TRACERÍA
Revista de Rehabilitación Arquitectónica | ArchitecturalRestorationJournal
Máster Universitario en Rehabilitación Arquitectónica |Universidad de A Coruña

Inspection and Structural Repair of the Fire Damged Library Piers of the Glasgow School of Art

Inspección y reparación estructural de los pilares de la biblioteca de la escuela de arte de Glasgow dañados por incendio

1. Mackintosh Library as found after fire

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Tracería - Revista de Rehabilitación Arquitectónica

http://bit.ly/traceria
N° 1 (2015)
Páginas 9-14
Fecha de recepción 28.10.2015
Fecha de aceptación 7.1.2016

Resumen
Este artículo cubre todas las etapas desde la inspección hasta las reparaciones propuestas de las columnas de la biblioteca que se dañaron por incendio en La Escuela de Arte de Mackintosh en Glasgow. Estos son los elementos estructurales que fueron dañados más gravemente y para proporcionar una reparación sensible y eficaz, la etapa de investigación es fundamental. El artículo detalla los métodos diferentes que se utilizaron y los resultados. Se proporciona un resumen de la condición de la fábrica de la sillería con causas supuestas de las lesiones de los elementos, secciones y la superficie de los bloques. Finalmente habla de los métodos de reparación propuestos para las zonas separadas y más globalmente para la fachada entero.

Palabras clave
Mackintosh, library, daño por incendio, albañería, pilar

Abstract
This report covers the stages from inspection to the propsed repair of the fire damaged library piers to the west facade of the Mackintosh School of Art. These were the structural elements most heavily affected by the fire and in order to provide an effective and sensitive repair programme the investigation stage is critical. The article details the different methods used and the conclusions that can be drawn from them. An overview of the stone condition is given with assumed causes for damaged elements, sections or stone surfaces. Finally the proposed repair techniques are discussed for the separate areas of the piers as well as more globally for the whole façade.

Keywords
Mackintosh, library, fire damage, masonry, pier

BACKGROUND

On the 23rd of May 2014 the west wing of the iconic Mackintosh School of Art in Glasgow was severely damaged by fire. The fire, starting at basement level, quickly spread throughout the internal timber lined voids that formed part of an innovative hot air heating system. This made it incredibly difficult for the firefighters to contain the fire and resulted in extensive damage to the west wind of the building.

Several studios were affected and much of the roof was destroyed but the most important damage occurred in the Mackintosh Library. The library was an intricate space which stretched over two levels. A mezzanine level supported on dark timber elements split the space vertically. The suspended lighting, bookcases, balustrades, chairs and work tables all feature art nouveau motifs.

2. Mackintosh Library before fire damage

The architectural competition for the building of the new Glasgow School of Art took place in 1869. A design by Mackintosh, a young draughtsman at the time, was submitted through the firm Honeyman and Keppie for whom he was working. After a series of reviews by the client, the Mackintosh design was eventually accepted. Due to issues with the funding of the project, the building was constructed in two phases. Phase one consisted of the building of the central and eastern half while the construction of the remainder of the building awaited the securing of additional funds. Phase one was completed in 1899 and included the museum, director's office and the board room. The second phase of the building followed eight years later and was completed by 1909 [1]. In sharp contrast to the austere facades to the south and east of the original section, the west wing features a much more dramatic design. The west gable features three dominating vertical windows. It is considered that this section of the building gave birth to a new style of European architecture of the 20th century. The imposing gable end was of course reserved for the most important interior and the Mackintosh Library was therefore positioned here.

INSPECTION OF FIRE DAMAGE TO PIERS

The focus of this article is to look at the structural implications of the fire on the fabric of the building. The structural systems utilized within the building are fairly traditional with several examples of more modern elements which were relatively new at the time of construction. The building is constructed with bearing masonry with floors constructed from a mixture of concrete filler joists and timber joists supported on steel rolled sections.

3. West gable facade before fire damage

Stone Damage

The location of most severe damage to the fabric of the building has been the stone piers of the west gable that form the vertical sections between the triple height library windows. These consist of masonry blocks with no rubble infill. Photos taken just after the fire show clear cracking and loss of material of the block surfaces due to the extreme heat generated during the fire and possibly more importantly the rapid cool down caused by dowsing the stones in water while extinguishing the fire (fig. 4). It was determined that the piers had lost about 6-7% of the area of original stonework as an average value with those areas worst affected losing up to 10%. This was not considered to be structurally significant due to the large factors of safety usually found in bearing masonry construction. Many of the blocks of masonry had cracked throughout their entire width and this cracking seemed to follow a pattern vertically, effectively splitting the columns front to back. This had more serious implications as it could affect the overall stability of the columns by increasing their slenderness.

4. Loss of masonry of the library piers

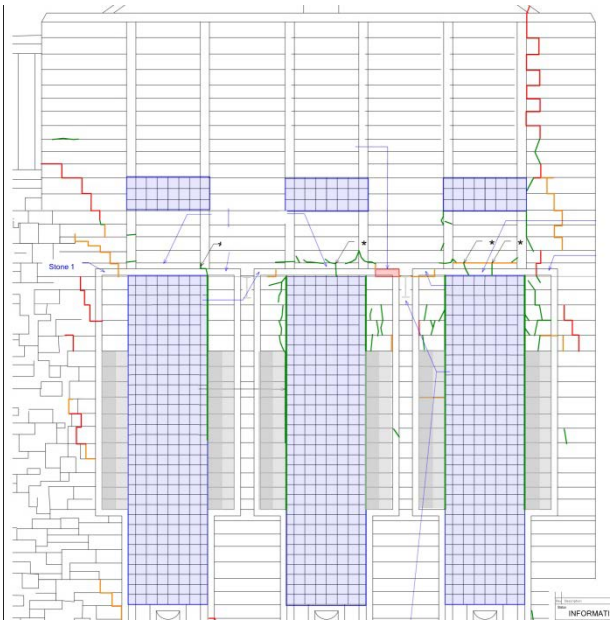
It was concluded from the inspections that some temporary stabilisation was required in order to secure the piers laterally. This consisted of the bracing, front to back of the piers at four intervals, effective pushing the piers together.

The stone in the piers is fine grained sandstone, a very consistent material that comprises mainly silica. The damage that occurs at high temperature is usually mechanical and not chemical resulting from expansion. The damage is due to a stress differencial between different parts of the stone blocks. As the exterior surfaces of the blocks are heated quickly, it expands quickly. The interior body heats up and therefore expands at a steadier rate and creates a difference in stress within the block. This ultimately results in a fracturing of the block in circular layers. This is shown by the curved faces of the blocks of the pier where before the blocks were square. This process also occurs in reverse during cooling and could again be more critical due to the sudden nature of dowsing the stone in water. It is interesting to note that although unavoidable in order to save the building, it can in fact be the process of extinguishing the fire that does the most damage to its fabric.

More than a year on from the fire, a secondary type of stone damage is being noticed that is less severe but could cause problems in the future. It is shown in the form of spawling of the weakened and more friable stone surfaces due to weathering effects. This is most common alongside cracking in the stone where moisture can enter.

Movement of Facade

In August 2014 a thin section of one of the carved stone blocks next to the lintel of the large openings fell from the building and landed in the carriageway of Scott Street. It fell within the fenced off area but this motivated an immediate inspection from ground level and followed by a detailed high level inspection by crane of the exterior surface. The individual blocks cracking patterns were mapped onto a drawing in order to build a global image of the effects on the façade (fig 5). It concluded that the most significant damage to the masonry occurred at the head of the piers with many cracks propagating through the blocks (shown in green). It also identified that each of the large stone lintels had split throughout their entire body.



5. Mapping of crack patterns on the facade

- Hairline Cracks to Mortar Joints
- Cracking to Mortar Joints
- Cracking to Stone Blocks

The global image shows opening up of the mortar joints down the north edge of the façade in a diagonal pattern. A vertical opening up on the joints was also identified running down the south edge which extended a considerable distance. These patterns are understood to be related to an outward movement of the façade due to actions of the fire. Due to the

intense heat of the fire in the library space, the long steel RSJs supporting the floor of the gallery above expanded, significantly. As they were constrained in wall pockets, this induced significant stresses in the fabric of the façade accounting for the localised cracking of the masonry blocks and lintels at the pier heads and has lead to the more significant movement of the facade. It is concluded that the splitting of the lintels is a result of mechanical stresses due to the shift of the façade and not due to the stresses related to heat. The lintels do not show any further damage aside from minor surface spawling and discolouration. The stone fall near the middle lintel is thought to be related to this mechanical stress. The shearing off of the section is assumed to have happened at the time of the fire but it was held in place for several months by the mortar.

Digital Scanning

A digital scan of the west gable was carried out prior to and following the fire by the Glasgow School or Arts Digital Design Studio. This has proved incredibly useful as it has allowed the comparison of the current position of the façade with reliable benchmark data. The scans have shown a clear increase in horizontal displacement towards the heads of the columns which is displayed in fig 6 with the red sections indicating a maximum displacement of 15-20mm and the green indicating a minimum displacement of 0-5mm. These results support the idea that the columns have been pushed out at the head.

Crack Monitoring

A monitoring programme of the west gable was developed and implemented by David Narro Associates in order to monitor individual cracks and more importantly the movement of the whole façade. This comprised regular visual inspections of the high level cracking around the lintels of the openings. Demec studs were also used to take accurate measurements of the spreading of cracks. These are small metal disks fixed to either side of cracks in several locations. Accurate measurements can then be taken between them using calipers. During the course of monitoring it was concluded that during the time after the fire the façade had not continued to move.

6. 3D digital scan comparison showing displacement of piers

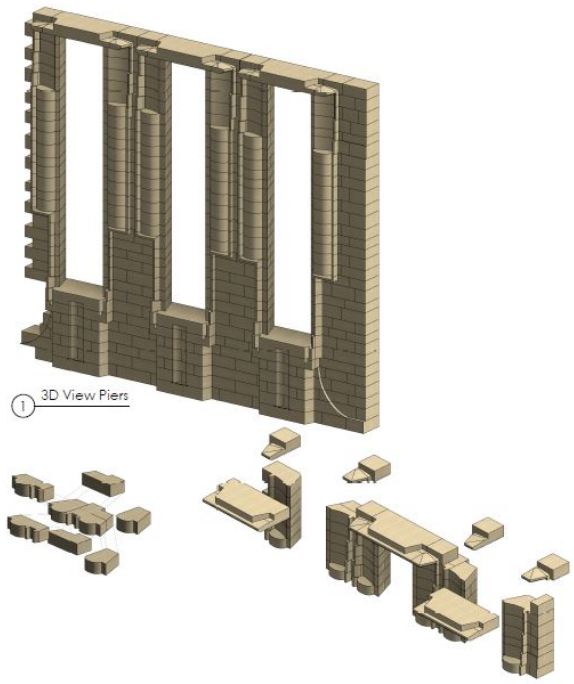
Modeling of Piers

As part of the repair, the piers will be completely dismantled. In order to understand and keep a record of the individual blocks in the piers, a 3D AutoDesk Revit model was produced. Each of the blocks was modeled individually and the piers were effectivlet constructued digitally within the model. Furthermore each of the blocks was given a reference which is collated along with their individual volume in a stone schedule. This will facilitate the process of labeling and identifying individual blocks during the dismantling and assessment process (fig 7).

PROPOSED REPAIRS

The task of repairing the piers is a delicate one due to a number of critical factors. The first being the structural role the piers play in the support if the west façade. These piers form the centre piece of what is arguably the most impressive façade of the Mackintosh building. The piers climb an impressive three story heigh without lateral support which is a unique feature in a building of this period. The damage they have sustained has affected this structural integrity and is a priority when it comes to their repair. The method severity has deemed it necessary to implement a full scale dismantling repair and

replacement of the entire piers. The second factor that is of great importance is the aesthetic of the piers. As part of the repair it is deemed necessary to replace a certain quantity of masonry. This causes concern due to a possible incontinuity of the look of the blocks with repect to one another whether it is colour, texture or the way in which it weathers.



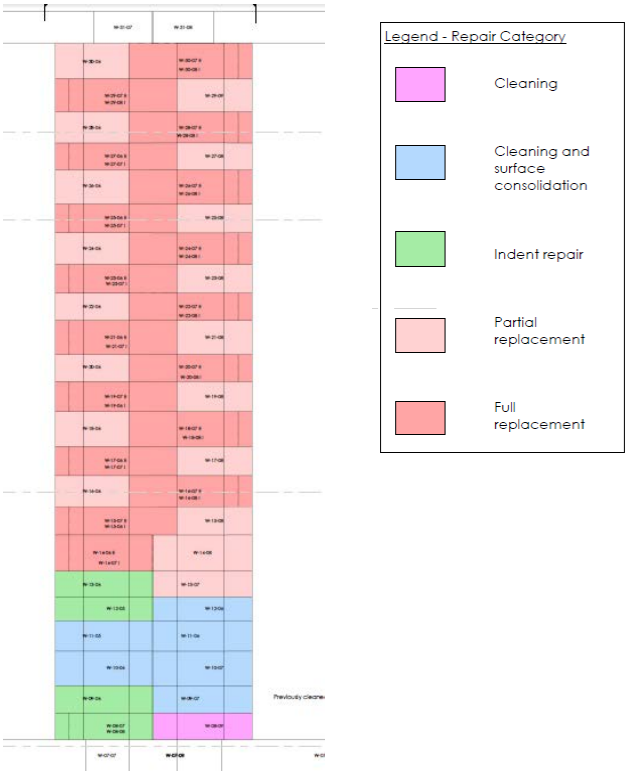
7. AutoDesk Revit model of piers using individual blocks

Temporary Works

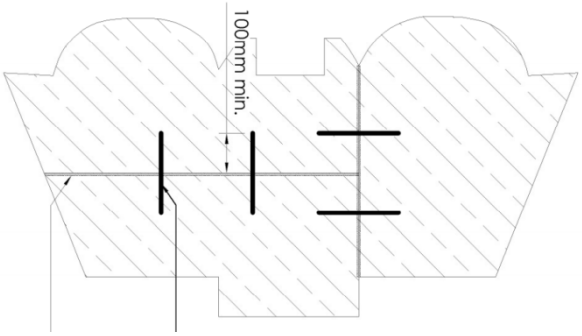
The temporary works for this project are critical due to the scale of the repairs and the structural role of the element in question. The elements in question are not typical of traditional masonry buildings and extend over three levels. For this reason the propping must provide sufficient vertical load capacity but also, it must provide the same lateral stability that will be removed with the piers. Lateral stability is perhaps critical due to the outward movement of the façade and reduced level of connection with the return walls. The aim is to prop along a horizontal line running under the lintel level of the openings which will require needling of the masonry at the head of the piers. The loading from above this line will be transferred vertically downwards onto the sills of the openings.

Stonework Repairs

By means of close inpection of the entire piers, the needs of each stone block have been assessed. This ranges from the most severe cases where complete replacement is necessary to the least where a surface cleaning would be sufficient. Diagram 8 shows the proposed level of repair that each block requires. The repair measure that falls between these two extremes and will be used for the majority of the blocks involves salvaging sections of the blocks where possible and incorporating new sections as a partial repair. The individual elements will be bonded with stainless steel dowels resin anchored into one another as per diagram 9.



8. Section showing propsed dowel repair of masonry blocks



9. Section showing propsed dowel repair of masonry blocks for partial repair.

Lintel Repairs

A critical part of the repair is the lintel repair. Lintels are a unique element in masonry structures which resist load by mainly compression whereas lintels act as beams with a tension face on their underside and compression on top. The cracking of the lintels through their entire body has essentially rendered the lintels useless as no tension can be resisted. It has been deemed too comlex an exercise to remove the lintels due to two main reasons. Firstly the propping

and needling structure result in the sacrifice of a much larger cuantity of masonry due to the inability to use the window openings as propping points. Secondly and more importantly, the lintels are of such large dimensions that it would be almost impossible to source blocks of the appropriate stone to replace them. The chosen repair method is therefore the application of strips of carbon fibre which will unite the two sections and allow the lintels to function as a monolithic block once again. The strips will be applied to the underside of the lintels while they are propped. This means that when the lintel is reloaded, the tension face of the lintel will be once again able to resist the forces.

Repair Philosophy

The repair to this section of the building follows the philosophy of minimum intervention however in this case the minimum is actually very substantial. The great care taken in inspecting each individual stone has allowed for the most possible original material to be retained or salvaged and only replaced where absolutely necessary. All materials to used in the pier repairs are like for like and a great deal of research has been done into the exact stone type in order that a similar type is sourced. Due to the nature of the damage to the Mackintosh School of Art the conservation philosophies that usually apply do not seem as appropriate. The damage that it has sustained was sudden and unexpected and does not hold historic value like it would in the deterioration of a gothic cathedral for example.

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Images

Fig. 1 D. Echlin (2014)
Fig. 2 Glasgow School of Art (2015)
Fig. 3 Glasgow School of Art (2015)
Fig. 4 D. Echlin (2014)
Fig. 5 D. Echlin (2014)
Fig. 6 Z.Guidera (2015)
Fig. 7 Z.Guidera (2015)
Fig. 8 R.Sampson (2015)
Fig. 9 R.Sampson (2015)