THE PLASTER CEILINGS OF BUCKINGHAM PALACE AND WINDSOR CASTLE: THEIR CONSTRUCTION, CONDITION AND CONSERVATION

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Abstract. *Alan Conisbee & Associates and Richard Ireland were engaged by the Royal Household Property Section to inspect and assess the historic plaster ceilings and their supporting structure within Buckingham Palace and Windsor Castle. Following the partial collapse of the Apollo Theatre ceiling in London in 2013 great importance has been placed on the inspection and certification of all historic plaster ceilings throughout the United Kingdom. This paper presents the key challenges of the project included the facilitation of access to constrained spaces, asbestos removal and cleaning of delicate fabric, surveying, digital monitoring, structural and plaster defects. Furthermore we discuss the key project outcomes including lessons learnt and best practice methodologies and practicalities behind inspections of this kind. The paper concludes with an outline of significant discoveries and ongoing laboratory testing of undernailed historic timber connections.*

1 INTRODUCTION

Following the internal collapse of part of the suspended fibrous plaster ceiling (decorative plasterwork composed of plaster of Paris reinforced with hessian) at London's Apollo Theatre (built in 1901) in 2013, an investigation took place which culminated in the release of formal guidance for owners and operators of properties with suspended historic plaster ceilings, produced by the Association of British Theatre Technicians (ABTT). During the investigation by Richard Ireland it was discovered how little was known about the various techniques and materials used in the fabrication of suspended fibrous plaster ceilings and their mechanisms of decay and longevity. This led to an amendment to the ABBT guidance on ceilings which now recommends a thorough one-off baseline survey by a competent plaster specialist and structural engineer detailing the ceiling and structure fabrication methods, materials, support system and condition. Emphasis is put on the need to physically examine both sides of a ceiling as extensively as practicably possible, requiring access to the ceiling voids and the upper and lower ceiling surfaces.

In 2015 the Royal Household identified the need for a thorough inspection of all suspended ceilings and their supporting structures, subsequently Alan Conisbee & Associates Ltd (Conisbee) were engaged in 2016 by the Royal Household Property Section (RHPS) to assess the condition and structural integrity of the ceilings throughout Buckingham Palace and Windsor Castle. The RHPS acknowledges its duty of care towards those visiting and occupying these buildings and understands the need to undertake detailed inspections and assessments of all suspended plaster ceilings within them in light of the potential risks associated with unchecked deterioration of such fabric. Conisbee's brief was extensive and entailed undertaking structural inspections, managing plaster specialists, surveyors, access consultants and asbestos consultants & contractors, all within the challenging constraints presented by these two unique, historic, working buildings. The following tasks were undertaken:

- Design of permanent safe means of access in advance of surveys and inspections or to ascertain if the current access is safe and suitable for use.
- Survey of all structural and plaster elements for each suspended plaster ceiling throughout Buckingham Palace and Windsor Castle combining inspections from above and below where practicably possible.
- Review of external building fabric likely to impact on each ceiling specifically in terms of age, water damage and/or movement.
- Provision of detailed room specific reports on structural and fabric condition together with prioritised recommendations for repair and ongoing maintenance and inspection, including individual timescales for re-inspection.
- Certification of all ceilings in a condition acceptable for the use of that room and/or area.

Conisbee and plaster specialist Richard Ireland undertook hands-on assessments of 74 ceilings at Ground floor and Principal floor levels at Buckingham Palace equating to approximately 7000m^2 of ceiling surface. Furthermore at Windsor an additional 54 ceilings were deemed sufficiently ornate and culturally significant to require investigation, equating to a further 6000m^2 of ceiling surface, two thirds of this within the State Apartments at Principal floor level..

2 BRIEF HISTORICAL DEVELOPMENT AND CONSTRUCTION

Buckingham Palace is a Grade I listed building in central London and is the principal residence and administrative headquarters of the monarch of the United Kingdom. As well as providing accommodation for the Monarch and the Royal Family it hosts State visits, Investitures, receptions, dinners and many other formal functions, and its State Rooms are open to the public during the summer months. The core of the present building was begun in 1703 and comprised a large townhouse remodelled and enlarged by John Nash in the 1820's after the site was acquired by King George III[1]. On Queen Victoria's accession in 1837 Buckingham Palace became the principal Royal residence during which it underwent external and internal alterations, notably to the east front and the State Room ceilings, a typical internal view of which is shown in Figure 01.

Windsor Castle is a Grade I listed Scheduled Monument under the Ancient Monuments and Archaeological Areas Act 1979 and contains internationally significant historic fabric from the twelfth to the twentieth centuries. It is one of the most archaeologically complex secular historic buildings in the United Kingdom and the largest continuously occupied castle in the world[2], containing accommodation for the monarch and her family, plus offices, workshops, stores and staff accommodation, and is a hugely popular tourist attraction open 363 days each year. Although Norman and medieval at its core Windsor Castle today is essentially a Georgian and Victorian creation based on extensive neo-Gothic remodelling carried out during the early 19th century.

3 CEILING VOIDS AND SUPPORT STRUCTURE

The Buckingham Palace and Windsor Castle State Apartments are highly significant heritage assets and of great architectural and historical value, both featuring craftsmanship of the highest quality particularly in their decorative aspects. Redecoration and other alterations are usually representative of a change of reign which is also of historic significance. To support these highly enriched ceilings complex iron and timber framing structures were used to create and support their unique shape and form.

At Buckingham Palace the self weight of the plaster ceiling is typically transferred to primary structure through timber laths (thin strips of oak or pine interspaced with narrow gaps) secured with iron nails to small timbers interconnected by a combination of skew nailed butt joints, scarf joints, notched laps and hangers. This timber support frame is typically hung from inverted T section cast iron beams which also support clay pot jack arches integral to the ceiling support system, supporting iron hangers fixed to the primary timber members. A typical example of this is shown below in Figure 02. Where ceilings occur directly below roofs they are generally supported directly by the roof structure (typically timber trusses but occasionally wrought iron of various ages and configurations) spanning between the perimeter walls.

The ceiling support systems at Windsor Castle differ due to the building's much greater age, some of its timber floor and roof structures dating from the 14th century. This structure was retained to support the later lath and plaster ceilings constructed as part of James Wyatt's internal remodelling in the 19th century, with secondary supporting structure typically being integrated into the traditional timber joist and beam floors and trussed timber roof structures in a more direct manner than is the case at Buckingham Palace. The ceilings at both Windsor Castle and Buckingham Palace are predominantly of lime putty mixed with coarse sand and animal hair, applied by trowel to riven hardwood laths nailed to the undersides of the supporting overhead timber structure.

Figure 01: (Left) Interior view of the Blue Drawing Room 1830's highly enriched lath and plaster ceiling. (Right) KCIIDR baroque painted plaster ceiling by Antonio Verrio dated 1684 at Windsor Castle.

Figure 02: (Left) Internal view above the Blue Drawing Room ceiling, from within the void, highlighting the repeating timber primary beams and typical timber coving structure and back face of the ceiling laths. (Right) KCIIDR rear face, comprising timber floor joists and secondary ceiling members

The earliest ceilings at Windsor Castle are the three surviving oil painted schemes by Antonio Verrio dated 1675-84 which survived George IV's redecoration program of the 1820's, as shown above in Figure 01. Around this time, ceilings at both Windsor Castle and Buckingham Palace were extensively remodelled by James Wyatt and John Nash respectively, both using the plasterer Francis Bernasconi (1762-1841). By the 1800s, pozzolanic additives and gypsum, were used to achieve faster setting lime-based plasters which were typically harder and more brittle, incorporating less hair, and applied in thicker layers to riven or sawn timber laths. This development in materials for plaster ceilings produced a heavier and comparatively less flexible system than earlier periods leading to ceilings characterised by deep compartments created by run-moulded lime plaster ribs and downstand beams, enhanced by the application of cast plaster enrichment fixed with adhesive plaster and ferrous armatures of wire and nails.

4 INSPECTION STRATEGY

Inspections were restricted by the extensive presence of asbestos, debris, dust, detritus, confined spaces and the necessity to preserve historic fabric through minimal intrusive inspection (e.g. significant removal of historic floorboards or areas of plasterwork was neither proposed nor permitted). We therefore implemented a comprehensive but complex process of enabling works prior to our structural and plaster inspections which generally comprised (1) Documentation, (2) Digital Surveying, (3) Access, (4) Cleaning, (5) Inspections, (6) Repairs, (7) Certification and (8) Monitoring and Management.

4.1. Documentation

First, photogrammetric reflected ceiling plans were produced by combining point cloud laser scans with conventional digital photographs, these being essential to record the ceiling condition with a gridded overlay for cross-referencing specific areas during close up visual inspection via Mobile Elevated Working Platform (MEWP). This condition information, including crack patterns, deformation and water staining, serves as a baseline upon which all future condition surveys, assessments and repairs will be based. This may also include monitoring the influence on ceiling condition of nearby construction works.

4.2. Digital Surveying

As well as photogrammetry, laser scanning of the ceiling undersides enabled collation of a 3D point-cloud database for future use including the formation of 3D Revit models, 2D reflected ceiling plans and deformation mapping. To enable deformations to be graphically identified from this baseline scan, coloured, contoured distortion maps of ceiling soffits were produced that illustrate deviations from the plane of an agreed datum plane. A baseline scan was established at the start of our appointment in 2016 and repeated quinquennial scans in the coming years will allow clear and rapid identification of new or ongoing distortions which may require further hands-on investigation. This approach, combined with monitoring of the ceiling, will be utilised to minimise re-inspection requirements and so avoid problematic access into the constrained voids behind the ceilings. The initial data obtained led us to target key areas such as those outlined in Figure 03. Local distortion of the Ball Supper Room ceiling aided discovery of a failed roof truss bearing which had caused the ceiling to distort, as captured within the scan, and a new stainless steel bracket was subsequently installed to remedy this. The complicated structural arrangement within the Ball Supper Room and its challenging access constraints would have otherwise made this process much more lengthy and challenging.

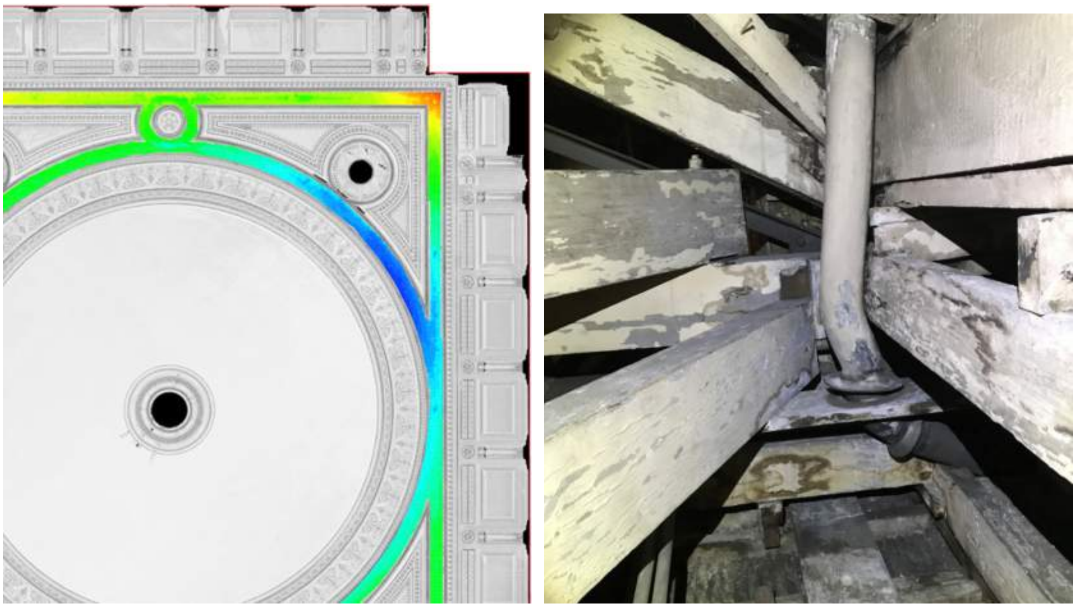

Figure 03: (Left) Distortion mapping of the soffit of the Ball Supper Room. (Right) Photograph of structural defect within the void above, located via the underside distortion. Dropped truss connection was resting on the floorboards and partially supported by a lead drainpipe which has since been repaired.

4.3. Access and Cleaning

An early difficulty was presented by the asbestos within the void spaces and the large amount of dust and debris that had accumulated on the ceiling surfaces, the latter sufficient to obscure the rear surface of the ceiling including the projecting plaster nibs securing the plaster ceiling to the laths, and also the structural connections. At Buckingham Palace alone, 14 individual ceilings above the State Apartments were cleared of 15 tonnes of dust, debris and asbestos to allow safe walkway construction and subsequent structural and plaster inspection and appraisal. Inspection of the topside of ceilings and their supporting structure was carried out above 15 rooms with a requirement for dedicated permanent safe access systems within 7 of these. This process required close collaboration between ourselves, the RHPS, access consultants and asbestos removal contractors to ensure access walkways were constructed safely (some areas posed significant risks of falls from height), as well as managing the health and safety implications of the contaminated environment. Personal air monitoring equipment was used to ensure exposure to asbestos remained at an acceptable level and once walkways were constructed asbestos contractors undertook a fully licensed clean. Trial cleans at targeted areas were undertaken using a soft head brush to ensure that a licensed clean of the plaster nibs could be achieved without causing damage or loss of the historic fabric.

4.4. Inspections and Repairs

Structural and plaster inspections and repairs are discussed in detail in sections 5 and 6.

4.5. Certification

Conisbee produced detailed reports and documentation of the construction, condition and safety of each ceiling and its supporting structure, plus further documentation outlining material condition, performance, management, access, cleaning requirements and asbestos status. A key project task and ABTT guidance note 20 requirement involved the production of certificates outlining the condition and status of both the plasterwork and structure, a collaborative document produced by Conisbee and the plaster specialist. Each certification took the form of comprehensive condition reports and one-page summary documents for use as quick reference guides outlining the current condition and safety of the ceiling, maintenance requirements and recommended future actions.

Figure 04: (Left) Ball Supper Room ceiling inspections via cherry picker. (Right) Inspection via rope access

4.6. Monitoring and Management

The access constraints were such that it was not practically possible to inspect several ceilings from above, and whilst it is possible to draw a reasonable degree of confidence from underside inspections a further programme of remote underside monitoring is currently being conducted. As part of the early documentation period all ceilings were laser scanned from below in 2016 to provide a basis for a programme of ongoing monitoring comprising comparative overlaying of repeat scans. Control protocols have also been established for the RHPS which includes regulating access to safe access walkways and other areas above especially sensitive ceilings in order to reduce vibration related damage.

5 STRUCTURAL INSPECTION AND REPAIR

Following completion of our inspections we undertook the structural assessment of each ceiling support structure in general accordance with the following procedure:

- Understanding the structural system (construction, load transfer, integrity, stability).
- Condition assessment of structural members and investigation into the causes of any defects discovered.
- Detailed investigation of structure directly supporting defective areas of plaster as identified in the underside inspections.
- Quantitative and qualitative investigation of structure supporting areas where considerable deviation/deflection of plaster was recorded during underside inspections.

5.1. Undernailed timber connections

Individual vertical undernailed connections between timber members were commonly encountered, directly supporting the ceilings within both Buckingham Palace and Windsor Castle. This form of fixing would doubtless have proven quick and effective when installing the ceiling structure, however their prevalence generates some concerns regarding their structural integrity, specifically the quantified pull out resistance of historic square cross section wrought iron nails from the parent timber in which they are embedded and their ability to effectively withstand tensile loads, especially those applied dynamically.

Figure 05: (Left) Dropped underside nailed connection within Windsor. Similar defects are endemic throughout both the Windsor and Buckingham Palace estate. (Right) Nail sickness and splitting to timber elements in the East Drawing Room, likely accelerated by moisture ingress.

To date our assessment of the adequacy of such connections has been reasonably but wholly based on their historic performance in satisfactorily supporting the dead and imposed loads to which they have been subjected, however this may not accurately reflect their true load capacity. Owing to this, the paucity of relevant codified guidance and the wide variety of variables at play. Conisbee and the RHPS are currently collaborating with the Centre for Engineering Materials at the University of Surrey to undertake in-situ site testing of historic nails. These tests will empirically determine the influence of key variables – embedment, load magnitude and load type – on pull out resistance using original reclaimed historic nails recovered from the Palace and Castle void spaces. Preliminary results suggest that the pull out resistance of such nails is strongly influenced by the timber species, nail embedment and environmental conditions, and further research is in progress which will quantify these factors in detail.

5.2. Insect attack and moisture related decay

One of our key challenges in conserving the historic timber structure lay in justifying the retention of areas affected by insect attack, particularly at Windsor Castle where it was typically more advanced and severe. Generally only the edible sapwood was lost, suggestive of furniture and/or powderpost beetles, and presently assessment is being made at the areas of advanced attack with a view to ensuring the internal condition of the timbers and key connections is not compromised. This work will serve to produce an overview strategy on how to manage the insect damage and appraise its severity and longevity. Similarly, often due to the presence of deep box gutters to the rear of parapet walls decay of timber truss bearings has been an ongoing historic issue and remains an ever present threat to the macro-integrity of the roof and ultimately the ceiling structure. Decay detection drilling has been undertaken in various locations to quantify the extent of section loss, with subsequent calculations to certify the long term adequacy of the timber structure.

5.3. Calculations and analysis

Analysis was typically undertaken through hand calculations to understand the existing stress state of the structural elements and gauge the overall response to imposed loading. Primary timbers are generally of good quality, dense, dry oak and mostly of adequate capacity to perform as intended. Often however modern prescribed serviceability limit states on permitted deflection are not met such that restrictions on access have been imposed to reduce any potential detrimental effect on the ceiling below through bowing, sagging or other similar movement of the timbers that may crack the plasterwork. Unquantified vertical undernailed connections remain an outstanding unknown currently under investigation as discussed previously.

5.4. Structural repairs

In accordance with accepted conservation engineering principles structural repairs typically comprised reversible and distinct simple bolted stainless steel straps or bespoke traditional timber repairs where needed, usually to consolidate failing hangers or connections.

With a view to minimal intervention these have been limited to essential repairs with monitoring and management preferred in lieu of more invasive interventions.

6 PLASTER INSPECTION AND REPAIR

'Plaster' is a generic term describing two entirely different white materials used in building fabrication: lime ($CaCO_3$) from limestone, and gypsum ($CaSO_4$) [1], also known as plaster of Paris, from gypsum and alabaster rock. In the UK and Ireland decorative run mouldings, added to the ceiling flatwork from the early C.16th, were generally executed in lime. By the mid C.18th gypsum was added to accelerate set, and also used to cast solid enrichment. The older methods were gradually ousted during the C.19th by faster setting alternatives including sand and cement based plasters and latterly the invention of 'fibrous plaster' (a gypsum and hessian composite) in 1856. Period and stylistic development are indicators of fabrication material, but only determinable by hands-on inspection of both faces and chemical analysis. The presence and ratio of lime and gypsum is key in determining performance and decay mechanisms. The ceilings at Buckingham Palace and Windsor Castle are mainly of lath and plaster. Lime plaster is trowelled onto a flexible support, in this case riven hardwood laths, forming nibs protruding between and behind the laths. Earlier lime-based plaster ceilings are capable of greater deflection and distortion than later harder setting plasters with added gypsum characterised by less flexible and thicker ceiling plasterwork.

6.1. Common issues and repair measures

Lime plaster performs equally in externally and internally, though the overhead timber support is more sensitive. A common source of ceiling failure is poor exterior rainwater management leading to persistent water penetration causing support failure by fungal and insect attack. Decorative projections such as the large Ballroom ceiling roses at the Buckingham Palace include additional internal support using ferrous armatures of nails or wire and timber - all sensitive to elevated moisture levels which deteriorate in poorly maintained conditions. Good plaster nib formation depends on correctly sized gaps between laths. For this reason, plasterers undertake their own lathing. Gaps too wide or narrow prevent adequate key formation and can lead to failure - especially where a mix weakened by being too wet compromises material integrity.

For lath and lime plaster ceilings, the much used 'builders' method for securing a lath and plaster ceiling considered to be at risk, typically involves wholesale pouring of plaster of Paris over wire mesh or hessian reinforcement laid and secured between bays. This is entirely unsuitable and should have no place in the conservation of sensitive historic decorative lime plasterwork. Poured plaster of Paris has several potentially disastrous drawbacks as it introduces large quantities of heavy wet material to sensitive fabric and furthermore once set the rigidity of the set plaster in turn accentuates any ongoing deflection forces at boundary edges, destabilising otherwise coherent existing plaster.

The preferred method utilises stainless steel washers suspended by wire inserted through small holes drilled through the ceiling plaster and tied off to perforated galvanised band secured between the joists above[4]. The overall goal is to provide additional support to delaminating areas of historic plasterwork. A washer diameter of around 25mm provides a balance between effective support and minimising physical impact to the ceiling plaster. Restraint sites should form a flat seating to maximise washer contact and should be recessed no more than allows subsequent filling and covering. Where access from above is not possible, the use of screws becomes unavoidable. This is less ideal as it is more difficult to accurately determine the location of reliable supporting timber structure and can easily lead to the repeated drilling of the ceiling fabric to locate suitable structures for fixing to. Screws should be of the smallest diameter required with narrow parallel shafts of sufficient length to make a secure fixing in the selected timber. The technique is intended to be used locally in a spirit of minimum intervention and not intended for systematic thoughtless wholesale gridding and is the method being implemented on decorative plaster ceilings and heavy decorative plaster enrichment in both the Buckingham Palace and Windsor Castle where our investigations have identified defects and potential risk of loss.

Figure 06: (Right) Ceiling restraint washers tied back to the timber support structure above via perforated metal band. (Left) Example restraint fixings to plaster ceiling.

7 CONCLUSIONS

We have described in this paper the strategic inspection and assessment of a large number of historic plaster ceilings and their corresponding supporting structure throughout Buckingham Palace and Windsor Castle, each Grade I listed buildings of international significance and importance. Our inspections have implemented the recommendations contained within the latest ABTT guidance and demonstrate the many practical challenges we have encountered when attempting to satisfy these certification requirements. To safely access often restricted, confined, obscured and contaminated spaces located above fragile plasterwork ceilings suspended over rooms in regular use required considerable planning, design and execution. Some of these challenges and limitations are site-specific owing to the special and unique genesis and usage of the buildings, however many are generally and usefully applicable to a wide range of common building types from all periods. The observed defects and their proposed remedial measures are summarised in Table 01 below:

Table 01: Summary of defects observed and proposed remedial actions

Typical type of defect	**Degree of defect**	**Action**
Cracked or distorted plasterwork	Mild	No immediate action; monitor periodically
	Moderate	Inspect corresponding ceiling area above and relevant supporting structure; undertake frequent monitoring or repairs as required.
	Severe	Immediately inspect corresponding ceiling area above and relevant supporting structure; undertake urgent repairs as required.
Waterstained plasterwork	Mild	No immediate action; monitor periodically
	Moderate	Inspect corresponding ceiling area above and relevant supporting structure; undertake further investigations or repairs as required.
	Severe	Inspect corresponding ceiling area above and relevant supporting structure; undertake further investigations or repairs as required.
Distorted or deformed structure	Mild	No immediate action; monitor periodically
	Moderate	Immediately inspect relevant structure at close hand; undertake repairs as required.
	Severe	
Failed structure	Mild	Immediately inspect relevant structure at close hand; undertake repairs as required.
	Moderate	
	Severe	
Fungal or infestation decay of timber structure	Mild	No immediate action; monitor periodically
	Moderate	Inspect relevant structure at close hand; undertake treatment, repairs and monitoring as required.
	Severe	Immediately inspect relevant structure at close hand; undertake treatment, repairs and monitoring as required.
Corrosion of metallic structure	Mild	No immediate action; monitor periodically
	Moderate	Inspect relevant structure at close hand; undertake treatment, repairs and monitoring as required.
	Severe	Immediately inspect relevant structure at close hand; undertake treatment, repairs and monitoring as required.

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REFERENCES

[1] Bradley, A., Pevsner, N., Schofield, J. (2003). *The Buildings of England: London 6: Westminster.*
[2] Colvin, H.M. (1976). *The History of the King's Works.*
[3] Henry, A. and Stewart, J. (2011). *Mortars, renders and plasters*. Farnham: Ashgate.
[4] Ireland, R. (2014). Decorative lime plaster - conservation and repair. *The journal of the building limes forum*, 21, pp.24-39.