TERRA EDUCATION III

PERSPECTIVES POUR LE DÉVELOPPEMENT DE L'ENSEIGNEMENT SUR LES ARCHITECTURES DE TERRE

PERSPECTIVES FOR THE DEVELOPMENT OF EDUCATION ON EARTHEN ARCHITECTURES

International Scientific Workshop 02

CRAterre ENSAG

LABEX AE&CC

TRAINING FOR THE SEISMIC RETROFITTING OF EARTHEN BUILDINGS IN PERU

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ABSTRACT

The Getty Conservation Institute's Seismic Retrofitting Project (SRP) aims to combine traditional construction techniques and materials with high-tech methodologies for seismic strengthening of historic earthen buildings in Peru. The first phases of the project included identification and assessment of four prototype buildings, followed by laboratory testing, in-situ testing, and numerical analyses of the four sites, as well as the preparation of retrofitting designs and construction drawings. Retrofitting interventions have now been carried out at the 17th century Church of Kuñotambo, and construction drawings completed for the 18th century Cathedral of Ica. As part of the project, a series of technical training workshops on seismic interventions were held for over 80 specialized professionals of the Peruvian Ministry of Culture. These workshops included a theoretical introduction to conservation and the project methodology, structural testing and modeling, and practical, hands-on exercises on masonry underpinning, buttresses, timber ring beams and roofing solutions for seismic reinforcement of adobe buildings. Three more workshops are planned on the conservation of wall paintings. This paper describes the organization of the workshops focusing on the theoretical and practical exercises carried out and the impact of the workshops on course participants.

1. INTRODUCTION

This paper presents the results of a series of training workshops organized by the Getty Conservation Institute's (GCI) Seismic Retrofitting Project (SRP) in collaboration with the Peruvian Ministry of Culture. The Seismic Retrofitting Project seeks to combine traditional construction techniques and materials with high-tech methodologies to design and test easy-to-implement seismic retrofitting techniques to improve the structural performance and safety of earthen buildings. Following the strong 2007 earthquake in Pisco, Peru, the GCI conducted a survey of damages to historic adobe buildings. Beginning in 2009, four prototype buildings were selected for further study and a program of documentation, testing and structural modeling was designed to determine the most effective seismic interventions. The testing phase was carried out by engineering consultants from The Pontifical Catholic University of Peru (PUCP), and the University of Minho. The results of the testing and modeling phase were published in reports on the GCI website (Cancino & Lardinois, 2012) and in several articles (Ferreira *et al.*, 2014; Karanikoloudis & Lourenço, 2016; Quinn, N. *et al.*, 2012; Torrealva & Vicente, 2016; among others).

Following the testing and modeling phase of the project, construction drawings were developed for two of the SRP prototype buildings: the 18th century Cathedral of Ica and the 17th century Church of Kuñotambo (Fig. 1). The church of Kuñotambo was selected as the first site for implementation and conservation works, begun in 2017, are now nearing completion. This work included interventions to seismically strengthen the church while conserving and protecting its intact wall paintings. Seismic reinforcement implemented at the church of Kuñotambo included the repair and repointing of stone foundations, reinforcement of existing buttresses and construction of additional buttresses, the insertion of timber corner keys, and the construction of a new roof incorporating a structural ring beams, tie beams, and new roofing layers. The church's important wall paintings were also documented, stabilized and conserved.

2. STRUCTURAL WORKSHOPS

The training workshops grew out of discussions between the GCI and the Ministry of Culture, aimed at finding ways to disseminate the methodology and techniques developed by the project, both for structural interventions and wall paintings conservation. Five workshops in total were initially planned. At the time of writing, two workshops

Fig.1 : Church of Kuñotambo before intervention

have been held, with three more planned in 2018-2019. The first two workshops focused on disseminating the structural interventions developed by the project, while the next workshops focus on techniques of documentation, condition recording, and cleaning and consolidation of wall paintings on earthen supports.

Two 3-day workshops were held on structural techniques for seismic reinforcement. Each workshop was attended by forty participants from the Peruvian Ministry of Culture, including architects, engineers, conservators and masons. The first workshop focused on the theme of structural reinforcement of foundations including underpinning and buttresses, while the second workshop addressed timber reinforcement including ring beams, corner keys, tie beams, and roof structures.

The first workshop was held in August 2017 in Cusco and Kuñotambo, with a second held in November 2017. The program began with presentations and theoretical exercises held in Cusco, followed by site visits to the church of Kuñotambo.

The theoretical component was comprised of lectures and group exercises. The group exercises were especially important to create dialogue between participants and to discuss how the project methodology applied to their own projects. The structure of the theoretical component included the following lectures and exercises:

- Presentation on the history and significance of the Church of Kuñotambo
- Introduction to the theory of conservation and to the project methodology
- Group activity #1: Philosophy of intervention
- Presentation on seismic testing in the laboratory
- Presentation on non-destructive testing of the site and numerical modeling
- Group activity # 2: Guiding principals for conservation
- Presentation on the retrofitting and conservation proposal for Kuñotambo
- Group activity # 3: Intervention proposals in groups
- Project architects present conservation works carried out on site
- Group activity #4: Differences and similarities between group proposals.

2.1. GROUP EXERCISES

As part of the theoretical component of the workshop, four group exercises on conservation planning were held. These focused primarily on one particular aspect of the conservation planning process – the need to identify elements of significance in a site in order to prioritize and plan levels of intervention (see fig.2). Following introduction to the history and theory of conservation and the key conservation charters, participants broke into groups for Activity #1 where they used Kuñotambo as a case study to identify the values of the site. They were provided with plans, elevations and other information on the site and were asked the following questions:

1. What are the main elements of the church?
2. Why is the church important?
3. What specific elements are evidence of this importance?

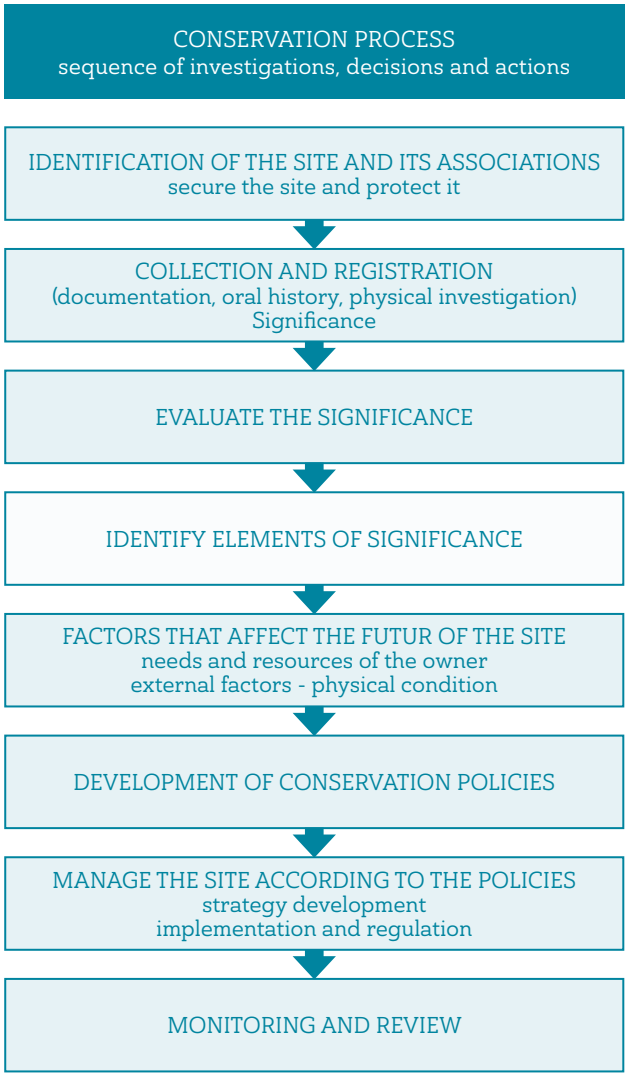

Fig.2 : The conservation planning process, highlighting the identification of elements of significance

4. What are the attributes or characteristics that make these elements give value to the site and how significant are they?
5. What are the elements that could tolerate more change – interventions – without affecting the total significance of the site?

Participants were instructed to prioritize the level of significance for each element identified in question # 3 based on whether it can tolerate interventions or not:

- Does not tolerate changes / interventions: High significance
- Could tolerate minimal changes / interventions: Average significance
- Tolerate changes / interventions: Low significance

The goal of this 60-minute exercise was to give participants a basis for understanding significance and making decisions about what are acceptable levels of intervention depending on the significance of a given element of a site.

Following a presentation on the seismic testing and modeling components of the project, participants again broke into groups for Activity #2. This 45-minute exercise was designed to demonstrate the guiding principles that helped the team decide the level of structural interventions for the site. This exercise demonstrated the priorities that must be balanced when considering safety, security and cost vs. conservation ethics. While architects and engineers often hold differing priorities, the team needed to first agree on the conservation and engineering criteria to be considered when making decisions about interventions. These are shown in table1 below. The participants discussed this criteria and each group completed a table which gave a numerical weight to each criteria, ranking the various criteria according to their importance for each group. This exercise was interesting as, while groups with more engineers ranked engineering principles slightly higher, most groups looked for compromises in order to preserve authenticity and architectural configuration.

Activity #3 was designed for the participants to suggest an approach to the conservation of the structure. In this activity the participants used drawings to plan interventions and debate the level of intervention necessary to secure the church. Each group was led by a moderator, and participants were asked the following questions:

1. Taking into account that part of the foundation is in poor condition, what solutions would the group propose, what materials would it use and why?
2. Based on your experiences, do you believe that the walls should be partially or completely repaired or replaced completely? How would you do it in each case and why?
3. It has been observed that the east wall is out of plane. What would you do to correct the problem, why and how?
4. Knowing that the corners are prone to structural cracking during a seismic event, what do the participants suggest to strengthen them and how are the mural paintings near these interventions protected?
5. Taking into account that the roof is not original, is it possible to propose a new roof? Why? With what materials and techniques?

Participants were then asked to present their proposals and discuss the technical aspects of it with the group.

Table 1: Principles of conservation and engineering

Principles of conservation	Principles of engineering
Minimum intervention	Security
Reversibility/Re-treatability	Durability
Authenticity	Feasibility
Preserve architectural configuration	Economy
Preserve original techniques/materials	
Distinguish new from the original	
Easy maintenance	
Compatibility of materials	

Fig.3 : Non-destructive testing demonstration at Kuñotambo

Fig.4 : Workshop Participants repointing a section of masonry wall

Following activity #3, the interventions carried out on site were presented to the participants in detail with a focus on the timber reinforcement, roofing and masonry repairs. Finally exercise #4 was a short discussion which asked the participants to compare their proposals and what was executed on site, and to assess whether their own proposals respected the elements identified as significant in the previous exercises, and if their proposed interventions followed the guiding principles (e.g safety, authenticity, reversibility, etc.) that the group had ranked as being most important in Activity #2.

These group exercises – though complicated to organize, with each exercise requiring a script, preparatory materials and moderators – fostered very important discussions which brought participants directly into the conservation decision making process. The exercises also allowed interdisciplinary teams to learn from each other's expertise.

2.1.1. PRACTICAL EXERCISES

For the practical component of the workshops, participants traveled to Kuñotambo, about 2 hours from Cusco, to visit the site and engage in practical exercises on site. There participants divided into groups of 20 where they first visited the worksite to see the retrofitting work being carried out (buttresses, timber reinforcement, and roofing) and the work on the conservation of wall paintings on the interior of the church. Following this, one group took part in a demonstration of non-destructive testing techniques for structural assessment (Fig. 3), while the second group learned about mortars and masonry conservation techniques used in the project.

The non-destructive tests included demonstrations of thermal imaging, sonic testing, and dynamic testing. Engineers from PUCP and University of Minho demonstrated these techniques and participants learned how the tests are applied in the field to develop data for a numerical simulation of seismic movement. Posters showing examples of the use of each technique were displayed on site. Participants then had the opportunity to try the thermal camera, as well as sonic and dynamic tests on samples of adobe, stone and wooden beams.

The second exercise of the day demonstrated the materials and techniques used for masonry conservation at Kuñotambo. As Kuñotambo has an earth and stone foundation, the demonstrations introduced the mortar mixtures developed for the project, with an emphasis on the use of lime mortars. This included a demonstration of mortar properties, a discussion of mortar components and behavior, the mortar formulation used in Kuñotambo, and the cycles of lime and cement.

The presenters discussed why cement is not an appropriate material for historic earthen buildings, and conducted demonstrations which illustrated this point. The demonstrations included field tests for mortar materials

Fig.5 : Section of a timber reinforced buttress at Kuñotambo
Drawing: GCI/DDC-C

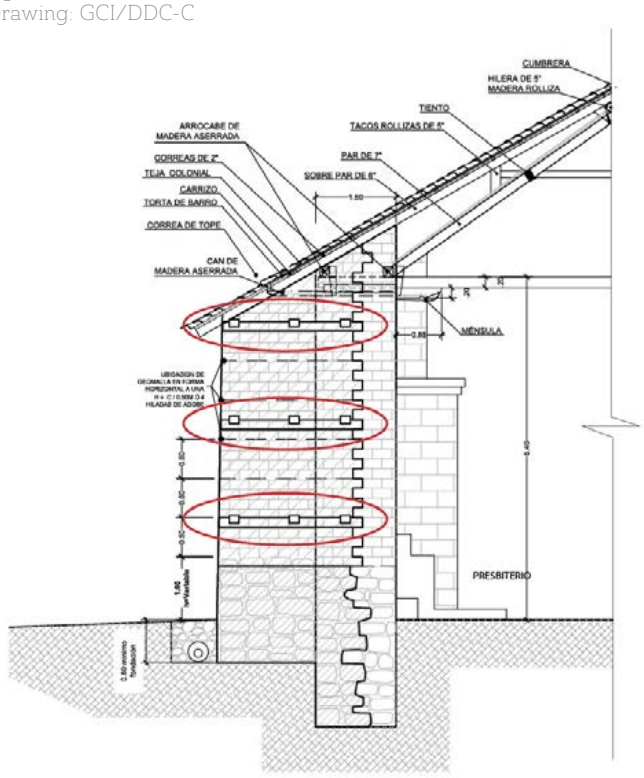

Fig.6: Group photo, SRP structural interventions workshop

including portable microscopy, shrinkage tests, rebound hammer, and RILEM adsorption. The rebound hammer and RILEM adsorption was especially effective at showing the hardness and lack of permeability inherent in cement-based mortars.

Participants then broke into five groups and made five predetermined mortar mixtures utilizing lime or earth-based materials with a variety of aggregates. The five mortar mixes included:

- 70% earth, 25% clay, 5% lime
- 60% earth, 30% clay, 10% lime
- 50% earth, 50% clay, 5% cal
- 30% lime, 70% sand
- 90 % earth, 10% finely chopped straw

Each group was responsible for using their mortar mixture to repoint a one-meter square area of masonry (Fig. 4). They were provided with repointing tools and instructed in proper working techniques for compacting and finishing mortar joints. The practical exercise was followed by a discussion session on mortars to compare the results of the five mixes and answer outstanding questions.
Following the mortar sessions, both groups climbed on scaffolding to observe the installation of timber reinforcements. One group observed how new buttresses were constructed and tied to the historic masonry with wooden keys and geomesh (Fig. 5), while the other group observed the structure of the roofing including the ring beam and tie beams that strengthen the upper walls of the structure.

In both cases, posters of construction details were provided to show how architectural plans are implemented, and how in the case of seismic retrofitting, the plans must be followed precisely or the whole reinforcement system could fail in the event of a strong earthquake.

3. EVALUATION AND IMPACT

Evaluations were carried out for the two workshops on structural stabilization. A three-part survey was administered to all participants. In the first section they were asked their level of understanding of the topics before taking the course. In the second section they were asked their level of understanding of the same topics after taking the course. The third part asked them to rate the course in terms of:

- General workshop organization
- Time dedicated to each presentation and activity
- Utility of didactic materials
- Clarity of presentations Relevance / Usefulness in your work
- Presentation of the mural painting work in Kuñotambo
- Demonstrations of non-destructive tests in Kuñotambo
- Demonstrations and mortar exercises
- Demonstrations of corner keys and ring beams

Participants were also given the opportunity to comment in writing on the themes and activities of the course they found the most and least useful. The evaluation results were generally positive. Most participants appreciated the field

sessions, highlighting the presentations on wall paintings and the opportunity to engage in hands-on practice in the non-destructive testing and mortars sessions of the workshop. Most stated that their level of knowledge had increased regarding certain topics, with seismic testing and modeling, and seismic reinforcement highlighted as new subjects to many participants.

While a paper survey is obviously not a complete evaluation of the impact of a workshop, surveys taken over the course of the two workshops and feedback from participants has shown that participants learned a great variety of new techniques and approaches, and that these efforts have had a positive impact on the work of the Ministry and its staff, as well as for the dissemination of the project methodology in Peru.

4. CONCLUSIONS AND NEXT STEPS

The two structural workshops carried out as part of the seismic retrofitting project are an initial step in a longer term program of training related to the SRP project. Three more workshops are currently being planned to disseminate the project methodology for the consolidation of wall paintings prior to the retrofitting of the site. This program will include: 1) documentation; 2) condition assessment, and, 3) consolidation and cleaning of wall paintings on earthen supports.

A third phase of training will begin during construction activities for the project at the Ica Cathedral. Seismic testing, modeling and a retrofitting design have already been completed for this component of the SRP project, and construction is expected to begin at the end of 2018. As part of the Ica project, training workshops on seismic retrofitting and conservation of decorative plaster and timber will be carried out. The GCI hopes that these training activities will contribute to the dissemination of sensitive retrofitting techniques for historic earthen buildings in Peru.

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