Iscarsah
International Scientific Committee on the Analysis and Restoration of Structures of Architectural Heritage
5
newsletter
December 2013
ICOMOS
International Council on Monuments and Sites
Conseil International des Monuments et des Sites

Message of the President of ISCARSAH Stephen Kelley

My dear friends and colleagues!
I am writing you from the island of Bohol in the Philippines where I have been consulting with UNESCO and local authorities on natural disaster damage assessment to cultural heritage brought on not only by the October 2013 Bohol Earthquake but by Typhoon Haiyun/Yolanda which struck in November. The needs here are great for monetary as well as expert technical assistance. The cultural heritage here is rich and our attention has been focused on a group of Spanish-era churches that are 2 - 300 years in age and composed of triple leaf masonry walls faced with coral stone that are buttressed and roofed with timber framing and roofing of either clay tile or corrugated sheet metal. It will be interesting to see if the global community can find ways to aid in restoration and seismic retrofit efforts.
It will also be interesting to see if ISCARSAH or other committees can participate as well.

The left transept of Santissima Trinidad Parish Church, a cruciform church constructec circa 1800 in Loay, Bohol, Philippines. This is one of a handful of Spanish-era churches that were left standing after the October 2013 earthquake.
La Purisima Concepción Church located in the fishing village of Guiuan, Samar was constructed in 1718. This is one of the few churches in the Philippines with its original altars, carvings, painted ceiling, and architecture still intact and was extensively decorated with natural shells embedded in the interior walls. These photos reflect the extensive damage from Typhoon Haiyun/Yolanda.

ISCARSAH is in the planning stages of development of a Conservation Engineering training course that would be taught as a module within a larger training course on Risk Preparedness with the International Committee on Risk Preparedness (ICORP). This idea was first discussed during the ICOMOS GA in Paris in 2011 and was further developed at the recent ICORP meeting in Kathmandu. The idea is to have a well-developed course that would be tailored to regional (climatic, technical, cultural, political, etc.) needs and utilizes regional ISCARSAH instructors along with a core group of experts. The initiative is being spearheaded by Vice President Görün Arun. Please contact her directly or through the listserv if you would like to participate.
We are finding that the ISCARSAH Facebook and Linkedin sites are a great outreach tool for potential members in the Middle East and Asia. The Facebook page is followed by 369 and the Linkedin page has 179 members. These followers and members grow almost daily and most are not members of ISCARSAH. We are looking for someone who can dedicate time to the administration of one or both of these sites.
The administration has thus far been fairly casual because they are handled by hopeless amateurs (me!).
Do we have associate members who might want to take on this task and give this area the attention and expertise that it so richly deserves? Please let us know if you are that person.
The year 2014 will prove to be a busy year for ISCARSAH. We are planning to have two meetings: during the SAHC2014 Conference in Mexico City (week of October 13) and during the ICOMOS General Assembly in Florence (week of November 9). Please stay tuned to the listserv and ISCARSAH website for details.
We will soon hold an election for positions on the ISCARSAH bureau. I will stand for my last term as President. Both Görün Arun and Maya Segarra-Lagunes will also stand for Vice President. Debra Laefer will stand for Secretary General. That leaves one VP slot that is available. If you are interested please contact me directly. I would like to thank Lyne Fontaine, outgoing SG, for her hard work and fidelity over the past six years. I would also like to thank Peter Elliott, outgoing VP, for his hard work and fidelity over the past three years. We as a committee should think boldly about the 2017 transition to a new President. Please let us know if you might be interested.

Sincerely,

Stephen J. Kelley
President - ISCARSAH

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International Scientific Committee on the Analysis and Restoration of Structures of Architectural Heritage

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Newsletter n. 5
December, 2013
ISSN 2306-0182

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Шуховская башня в Москве
Šuchov Tower in Moscow

March 11, 2014

Mr. Vladimir Shukhov!

The International Scientific Committee on the Analysis and Restoration of Structures of Architectural Heritage (ISCARSAH) was founded by ICOMOS in 1996 as a forum and network for engineers involved in the restoration and care of building heritage. The first meeting of the ISCARSAH took place at the Engineering University in Rome in March of 1997 our committee of more than 100 members meets yearly in venues all over the world. Members of the ISCARSAH are composed of internationally renowned engineers, scientists, architects, specialists, and educators with representation from Europe, Asia, Australia and North and South America.

ISCARSAH is extremely distressed to learn of the threat to the Шуховская башня in Moscow. As you mention in your letter to President Putin and as we have followed from the international media, the Communications and Press Ministry has recommended dismantling the Tower before it collapses.

We are familiar with the constructivist architectural works of your great grandfather, Влади́мир Григо́рьевич Шу́хов, and realize that his contribution to the built environment is just one of his many achievements. His comparison to Gustav Eiffel is apt due to his development of hyperboloid structures of which Moscow's 160 meter high Шуховская башня is the most famous example. Its construction date of 1922 is critically important - very little construction took place in the Soviet Union at this time due to the economic policies of War Communism. Construction focused only on power, industry, and housing during this period and the Шуховская башня is a prescient example leading the way for Soviet avant-garde architecture that would flower in 1928.

The Шуховская башня, an iconic symbol and landmark in the southern part of Moscow, suffers from a lack of appreciation and proper care as does many other examples of 20^{th} Century architectural heritage in the world. This tower is also a "landmark" in many architectural and structure engineering schools throughout the world. It inspires many architects and engineers to use such systems in an innovative manner and to develop innovative structural solutions that changed the demands of the construction industry.

It would be beneficial for Russian and World Heritage if the administrators understand that the conservation and enhancement of the architectural heritage offers a platform to observe the continued development of novel technologies and has to be our commitment to maintain the social, economic and environmental traditions.

The ISCARSAH stands ready to assist in any manner that you might deem beneficial to this critically important cause. Please feel free to add our names to your letter to President Putin.

Best regards,

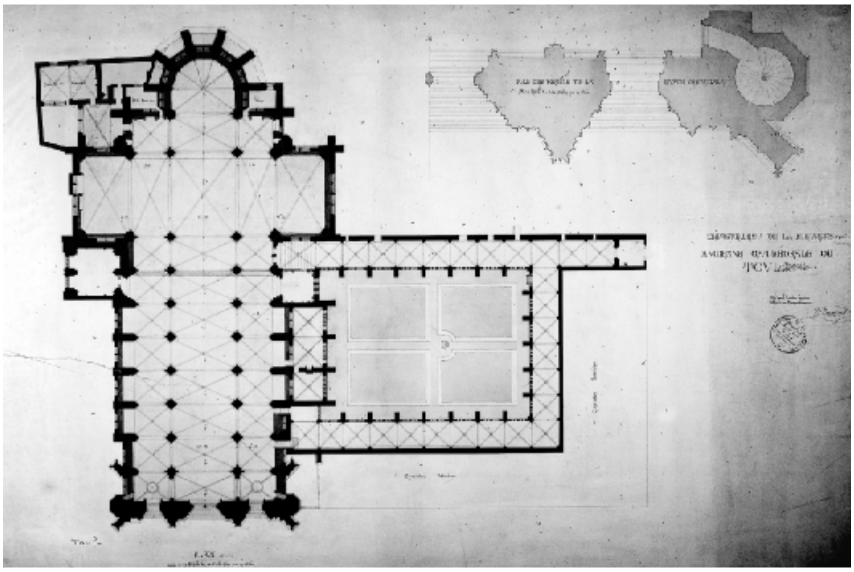
Prof. Stephen Kelley (USA), SE, AIA President - ISCARSAH
Prof. Dr. Görün Arun (Turkey), Mimarlik Facultesi, Yildiz Technical University Vice President ISCARSAH
Prof. Dr. María Margarita Segarra Lagunes (Mexico-Italy), Dipartimento di Architettura, Università degli Studi Roma Tre, Vice President ISCARSAH
Prof. Dr. Debra Laefer (USA), School of Architecture University College Dublin Secretary General ISCARSAH

Šuchov Tower in Moscow.

La restauration du cloître de la cathédrale de Toul
Ou un « écosystème » médiéval retrouvé

Pierre-Yves Caillault
Architecte en Chef des Monuments Historiques

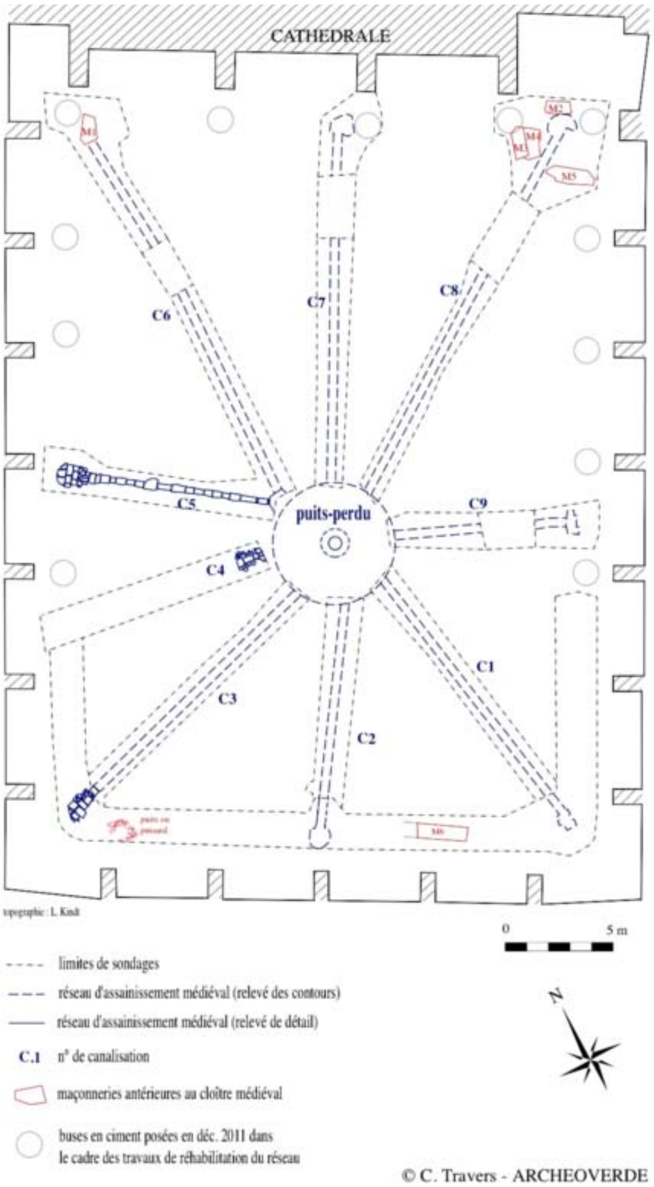
En matière de « développement durable », les monuments anciens sont bien souvent riches d'enseignements. Ainsi, lors de la restauration du cloître de la cathédrale de Toul, l'écosystème mis au point par les constructeurs du Moyen Âge pour recueillir (et recycler) l'eau de pluie venant des toitures a été mis au jour, restauré et remis en fonction. Au-delà d'une restauration permettant de retrouver les dispositions anciennes du monument, il s'agit ici de montrer la pertinence et la permanence des principes de la construction médiévale dans le contexte de nos préoccupations actuelles concernant le respect de l'environnement.
La cathédrale Saint Etienne, construite entre le début du XIIIème siècle et le milieu du XVIème a un cloître sur son côté sud bâti entre 1346 et 1411. A la suite des dégâts causés par la Seconde Guerre mondiale, d'importants travaux de restauration ont été menés mais il faudra attendre les années 1982-1991 pour voir le grand chantier de reconstitution du haut comble (nef, transept et chœur) et ce n'est qu'entre 2009 et 2013 que furent restaurées les toitures du cloître (encore constituées de tôles), objet de notre récente intervention. A cette occasion, nous avons mené des travaux d'assainissement et d'amélioration du recueil et de l'évacuation des eaux pluviales.
Alors que notre projet consistait à restaurer et à prolonger l'usage des gargouilles médiévales, nous avions prévu d'enterrer des bacs en béton préfabriqué reliés entre eux au droit de chacune d'elles et d'évacuer les eaux de pluies ainsi recueillies dans le réseau urbain. Les nécessaires sondages archéologiques précédant cette opération, réalisés par l'INRAP sur les prescriptions du Service Régional de l'Archéologie révélèrent des fragments d'anciennes canalisations mettant en relation le point



Plan de la cathédrale de Toul par Emile Boeswilwald - 2ème moitié du XIXème siècle.

Vue de l'intérieur de la citerne.

d'impact de l'eau s'écoulant des gargouilles avec une construction enterrée, une citerne, située au centre du cloître. Explorant l'intérieur de cette citerne, nous avons découvert une construction en très bon état de conservation, constituée d'une coupole appareillée structurée par huit arcs rayonnants qui se rejoignent sur un oculus au-dessus duquel était posée la margelle d'un puits. Au centre de chacun des quartiers de voûte avait été ménagé un exutoire en pierre, contemporain de l'ouvrage. Il devenait évident que les exutoires correspondaient aux canalisations en pierre dont quelques fragments avaient été reconnus par sondages. Les auteurs des sondages archéologiques ont pu apprécier le bon état de conservation de la citerne et mettre en évidence la conception d'origine des [...] rigoles en pierre plates grossières [...] destinées à récupérer les eaux de pluie qui se déversent des gargouilles. Le rapport de l'INRAP est complété par l'observation suivante: «...ces rigoles sont aujourd'hui à l'état d'abandon et ne sauraient remplir leur fonction efficacement. Un large drain implanté postérieurement à l'est de la citerne, a manifestement pour fonction l'évacuation de l'eau qui viendrait la remplir. Cette structure marque l'abandon de la citerne et pourrait coïncider avec l'obturation de la margelle... ».
A partir de cette première reconnaissance archéologique, nous étions convaincu de l'intérêt du dispositif mis au jour, tant sur le plan historique que d'un point de vue technique. En effet, le cloître est implanté en contrebas des terrains environnants et l'évacuation des eaux de pluie dans le réseau urbain ne pouvait se faire de façon gravitaire ; de plus, le raccordement au réseau existant imposait de traverser des structures anciennes pour rejoindre l'espace public. Rappelons par ailleurs que les quantités d'eau à évacuer ne concernent pas uniquement les toitures du cloître mais toutes celles du flanc sud de la cathédrale.



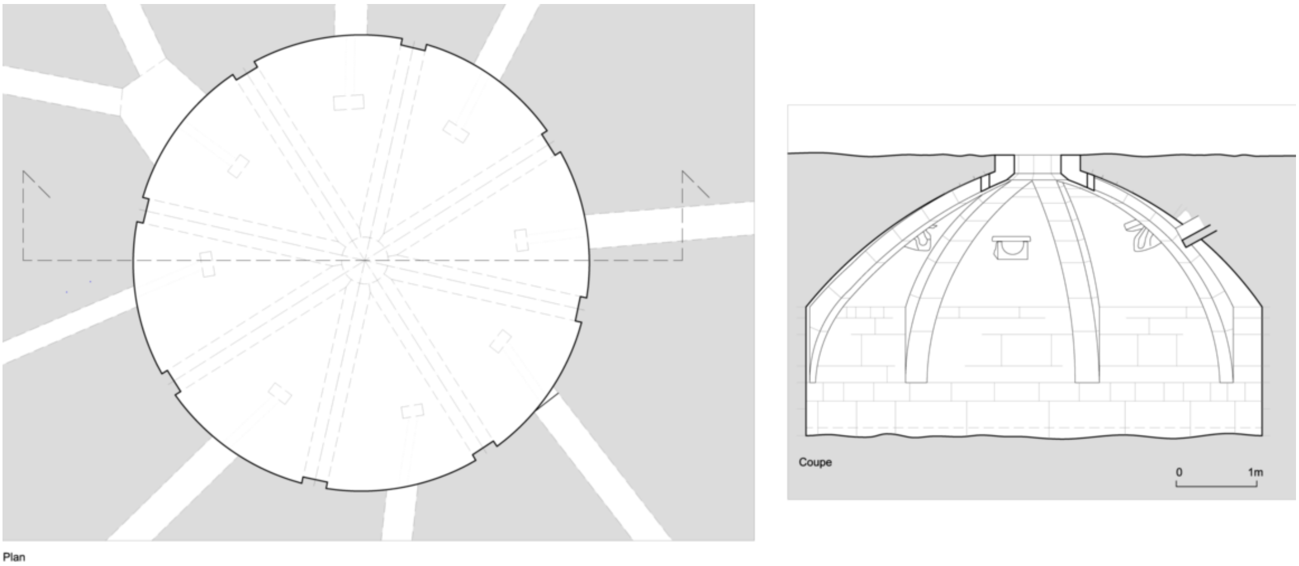
Plan du cloître.


En cours de travaux, vue du réseau d'assainissement médieval.

Le maître d'ouvrage fut rapidement acquis à notre nouveau projet consistant à reconnaître l'ensemble du réseau ancien, à le restaurer et à le compléter afin de retrouver l'équilibre qu'avaient mis au point les concepteurs du Moyen Âge. Nous décidions alors de mettre au jour l'ensemble du réseau enterré, tâche qui fut confiée à Cécile Travers, archéologue spécialiste des jardins historiques. La fouille systématique entreprise sous sa direction a permis de reconnaître un ouvrage en bien meilleur état que les sondages préalables ne laissaient espérer.
En coordination avec les tailleurs de pierre, les canalisations reconnues ont été restaurées en conservation et les parties manquantes ont été complétées par des éléments en PVC afin de rétablir la continuité du système. Dans l'ouvrage médiéval, seules huit gargouilles étaient reliées à la « citerne » centrale (celles des quatre angles et du milieu de chaque côté du cloître). Nous avons partiellement conservé notre projet initial par la mise en œuvre de bacs enterrés au droit de chaque gargouille. Ces bacs reliés entre eux déversent l'eau récoltée dans les anciennes canalisations restaurées vers la citerne ; ceux qui ne sont pas directement situés au-devant d'un canal en pierre se déversent latéralement et alimentent les canaux situés de part et d'autre.

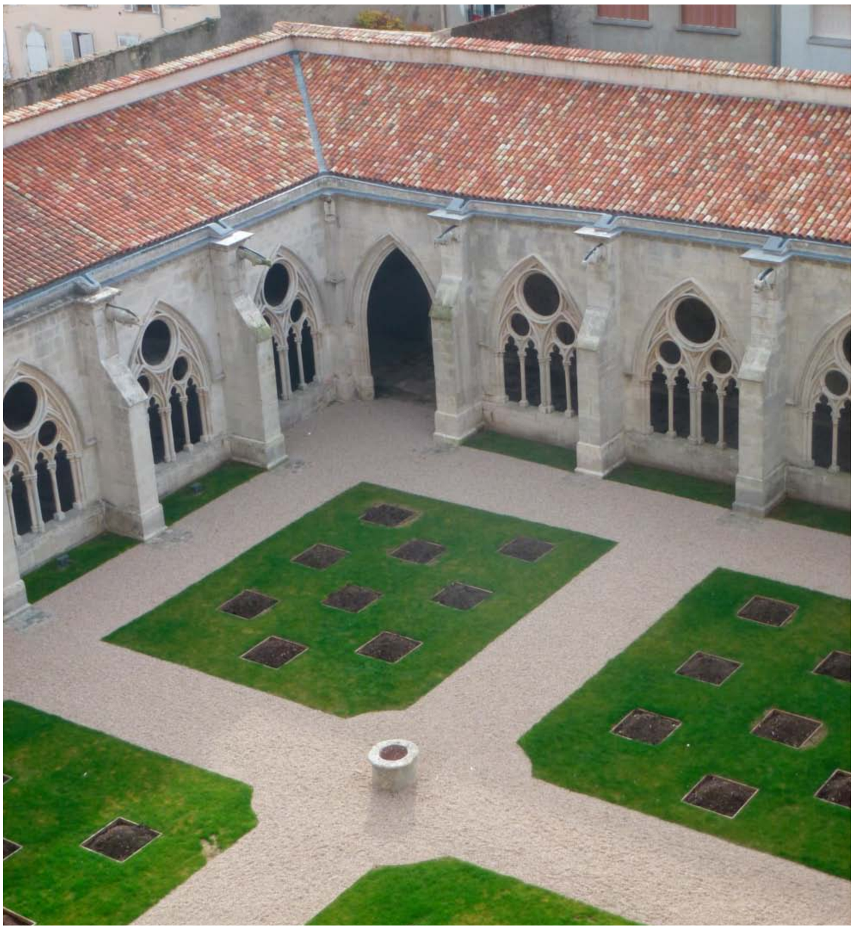
Intérieur de la citerne, détail d'un exutoire.

Vue du cloître après la remise en service du réseau d'assainissement.



Toul, Cathédrale Saint-Etienne. Citerne du cloître. Plan et coupe (P. Y. Caillault, ACMH, juillet 2013).

Ainsi, le système médiéval a été amélioré permettant désormais de récolter l'eau issue de toutes les gargouilles et les bacs enterrés reliés deux à deux préviennent l'éventuelle surcharge de l'un d'entre eux.
Le fond de la « citerne » analysé après en avoir vidé le remblai qui s'y trouvait (opération archéologique effectuée par C. Travers) s'est révélé constitué d'un empierrement et non d'un dallage comme on pouvait s'y attendre.
Après de fortes pluies, la « citerne » se remplit avec l'eau canalisée depuis les gargouilles puis, son niveau s'abaisse progressivement et laisse en permanence une quantité d'eau suffisante pour y puiser de quoi arroser les végétaux du cloître.
Plutôt qu'une citerne, il s'agit d'un « puits perdu » dans lequel on peut à tout instant puiser de l'eau...
Notre chantier aura permis de donner une seconde vie à cet ingénieux dispositif et peut-être de mieux tirer les leçons que nous donnent l'analyse et la compréhension des édifices du passé.



Vue du cloître après les travaux (angle sud/ouest).

Vue du cloître après les travaux (angle nord/est).

Règlement parasismique des constructions en terre au Maroc (RPCT)

Khalid El Harrouni
Ecole Nationale d'Architecture, Rabat Instituts, Morocco

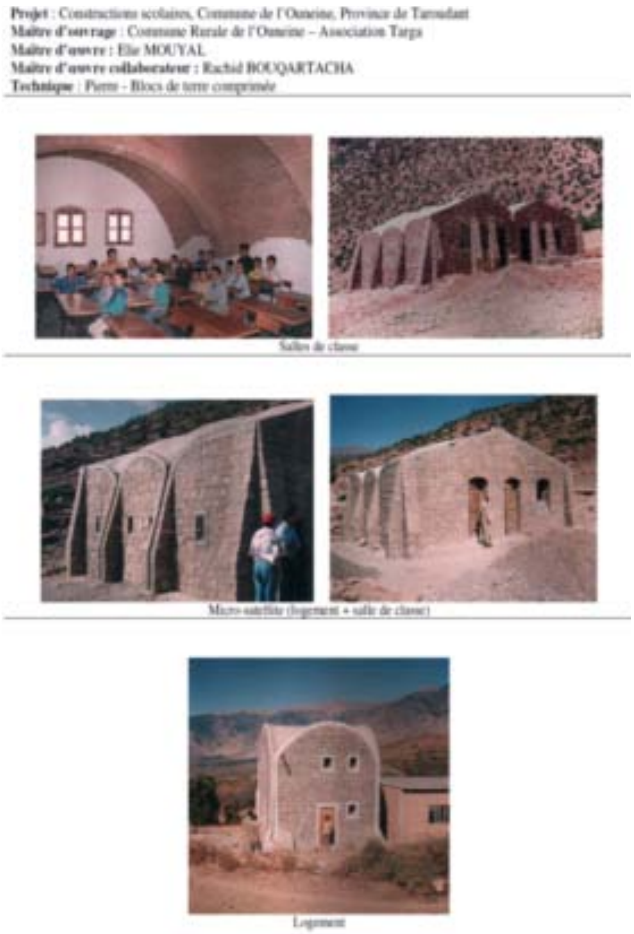
I. Introduction

La construction en terre a hérité d'une tradition vernaculaire, des techniques et des solutions judicieuses qui ont évolué avec l'esprit et l'objectif, de mieux valoriser les propriétés des matériaux locaux et plus particulièrement le matériau terre de construction. Elle représente un patrimoine socioculturel de plusieurs générations, et le témoin authentique de notre architecture traditionnelle.
Durant les dernières décennies, la protection sismique des constructions en terre a été au centre d'intérêt de décideurs, professionnels, chercheurs, utilisateurs et constructeurs. Tous ces acteurs sont presque unanimes sur le fait que la construction en terre n'est pas aussi vulnérable qu'on le croyait, vis-à-vis des secousses sismiques car plusieurs constructions en terre à travers le monde, notamment nos remparts imposants, nos médinas impériales et nos Kasbah et Ksour en pisé, en adobe et en terre cuite, ont survécu les événements historiques de séismes destructeurs.
Cette performance sismique est le résultat de l'utilisation des règles de bonne pratique concernant le choix de matériau terre, d'une conception simple et régulière, des conditions de mise en œuvre de qualité, des systèmes de protection contre les effets de l'eau et finalement les dispositions constructives concernant particulièrement les fondations et soubassements, les ouvertures dans les murs, les renforts d'attaches et de contreventement horizontal (diaphragmes) et vertical (renforts et structures en bois incorporées).
Il est donc de notre devoir de valoriser d'une manière rationnelle les performances de la construction en terre pour qu'elle demeure entre autres, la solution économique et écologique retenue de l'habitat en milieu rural.
Il faut noter que plusieurs pays disposent de documents normatifs et guides destinés à la protection sismique des constructions en terre.
Le Règlement Parasismique des

Ksar Jranat, Erfoud (Réhabilitation par Al Omrane).

Séisme Al Hoceima (Nord du Maroc) en 2004, milieu rural.

Constructions en Terre vient d'être adopté au Maroc. Ce qui permet de doter notre patrimoine de constructions en terre de normes et de recommandations techniques pour promouvoir ce secteur de construction en milieu rural et même en milieu urbain au même titre que les constructions en matériaux conventionnels.
Plusieurs travaux au niveau national et international ont été réalisés en vue d'élaborer les spécifications techniques des constructions en terre : pisé, adobe, bauge, maçonnerie de pierres et briques de terre compressées.
La mise en application du Règlement Parasismique des Constructions en Terre vise les aspects importants suivants :
• Le développement d'une architecture écologique en harmonie avec l'héritage vernaculaire, et l'exploitation des expériences riches et séculaires de cet héritage ;
• La prévention de l'extension de l'informalité, et éviter son expansion au milieu rural ;
• La préservation de la diversité architecturale du pays ;
• La participation au ralentissement de l'inévitable exode rural ;
• La réalisation d'économie d'énergie en freinant la généralisation du recours aux matériaux à haut intrants énergétiques (acier, ciments et autres) et en réduisant les frais de transport des matériaux de construction par l'utilisation et la valorisation des matériaux locaux.
Les conditions socio économiques, techniques et technologiques actuelles, à court et moyens termes du milieu rural ne permettent pas d'avoir recours d'une manière systématique à l'architecte et à l'ingénieur. Pour atteindre les objectifs cités ci-dessus, ce règlement est conçu en deux volets pour être plus flexible et faciliter sa mise en application.
• Premier volet : Guide Parasismique d'Auto–Construction en Terre
Ce règlement concerne les constructions en terre qui sont réalisées sans faire appel aux études architecturales et techniques. Ce guide est un recueil de prescription de règles de bonne pratique et de savoir faire en matière de protection sismique des constructions en terre.
Ce guide est plus simple à mettre en œuvre et convient parfaitement



pour réglementer l'auto construction en terre.

• Deuxième volet: Règlement Parasismiques des Constructions en Terre (RPCT)

Ce règlement est destiné aux architectes, ingénieurs et techniciens chargés de la conception et le dimensionnement des constructions en terre. Il concerne les performances requises des structures de contreventement des constructions en terre vis-à-vis des séismes.

II. Domaine d'application du règlement RPCT

Le concepteur doit être en mesure de trouver des solutions adaptées et optimisées au contexte du projet de réalisation d'une construction en terre pour atteindre les performances sismiques requises. Les principes de base de la justification parasismique des constructions en terre sont similaires à ceux de la maçonnerie non armée. Le principe des Etats Limites est adopté pour une mise en conformité avec celui de la conception et le dimensionnement des constructions en matériaux conventionnels.

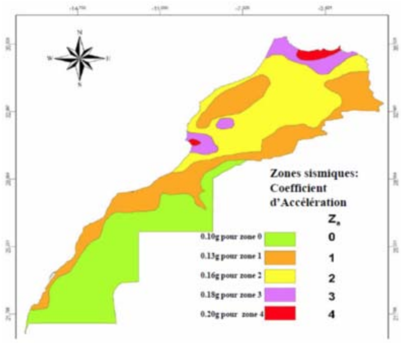
Le Règlement Parasismique des Constructions en Terre s'applique :

1) Aux constructions en terre soumises à l'obligation de recours à un architecte et à un bureau d'études pour l'obtention du permis de construire. Les éléments porteurs principaux sont des murs en adobe, pisé, bauge ou moellons de pierres à mortier de terre. Le matériau terre peut être stabilisé ou non.

2) Les Constructions sont limitées à un niveau en zones d'accélération maximale (de 18%g à 20%g) et à deux niveaux en zones d'accélération maximale (de 10%g à 16%g).

3) Les constructions en terre d'importance vitale de type : hôpitaux, cliniques, établissement de protection civile, les postes de police, les bâtiments administratifs de centre de décision en cas de séisme, sont limités à un seul niveau dans toutes les zones.

4) Les constructions en terre destinées au grand public de type : écoles, universités, bibliothèques, musées, grands lieux de culte, centres commerciaux, etc.…, sont limitées à un seul niveau en zones d'accélérations maximales (de



Zones sismiques au Maroc.

18%g à 20%g).

5) La hauteur maximale des murs porteurs en terre est 4m pour une construction à un seul niveau et 6.5m pour une construction à deux niveaux.

Les zones d'accélération maximale sont données par la carte de zones sismique au Maroc.

Référence:

Royaume du Maroc, « Règlement Parasismique des Constructions en Terre (RPCT2011) », Bulletin Officiel n. 6206, 21 Novembre 2013.

Rubble Stone Walls and Reinforced Concrete Frames:
Heritage Structures Reveal the Hidden Truth about Risk and Resilience during the Haiti Earthquake

Randolph Langenbach
Building Conservator (www.conservationtech.com)

Introduction

This article is about the effects of the 2010 earthquake in Haiti, a subject I have long wished to share with my ISCARSAH colleagues. With it, I also wish to honor the contributions of the other members of the World Monuments Fund/ICOMOS mission to Haiti undertaken after the earthquake to help in the effort to preserve the remarkable collection of 19th and early 20th century houses of traditional construction, almost all of which, although damaged to varying degrees, survived the earthquake. These houses, which had become known by the English term, "Gingerbread Houses" (not "pan-espice" as it would be in French), had previously been listed by the World Monuments Fund on their 'Watch List' of structures at risk.

Three of the members of the WMF mission team: Steve Kelley, Patrick Sparks and I, are members of ICOMOS-ISCARSAH. The two other members included architect Martin Hammer, noted for his international disaster recovery work in Pakistan and particularly for his work with straw-bale construction, and a builder, Kevin Rowell, noted for his work using traditional materials and technologies. All of the team members generously agreed to volunteer for this mission, with only a small stipend for the preparation of the mission report which became a book co-authored by all members of the team and published by the World Monuments Fund. This book can be downloaded in English, French or Spanish for free from the World Monuments Fund Website that can be accessed from this link: **www.haiti-patrimoine.org**

The Gingerbread Houses of Port-au-Prince

This article describes the findings of that mission, as well as the use of the Pictometry aerial survey data that Pictometry International generously donated to ICOMOS for the mission. For the mission, this aerial survey was of immeasurable importance because the oblique views allowed us, together with the Haitian homeowners in meetings at the co-sponsoring organization FOKAL, to identify the location of their Gingerbread Houses better than straight-down aerial and satellite views, by revealing their architecture from the side. Their significance became increasingly clear when I began to use them to survey the earthquake damage across the entire damage district.

Figure 1. Like a scene from Dante's Inferno, central Port-au-Prince, 4 months after the earthquake.

Using Adobe Photoshop to merge the hundreds of Pictometry photographs taken from the belly of an aircraft into large maps where the side views of every building were visible taught me the power of this data to provide an impartial and comprehensive view of the building construction and the extent and nature of the damage over large areas of the damage district – areas when seen from the ground would be only in the best of circumstances a small portion of the scene. Even the most impartial observer on the ground would tend to migrate towards areas where the damage was most pronounced, which then affects the objectivity of the assessments, while the comprehensive aerial views can help to avoid this problem.

When our team arrived in Port-au-Prince in April of 2010, four months after the earthquake, we had seen the imagery in the news and early reconnaissance reports. We were first taken to the Oloffson Hotel where we found ourselves in a 120 year old three story unreinforced brick masonry building in excellent condition that had never closed after the earthquake. The only marks on it left by the earthquake were cracks so small that to show them in slide shows later, arrows and circles were needed to point them out, even though a new 9 story hotel lay completely pancaked behind it. In fact, the largest crack found in the walls of this building turned out to be from a rusty bolt embedded in the brick wall!

Figure 2. Left: April 2010 Exhibition at FOKAL in Haiti of murals if the Gingerbread District made from Pictometry images. Right: View showing the Gingerbread houses picked out of the aerial images by their distinctive architecture. The National Palace, which collapsed, is visible in the upper left.

We then began to survey the historic late nineteenth century houses, almost all of which had suffered through a half-century of neglect, some of which were constructed of rubble stone masonry laid in earth mortar, confined only by piers of fired brick in deteriorated lime mortar. Almost all of these houses - even those of rubble stone - were still standing. Some were heavily damaged, but almost all were still standing after an earthquake which was by then reported to have killed as many as a quarter-of-a-million people!

To put this in perspective, a quarter-of-a-million fatalities places this earthquake side-by-side with the Tangshan earthquake of 1976, which caused more fatalities than any other in the 20th century – by an order of magnitude, and more than all but one in all recorded history. With the poverty and bad construction known to exist in Haiti this seemed plausible, especially since it was initially reported by the USGS that this earthquake was calibrated in their initial 'shakemaps' as a Modified Mercalli Intensity (MMI) of IX in Port-au-Prince – a statistic that would later change, as is reported below.[1]

Figure 3. The unreinforced brick masonry Hotel Oloffson, Port-au-Prince after the earthquake.

Determining earthquake intensity in the absence of instrumentation

At the time of the earthquake, it was the widespread collapse of the more formally constructed buildings in Port-au-Prince that undoubtedly fed the perception that a classification of the intensity as an MMI-IX and even an MMI-X (as is still reported in Wikipedia) was correct – not just in the epicentral area near Léogâne, but also extending through Port-au-Prince, 34 km to the east, and even including Pétionville, an additional 8 km further east. At that time it was thought that the fault rupture extended under Port-au-Prince, but this was later determined by USGS to be incorrect.

Two buildings that may have influenced the setting of a high MMI were the pancake collapses of the five star Hotel Montana, and the former five star hotel used by the UN to house its staff in Haiti (Figures 4 & 5). The Hotel Montana had been heavily used by visiting US governmental officials. These two collapses alone killed the head of the UN mission together with much of its staff, as well as a number of US and European dignitaries. Knowledge of these events spread fast, including to the US Geological Survey (USGS) which within hours of the earthquake began publishing their famous shakemaps that, in addition to instrument data where it existed, included subjective data based on analysis of the initial news reports and over the phone interviews.

Figure 4. Five star collapses in Petionville: left: Hotel Montana before, and center after the earthquake (Google images).

Figure 5. UN Headquarters after the earthquake (Google images).

Unfortunately, there were at that time no seismographs in or near Haiti, and so the use of the Modified Mercalli Scale criteria to classify the damage became particularly important as a measure of the ground shaking in this earthquake. Since it must have seemed inconceivable to USGS that these hotels would be less structurally sound than the shanty-town houses that surrounded Port-au-Prince by the hundreds of thousands, the estimation of a high death toll seemed reasonable.

But then, how does one reconcile the still-standing houses with walls of rubble stone, or the practically undamaged Oloffson Hotel with an MMI-IX or X? The reaction of many when told of this is to say that the sites may have experienced less shaking than those areas that were devastated – a not unreasonable response. In fact, a detailed geological study was conducted by a team from the University of Texas, Austin shows the soil strata under the down-Town area to be more responsive to seismic vibrations. However, just up the slope behind the Oloffson a modern nine-story reinforced concrete hotel building pancaked. The chances of a difference in seismic shaking in such close proximity being the reason for such a difference in building performance seems very remote, although the difference in height and stiffness of the buildings may have contributed to the difference in performance. Similarly, throughout the Gingerbread district, which is to the east of the area identified by UT as being the most vulnerable to seismic resonance, the intermingling of the surviving Gingerbread houses with many buildings of more recent construction – usually of RC or concrete block with RC floors, many of which collapsed – made it unconvincing to explain differences in the extent of damages and collapse by underlying soil differences alone.

The Gingerbread houses were of three main construction types: (1) brick and rubble stone masonry, (2) braced wood frame with brick or rubble stone infill, known there by its French name colombage, and (3) 100% braced wood frame of traditional timber framing and/or American balloon framing with wood board cladding. One important feature of those of masonry is that most, if not all, had an iron band imbedded in the walls at the floor and roof levels – which did help to restrain the walls from spreading. Such probably exists in the Hotel Oloffson, but because the building remained intact, and surface hardware, if it exists, is hidden by the wood verandas. Neither this, nor any existence of rubble masonry in its walls could be confirmed, but the existence of a tie and the absence of rubble stonework are both likely, considering the building's good performance.

In almost all cases, the timber framing elements were compromised by termite damage and/or fungal decay – which was in a few cases very extensive. Despite the almost universal lack of maintenance and commonly found decay, it was rare to find even a partial collapse at any of these houses, regardless of construction type. In the buildings with rubble stone, in quite a few instances, the rubble stone sections of the walls showed different gradations of damage from the shedding of exterior stucco to the partial or total falling out of a stone panel – leaving the building still standing on the brick piers which surrounded the rubble sections of the walls.

This damage survey of the Gingerbread houses turns out to be particularly significant when one considers that Giuseppe Mercalli largely used masonry buildings to calibrate the scale above the level of VI when, in the late 19th

Figure 6. Brick and empanelled round-rock rubble stone construction, as is typically found in many of the Port-au-Prince "Gingerbread" Houses from the late 19th century, showing different levels of damage from onset, to collapse of the rubble panels. Center: The 2 ½ story Villa Castel Fleuri Mansion was of rubble stone between brick piers and window surrounds, and only the staircase projection collapsed. The onset of inelastic deformation of the rubble stone panels is visible where the surface stucco has come off. Right: The Dufort House still standing on its brick piers after the collapse of the rubble stone panels. This house is now being restored by FOKAL. Many reinforced concrete buildings nearby collapsed.

century, he developed the scale that bears his name. An earthquake classified as a IX on the MMI scale would be expected to cause "*Damage to masonry buildings… from collapse to serious damage*" whereas what was found in the WMF survey seems closer to the description for an MMI-IV: "…*damage to some poorly built unreinforced masonry buildings [and] some cracks even in better built masonry buildings if not reinforced*." Thus the Oloffson Hotel would qualify as a "*better built masonry buildings*," while the brick and rubble stone mixed construction houses, because of the existence of the rubble stone in clay mortar, inarguably can serve as examples of "*poorly built masonry buildings*." So, using these examples, it would seem that this earthquake is more accurately classified as an MMI-VII, rather than an MMI-IX or X, as has been often cited.

A 'Desktop' Damage Assessment

In the months following the WMF mission, Pictometry generously agreed to extend my access after their invitation to give an address at their annual conference in Orlando, Florida. With this opportunity and the Orlando address in mind, I began to survey the entire damage district in what I call a 'desktop' damage assessment. The WMF mission had already made us all aware of what seemed to be a counter-intuitive discrepancy between the performance of the more than century-old Gingerbread houses of brick, rubble stone, and timber construction that we had come to survey and the rest of the building stock in which the reported quarter-of-a-million people died. However, earthquakes often show anomalies where even seemingly identical buildings constructed next to each other at the same time can show radically different damages, with one collapsed and the other showing minimal damage. Although a century or more old, these were constructed as upper class houses in what is now largely a world of urban poverty in Port-au-Prince.

Figure 7. Left: Pancake collapse of a reinforced concrete building that was located in the Gingerbread District of Port-au-Prince. Right: As a remarkable example of the inherent strength and resilience of a well-constructed reinforced concrete building, this one in Rikuzentakata, Japan was swept onto its side and carried upstream by the March 10, 2011 earthquake and tsunami without being crushed or collapsed (AFP/Getty).

The first step in my desktop survey was to take the results of a World Bank sponsored post-earthquake desktop survey and compare it with the visual information provided by the four directions of oblique views in the Pictometry data. The World Bank had asked members of EERI and the earthquake engineering community to access a special layer in Google Earth which had high-resolution straight-down imagery from a flown survey rather than satellite imagery, and from this imagery mark those buildings showing evidence of partial or total collapse.[2] Since straight down photography shows the roofs rather than the sides of buildings, this required judgment based on the debris field around buildings and the distortion of the roofs.

This allowed me to look first at those areas with evidence of concentrated areas of damage – where the red marks from that survey were densely packed. Following that, I looked at increasingly large areas – mainly over the informal settlements known as "*bidonvilles*" or "tin-can-cities" – where the largest concentrations of the population are located. The results of this were revealing. In summary, despite the fact that there were significant areas of concentrations of building collapses, area after area in the heart of the damage district were revealed as having remarkably little visible evidence of even partial collapses.

In fact, a good number of the buildings in the *bidonvilles* identified in the World Bank survey as collapsed turned out to be misidentified only because they were constructed with roofs that were uneven and discolored – the kind of thing impossible to be able to see from straight-down images alone. Interestingly, the World Bank survey proved to be far more accurate for the downtown commercial buildings than for the *bidonvilles* because there the collapses were more easily discerned.

Figure 8. View of 4 Carrefour Feuilles area bidonville, close to the city center, Port-au-Prince (© Pictometry).

Figure 9. View of 4 Carrefour Feuilles area bidonville, close to the city center, Port-au-Prince showing the unsophisticated rough construction of informal settlement dwellings, with incomplete frames, round-rock rubble stone retaining walls, and unreinforced concrete block construction – that nevertheless did not collapse (Source: Carlos Barria-Reuters).

There were areas – as confirmed by the news and reconnaissance photography on the ground – which did show extensive or complete devastation, and for these, the Pictometry images also have proved to be a remarkable diagnostic resource.[3] Unlike with Google Maps or Google Earth, working directly with the Pictometry website allowed me to download the actual original photographic images as jpgs. This then enabled me to be able to import them into Photoshop, and align two sequentially shot images so that the area of overlap could be excised. This then allowed the export of the images as stereo pairs.

One may ask why this would provide scientific data beyond the possible entertainment value of looking at ruins in 3D, but it proved to be invaluable. It showed that every surveyed area in the bidonville settlements where the damage was widespread or total to be located on a steep slope, and those areas where there were few or no collapses, the slopes were less. Looking at these intact areas more carefully, the damage that one could see in the areas where the damage visible from the air consisted only of isolated wall collapses (often of walls that were under construction at the time of the earthquake and thus without roof or top plates), while in the steep areas, total collapses could often be seen where buildings had cascaded down the hillside, with one perhaps falling on one below, or a foundation being undermined in a mini-landslide. If one considers that poor people will probably not bother to build retaining walls, or if they have, perhaps they have done so without the engineering know-how or access to the proper materials to assure that they will resist earthquake vibrations, this difference between the sites is logical. In fact, many of the retaining walls in Haiti, where they did exist, were of dry laid round river stones between widely spaced concrete columns.

When I embarked on this desktop survey, I did not have a particular idea of what I would find, as my access to sites during the short visit to Haiti for the Gingerbread mission was focused on that one particular area. I had the opportunity to make only a single trip to the city center – which was forced by circumstance to be particularly short when we helped a mother find medical help to save the life of her baby burned badly from a campsite fire. In fact, I expected to find in the desktop survey what the news reports had described – almost total devastation within the informal settlements. The vast encampments of displaced people seemed to reinforce this impression, but many of these people, I later learned, were displaced from buildings that were still sound, but which they were afraid to return to.[4]

As I moved systematically in Pictometry over the landscape of Port-au-Prince, scene after scene came into view showing intact buildings, and I began to realize that this was potentially a significant finding. This was especially the case when a similar survey over the city center revealed the kind of almost total devastation that one expected to find throughout the *bidonvilles*, but which turned out to be concentrated only on particularly steep sites.

There were three areas that were particularly representative of these findings: informal settlements (1) on the hillside above Pétionville a short distance from where the Hotel Montana and the UN residential hotel had stood, (2) on the hillside nearest the city center, the National Palace and the Gingerbread district, and (3) the area known as *Cite Eternal* located on an alluvial fan closer to the epicenter than almost all of the rest of Port-au-Prince. In the case of (1) no collapses could be found, and the damage was thus limited to repairable damage to the dwellings. Colleagues of mine, architects Christopher Andrews and Seth Wachtel of the San Francisco Bay Area, visited this settlement subsequent to the earthquake and confirmed the finding that little damage and displacement of the occupants occurred at this site. At (2), a hillside area showed pockets of heavy damage, but the vast preponder-

Figure 10. City Eternal an informal settlement on an alluvial fan next to downtown Port-au-Prince, with insets (left) showing 2, 3, and 4 story buildings still standing without visible damage, and only evidence of one collapsed building in the view, and (right) evidence of the collapse of RC frame structures, including an open air market structure among other buildings.

ance of the tightly packed cluster of homes that spread over the hills showed little damage visible from the air within the high resolution of the Pictometry images (Figures 8 & 9).

Number (3), known as *Cite Eternal*, was even more remarkable for a number of reasons in addition to being closer to the epicenter (Figure 10). One would normally expect that an alluvial soil site like this would be particularly vulnerable – especially for taller buildings, but three and four story structures appeared in the imagery to not show visible damage, although there may be damage invisible from the air. Also interesting was to find that several buildings around a large central market structure that were of more formal construction of reinforced concrete frame with infill walls collapsed. The rest of the settlement consisted of construction that was more common to informal buildings, which could only be loosely described as confined masonry or simply concrete block construction.

This particular observation was consistent with the larger issue that defines what has happened to the building stock in this earthquake. If the buildings in the informal settlements not on steep sites proved to be more earthquake-resistant than expected, one must then ask the question *why*. As has been documented by the University of Texas – Austin geologists, the soil strata differences can account for some of the excess of damage in the city center, but it is not enough to simply turn to the geological reports to explain all of the difference that one finds. If so, then what about *Cite Eternal* which, at best, is on similar, but more recent, alluvial strata to that under the downtown area where the concentration of the collapses of formal multi-story buildings of recent origin occurred – including many government buildings.

Does this defy the improbability that poor people without training on land they do not own would use higher quality materials, better engineering, and better construction quality control than that found in the formal, contractor-built, and even sometimes engineered structures downtown and in Pétionville? The answer to this question is *no*. The quality of the design, construction and even the materials used in the informal settlements was in fact quite poor as one would expect – they just did not often collapse (Figure 9).

The clue that I believe helps to explain this is the performance of the brick and rubble stone Gingerbread houses. This provides some evidence that the earthquake shaking in most of Port-au-Prince was no greater than an MMI-VII. Only an understanding of this explains the survival of the rubble stone houses and the informal settlement houses – the earthquake, although big, was simply not as strong as had been thought. In fact, the USGS did report that the earthquake was only an MMI-VII in Port-au-Prince in their last and most accurate shakemap published on March 4, 2010 after all of their scientific data had been reported and analyzed and this was also the same as was reported by the UN/European Commission. If this is all true, then the most challenging question is *why did the formal construction – most of which was of reinforced concrete – fail so catastrophically?*

It would be easy here to list all of the reasons why a reinforced concrete moment frame with infill building constructed in Haiti would have defects, such that could cause a collapse in an earthquake, but my ISCARSAH colleagues would already know these reasons. In fact, one colleague from Ove Arup Engineers in Haiti for OXFAM prepared a list of reasons which he shared with me of what he observed were faults he frequently found in the construction of RC buildings. The list came to 20 items, any one of which could have caused the onset of a collapse.[5] However, what is interesting to explore here in relationship to the Pictometry data is why the slum housing – much of which was made of concrete and which, as I have mentioned above, *even of lower construction quality than that of the downtown RC frame buildings* – did better.

At this point in the analysis two facts have been determined: (1) It appears that a reasonable calibration of the shaking using the criteria set by the Modified Mercalli Scale that shows that the earthquake over much of Port-au-Prince, including the city center area, was in the range of an MMI-VII rather than higher. (2) Except for the steep sloped areas, the informal housing of a mixture of concrete block and partial concrete frame and slab elements with site-mixed concrete, salvaged rebar and other materials constructed with little or no training, even if manifesting damage, almost entirely remained standing.

Thus, what still needs to be determined is why a greater share of these poorly made houses – many of which were of more than one story – survived than of the downtown buildings. The conclusion that I have come to is that, no matter how rough the construction was in the *bidonvilles*, the houses were primarily constructed with solid walls, and the reinforced concrete framing elements did not constitute the primary lateral-resisting structural system.

In recent years, 'confined masonry,' in which infill walls are constructed before the reinforced concrete frames, has increasingly been found to be quite resilient. The problem with even applying such terms-of-art in the *bidonville* areas is that many of the houses had incomplete frames, misplaced rebars, large rock pockets, and other faults, but all needed walls to serve as buildings – and for poor people room sizes are small, and thus a level of redundancy is inevitable, as well as the fact that walls go to the ground without an open ground level story (Figures 9 & 10). Because this earthquake was an MMI-VII rather than a IX masonry buildings, by definition, of poor construction are expected to survive with significant damage – so their survival is to be expected, as it is consistent with the survival with damage of the rubble stone buildings.

That then is what is significant about the findings of this Pictometry study – the multi-story RC moment frame buildings with infill masonry that collapsed did so at a level of shaking that did not collapse 19th century buildings constructed of brick and rubble stone, the only reinforcing in which was an iron tie at the second floor level. These RC collapses happened over a wide enough area to buildings of varying height with enough difference to make it difficult to attribute this phenomenon to building-ground resonance alone, as, for example, was a very important phenomenon in the 1985 Mexico City Earthquake.

After arriving at these findings from the Pictometry desktop-survey, I have found that two scholars on the EERI reconnaissance team, Anna Lang and Justin Marshall, came to similar conclusions based on their inspection of buildings on the ground in the *bidonvilles*, as well as in the city center.[6] In their paper, they agree that Haitian RC construction is generally so haphazard that even the use of the term "confined masonry" gives credit for confinement that is incomplete – so they used the terms "column-first" and "wall-first" to distinguish these two types by the order in which the walls and framing elements were constructed. They reported that they observed that "*Infilled frame systems ['column-first'] performed poorly and account for the majority of structural collapses [whereas] buildings assembled in a manner similar to confined masonry ['wall-first'], however, performed well and experienced little damage*." They found this to be the case even though they found that the construction of the 'wall-first' buildings were usually seriously flawed and deficient, which they describe in detail.

How can one fix this in the future? This is a subject for another article, but one place to begin is to explore a recommendation that all construction – except that meeting certain engineering oversight and peer review, with on-site supervision and quality control – be of construction which does not in any way depend on the beam/column intersections of frames for lateral resistance. Such can be of confined masonry, as is already popular in many developing countries, ideally with published and widely circulated guidelines. Consistent with Lang and Marshall's observations, and also with the experiences in India where the government has included "Rules of Thumb" and simple to use guidelines for non-engineered buildings which serve in lieu of formal codes, a requirement that non-engineered RC construction be 'wall-first" would be a manageable first step towards improved life-safety conditions for such construction. For more formal and taller buildings, shearwalls, or the 'Armature Crosswalls' I have proposed for a more economical alternative, are more dependable than moment frames alone.[7] Exploring how to implement such provisions in Haiti and other places similarly at risk, both for existing buildings and for future new construction, is an important subject to explore further than is possible in this article.

Casualties under Pancakes

After undertaking this study, one is forced to ask: "*Where did the oft-reported quarter-of-a-million people die?*" The corollary to this question is: "*Where did this large casualty estimate come from?*" Early in this research, I came across a report that may have served as an early stimulus for such a large figure. It published by RMS (Risk Management Solutions) Corp only 10 days after the earthquake. This report predicted that the casualties could be as high as 250,000 people[8]. This conclusion was based on a USGS shakemap published four days after the earthquake that showed the fault rupture extending under central Port-au-Prince, and an estimated intensity of MMI-IX. In the weeks following the earthquake, the Red Cross reported casualties in the range of 40,000 to 50,000, but the much larger number has seemed to stick, being consistently cited within fifty thousand either way for the past four years. This has been particularly interesting since the data to back up such high numbers was so weak, and because Haiti lacked census data to be able to establish the pre-earthquake population of the area with any certainty and getting an accurate count in the chaos of the post-earthquake environment was impossible.

It is interesting also to see why RMS did come up with this casualty estimate of 250,000 fatalities. On page 7 of the report, it says:

The building vulnerability was assumed to map on average to unreinforced masonry construction, which is extremely susceptible to collapses and heavy enough to cause significant casualties to occupants. This is consistent with the prevalent construction type in the urban regions of Haiti (i.e., blocks/concrete), but actual construction practices vary and include reinforced concrete, reinforced masonry, and unreinforced self-constructed buildings.

After I found this RMS report, I contacted the author of the report, Patricia Grossi, and asked her: "*If at the time you wrote the report, the USGS shakemap had been the one later published on March 4, which reported an MMI VII for Port-au-Prince, would your casualty estimate been different?* Her answer was "*absolutely – it would have been much lower.*" Thus, perhaps an answer to the question of where the quarter-of-a-million people died, may only be that countless numbers of people did die, but not a quarter-of-a-million. The purpose of my research has not been to call into question the body count – and in my experience even the 46,000 to 85,000 people later estimated by anthropologist Timothy Schwartz in a report for USAID that was found and published by the Associated Press on June 2, 2011 is still a vast number of casualties, beyond the scope of wholly accurate counting and of huge impact on the survivors. It is in scale with that experienced in Pakistan in the 2005 Kashmir earthquake and in Iran in the 2003 Bam earthquake, and exceeds the official estimates of even the two catastrophic earthquakes in Turkey in 1999 combined.

My purpose was to try to isolate what can be learned by the Haitian tragedy that may constructively change our thinking about how to influence building construction and maintenance in areas of earthquake risk – by accepting the fact that bad construction of buildings is inevitable. After the earthquake there have been concerted efforts to improve the education of Haitian engineers and builders to raise the standards of reinforced concrete construction, but it is equally important to approach the problem of building construction from a philosophical standpoint – that is to accept the fact that a certain percentage of buildings will be substandard, and thus try to modify the common structural systems in use today such that substandard does not inevitably mean they be so extremely dangerous as they proved to be in Haiti. The difference is what has been demonstrated by the still standing primitive houses in the *bidonvilles* and the pancaked downtown commercial and government buildings. It is not a difference in quality of construction, but a basic difference in typology.

There is a simple reason why RC frames can be so vulnerable if mistakes are made. Design level earthquakes are expected to cause structural damage, even to well-constructed buildings that meet modern codes. With an RC frame structure – the beam/column connections are thus expected to begin to break. Under such circumstances, preventing the building from collapsing, while at the same time allowing its structural frame to yield - that is an engineer's art of the highest order - way beyond the knowledge and capacity of the usual contractors responsible for building these structures. Thus what is needed particularly in developing countries with limited training, enforcement and inspection is the use of construction typologies that are less dependent on good design, and construction quality, than is standard RC infill 'column-first' frame construction.

Conclusion

A report on the Calabria earthquakes of 1905 and 1908 by Italian engineers in the 1932 treatise by John Ripley Freeman described the damage to reinforced concrete dwellings in Melicucca in 1905[9]. Exactly what kind of RC structural system is the subject of the description is not known, but the quotes are interesting nevertheless in light of the vast differences found in the RC buildings in the Haiti earthquake. It says the "*reinforced concrete… dwellings… were nearly all tumbled down in spite of the fact that… the shocks were less violent than elsewhere… because of the poor quality of material used, and lack of proper joints or connections between thevarious members…"* In this description they said these were houses whose builders…classed… as "*reinforced concrete structures* [but] *the subcommittee reported that they had no right to this classification*".

In the next paragraph, they described *"four structures of reinforced concrete in Messina* (where the shaking was much greater) *which remained wholly unharmed… examples of the capabilities of this material when properly used*." These quotes indicate that over a century ago, near the beginning of the modern invention and use of reinforced concrete, it was already being discovered that variations in construction quality resulted in the difference between perfect performance and catastrophe. It is also interesting to see that professional expectations of its potential for good performance should mean that the use of the term "reinforced concrete" should not be allowed. Today, a century later, the same spread from superlative to abysmal performance in earthquakes is still a characteristic of the system.

Figure 11. National Palace in Port-au-Prince after the earthquake and partial demolition, revealing the reinforced concrete frame infilled with rubble stone (© Pictometry).

Figure 12. Detail view showing the reinforced concrete frame with round rock rubble stone infill of the 1916 structure exposed during the demolition of the ruins of the National Palace.

In Haiti, the two iconic symbols of the destruction wrought by this earthquake were the National Palace (Figure 11, 12) and the National Cathedral. Both were reinforced concrete. The cause of the collapse of these two structures, as well as many other 100+ year old churches, was the corrosion of the rebars after a century of exposure to moisture in the tropical environment. Yet only a few blocks away from both, and resting on the very soil identified as subject to the highest shaking, is another structure that few have seen and which has rarely been in the news, but which stands as a remarkable monument to resilience when almost every building around it collapsed – the Saint Louis de Gonzague Chapel (Figure 13). It was as high and about half the length of the cathedral, and about 20 years older – but little damage was visible on the exterior. The structure was of brick masonry with an iron or steel frame. Not only has it not rusted out, despite its age, it has remained standing, even as all of the school buildings around it, some of concrete, and others of timber, collapsed. Much still needs to be known about this church, but perhaps when we are looking at this structure we are looking at the future, and not just at the past. Embodied in this magnificent survivor may be at least one idea of how we can build durable and safe buildings in earthquake areas that can remain standing after an earthquake a century later.

Figure 13. Saint Louis de Gonzague Chapel ca. 1890 in central Port-au-Prince showing external lightweight steel frame on masonry walls.

Footnotes

[1] A more detailed discussion of this research will be published in: Randolph Langenbach (forthcoming) "*Was Haiti in 2010 the next Tangshan in 1976*" ICOMOS Symposium: Tangible Risks, Intangible Opportunities: Long-Term Risk Preparedness and Responses for Threats to Cultural Heritage, Beijing, China, 2012, Proceedings.
[2] **http://www.unitar.org/unosat/node/44/1425**
[3] Further information by scholars in a number of different disciplines can be found in the papers contained in the "2010 Haiti Earthquake Special Issue" of Earthquake Spectra, Volume 27, Number S1, October 2011, published by EERI, Oakland, Ca. USA.
[4] **http://www.buffalo.edu/news/releases/2010/01/10872.html**
[5] Kubilay Hicyilmaz. 2010. Email correspondence with author dated May 31, 2010. To see the list, go to: **http://www.haiti-patrimoine.org/Haiti-RC.pdf**
[6] Anna F. Lang and Justin D. Marshall. 2011. "Devil in the Details: Success and Failure of Haiti's Nonengineered Structures," *Earthquake Spectra*, Vo. 27, No. S1, Earthquake Engineering Research Institute (EERI), Oakland, Ca., USA.
[7] Randolph Langenbach. 2008. Learning from the Past to Protect the Future: Armature Crosswalls, *Engineering Structures*, Elsevier. Vol. 30, No. 8, August 2008, pp. 2096-2100 (**www.conservationtech.com/armaturecrosswalls.html**)
[8] RMS FAQ: 2010 Haiti Earthquake and Caribbean Earthquake Risk: **http://www.rms.com/publications/Haiti_Earthquake_FAQ.pdf**
[9] John Ripley Freeman (1932). *Earthquake Damage and Earthquake Insurance*, McGraw-Hill, New York.

Streets of Jacmel, Haiti

Allen Lowry AIA

James Monday Architect

Abstract

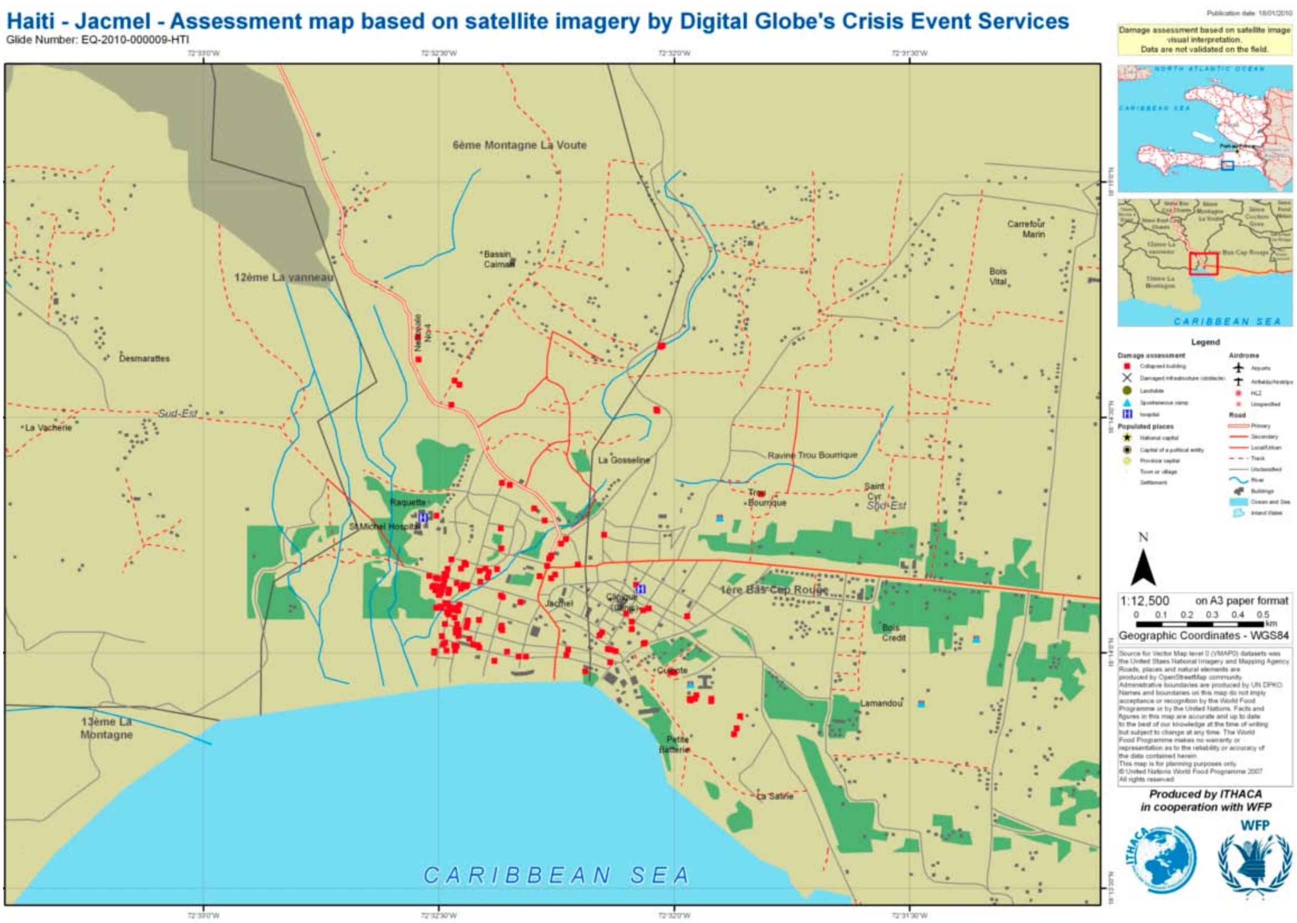
This prospectus states a need and posits a scope of work for the renovation of the Historic Port area of Jacmel, Haiti. After 200 years of important commercial activity, the historic core is in ruins and in danger of being lost to neglect and improper development. Now a UNESCO World Heritage Watch List Site, the need for preservation is more widely perceived.

Known as a unique cultural arts center for Haiti, as well as for its unique yearly Kanaval celebrations, Jacmel has nonetheless remained isolated enough to fail to attract capital investment that would have kept it healthy. Lacking dependable air service, good roads or a serviceable port for cruise ships, Jacmel stands to miss out on the current wave of development seen elsewhere in Caribbean. We are focused on the restoration, renovation and re-development of two port area streets and the beauty of buildings and culture dating to the mid-19th Century.

Jacmel Introduction

Jacmel was founded in 1634, and was one of the major commerce centers in the Caribbean for coffee and cocoa crops grown on the mountainous south coast of Haiti. Most buildings in Jacmel date to the 18th and 19th centuries and are unchanged from their original forms. Jacmel was the original and best deep-water port for Haiti. Many ships called here daily to exchange export crops for fuel and hardware goods. The original Douane (customs) building and virtually all merchant and warehouse buildings remain, though all require extensive repair. Though never a major recreation center, Jacmel acquired and retains a reputation as Haiti's "artist colony". This is a solid foundation on which to build Jacmel's future. This quiet corner of Haiti offers beautiful beaches and soft breezes. The town's downtown district offers a strong immersion in Haitian culture and art, in a setting of fine old historic buildings. This project will demonstrate how sensitive restorations can preserve the past while securing a viable commercial and cultural future for Jacmel, in defiance of historical political and cultural oppression over the past four centuries.

This study was begun in 2012 with a three week trip to Port-au-Prince and Jacmel. We visited many sites and met people from all walks of life, witnessing their struggle and their power to overcome incredible hardships. Allen Lowry returned in 2013 to conduct additional research and to establish better local relationships. It is clear that a more



comprehensive effort is required to accurately evaluate and frame a workable master plan for the historic port and commercial/cultural center of Jacmel, especially now that it is on the UNESCO World Heritage Site Watch List. We believe that our expertise and ability to form consensus with residents can be instrumental in creating a balanced plan between restoration, preservation and new development for Jacmel.
We intend to help create an engine for the indigenous arts culture in Jacmel to stimulate change for economic prosperity in the region by establishing an environmental workshop where artists and critical thinkers take charge of their future and resolve their conflicts with internal and external governments and corporations who have lorded over them to fulfil their own interests. We believe that the Jacmelian culture has the power to stimulate change and that by creating a space for dialogue and activism within this arts colony, new opportunities for re-imagining economic realities will emerge and prevail over traditional institutional conflict and oppression.
We hope that this prospectus will lead to joint venture partnerships and funding to produce a report similar to the Preservation of The Gingerbread Houses of Haiti, by the World Monuments Fund / ICOMOS, the Prince Claus Fund and FOKAL; and that we will be able to establish a community based field office in Jacmel to reach these goals.

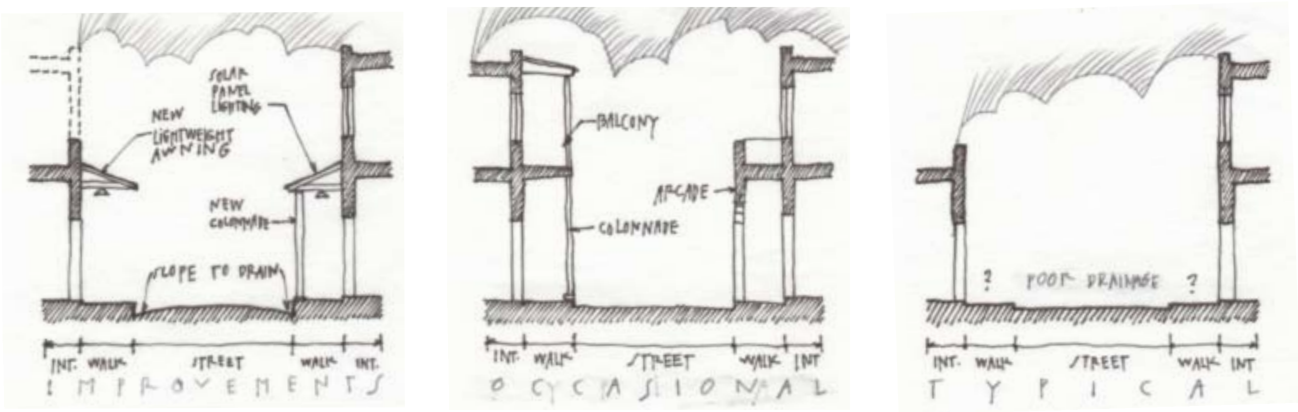
Jacmel History

Founded before Haiti's independence from France in 1804, Jacmel's port served the transport needs of large commercial operations, exchanging crops such as coffee, cacao, sugar and tobacco for foreign trade products. Once wealthy, the city of 60,000 was the first on the Hispaniola Island to have electricity, street lighting and telephones. Jacmel has strong ties to South America and was once home to notables such as Simon Bolivar and John James Audobon.
The large scale of trade necessitated large processing and storage facilities. The port area has many fine examples of old masonry warehouses, many worthy of preservation. Streets were generally wide and offered shaded sidewalks to pedestrians through a series of connected arcades and overhanging balconies. Many of those built of wood burned down in fires, notably the fire of 1895 from which there was only modest permanent recovery. Today, the streets of Jacmel are generally hot and barren and often unpaved. Virtually, all human activity takes place in the few areas of shade, or indoors. Signage and street lighting are virtually non-existent.

Jacmel: Typologies of the city after the 2010 Earthquake

The Ministry of Public Works, Transport and Communications (MTPTC) and The Institute for the Protection of National Heritage (ISPAN) are responsible for "tagging" all damaged buildings in Haiti with ratings that indicate the structural integrity and the occupancy risk to the public with painted stencils and freehand strokes of numbers & colors that are a kind of institutional graffiti. Artists (particularly in the small coastal town of Jacmel) have added their own hieroglyphic narrative on current conditions that are transitive and ephemeral in nature (due to their use of pastel crayons & chalk). The city walls and doorways are their canvasses. If the message is embedded in the medium, their art delivers a powerful statement of their struggle & their optimism in recovery.

Assessment of Buildings & Sites for Development in the Historic Port District.
MTPTC Designation RED: UNSAFE. The building is not reusable with out major structural repairs.
MTPTC Designation YELLOW: RESTRICTED USE. The building is temporarily unserviceable, with significant structural damage.
MTPTC Designation GREEN: SAFE. The building is serviceable, with no or minor structural damage.
VACANT PROPERTY: Suitable for Development.



Jacmel Commerce Street.

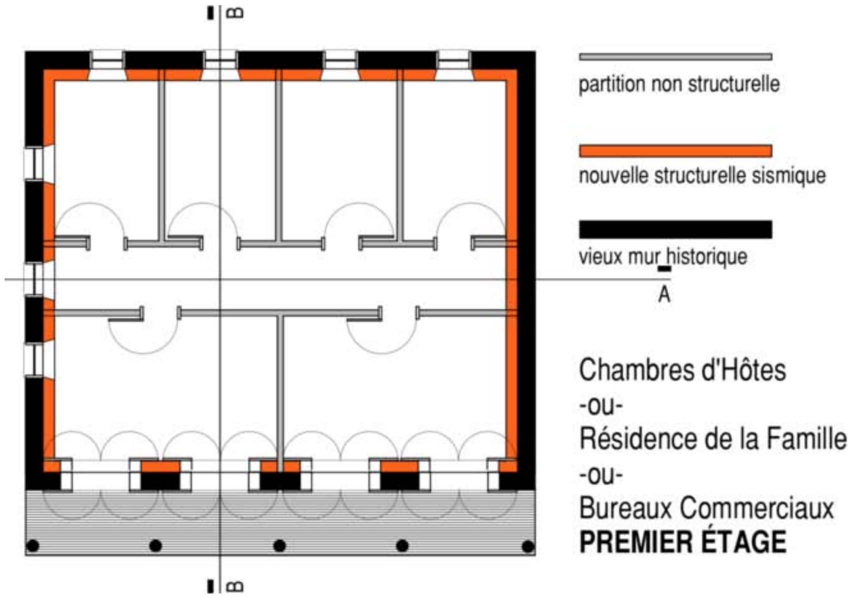
Jacmel: Typologies of the city Douane / Historic Port District

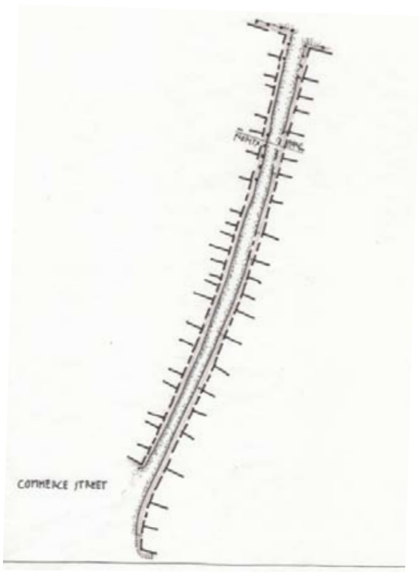
Jacmel is under consideration by UNESCO as a World Heritage site and is currently on their Watch List. Rue Commerce and Rue St. Anne are most associated with this history but are in precarious shape due to the 2010 earthquake. Every new restoration project will leverage both tourist and donor funds necessary to launch and continue life in this remote but beautiful region of Haiti.

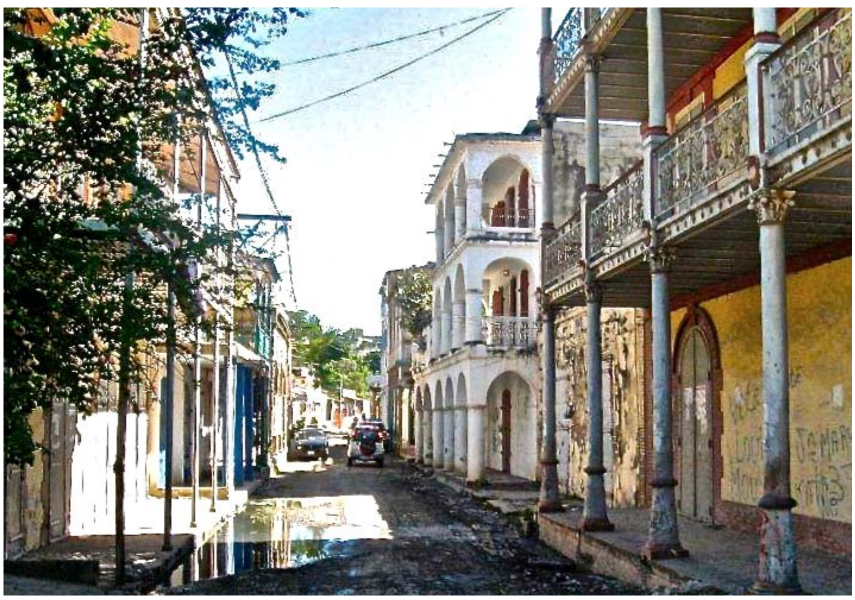
Jacmel: Typologies of the city Rue du Commerce Preservation, Redevelopment Strategy

In general, Jacmel buildings are made of un-reinforced masonry brick or concrete block walls with minimum reinforced concrete or wood beam floors. This method of construction results in buildings that are extremely susceptible to failure in seismic or ground settlement situations.

Poor foundations can exacerbate failures during ground movement events. "X" shaped wall cracking and failures are classic indications of structures lacking sufficient strength to resist even minor seismic events.







Haiti has demonstrated its exposure and susceptibility to major earthquake damage and loss of life, particularly in the southern regions.
The Plantain Garden Zone Fault, active in 2010 is a major threat to strike again. In Jacmel, the typical mode of wall failure expresses this condition; and indicates a need for customized preservation and restoration techniques for walls built in this fashion. Failure to address this threat will lead to further damage, destruction and loss of life.
Such damage will continue to set Jacmel back and will create a real and perceived danger to visitors and investors. The risk to investment in Jacmel's future development will be extremely limiting without establishing and enforcing proper standards for repair.
Restoration of Jacmel's "historic fabric" is essential to its economic and cultural recovery. Historic fabric is original construction, including the original materials, design, finish and placement that allows measurement of the historic truth of the built environment.
One may repair original construction and preserve historic value by restoring and reinforcing what remains, or by replacing structure and buildings with material of identical type and origin.
When streets are repaired, build them back better with adequate drainage, raised sidewalks & underground utilities. Add integrated solar powered lighting to increase pedestrian safety at night.
Add street names at street corners: painted on buildings by local artists.
When buildings are renovated, build them back better with engineered seismic reinforcing materials.
If new buildings are not realistic, retrofit building façades and convert vacant lots to other uses, like pocket parks and local vendor markets.
Add new lightweight porticos and colonnades wherever possible to strengthen the fabric of Jacmel's architectural heritage.

Jacmel: Typologies of the city Re-Development

Every site within the Historic Port District will be fully documented and evaluated by a team of trained restoration architects & engineers to determine the structural integrity and potential for preservation, restoration and/or new development.
Every proposed restoration project will be evaluated for its construction cost and economic potential within a new master plan and guidelines for Historic Port District Standard Guidelines.
Adaptive re-use of existing buildings will be given first priority, to include new spaces for shops, restaurants, galleries, artist's studios, outdoor markets and housing.
With additional funding support, new development sites for hotels, cafés, restaurants & shops along the Embarcadero will be recommended under Historic Port District Standard Guidelines that we will write in partnership with local artists, planners and critical thinkers.

Preservation, Renovation and New Development in the Historic Port District.
BLUE: Re-developed under Historic District Standard Guidelines.
GREY: Renovated under Historic District Standard Guidelines.
GREEN: Restored under Historic District Standard Guidelines.
ORANGE: New Development Site designed to meet Historic District Standard Guidelines.

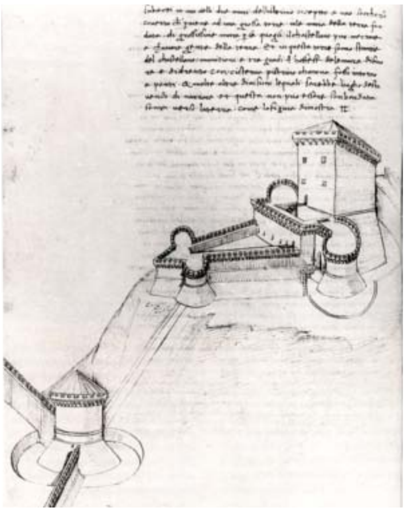
El proyecto de consolidación de la torre de Francesco di Giorgio Martini en Cagli (Italia)

Stefano Gizzi
Soprintendenza per i Beni Architettonici delle Marche - ICOMOS Italia

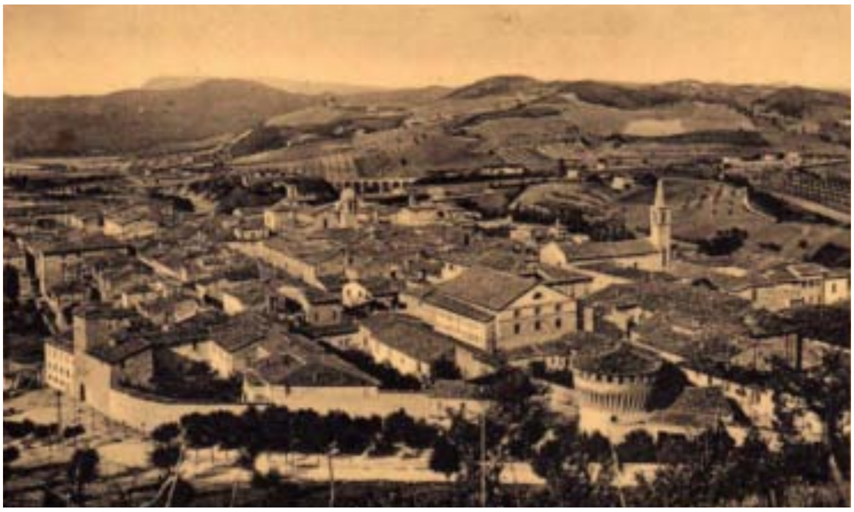
En el marco de la actividad de tutela y conservación que lleva a cabo la Soprintendenza per i Beni Architettonici delle Marche (Italia), se ha previsto, para el año 2014, el inicio de las obras de restauración de una estructura de gran interés y valor histórico, perteneciente al sistema defensivo diseñado por el arquitecto del siglo XV Francesco di Giorgio Martini – célebre por su Tratado de Arquitectura Civil y Militar –, hoy en un estado que amenaza la completa ruina, causada en parte por la destrucción sistemática e intencional iniciada ya pocas décadas después de su construcción.

Se trata de un torreón colocado en la cima de una colina, con vista hacia al centro histórico de Cagli, pequeña población, sugestiva y bien conservada, que surge en el centro de Italia y constituye todavía hoy un notable ejemplo de ciudad renacentista. Dicha torre es uno de los pocos residuos aún existentes del sistema fortificado que protegía la ciudad y que constituía uno de los ejemplos más significativos de edificios de carácter militar realizados por el arquitecto de Siena en las Marcas del Norte[1].

Los escasos restos conservados y que hoy en día se muestran irregulares y discontinuos, aislados y en grave estado de decadencia, estuvieron, al contrario, perfectamente y magistralmente conectados entre ellos, come se puede apreciar en la perspectiva aérea de Francesco di Giorgio Martini, conservada en el Códice Magliabechiano de la Biblioteca Nacional de Florencia[2]. El dibujo muestra cómo la torre superior estuvo ligada a la torre circular inferior por medio de un pasaje subterráneo, que todavía existe, aunque parcialmente ocluido.



El complejo fortificado de Cagli en el dibujo de Francesco di Giorgio Martini. (Florencia, Biblioteca Nacional, Códice Magliabechiano II. 1. 141, fol. 68 v.).



Vista panorámica de Cagli. En primer término, la torre inferior.

El convento de los capuchinos (a la izquierda) y las ruinas de la torre superior (a la derecha).

Como mencionado anteriormente, la destrucción deliberada comienza ya en la época del Duque Guidobaldo da Montefeltro (hijo del célebre Duque de Urbino, Federico da Montefeltro), el cual, en 1502, durante la guerra contra el hijo del papa Alejandro VI Borgia (el Duque de Valentinois), ordenó su desmantelamiento. La destrucción no fue, sin embargo, total, ya que se conservó enteramente la torre inferior y una parte de las estructuras defensivas que fueron incorporadas en el cercano convento de los frailes capuchinos, erigido a mediados del siglo XVI.

Dada su importancia histórica, la Soprintendenza ha incluido en su

programa trienal de intervenciones, la restauración de los restos de la torre superior, gracias a la disponibilidad de recursos extraordinarios recabados de los fondos de la lotería, que permitirán ejecutar la obra en tres fases[3].
Desde el punto de vista estructural, uno de los temas preocupantes concierne el acentuado debilitamiento de la base de los muros de mampostería de la torre. A primera vista, la intención sería la de reconstruir intensivamente las partes faltantes; sin embargo, es importante señalar cómo ya, en proyectos anteriores lamentablemente no financiados, la Soprintendenza había adoptado el criterio de la mínima intervención (según la acepción acuñada por Gustavo Giovannoni), es decir limitando lo más posible la transformación de la imagen del edificio. Por lo tanto, el proyecto se concentra sobre todo en la reintegración del núcleo de mampostería, en línea con otras intervenciones efectuadas en Italia sobre todo en contextos arqueológicos, como el Templo de Venus Cnidia en la Villa Adriana, la tumba de los Horacios y Curiacios en Albano o los diversos sepulcros de la época romana existentes en la via Appia Antigua.
Efectivamente, este tipo de intervención se ha afirmado, desde los inicios del siglo XX, en varios monumentos famosos de la antigüedad, empezando por la restauración, de los años Veinte del Novecento y dirigida por Jules Formigé, de los Trofeos de Augusto en La Turbie (Monte Carlo), quien logró detener, restaurando únicamente el núcleo, el deterioro muy avanzado de ese edificio de la época imperial.

Porción del sistema defensivo superior y su estado de deterioro.

Las estructuras de la torre superior con el paisaje de las Marcas.

A la izquierda y al centro, ambientes interiores abovedados; a la derecha, detalle del núcleo de mampostería, con inserciones de la piedra llamada *marmarone rosado*, presente en otros edificios militares de Francesco di Giorgio Martini.


Estado de deterioro de la base del muro de la torre.


La torre superior, reducida a núcleo, con fragmentos en *opus listatum.*


La torre inferior, recién restaurada.


Interior del pasaje de conexión entre las torres superior e inferior.

Los muros de la torre superior de Cagli están constituidos por un relleno de mampostería realizado en piedra caliza, mezclada con fragmentos de piedra y de ladrillo. La piedra caliza es la llamada *marmarone* rosado de Cagli, diferente del *marmarone* almendrado, presente en las fachadas de los palacios monumentales de la zona. Se trata de una piedra compacta y dura, que se encuentra en otros edificios atribuidos a Francesco di Giorgio Martini, existentes en el territorio de las Marcas[4]. El paramento original, del que se conserva sólo una parte muy limitada, está también realizado en piedra caliza y en piedra rosada de Cagli, dispuesta en hiladas regulares, mientras que en algunas partes, probablemente de épocas posteriores, se presenta como un *opus listatum*. En otros puntos del edificio se reconocen diferentes intervenciones efectuadas a partir del siglo XVI; sin embargo las más incongruentes parecen ser las ejecutadas en épocas más cercanas a la nuestra, de las que desafortunadamente no se conserva documentación alguna. El acabado final de las torres, tanto de la superior como de la inferior, consistía en una fina capa de revoco, de la cual se han encontrado algunos restos bajo la cornisa de la torre inferior, que, al contrario de la superior, se encuentra muy bien conservada y ha sido restaurada recientemente.

El proyecto de restauración se basa en el uso de técnicas y de tecnologías tradicionales, con reintegraciones de la mampostería faltante, efectuadas al pie de los muros para evitar el riesgo de colapso por cargas puntuales, así como en la restitución mínima de algunos sillares con el fin de otorgar mayor resistencia a la base. Se evitarán inserciones ocultas de elementos metálicos, que darían lugar a un comportamiento estático muy localizado, y someterían el antiguo núcleo a una función puramente estética. Si bien es cierto que del *marmarone* rosado existen varias canteras históricas en los alrededores de la ciudad, uno de los problemas de esta intervención es que tales canteras están hoy protegidas por la ley y no está ya permitido extraer material; sin embargo se debe recordar que, en otros países del Mediterráneo, en el caso de la restauración de algunos monumentos excepcionales se ha permitido volver a cavar la piedra de las canteras cerradas, como ha sucedido, por ejemplo, con las de mármol pentélico, que el arquitecto Manolis Korrès logró reabrir para intervenir en el Partenón. La operación se completa con el uso de un mortero a base de cal, libre de sal, mezclado con arena de *pozzolana*, capaz de garantizar una excelente resistencia. Se prevé también la eliminación de los empujes de la tierra y la remoción de las raíces y de la vegetación, prestando la máxima atención a la relación con el contexto ambiental y paisajístico de los alrededores. Se trata, por ahora, de una intervención dirigida más a la consolidación que a la reconstrucción de una hipotética *facies* de la torre superior, que sólo sería posible realizar en caso de que se encontrara nueva documentación de archivo.

Notas

[1] M. Dezzi Bardeschi (ed.), *Francesco di Giorgio e l'ingegneria militare del suo tempo*, Artigraf, Firenze 1968; G. Volpe, *La Rocca di Cagli*, en F. P. Fiore – M. Tafuri (ed.), *Francesco di Giorgio architetto*, Electa, Milano 1993, pp. 226-229; D. Cardamone, *L' "ingegnario" Francesco di Giorgio Martini nelle Marche*, in "Rimarcando", n. 2, 2007, pp. 68-73.

[2] Firenze, Biblioteca Nazionale, Codice Magliabechiano II. 1. 141, fol. 68 v.

[3] Director Regional de Bienes Culturales Lorenza Mochi Onori, Soprintendente Stefano Gizzi, Proyecto Biagio de Martinis, Consulente Mario Lolli Ghetti.

[4] Cfr. A. Mazzacchera, *La Rocca e il Palazzo pubblico del Duca Federico da Montefeltro. Nuovi documenti e riflessioni sulle fabbriche di Francesco di Giorgio a Cagli*, en F. Colucci (ed.), *Contributi e ricerche su Francesco di Giorgio nell'Italia Centrale*, Simposio di Studi, (Urbino, 22 marzo 2003), Ed. Comune di Urbino, Urbino 2006, nota 51 a p. 128.

Comparison of calculated and measured dynamics characteristics of the Church of St. Peter and St. Paul, Prague (Czech Republic)

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Stanislav Pospisil - Structural Engineer. ITAM Czech Republic

The Church of St. Peter and Paul, in Prague, Czech Republic, is a historical construction. It was observed that the triangular gable wall in the façade, due to the ringing of the bells, started to vibrate out of its plane. The dynamic properties of the church were measured with accelerometers in 2002, and then it was concluded that the gable was in resonance with the ringing of the bells, so it was necessary to retrofit it. In the year 2007, after the retrofit of the gable, again the dynamic properties of the church were measured, and it was concluded that the gable was not in resonance with the ringing of the bells.
The values of the dynamic characteristics of the building, before and after the retrofit of the gable, were obtained only using experimental techniques. In this investigation these parameters were obtained with structural models, and then they were compared with the experimental values.
With the structural model and the experiment for the year 2002, it was possible to determine that the gable was in resonance due to the ringing of the bells. And in with the model and the experiment for the year 2007 it was possible to conclude that the retrofit works avoid the resonance phenomena.

1. Introduction

The Church of St. Peter and Paul, is a historical construction that was built between the 19th-20th centuries with traditional materials (stone, bricks, covered with slate on wooden truss). It was observed that the triangular gable wall in the façade, due to the ringing of the bells, started to vibrate out of its plane. Because of this situation, the dynamic properties of the church were measured with accelerometers in 2002, and then it was concluded that the gable was in resonance with the ringing of the bells, so it was necessary to retrofit it. In the year 2007, after the retrofit of the gable, again the dynamic properties of the church were measured, and it was concluded that the gable was not in resonance with the ringing of the bells.
The values of the dynamic characteristics of the building, before and after the retrofit of the gable, were obtained only using experimental techniques. The other possibility to obtain these values is with structural models. In this investigation these parameters were obtained with structural models, and then they were compared with the experimental values.
If the mechanical properties and geometrical characteristics that are necessary to take into account for the model are conservative, and the boundary conditions are according to the real conditions, the values are going to be acceptable (in the tolerance range).
In this specific case, the experimental results of the frequency of the historical building were very useful because they helped to calibrate the analytic model.

1.1 State of the art

The mechanical properties of historical constructions, together with their complex configurations, often make it difficult to apply dynamic actions in order to study their structural response.
In structures as bell towers, the motion of one or more of the bells present can be exploited to produce distinct dynamic actions. In that case, it is possible to compare the experimental dynamic behavior of such a tower with the values predicted by discrete models. This procedure was followed in different historical buildings, for instance:
(a) Matilde's Tower in San Minitao Italy (Beconcini et al, 2001).
(b) The Wisłoujście Fortress in Gdańsk, Polland (Szymczak et al, 2006).
(c) The Arch-Cathedral Belfry in Vilnius, Lithuania (Szymczak et al, 2006).
(d) San Nicolás bell tower in Valencia, Spain (Ivorra et al, 2006).
In all the cases, according to the results that were obtained in the

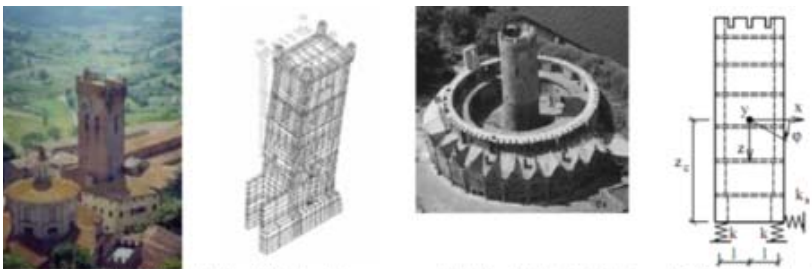
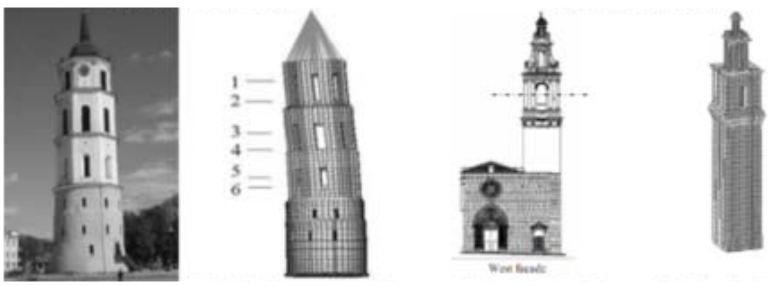


Figure 1. Discrete Models of Historical Constructions(a) Matilde's Tower in San Miniato, Italy (Beconcini et al., 2001); (b) The Wisłoujście Fortress in Gdańsk, Polland



(c) The Arch-Cathedral Belfry in Vilnius, Lithuania (Szymczak et al, 2006); (d) San Nicolás bell tower in Valencia, Spain (Ivorra et al, 2006).

investigations, when the values of the frequencies were compared, they were acceptable because they were in the tolerance range (±10%). The experimental values corresponds to the frequencies values that were measured "in situ" with accelerometer. The predicted values were obtained with discrete models. The pictures of the towers and their structural model are presented in Figure 1.

1.2 Scope

For the structural model, because it was focused in study the response of the gable, before and after the retrofit, only a section of the structure was modeled, with Finite Element Analysis, using the software SAP 2000. For this model, the elements were considered as shells (2D elements), the soil was considered as completely rigid, the masonry was assumed as homogeneous and isotropic, and the analysis was carried out only in the linear range.The calculated dynamic characteristics correspond to the eigen frequencies values obtained with the dynamic analysis of the structural model.

For the measured dynamic characteristics, the previous data (ITAM Reports) for the year 2002 (before the retrofit) and the year 2007 (after the retrofit) were taken into account. In both cases the structure was excited by the ringing of the bells, and then the frequencies were obtained analyzing the results in the frequency domain. The results that were analyzed in this investigation were the values that were obtained due to the dynamic excitation caused by the bells J1 and J2.

2. Description of the Structure

The Vratislav II´s Kostel Sv Petra a Pavla (Church of Sts Peter and Paul) is located in Vyšehrad, in Prague, Czech Republic. According to the ISCARSAH (International Scientific Committee For Analysis and Restoration Of Structures of Architectural Heritage) Recommendations (2001), it is very important to recognize that conventional calculation techniques and legal codes or standards oriented to the design of modern constructions may be difficult to apply, or even inapplicable, to ancient structures. And because of that, it states the importance of a scientific, multidisciplinary approach involving historical investigation, inspection, monitoring and structural modeling and analysis (Figure 2).

So according to these recommendations, it was reviewed the history of the church, the present condition (structural configuration), the monitoring (data), and then the structural model that was performed.

Figure 2. ISCARSAH Recommendations (2001): History; Present condition; Monitoring; Structural Modeling.

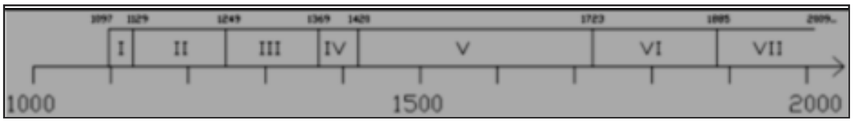


Figure 3. Time Line.

2.1 History

The history of the Church of St. Peter and Paul at Vyšehrad starts after the year 1070, when the King Vratislav I founded the Chapter House. According to Necavátal (2000), the church has been rebuilt and modified since 1070, so its history could be divided in 7 periods (the time line is shown in the Figure 3): I. Romanesque (First Stage); II. Romanesque (Second Stage); III. Early gothic; IV. High gothic; V. Renaissance; VI. Baroque; VII. Neo Gothic. The seventh building stage was a neo-Gothic reconstruction, which has been preserved up to the present. It took place between 1885 and 1903 according to plans of the master builder, Joseph Mocker. Regarding the bells, they have been preserved from the original Renaissance section of the building, and they now grace the present neo-Gothic church.

2.2 Present Condition (Structural Configuration)

The cathedral was built with traditional materials (stone, bricks, covered with slate on wooden truss). The building is made up of three naves (Figure 4, plan view); its total width is 30 m and the length 56 m . The height of the roof crest is 28 m. As it could be observed in Figure 5, there are two towers in the façade: both have the same height: 60 m. The square cross-section of each tower is 7 m × 7 m, the bells are hung in classical wooden stools placed at the level about 29 m. There are two old bells in the southern tower (J1, J2), four recently mounted ones in the northern tower (S1 – S4). All bells exert swaying motion driven separately by electric motors. Besides, there is a set of 12 stable bells with clappers controlled by computer in northern tower, used for playing some song. The material of the walls is masonry mainly constituted by stone and lime mortar. The thickness of the masonry of the building varies between 0.3 m and 1.2 meters, it depends where the masonry is located in the building. Basically the thickness of the lateral walls is 1 m, and the thickness of the walls that are in the façade is 1.2 m.

Regarding the mechanical properties, conservative values for this masonry are: specific weight 22 KN/m3 and elastic modulus 4 GPa

Between the two towers, it is also possible to see the gable, but its description is in the next section. The church interior was recently refurbished and also its structure seems to be in good order and condition (Figure 6). In the lateral view (Figure 7), it could be seen that also the state of the walls are in good condition.

2.3 The Gable

A gable is the generally triangular portion of a wall between the edges of a sloping roof. The shape of the gable and how it is detailed depends on the structural system being used

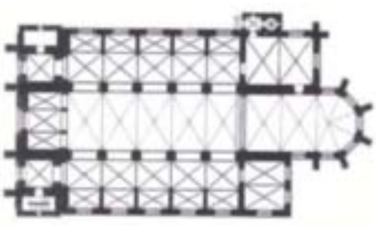


Figure 4. Plan View. (Necavátal, 2000); Figure 5. Front View (Necavátal, 2000).

Figure 6. Interior of the Church (Necavátal, 2000); Figure 7. Lateral View(Necavátal, 2000).

Figure 8. Main facade and detail of the gable.

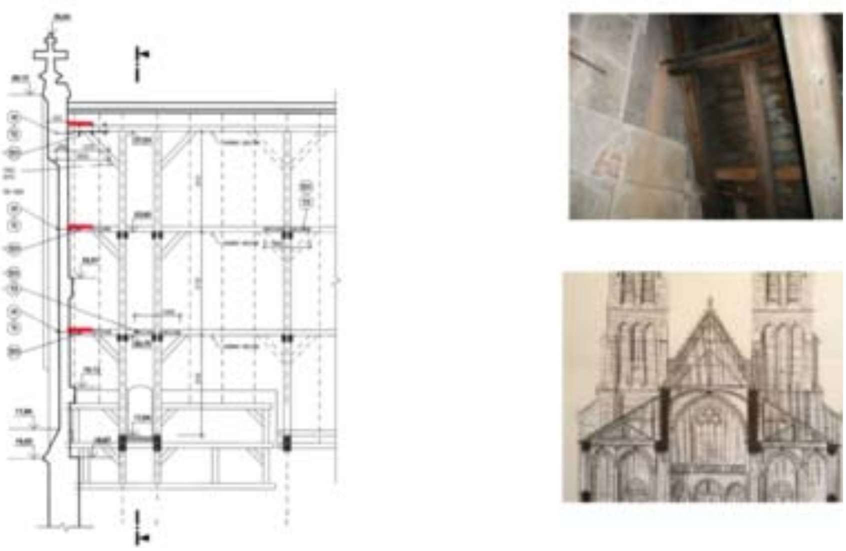


Figure 9. Details of the retrofit of the gable (ITAM, 2007): (a) Lateral view; (b) Detail of the retrofit; (c) Detail of the timber truss.

(which is often related to climate and availability of materials) and aesthetic concerns. Thus the type of roof enclosing the volume dictates the shape of the gable.

In the Church Sts Peter and Paul, the triangular gable wall over the main entrance starts at the height of 19.60 m above the church floor, its width between both church towers is 9.0 m and the height of its rectangular part fixed into the towers is 2.60 m. The height of the free-standing triangular part is 8.70 m and the cross on its top reaches the height 30 m. The gable wall does not lean against the wooden construction of the roof covering the main nave of the church. The thickness of the masonry of the gable is 0.57 m, but the niches containing statues reduce it to 0.27 m. (Figure 8).

In the year 2002, a study of the church (ITAM, 2002) concluded that the swaying bells excite the structure by considerable horizontal forces with frequencies of one, two and three multiple of the bells motion. This excitation can be amplified by resonance effect of an arbitrary structural element, which is tuned to one of these frequencies. Because of that, some works (repair measures) were developed in the gable.

2.3.1 Repair Measures of the gable

In order to change the natural frequency of the gable, some steel plated were anchored in the gable and fixed to the structure of the roof. In the Figure 9 (a) is presented in red, the position in the lateral view of these steel plates.

In the Figures 9 (b) is presented the detail of how the steel plate was anchored in the gable and then fixed in different timber elements. The objective was to take advantage of the stiffness of the timber truss out of the plane (this structural element is presented in the sketch in the figure 9 (c).

With this work, it was possible to change the restrictions of the movement of the gable out of its plane, and as it was reviewed in the experimental tests it helped to avoid the resonance phenomena. Also in the structural mode, it is going to be possible to take into account this retrofit.

3. Monitoring (Data)

The data that was analyzed corresponds to the measurements on the church building that were done by ITAM (Institute of Theoretical and Applied Mechanics, Academy of Sciences of the Czech Republic) in the year 2002 and 2007.

3.1 Explanation of the Procedure

The ringing of the bells was used in order to excite the structure. There are two old bells in the southern tower (J1, J2). The bells exert swaying motion driven separately by electric motors. Besides, there is a set of 12 stable bells with clappers controlled by computer in northern tower. The characteristics of the bells are given in Table 1 and the picture of one of the bells is presented in Figure 10.

Figure 10. Bell J1.

Table 1. Parameters of the Bells J1 y J2 (ITAM, 2002)

Bell No	Tone	mass (kg)	f requency(Hz)
J1	E1	1000	0.44
J2	F sharp1	600	0.44

Note: The frequencies of bells' swaying were averaged from the measured response

Table 2. Description of the Position of the Points (Itam, 2002)

Point No	Position	Structural element
12	Southern tower top	Southern tower
20	Southern tower above bells	
2	Southern tower bells level	
21	Southern tower gable base level	
22	Southern tower bottom	
6	Gable top	Gable
7	Gable low, center	
8	Gable low, right	
9	Gable low, left	
4	Gable base	
10	Northern tower above bells	Northern Tower
11	Northern tower gable base level	

Figure 11. Measuring points in the façade (ITAM, 2002)

Figure 12. Measuring Point in the Façade, Point 8; Figure 13. Measuring Point in the Façade, Point 10.

In order to recover the structural response of the structure, due to the dynamic excitation of the ringing of the bells, 12 measuring points were chosen on the front wall of the church They were placed in the following positions: 5 along the height of the southern tower, 5 on the gable wall, and 2 on the northern tower. The description of each point is described in Table 2 and in Figure 11 is presented the position of each point. In each point an accelerometer was placed. For instance in the Figure 12 is presented the accelerometer in the point 8 and in the Figure 13 is presented the accelerometer in the point 10. The objective was to measure the acceleration out of the plane of all these points due to the swaying of each bell.

3.2 Evaluation of the Result

For each point, once its data was analyzed, the Root Mean Square (RMS) of the displacements in millimeters (mm) and the frequency peaks in Hertz (Hz) were evaluated. As the registrations were more or less of the sinusoidal shape, the informative maximum amplitudes were checked as √2 × RMS value.

So for instance, due to the dynamic excitation of the ringing of the bell J1, in 2002, it was possible to recover in the point 6 the graph that is presented in the Figure 14. In those graphs is possible to determine according to the spectral density (mm2/s) the peak that correspond to the frequency related with the modes of structure.

According to the results for the point 6, is possible to determine that the peak is related with a frequency of 0.88 Hz, and the other peaks of spectral density with frequencies of , 1.76 Hz and 2.64 Hz. The frequency that has the highest value of spectral density is 0.88 Hz, so for this reason in the Table 3, this value is underline. In the Table 3, is presented the values of the peaks frequencies for each point, due to the dynamic excitation with the ringing of the bell J1 and the bell J2.

In this Table, as it was commented before, the value of the frequency that has the highest value of spectral density in each point in underlined. The other value that is presented corresponds to the RMS of the displacement in millimeters.

In the structure, the swaying bells excite it by considerable horizontal forces with frequencies of one, two and three multiple of the bells' motion. This excitation can be amplified by resonance effect of an arbitrary structural element, which is tuned to one of these frequencies.

The important vibrations found on the construction were those of the free standing triangular gable over the church entrance. It behaved as a cantilever and - due to the resonance effect – amplifies the negligible excitation of the base into about centuple response of the top. Actually, in the Table 3, the highest value of RMS displacement is for the point 6, and this one is located in the top of the gable.

In the report of 2002, the ITAM stated that: "The gable wall of the church under consideration is most probably damaged due to the ageing process of its masonry, and has to be retrofitted either by restoration the mortar joints or by reinforcing the gable, e.g. by an additional supporting system inside the church garret." Due to this recommendation, it was performed a retrofit work, that is described in the section 2.3.1 Repair

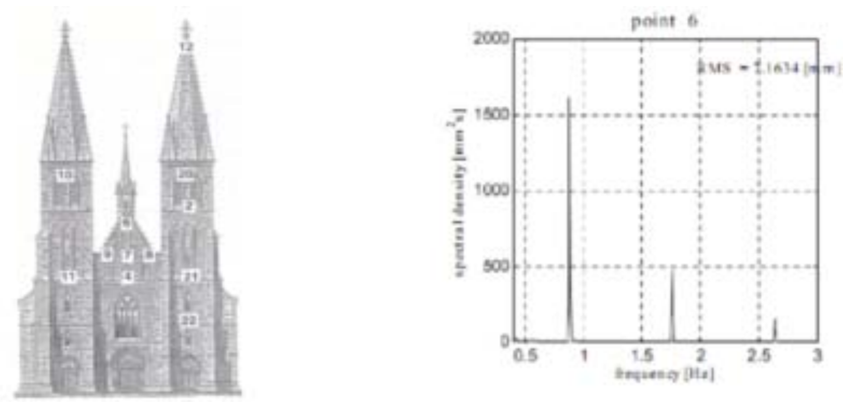


Figure 14 Measuring points in the façade Points 4 (2002). (ITAM, 2002).

Point No	Bell J1 Freq (Hz)	Bell J1 RMS (mm)	Bell J2 Freq (Hz)	Bell J2 RMS (mm)
12	0.44; 0.88; 1.32	0.154	1.32	0.325
20	0.44; 0.88; 1.32;1.77	0.108	0.44; 0.88; 1.32	0.218
2	0.44; 0.88; 1.32;1.77	0.08	0.44; 0.88; 1.32	0.218
21	0.44; 0.88; 1.32;1.77	0.051	0.44; 0.88; 1.32	0.058
22	0.44; 0.88; 1.32;1.77	0.054	0.44; 0.88; 1.34;1.77	0.048
6	0.88; 1.76; 2.64	7.163	0.88; 1.33; 1.77; 2.66	4.944
7	0.44; 0.88; 1.32; 1.77	0.063	1.32	0.233
4	0.44; 0.88; 1.32; 1.77	0.053	0.88; 132	0.078
11	0.44; 0.88; 1.76	0.050	0.50; 0.88; 1.78	0.040

Table 3. Results for 2002 (ITAM, 2002).

Bell	Bell J1				Bell J2			
Year	2002		2007		Year		2002	
Point	f	RMS	f	RMS	f	RMS	f	RMS
12	1.32	0.15	1.32	0.21	1.32	0.32	1.33	0.69
20	1.32	0.11	1.32	0.13	1.32	0.22	1.33	0.43
2	1.32	0.08	1.32	0.10	1,32	0.211	1.33	0.32
6	0.88	7.37	1.32	0.06	0.88	5.48	1.33	0.18
11	0.88	0.05	1.32	0.004	0.88	0.04	1.33	0.006

Table 4 . Comparison of the Results Measured Before (2002) and After (2007) the Retrofit.

Measures. Once all the works of retrofit were done, in 2007 the ITAM was asked again to measure the dynamic response of the structure, and specifically of the gable due to the ringing of the bells. The results of the measures of 2007, and there correspond value of 2002, are presented in the Table 4.
So according to these results, it is possible to determine that the frequency of 0.88 Hz is not present anymore in the structure once the retrofit work was done. This frequency was related in 2002 with the resonance of the gable, and according to the results of 2007, the retrofit is good, because it changed the boundary conditions of the gable, and then its natural frequency, in the way that nowadays the gable is not in resonance with the ringing of the bells.

4. Structural Model

Initially, it was used a simple model for the Gable, the problem with this model, was that it was possible to obtain a good approximation of the first mode, but for the other modes, second or third, the results were so far of the experimental value.
Because of this situation, a model of the façade was carried out, and the elements where shells (2-D elements with thickness).

The masonry corresponds to a historical construction, so to be concerned about the cracks and general damaged in the masonry, a value of effective inertia was taken into account. Because of this consideration, instead of a value gross value of the second moment of inertia (Igross) a value of effective inertia was calculated and it was part of the input in the mechanical properties.
The relation of the effective Inertia (Ieff) and the gross Inertia (Igross), is established with the following equation:

$$Ie_{ff} = \alpha I_{gross} \qquad (4.1)$$

In this equation ɑ corresponds to a rigidity coefficient. This value of ɑ varies between 0.5 and 1. According to the results that were obtained, the values of frequency that were closer or at least in the tolerance range were when a value of a was considered equal to 0.6, so the results that are presented correspond to this value of ɑ.

4.1 Model for 2002

For the model of year 2002, initially a model focus on the gable was performed (Figure 15), the problem with that model was the fact that the eigen frequency was 1 Hz, and then the values of the eigen frequencies for the modes tow and tree were 4.5 Hz and 5.8 Hz. Values that if they are compared with the experimental values are so far away, specially for the second and third mode.
The problem with this first model approach is related with the fact that the boundary conditions that were taken into account did not reflect the real situation of the connection of the gable and the towers. The restriction out of the plane was completely fixed, but the real situation is that there is a stiffness associated due to the walls out of the plane and the mechanical properties of the masonry that influences it. In this model was assumed that the restrictions out of the plane (the green points in Figure 15) were fixed, but the real situation as it was commented, is that they could move out of the plane but with the restriction of the towers, walls out of the plane and the façade.

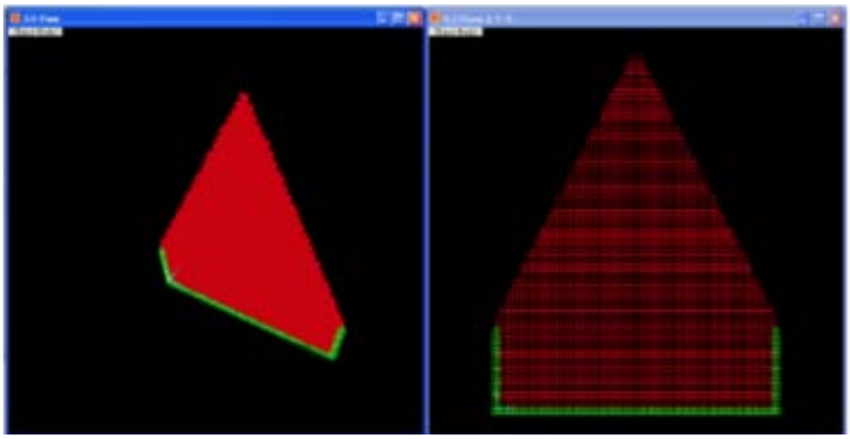


Figure 15. Simple Model of the Gable.

in this 3 D model, the elements that composed it, are 2D shell elements.
Once the geometrical configuration of structural model of 2002 was figured out, it was defined the thickness of each element.
In the model different colors were assigned to a specific thickness, according to that selection, in the Figure 17 is presented the façade of the model. The four values of thickness that were determined were 30 cm, 60 cm, 100 cm and 120 cm, and respectively the colors that were assigned were green, red, yellow and blue.

Because the model that was performed did not bring good approximations, and the boundary conditions that were assumed did not reflect the real situation, it was decided to model a section of the building.
In the Figure 16 is presented the section of the church that was considered. The reason of why also the towers were included in the model was that they could help to model better the restric-

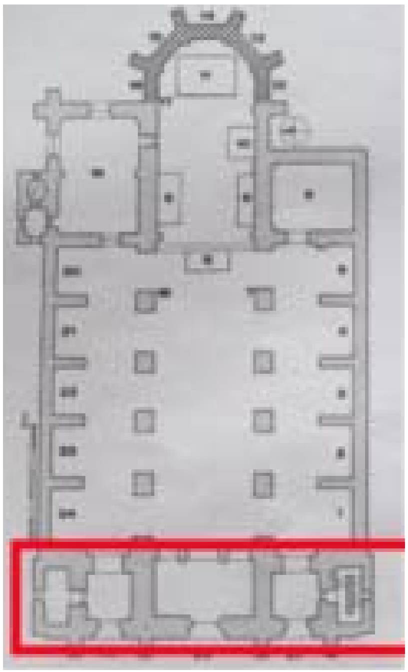


Figure 16. Section of the Church that was Modeled.

tions out of the plane and also that in them are the bells and the spires, and they are considerable weighs that influence the result of the eigen values.
According to the recommendations of Lourenço, 2001, that were already commented in section 3.1,

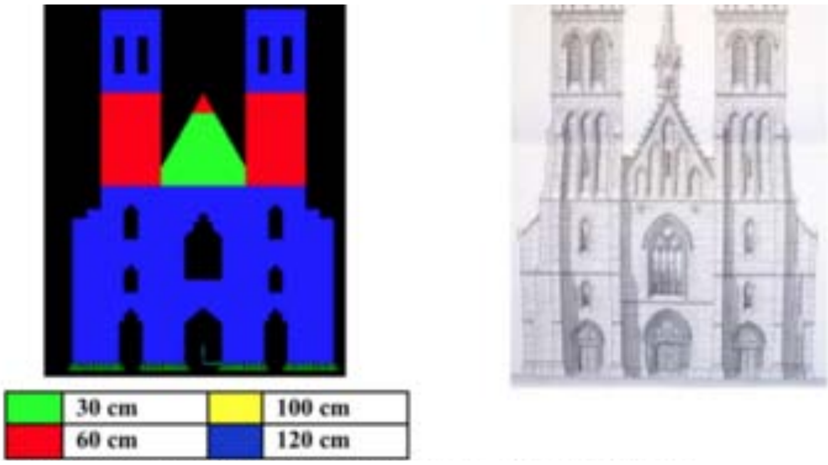


Figure 17. Thickness of the Shell Elements in the Structural Model.

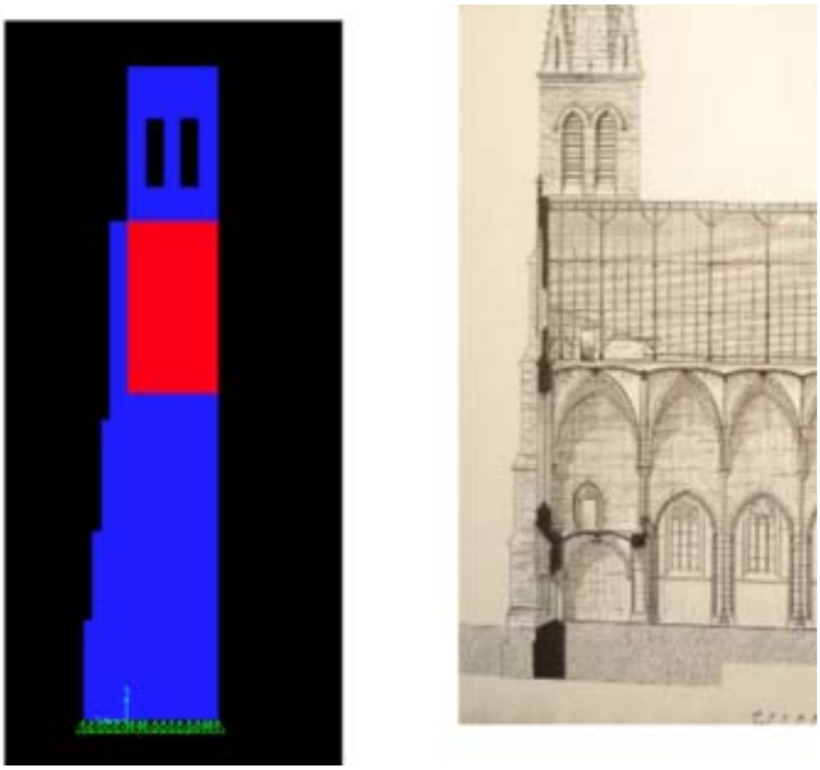


Figure 18. Change in the Length of the Walls Perpendicular to the Façade.

In the façade presented in Figure 17, is possible to see that the thickness of the gable is 30 cm, and in its top is 60 cm, in order to considerer the fact that in this part has a spire. The sculptures that are in this area were not included because they are not linked to the gable.
For the tower there is a section were the masonry is thicker, it is between the height of 19 m and 29 m. Because of that reason in the model is possible to see that in this section of the tower the color of the elements is red (60 cm)
Another important fact that had to be considered was the openings, specially the arches over windows and door openings. Initially the arches were not considered, but once the first results were obtained, it was observed that they influenced the stiffness of the façade out of the plane.
The walls out of the plane were considered, because they are related with the restriction out of the plane of the façade. In the model those walls were review in order to represent as much as possible its influence in the restriction out of the plane of the façade. In the model as it is presented in Figure 18, the difference of the length of wall was considered; the thickness of those walls is constant.

4.1.1 Results of the model 2002

For the model of 2002, three eigen values were obtained. The first mode is related specifically with the gable. It consists in the oscillatory movement of the gable out of its plane, the value of the eigen frequency is 0.83 Hz, in the Figure 57 is presented the modal shape. As it could be seen, in Figure 17, the movement is related with the gable out of its plain. Just in order to take into account, the excitation due to the bells was 0.44 Hz, so the value of this mode corresponds to a harmonic of that value, so clearly the gable is in resonance.
For the second mode, i is related with the towers, moving out of the plane of the façade. In the structural model, it was obtained two values of eigen values that were very closed, 1.35 Hz and 1.36 Hz. In order to compare those values with the experimental values, they were grouped as mode 2, but in order to see the difference in the mode shape, they were called mode 2a and mode 2b. The modal shape of the mode 2a corresponds to the movement of the two towers in the same direction, out of the plane of the façade, The mode 2b corresponds to the movement of the towers in opposite directions, again out of the plane of the façade.

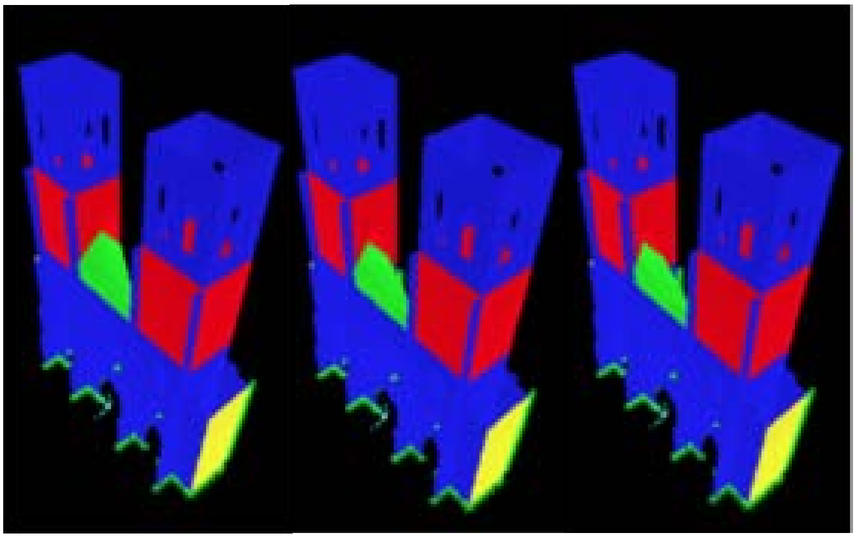


Figura 19. Mode 1 (Model for Year 2002).

For the third mode, the modal shape is related with the towers, moving in the plane of the façade in the same direction and moving out of the plane of the façade in opposite directions. The reason of this movement is that in plane there is transversal symmetry but in the longitudinal axes there is an asymmetry, the value of the frequency is 1.95 Hz.

4.2 Model for the year 2007

For the model of the year 2007, in order to considerer the retrofit of the gable, some restriction were placed for the gable, in the Figure 20, is presented the restrictions out of the plane that were assumed in the model.

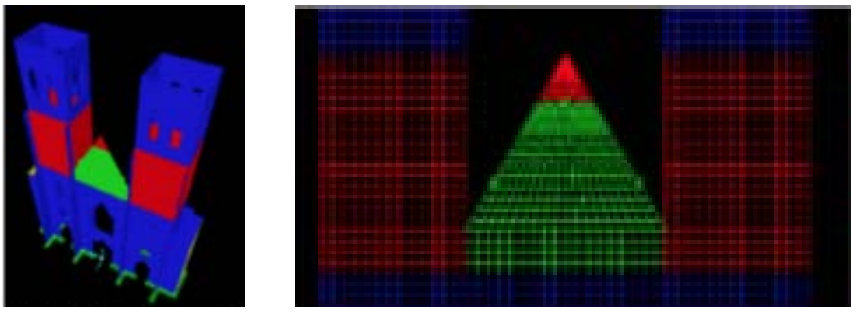


Figure 20. Model of the Structure for 2007 (after the retrofit).

4.2.1 Results of the model 2007

Once the restrictions out of the plane were assumed, in order to take into account the retrofit, the models shapes that were obtained are described. With the retrofit due to the restriction out of the plane of the gable, as it was expected, the mode related with it, disappeared. So for the model for 2007, only two eigen values were obtained.
The first mode corresponds to the second mode before the retrofit. As it happened with the mode 2 for the year 2002, in this case, it was obtained two values for the mode 1. The modal shapes were called mode 1a and mode 1b. In the structural model, it was obtained two values of eigen values that were very closed (1.35 Hz and 1.36 Hz) In order to compare these values with the experimental values, they were grouped as mode 1, but in order to see the difference in the mode shape, they were called mode 1a and mode 1b. The modal

shape of the mode 1a corresponds to the movement of the two towers in the same direction, out of the plane of the façade.
The mode 1b corresponds to the movement of the towers in opposite directions, again out of the plane of the façade
The mode 2 corresponds to the mode 3 for the structure in 2002. The modal shape is related with the towers, moving in the plane of the façade in the same direction and moving out of the plane of the façade in opposite directions. The reason of this movement is that in plane there is transversal symmetry but in the longitudinal axes there is an asymmetry. The value of the frequency is 1.95 Hz.

5. Comparison of the results

The results of frequencies that were obtained "in situ" were compared with the values that were calculated, this comparison was done before and after the retrofit, as it is shown in the sketch in Figure 21.

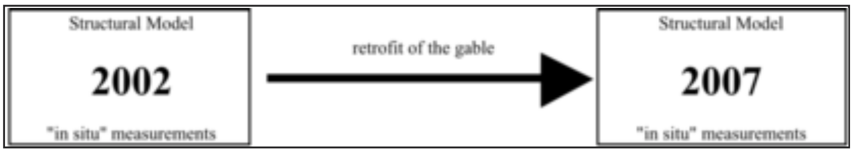


Figure 21. Comparison of the results.

5.1 Experimental results of the Data 2002 and 2007

According to the analysis for each point, it is possible to determine the value of the value of the frequency related for each mode of the structure. Those values are presented in the Figure 22, and then they are going to be compared with the results obtained in the model.

5.2 Results of the Model

As it was explained in section 4, the results were obtained for a value of ɑ equal to 0.6. The results of the frequencies for the structural model for the year 2002 before the retrofit are presented in the in Figure 23. And the frequencies that were obtained with the structural model are presented in Figure 24.

5.3 Comparison

In order to compare the calculated frequencies with the measured frequencies, it was defined a tolerance range of 10 % for the values. This tolerance was assumed in order to accept that is not possible to take into account in the model all the conditions of the materials, structural elements and the building, the variability in the mechanical properties of the elements and the assumptions that were described before in the scope.

5.3.1 Before the retrofit, 2002

In the Figure 25 is presented the results of the model whit their respectively tolerance range. As it could be seen, all the values that

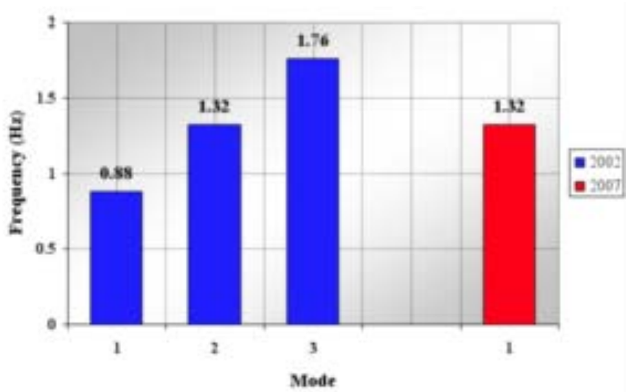


Figure 22. Experimental Frequencies. Results of the Experi-

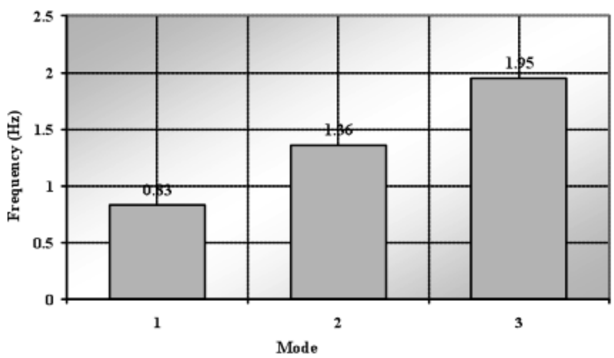


Figure 23. Frequencies of the Model 2002. Frequencies Be-

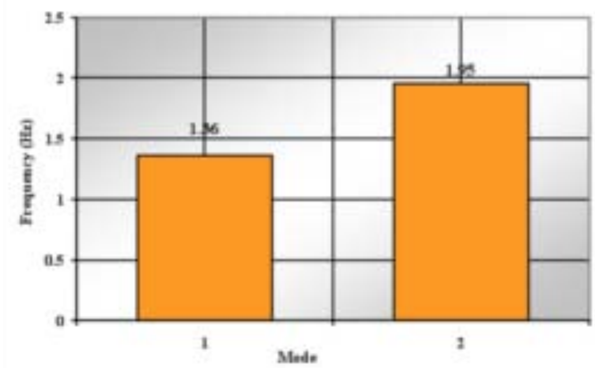


Figure 24. Frequencies of the Model 2007. Frequencies after the Retrofit 2007.

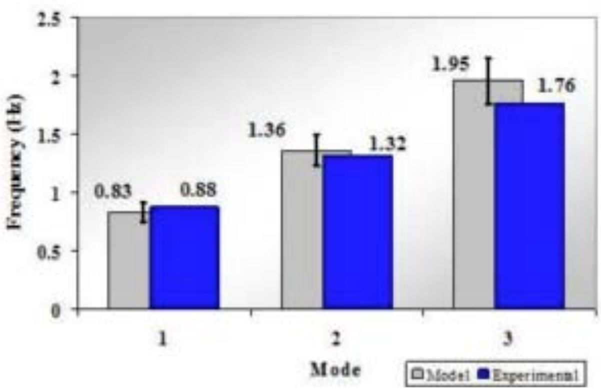


Figure 25. Comparison of the First Mode, 2002.

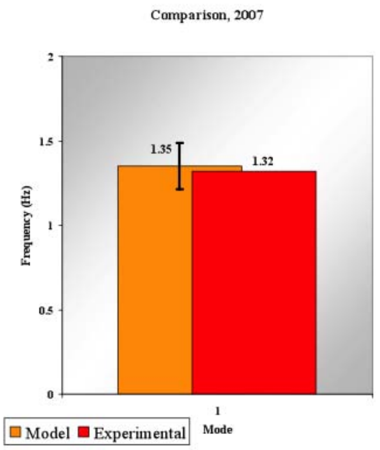


Figure 26. Comparison of the first mode 2007.

were obtained "in situ" are in the tolerance range.
As it was commented before, the value for the first mode was related strongly with the value of the effective inertia. If the analysis is elastic, in order to obtain better results is important to take into account that value α, because it is a way to consider the loss of section and internal cracks of the masonry.
For the second mode the value is related with the stiffness of the springs. In this specific case, a value was taken (1 Ton/mm), and it was conservative. This value could be obtained also with experimental tests in situ or another possibility is to model all the structure and then check this value.
The third mode is just in the limit. In monitoring, the higher modes are more difficult to measure. The other fact is that this mode his related with a lateral movement and is accomplished with the movement in opposite directions of the towers.
The reason of that movement is because this section has only one symmetrical axes; the longitudinal is not symmetric so in this mode is possible to determine torsion in the modal shape. Since the accelerometers were only placed in the façade, and they were measured the acceleration only out of the plane, it is possible that the values recovered were only related with the participation of the mode in that direction.

5.3.2 After the retrofit, 2007

For the year 2007, it is only compared the first mode. As it was done for the first mode in the previous model, it was defined a tolerance range (±10%). In the graph of the Figure 26 is presented the comparison of the results. Those values are so close, and the results are acceptable in the way that the value obtained in the experiment is the range of tolerance of the value that was obtained in the model.
In both cases, it was proved that the retrofit works, it completely avoided the resonance phenomena in the gable.
According to the results that were obtained in the model and in the experiment, once they were compared it was found that:
- in the structural model and the experiment for the year 2002, it was possible to determine that the gable was in resonance due to the ringing of the bells
- in the structural model and the experiment for the year 2007, it was possible to determine that the retrofit works avoided the resonance phenomena.

6. Conclusions

- It is possible to obtain values of frequencies with a structural model close to the values that were obtained with the experiment, if in the model the values of the mechanical properties of the masonry are conservative and the boundary conditions reflect the real situation of the structure.

- In the analysis of the results of the dynamic response of the building, it was necessary to review the frequencies that were recovered in each measured point, in order to obtain the frequencies of the building. It was found in the results of 2002, that because some points were related with the first mode, it was not possible to measure the first frequency in those points (2, 12 and 20).

- When performing a linear dynamic analysis in a historical building, in order to take into account the loss of section and internal cracks of the masonry, a value of effective inertia, as opposed to gross inertia, yields results closer to the measured values.

- With the structural model and the experiment for the year 2002, it was possible to determine that the gable was in resonance due to the ringing of the bells. Also in the model and the experiment for the year 2007 it was possible to conclude that the retrofit works avoid the resonance phenomena.

- In the structural model it was possible to exclude elements that were part of the building as bells and spires, and obtain acceptable results because their inertial masses were included in the model. Without these masses, the values of eigen frequencies were not in the acceptable range.

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