Summary Report of STSM January 2013

Natalie Quinn
University College London (UCL)

1 Introduction

The following report outlines the work carried out during the short-term scientific mission (STSM) hosted by Prof. Thierry Descamps at the University of Mons. The mission took place in January 2013 for a period of four weeks.

2 Background

The coast of Peru is one of the most seismically active regions in the world. It also has a large number of important historic residential buildings built after the arrival of the Spanish in Peru in the mid-16th century. These buildings are particularly susceptible to earthquakes and little research has been carried out to analyse their behaviour or determine how best to protect them. Work is currently being carried out at UCL to investigate the global behaviour of these buildings during an earthquake by means of finite element analysis, in order to assess their vulnerability and recommend suitable retrofitting measures. The ground floor of these buildings is usually adobe, with the upper storeys in quincha, a traditional construction technique consisting of a timber frame with cane and mud infill, covered with a layer of lime plaster. Despite a large number of these buildings still being in existence, no consistent study has been conducted to characterise this typology and understand the mechanical behaviour of the quincha.

In order to accurately develop a global model for the whole building, it is necessary to fully understand the behaviour of each of the quincha walls. The mechanical properties of the infill material and its connection to the frame are highly variable and difficult to determine. Therefore an approach has been taken to characterise the timber frame with a high degree of accuracy to ensure that the contribution of the infill can be globally quantified from the overall experimental results. A typical section of a quincha wall (shown in Figure 1 and Figure 2) was considered by carrying out a series of racking tests in UCL with, and without, the infill. Finite element models of the test frames were created using ALGOR, and parametric analyses were carried out to identify the most critical parameters. The lateral stiffness is provided by the bending resistance of the frame, the connections, the bracing, and the infill but how much each component contributes to the overall stiffness is unknown.

The beams and posts are connected together by mortice and tenon joints, shown in Figure 3. Preliminary analyses of the two frames with the commonly accepted assumption that all mortice and tenon joints could be considered as simply pinned resulted in lateral displacements twice as large as the experimental ones, indicating that the pinned assumption is oversimplified. Therefore, the connections will be considered semi-rigid with a given rotational stiffness. As there are numerous mortice and tenon connections in the building, each with different geometries and material properties, a simple analytical technique is required which is sufficiently accurate to represent the realistic behaviour of the frame.

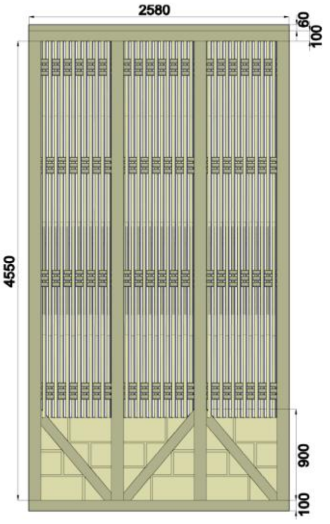

Figure 1: : Typical Second Floor Frame (Frame 1)

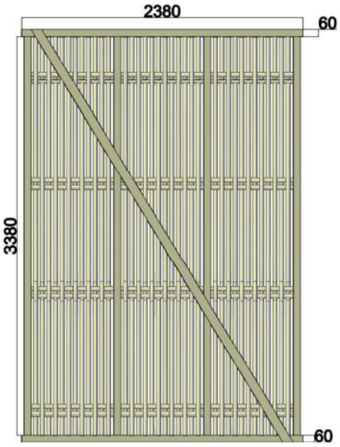

Figure 2: Typical Third Floor Frame (Frame 2)

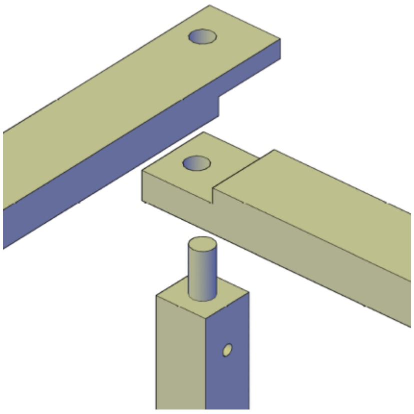

Figure 3: Mortice and Tenon Joint

Prior to the STSM, the rotational stiffness of the connection was estimated using the component method. This technique was simple to carry out, but greatly overestimated the stiffness of the joint. In addition, although the bracing member was critical to the behaviour of the frame, and the connection between it and the frame had failed during tests, its strength and stiffness was undetermined.

3 Purpose of the STSM

The overall aim of the STSM was to develop a method to determine the stiffness and strength of the connections found in the quincha frame, so that it can be modelled with a greater level of confidence but without the need for detailed analysis of each individual joint. This will enable an accurate representation of the timber frame to be developed. Subsequently the infilled frame will be considered, focusing in particular on the interaction between the frame and the infill. Prof. Thierry Descamps has a great deal of experience in the investigation of carpentry joints, and has previously carried out research on the rotational stiffness of connections using analytical and finite element techniques. Bearing this in mind, the objective can be divided into three categories;

- Improvement of the existing estimate of the rotational stiffness of the mortice and tenon joint;
- Assessment of the strength and stiffness of the diagonal bracing member;
- Improvement of the representation of the infill in the model.

4 Description of Work Carried out & Major Results

4.1 Rotational Stiffness of the Mortice and Tenon Joint

Work had been carried out prior to the STSM to determine the rotational stiffness of the connection using the component method. The component method divides the joint into a number of components, one for each pair of surfaces in contact. The stiffness of each component is represented by a series of springs of a given stiffness, which combine to give the overall stiffness of the joint. Previously the centre of rotation of the joint was assumed to be in the centre of the tenon, however this resulted in an over estimate of the stiffness when compared to experimental work carried out in UCL.

During the STSM, the method was improved by moving the assumption of the centre of rotation to a number of positions and comparing with experimental results. It was found that when the position for the centre of rotation was directly below the shoulder joint, half way through the depth of the beam, results were much closer to the experimental results as shown in Figure 4. This was backed up by observations during the experimental work in UCL.

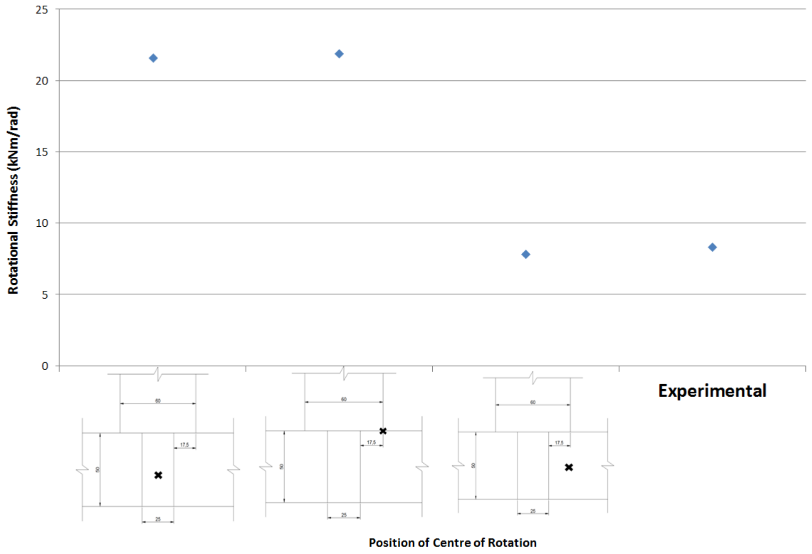

Figure 4: Comparison of Rotational Stiffness for different positions of centre of rotation

Using this new improved method, a range of values of possible rotational stiffness was established from data collected onsite. The width of the tenon ranges between 25 and 50mm, while lengths have been observed of 20 and 150mm. The only parameter relating to material properties used in the analysis is the elastic modulus, so this was varied between the ranges of group C of the Peruvian National Code for Timber. Using this method within the range, it was concluded that the joint stiffness could potentially vary between 0.1kNm/rad and 100kNm/rad. However, within this range, only variations in rotational stiffnesses less than 20kNm/rad had a significant impact on global behaviour. Since the length of the tenon was found to be the most significant parameter, the relationship between rotational stiffness and length was investigated. This concluded that it was necessary to compute the rotational stiffness individually for tenons measuring less than 70mm. Tenons longer than this length will be given an average value as small changes have little effect. This greatly reduces the number of calculations that need to be carried out, and the technique can be carried out quickly for a large number of joints geometries.

4.2 Analysis of the Diagonal Connection

Frame 2 consists of a diagonal bracing member, connected to the frame by a nailed lap joint. In order to model the braced frame, it is necessary to accurately represent the connection between the bracing member and the frame. During tests carried out in UCL prior to the STSM, this connection failed, but since the geometry of the connection in the test frames was different to that found onsite, it was uncertain whether the geometry onsite was likely to fail.

During the STSM, calculations to determine the strength and stiffness of the connections with varying geometries were carried out. The ultimate capacity of the connection was determined according to Eurocode 5, while the axial stiffness was computed using the component method. The results showed that the ultimate capacity of the connection onsite was indeed larger than the test results, but it was still relatively low. The values computed were input into the model, giving results very similar to those obtained during racking tests for the braced frame. Therefore, it was concluded that these analytical techniques are sufficiently accurate for determining the strength and stiffness of the connection. The comparison between experimental and modelled results for tension and compression is shown in Figure 5 and Figure 6.

Tension

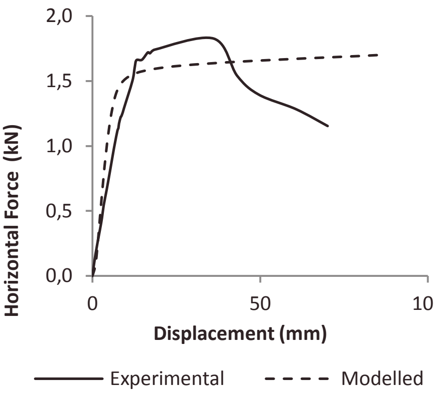

Figure 5: Comparison between experimental and modelled results for Frame 2 without infill in tension

Compression

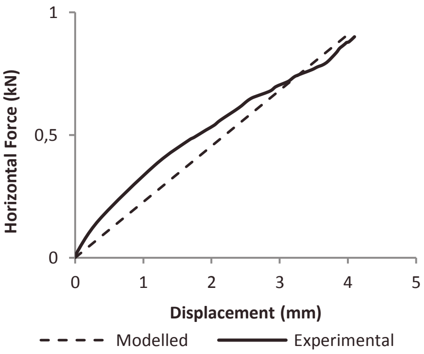

Figure 6: Comparison between experimental and modelled results for Frame 2 without infill in compression

4.3 ABAQUS Model

Prior to the STSM all models had been built in 2D using ALGOR, with the frame modelled using 2D beam elements and the infill modelled using plate or shell elements. The connection between the infill and the frame was modelled using unidirectional springs in the form of gap elements. These elements can transmit compressive forces but have no tensile capacity enabling the plate elements representing the infill to separate from the frame. This enabled parametric analysis to be carried out varying properties of the infill and frame. However, friction between the elements was not considered, and the canes passing through the posts horizontally were not taken into consideration.

In order to assess the influence of frictional forces between the infill and frame, and determine the connection between the horizontal bamboo members and the infill, a 3D model was created using ABAQUS. With this program it is possible to vary the frictional coefficient and properties of the infill to assess the impact on the overall behaviour.

During the STSM, a model of the timber frame was developed and analysed. The model was built using 3D brick elements, with all connections represented as they existed in the test frame. Hard contact was generated between the elements but friction was ignored. This model yielded results very similar to the experimental tests. After the STSM, further work will be carried out to improve this model and add the infill to the model, as well as frictional contact.

5 Conclusions

The work carried out during the STSM successfully concluded the analysis of the quincha frames without infill, and when the findings from the joint analyses were input into the existing numerical models, the modelled behaviour correlated closely with the behaviour of the experimental frames. In addition, the basis of the model of the infilled frame was completed. During the STSM a number of valuable discussions were held on the methodology of the project and, a meeting was arranged with Prof. Hervé Degée at the University of Liège to discuss aspects of the modelling relating to dynamic analysis.

6 Future Collaborations and Publications

A paper has been submitted to SHATIS '13, the 2nd International Conference on Structural Health Assessment of Timber Structures. Following the completion of the work on the infilled frames, it is hoped that a journal paper outlining all the work on the frames will be submitted.