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OF MONUMENTS AND HISTORICAL CONSTRUCTIONS

Master's Thesis

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THE GUARDIAN OF THE PONTIFICAL STATE - Structural Assessment of a Damaged Coastal Watchtower in South Lazio.

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ABSTRACT

'THE GUARDIAN OF THE PONTIFICAL STATE- Structural Assessment of a Damaged Coastal Watchtower in South Lazio'.

For centuries the coast of the Mediterranean sea has been also the stage for devastating raids, rapes and terrible events. The coastal watchtowers built during this period represent a physical expression of the fear and incertitude within the population. However, today, these constitute remarkable structures with a significant historical and cultural meaning, impregnated of social, economic and political values.

'The Guardian of the Pontifical State' focuses on the understanding of the coastal defensive system of the Pontifical State developed during the centuries, concentrating on the analysis, diagnosis and remedial measures of a 16^{th} century coastal watchtower in the South of Rome, Italy.

Torre Gregoriana, in the city of Terracina, held a vital role in the defense system as it connected the borders of the State with its northern part, closer to the Eternal City. During the WWII the watchtower was blown up in order to block the *Via Appia* (one of the main road from the South leading to the capital) and cover the German withdrawn to the North. Today, only the ground floor stands. Further to these precarious conditions, a quite slow but inevitable degradation process undermines the stability of the structure and the conservation of its authenticity.

The purpose of the study is to achieve a comprehensive diagnosis of the structural conditions of the building leading to a possible conservation proposal and reconstruction project . This would endorse an empirical approach to the analysis of these structures so to produce a global methodology of intervention which could be applied to most of the watchtowers dislocated all around the territory, for both immediate or future interventions.

The study of Torre Gregoriana constitutes, indeed, an 'open book' reading on the history of the area and represents an inestimable opportunity for understanding and deepening the knowledge about the construction techniques, material characteristics and intervention evolution of the structural typology, typical of an era so strongly entwined with the cultural, economical and political aspects of the region.

RESUMO

' O GUARDIÃO DO ESTADO PONTIFÍCIO-Avaliação Estruturais de uma Torre Costeira Danificada do Sul doLácio'.

Por séculos, a costa do mar Mediterrâneo tem sido também palco de ataques devastadores, estupros e terríveis acontecimentos. As torres costeiras construídas durante este período representam uma expressão física do medo e incerteza na população. Todavia, hoje, estas estruturas constituem notável com um importante significado histórico e cultural, impregnado de valores sociais, econômicos e políticos.

'O Guardião do Estado Pontifício' centra-se na compreensão do sistema de defesa costeira do Estado Pontifício desenvolvida ao longo dos séculos, concentrando-se na análise, o diagnóstico e as medidas de reparação de uma torre de vigia costeira do século 16 no sul de Roma, Itália.

Torre Gregoriana, na cidade de Terracina, tinha um papel vital no sistema de defesa, uma vez que ligava a fronteira do Estado com a sua parte norte, mais perto da Cidade Eterna. Durante a Segunda Guerra Mundial a torre de vigia foi esplodida, a fim de bloquear a Via Appia (uma das principais estradas que a partir leva a à capital) e cobrir a retirada alemã para o Norte. Hoje, permanec apenas o piso térreo. Além destas condições precárias, um bastante lent, mas inevitável processo de degradação compromete a estabilidade da estrutura e da conservação da sua autenticidade.
O objetivo do estudo é realizar um diagnóstico detalhado das condições estruturais do edifício, levando a uma possível proposta de conservação e projeto de reconstrução. Isso endossa uma abordagem empírica para a análise dessas estruturas de modo a produzir uma metodologia global de intervenção que poderiam ser aplicadas à maioria das torres deslocadas em todo o território, tanto para intervenções imediatas ou futuras.

O estudo da Torre Gregoriana constitui, na verdade, uma leitura de um 'livro aberto' sobre a história da região e representa uma oportunidade inestimável para a compreensão e aprofundamento do conhecimento sobre as técnicas de construção, as características do material e da evolução da tipologia de intervenção estrutural, típico de uma era tão fortemente entrelaçada com as tradições culturais, econômicos e políticos da região.

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I. INTRODUCTION

THE RESEARCH BATTLEFIELD

1.1 Setting the Context: the Problems of Local Heritage

The importance of tangible and intangible heritage that accompany people in the everyday life is usually not enough emphasized, fading away too often in a mist of indifference and misunderstanding. The commonly mistaken conception of historic buildings restricted only to those structures of well established cultural and historical values imposes to shift the public's sensibility to conservation for only enough 'important' structures, leaving out an immense part of the existing historical heritage. Why should a piece of brick coming from the sunny roads of Pompeii be considered intrinsically more 'important' than a stone from any old building in the historic center of a town or village? Both the brick of Pompeii and the stone of the old building, in fact, equally express, in a physical form, the reality of a particular point in time and space of a certain culture. Conservation should be intended, therefore, not as a totally objective field whose theory and approach can be generalized and standardized, but as a multi-subjective process based on case specific considerations and on the assessment of the value of a building in relation to itself and its surroundings.

'The Guardian of the Pontifical State' tries to scale down to a local level the enthusiasm for conservation of historic buildings, in order to sensitize the stakeholders involved to a more appropriate consideration of the real potential of their surrounding local heritage. The research focuses on the understanding of the coastal defensive system of the Pontifical State developed during the centuries, and it concentrates on the analysis, diagnosis and remedial measures of a 16th century coastal watchtower in the South of Rome, Italy, named Torre Gregoriana.

1.2 Setting the Topic: The Defensive System of the Pontifical State

Nowadays over two thirds of the Italian population inhabits the coastline. It has not been always this way: for centuries, in fact, the coast was left mainly unmanned and deserted, stared with preoccupation and mistrust by local people. What could come from the Mediterranean sea, together with goods and cultured visitors, were too often devastating raids, rapes and terrible events. Coast watchtowers embodied, therefore, a tangible proof of such an increasingly fear within the population and still represent today the only left evidence of an unstable period made of insecurity and incertitude. From the early 15th century, following some military defeats of the Christian army, the Popes started to strengthen the protection of their State by installing a network of fortified towers capable to defend from the continuous attacks and, above all, spread the alarm throughout the region till reaching the city of Rome in relatively short time. Such defensive system is the object of the study presented here. The importance of this building typology derives from the social impact of these defensive structures and their flexible adaptability during time that allowed to conserve them till the modern era. The case study of Torre Gregoriana attempts to outline the technical characteristics concerning the building technique, the materials and the historical development of the tower, located in the city of Terracina, about 100 km from Rome. The peculiarity that makes this work new and different from others already published is not its final objective, but more the means through which to achieve the analytical and diagnostic goals. The research here presented attempts to integrate the 'what to do' in conservation, stemming out from an abstract and theoretical discourse, with 'how to do it' based on a more scientific, empirical process. More specifically this work tries to deepen the knowledge about the construction techniques, material characteristics and intervention evolution of the structural typology in question, taking into account the economic, cultural and political processes that influenced its development. The purpose of the study is to achieve a comprehensive diagnosis of the structural conditions of the building leading to eventual strengthening/conservation proposals. Moreover this would endorse an empirical approach to the analysis of these structures so to produce a methodological case of intervention which could be replicated and scaled-up to most of the watchtowers dislocated all around the territory, for both immediate or future interventions.

1.3 Setting the Problem: Structural Analysis of Torre Gregoriana

Torre Gregoriana in the city of Terracina held a vital role in the defense system as it connected the borders of the State with its northern part, closer to the Eternal City. After the WWII the watchtower was blown up in order to block the *Via Appia* (one of the main road from the South leading to the capital) and cover the German withdrawn to the North. Today only the ground floor stands. Adding to these precarious conditions, a quite slow but inevitable degradation process undermines the stability of the structure producing profound concerns regarding both ethics and safety requirements. The relevance of this structure stays in the fact that it constitutes an 'open book' on the history of the area and represents an inestimable opportunity for researching the structural capacity of such fortifications, experimenting a conservation process made of a balanced mix between the traditional expression of the building and its modern functionality.

The research is divided into two distinct sections: the first part is introductive to the defensive system of watchtowers and it includes two chapters; the second part focuses on the structural conditions and behavior of Torre Gregoriana, and features the last three chapters. The current chapter introduces the research statement and questions, setting the context on which to further develop the case study. An historical overview of the development of the whole defensive system, a classification attempt of the structural typologies observed and a preliminary safety analysis of the geometrical ratios are instead outlined in the second chapter. The third section deals with the visual inspection of Torre Gregoriana, surveying the geometry, material composition and damage patterns of the existing part of the building and providing the establishment of cause-effect relationships concerning the degradation of the fabric. The forth chapter focuses on the intervention proposal for the conservation of the existing structural fabric of the building in respect of the original meaning of the structure and the latest international conservation policies. The last chapter analyzes the structural details for the design of a reconstructed tower similar to the original one.

The next chapter introduces the mechanism of the defensive system, exploring the building typology and its structural characteristics.

II. THE 'MASONRY ARMY'

UNDERSTADING THE MECHANISMS OF THE DEFENSIVE SYSTEM

2.1 Historical Effects on the Evolution of the Network

The history of fortifications along the coastline of Lazio, Italy, undoubtedly reflects the political development of the Pontifical State and its economic conditions during the centuries. In fact, the alternation of periods of proliferation of watchtowers with moments of abandonment and degradation coincide almost symptomatically with the ascent and decline of the power of the Papacy. It is determinant therefore, in the context of this study, to understand the succession of historical events in order to determine their effects on the performance of the defensive system.

Subsequently the fall of the Roman Empire the coast of the peninsula became an easy prey of the increasingly numerous bands of adventurers coming from Africa. Nothing could be done to contain the spreading phenomenon of raids on the coast as, at the same time, the inland invasion of the barbarians was causing massive destruction and catastrophes. As a result the coast remained undefended till a controlling political system was finally established. It is only at the beginning of the 9th century that Pope Leo III felt the need for the safeguard of the coast of Lazio against the Saracens that infested the Tyrrhenian. The relevance of the incursions became very significant leading at times to real invasions. Some general defensive measures were provided, including the development of sighting constructions (*'vedette'*) scattered along the coast in proximity of inhabited centers. However the primordial watchtowers did not compose a homogeneous network and they were not able to provide the necessary geographical continuity in the 'raising of alarm' system. The instauration of feudalism in the 12th and 13th century introduced in the region of Lazio the development of baronial struggles throughout the *Campagna Romana* (Roman countryside). Medieval fortifications started to be erected in defense of small feuds and hence a part of the modest existing coastal system was absorbed in a complex net of up-country constructions. Due to a relatively calm and politically stable period, the development of further coastal constructions experienced a halt during the 14th and 15th centuries, when the defensive system along the coast of the Pontifical State was constituted primarily by medieval and ancient 6th century watchtowers. A process of rehabilitation of the old constructions would have implied major modifications to the structures (foundations in particular)due to the technological improvement of firearms. Such an economically intensive procedure was not felt as an urgent necessity and the old network was considered still sufficient and adequate for satisfying the defensive needs. Despite this the Pontifical State lined-up auxiliary ships to block any enemy incursions, especially in the most remote stretches of coast between *Monte Argentario* (Tuscany)and *Terracina*(Latium).

In the beginning of the 1500s the Mediterranean area experienced a radical rebalance of the political and economic arrangement, staging a crushing hegemony of the Turks and Barbary corsairs (based in

Berber African ports such as Tunis, Tripoli, Algiers and Salè) in continental Europe. It is necessary at this point to explore more in depth the vicissitudes of this particular moment in history as they represent a turning point in the approach to coastal defense policies. Historical records underline the drama of systematic and periodic devastating actions on the Tyrrhenian ports: on the 28th of August 1534 the Algiers fleet, lead by Hayreddin Barbarossa, conducted one of the most shocking and violent attacks, raiding the towns of Gaeta, Sperlonga, Fondi and Terracina, and reaching the Tiber outlet. Western powers struggled to organize an effective defense and incurred in crushing defeats: in 1541 a counter-attack to Algiers failed disastrously; in 1552 a allied force lead by the imperial admiral Andrea Doria and the emperor himself, Charles V, was ingloriously defeated in the Tyrrhenian sea, between the island of Ponza and Terracina. The situation of alarm escalated and the terror of an imminent devastating attack spread all over the State and the feuds: in 1500 Marcantonio Colonna, a local landlords, wrote to his vassals *"…Dovete sapere che l'armata del Turco ha rotto l'armata del Re nostro in Barberia (…) per tanto vi ordiniamo che dobbiate subito fare sgomberare tutte le vostre robbe, donne et putti. E farete fare le guardie a quelli che vi resteranno (…) ve possiate salvere tutti/ You should know that the Turkish army defeated our King at Barbary (…) therefore we order you to clear all your belongings and send away women and children. And you will make guard the people that will stay (…) may all of you save"* [De Rossi, 1990:14].The escalation culminated with the beating of the Spanish forces of Philip II in 1560 outside the Gulf of Gabés in Tunisia. This, openly considered as one of the most relevant events of this period, generated profound consternation and fear throughout the Christian world and threatened the independency of the major political powers. The situation overturned the conditions of stability and induced the European kingdoms, including the Pope, to take emergency measures. The main objectives were to patrol the coast and to begin a process of reorganization and restoration of the established tower system with eventual integration of new constructions. The coastal defense system of the Pontifical State underwent a consistent and radical transformation. Multiple Papal amendments endorsed a total revision of the network and imposed to local lords the integration of new structures to be located at the weakest spots along the coast. For example in 1562 *"the pope Pius IV(1559-1565) ordered landlords Nicolò and Bonifacio Caetani to build four watchtowers to be located on the Circeo promontory "* as this area *"favored the incursions of pirates (…) thanks to the wild vegetation and the roughness of the rocky coast"* [Coppola, 1994]. Furthermore the pope imposed a comprehensive restoration of the medieval fortifications that could, in such an emergency status, provided still valuable defensive measures. The fire capacity of different military constructions was consistently increased and their structural characteristics were adapted to resist the increased power of firearms. Only the next pope, Pius V (1566-1572) tried to regulate an integrated and organic project of coastal defense. *"The 9th of May 1567, the pope emanated the 'Consitutio de aedificandis turribus in oris maritimis', nominating Martino d'Ayala responsible for the construction of a network of fortifications along the whole Pontifical State, from Porto Empedocle to Terracina"* [Coppola,1994]. The system was based on a chain-like pattern of fortified spots, connected between each other, with the scope of the sighting of enemy fleets and possible offense. However the bureaucracy stemming out the overriding of jurisdictions between local and central authorities, undermined the feasibility of the project and forced to keep it on hold. The popes in fact tended to commit their feudatories the construction of the towers delegating consequently the responsibility of the related costs. The involvement of local authorities complicated the overlapping of administrative rights upon the fortifications. The process resulted in an overcharged managerial framework instead of a streamline and more dynamic administration, which was truly needed. Furthermore the scarce attention and effort in monitoring the military performance of the fortifications, especially in terms of soldiers efficiency, worsened the already deficit defense system and lowered considerably its coordination capacity. In 1571 the Holy League succeeded in defeating once for all the Ottoman forces in the Battle of Lepanto (7th October) and stopped their further advance in Europe. This spread optimism and great relief around the Christian world and especially around the tormented coast of Latium that now enjoyed a period of calm. The commitment to create an integrated defense system slowly vanished.

The unsolved administrative issues came to surface and aggravated during the 17th century. The Popes had to deal with disciplinary problems and efficiency of the towers and their staff. The number of regular inspections increased. The reports produced underline the cases of indiscipline, insubordination and abuse of power that tower-keepers and members of the garrison were inflicting on the local population.

The political changes of the 18th and 19th century in particular, imposed a re-organization of the socio-economical arrangement on an international scale. The defense system of the Pontifical State participated actively in the process of transformation. During the Napoleonic invasion the coastal watchtowers faced numerous assault attempts of the English navy. The result is ambiguous as from one point of view the struggles confirmed the military value of the fortifications and their ability in defending the territory, even against a more technologically advanced army, and on the other hand, as De Rossi states *" the advent of the French left a relevant footprint on the coast of Latium (as) during memorable conflicts some towers were destroyed or seriously damaged by the English"* [De Rossi, 1990:22]. On the ground of such alternate outcome, after the Papacy regained the independency from the French in the middle of the 19th century, a project of strengthening and restoring the defense system was formulated but never developed. The organization of the network, even if radically transformed in its use and function, remained structurally unchanged till the first half of the 20th century. During the last world war a number of towers, especially in the South, were completely destroyed or irreparably damaged and the effects can still be noticed. Nowadays most of the structures are still waiting for restoration, conservation and consolidation measures in order to revive the glorious and tormented events they witnessed during their lifetime.

2.2 A Glance to the Communication System: Organizational Efficiency and Building Typologies

The exploration of the system arrangement along the territory is a necessary research activity in order to interpret correctly the communication system. The investigation focuses on the network at two different levels: global, concentrating on the determination of the organizational efficiency and communicational potential of the whole system; local, focusing on the structural performance and military validity of each fortified construction.

The system, if investigated globally, manifests some distinct peculiarities. The Pontifical State of the 16th century controls a region along the coast stretching from Montalto di Castro, in the North, to Fondi in the South of Latium. The system counts almost sixty fortified structures which, although not all simultaneously active, constitute the core of the coastal defense (*Figure 1*). A total of 250 km of coast are covered.

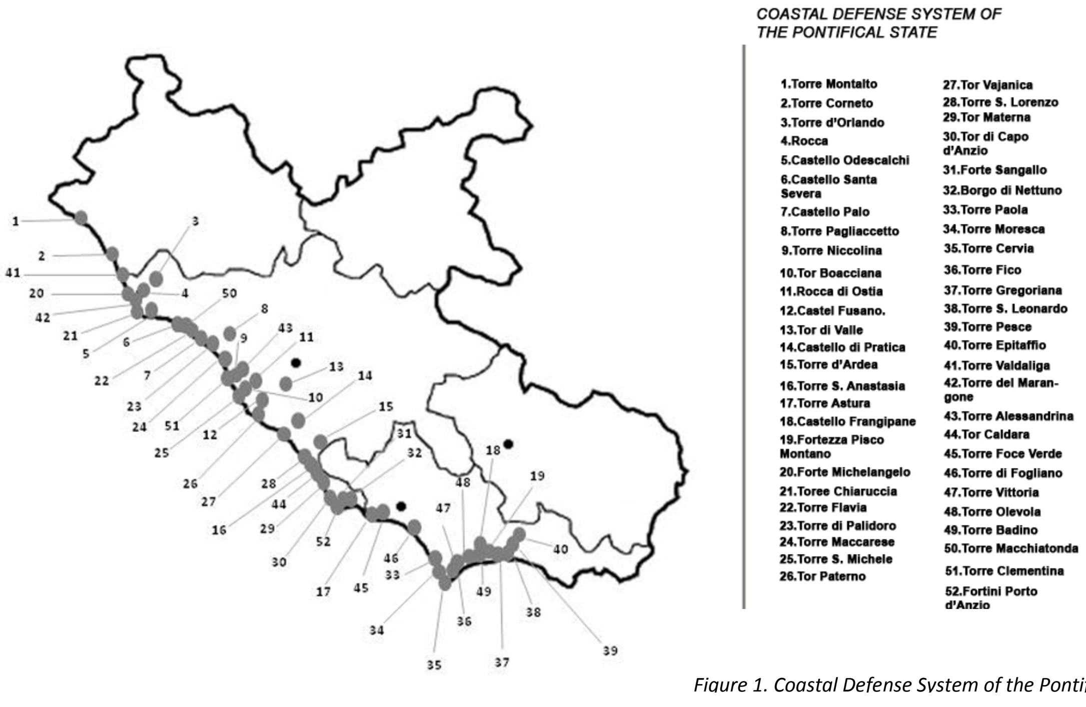


Figure 1. Coastal Defense System of the Pontifical State

The defensive system has its focus in the city of Rome which, functioning as a watershed, determines a considerable division in the concentration and relevance of the fortifications between the North and the South parts of the coast. Such differential development postulates that the defense system evolved in the North and South at different rates. To understand adequately this phenomenon, three elements should be taken into consideration. Firstly, it should be underlined that important centers North of the Eternal city developed independent defensive systems in the middle ages, which was a few centuries before the need for an integrated defense network was even conceived. The ports of Civitavecchia and Ostia for example, with their numerous towers and remarkable fortifications represented throughout the history of the coastal defense system authoritative strongholds. On the same stretch of the coast a series of castles provided further security to the territory (Odescalchi and Santa Severa castles, just

South of the port of Civitavecchia, and the Palo and Fusano castles, situated in the proximity of Rome). The constructions of Anzio and Nettuno, some kilometers South of the city, also exhibited a powerful defense system, showing a combination of building typologies as towers and fortresses. Secondly the unbalanced distribution of the defensive system along the State should be understood as highly conditioned by the fact that pirates incursions had not a geographically homogeneous intensity and duration, but were unpredictable and random. Thirdly, the feudatory system imposed interminable bureaucratic procedures and administrative obstacles that rarely enabled the carrying out of integrative defense proposals on time, to the detriment of the less developed zones of the coast such as the South. It is fact not negligible that the South part of the coast, despite the higher vulnerability and the natural predisposition to enemy incursions, had a conspicuous delay in setting up an appropriate defense and a lack of fortified strongholds that could provide a minimum defense for the population. The combination of the mentioned elements results in a basilar coordination deficiency which is reflected in an inefficient and expensive defense system.

If the defense system can be globally defined as inadequate, considering each building separately, its well designed structural organization and military and architectonic relevance cannot be denied. Historical accounts from different periods, in fact, highlight very successful operations of capture of enemies, strenuous defense and fearless counterattacks. Moreover, to be noticed that, such constructions were considered offensive and threatening still during modern conflicts. The figure below (*Figure 2*) shows that eleven of the fortifications were completely destroyed during either the Napoleonic invasion or the WWII, more were seriously damaged and reduced to ruins and others had to be restored or even reconstructed in the recent years. Therefore, this perseverance with which structures of the defense system were physically eliminated, concludes unquestionably about the high credit the fortifications were given by enemies, even in modern eras.

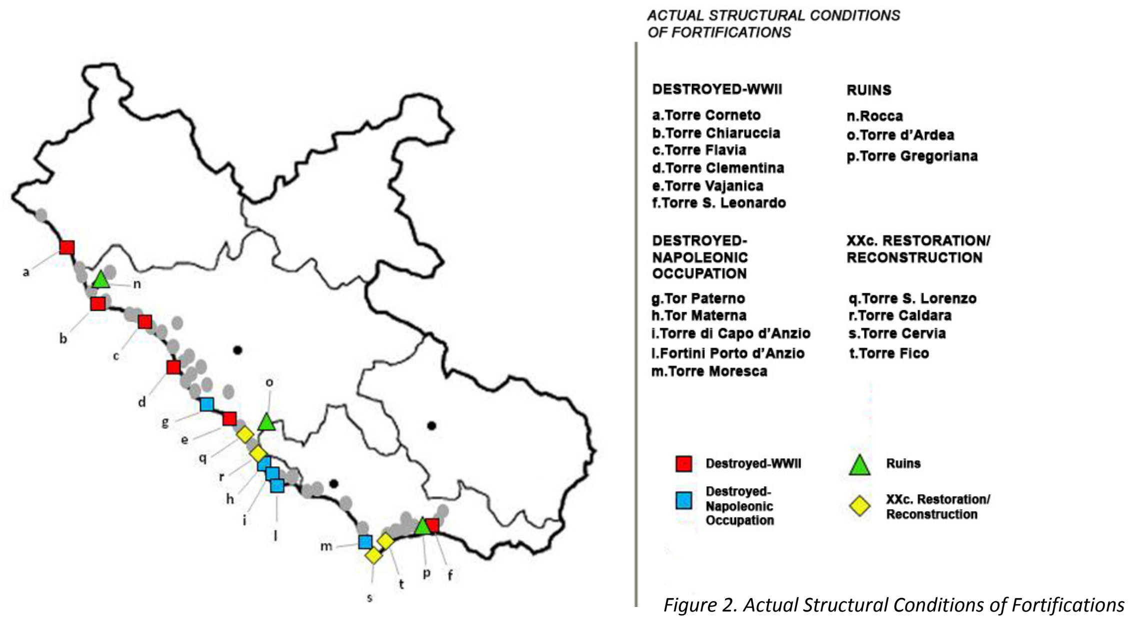


Figure 2. Actual Structural Conditions of Fortifications

It is essential at this point to unveil the composition of the defensive network and discuss the types of construction that characterize it. The building typologies composing the network are multiple, varying from fortresses to castles and watchtowers (*Figure 3*). Fortresses are integrated to the defense of the Pontifical State during the 16th century. Their relevant structural elements usually include the main great-tower, either of cylindrical or square plan, and the perimeter bastions. As already mentioned they are located mainly at strategic spots of the defense such as ports (like in Civitavecchia and Nettuno) or at outlet of important river (Ostia on the Tiber). Of great military value are the Michelangelo's Fort (1535) in Civitavecchia, with its virile great tower and magnificent cylindrical bastions, and the Julius II Fort(1483-1487) in Ostia which encompasses a former 15th century watchtower in its characteristic triangular plan with perimeter 'firing houses' and two solid bastions. Another remarkable fortress is the Sangallo Fort(1501-1503) in Nettuno, constituted by a quadrilateral plan with four perimeter towers and a square base central great-tower.

Figure 3. Examples of Building Typologies.Clockwise From Top Left: Michelangelo Fort, Santa Severa Castle, Torre Olevola, Torre Palidoro, Tor Caldara

The castles belonging to the defense system constitute a structural development of medieval towers (11th-12th century) fortified and strengthened during the centuries. Examples are the Odescalchi Castle in Santa Marinella which was built around a 11th century cylindrical tower in the 15th century and strengthened with the addition of bastions in the 17th century; the Santa Severa Castle, established on a 10th century tower with the placement of a cylindrical tower ('Saracen Tower') in the 16th century, and the Palo castle developed on a 11th century fortifies settlement and modified in the 1500s. Of different typology are the castles of Fusano, Pratica, Sforza-Cesarini in Ardea and Frangipane in

Terracina. The origins of such structures are connected to the incorporation of a *castrum* (i.e village) within the fortified walls. Their function was not only strictly military, with the objective of offense and defense, but had more a social aim. For example as Simonetti and Cacciotti highlight *"the population of Ardea had the right to shelter in the Sforza-Cesarini castle"* [Simonetti - Cacciotti 2010] and similarly it was possible for the population of Fusano and Terracina. The structural arrangement and aesthetic appearance of these castles also remark their social function. In fact they appear less massive than the military fortresses and more similar to palaces or baronial residences.

Watchtowers constitute the most widespread building typology along the coast. Many examples can be found in different settings and locations. Figure 3 shows three of many types of towers observable on the coast of the Pontifical State. In order to avoid a generalization of the features of this structural typology, which could be counterproductive in the context of this study, a closer inspection and categorization should be carried out. Their characteristics are discussed in detail in the next section.

2.3 Characteristics of the Watchtowers: an Attempt of Classification.

The attempt to create a defensive system coherent and organized throughout the coastline, as previously mentioned, often clashed with problems of administrative nature, deriving from the complexity of the feudatory system, and with the geographical and cultural variations around the territory. Such heterogeneity of conditions is tangibly proven by the different peculiarity that identifies each building composing the defensive system. It is possible in fact to classify the watchtowers depending on the period they were built (*Figure 4*), their location and their structural characteristics.

In the 15th century the poor network of medieval towers was strengthened with additional watchtowers on the coast, mainly for the safeguard of inhabited centers such as *Torre Montalto* in defense of Montalto di Castro and *Torre Corneto* in Tarquinia. The defense at the two branches of the Tiber outlet was also potentiated by the introduction of *Torre Niccolina* and the strengthening of *Tor Boacciana*. A part for the restoration of medieval towers South of Rome, as in the case of *Torre Astura*, the rest of the coastline till the border with the Kingdom of Naples remained vulnerable.

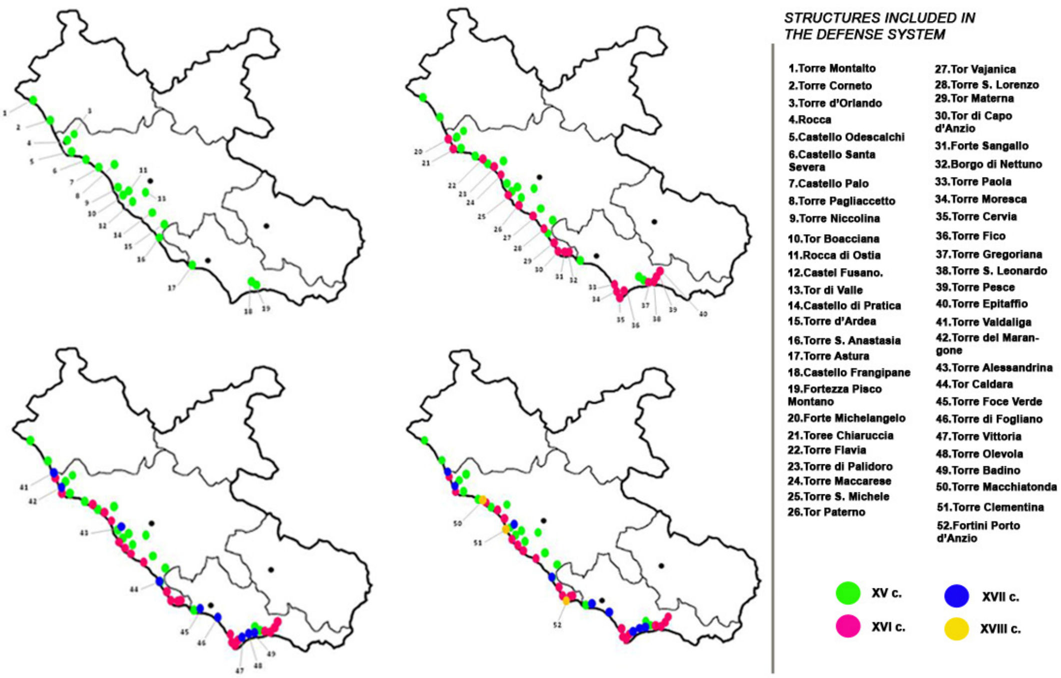


Figure 4. Historical Development of Defense System

In the 16th century, under the stimulus of the escalating Ottoman supremacy in the Mediterranean, sixteen new towers were built. Four towers were inserted in the stretch of coast between the well fortified Civitavecchia and Ostia. *Torre Chiaruccia* was built to connect the port of Civitavecchia to the castles Odescalchi and Santa Severa; *Torre Flavia* (1568) put in communication the Santa Severa castle with the Palo castle and finally *Torre Palidoro* (1562) and *Torre Maccarese* connected Palo to the outlet of the Tiber and therefore to the city of Rome. Other towers were built to substitute those that became inefficient, either due to their state of decay or to the withdrawn of the sea or the deviation of river waters, as in the case of *Torre San Michele* designed by Michelangelo in 1560 which absorbed the custom function of Tor Boacciana. The North part of the defensive system was also connected to the important center of Anzio through *Torre di San Lorenzo*(1570), *Tor Materna* and *Torre di Capo d'Anzio*. Two other stretches of the coast were strengthened: first on the wild Circeo promontory four towers were introduced (*Torre Paola* 1563, *Torre Moresca* 1562, *Torre Cervia* 1563 and *Torre Fico* 1563) and secondly the gulf in front of Terracina was provided with a network of four new towers (*Torre Gregoriana* 1584, *Torre S. Leonardo*, *Torre Pesce* and *Torre Epitaffio*) out-looking South and communicating with the defense system of the Kingdom of Naples. In the 17th century the net of fortifications was tied up by new constructions to shorten the average distance between the towers. *Torre Valdaliga* (1616) and *Torre Marangone* (1605) were introduced to better communicate between the farthest North towers (Montalto and Corneto) with Civitavecchia. Moreover the 15th century Torre Niccolina, abandoned due to the withdrawn of the sea, was substituted by *Torre Alessandrina*(1662). In the South the stretches of coast between Anzio-Nettuno and Circeo and between Circeo and Terracina were connected with the construction of respectively *Torre Foce Verde* (1660) *Torre Fogliano* (1622) and *Torre Vittoria* (1624), *Torre Olevola* and *Torre Badino* (1610).

During the 18th century the defense system remained unchanged, a part from the reconstruction of inadequate towers (Torre Olevola) and the substitution of unusable towers, such as the Torre Alessandrina at the Tiber outlet which was replaced by *Torre Clementina* in 1773.

The fact that for almost two and a half centuries towers were still being built or strengthened raises concerns regarding the defensive capacity of the network. This clearly implies that the system was incomplete and insufficient or at least inadequate to the military effort required for a certain period.

The location of the towers constitutes another interesting feature on which it is possible to ground an approximate classification of the structures. The location of the fortifications, in fact, is never random but it reflects both the military technical capacity and defense needs during a specific period of time. Towers composing the defense system were located, after centuries of successive strengthening attempts, with the specific objective to create a fine net of 10-20km distant fortifications, in order to homogenize the system and allow an efficient and prompt communication. However a distinction can be made. Old towers, such as *Torre d'Orlando*, *Torre Pagliaccetto* and *Torre d'Ardea* are built on in-land hills as their function was strictly of sighting the sea and alarming the population in case of incursions. On the other hand, newer structures are located closer to the coast and can be divided into two groups. To the first group belong towers built in proximity of the shores. This group includes a relevant number of towers introduced in the 16th and 17th centuries: Tor Chairuccia, Torre Flavia,*Tor Paterno*,Tor Materna ,Tor Capo d'Anzio, Torre Fogliano and the towers on the Circeo promontory till Torre Epitaffio at the borders with the Kingdom of Naples. However a further distinction is possible. Some structures of the first group served mainly as a communication bridge between two strategic stretches of the coast, and therefore their location is determined strictly on the basis of the exigency of shortening the distances and accelerating the passing on of information. The location of the rest of towers of this group is determined instead by the demand for strengthening strategic spots and important centers of the coast, regardless their allowable maximum distance. This could explain the vicinity of towers in specific areas and their high concentration (such as in Civitavecchia, Ostia, Anzio).To the second group belong the towers located to guard rivers or secondary water streams leading deep inside the Pontifical territories. These structures, besides clear defensive aims, functioned also as custom-houses and tax offices in order to regulate the traffic of goods entering the State. To this group belong Torre Palidoro, Torre Maccarese, the towers on the Tiber, *Tor Vajanica*, Torre Foce Verde and Torre Badino.

A further classification can be made considering the different technical characteristic of the structures (*Figure 5*). This could be considered as the most significant and simple to identify, yet because it is the most visual of the classification parameters.

Figure 5. Classification Parameters. 1Foundations. 2Shape. 3Geometry

The first constructive element on which the towers might differ is the foundation. A number of structures in fact are built on top of Roman ruins, which ensures a perfectly consolidated ground on which to develop a military building. The existence of older settlements provided structural stability and avoided ineffective consumption of time and resources. Such practice is not strictly related to a specific time in history but it is quite widespread as examples can be seen throughout the assembly period of the defense system: Torre Valdaliga(1616), Torre Flavia(1568), Tor Boacciana(1420),Torre Astura (1426) and Torre Vittoria(1624) can be considered a tangible proof as they are built on former Roman villas or military stations. However, as De Rossi highlights, *" the necessity to comply with new strategic needs impeded the use of roman ruins as basement (…)"* and therefore the majority of watchtowers of the defense system are *"erected on appositely designed foundations, which include a timber frame structure topped by a concrete platform"* [De Rossi, 1990:16].

The second constructive element that consents a differentiation of towers is the shape of the plan. The cylindrical base is characteristic of medieval towers. This shape, in fact, allows a complete visibility, thank to the absence of blind corners, constituting an optimum conditions for sighting the coast. This is the case of the original towers now embedded in the castles Odescalchi and Santa Severa. Although not medieval, also of cylindrical plan are Torre Paola, Torre Moresca, Torre Cervia and Torre Fico. In this case the choice of the shape of the plan derives from the restricted site conditions, as the roughness of the high cliffs did not allow enough surface to build a quadrangular tower. Furthermore the numerous creeks in the area imposed to maximize the visibility to all the possible perspectives (excluding the side against the mountain). The quadrangular shape, on the other hand, allows to exploit the concept of bastion to orientate the tower with one corner only towards the sea in order to reduce the impact surface presented to the enemies and consent the slipping of cannon balls along the inclined walls. In any case, both the circular and the quadrangular towers are originally built, or adapted successively in time, with a conspicuous inclined protection at the base called *'scarpa'*, in order to strengthen the structure in case of attack.

The third constructive element which contributes to categorize the towers, concerns the different geometric properties of the constructions. However from this perspective the system can be considered very heterogeneous and a precise classification is not realistic. The next paragraph will discuss the importance of such properties in terms of safety and structural vulnerability.

Concluding, the watchtowers typologies can be defined on the basis of geometrical or constructive characteristics. While the geometrical features, although very heterogeneous in the context of the defense system, are easy identifiable, constructive characteristics depend on parameters, such as wall typology, material characteristics and structural evolution, which are usually concealed in the physicality of the building. Therefore a comprehensive analysis of the physical, mechanical and structural properties of the towers and of their components, is recommended in order to adequately answer the research questions posed as guidelines of this research.

2.4 Preliminary Assessment of Structural Vulnerability of Masonry Towers.

The highly complex behavior of historic masonry raises significant concerns regarding the structural vulnerability of ancient buildings. In the context of the defensive system of the Pontifical State, it is of great importance to assess the structural performance of the fortifications in order to determine their stability and their safety to dynamic actions. The assessment appears relevant for two main reasons. Firstly it should be mentioned , as explained by Lourenço and Roque, that *" countries of the Mediterranean basin are particularly at risk due to the large number of ancient monuments"* whose vulnerability to dynamic loading is particularly accentuated because of *"the absence of connections (between the different structural components)"* [Lourenço and Roque,2005:200]. Secondly, the prolonged exposure of the defense system to consistent weathering action and the state of abandonment of a number of constructions, accelerate the decay of the material properties, eventually inducing partial or total collapse.

The approach to vulnerability assessment adopted here is based on the evaluation of simple geometric characteristics and aims at rapidly detecting if there are severely exposed structures which would need a more accurate and complex analysis. Four towers belonging to the Pontifical State network are investigated. These include Torre San Michele(1560), Torre Paola(1563), Torre Gregoriana(1584) and Torre Olevola(1630). The selection of the fortifications analyzed is grounded on the attempt to encompass the widest range of building typologies and structural peculiarities, in order to enable a scaling up of the vulnerability assessment to the whole defensive system (*Figure 6*).

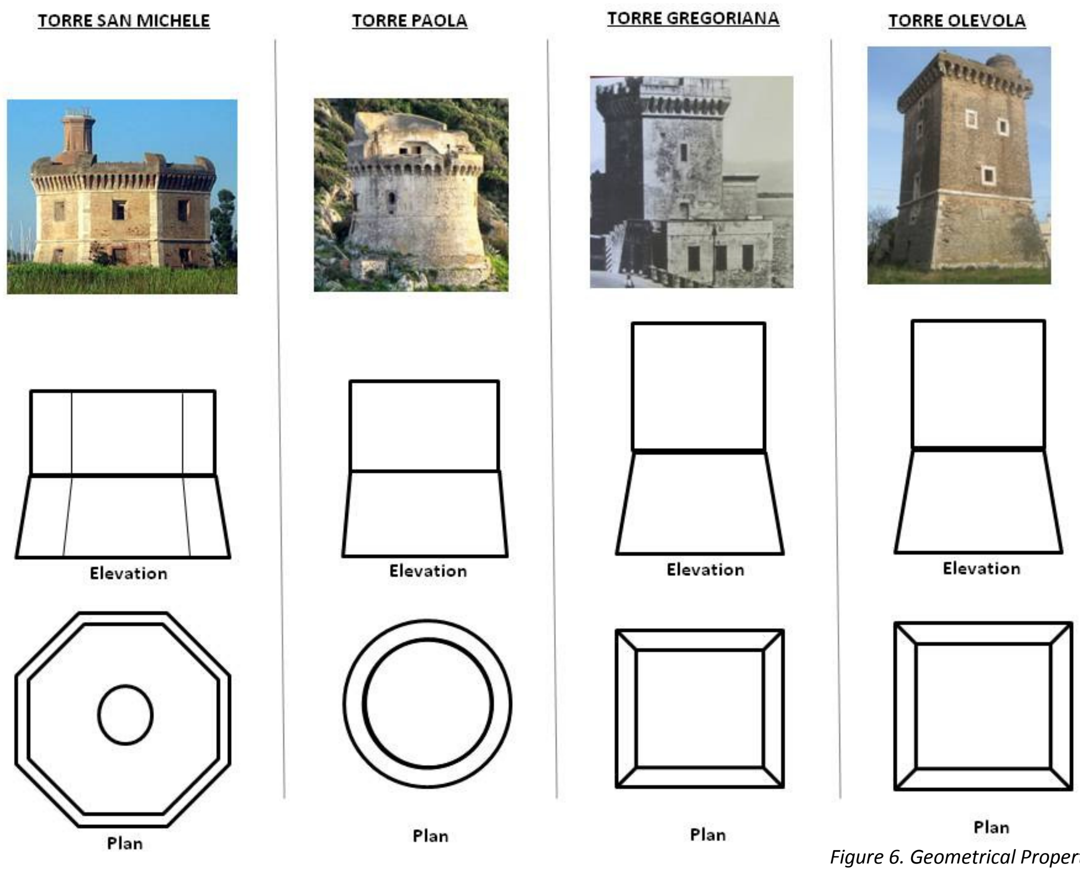


Figure 6. Geometrical Properties

The estimation of the structural vulnerability involves the determination of simple geometrical ratios related to historic constructions which are symmetrical in plan. The ratio of the width over the height allows to evaluate the degree of stability of the towers and their slenderness. The percentage of the earthquake-resistant plan area contributes to the determination of the structural response to seismic actions, and the capacity of buildings to withstand dynamic actions. The ratio of the percentage of earthquake-resistant plan area and the height of the structure identifies the distribution of such an area over the different levels of the towers.

The analysis of the width over height ratios shows very straightforward and self-explaining results (*Figure 7*). Considering the average base thickness and the full height of the tower, the structures appear relatively stocky. Tor S. Michele, designed as a fortified tower, presents an astonishing factor of 1.5 which implies a ratio W/H of 3:2. Moreover both the cylindrical and square towers, although revealing a slightly less stocky geometry, expose also a quite high ratio of approximately 1:2.

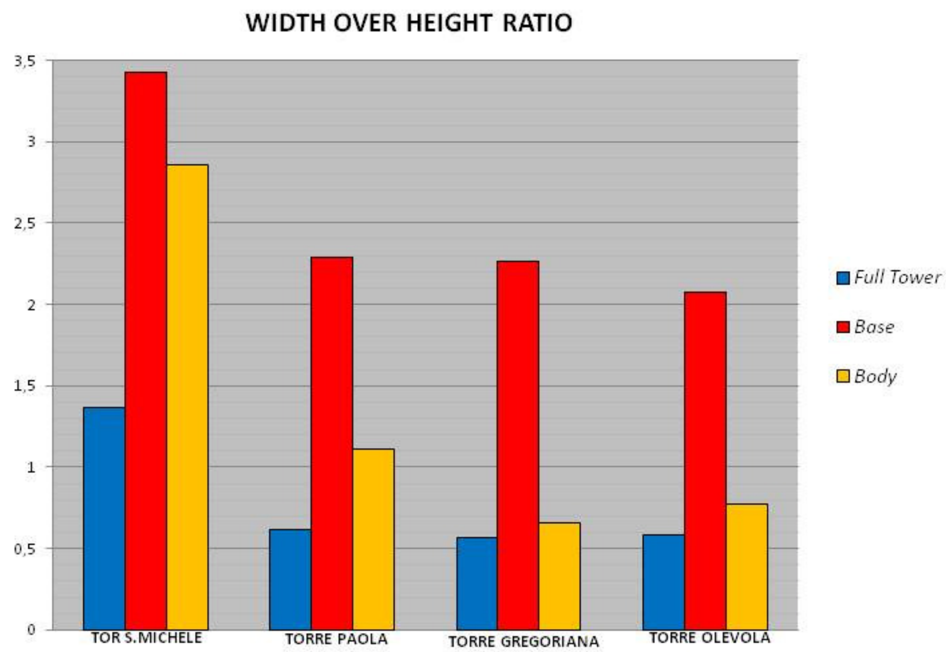


Figure 7. Width Over Height Ratio

The two last columns in the graph (red and yellow)show the contribution of the base and the raising body of the buildings. It is noticeable the consistent influence that the enlarged section at the base has in providing solidity and stability to the structures, with a width to relative height ratio greater than 2. Although similar, the body of Torre Gregoriana and Torre Olevola differ from those of the circular Torre Paola and the octagonal Tor S. Michele and exposes a much more slender and agile geometry.

The percentage of earthquake-resistant plan area is determined with respect to the full floor plan. The factor is a good indicator of the vulnerability of the structure and it considers the participation of the vertical structural elements in resisting horizontal loads. The percentage should be determined in both the principal axes of the plan. However, due to the perfect symmetry in plan of the defensive towers, the values obtained are identical. The results underline the massive physicality of the fortifications (*Figure 8*), compared to the values below 10 percent referred in Lourenço and Roque, 2005. However it is possible to highlight some differences between the different structures analyzed. In the base of Tor S. Michele almost 40 percent of the area contributes to the resistance to earthquakes, while in the raising body the percentage stabilizes around 20 percent. The results of the square towers (Torre Gregoriana and Torre Olevola)show that the participation of the walls in the base is around 60 percent of the total floor area, while in the body it reaches 25 percent.

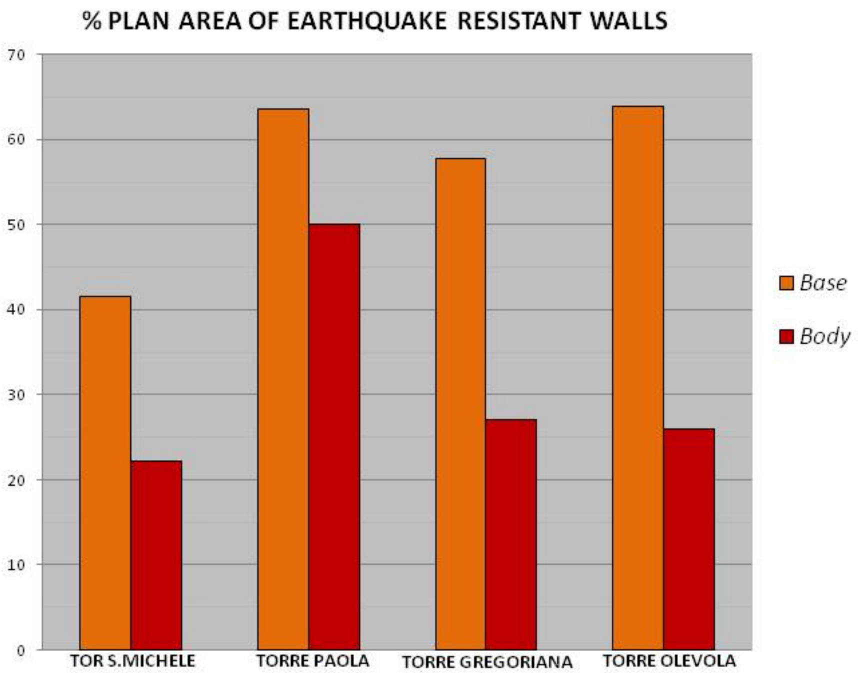


Figure 8. Percentage of In-plan area of Earthquake-Resistant Walls

Particular results are observed for Torre Paola. The circular shape of the plan, in fact, enables to distribute the stress derived from seismic action in a way that the whole perimeter walls participate in resisting the loading in any direction. Almost 50 percent of the floor area of the body can be defined as earthquake-resistant. However it should be noticed that despite the favorable geometrical shape the percentage of resting area of the base is not much different to that of the square towers, confirming the constructive trend in military fortifications of that time of massive strengthening of the lowest part of the tower.

The last factor analyzed involves the distribution of the resisting plan area of the towers with respect to their heights. The percentage of plan resistant area over the full height of towers reveals similar results for Tor S. Michele and the square towers but again different values can be observed for the cylindrical Torre Paola (*Figure 9*). As far as the percentage resistant area in the body is concerned the values are the following: 1.5 percent per meter in Tor S. Michele, over 4 percent per meter in Torre Paola and over 1,5 percent per meter in Torre Gregoriana and Torre Olevola.

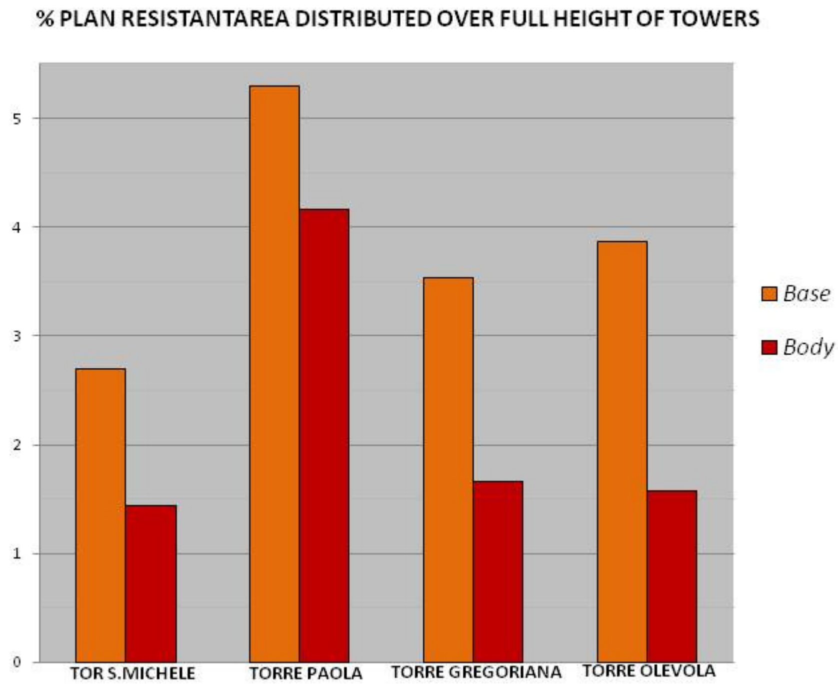


Figure 9. Percentage of Earthquake-Resistant In-Plan Area Versus Full Height

The percentage of the area at the base distributes differently: almost 3 percent per meter in Tor S. Michele, over 5 percent per meter in Torre Paola, 3,5 percent per meter in Torre Gregoriana and almost 4 percent per meter in Torre Olevola. It should be underlined that the distribution of the percentage per meter height of the base appears more decisive in determining the structural performance of the towers than that of the raising bodies.

Further to the above outlined analysis of factors depending on dimensional characteristics of the fortifications, an investigation of simple geometrical ratios for walls and vaulted floors has been carried out in order to better understand the contribution of sub-structural elements to the overall vulnerability of the constructions.

The walls of the inspected towers (*Table 1*) have an average thickness at the base that oscillates between 2,5 and 2,75 meters, varying at the body between 1,56 and 2 meters. The ratio between the clear width and the thickness of the wall at the base is higher for Torre Paola (a value of 6,28 m) and lower for the square towers. The same ratio for the raising body of the towers remains constant in the case of the circular tower, and increases in the other three structures, almost doubling in the case of Torre Olevola. The ratio between the height and the thickness of the wall at the base reveals Tor S. Michele to have the highest value, while the rest of the investigated towers present a lower value and therefore a shorter height with respect to the thickness of the walls. The same ratio at the body increases consistently for Torre Gregoriana and Torre Olevola whose heights, as previously seen in the W/H results, are bigger for this part of the structure and , at the same time, the thickness of the walls is reduced by almost 40 percent.

WALLS (All values in m.)		Tor S.Michele	Torre Paola	Torre Gregoriana	Torre Olevola
Base	Av.ge Thickness, t	2,5	2,75	2,4	2,505
	Clear Width L	5,758	17,27	4,4	3,9
	Height	6	4,3	4,1	4,7
	L/t	2,303	6,280	1,833	1,557
	H/t	2,4	1,564	1,708	1,876
Body	Av.ge Thickness, t	2	2	1,8	1,56
	Clear Width L	5,758	12,56	3,7	5,58
	Height	8,4	6,7	11,2	10,8
	L/t	2,879	6,28	2,056	3,577
	H/t	4,2	3,35	6,222	6,923

Table 1. Geometrical Properties Walls

Barrel vaults can be found in Torre Gregoriana, Torre Paola and at the last level of Torre Olevola (*Table 2*). The thickness, span and rise of the vaults may vary between towers and between levels of the same building. The ratio rise to span is between 1:3 and 1:2.The ratio between the thickness and the span of the vaults is almost double in Torre Paola with respect to the other structures. In Torre Gregoriana and Torre Olevola the same ratio has values between 1:10 and 1:20.

VAULTED FLOOR (All values in m.)		Torre Paola	Torre Gregoriana	Torre Olevola
1° floor	Thickness	0,399	0,255	
	Span	3,776	4,513	
	Rise	1,729	1,57	
2° floor	Thickness	0,545	0,373	
	Span	3,83	4,493	
	Rise	1,636	1,687	
3° floor	Thickness		0,392	0,452
	Span		5,199	5,831
	Rise		2,139	2,44
1° floor	R/S	0,458	0,348	
	T/S	0,106	0,057	
2° floor	R/S	0,427	0,375	
	T/S	0,142	0,083	
3° floor	R/S		0,411	0,418
	T/S		0,075	0,078

Table 2. Geometrical Properties Vaults

Concluding the analysis of the geometrical characteristics of the structure and sub-structures of the defense towers provides useful information regarding the preliminary assessment of the vulnerability to dynamic and long-term actions. The towers investigated can be considered stocky as W/H varies between 3:2 and 1:2, and consequently stability issues related to slenderness can be excluded. The in-plan area ratio oscillates between 40 and 65 percent for the base and 20 and 50 percent for the body of the towers. These values comfortably comply with the 10 percent minimum percentage of in-plan area required by the Eurocode 8 and therefore their seismic vulnerability can be considered low. It has been shown that in the case of the towers, the resisting area of the base with respect to the full height of the building influences deeply the overall resistance capacity of the structure. The relationship between the percentage of resistant area and height ranges between 2,5 and 5 for the base and between 1,5 and 4 for the body. The thickness of the walls is considerable at the base (between 2 and 3 m) and it reduces at the body of the towers (up to 1,56 m). The ratio of the height over the thickness shows values included between 2,4 and 6,9. According to the Eurocode 8 the unreinforced masonry walls analyzed could be defined as earthquake resistant as the ratio H/t is lower than 9 and their thickness is greater than 350 mm [EN 1998-1:2004:198]. The rise to span of the vaults is between 1:2 and 1:3. Consequently, in all the analyzed cases, the span is at least double or three times the length of the rise, which indicates a semi-circular to a slightly shallow arch. The minimum thickness of the vault varies between 255 and 545 mm. The thickness to span ration varies between 1:20 to 1:7.

However, it should be highlighted that this simplified approach to the structural assessment of historic masonry shows limitations of informational and technical nature. Measurements and dimensions have a purely indicative value and might not reflect precisely the reality, and moreover the complying of the ratios with technically approved standards should not be considered sufficient to comprehensively assess the vulnerability of the fortifications in the defensive system of the Pontifical State. In fact, these should be understood only as general indicators of structural performance of the towers. Further information can be gathered in order to obtain more specific result and analyze, as done in this study, a particular case.

In order to deepen the technical knowledge about the fortifications in the Pontifical State defensive system, the next chapter will deal with a throughout analytical and diagnostic investigation of a specific tower of the network.

III. THE GUARDIAN

A SURVEY OF THE STRUCTURAL CONDITIONS OF TORRE GREGORIANA

3.1 Introduction to the *'Guardian of the Pontifical State'*.

The aim of this chapter is to inspect the technical characteristics and the actual conditions of a specific watchtower, in the perspective of an accurate analysis of its structural performance. Torre Gregoriana represents one of the most important constructions belonging to the southern stretch of the Pontifical State's defense system being considered for centuries a mute custodian of local vicissitudes and memories. For its location, history and remarkable architecture the tower truly embodies the role of *guardian of the coast*. The significance of *'guardian'*, that is the *"one that guards, watches over, or protects"* (Oxford English Dictionary, 2002), implicitly exalts the honorable function of controlling that the guardian is required to accomplish with and its overwhelming responsibility of protecting, which inspires to the observers a profound sense of affection, respect and gratitude. The choice of the expression the *'guardian of the Pontifical State'* is therefore not casual but it aims to underline the relevance of Torre Gregoriana in the context of the overall defensive system, highlighting its leading role as a fortified structure.

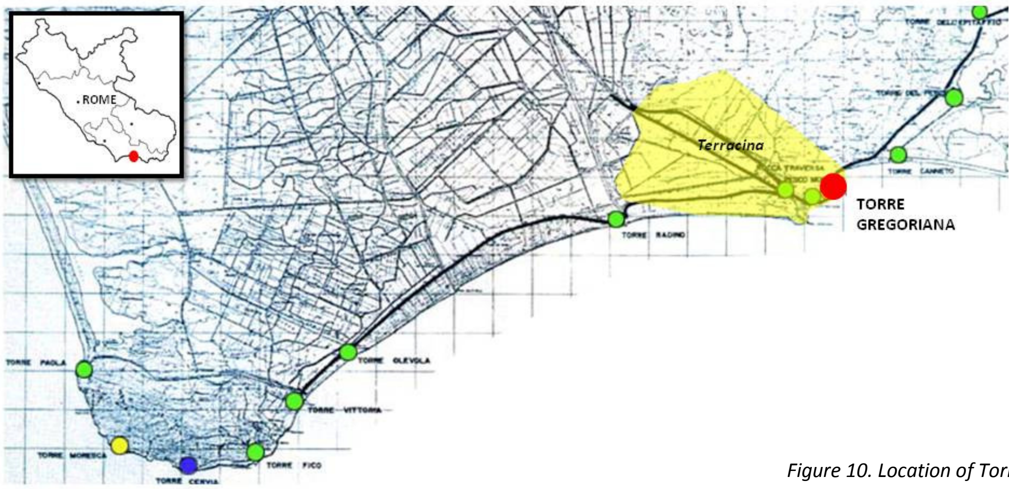


Figure 10. Location of Torre Gregoriana

The tower is located in the city of Terracina, South Lazio, about 100km from the city of Rome (*Figure 10*). The fortification is erected along the *Appia* road, on a small area on the rocks 3-4 meters above the sea level . The distance between the tower and the opposite mountain's rock face is about 8 meters (Map in *Figure 11*). More than being an admired landmark, the exposed position allows to consider the structure a military post of strategic importance . As Giulio Cesare Grillo, general director of the Pontifical fleet, underlines *" further being strong ashore, for its location in narrow passage, it is also strong on the seaside, as it overlooks the southern coast till Sperlonga* (in the Kingdom of Naples)*, preventing the enemy from reaching the shores"* . Furthermore Grillo remarks that, for its military relevance, Torre Gregoriana should be *"guarded with adequate vigilance being in a locus exposed to the sea and to incursions from the inner land"* (G.C. Grillo, 1618-1624). In the late 16th century, Pope

Gregory XIII visiting Terracina *" ordered to build, as defense from bandits and corsairs, a tall and expensive fortified tower equipped with guns, gunpowder and ammunition"* (M.A. Ciappi, Senese, 1596) The tower was built in 1583 and the Pope gave it his name.

The original structure of Torre Gregoriana observes the general characteristics, set by the Pontifical responsible for the defensive network Martino d'Ayala, outlined in the *'Consitutio de aedificandis turribus in oris maritimis' (*see chapter 2, paragraph 1*).*

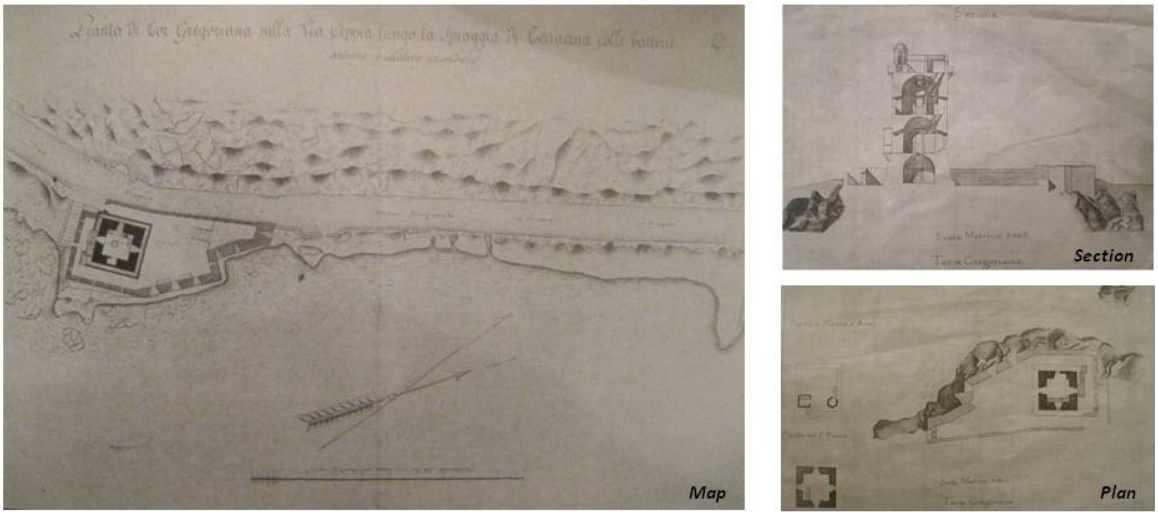


Figure 11. 19th Century Plans and Section

The 19th century section and plan show the original layout of the building (*Figure 11*). The structure features a trunk-pyramidal base of 10 m side and 5 m of height. Originally the base had no openings and it was inaccessible from the outside. The overall height of the structure is 17 m and includes three different levels. The ground floor, composed by the base, is mainly used as storing room for firearms and as warehouse for goods. A stone ring around the top of the base, called *'cordonatura'*, marks the level of the raising body. The main entrance to the tower is located at the first floor by means of masonry staircase leant against the West façade of the base. The peculiarity of the staircase is that it stops at a distance of about 2 m from the entrance door where a drawbridge would have been originally found. This level is dedicated to the accommodation of the captain (referred to as *'torriere'*) and his office. An internal wooden staircase leads up to the second floor dedicated to guest the soldiers. At the top level of the tower, the terrace constitutes the firing space (defined as *'piazza d'armi'*) which is provided with medium-range firearms and the necessary equipment for signaling the danger. A small roofed deposit is present at one corner of the terrace for storing ammunition . The top of the tower is crowned with a number of brackets that allow the formation of firing openings around the tower aimed to the defense in case of an attack by land. The living spaces of the three levels are vaulted and have different dimensions. However the actual structural conditions of Torre Gregoriana are profoundly different from this description. The next sections analyze the structural evolution of the building and its transformation during the centuries, introducing the geometrical characteristics, the material composition and the damage classification of the existing fabric.

3.2 A Complex Structural Evolution.

Torre Gregoriana, as most of the coastal watchtowers, experienced continuous structural adaptations and additions, transforming its appearance at a steady pace of roughly one century (*Figure 12*). Apollnj Ghetti remarks in his studies that *" although the tower existed and was functional during the most bloody and cruel incursions of pirates, almost no records can be recalled regarding its active participation to military actions. On the contrary many more vicissitudes regard the succession of structural changes and the complex evolution of the fabric"* (F.M. Apollonj Ghetti, 1982:24).

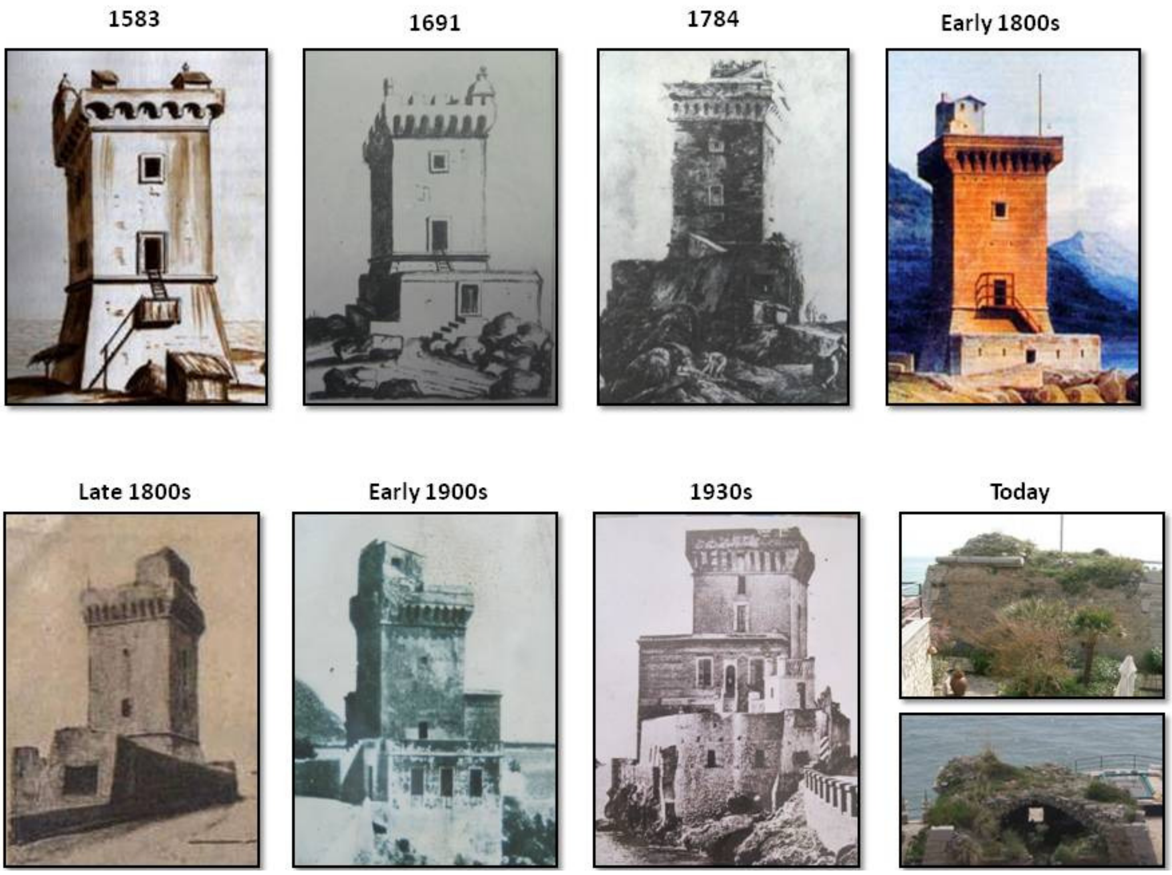


Figure 12. Structural Evolution

According to the historical and photographic evidence available, the original layout of Torre Gregoriana, and of its immediate surroundings, mutated through four remarkable phases. Each phase indicates a specific moment in time at which important structural changes are performed(*Figure 13*). Previous to the outlining of the relevance of these transformations, some consideration involving the originality of the 16th century construction should be discussed. Discordant opinions between scholars question the fact that the tower was newly built, arguing that this was instead the product of a restoration of an older structure, already existent on site. A strong position is taken by Lugli for example, which tries to endorse this hypothesis analyzing in great detail the history of the name of the tower. Torre Gregoriana, in fact, was identified till the beginning of the 17th century as *'Torre Nuova'*, the new tower. According to Lugli the adjective *'new'* is not casual but reflects the fact that it existed, in that location, an older structure which Pope Gregory successively *" restored and gave the* *denomination"* (G. Lugli,1926: col.213, n.2). Unfortunately no clear information can be found, and the possibility of the existence of an older tower remains unproven. On the other hand much more detailed and documented are the changes that occurred to the fortification during the four phases of transformation.

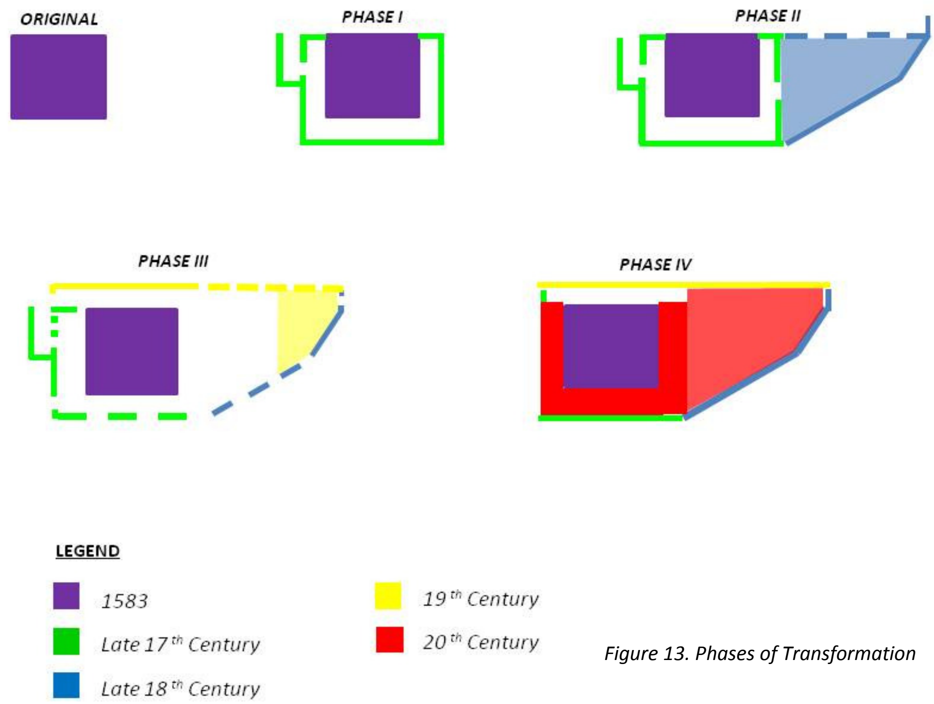


Figure 13. Phases of Transformation

The first phase of structural transformation occurs during the end of the 17th century. The introduction of a *'falsabraca'* around the building is documented by the drawing of Miselli of 1691 (*Figure 12*). This element, described by Bianchini, consists of a *" 3m high masonry enclosure of 37 x 20m, built near the structural walls of the fortification"* (A.Bianchini, 1952). It has to be highlighted that the falsabraca constitutes an integration to the original structure which is characteristic of Torre Gregoriana as no other similar examples can be found in the rest of the defense system. Peculiar to this phase is the installation, along the perimeter walls, of small apertures on the road and seaside allowing the tower to increase the number of firing positions and consequently its military capacity.

During the second phase of its evolution, in the 18th century, the structure of the tower remains intact. Consistent interventions are however reported, such as *" the repair of the roof of the ammunition deposit in the terrace level, the reconstruction of the internal wooden stairs and limited intervention to prevent water infiltration at the ground level"* (A.Corbo, 1989:14). The most relevant changes occur to the area surrounding the building. From the inspection carried out in 1789 by Pontifical officials it is possible to notice that the area internal to the falsabraca presents a triangular shaped room (*Figure 13*) with a pitched-roof cover. Although reported as badly kept and quite unhealthy to accommodate people, this area is used as an additional living space by the soldiers. These changes are also shown in the print of Du Cros, dated 1784 (*Figure 12*).

The third phase of the structural evolution occurs in the second half of the 19th century. The North side of the perimeter wall, along the Appia road, is further enlarged and additional firing openings are introduced. The roofed triangular area described in the previous phase is substituted by a smaller elevated platform from which it is possible to defend easily the bay to East of the tower. The whole complex at this stage truly resembles a fortified construction and loses its appearance of simple watchtower.

The last phase presents dramatic structural transformations due to the change of use of the building. Torre Gregoriana ceases its military role to become a residential villa. In 1903, on the South and East sides, a L-shaped building is added around the tower, with the specified intent *" to form a portico around its base and protect from degradation its most exposed façades"* (B. Amante, 1903:240). By the 1930s the tower is fully surrounded by 6m tall masonry structures on the East and South elevations, and by a 4m tall construction on its West façade overlooking the port of Terracina. The effect of such transformation is shown by a series of photographic images and postcards here published(*Figure 12*).

After the last phase of transformation, the structure is imposed a drastic modification by the events of WWII. In 1944 the whole complex of Torre Gregoriana is mined and blown up. What remains today is the base and about half of the ground floor barrel vault.

The next section describes in detail the aftermath of this occurrence and outlines the conditions of the existing portion of the tower.

3.3 Visual Inspection of Torre Gregoriana.

The analysis of the current structural conditions of the tower is based on a throughout in situ inspection and on the elaboration of the photographic surveys of each visible structural element. Qualitative and quantitative investigation of Torre Gregoriana permits the assessment of parameters necessary for the development of the structural analysis. The inspection carried out on Torre Gregoriana focuses more specifically on three main characteristics: the geometrical data, which allows to identify the current shape and dimensions of the building, the material composition of the structure, which helps indicating the different materials present in the tower, and finally the damage survey which categorizes the types of decay visible on the fortification. The following sections explore separately each one of these characteristics.

3.3.1 Geometry.

The geometric survey provides an approximation of the actual dimensions of elevations and plan of Torre Gregoriana (*Figure 14*). The four elevations have a width of 10,4 m and a variable height of 4,6 m.

-The South elevation shows a 2 x 1,8 m opening in the middle of the façade which regresses inwards to an aperture of 1,5 x 0,7 m. The height of the elevation decreases considerably on the left-hand corner, where about 25 percent of the original dimension can be still observed. On the right-hand corner of the elevation the cornerstones reach almost the full original height. The top of the elevation between the corners is of irregular shape and quite variable in its dimensions.

-The West elevation features the current entrance to the base of the tower which is 2 m high and 0,9 m wide. The right-corner of the elevation presents a shortened elevation about 1,5 m high which constitutes a mirror image of the adjacent South façade.

-The North elevation is considerably reduced in the middle section. Part of the original opening has been reconstructed after the war. However at the corners the elevation still preserves its original height.

-The East elevation is the most complete and intact one and its surveyed dimensions reflect closely the originals. On this side of the tower four elements of the former stone ring are identified. The centre of the façade exhibits a 1,6 x 0,7 m opening which regresses inwards to a 0,7 x 0,5 m aperture.

It should be noticed that the stone elements at the base of the tower are not possible to inspect in the North and East elevations, and partially visible in the West side of the building. On the contrary the South elevation allows to detect stone elements of unknown width, variable length and 0,6 m height.

-The plan of Torre Gregoriana has a square shape of 10,4 m side at the base, and of 8m side at the first floor level. The existent portion of floor slab on top of the tower is of 37,4 m^2 (about 50 percent of the 64 m^2 of the full plan area) and two considerable voids are visible in the plan as a consequence of the blast. The southwards void is located at the South-West corner of the base and has dimensions of 2,8 x 1,7 m. The second void, concentrated on the North side of the plan is of irregular shape and has rough dimensions of 4,3 x 2,8 m.

The actual geometry of the structure therefore is consistently reduced if compared to its original one. The raising body and the 20th century additions have been completely swept away. However the existing fabric still features the full structure of the base of the tower and, partially, the original extent of the vaulted system of the ground floor.

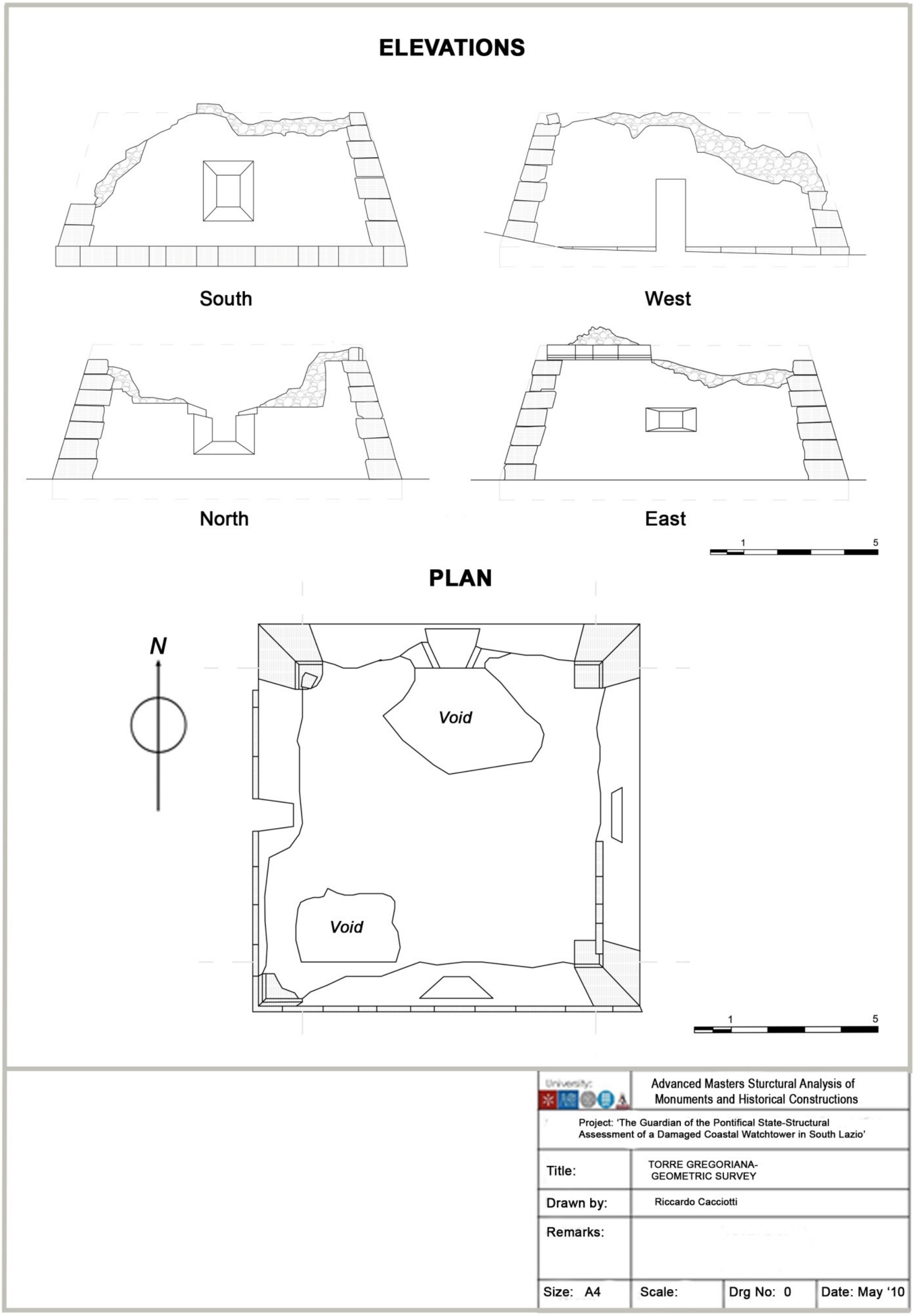


Figure 14.Torre Gregoriana- Geometric Survey

3.3.2 Materials.

The remaining fabric of Torre Gregoriana is composed by different materials that can be grouped into two categories: the category of primary materials, which include stone and brick units, identifies the constituents of the structural skeleton of the tower; secondary materials, instead, function as finishing or repairing elements of the construction and include plaster, stones and bricks of different characteristics.

The primary materials show a widespread distribution throughout the building. Stone is certainly the most common material and it is an essential component of the base, the walls and the vault of the tower. The type of stone observed in Torre Gregoriana is a local limestone, almost certainly coming from the opposite *S. Angelo Mountain*. The limestone is characterized by a dense and compact texture, with a minimal presence of quartz or clay impurities, ensuring a qualitative structural performance. The color of the stone varies between white and grey, depending also on the severity of exposition to weathering agents. Stone parallelepipeds of relevant size are present all around the tower, at the bottom of the base (*Figure 15*). The function is to transfer the compressive loading generated by the weight of the walls of the tower, into the foundations and the ground. The elevations and the plan of the fortification (*Figure 15*,*Figure 16 and Figure 17*) show the presence of limestone blocks, with two exposed faces inclined at 15° to the vertical, at the corners of the tower. These elements improve the connection between orthogonal walls, strengthening the resistance of the structure to a possible impact of gunfire. The East elevation of Torre Gregoriana (*Figure 16*) exhibits four remaining limestone units of the original ring ('cordonatura' see paragraph 3.1) topping the base of the structure. These elements contribute reinforcing the rigidity and solidity of the upper part of the base. Limestone units are also noticeable in the exposed parts of rubble wall, which constitutes the nucleus of the masonry of Torre Gregoriana. In fact, stone units of different shape and size can be found in the section of the walls and in the vault of the tower. Further details regarding the composition of the section of the tower will be discussed later in this paragraph.

If stone can be considered the most widespread structural material, brick certainly constitutes the one with the greatest visual impact. The façades of the base are covered with a layer of clay bricks. The dimensions of a unit are 4-5 cm thickness, 25 cm length and 15 cm width. The physical characteristics of the bricks range conspicuously: the color varies between light brown-yellow to orange-dark red, the texture is heterogeneous with voids and particles of different sizes. The heterogeneity of the bricks can be due to the different chemical and mineral contents of the raw materials in the bricks, to the localized repairing over time and substitution with new units, and to the different exposure of the four sides of the tower to weathering. The plan of the structure (*Figure 17*) shows that bricks are also used in the half-spiral stairs and for the shaft of the staircase itself. It should be underlined that a limited amount of bricks can be sporadically found in the vault and in the wall section, used more for constructive needs rather than for structural purposes.

The secondary materials have no clear participation in the structural performance of the building but contribute protecting the construction from external agents and repairing structural and non structural damages to the fabric. Plaster is present on almost all the façades of the building. However the portions of plaster still visible are limited and surely not older than one century. The plaster is composed by two layers: one underneath layer in contact with the façade and a finishing layer. The overall thickness is up to 2cm (the lower layer varies between 0,5-1cm, while the exposed layer is 1-1,5cm thick). The plaster is cement based and the color ranges from light to medium dark grey. The lower layer shows a coarse and medium size aggregate, while the texture of the upper layer presents homogeneous and fine constituents. In Figure 15, on the West façade, it is shown that also the cornerstones were plastered during an unspecified time period. It should be underlined that the type of plaster remaining is with high probability designed for rendering of interiors, as the base of the tower constituted the internal façades of the structural additions of the 20th century. The inadequacy of the plaster to the exterior might explain the reduced amount of plaster still conserved on the exposed façades of the tower.

Repaired areas are inspected on the West and North elevations of Torre Gregoriana. These are made with the use of mixed materials such as stone, bricks and mortar. The repair on the West façade features small size, angular stones and wedges of broken bricks bound by a lime based mortar. Stones are of different type and seem to be randomly selected. The material used on the North elevation is brick. The whole repaired section in *Figure 17* was reconstructed after being blown up during the WWII. New red solid bricks, whose dimensions are similar to the original ones, are employed for the external leaf of the wall, while a mix of reused material is used for the wall section (stone, brick, tuff and concrete). Further finishing materials can be individuated in the plan of the tower (*Figure 17*). Red and square floor tiles are used for finishing the first floor level. No information is available regarding the authenticity of these clay tiles. Under the floor tiles a layer of cement based material finishes the level of the top of the vault.

Other types of stones should be included in this group of secondary materials, such as the marble slates used for finishing the second flight of stairs leading from the ground to the first floor (*Figure 17*).

The mechanical properties of both primary and secondary materials can be determined proportionally to their level of degradation. The functional efficiency of stone and brick units will be commented , based on the actual structural conditions and damage distribution outlined in the next section.

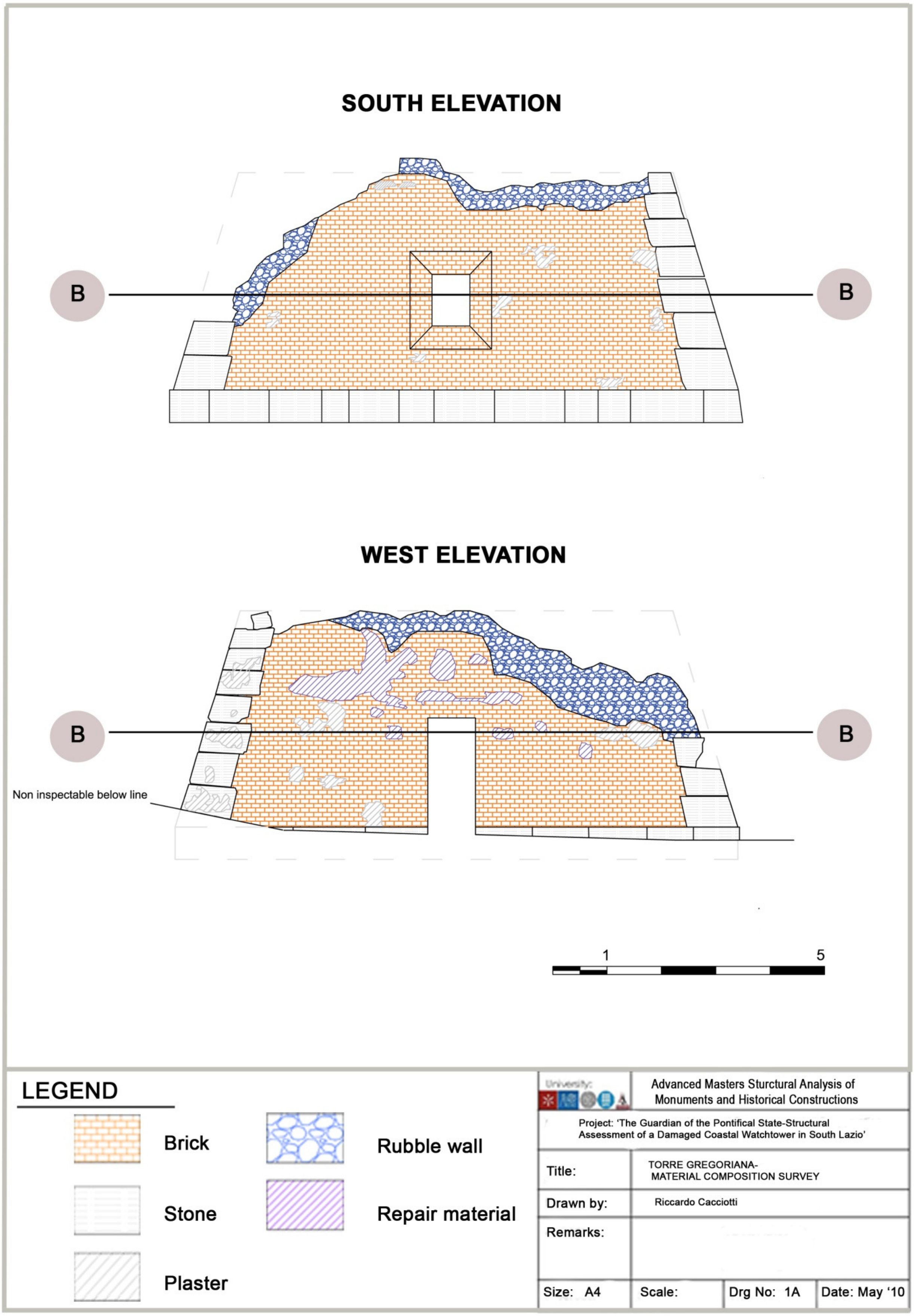


Figure 15. Torre Gregoriana- Material Composition S-W

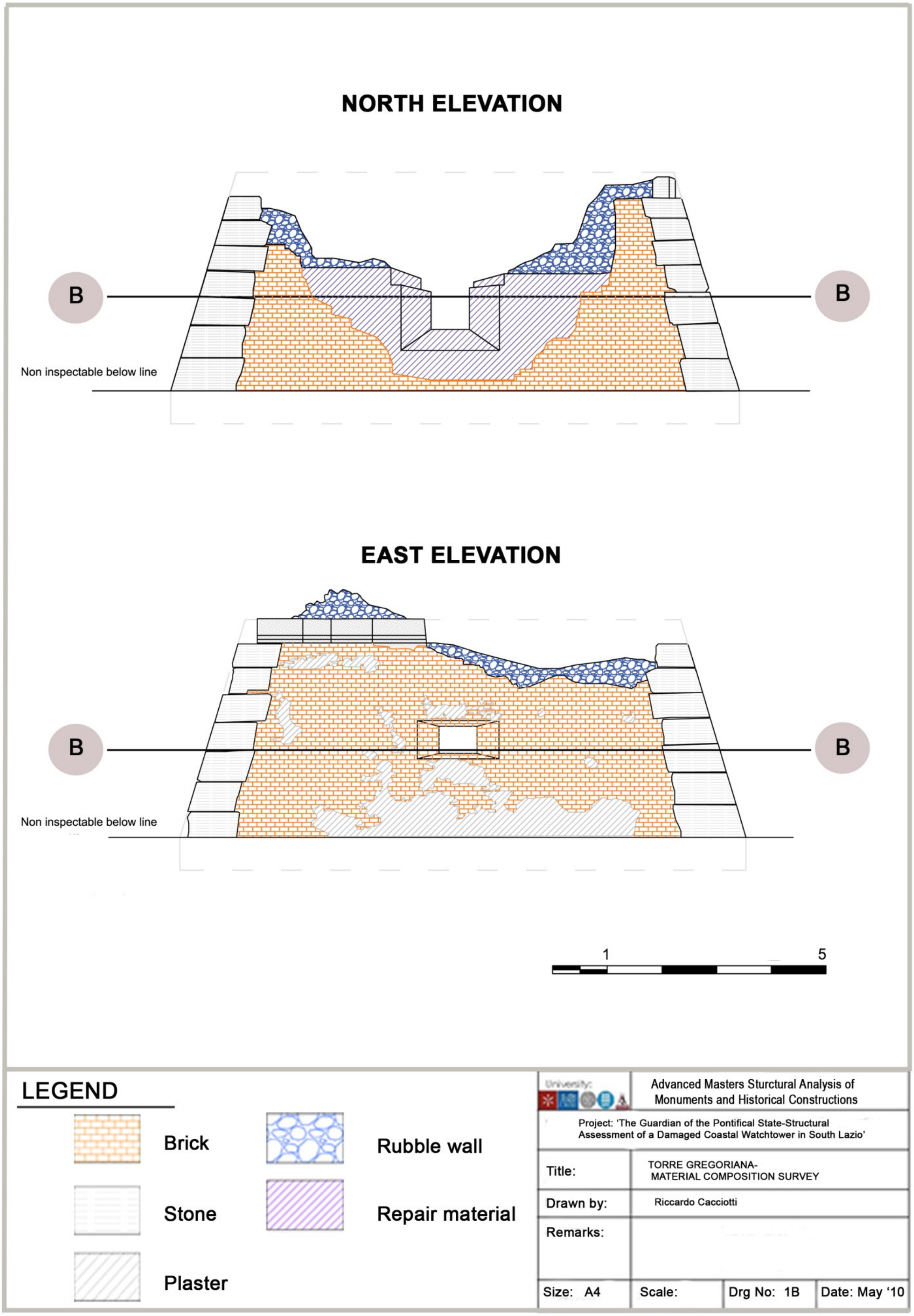


Figure 16. Torre Gregoriana- Material Composition N-E

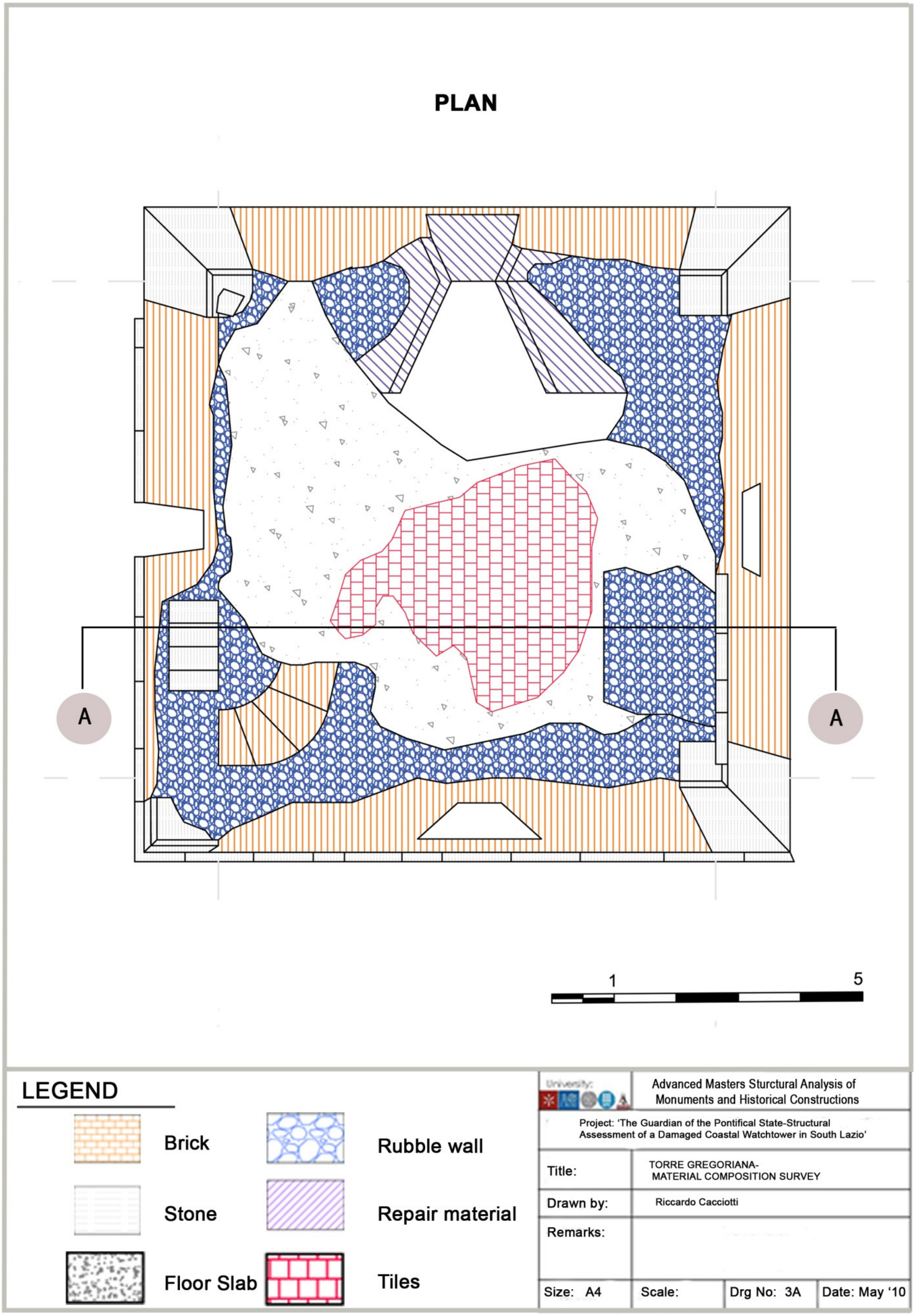
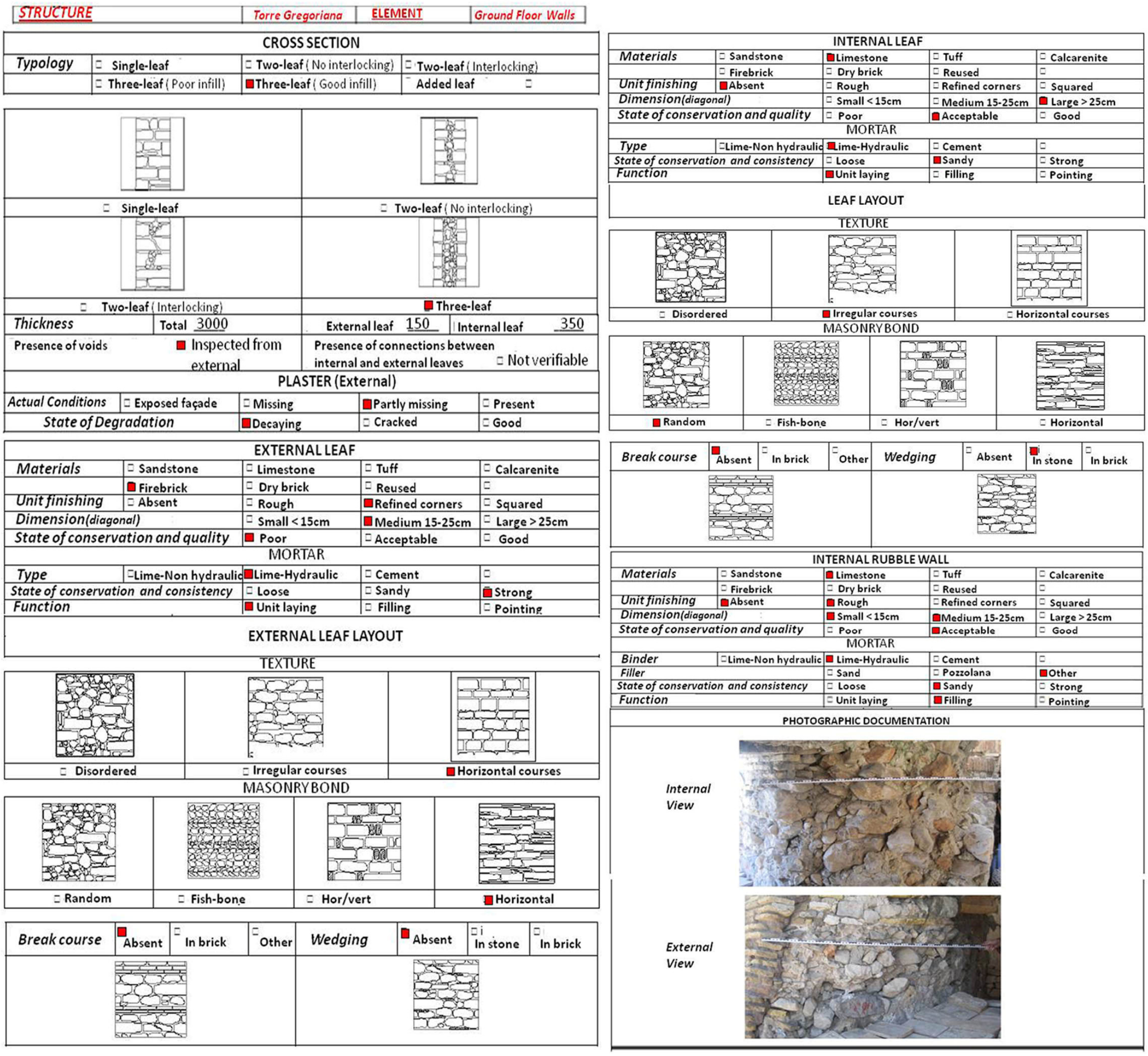


Figure 17. Torre Gregoriana- Material Composition Plan

As previously mentioned, particular attention is required to characterize the material of the cross section of Torre Gregoriana in order to achieve a more accurate picture of the structural elements of the building.

The form shown below (*Figure 18*) summarizes the essential characteristics of the walls and of its composing materials. Sections A-A and B-B (*Figure 19*) show respectively a vertical and horizontal section of the base. The wall is composite and its internal nucleus, the rubble wall, constitutes a conspicuous part of the whole section.



STRUCTURE	Torre Gregoriana	ELEMENT	Ground Floor Walls

CROSS SECTION

Typology	Single-leaf	Two-leaf (No interlocking)	Two-leaf (Interlocking)
	Three-leaf (Poor infill)	■ Three-leaf (Good infill)	Added leaf

Single-leaf / Two-leaf (No interlocking) / Two-leaf (Interlocking) / ■ Three-leaf

Thickness	Total 3000	External leaf 150	Internal leaf 350
Presence of voids	■ Inspected from external	Presence of connections between internal and external leaves	Not verifiable

PLASTER (External)

Actual Conditions	Exposed façade	Missing	■ Partly missing	Present
State of Degradation	■ Decaying	Cracked	Good

EXTERNAL LEAF

Materials	Sandstone	Limestone	Tuff	Calcarenite
	■ Firebrick	Dry brick	Reused	
Unit finishing	Absent	Rough	■ Refined corners	Squared
Dimension(diagonal)		Small < 15cm	■ Medium 15-25cm	Large > 25cm
State of conservation and quality	■ Poor	Acceptable	Good	

MORTAR

Type	Lime-Non hydraulic	■ Lime-Hydraulic	Cement	
State of conservation and consistency	Loose	Sandy	■ Strong	
Function	■ Unit laying	Filling	Pointing	

EXTERNAL LEAF LAYOUT

TEXTURE: Disordered / Irregular courses / ■ Horizontal courses

MASONRY BOND: Random / Fish-bone / Hor/vert / ■ Horizontal

Break course	■ Absent	In brick	Other	Wedging	■ Absent	In stone	In brick

INTERNAL LEAF

Materials	Sandstone	■ Limestone	Tuff	Calcarenite
	Firebrick	Dry brick	Reused	
Unit finishing	■ Absent	Rough	Refined corners	Squared
Dimension(diagonal)		Small < 15cm	Medium 15-25cm	■ Large > 25cm
State of conservation and quality		Poor	■ Acceptable	Good

MORTAR

Type	Lime-Non hydraulic	■ Lime-Hydraulic	Cement	
State of conservation and consistency		Loose	■ Sandy	Strong
Function		■ Unit laying	Filling	Pointing

LEAF LAYOUT

TEXTURE: Disordered / ■ Irregular courses / Horizontal courses

MASONRY BOND: ■ Random / Fish-bone / Hor/vert / Horizontal

Break course	■ Absent	In brick	Other	Wedging	Absent	■ In stone	In brick

INTERNAL RUBBLE WALL

Materials	Sandstone	■ Limestone	Tuff	Calcarenite
	Firebrick	Dry brick	Reused	
Unit finishing	■ Absent	■ Rough	Refined corners	Squared
Dimension(diagonal)		■ Small < 15cm	■ Medium 15-25cm	Large > 25cm
State of conservation and quality		Poor	■ Acceptable	Good

MORTAR

Binder	Lime-Non hydraulic	■ Lime-Hydraulic	Cement	
Filler		Sand	Pozzolana	■ Other
State of conservation and consistency		Loose	■ Sandy	Strong
Function		Unit laying	■ Filling	Pointing

PHOTOGRAPHIC DOCUMENTATION

Internal View

External View

Figure 18. Cross Section Characterization Form. Source GNDT, 2006

The cross section typology is a three-leaf wall with good quality rubble infill. The total thickness of the wall at the bottom of the base is 3 m, of which 0,15 m is the width of the external leaf and 0,35 m the thickness of the internal one. The presence of internal voids in the rubble wall is not verified but limited spaces are observable from the outside of the base, running inwards deep into the masonry.

Bricks cover the external façades of the tower and constitute its external leaf. The conditions of the material vary depending on the exposure of the façade to weathering, however the state of conservation and consequently the quality of the brick units is expected to be poor. The mortar used to lay the units, although very eroded in localized spots, appears to be strong and compact. The binder is hydraulic lime and the aggregate is composed by poorly graded particles, of 4-7 mm angular shape and of different calcareous nature. The leaf layout is regular and features ordered horizontal courses of bricks with no break- course nor wedging between courses.

The internal leaf is predominantly composed by large limestone units (greater than 25 cm diagonal dimension), and with a random shape and finishing (rounded, angular and squared). The state of conservation of the leaf is discrete although some of the units are loose and badly bound to the texture of the wall. The mortar used for laying the stone units appears of loose consistency. The binder is hydraulic lime with well graded sand and silty soil as aggregate. The units are randomly located into irregular courses with the aid of stone wedging.

The rubble wall is composed mainly by limestone and mortar. The size and shape of the stone is very heterogeneous as it can vary considerably between 40 cm long angular units to 4-5 cm rounded or irregular particles. The units in the rubble wall are randomly arranged and no regularity can be observed. The mortar used to fill the voids between stones is generally in mildly loose conditions. The binder is hydraulic lime with a poorly graded mix composed by pebbles, crushed rocks and calcareous and basalt particles.

It has to be noticed that the homogeneity and continuity of the above properties of the walls of Torre Gregoriana is not ensured.

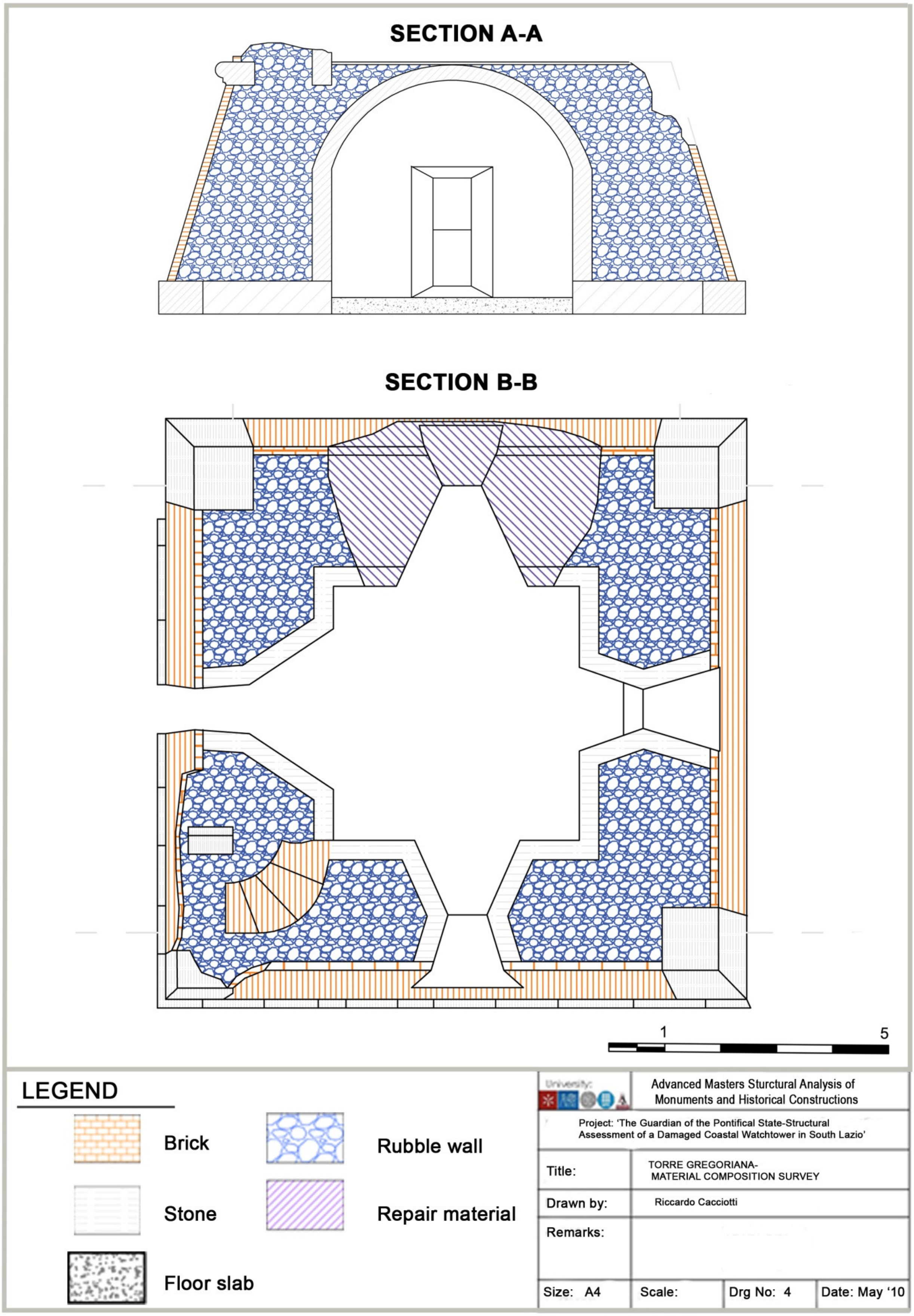


Figure 19. Torre Gregoriana- Material Composition Section A-A, B-B

3.3.3 Damage.

The actual conditions of Torre Gregoriana are affected by a prolonged period of abandonment and negligence following the WWII. The visual inspection carried out concentrates on the different types of damage that, interacting between each other, result in a rapid decay of the structural fabric. The survey points out the magnitude of such decay, providing a classification of adverse actions which might result threatening to the structural stability and material integrity of the watchtower. The typologies of damage include cracking, mechanical decay, weathering and biological attack(*Figure 20*).

Figure 20. Damage Typologies

Cracking concentrates mainly at the top of the base of the tower, in proximity of corners, and run either vertically downwards or in directions of the openings. The cracks observed have considerable lengths of 1 to 3m and a variable width of 2-4mm. The majority of the crack surveyed involve areas of the external façades. However each elevation a different distribution of cracks on the four sides of the tower (*Figure 22 and Figure 23*) and distinctions can be made. The South elevation (*Figure 22*)highlights the presence of localized cracks at the top boundary of the external brick layer. More cracks are visible at the left-hand corner running parallel to the inclination of the adjacent façade. Straight, vertical cracks appear on the stone blocks at the base of the elevation. The West elevation (*Figure 22*) features diagonal cracks concentrated at the left-hand corner of the façade, running top to bottom the full height of the base. Shorter diagonal cracks are also visible at the other corner in proximity of the base. It should be noticed the presence of cracks running from the top of the base parallel to the opening which considerably detach the door masonry frame from the rest of the fabric.

The North elevation (*Figure 23*) shows cracking damage limited to two cornerstones at the right-hand corner of the façade. The cracks observed on the East elevation (*Figure 23*) concentrate at both top corners and run parallel to the inclination of the adjacent façades. Further vertical cracking is showed in proximity of the opening and in the section of masonry directly above the aperture. The plan of Torre Gregoriana shows the concentration of cracks at the corners of the building(*Figure 24*). The damage is visible exclusively in the remaining portions of rubble walls while such damage cannot be clearly detected in the floor slab due to the poor conditions of its top layer which does not allow to determine any crack pattern. The internal part of the barrel vault exposes a quite characteristic crack pattern (*Figure 25*). The cracks run mainly parallel to the directional axis of the vault. A relevant amount of cracks is also visible at its corners. Denser cracking pattern is identified at the edges of the existing vault, in proximity of the two holes created in the floor slab after the destruction of the tower. It should be underlined that severe cracking (with a width between 1-2cm) is identified at the middle of the vault, running the full length of the structural element.

Mechanical damage indicates an artificially produced decay caused by human activities. In the case of Torre Gregoriana mechanical damage relates mainly to structural needs, raised for the introduction of the additional buildings leant against the base of the tower during the early 20th century, and to the secondary effect of the blast in 1944 (e.g. fall of structural elements and rubble against the tower). The mechanical damage involves both brick and stone sections of the building. Relevant damage can be seen right below the remaining elements of the stone ring at the top of the base (fig.). A horizontal cut in the masonry, running around the tower, is visible in the South, West and East elevations, at a height of about 3,5 from the ground (*Figure 22 and Figure 23*). Further localized mechanical damage is identified on all the four façades of Torre Gregoriana. The middle of the vault presents also a 25x15cm cut for accommodating a ceramic pipe descending from the first floor to the ground level. This might have been used to convey rainwater from the top of the tower into the basement which functioned as a water tank during the 18th century.

The effects of weathering are considerable and even worsened by the marine environment in which the tower is located. Although the temperature difference between the cold and hot seasons is not marked, the action of the wind is constant and occasionally strong. This action transports highly erosive agents from the sea accelerating the decay of the fabric. The inspection reveals, in fact, that the South and West elevations (*Figure 22*), being very exposed, suffer the most from the weathering action. On the South façade a large area of the brick layer is eroded, while on the West façade the top part shows a consistent damage and a quick degradation. The effect of rain and water infiltration is visible in the plan of the tower (*Figure 24*). The exposed sections of rubble wall and the edge of the floor slab northwards are relevantly affected by weathering action. Stains and humidity on the internal part of the vault (*Figure 25*)remarks the presence of water infiltration through the element leading to the loss in mechanical properties of the materials. It has to be also underlined that the absence of protective layers on the structure such as plastering amplifies the impact of weathering and its influence on the fabric.

The last typology of damage deals with the biological attack. Vegetation growth on the structure Torre Gregoriana is widespread and easily individuated. The visual inspection underlines that different types of plants, bushes and algae flourish on the building's fabric. Grass and bushes proliferate on the horizontal surfaces of the building as the first floor slab and the exposed rubble wall sections along the top of the base. In some sporadic cases the biological attack involves plant with long and robust root which can seriously damage the tower. As far as the façades are concerned, the presence of circumscribed attacked areas can be observed. Moreover algae can be individuated on particularly humid spots on the internal surface of the vault(*Figure 25*).

Another threatening damage which has not been discussed so far regards the detachment of the external leaf of the tower walls (*Figure 21*).

Figure 21. External Leaf Detachment

The detachment of the bricks is significant. On the South façade large voids are visible, with a gap of up to 10cm width. The detachment interest a not clearly identified area which surrounds the whole opening. Less dramatic is the detachment of the external leaf in correspondence of the aperture on the East elevation. The surveyed gap between two layers of the wall is around 1cm.

The next paragraph will process the analytical findings of the visual inspection and outline an simple diagnosis of the structural conditions of the tower.

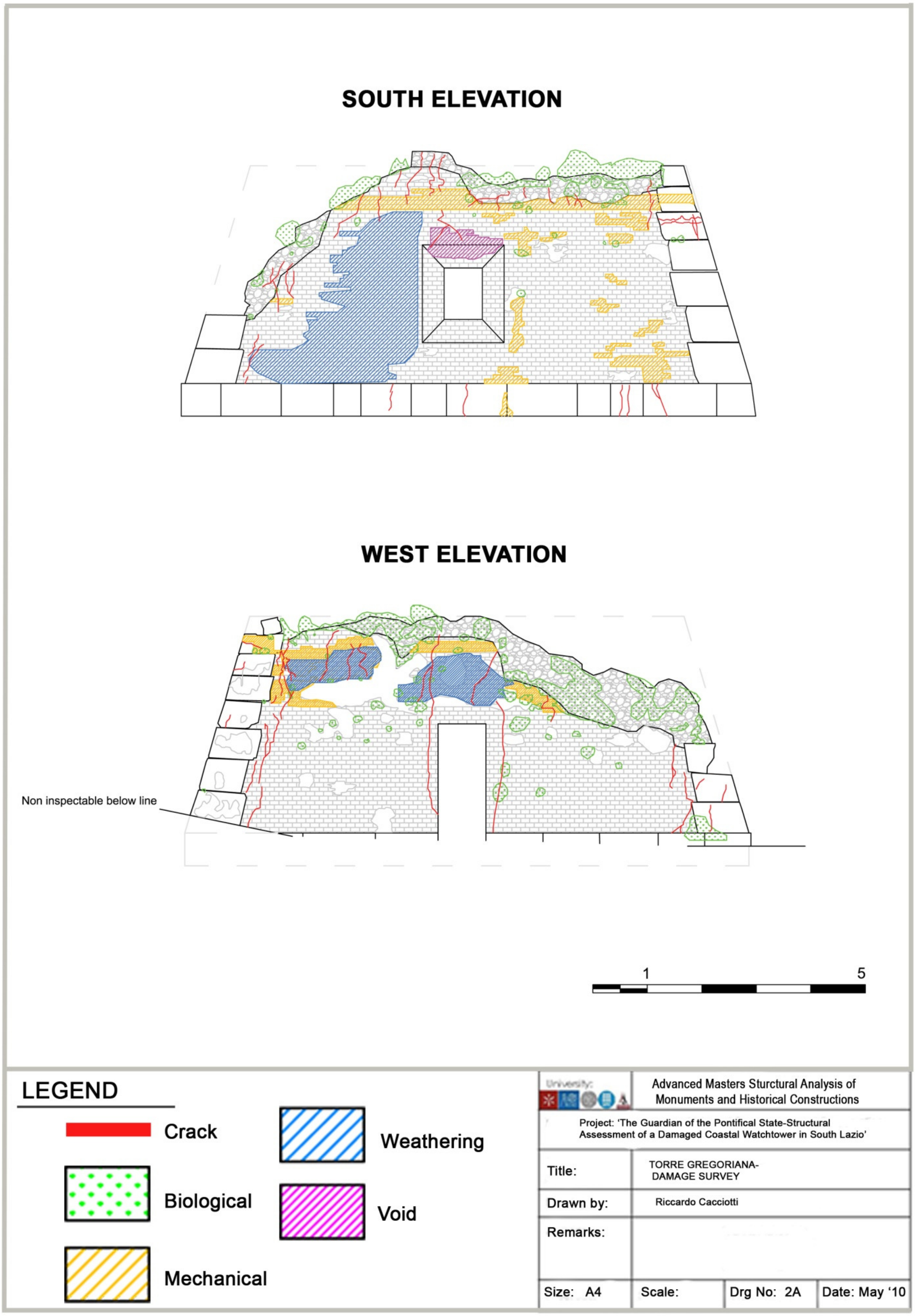


Figure 22. Torre Gregoriana- Damage Survey S-W

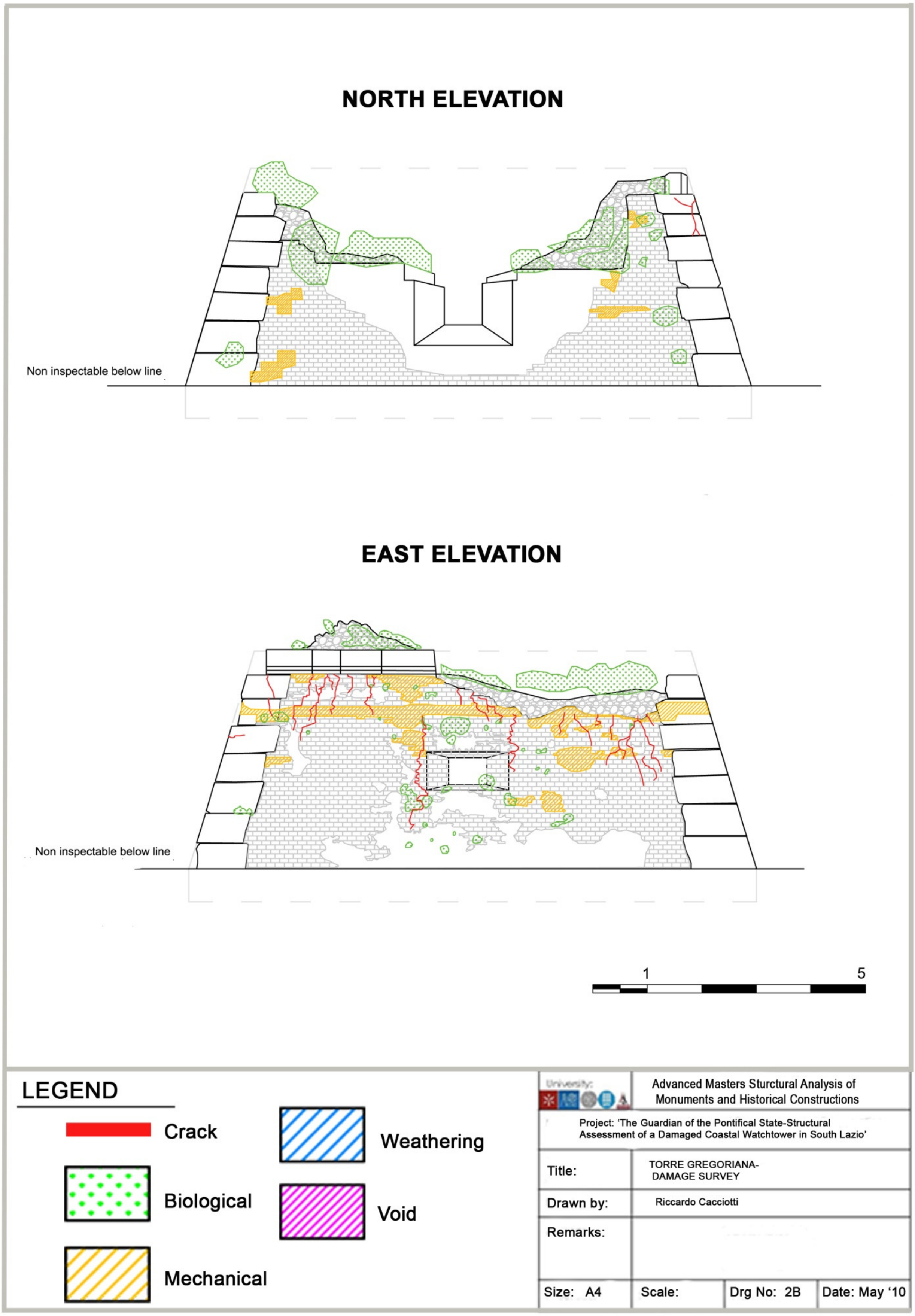


Figure 23. Torre Gregoriana- Damage Survey N-E

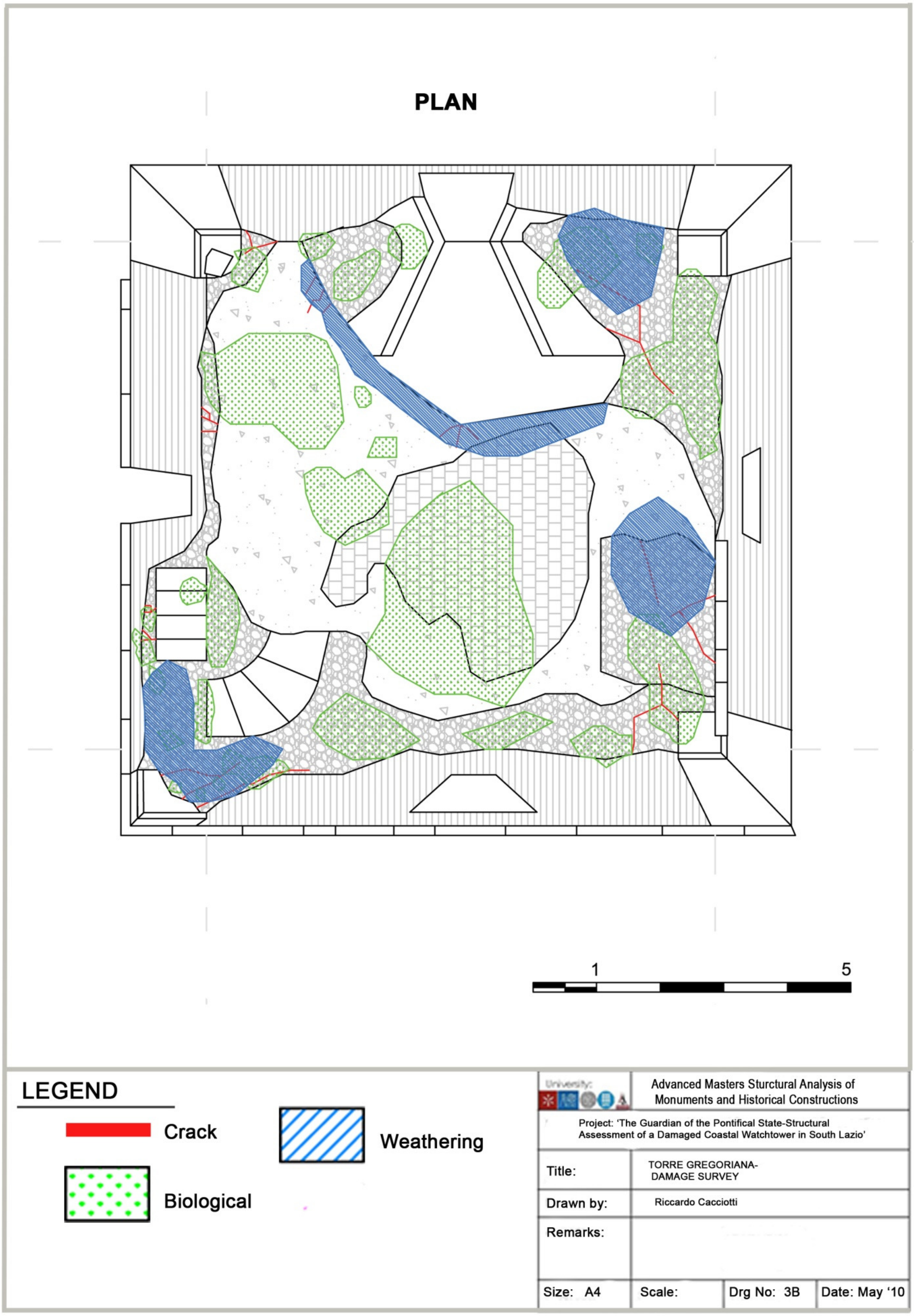


Figure 24. Torre Gregoriana- Damage Survey Plan

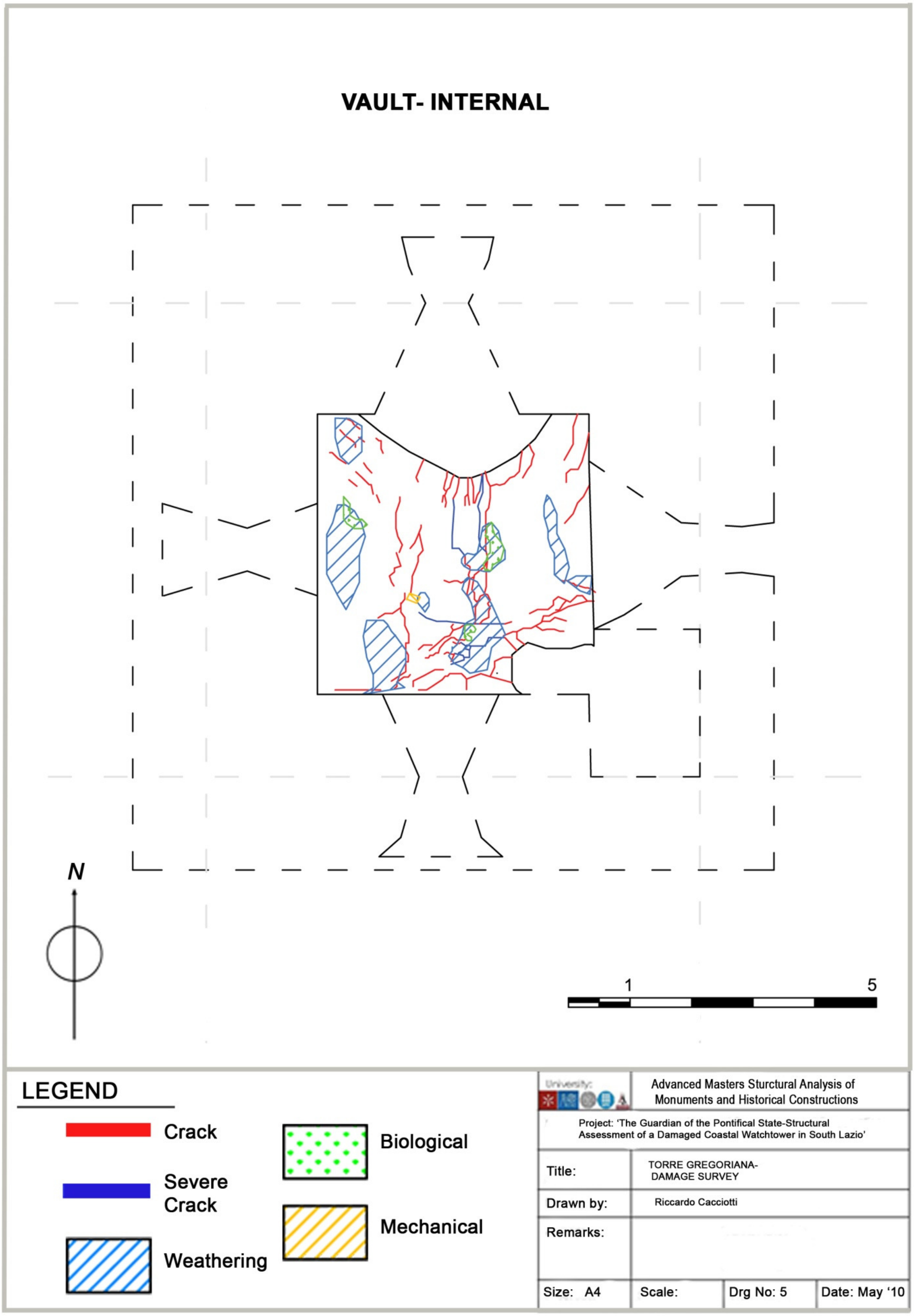


Figure 25. Torre Gregoriana- Damage Survey Internal Vault

3.4 Assessment of Current Structural Conditions.

The evidence provided by the visual inspection of Torre Gregoriana allows to draw clear conclusions concerning its general conditions.

As seen in paragraph 3.2 *A Complex Structural Evolution.* the structural evolution of the building involves mainly the surrounding area of the tower and minimally the structure itself. The only difference between the original and actual base of the tower is constituted by the openings introduced on the four elevations during a phase successive to its construction. Therefore the actual structure of the building does not show successive transformations and, consequently, the conditions of the tower was not significantly influenced by the development of the building during the centuries, with the exception of the WWII explosion.

The survey of the actual geometry of the building remarks the existence of building elements which are not structurally deficient or incomplete but can constitute together a complete structural system, able to perform independently from the loss of conspicuous sections of the tower. The stability of such system, as assessed in the preliminary analysis of chapter 2, paragraph 4, can be proven based on simple geometrical ratios. The current geometrical characteristics of Torre Gregoriana, in fact, allow to exclude a structural vulnerability of the construction due to its quite stocky nature (width/height ratio is 2) and massive walls.

From the visual investigation of the materials it stems out that the state of conservation of the masonry is good and the quality of its components, such as mortar, bricks and stones, discrete. The damage found on the building fabric has a limited relevance and distribution. Cracking results mainly from the structural trauma of the blast occurred in 1944. Cracks in fact are induced by the displacement of the four corners of the base outwards due to the explosion and the consequent loss of the reinforcing stone ring around the top of the base. It should be underlined however that such movement has been contained and it is currently inactive. The vault appears to be stable although the cracking pattern highlights localized loss of cohesion of the material. This could be due to the amorphous shape of the vault dictated by the missing parts, which reduces conspicuously the compression at the edges of the element, inducing a vault behavior deviating from the typical one dimensional arch. The photographic evidence of the tower in the 1960s compared to the damages here surveyed, suggests an inactivity of cracks as the conditions of the structural elements have not sensibly changed over time. Further damage observed, such as mechanical damage, weathering action and biological attack, affects only superficially the base of the tower and therefore does not represent a serious threat to its structural conditions.

Concluding the visual inspection of Torre Gregoriana underlines overall good structural conditions of the building. The diagnosis of the analytical findings can be sufficiently validated only by the qualitative and quantitative evidence provided in this chapter. In fact the massive geometry of the building, the reasonable quality of its materials and their layout and the low damage induce to consider further in-situ and laboratory testing, in the perspective of this study, not required.

If Torre Gregoriana can be therefore considered in good structural conditions, on the other hand the slow process of degradation produced by the interaction of non structural damages should be addressed by a coherent conservation plan in order to prevent a more severe state of decay and consequently a worsening of the overall structural reliability.

The next chapter will analyze the possible consolidation and restoration interventions of the actual structure and set the context for a hypothetical reconstruction, if applicable, of the full tower with alternative technical specifications.

IV. THE BATTLE AGAINST DEGRADATION

A CONSERVATION PLAN FOR TORRE GREGORIANA

4.1 The Preservation of Heritage: Tangible and Intangible Values.

The development of a conservation project specific to any building requires, further than technical knowledge of the structure in question, a sensible understanding of the multiple effects on the socio-cultural level implicitly involved. The abstraction of historical constructions as physical expressions of a society, with geographical and temporal peculiarities, is indeed a widespread conception in the field of conservation. As the ICOMOS *'Principles for the Analysis, Conservation and Structural Restoration of Architectural Heritage*' of 2003 recognizes, the physical heritage should be considered strictly within *"the cultural context to which it belongs"* (ICOMOS, 2003; Pt 1.2)and the preservation of the fabric should, therefore, not merely involve the material tangibility of the structures, but also consider the profound intangible aspects related to them. The question of conservation poses therefore issues of multidisciplinary nature strongly entwined between each other, which need to be carefully addressed.

Torre Gregoriana constitutes an example in which emotional and cultural values, such as identity, symbolic, archeological and documentary traces, interact with the material structure impressing an indelible perceptual, subjective image on its masonry fabric. The clarity and legibility of such image strongly depends on the state of conservation of the building and, consequently, on its capacity to express its values. This chapter is intended to outline a comprehensive conservation plan of the remains of the tower. The aim of the conservation measures is to control the process of degradation and to prevent decay of the building, in order to exalt its emotional and cultural values, while at the same time conjugating them with functional needs related to the use and safety of the tower. The plan involves two main processes of intervention: firstly the 'restoration' of the building, intended as the revival of the original concept or legibility, through the cleaning of the fabric, the reintegration of details and features and the replacement of decayed sections; secondly the 'consolidation' which involves the physical addition or application of supportive material into the texture of the building in order to ensure its continued durability and structural integrity. The development of these processes should be constrained by an appropriate regulatory framework necessary to safeguard both the tangible and intangible values of Torre Gregoriana. In this perspective the interventions should be *"minimum and reversible or repeatable, should not preclude the possibility of later access to all evidence incorporated in the object, and should allow the maximum amount of existing material to be retained"*; moreover *"if additions are necessary, should be less noticeable than original material, while at the same being identifiable and be harmonious in color, tone, texture, form and scale"*(M. Drdácký, 2009: MSAHC-SA6,Lec1).

The following sections describe in detail the proposal for the conservation of Torre Gregoriana specifying the type of the interventions together with their impact and costs.

4.2 A Defense for the Tower: Intervention Proposal.

The structure of Torre Gregoriana, although reduced to its trunk-pyramidal base, features a complete system of structural elements. As seen in the previous chapter, the degradation process of the fabric depends on different actions of either human or natural nature. The South and West façades suffer the prolonged exposition to severe weathering agents from the seaside. The absence of protection on the external surfaces produces a significant erosion of the material and its subsequent decay. Mechanical damage results from human activities and identifies the traces of past interventions. The long period of abandonment due to the inaccessibility and practicability of the tower, endorses vegetation growth which is widespread on the structure and particularly concentrated on the horizontal surfaces. Cracking is limited and not structurally threatening but requires to be addressed in order to prevent further loss of cohesion between the masonry units. The detachment of the external leaf on the South and East façades of the tower is significant especially at the areas surrounding the main openings.

The conservation plan includes a series of interventions, which comply with international conservation guidelines, aiming at tackling the degradation process through the preservation of the fabric and the ensuring of its structural integrity. The following is proposed:

-Removal of vegetation and cleaning. The biological activity present on external and internal surfaces of Torre Gregoriana should be addressed by applying an appropriate chemical product specific to the type of vegetation to be eradicated. Higher plants, intended as "*those plants which have definite vascular system"* (O.P.Yadav), include grass and bushes visible on the outside of building. These should be treated by spraying a solution of glyphosate biocide and water. Algae, moss and lichens, generally referred to as lower plants, are visible on the internal surfaces of the walls and vault of the tower. A quaternary ammonium salt product is proposed to neutralize these physiologically active organisms on the fabric. The application should be done by means of bandage or clothes soaked in the chemical solution. It is advisable to repeat the application on the internal walls once the conservation project is completed and the internal environmental conditions of the tower are stabilized. This would avoid re-colonization of the internal masonry surface. All chemical products employed for the vegetation removal should comply with the European Biocide Directive 91/414/EEC and the Italian implementing measures in force, if applicable.

The removal of vegetation, both on interior and exterior façades, should be followed by cleaning of the material. Debris should be removed while intact limestone units, bricks and floor tiles should be carefully collected and stored for reuse. Soiling and inactive biological particles resting on the fabric should be removed by applying a solution of pH-neutral detergent and water by means of a soft natural hair brush. This procedure must be coupled with subsequent rinsing of the treated surfaces.

-Injection of cracks. The consolidation of the base of the tower through mortar injection allows to re-gain a monolithic behavior of masonry. Injection is a common consolidation practice whose efficiency is proven by experience and scientific data, and it complies with the principles set in the *Venice Charter* (1964: Art. 10). It is of primary importance that the mortar presents mechanical and physical characteristics compatible with the original material. Injection of the detachment of external façades should be conducted first. The internal connection of detachment with cracks in limestone cornerstones, if present, should be monitored during the injection of the external façades. If mortar runs also inside the cracks in the stone blocks, epoxy application should be substituted with pointing using lime-based mortar with color matching of the matrix of the stone. Otherwise epoxy injection can be applied as described below. It should be noticed that hair cracks, being impermeable, should not be injected. Furthermore direct injection of cracks, for a minimum crack width of 8 mm, should be applied on all visible surfaces.

- *Injection of external leaf detachment*. The East and South façades of Torre Gregoriana require the re-stabilization of cohesion between the external leaf and the wall nucleus, and the filling of voids and cracks (*Figure 26* and *Figure 27*). Previous the operation of injection, the wall should be sealed off by lime-based mortar repointing to prevent leakage of grouting. The injection should be 200 mm deep with *"a diameter of 12 mm, distance 0,5-0,7 m in vertical direction and about 0,5 m in horizontal direction"* (Zagorcheva, 1988). Distances might be adjusted on-site in order to locate inlet holes exactly at joints between masonry units. A staggered pattern of the holes is preferred so to maximize the façade area involved in the intervention. It is recommended for the injection to use a lime-based mortar with no cement content, low content of soluble salts, and very fine aggregate to ensure high fluidity of the material. Furthermore *"for the injection of masonry structures",* the injection normally should *"proceed at pressures lower than 2 bar"* (R. Ferreira, 2009: MSAHC- SA6, Lec8). Cracks in the external leaf of the West façade, being thicker and easily accessible from the exterior, should be injected directly with mortar similar to the one described above. The need for a possible localized application through injecting holes on the West wall should be assessed on-site and carried out as outlined above.
- *Injection of cracks in limestone blocks*. The type of repair here outlined is suited for *"dormant (inactive) cracks no larger than 1 cm wide"* (Public Building Service, Washington D.C., 1998). Cracks in limestone blocks should be cleaned and injected with epoxy-based repair adhesive. Exposed faces of stone around cracks should be appropriately masked and protected against staining from the application. Cracks should be wiped with acetone and dried thoroughly. Epoxy material should present high modulus, low viscosity and moisture insensitivity. It is advisable that *"limestone dust and/or pigment is added to the mix in order to match the color matrix of stones"* (Public Building Service, Washington D.C., 1998). The epoxy adhesive should be used also to glue separated parts of stone blocks.

-Reconstruction of decayed parts and details. The reconstruction of the missing parts of walls, staircase, vault and stone ring of Torre Gregoriana responds to the need of integrating and completing the original structural and historical nature of the building. It should be mentioned that international conservation guidelines allow such operation in case the damages of the structure *"detract from the interesting parts of the building, its traditional setting, the balance of its composition and its relation with its surroundings"* (Venice Charter, 1964: Art.13). However compatibility of materials and technique used should be ensured as *"replacements of missing parts must integrate harmoniously with the whole, but at the same time must be distinguishable from the original so that restoration does not falsify the artistic or historic evidence"* (Venice Charter, 1964: Art.12).

- *Reconstruction of walls.* The top part of the East, South and West elevations and almost half of the North façade of the tower should be rebuilt in order to level with the first floor of Torre Gregoriana (*Figure 26* and *Figure 27)*. The reconstruction of the walls should refer to the cross section characterization outlined in section *3.3.2 Materials.*, Figure 18 and Figure 19. Hand-made brick of compatible size, texture and color should be used for the external leaf of the façades. Angular and rounded local limestone units with diagonal dimensions greater than 25 cm should be employed in the reconstruction of the internal leaf. The rubble wall should be reconstructed by using limestone of heterogeneous size and shape. In this perspective debris available on top of the tower could be re-used. The small part of rubble wall raising from the first floor level, and visible from the East façade of the building (*Figure 27*) should be dismantled till the first floor level and the limestone and brick units should be employed in the reconstruction of the walls. Photographic evidence during the phase of dismantling should be provided in order to produce documentation of the layout and composition of the element, and made available for consultation. The procedure of dismantling is justified by two main reasons. First, the consolidation and waterproofing of this part of rubble wall seems very complex unless an invasive intervention is carried out. Furthermore the rubble wall currently functions as a 'sponge', producing the infiltration of rainwater inside the wall nucleus and consequently technical problems at the lower level. The second reason regards the safety of the use of the building and its surroundings. The state of conservation of this part of rubble wall, in fact, is poor and the probability of stone falling becomes highly probable with time. It should also be noticed that *"dismantling and reassembly"* could be undertaken *"as an optional measure required by the very nature of the materials and structure when conservation by other means is impossible, or harmful"* (Principles for the Analysis, Conservation and Structural Restoration of Architectural Heritage, 2003: Pt 3.17).

  Lime-based mortar with local calcareous and silty soil aggregate should be used for laying the courses of the external and internal leaves, while a lime-based mortar with coarse calcareous and basalt aggregate should be used for the rubble wall. Local limestone should be cut in blocks of similar shape and size to the original using traditional techniques by local artisans in order to rebuilt the South-West corner of the tower and integrate missing parts of the other corners. Pointing mortar as described in the repointing section below should be used to finish the reconstructed sections of the walls. It should be remarked that on the North wall an opening of dimensions similar to those of the aperture on the South façade should be reconstructed. Note that walls have to be reconstructed accordingly with the drainage system outlined in the water-proofing section of this plan.

- *Reconstruction of staircase.* The shaft of the staircase should be reconstructed by using large masonry units covered by a layer of hand-made clay bricks. The mortar should be similar to that described for the reconstruction of the internal leaf of the walls. The existing steps should be repaired or replaced where necessary with compatible material and repointed.
- *Reconstruction of vault.* Previous the reconstruction, the existing vault should be consolidated by injecting the cracks with lime-based mortar with no cement content, low content of soluble salts, and fine aggregate. The consolidation process is intended to avoid further displacement generated by the reconstruction of the vault and the redistribution of stresses. The missing part of the vault to the North side of the tower should be reconstructed by using wooden formwork modeled on-site. The formwork should be propped from the ground. The floor of the base of the tower should be protected against mechanical damage or staining. Loose units and decayed material at the edge of the existing part of the vault should be removed and reused. The shell of the vault, which constitutes a 30 cm deep structural element, should be built with local limestone units. The units should be preferably flat and cuneiform with average length of 20-25 cm. Limestone wedges are also needed to ensure contact between highly irregular stones and filling of voids. A lime-based mortar with sand, basalt and calcareous aggregates should be used. It is important to ensure good interlocking between the original and new part of the vault by means of transversal stone units overlapping for a distance twice the unit size.

  The edge of the void part on the South-West corner of the building should be cleaned and the loose and decayed material should be removed and reused. Consolidation of this part of the vault should be ensured with limestone units and lime-based mortar. The edges of the void should be modeled to a rectangular shape in order to fit a 1,7 x 1,7 m galvanized steel panel. The panel should feature on its left side a hinged trapdoor of 0,8 x 0,8 m dimensions to allow access to the first floor from the base. The panel should be resting on the walls of the tower and the staircase shaft. Moreover its edges should be sealed with impermeable material and a masonry frame 10 cm wide should be put around the panel on the top of the tower. The level of the frame should be about 2 cm higher than the level of the surrounding floor tiles in order to prevent water infiltration into the lower level.

  Once sufficient strength in the structural shell is achieved, infill material should be added on the vault to a level 10 cm below the existing floor tiles. Limestone angular blocks of 25-30 cm diagonal dimension should be employed to fill the volume at the springing of the vault. While approaching the center of the vault, stone units should be flatter and smaller. Angular units of 3-4 cm diagonal dimension embedded in mortar should be used at the center of the vault. Lime-based mortar with 1-2 mm calcareous aggregate and earth should be used. Mortar is intended to be the predominant infill material of the vault. A further 8 cm layer should be placed on top of the infill to finish its irregularities. The layer should be constituted by a mix of lime, 1-2 cm calcareous pebbles and sand. Note that the vault has to be reconstructed accordingly to the drainage system outlined in the water-proofing section of this proposal (*Figure 28*).

- *Reconstruction of stone ring.* The stone ring at the top of the base of Torre Gregoriana constitutes an essential structural element and an architectural detail characteristic of the construction. The reconstruction of a partial section of the ring should be conducted through anastylosis, that is collecting stone elements belonging to the original ring still available on-site (currently visible on the rocks adjacent Torre Gregoriana and in the sea below it) . The rest of the ring should be built with limestone blocks with similar profile to the original. In accordance with the Venice charter article 13, the new elements should present similar length of about 1 m in order to be easily identifiable from the original ones, which present instead variable lengths. It should be noticed that the damage to the original fabric of the tower produced by this intervention is almost inexistent, as the part of walls on which the ring has to be located is also being reconstructed and can be easily designed to accommodate the new structural elements. The existing stone elements on the East side should be repointed with lime-based mortar and the new ones should be placed with lime-based mortar and sand aggregate. The stone replica at the right corner of the South façade and the two at the corners of the North façade should present a 20 x 15 cm cut to allow the drainage of the water collected by the top surface(*Figure 28*).

<u>- Repointing of joints (in preparation for rendering).</u> Repointing is required on all the exposed sides of the tower and in the joints between limestone blocks both at the base or the corners of the building. Old degraded mortar should be raked out at a depth *"twice the thickness of the joint"* (M. Drdácký, 2009: MSAHC-SA6,Lec8), about 3 cm in the case of joints between bricks and 1-1,5 cm for the joints between stone blocks. The use of automated tools must be as limited as possible in order to contain damage to the masonry units. Repointing mortar should be constituted by a mix of lime binder and well graded calcareous aggregate. Where needed repointing should be provided also on the internal leaf of the walls with compatible lime-based mortar.

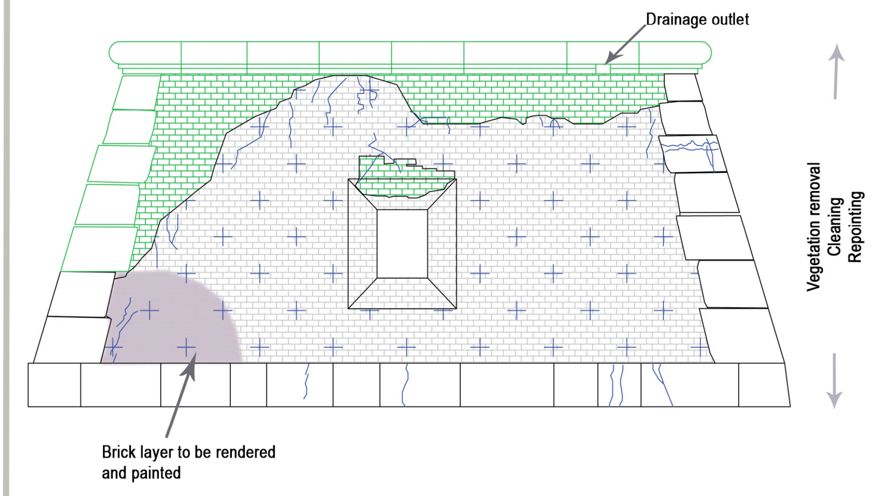
<u>-Water-proofing and drainage.</u> The reconstructed first floor requires a water-proofing and drainage system in order to discharge rainwater collected by the flat roof. A lead valley gutter should be fitted along the perimeter of the first floor, besides the stone ring. The gutter should be 15 cm wide and able

to connect the higher level of the floor tiles with the openings provided in the stone ring. A flexible polymeric water-proofing membrane should be laid on top of the first floor slab. The membrane strips should present an overlapping of about 80 mm and extend inside the valley gutters for at least 3-4 cm. A further 2-3 cm layer of lime-based mortar and sand on top of the membrane should be used to lay the floor tiles. Tiles should be compatible with the existing ones. They should be made in terracotta and treated for exposure to the external environment. Tiles should be also inclined so to direct the water towards the exhaust opening, accordingly to Figure 28.

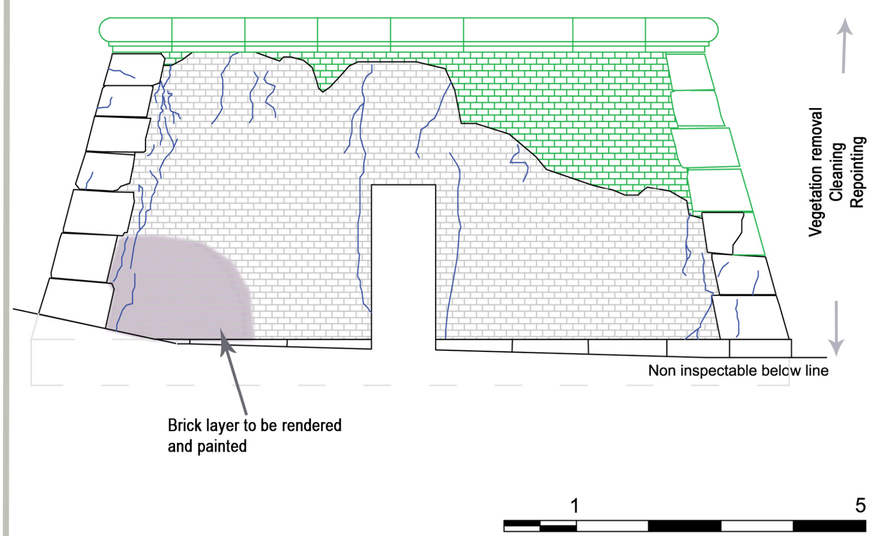
-Plastering and painting. The protection of the external and internal walls is required in order to prevent the degradation of the fabric and to re-instate the authenticity and original appearance of Torre Gregoriana. The external façades should be rendered with a 1-2 cm thick lime-based mortar with fine sand aggregate. The color should match the light-gray residues of original plaster present on the surfaces. As shown in the historical documentation of the tower before the 20th century additions, cornerstones should remain exposed. The rendered façades should be treated with two coatings of silica-based paint. The render on the South and North façades should modeled and inclined to prevent the running of water, coming from the top drainage outlets of the stone ring, into the window openings. The internal walls should be rendered with a lime-based plaster and treated with silica-based paint compatible with the existing plaster. Special care should be taken for the treatment of the internal vault surface. Existing plaster should be consolidated and the existing painted ceiling should be adequately restored and protected. Missing plaster should be replaced and painted as explained above.

The next section analyzes the current costs required for the development of the proposed conservation plan of Torre Gregoriana.

SOUTH ELEVATION



WEST ELEVATION



NOTES

1. PRELIMINARY
-5m high external metal scaffolding to be placed around base.

2.REMOVAL AND CLEANING
-External treatment with glyphosate biocide
-Internal treatment with quaternary ammonium salt biocide.
-Façades to be cleaned with neutral soap solution.
-Debris to be removed and disposed.

3.CONSOLIDATION
-Detachment to be injected, 200mm deep, with lime-based fine aggregate mortar.
-Cracks in masonry, 8mm minimum width, to be injected directly with lime-based mortar.
-Cracks in limestone blocks to be injected with epoxy based adhesive.

4.RECONSTRUCTION
-Walls to be rebuilt in local limestone and hand-made clay bricks.
-Loose material to be removed, selected and reused.

-Staircase to be rebuit in local limestone and internally covered with hand-made clay brick layer.

-Stone ring to be rebuilt with 1m long limestone blocks appropriately modeled.
-Blocks to be laid in lime-based mortar and joints pointed.
-20 x 15cm drainage outlets to be cut as indicated in drawings.

5.REPOINTING
-Joints to be raked out at a depth of 3cm.
-Lime-based mortar with well graded calcareous mortar to be used.

6. WATER-PROOFING
-See drawing 6C.

7.RENDERING AND PAINTING
-Brick layer to be rendered with 1-2cm thick layer of lime-based mortar with fine aggregate.
-Rendering should be provided, where necessary, on the internal walls ond vault.
-Internal and external surfaces to be treated with two coatings of silica-based paint.

Drawing to be read in conjunction with drawings 6B and 6C.

LEGEND

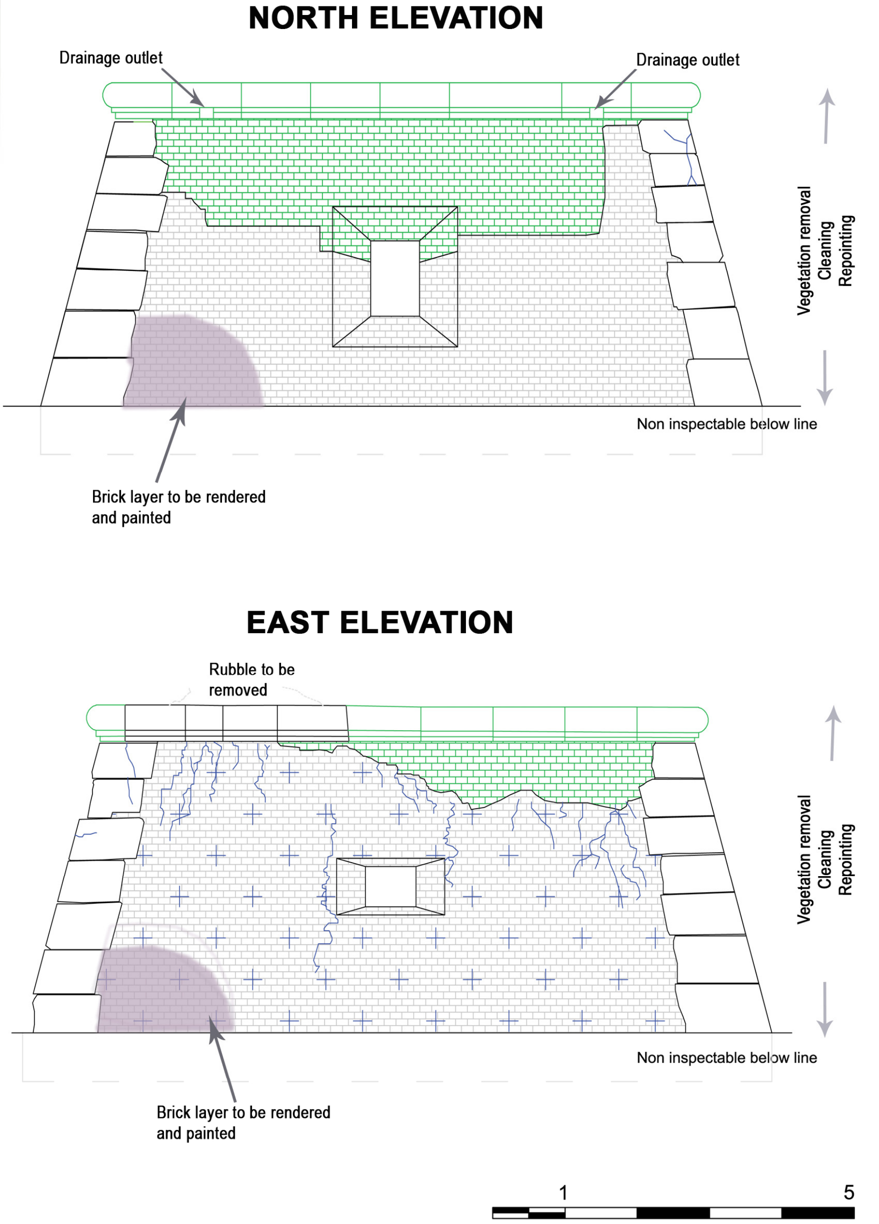
Reconstruction

Injection-Crack

Injection-Detachment

University:	Advanced Masters Sturctural Analysis of Monuments and Historical Constructions		
Project: 'The Guardian of the Pontifical State-Structural Assessment of a Damaged Coastal Watchtower in South Lazio'			
Title:	TORRE GREGORIANA-CONSERVATION PLAN		
Drawn by:	Riccardo Cacciotti		
Remarks:			
Size: A4	Scale:	Drg No: 6A	Date: June '10

Figure 26. Torre Gregoriana- Conservation Plan S-W



NOTES

1. PRELIMINARY
-5m high external metal scaffolding to be placed around base.
-North façade scaffolding to be protected with synthetic safety net.

2.REMOVAL AND CLEANING
-External treatment with glyphosate biocide
-Internal treatment with quaternary ammonium salt biocide.
-Façades to be cleaned with neutral soap solution.
-Debris to be removed and disposed.

3.CONSOLIDATION
-Detachment to be injected, 200mm deep, with lime-based fine aggregate mortar.
-Cracks in masonry, 8mm minimum width, to be injected directly with lime-based mortar.
-Cracks in limestone blocks to be injected with epoxy based adhesive.

4.RECONSTRUCTION
-Walls to be rebuilt in local limestone and hand-made clay bricks.
-Loose material to be removed, selected and reused.

-Staircase to be rebuit in local limestone and internally covered with hand-made clay brick layer.

-Stone ring to be rebuilt with 1m long limestone blocks appropriately modeled.
-Blocks to be laid in lime-based mortar and joints pointed.
-20 x 15cm drainage outlets to be cut as indicated in drawings.

5.REPOINTING
-Joints to be raked out at a depth of 3cm.
-Lime-based mortar with well graded calcareous mortar to be used.

6.WATER-PROOFING
-See drawing 6C.

7.RENDERING AND PAINTING
-Brick layer to be rendered with 1-2cm thick layer of lime-based mortar with fine aggregate.
-Rendering should be provided, where necessary, on the internal walls ond vault.
-Internal and external surfaces to be treated with two coatings of silica-based paint.

Drawing to be read in conjunction with drawings 6A and 6C.

LEGEND

Reconstruction

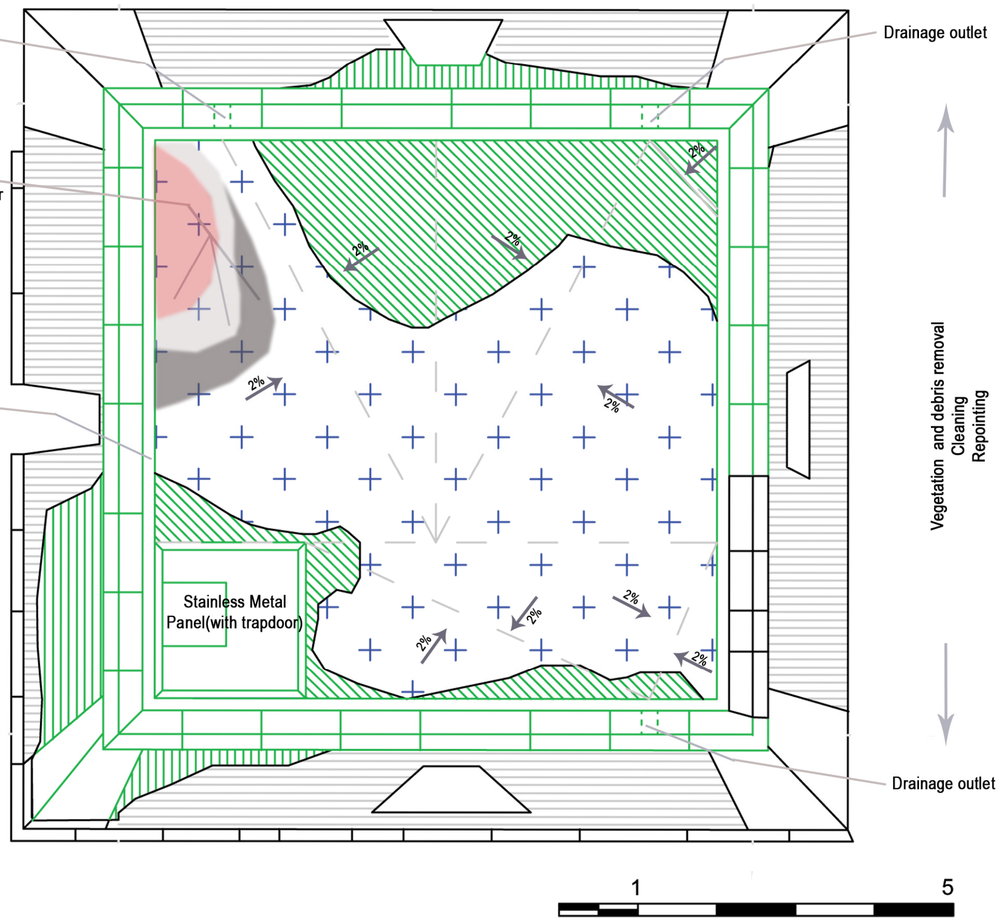
Injection-Crack

Injection-Detachment

University:	Advanced Masters Sturctural Analysis of Monuments and Historical Constructions
Project: 'The Guardian of the Pontifical State-Structural Assessment of a Damaged Coastal Watchtower in South Lazio'	
Title:	TORRE GREGORIANA-CONSERVATION PLAN
Drawn by:	Riccardo Cacciotti
Remarks:	
Size: A4	Scale:
Drg No: 6B	Date: June '10

Figure 27. Torre Gregoriana- Conservation Plan N-E

PLAN



NOTES

1. PRELIMINARY
-5m high external metal scaffolding to be placed around base.

2.REMOVAL AND CLEANING
-External treatment with glyphosate biocide.
-Internal treatment with quaternary ammonium salt biocide.
-Debris to be removed and disposed.

3.CONSOLIDATION
-Detachment to be injected with lime-based fine aggregate mortar.

4.RECONSTRUCTION
-For vault wooden formwork should be used and propped with wooden piles.
-Loose material should be removed, selected and reused.
-Vault to be built in local limestone and lime-based mortar.
-1,7 x 1,7m galvanised steel panel to be placed in SW corner with a 0,8 x 0,8m aluminium trap door with handle

-Stone ring to be rebuilt with 1m long limestone blocks appropriately modeled.
-Blocks to be laid in lime-based mortar and joints pointed.
-20 x 15cm drainage outlets to be cut as indicated in drawings.

6.WATER_PROOFING
-3mm polymer bitumen membrane to be used.
-Lead flashing to be used in valley gutters and drainage outlets.
-25 x 25cm terracotta tiles should be used and laid on a 1-2cm layer of lime-based mortar.
-Floor should be inclinated as shown on the drawing. Adjustments should be made onsite
-Stainess steel channel shaped outlets to be used at openings in stone ring.

Drawing to be read in conjunction with drawings 6A and 6B.

LEGEND

Reconstruction

Injection-Crack

Injection-Detachment

University:	Advanced Masters Sturctural Analysis of Monuments and Historical Constructions		
Project: 'The Guardian of the Pontifical State-Structural Assessment of a Damaged Coastal Watchtower in South Lazio'			
Title:	TORRE GREGORIANA-CONSERVATION PLAN		
Drawn by:	Riccardo Cacciotti		
Remarks:			
Size: A4	Scale:	Drg No: 6C	Date: June '10

Figure 28. Torre Gregoriana- Conservation Plan Plan

4.3 Cost Analysis and Conservation Plan Estimation.

This section outlines the different categories of works necessary for the development of the conservation plan proposed. The cost analysis is based on the *'Price Book 2007- Part A (Construction Works)'*, published by the *Office of Public Works* of the Region of Lazio. These categories include preliminary works, removal and cleaning, consolidation, reconstruction, repointing, water-proofing, rendering and painting. The costs take into account the materials, equipment and labor necessary for each category, and can be summarized as follows:

1.PRELIMINARY

1.1. *External tubular metal scaffolding*, framed system suitable for heights up to 20 m, including assembly and disassembly, transport, wooden planks, double parapet, protection, anchorages and any other element necessary for providing full functionality:

- for first 30 days m^2 € 12,91
- for each month after above m^2 € 1,91

1.2. *Synthetic-fiber safety net on North façade (road side),* reinforced, for protecting exposed scaffolding, including renting of material for the whole duration of works, disassembly and collection at end of the works. m^2 € 2,32

2.REMOVAL AND CLEANING

2.1. *Removal of first floor paving and debris,* conducted using adequate tools and including mortar removal and cleaning, the selection and storing of reusable materials, excluding the lowering of material to ground level:

- terracotta tiles m^2 € 10,33

2.2. *Pulling or lowering of materials,* by means of mechanical lift if authorized by the project, including the price of loading and unloading:

- volumetric valuation m^3 € 20,66

2.3. *Transport of materials by wheel-barrel,* of different nature and consistency, within the site boundaries, including loading and unloading:

- for a distance up to 50 m m^3 € 24,27

2.4. *Glyphosate biocide application* on external façades and horizontal surfaces, it includes application and removal of vegetation and clearing off-site. m^2 € 5,33

2.5. *Quaternary ammonium salt biocide application* of internal vertical surfaces and vault, it includes application. m^2 € 12,66

2.6. *Cleaning with neutral soap solution,* of façades and surfaces made of rendering, concrete, bricks, tuff, stone and ceramic. It includes protection of elements from staining, application with soft natural hair brush and rinsing of treated areas with pressurized water. The price includes the disposal of residues after treatment, protection and safety measures for laborers. No scaffolding. m^2 € 10,33

3.CONSOLIDATION

3.1.*Detachment of East and South elevations*

3.1.1. *Consolidation of three-leaf walls,* with perforation and injection of mortar, including preparation of masonry area to be treated, realization of injection pattern and holes by electric drill, fixing of injection inlets in the cavities, injection with lime-based mortar, removal of injection inlets, repointing of holes, cleaning and removal of debris:

- for drilling depth up to 0, 50 m average thickness m^2 € 69,10

3.2.*Cracks on West elevation and internal vault*

3.2.1. *Repair of cracks on vertical masonry surfaces and vaults*, of any type shape and thickness, conducted through removal of loosen parts, cleaning with high-pressure water. It includes injection with lime-based mortar of cracks 8 mm minimum width, the removal and transport of material and renting of necessary tools for the application.

For vertical surfaces:

- one side of wall only m^2 € 40,75

For vaults:

- intrados m^2 € 58,23

3.3.*Cracks in limestone cornerstones*

3.3.1. *Injection with epoxy-based repair adhesive,* perforation, filling and gluing of cracks including pre-treatment of surfaces and protection of the element from staining, injection with epoxy adhesive, rental of necessary equipment and cleaning after treatment:

- medium size cracks m € 133,76

4.RECONSTRUCTION

4.1.*Walls*

4.1.1. *Demolition of masonry structure* on top the East façade and where else necessary, of any type, shape and thickness including rendering, bricks and stone layers. The price includes the execution of works, application of safety measures, lowering of material and transport within the site boundaries and storage of reusable material:

- local stone masonry with brick layer m^3 € 91,35

4.1.2. *Masonry works* of any type, shape and thickness, composed by calcareous stones or of different sizes and lime-based mortar with local aggregate. It includes equipment necessary and application of safety measures:

- with reused stone, including selection of units m^3 € 166,85
- with provision of new local stone units m^3 € 200,25

4.1.3. *Masonry works for exposed brick façades*, executed with solid bricks and lime-based mortar including cleaning and pointing of joints and any other necessary action for completing the works :

- hand-made clay bricks (25 x 15 x 4 cm) m^2 € 152,05

4.2.*Staircase*

4.2.1. *Stone masonry works* of any type, shape and thickness, composed by calcareous stones of different sizes and lime-based mortar with local aggregate. It includes equipment necessary and application of safety measures:

- with provision of new local stone units m^3 € 200,25

4.2.2. *Brick masonry works,* executed with solid bricks and lime-based mortar including cleaning and pointing of joints and any other necessary action for completing the works:

- hand-made clay bricks (25 x 15 x 4 cm) m^2 € 152,05

4.3.Vault

4.3.1. *Demolition of masonry structure*, of any type, shape and thickness including rendering, coatings, bricks and stone. The price includes the execution of works, application of safety measures, lowering of material and transport within the site boundaries and storage of reusable material:

- local stone masonry m^3 € 91,35

4.3.2. *Rental of provisional propping,* and wooden elements necessary, including equipment and additional material for assembly, maintenance, disassembly and collection at the end of the works.

m^3 € 264,94

4.3.3. *Formwork for vault,* including wooden centering for arches or vaults in concrete or masonry, assembly, disassembly and collection after works:

- for span between 5 m and 10 m m^2 € 118,76

4.3.4. *Masonry works* of any type, shape and thickness, composed by calcareous stones or of different sizes and lime-based mortar with local aggregate. It includes equipment necessary and application of safety measures:

- with reused stone, including selection of units m^3 € 166,85
- with provision of new local stone units m^3 € 200,25

4.3.5. *Stone frame around opening*, with natural stone slabs with a thickness of 2 cm and length greater than 18 cm. It includes smoothening of exposed surfaces and corners, laying with lime-based mortar, pointing and sealing of joints:

- limestone m^2 € 72,30

4.3.6. *Steel panel* of any thickness and dimension, including laying and masonry works necessary for fitting on-site:

- steel Fe430B kg € 2,76

4.3.7. *Galvanization of steel elements* with protection treatment against corrosion through immersion in liquid zinc at 450 °C accordingly to the norm UNI-E-10147. kg € 0,72

4.3.8 . *Trap-door* in anodized aluminum, accordingly to the norms UNI EN:

One-side hinged trap door provided with handle:

- 0,70x1,30 m (0,91 m^2) each € 279,92

4.3.9. *Lime layer* composed by a mix of lime and calcareous aggregate to be employed as leveling layer below water-proofing and paving:

- 20 mm thick m^2 € 6,20
- for every 10 mm thickness exceeding the above m^2 € 2,07

4.4.*Stone ring*

4.4.1. *Limestone blocks,* with simple profiles and smoothed surface, for exposed blocks exceeding 10 cm of thickness. It includes the necessary masonry works, laying in lime-based mortar and pointing:

- limestone m^3 € 1.001,93

4.4.2. *Additional works for profiling the blocks,* semicircular finishing of variable thickness between 30 and 50 mm:

- for marble and limestone m € 34,86

4.4.3. *Mechanical cutting of drainage outlets in blocks:*

- hard stone each € 1,45

5.REPOINTING

5.1. *Additional works for exposed masonry wall,* including raking out of degraded mortar and lime-based mortar repointing of joints on surfaces. It excludes scaffolding:

- for raking out and repointing m^2 € 7,98

6.WATER-PROOFING

6.1. *Lead flashing* of any thickness, including welding, modeling, cutting, transport and laying of material:

- for valley gutters and drainage outlets kg € 6,58

6.2. *Adhesive primer of oxidized bitumen*, additives and solvents with 50% dry residue and viscosity FORD no. 4 at 25 °C of 20+25 sec.:

- 300 gr/m^2 m^2 € 1,03

6.3. *Impermeable layer* composed by impermeable membrane of elasto-plastic polymer bitumen and reinforced with polyester net. It includes application and laying of the membrane and additional equipment and works necessary:

- 3 mm thick m^2 € 7,75

6.4. *Terracotta tiles,* dimensions 25 x 25 cm or 30 x 30 cm, including laying of 1-2 cm lime-based layer, inclination of plan, cutting, pointing and finishing of joints. m^2 € 34,09

7.RENDERING AND PAINTING

7.1. *Plastering* of external and internal surfaces includes application, shaping and leveling with appropriate tools and any additional works needed for the completion of the intervention:
- with lime-based mortar and sand m^2 € 20,81

7.2. *Treatment with mineral paint* with silica-based paint, including two applications, excluding the scaffolding and preparation of the surfaces. m^2 € 9,30

The estimation of the cost for the proposed conservation plan of Torre Gregoriana is presented in Table 3 below. The total expenses according to the latest price update for the region of Lazio are estimated to be € 51,400 (plus VAT).

Concluding, the assessment of the structural conditions of the tower, together with the observance of internationally recognized conservation principles, allow to develop a specific plan subdivided into seven categories of necessary works. This specific plan, focused on the preservation of the original fabric, the minimum intervention and the exhaltation of tangible and intangible values of the structure, is required in order to win, as the title of this chapter underlines, a 'battle against degradation', the last battle of the 'guardian', and to return to Torre Gregoriana the dignity of its historical and cultural role.

The next chapter sets the debate regarding post-war reconstruction in the context of the case study. The legislative framework at international, national and local level, regarding this subject is presented, together with European and regional examples of reconstruction of historic structures. Using these assumptions as a starting point, the intent is to provide technical support for the reconstruction of the full original structure of Torre Gregoriana together with the outline of the new possible structural characteristics and their response to seismic action.

Intervention	Element	Description	Unit	Cost per unit(€)	Quantity	Cost (€)
1.PRELIMINARY	Whole structure	*1.1.External tubular metal scaffolding + (2x 1.91)*	m^2	16,73	208	3479,84
	North façade	*1.2. Synthetic-fiber safety net*	m^2	2,32	52	120,64
2.REMOVAL AND CLEANING	Top of structure	*2.1. Removal of first floor paving and debris*	m^2	10,33	34,04	351,63
		2.2. Pulling or lowering of materials	m^3	20,66	3,4	70,24
		2.3. Transport of materials by wheel-barrel	m^3	24,27	3,4	82,52
	Outside	*2.4. Glyphosate biocide application*	m^2	7,33	138,84	1017,70
	Inside	*2.5. Quaternary ammonium salt biocide application*	m^2	8,66	64,81	561,25
	Outside	*2.6. Cleaning with neutral soap solution*	m^2	10,33	138,84	1434,22
3.CONSOLIDATION	3.1.Detachment of East and South elevations	*3.1.1. Consolidation of three-leaf walls*	m^2	69,1	45,26	3127,47
	3.2.Cracks on West elevation and internal vault	*3.2.1. Repair of cracks on vertical masonry surfaces and vaults*				
		- one side of wall only	m^2	40,75	21,96	894,87
		- intrados	m^2	58,23	23,36	1360,25
	3.3.Cracks in limestone cornerstones	*3.3.1. Injection with epoxy-based repair adhesive*	m	133,76	7	936,32
4.RECONSTRUCTION	4.1.Walls	*4.1.1. Demolition of masonry structure*	m^3	91,35	4,72	431,17
		4.1.2. Masonry works				
		- with reused stone, including selection of units	m^3	166,85	2	333,70
		- with provision of new local stone units	m^3	200,25	33,08	6624,27
		4.1.3. Masonry works for exposed brick façades	m^2	152,05	21,25	3231,06
	4.2.Staircase	*4.2.1. Masonry works*	m^3	200,25	3,26	652,82
		4.2.2. Masonry works with bricks	m^2	152,05	8,128	1235,86
	4.3.Vault	*4.3.1. Demolition of masonry structure*	m^3	91,35	4,73	432,09
		4.3.2. Rental of provisional propping	m^3	264,94	1,5	397,41
		4.3.3. Formwork for vault	m^2	118,76	25,69	3050,94
		4.3.4. Masonry works				
		- with reused stone, including selection of units	m^3	166,85	2	333,70
		- with provision of new local stone units	m^3	200,25	9,59	1920,40
		4.3.5. Stone frame around opening	m^2	72,3	0,76	54,95
		4.3.6. Steel panel	kg	2,76	176,85	488,11
		4.3.7. Galvanization of steel elements	kg	0,72	176,85	127,33
		4.3.8 . Trap-door	each	279,92	1	279,92
		4.3.9. Lime layer				
		- 20 mm thick	m^2	6,2	50,27	311,67
		- for every 10 mm thickness exceeding the above	m^2	2,07	301,62	624,35
	4.4.Stone ring	*4.4.1. Limestone blocks*	m^3	1.001,93	6	6011,58
		4.4.2. Additional works for profiling the blocks	m	34,86	30	1045,80
		4.4.3. Mechanical cutting of drainage outlets	each	1,45	3	4,35
5.REPOINTING	Interior and exterior	*5.1. Additional works for exposed masonry wall*	m^2	7,98	210	1675,80
6.WATER-PROOFING	First floor level	*6.1. Lead flashing*	kg	6,58	213,12	1402,33
		6.2. Adhesive primer of oxidized bitumen	m^2	1,03	50,27	51,78
		6.3. Impermeable layer	m^2	7,75	51,84	401,76
		6.4. Terracotta tiles	m^2	34,09	51	1738,59
7.RENDERING AND PAINTING	Interior and exterior	*7.1. Plastering*	m^2	20,81	169,61	3529,58
		7.2. Treatment with mineral paint	m^2	9,3	169,61	1577,37
					TOTAL ESTIMATED COST (€)	**51405,65**

Table 3. Estimation of Cost for the Conservation Plan of Torre Gregoriana

V. HEALING THE WOUNDS

STRUCTURAL ANALYSIS FOR RECONSTRUCTION

5.1 The Challenges of Fast-Destruction.

The term reconstruction implicitly recalls a lengthy and controversial struggle made of discordant theories and multiple approaches to interventions on historic buildings. Reconstructing is mainly intended as the re-creation of vanished or non surviving parts of heritage for interpretative purposes. This process allows, in fact, to re-gain a physical form to an otherwise abstract entity surviving mainly in reminiscence and memories of the people. The importance to ensure the legibility and expression of a building should be considered essential for the own survival of cultural heritage. However the challenges set by fast-destruction impose a contrast between the need for re creating the legibility and expression, and the historical value of the footprint left by the man-made or natural destruction directly on the structural fabric.

In this perspective it is appropriate to mention, only briefly, two relevant case studies: one in Europe and another in South Lazio(*Figure 29*).

Figure 29. Reconstruction of Mostar Bridge and Torre Cervia

The first example concerns the reconstruction of the Mostar bridge, destroyed during the conflict of the 1990s. The structure used to express the social, cultural and economic relationships of a precise point in space and time. The physical destruction of the Mostar bridge represented, in the context of a period of nationalism and racism, the final step towards a total disintegration of the social and cultural fabric. Its reconstruction signifies therefore a strongly symbolical measure, exalting the end of the conflict and the opening of a new era of reconciliation. The importance of the symbols in the communicational process between the observer/user and the structure becomes, therefore, clear in the case of the Mostar bridge. The second interesting case concerns the reconstruction of Torre Cervia, already mentioned in the previous chapters, in the Circeo promontory. The tower, destroyed during a conflict in the early 19th century, was reconstructed in the 1970s. Although the technical details used for the reconstruction might have a questionable conservation worth, it is undeniable the value that the re creation of the construction gave to the functionality of the tower (even if for private use). As stated in the 'Declaration of Dresden' *"the destruction of a monument frequently results in completely new objectives for social use and their understanding after its reconstruction being established. This may range from the efforts to find a use of great public significance to residential use"*(Declaration of Dresden, 1982). Therefore the two fundamental characteristics necessary for an effective reconstruction should definitely regard communication and functionality.

In this context the case of Torre Gregoriana should be discussed. From the literature available, the reconstruction of the tower is presented as a way of restoring the original message expressed by the building. Corbo, in her description of Torre Gregoriana, highlights *"the existence of iconographic and historical documentation that allows the ideal reconstruction of the lost monument, which is an interesting expression of that military architecture adopted in the Pontifical State at the end of the 16th century for defending the cost of Southern Lazio"* (A.M. Corbo 1989:11). Apollonj Ghetti adds that the watchtowers are characteristic monuments *"of noticeable antiquity, to which are related the memories, mostly painful, of our sea history. It is therefore licit to deplore that it has not been provided yet the reconstruction of the coastal watchtowers destroyed during the last conflict"*(F.M. Apollonj Ghetti, 1982:32).

The objective of this chapter is to provide technical details for *'healing the wounds'* suffered by the tower during the last war. Such wounds affect not only the cultural value of local heritage, but also the social system which lost a physical mean for connecting to the temporal dimension of the local reality.

5.2 Technical Requirements: Geometry, Materials and Safety.

The reconstruction of the body of Torre Gregoriana should comply with a series of geometrical characteristics, satisfying minimum thickness, height and length for the new walls, together with the applicable material and safety requirements . It is here assumed that the thickness and materials used in the original walls should not be replicated. The objective is to find a reasonable small thickness compatible with new masonry in order to improve feasibility and cost effectiveness. The effective thickness of the walls for unreinforced masonry with any type of units (other than natural stone) should be 240 mm minimum; the ratio of the effective wall height to its effective thickness should not exceed 12; the ratio of the length of the wall to the greater clear height may not be less than 0,4 (Table 9.2, EN 1998-1:2004). The walls are assumed to be restrained at the top and bottom by timber floors or roofs spanning from both sides at the same level or by a timber floor spanning from one side having a bearing of at least 2/3 the thickness of the wall but not less than 85 mm. The reduction factor for the calculation of the effective height ρ_n, may be considered equal to 1 (EN 1996-1-1:2004).

Table 4 below shows the actual values of the ratios of the body of the tower to be reconstructed, in relation to the design thickness of walls that may be adopted. It emerges clearly that for a thickness less than 0,5 m these ratios do not satisfy the minimum requirements outlined above.

Thickness *(m)*	h_{eff1}/b	h_{eff2}/b	l/h_{eff1}	l/h_{eff2}
1	5,2	5,7	1,2	1,1
0,75	6,9	7,6	1,3	1,1
0,5	10,4	11,4	1,3	1,2
0,25	20,8	22,8	1,4	1,3

NOTE:
h_{eff1} = 5,2 m
h_{eff2} = 5,7 m

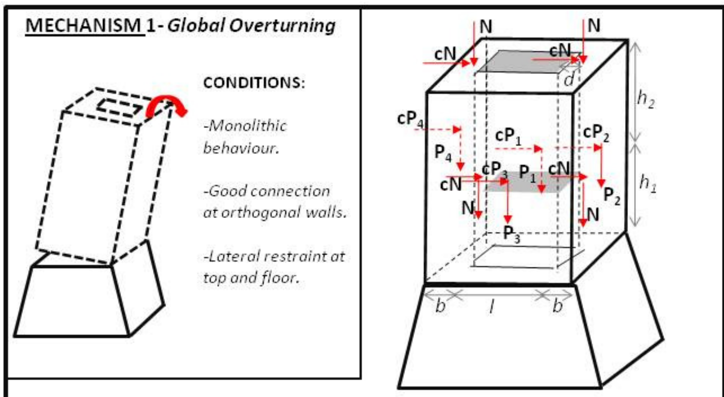
Below Geometrical Requirements

Table 4. Actual Geometrical Ratios

Further technical requirements might be introduced by a kinematic analysis of the failure mechanisms expected for the structure of the tower. Different models were analyzed; however only the most severe is presented here while the rest are shown in annex A.

Considering the lateral restraint in both directions at the floor and roof level, and the provision of good connection between orthogonal walls, a monolithic behavior of the body may be assumed. The relevant kinematic mechanism analyzed considers therefore a global overturning of the body of the tower (*Figure 30*).

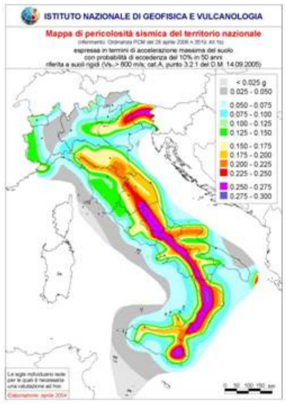
The values of the multiplier of the horizontal action α_0 (percentage of the weight applied horizontally),necessary for activating overturning, are expressed in terms of the possible thicknesses of the walls in order to assist for an adequate choice of a safe minimum. The values obtained range between 0,687 (for 1 m thickness) and 0,653 (for 0,25 m thickness). The site, according to the seismic hazard categorization *(Regional Act DGR 387/09 and DGR 835/09)*, is located in the seismic zone 3, subzone B. The maximum ground acceleration with a exceeding probability of 10 percent in 50 years (referred to rigid ground) is $0,062 < a_g < 0,1$ as shown in the seismic hazard map in Figure 30.(OPCM 3519/06).



$$\alpha_0 = \frac{0.5P_2 b + (P_1 + P_3)(b + 0.5l) + P_4(1.5b + l) + 2N(b - d) + 2N(b + l + d)}{(P_1 + P_2 + P_3 + P_4)\left(\frac{h_1 + h_2}{2}\right) + 2N(h_1 + h_2) + 2Nh_1}$$

α_0 *(g)*	b *(m)*	h_1 *(m)*	h_2 *(m)*	l *(m)*	d *(m)*
0,687	1	5,5	6	6	0,5
0,682	0,75	5,5	6	6,5	0,375
0,674	0,5	5,5	6	7	0,25
0,653	0,25	5,5	6	7,5	0,125

NOTES



SeismicClassification Terracina
(Regional Act DGR 387/09 and DGR 835/09)

- *ZONE*: 3 ($0.050 < a_g < 0.150$)
- *SUBZONE*: B ($0.062 < a_g < 0.1$)

Figure 30. Kinematic Mechanism- Global Overturning

The gap between the ranges of acceleration required for the activation of the mechanism and the actual expected acceleration is consistent and ensures the safety of the building (*Figure 31*). This gap is due to the participation of the whole mass of the body in the mechanism which produces a stabilizing moment as high as 65 percent of the overturning one. The graph shows the relationship between the activating acceleration and the wall thickness. Although all sizes are safe with respect to the kinematic mechanism analyzed and the influence of the thickness in the results is very moderate, thicknesses less than 400 mm should not be considered. This is calculated to be the lower limit complying with the geometrical requirements previously outlined. It should be noticed that thickness of the wall is constrained by the possible arrangements of 25 x 12,5 cm bricks, which make it possible to obtain many different thicknesses. The thickness of the walls of the body of Torre Gregoriana is selected to be about 500 mm, excluding width of mortar joints.

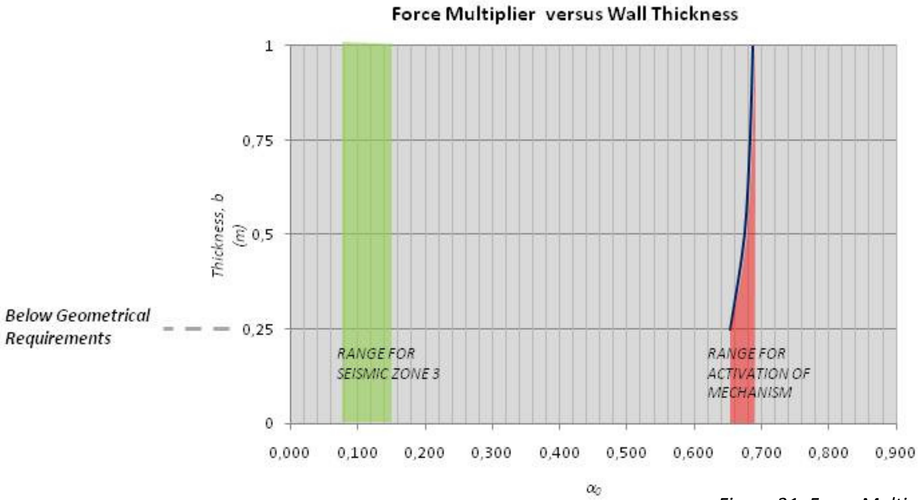


Figure 31. Force Multiplier versus Wall Thickness

Further technical requirements concern the materials involved in the structural analysis of the tower. The mechanical parameters should be determined in accordance with table 11D.1, attachment 2, OPCM 3274 (see Table 5 below). The values for the masonry at the base should be taken as the lowest of the range and corrected by the knowledge level of the inspection and the typology of consolidation carried out. The level of knowledge for the building is 1, as limited in-situ testing is available and consequently the knowledge factor to be used is 1,35 for all types of structural analysis (T.11.5.1, OPCM 3274). In addition, assuming that consolidation by mortar injection as per chapter 4, paragraph 2, is applied to the base, the average compression resistance of the material may be multiplied by 2. The new part of the tower should be reconstructed using solid bricks and mortar. The parameters to be used should take into account the highest values of the range presented in the table below.

	Tipologia di muratura	f_m (N/cm^2) min-max	τ_0 (N/cm^2) min-max	E (N/mm^2) min-max	G (N/mm^2) min-max	w (kN/m^3)
Base Masonry	Muratura in pietrame disordinata (ciottoli, pietre erratiche e irregolari)	60 90	2,0 3,2	690 1050	115 175	19
	Muratura a conci sbozzati, con paramento di limitato spessore e nucleo interno	110 155	3,5 5,1	1020 1440	170 240	20
	Muratura in pietre a spacco con buona tessitura	150 200	5,6 7,4	1500 1980	250 330	21
	Muratura a conci di pietra tenera (tufo, calcarenite, ecc.)	80 120	2,8 4,2	900 1260	150 210	16
	Muratura a blocchi lapidei squadrati	300 400	7,8 9,8	2340 2820	390 470	22
Body Masonry	Muratura in mattoni pieni e malta di calce	180 280	6,0 9,2	1800 2400	300 400	18
	Muratura in mattoni semipieni con malta cementizia (es.: doppio UNI)	380 500	24 32	2800 3600	560 720	15
	Muratura in blocchi laterizi forati (perc. foratura < 45%)	460 600	30,0 40,0	3400 4400	680 880	12
	Muratura in blocchi laterizi forati, con giunti verticali a secco (perc. foratura < 45%)	300 400	10,0 13,0	2580 3300	430 550	11
	Muratura in blocchi di calcestruzzo (perc. foratura tra 45% e 65%)	150 200	9,5 12,5	2200 2800	440 560	12
	Muratura in blocchi di calcestruzzo semipieni	300 440	18,0 24,0	2700 3500	540 700	14

Table 5. Mechanical Parameters of Materials

5.3 Structural analysis.

The structural analysis of Torre Gregoriana aims at understanding the behavior of the reconstructed part of the building and its interaction with the existing base of the tower, in the context of the latest seismic and building codes. More specifically the analysis is intended to obtain the necessary design parameters, and the safety assessment of the structure under earthquake prone conditions. The analysis outlined in this section includes a modal dynamic analysis (mode superposition) and a non-linear static analysis (pushover). For both analyses a FEM has been used (*Figure 32*). 3D solid elements with 4 nodes have been selected for modeling the masonry of the base and body of the tower. Shell elements were instead selected for the modeling of the second floor and the flat roof at the top of the tower. The total number of nodes is 4747 while the elements are 18302 (Element group 1: 10155 3D solid elements; Element group 2: 221 shell elements. Element group 3: 7926 3D solid elements). The finite element model is modeled and processed through the software ADINA v. 8.5.0.

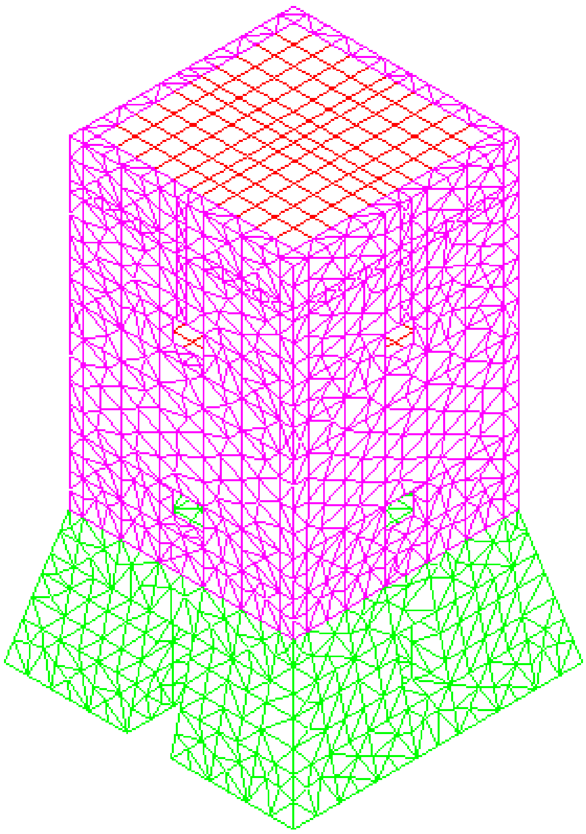


Figure 32. Finite Element Model in ADINA

5.3.1 Modal Superposition.

The modal analysis related to the design response spectrum constitutes a widespread approach for the determination of the design solicitations of a structure. As described in OPCM 3274 paragraph 4.5.3, the modal superposition analysis should consider all the modes for a total accumulated participating mass 85 percent of the total mass of the structure. Seventy modes are calculated for Torre Gregoriana and their participating mass is plotted against the number of modes (*Figure 33*).

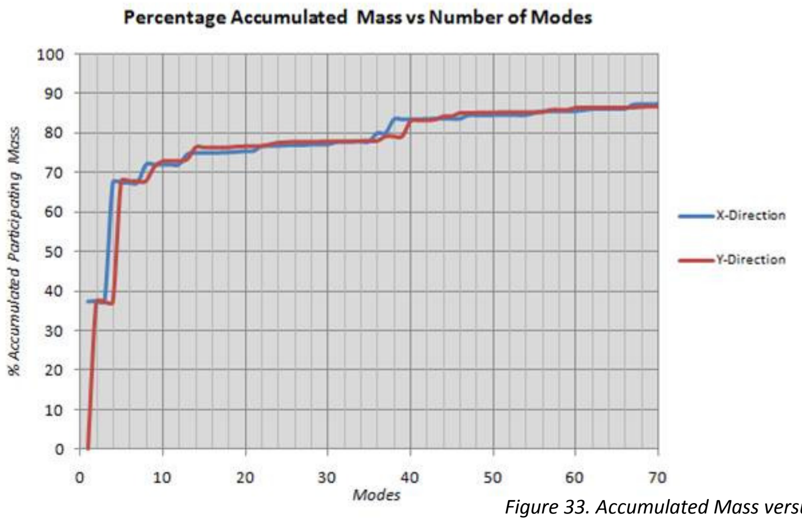


Figure 33. Accumulated Mass versus Number of Modes

As shown above, 55 modes are required in order to reach the minimum percentage required in both X and Y directions, which might seem excessive. However, of these 55 modes only few present a significant response impact and should be discussed. It should be mentioned, in fact, that the accumulated participating mass after only 4 modes reaches about 70 percent of the total. The remaining 51 modes contribute, in highly different proportion, to increase the accumulated participating mass by only 15 percent. The stepped pattern of the curves in Figure 33 identifies the most important and significant modes in terms of the response of the tower. The raise of each step is proportional to the participation of the mode. For participation factor is intended the ratio between the mass times modal shape, and the modal mass for each mode. In the X direction mode 1 (participation factor 56,3) constitutes the most determinant one together with mode 4 (-50,3). Modes 8, 13 and 38 (respectively -19,49, 14,78 and 17,7 participation factor) are much less important than the first two but their contribution to the 85 percent minimum is considerable if compared to the rest of all the modes. Similarly, in the Y direction, mode 2 and 5 (participation factor -56,1 and 50,8) accumulate a participating mass of about 70 percent of the total; modes 9, 14 and 40 (participation factor 17,4, -15,9 and 17,9) contribute to increase by 15 percent the total accumulated mass.

Examples of modal shapes for the X direction are presented in Figure 34 which represent the modes that govern the superposition response of the structure.

Modes

MODE	f (Hz)	MODE	f (Hz)
1	1,61	29	12,02
2	1,62	30	12,14
3	2,81	31	12,59
4	4,50	32	12,61
5	4,54	33	12,83
6	4,98	34	13,15
7	6,91	35	13,47
8	6,97	36	13,72
9	7,00	37	13,82
10	7,18	38	14,37
11	7,40	39	14,61
12	7,68	40	14,66
13	8,17	41	14,83
14	8,18	42	14,92
15	8,70	43	15,08
16	9,43	44	15,11
17	9,72	45	15,22
18	10,06	46	15,28
19	10,18	47	15,71
20	10,19	48	15,88
21	10,36	49	16,31
22	10,41	50	16,45
23	10,65	51	16,97
24	11,14	52	17,03
25	11,14	53	17,11
26	11,32	54	17,17
27	11,73	55	17,35
28	11,89		

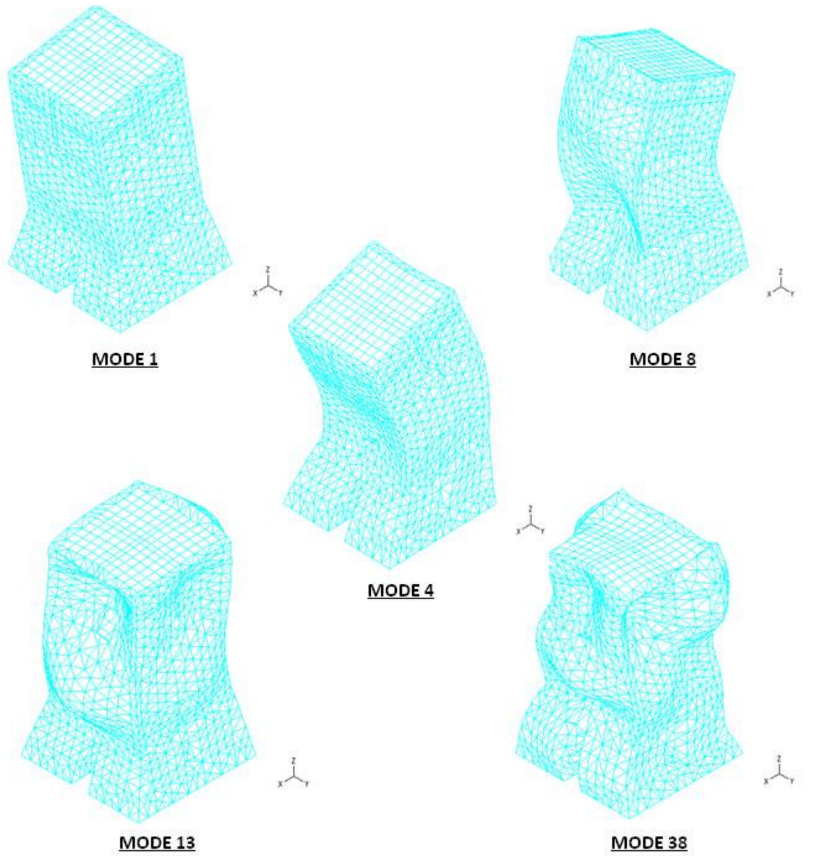


Figure 34. Governing Modal Shapes

For lower frequencies the structure swings mobilizing a conspicuous part of its mass about its vertical axis. Mode 1 presents a frequency of 1,61 Hz with a period of 0,62 s. The structure bends around the plane of contact between the body and the base. Mode 4 has a frequency of 4,5 Hz and a period of 0,22 s. The body of the tower is subjected to unidirectional bending and inversion of curvature. At the maximum deformation about the vertical axis the top of the tower and the second floor displace to opposite directions. For higher frequencies the deformation is more articulated. Mode 8 shows a frequency of 6,97 Hz and period of 0,14 s. The sides perpendicular to the deformation of the structure bend in two directions. Mode 13 has a frequency of 8,17 Hz and a period of 0,12 s. The deformed shape presents bending in two directions on all four sides of the tower. Mode 38 has a frequency of 14,37 Hz and a period of 0,07 s. The deformation occurs on all sides of the building with a number of deflection points at different height of the structure. Before proceeding to the superposition of the modes, the design response spectrum needs to be determined for the case of Torre Gregoriana.

The design response spectrum employed in the analysis is shown in Figure 35. The following parameters are considered: maximum horizontal ground acceleration a_g= 0,15g (Par. 3.2.1, OPCM 3274), soil factor S= 1, periods of separation between the different branches of the spectrum T_B= 0,15; T_C= 0,40 and T_D= 2 (T. 3.1, OPCM 3274).The design spectrum applied to the structure analyzed is reduced by a behavior factor q= 2, which is the average of the typical range for unreinforced masonry (T. 9.1, EN 1998-1:2004). The use of an 'over-strength ratio', as given in the Italian code, is not applicable because of the lack of redundancy of the structure. The dampness factor for the masonry structure is considered to be 5 percent.

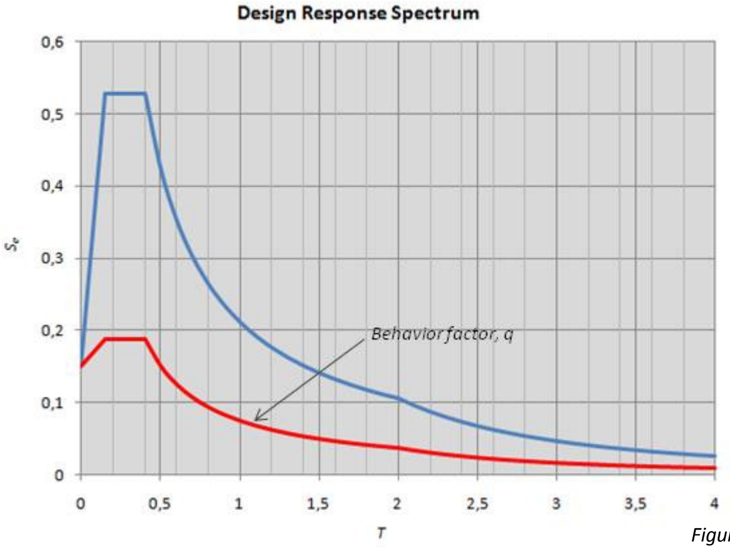


Figure 35. Design Response Spectrum

It should be noticed that the application of the spectrum is in the X direction only, as the structure is approximately symmetric with exception of the area of the openings at the base, which is greater in the X direction with respect to the one in the Y direction (respectively 7 and 3 m^2).

From the superimposition of the modes responding to the solicitation of the spectrum, results regarding the design stresses for Torre Gregoriana are obtained. Figure 36 presents the displacements in the main direction X, Y and Z. The highest movement of 0,0018 m occurs at the top of the tower in the X direction. The maximum displacements in the Y and Z directions, considerably smaller, are respectively 0,00016 m and 0,00046 m. It should be noticed how the movement of the tower seems governed essentially by the first mode of the structure, with an increasing displacement of regular intervals from the bottom to the top of the building. Notice that in the Y direction the results are clearly unsymmetrical due to openings at the base.

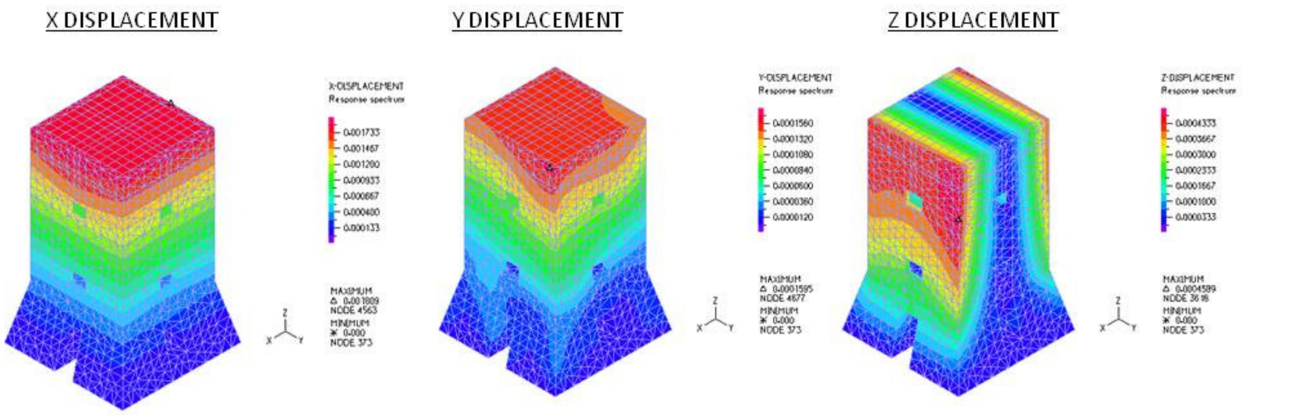


Figure 36. Displacement of Mode Superposition

The stresses found are outlined in Table 6. The effective stress presents a maximum compression value of 130 kPa. The maximum (unsorted) principal stresses P1, P2 and P3 are respectively 114 28 and 112 kPa. The distribution of high compression concentrates between the first floor opening and the contact plane between the base and the body, on the East façade of the structure. Stresses X-X, Y-Y and Z-Z should be carefully checked for assessing the need of reinforcement in each of these directions. Sigma X-X presents a maximum compression of 65 kPa, sigma Y-Y of 35 kPa and sigma Z-Z of 115 kPa. However such compression appears to be reasonably small if compared to the compression strength of the material. It should be noticed that tension, although present in an infinitesimal quantity in Z-Z direction, is not observed in the structure for the modal superposition analysis, and therefore reinforcement is not required in the reconstructed body of the tower according to this type of analysis.

	σ_{P1} *(KPa)*	σ_{P2} *(KPa)*	σ_{P3} *(KPa)*	σ_{eff} *(KPa)*
Max	114,3	28,1	112	129,9
Min	1,5	0,1	1,5	2,9

	σ_{XX} *(Kpa)*	σ_{YY} *(KPa)*	σ_{ZZ} *(KPa)*
Max	65	34,7	114,5
Min	0,1	0,1	-9,50E-07

Table 6. Calculated Stresses

However, it is interesting to underline the distribution pattern of stresses in the principal direction P1, shown in Figure 37. The West façade of the tower undergoes an almost uniformly distributed low compression stress with a minimum response to the applied spectrum. The South and North façades constitute the shear walls of the structure. The stress distribution in both façades is practically the same. The high compression stress builds up around the openings on the body converging diagonally towards the base on the East side. At the corners of the body the stress reaches its maximum. Stress singularities are also visible at the corners of the first floor openings. The compression on the East façade is symmetrical with respect to the vertical axis passing through the openings and it is distributed along horizontal bands. High compression concentrates at the contact plane between the body and the base of the tower.

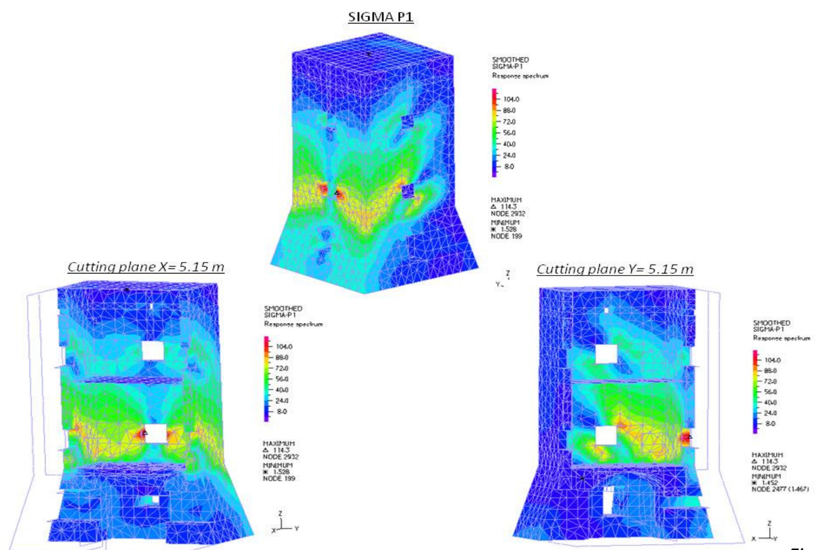


Figure 37. Principal Stress P1

The horizontal reaction at the bottom of the base is calculated to be 618 kN, about 7 percent of the total weight of the structure. This value is considerably lower than the PGA as it is controlled by the tower elastic frequencies. It has to be underlined that plots of all stress distributions are available for further consultation in annex B.

5.3.2 Pushover Analysis.

The pushover analysis allows the determination of the safety factor of the structure with respect to a failure mechanism due to the application of a horizontal force. The analysis is carried out by applying a mass proportional loading in the X direction. The curves in Figure 38 show the uniaxial stress-strain relationship for the two materials used for the non-linear analysis of the FEM.

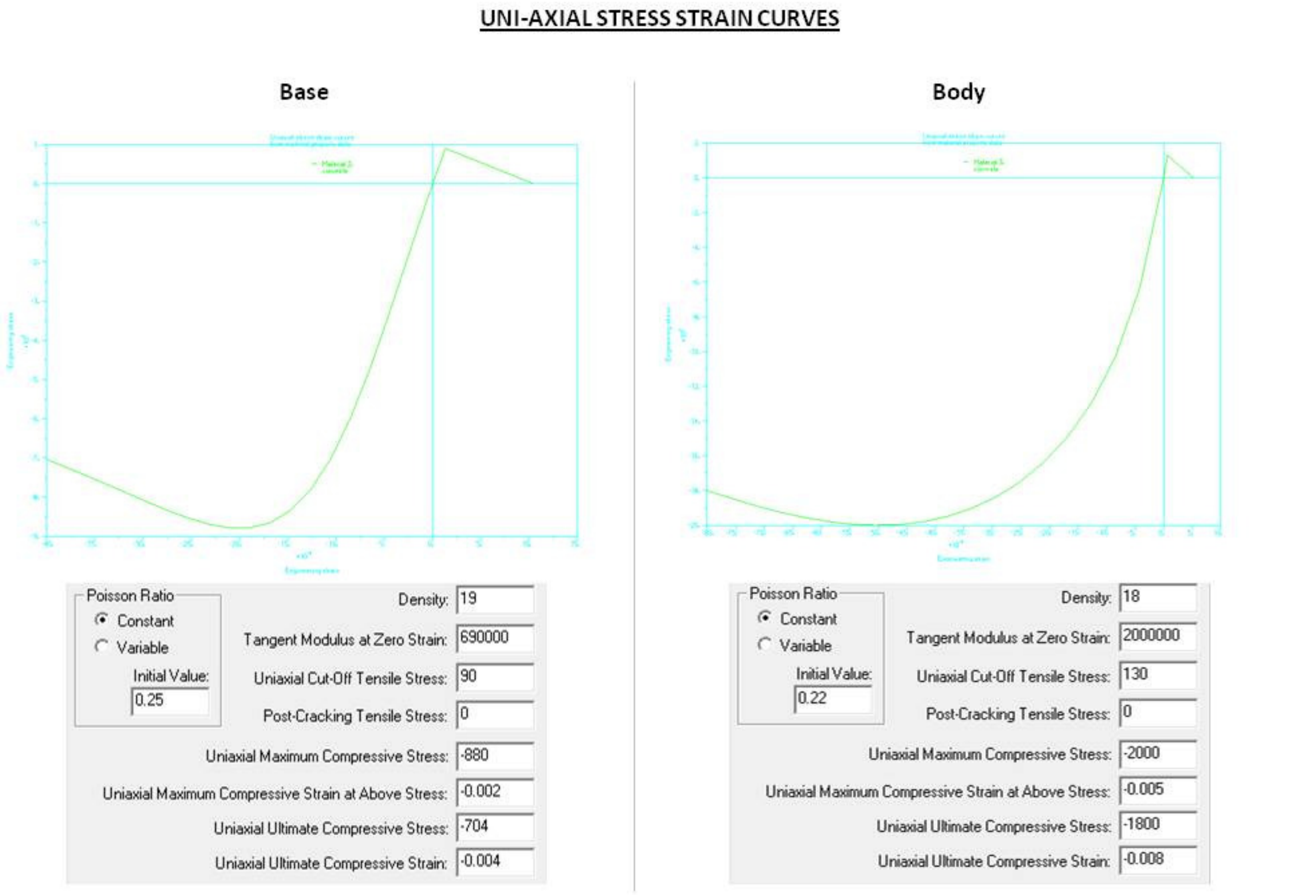


Figure 38. Stress Strain Curves for Modeled Materials

Figure 39 shows the relationship between the base shear and the displacement of the control point at the top of the tower (usually the node of maximum displacement). Two points are clearly identifiable on the plot. P_y is the yielding point of the building, at which the non-linear behavior begins. For a force of P_y= 2100 kN the control point is displaced by 0,0036 m and the first mechanism is expected to occur. The P_{peak} is achieved for a base shear of F_{peak}= 4000 kN, which corresponds to a displacement of 0,0115 m. At this point the maximum force is applied. Limitations due to the convergence requirements for the calculation of the FEM do not allow to go any further. After this point limit analysis of the mechanism could be used to achieve a final displacement and an approximation of the last section of the curve.

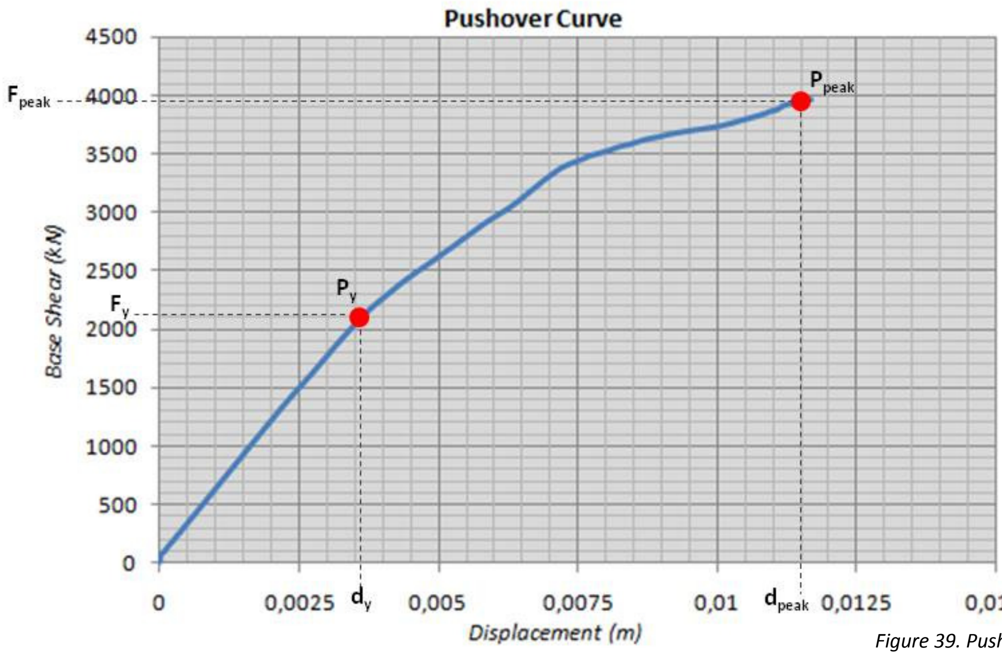


Figure 39. Pushover Curve

The cracks, strain and stress at the yield point are shown in Figure 40. The cracks develop at the diagonally opposite corners of the opening and move outwards. At this point the significance of the damage is sensible and the structure enters the non-linear behavior. The principal strain at this stage is included between 0,0004 and -0,0001. The maximum strain distributes at the corner of the base of the tower running into the shear wall of the first floor, towards the openings. The maximum effective stress is 460 kPa, within the allowable for the base material of 800 kPa. The maximum compression occurs at the top of the base on the East façade, running towards the opening of the shear walls. The horizontal force multiplier necessary to activate this first mechanism is equal to the ratio of F_y over the total weight of the structure (8468 kN), that is α_1= 0,248.

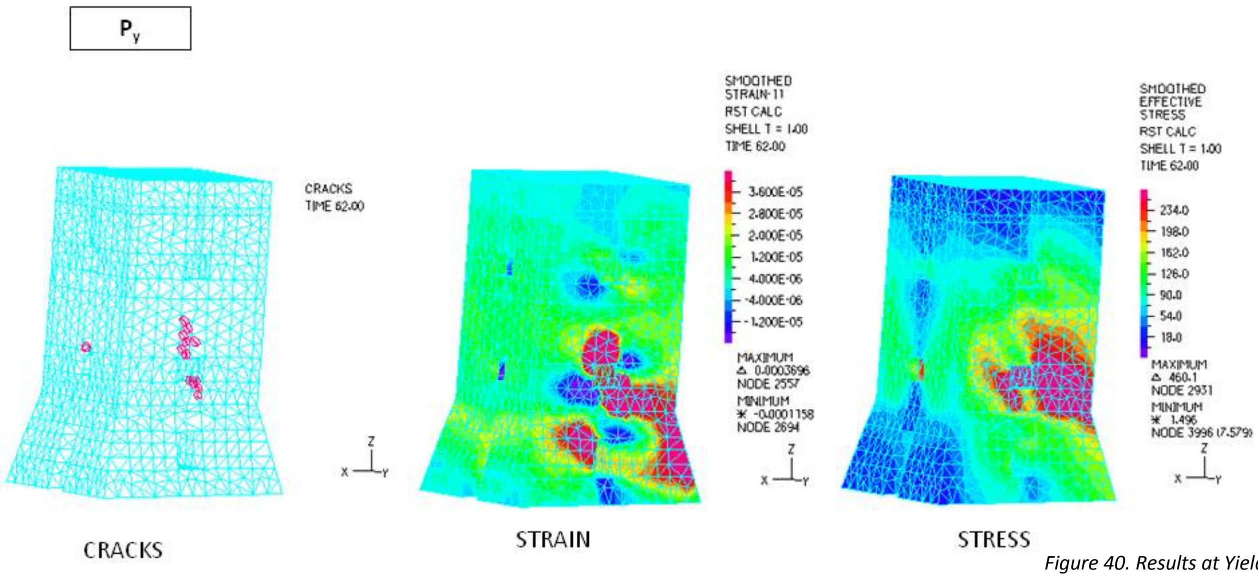


Figure 40. Results at Yield Point

The point P_{peak} represents the point after which the structure loses substantially its bearing capacity, dissipating increasingly applied energy and leading rapidly to collapse. Cracks, strain and stress for this point are presented in Figure 41. The failure mechanism at this point seems mostly by shear, with some localized bending. The walls of the South and North façades show conspicuous cracking running diagonally from the top of the first floor to the top of the base. The collapse mechanism to consider would be therefore the shear failure of the body of the tower in the direction of the horizontal force applied. The strain observed for the peak of applied force is included between 0.0017 and -0.00021. The distribution of high strain involves mainly the diagonal running from the bottom of the base to the top of the first floor. The maximum effective stress at the peak point is 1261kPa which would induce the failure of the base material as it passes the limit of compressive stress of 800kPa . The conditions described above for the peak horizontal force are expected for a horizontal force multiplier α_2= 0.473.

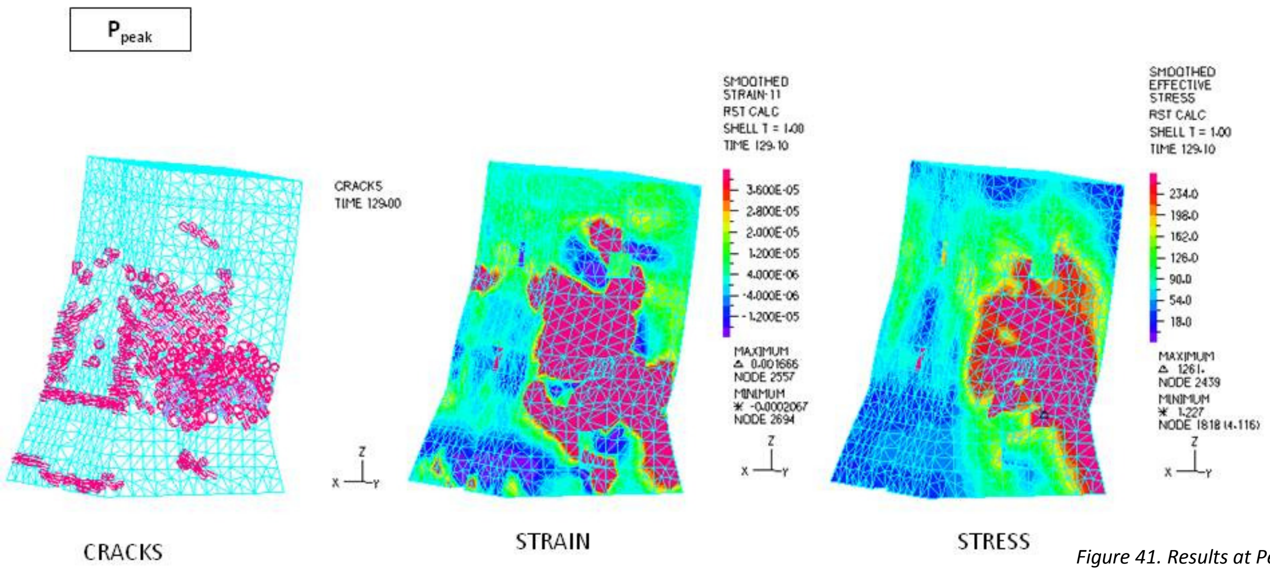


Figure 41. Results at Peak Point

To verify the validity of the horizontal multiplier required to activate the failure mechanism, a new kinematic model is proposed (*Figure 42*). The value of α is calculated to be equal to 0.502, in a reasonable range with the value derived from the pushover curve. Note that this value is much lower than the one obtained in section 5.2 as it features a diagonal failure and less stabilizing mass is involved.

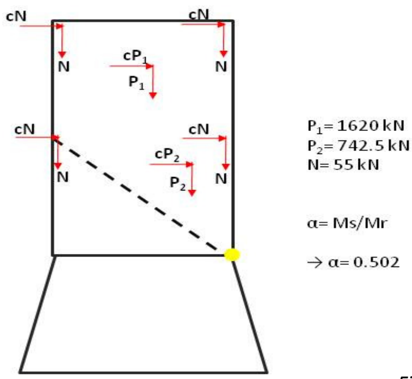


Figure 42. Safety Factor Verification

Comparing the multipliers obtained with the peak ground acceleration expected for the seismic zone under study a safety assessment can be made. The yield mechanism is initiated at α_1= 0,248, while the mechanism at peak applied force develops for α_2= 0.473. The PGA for the seismic zone 3 is 0,15g. Further verification of the safety factor for the reconstructed tower might be carried out following the procedure outlined in part 3 of EC8 and the Italian code (EN 1998-3:2005 and OPCM 3274). However the evidence provided above concludes that for the type of failure obtained by pushover analysis, Torre Gregoriana can be considered safe.

5.4 Considerations on the Structural Behavior.

The reconstruction of the body of Torre Gregoriana is a feasible option for integrating the existing part of the building and provides communicational and functional significance.

In this perspective a finite element model of the expected structure has been made and used for modal dynamic and pushover analysis.

The design parameters produced by the application of a reduced response spectrum in the elastic range, conclude on the low impact of the mode superposition behavior of the structure. Compression stresses reach a maximum of 130 kPa, while almost no tension is observed. Reinforcement of the structure is thus not required.

The pushover analysis suggests a shear failure of the body of the tower along the diagonal connecting the top and bottom of the first floor. Such failure is expected for a horizontal force multiplier α_2= 0.473 (if calculated from the curve) or α_2= 0.502 (from kinematic model). For the PGA observed on the hazard map, the structure can be considered safe.

Remarks on how to integrate the structural analysis with further studies that have not been carried out in this research, are presented in the final chapter, together with conclusions regarding the main findings of this work.

VI. CONCLUSIONS

The scope of the research is to integrate *'what to do'* , grounded on conservation theories, with *'how to do it'*, based on a technical-scientific process. The balanced blending of basic concepts of conservation practice with qualitative and quantitative data from the analysis make the work presented quite successful. The results obtained by the research clearly satisfy the goals set at its very beginning.

A deep knowledge about the construction techniques, material characteristics and intervention evolution of Torre Gregoriana is obtained from the analysis of chapter 3. The inspection carried out on Torre Gregoriana in fact concentrates on the geometrical data, which allows to identify the current shape and dimensions of the building, the material composition of the structure, which helps indicating the different materials present in the tower, and the damage survey which categorizes the types of decay visible on the fortification.

A comprehensive diagnosis regarding the structural conditions of the building is also achieved. The diagnosis of the analytical findings, due to the massive geometry of the building, the reasonable quality of its materials and their layout and the low damage, induces to consider good structural conditions of the building. However the slow process of degradation produced by the interaction of non structural damages should be addressed by a coherent conservation measures and interventions.

A conservation plan is proposed in the chapter 4. The aim of the conservation measures is to control the process of degradation and to prevent decay of the building, in order to exalt its emotional and cultural values, while at the same time conjugating them with functional needs related to the use and safety of the tower. The plan features a process of 'restoration' of the building, intended as the revival of the original concept or legibility, through the cleaning of the fabric, the reintegration of details and features and the replacement of decayed sections; and a process of 'consolidation' which involves the physical addition or application of supportive material into the texture of the building in order to ensure its continued durability and structural integrity.

The reconstruction of the body of Torre Gregoriana is proposed in chapter 5. The re-creation of the physical form allows the redefinition of the communicational and functional properties of the tower. Again the application of structural analysis methods such as mode superposition and pushover analysis to carefully selected conservation principles results in an integrated reconstruction project, feasible and sustainable.

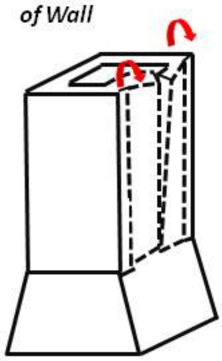
Important data have therefore been gathered and processed, and coherent results have been obtained by the analysis carried out. However further steps grounded on this research as a starting point are desirable.

This research, in fact, is meant to act as a platform on which to develop further studies concerning the watchtowers of the Pontifical State. An in-situ testing campaign could be started in order to achieve samples and average results regarding the actual mechanical parameters of the materials. Further seismic assessment could be carried out for towers located in earthquake prone zones with higher PGAs than that considered for Torre Gregoriana. An aimed inspection could be carried out on the defensive system to obtain the exact geometrical properties and cross section characterization necessary for an appropriate diagnosis of the building. A better understanding can be achieved regarding the development of the system from a constructive point of view. A generalized monitoring plan could be developed and implemented in a pilot project and then scaled-up to the whole system.

The research has been a trip in a fascinating and adventurous world of corsairs, guardians, sea life and wars. The hope is that the word 'end' for this adventure would signify the beginning for a new one.

ANNEX A- Kinematic Mechanism for Torre Gregoriana

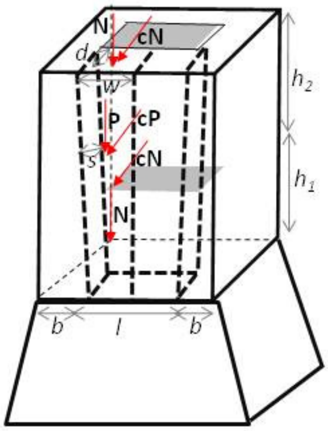
MECHANISM 2- ***Horizontal Flexure of Wall***



CONDITIONS:

-Good connection at orthogonal walls.

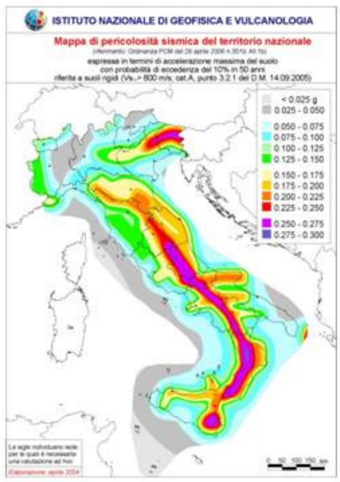
-Poor lateral restraint at top and floors.



$$\alpha_0 = \frac{0.5P + N\frac{2b}{3}}{P\frac{1.058h}{\sqrt{(\frac{0.529h}{0.324w})^2+1}} + 2N\frac{1.058h}{\sqrt{(\frac{0.529h}{0.324w})^2+1}}}$$

α_0 (g)	b (m)	h_1+h_2 (m)	l (m)	w (m)	s (m)
0,254	1	11,5	6	3	1,92
0,175	0,75	11,5	6,5	3,25	2,08
0,106	0,5	11,5	7	3,5	2,23
0,048	0,25	11,5	7,5	3,75	2,38

NOTES



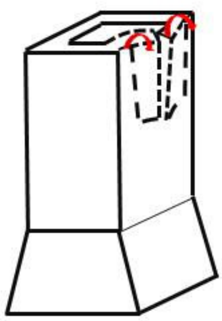
SeismicClassification Terracina

(Regional Act DGR 387/09 and DGR 835/09)

-*ZONE*: 3 ($0.050< a_g<0.150$)

-*SUBZONE*: B ($0.062< a_g<0.1$)

MECHANISM 3- ***Partial Horizontal Flexure of Wall***

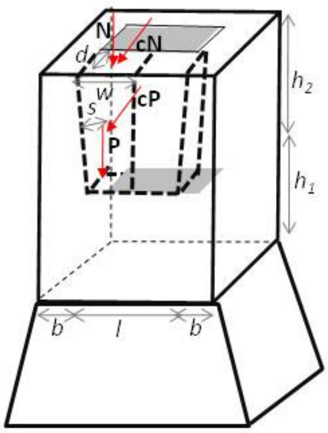


CONDITIONS:

-Good connection at orthogonal walls.

-Lateral restraint at floor.

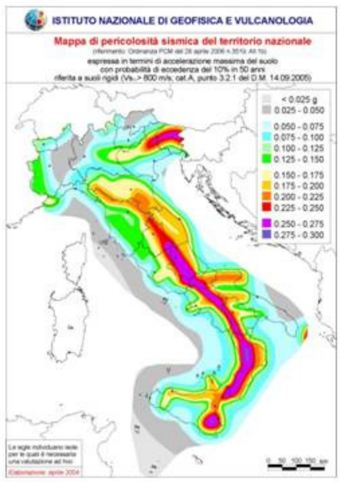
-Poor lateral restraint at top.



$$\alpha_0 = \frac{0.5P + N\frac{b}{3}}{P\frac{1.058h}{\sqrt{(\frac{0.529h}{0.324w})^2+1}} + N\frac{1.058h}{\sqrt{(\frac{0.529h}{0.324w})^2+1}}}$$

α_0 (g)	b (m)	h_1 (m)	l (m)	w (m)	s (m)
0,263	1	6	6	3	1,86
0,182	0,75	6	6,5	3,25	2,00
0,111	0,5	6	7	3,5	2,14
0,050	0,25	6	7,5	3,75	2,27

NOTES



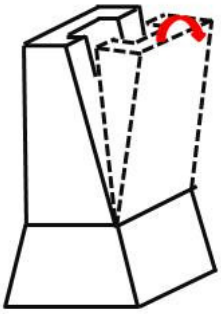
SeismicClassification Terracina

(Regional Act DGR 387/09 and DGR 835/09)

-*ZONE*: 3 ($0.050< a_g<0.150$)

-*SUBZONE*: B ($0.062< a_g<0.1$)

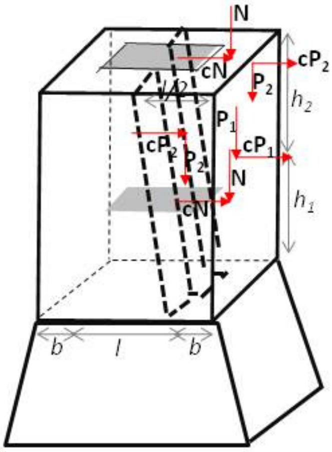
MECHANISM 4- ***Composite Overturning Of Wall***



CONDITIONS:

-Good connection at orthogonal walls.

- No lateral restraint at roof and floors.



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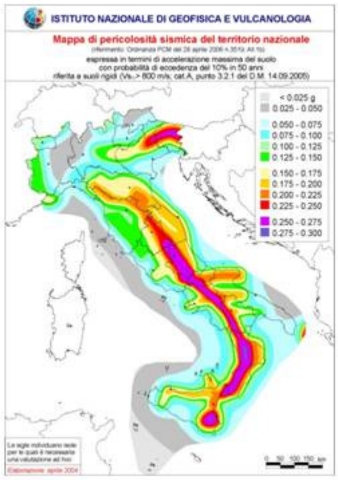


$$\alpha_0 = \frac{2N(b-d) + 0.5P_1 b + 2P_2\left(b + \frac{0.5l}{3}\right)}{N(h_1+h_2) + P_1\left(\frac{h_1+h_2}{2}\right) + Nh_1 + 2P_2\left(2\,\frac{h_1+h_2}{3}\right)}$$

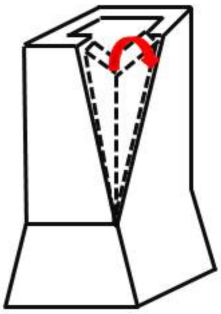
α_0 (g)	b (m)	h_1 (m)	h_2 (m)	l (m)	d (m)
0,141	1	5,5	6	6	0,5
0,121	0,75	5,5	6	6,5	0,375
0,099	0,5	5,5	6	7	0,25
0,073	0,25	5,5	6	7,5	0,125

SeismicClassification Terracina
(Regional Act DGR 387/09 and DGR 835/09)

-*ZONE*: 3 (0.050< a_g<0.150)

-*SUBZONE*: B (0.062< a_g<0.1)

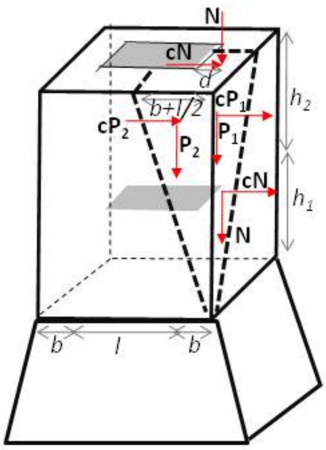
MECHANISM 5- ***Corner Overturning***



CONDITIONS:

-Poor connection at orthogonal walls.

- No lateral restraint at roof.



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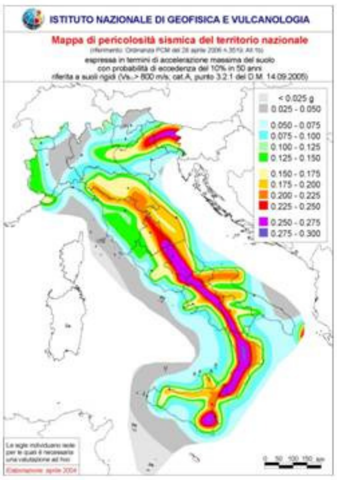


α_0 (g)	b (m)	h_1 (m)	h_2 (m)	l (m)	d (m)
0,141	1	5,5	6	6	0,5
0,121	0,75	5,5	6	6,5	0,375
0,099	0,5	5,5	6	7	0,25
0,073	0,25	5,5	6	7,5	0,125

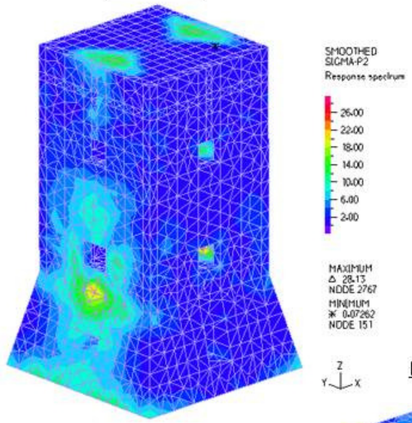
SeismicClassification Terracina
(Regional Act DGR 387/09 and DGR 835/09)

-*ZONE*: 3 (0.050< a_g<0.150)

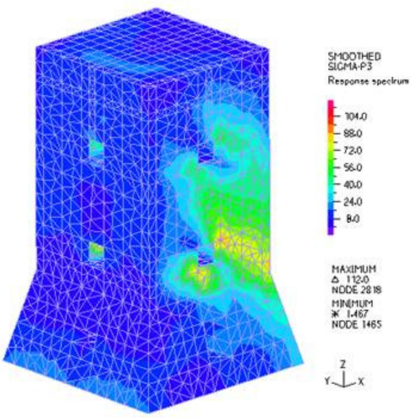
-*SUBZONE*: B (0.062< a_g<0.1)

ANNEX B- Mode Superposition Results

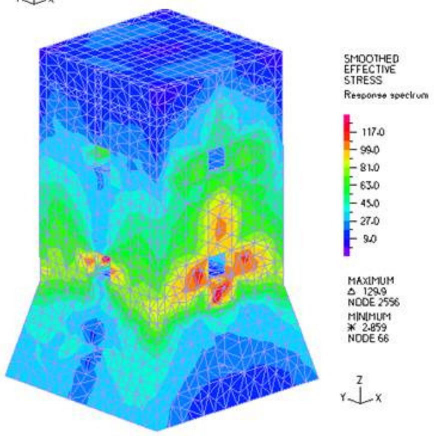
SIGMA P2



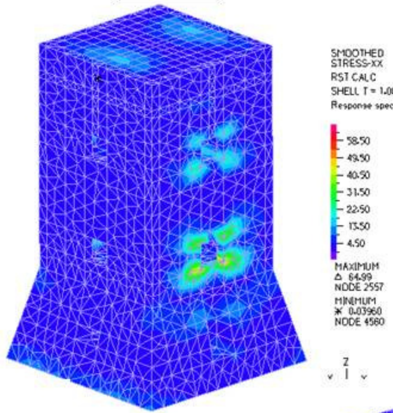
SIGMA P3



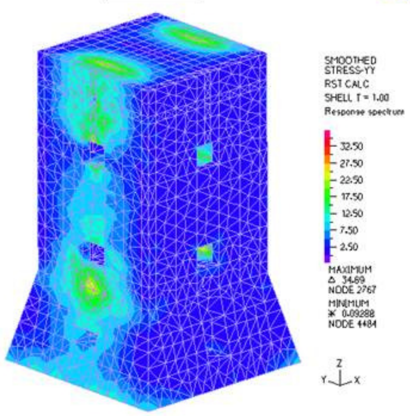
EFFECTIVE STRESS



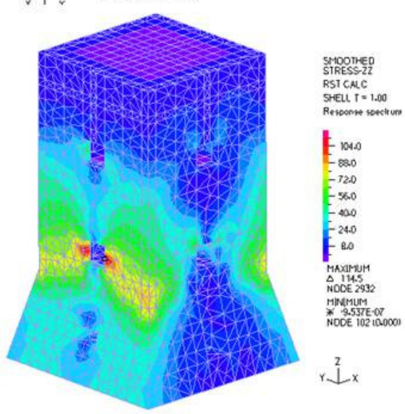
STRESS X-X



STRESS Y-Y



STRESS Z-Z



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