are present. Wall caps are beginning to loose and stones are becoming detached.



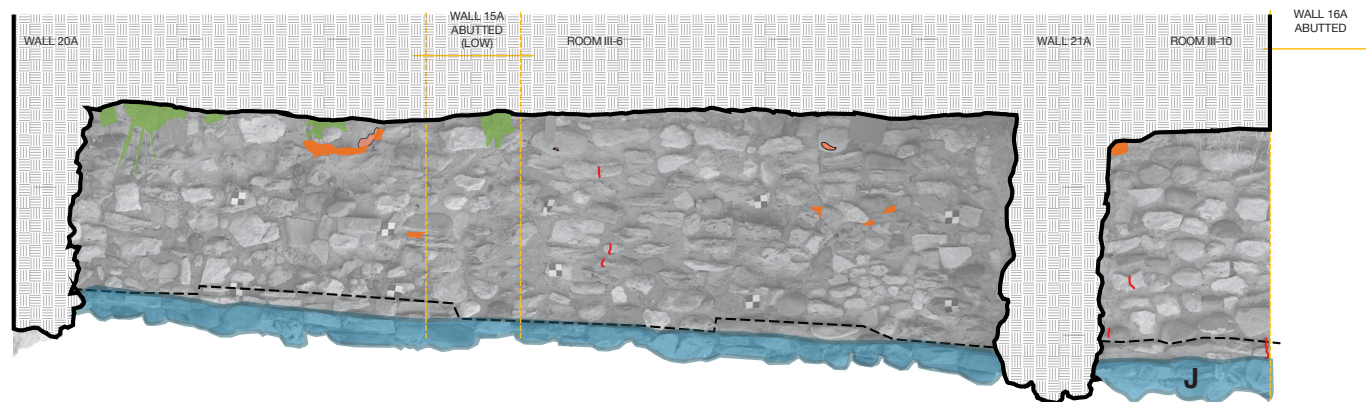
LEVEL 5

Multiple cracks are visible, including structural cracks or wythe separation. One or more stones are loose and the cap mortar has eroded to the point that original materials are exposed.

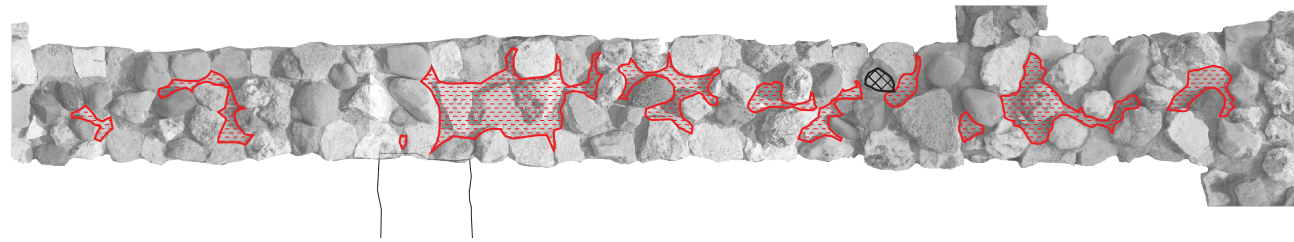


Appendix C:

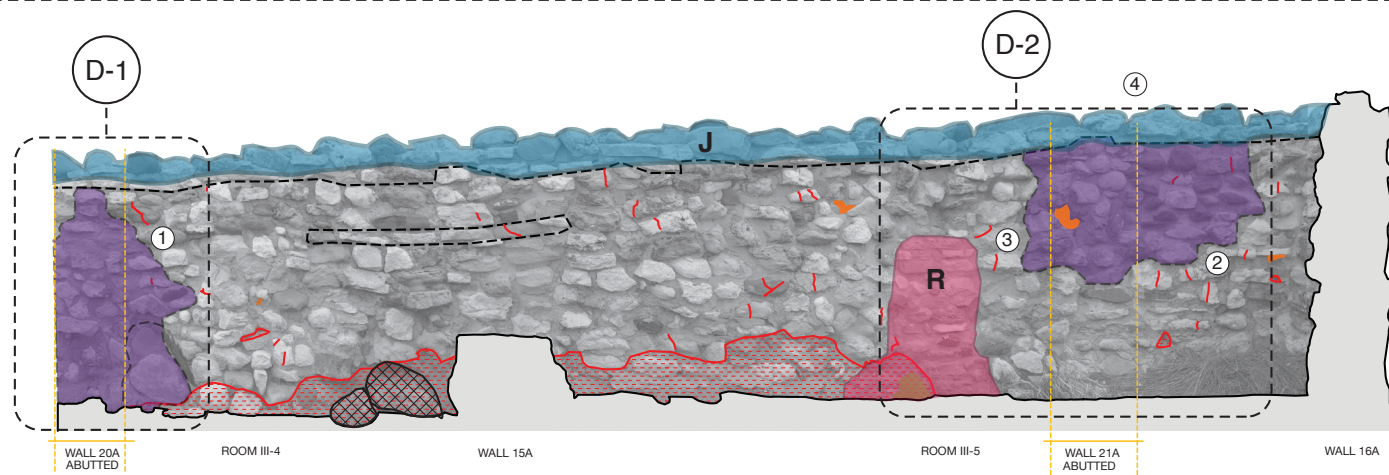
Comprehensive Conditions Assessment



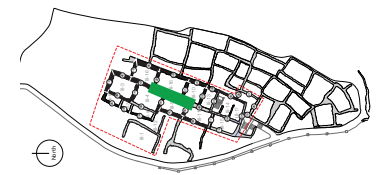
EAST ELEVATION OF WALL 4C



WALL CAP



WEST ELEVATION OF WALL 4C



Keyplan

LEGEND

Bulging	Efflorescence
Erosion	Masonry Loss
Burrowing	Roland Richert Repair 1953
Vegetation	Joel Shiner Repairs 1962
Structural Cracks	Flagstones Coursing

NOTES:

1. **Structural cracks** surrounding the northmost bulging on west wall support the fact that loads, probably from wall abutted behind is causing displacement.
2. Appearance of **structural cracks** surrounding the bulge, only in adjacent areas to abutted wall.
3. **Structural cracks** are visible between bulge, abutted wall and Richard's cement grouting repair.
4. Mortar on **caps** has eroded to the point where a more clay-ish, silt-like material is visible. Caps might be susceptible to water intrusion.

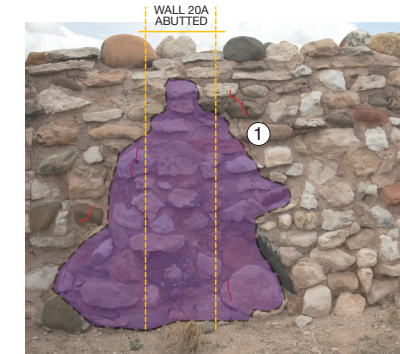


Before Richert Repairs

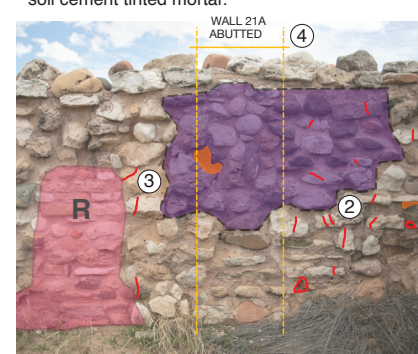


After Richert Repairs

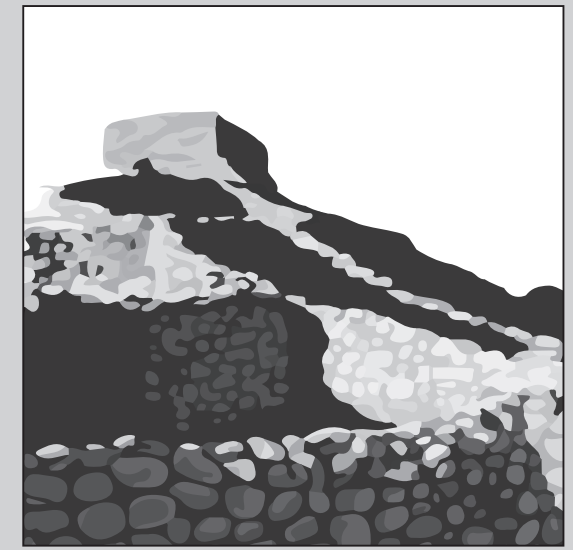
Wall was grouted with cement and finished with soil cement tinted mortar.



D-1 Detail Photo of Northmost Bulging West Wall



D-2 Detail Photo of Southmost Bulging West Wall



TUZIGOOT NATIONAL MONUMENT
25 Tuzigoot Rd, Clarkdale, AZ 86324

THE CENTER FOR ARCHITECTURAL CONSERVATION
Graduate Program in historic Preservation
The Stuart Weitzman School of Design
University of Pennsylvania

A THESIS ON:
A FRAMEWORK FOR RISK AND VULNERABILITY
ASSESSMENT OF THE RUBBLE MASONRY OF TUZIGOOT
NATIONAL MONUMENT

Dorcas Corchado, Student Researcher
Frank Matero, Thesis Advisor

CONDITION ASSESSMENT

WALL 4C

SOURCES: Rapid Assessment Survey - March 2019.

DRAWN BY: Dorcas Corchado

DATE: 05/17/19

APPENDIX-C