January 2023

Nave Ceiling Plaster Condition Assessment
Saint Ninian Cathedral
Antigonish, Nova Scotia

At the request of Mr. Schuegraf on behalf of St. Ninian's Parish Rector, Historic Plaster Conservation Services (HPCS) has prepared this report on the condition of the nave ceiling plaster at St Ninian Cathedral.

The walls and ceilings of St Ninian Cathderal are home to many murals painted by Ozias Leduc. The nave ceiling has four large murals within circular gold borders flanked by a quatrefoil motif. Leduc is recognized by Canada as a National Historic Person and one of the most important painters in Canadian History. The decorated plaster ceiling of the nave is one of the character defining elements of St Ninian Cathedral, and as such its preservation is fundamental to the preservation and historic value of the site.

The cathedral has been undergoing a long-term restoration that began over twenty years ago and has included several investigations and work phases. The nave ceiling is among the last remaining interior elements to be addressed.

Historic Plaster Conservation Services conducted testing of the plain face plaster ceiling of the nave in St Ninian's Cathedral on 22-23 November 2022. The plaster was tested using HPCS's Lug and Key Pull Test methodology to determine the current health of the ceiling plaster relative to its original 'as-built' strength. This report addresses the structural condition of the plaster by quantifying the current condition of the plaster support system. It does not directly address cosmetic surface conditions at the face of the plaster. Access to the face of the ceiling was not available for our visit so we were unable to inspect it closely. The following report explains our testing methodology, the results of the testing, and provides recommendations based on the results.

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How a Wood Lath and Plaster Ceiling System Works

The cathedral ceiling is plaster on sawn wood lath construction. The laths are nailed to strapping on the underside of the ceiling joists. The strapping is spaced consistently at approximately 30cm intervals. No defects or deterioration to the plaster substrate were found at any of the inspection locations.

The construction of this type of plaster system begins with nailing lengths of thin flat strips of wood called laths to the structural members of a ceiling – in this case the strapping. The laths are wet when installed and spaces are left between them. Once installed, the plasterer trowels a coarse base coat of plaster across the surface of the wet laths. Some of the plaster is pressed through the spaces between the laths and slumps over forming a plaster 'key' and 'lug' (see *Figure 1* below). The key is the portion of plaster between the laths, and the lug is the portion of extruded plaster that slumped over the back of the laths. The plaster lugs that are slumped over the back of the laths become hooks that anchor the plaster to the laths when the plaster sets. The result is a smooth hardened surface that is held in place by thousands of small plaster 'hooks'. The wet laths eventually dry and shrink away slightly from the set plaster. This is a mechanical system that depends on the condition of the lugs and keys.

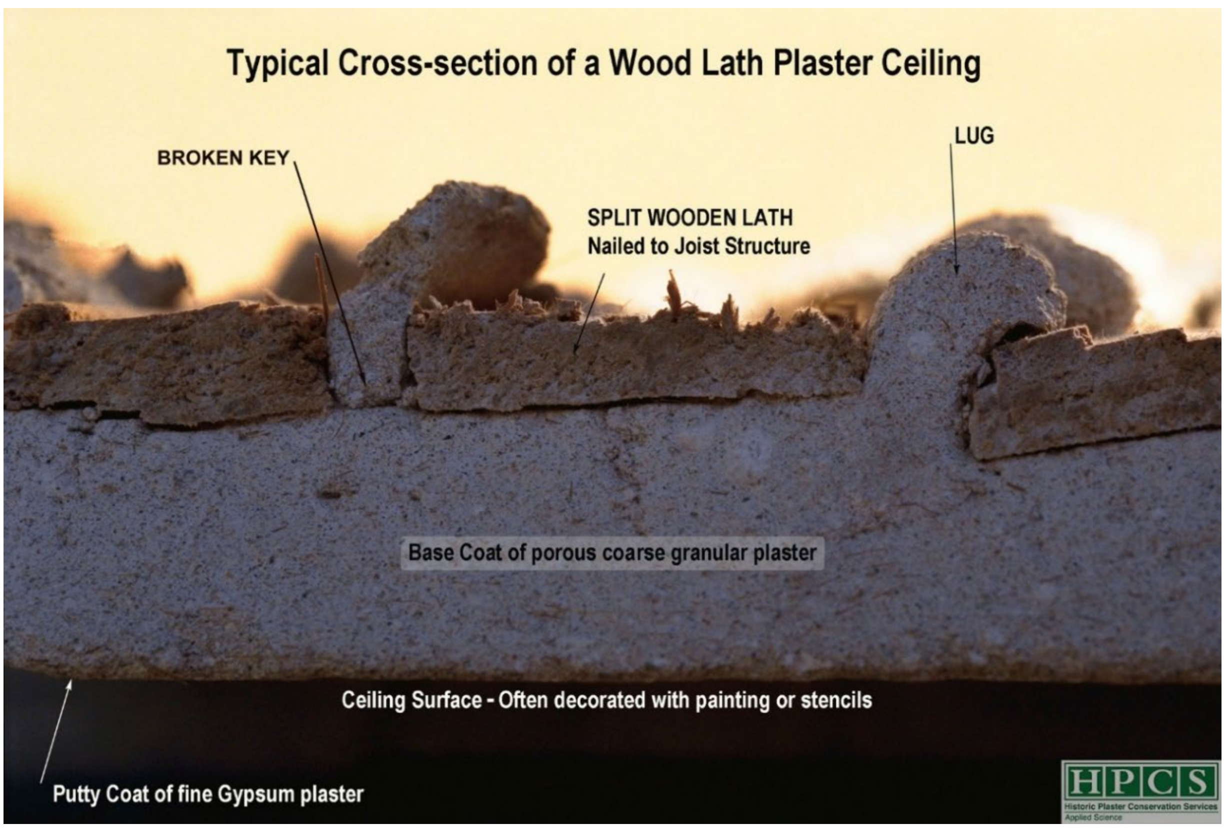

Figure 1: A visual inspection of this plaster would not reveal the broken key that is no longer supporting its share of the ceiling load. Without conducting the right testing the failed key will go unnoticed.

Despite how common this type of plaster construction is in 19th century buildings across North America, the way it functions, particularly as a system, is not widely understood.

Wood lath and plaster ceilings are frequently misunderstood as an adhered system in which the plaster is adhered like a type of glue to the wood lath behind it. In fact, this type of plaster ceiling is a mechanically suspended system. The system is quite ingenious because it allows for some building micro-movement, despite the brittle nature of plaster. Of course, the plaster's stability and safety are totally dependent upon the health of its keys and lugs.

The lugs and keys can be damaged in many ways over their lifetime. Common agents of deterioration are crushing by tradespeople conducting work in the attic, water infiltration from building envelope leaks or mechanical systems, excessive building movement from natural or manmade seismic events, or deteriorating structural systems. The most common systemic cause of deterioration is atmospheric moisture. Over decades moisture from humid air passes through plaster mobilizing salts and causing slow and steady weakening of the plaster. The former causes of deterioration can be avoided or prevented, but the later is a long-term inevitability.

As lugs and keys break, their share of the plaster load is transferred to adjacent keys. As more and more keys break, the workload transferred to the remaining keys increases exponentially to the point when an intervention is required to prevent a partial collapse or a complete system failure. Unfortunately it is often a partial collapse that prompts building owners or custodians to consider the health of their plaster.

If laths are too closely spaced or if plaster squeeze through during construction was insufficient, the result is a non-viable lug and key. These lugs and keys do not provide support for the plaster.

Figure 2: Non-viable keys. In the uppermost red circle, the lath spacing is two narrow for a functioning key. In the lower red circle, there was not enough squeeze-through to form a functioning lug.

General Attic Conditions

The attic space has been improved and well-maintained since building restoration efforts were undertaken in the early 2000s. There is a substantial system of secure platforms to navigate the space and access the lighting and mechanical systems safely. The space is well lite for general maintenance. There are no signs of any moisture in the attic. There are no signs of animal or insect infestations.

Figure 3: Attic conditions. Generally clean and well-kept. Mechanical systems are out of the way, and the catwalk is stable and secure.

The mechanical systems in the attic appear to be in good working order: ducts are securely installed away from the plaster, and no equipment is resting on the back of the plaster. Overall, the attic space is well-maintained and easy to navigate which makes routine maintenance and inspections much easier. This is among the healthiest attic environments I've seen in a cathedral of this period.

Plaster Observations

The plaster is covered with about 350mm of insulation. The earliest insulation is a single layer of paper backed rock-wool batts. The batts were later covered with loose fill cellulose insulation. During our investigation, we discovered at least two locations where the early paper backed batts have been removed and replaced with a poly vapour barrier and pink fiberglass batts. The extent of this newer insulation is unknown. The newer insulation may correspond with areas of the ceiling where repairs have been made, or where other work was performed in the attic unrelated to the plaster.

Figure 4: A partially cleared inspection location. The loose fill cellulose insulation covers a layer of rock-wool paper backed batts (removed in this image). The loose fill covers the top of the joists. Strapping runs perpendicular to the joists and is at roughly 30cm intervals. Note the near total lack of keys at this location even before testing (Location 3).

Figure 5: Newer insulation and a poly barrier were found at two of the test locations. The new insulation is hidden under the loose fill insulation so its extent is unknown.

The nave ceiling is a plaster on sawn wood lath assembly as described above. The plaster is three coat lime plaster typical for a building of this period. Where it has not been exposed to moisture in the past it is still reasonably hard, not overly friable. Where there are signs of past excessive moisture the plaster is more friable. There is animal (probably horse) hair reinforcement in the plaster, as is typical for this type of plaster. The hair is not as evenly dispersed throughout the plaster as would be ideal. We found many small 'clumps' of hair, but there is no indication this is problematic.

The laths are securely fastened to the strapping and there is adequate and even spacing between laths. The strapping is in good condition and is not detaching from the joists at any of the locations we were able to inspect. Although there is staining on the wood from water, we saw no sign of rotten timbers.

We discovered many piecemeal plaster repairs of varying quality. At test location #2 we found a portion of the ceiling that has been repaired with plywood. Presumably the plaster in this area was failing (or fell) and the area was patched with a plywood panel and filled over with some sort of patching compound.

Figure 6: Plywood can be seen through the lath spacing at this location. The plywood is flush against the lath. The plaster near the plywood is in poor condition.

HPCS Plaster Lug and Key Pull Test

The process of assessing a plaster ceiling is crucial to diagnosing problems and prescribing appropriate treatment. To improve this process for plaster on wood lath, HPCS has pioneered a method of measuring and quantifying the condition of an entire plaster ceiling system. Our systematic approach allows those responsible for a building to compare the present condition of the plaster to its original "as-built" condition, and thereby make more informed and better decisions about treatment options. We refer to this method as a "pull test" because it involves gently pulling on all the plaster lugs in pre-defined and measured areas of the ceiling to calculate the present condition of the plaster system. This is the preferred method of assessment because it is objective and quantitative.

Plaster Pull Test Procedure

Eleven test areas were randomly located across the ceilings of the nave. The test areas were on average roughly $1m^2$ each, some slightly larger, and some smaller, depending on the specific condition at each location. The total area tested is slightly more than 3% of the total area of the ceiling.

The procedure for our testing at the cathedral was as follows:

1. A test location was chosen.
2. Insulation was removed from the test area.
3. The “as-found” condition was photographed.
4. The area was cleaned of all debris and vacuumed with vacuum with a HEPA filter.
5. Measurements of the following were recorded:
    a. Area of the test location (length and width)
    b. Lath width and spacing (very consistent across entire ceiling in this case)
    c. Linear centimeters of potential key space in test area
    d. Linear centimeters of non-viable lugs/keys (inchoate lugs or key spaces too narrow to be effective). *In this case the lath spacing was consistent across the entire ceiling.*
6. Each lug was hand inspected and any with fractured keys were removed*
7. The test area was re-vacuumed to remove any loose plaster debris.
8. Total linear centimeters of remaining lugs and keys were measured and recorded.
9. A final ‘after testing’ photograph was taken.
10. The insulation was replaced.
11. A percentage of the ‘as-built’ strength was calculate.
12. The results were tabulated.

“As built” condition is the total linear centimeters of <u>viable lugs and keys</u>. This value is obtained by subtracting the total linear centimeters of non-viable keys from the total linear centimeters of key space.

The current condition of the ceiling is expressed as a percentage of the ‘as built’ condition and is calculated by measuring the linear cm of keys remaining after pull testing:

Linear cm of keys remaining / Linear cm of As Built keys X 100.

* Fractured keys are often not apparent visually because the fracture line is almost always beneath the surface where the key meets the plane of plaster at the lower face of the laths. They are easily identified by a gentle wiggle between thumb and forefinger: fractured keys will move under gentle pressure and good keys will not. This is why each key must be hand checked.

Lug and Key Pull Testing Results Table

Test Location	Area m2	Key Space Length (cm)	Non-Viable Key length	Total As-Built Key Length	Total Broken Key Length	Remaining Key Support
1	1.44	3003	390	2613	120	95%
2	0.80	1700	60	1640	900	45%
3	0.79	2046	N/A	2046	1926	6%
4	1.03	1968	320	1648	878	47%
5	0.75	1584	88	1496	30	98%
6	0.94	1980	100	1880	130	93%
7	0.76	1530	288	1242	30	98%
8	1.00	2214	30	2184	1140	48%
9	1.01	2360	502	1858	90	95%
10	1.34	2844	150	2694	768	71%
11	0.70	1615	N/A	1615	1362	16%

Test Location Notes

1. The plaster is in excellent condition. No obvious signs of previous intervention. There is a high percentage of non-viable keys (~13% of potential).
2. The plaster is badly compromised. There are stains and discolouration on the plaster from past exposure to water. Previous repairs at the edge of the location made with drywall compound and, oddly, plywood. See Figure 8 and Figure 6.
3. The plaster has almost no support keys remaining. The plaster is pulling away from the lath by as much as ten millimetres. There are stains and discolouration on the plaster from past exposure to water. **This area poses a potential safety risk.** See Figure 4 and Figure 10
4. The plaster is badly compromised. No obvious signs of past interventions or water leaks. There is a relatively high percentage of non-viable keys (~16% of potential).
5. The plaster is in excellent condition. Lugs are well formed. No sign of past moisture. The early rock-wool batts were replaced with a poly vapour barrier and pink fiberglass batts.
6. The plaster is in very good condition. No obvious signs of previous intervention. Lugs are well formed. Minor signs of past moisture.
7. The plaster is in excellent condition. High percentage of non-viable keys (~19%). No sign of past moisture. Rock-wool batts were replaced with poly barrier and fiberglass batts. Poly is attached to joists with copious amount of urethane spray foam.
8. The plaster is badly compromised. Some staining from past moisture visible. No sign of past intervention.
9. Very minimal key loss. Lugs are poorly formed, and high percentage are non-viable (>20%). No sign of past moisture or interventions.
10. Moderate key loss. Some staining from past moisture. No obvious sign of past interventions.
11. The plaster has almost no support keys remaining. The plaster is pulling away from the lath by as much as ten millimetres. There are stains and discolouration on the plaster from past exposure to water. **This area poses a potential safety risk.** See Figure 11

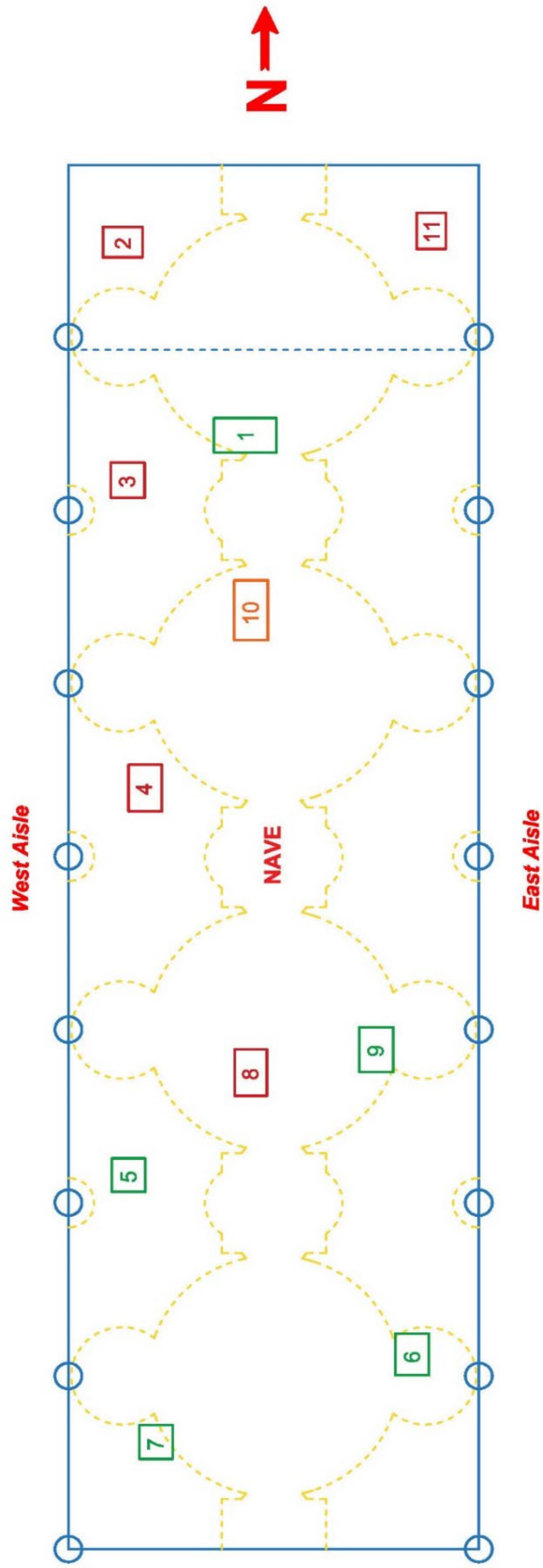

Figure 7: Plan view from attic showing approximate location of tests.

Figure 8: A test location after the insulation was removed and the area vacuumed. (Location 2).

Figure 9: The same location as in Figure 8 after keys were tested.

Figure 10: Near total key lost. Signs of water damage are clearly visible in the form of staining on wood (joists, strapping, and lath), and desiccated mold. There were many non-viable keys at this location, but it was difficult to count them as the plaster was sagging away from the lath enough to make it hard to distinguish old broken keys from non-viable.

Figure 11. Plaster sagging away from the lath at test location 11. A similar condition was found at Location 2 and 3.

Understanding the Results

Typical loss for ceilings of the same type and age as the cathedral and that present no serious problems are in the range of 10-15% (85-90% of keys remaining). When the average loss gets as high as 25% (75% of keys remaining), we recommend preventative maintenance. When the average loss reaches 40% or higher (60% or < keys remaining), there is probably a safety problem.

Usually, we average the test results to produce an overall snapshot of the health of a ceiling. In this case the polarized test results suggest that an average of the results is not meaningful.

We can draw some more specific conclusions about the condition of the ceiling by examining the results of the testing and inspection. The test results of five of the eleven locations are excellent (above 90%), while the results from five others are very poor (below 50%). There was one midrange result. These polarized results suggest a couple things.

The plaster ceiling is not suffering from a systemic failure at this point. Generally, if there is a systemic problem it effects the ceiling more evenly and the test results are more evenly spread across a narrow range (with the odd outlier). In fact, where this plaster has not been exposed to any excessive agents of deterioration, it is in good condition.

On the other hand, in areas where the plaster has been exposed to water repeatedly in the past, or likely where there have been previous interventions in the attic, the plaster is in very poor condition, and in some cases very near failure. Given that about half of the eleven test locations revealed poor conditions, and that the total area tested is about 3% of the ceiling area, it is near certain that there are more compromised areas. We also do not know the size of the damaged areas we discovered.

A lot of work has been done in the attic over the years to address all manner of building maintenance, from roofing and mechanical and electric systems repairs and upgrades, to insulating, installing the catwalk system, and regular visits to change the light bulbs in the nave, not to mention repairs to the ceiling. There is one documented incident of someone puncturing the plaster with their foot while working in the attic. Obviously, this instance was plain to see, and the damage was repaired. However, it's likely that the plaster has sustained more damage than this single foot fall over the past century.

We found a higher-than-average percentage of non-viable lugs and keys in several of the test areas. The non-viable keys we found were mostly the result of inadequate extrusion through the lath spaces resulting in lugs that don't 'hook' the laths, rather than inadequate lath spacing. We found a few instances where the plaster is pulling away from the lath due to heavy key loss and the non-viable keys just slipped through the lath spacing without breaking. The data indicates that inadequate key formation is not a cause for failure, however our observations of the locations where plaster is detaching from the lath tell that non-viable keys could be exacerbating failure by other causes.

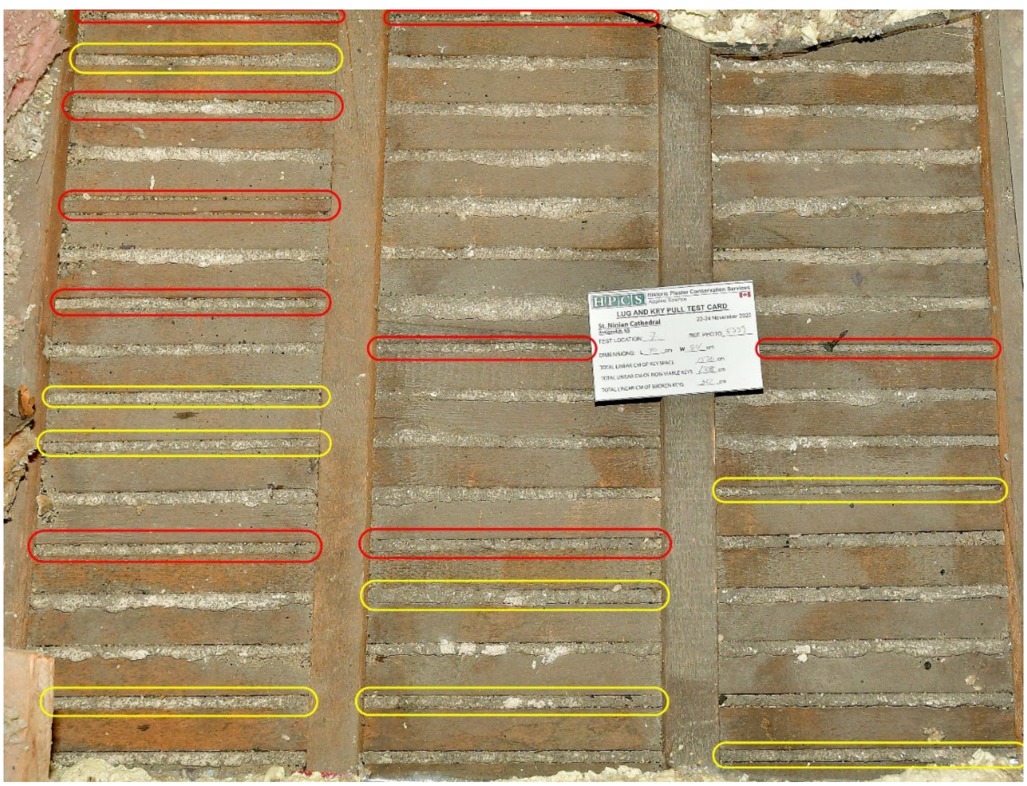

Figure 12: This is Test Location 7. Non-viable keys are circled in red. Substandard keys that are almost non-viable are circled in yellow. Almost 20% of the total potential keys in this area are non-viable and an additional ~15% are substandard.

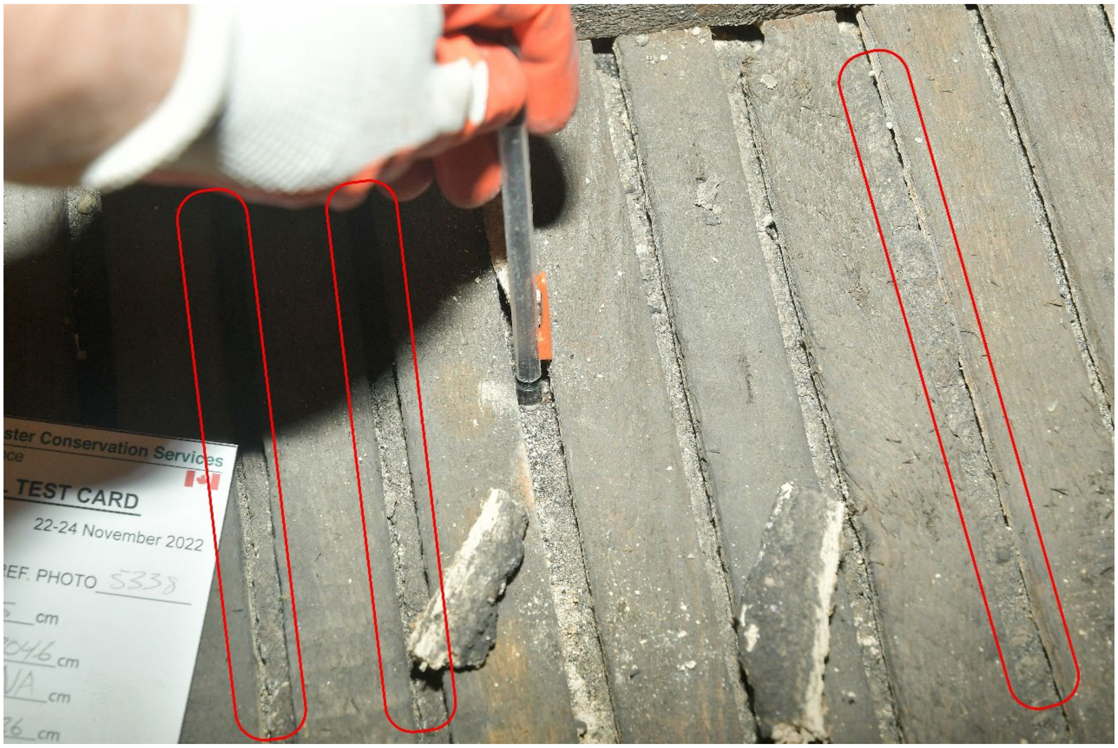

Figure 13: An area where the plaster is separating from the lath. Non-viable keys that have slipped through the lath spacing are circled in red. These keys did not break. (Three keys not circled were properly formed but had broken.)

Given the split findings from about 3% of the ceiling area, we can conclude with a great deal of certainty that a substantial portion of the ceiling plaster is compromised to a degree that warrants preventative action.

Recommendations

A plan and schedule for stabilizing the nave ceiling plaster should be developed as a high priority. Half of the plaster we uncovered and tested is in poor or very poor condition. Although we only tested about 3% of the ceiling area, we believe these findings are representative of the remainder of the ceiling.

Stabilization methods aside, there are two possible approaches one can take to address the failing plaster:

1. **Localized Repairs**. For this method a thorough full investigation of the ceiling would be made and all compromised areas of plaster found and marked out for treatment. These areas would be treated individually leaving the rest of the ceiling relatively untouched.

   The argument for this approach is that it is minimally invasive: areas of the ceiling found to be in good condition would be left untreated. If it is found that far less of the ceiling is compromised than is thought, the treatment of select areas may be less work repair work than other approaches.

   The arguments against this approach are several. A decision-making process would be required to determine what level of deterioration necessitates a repair. Some damaged areas could be mis-diagnosed or missed altogether. Localized plaster repairs of the traditional type would involve removing badly compromised material and replacing with ‘like’, which would necessitate a good deal of additional inpainting of the murals. Alternately a more modern approach of in-situ consolidation could be used to stabilize locally without removing original plaster (and more importantly, Leduc’s painting). However, both these localized treatments create new potential fault lines where original plaster meets new, or where unconsolidated plaster meets consolidated plaster. Finally, a localized approach would still require full removal of insulation and cleaning of the back of the plaster for a proper survey (the plaster cannot be assessed reliably from the face), which would mostly negate any potential time advantage in treating less of the ceiling. This is a big ‘once-in-a-generation’ project to undertake, it would be a missed opportunity if the entire ceiling isn’t strengthened while the opportunity exists.

2. **Plaster Consolidation.** For this method the entire ceiling would receive a consolidation treatment.

   The advantage of this approach is that the entire ceiling would be treated leaving no room for potentially missing damaged areas as a result of misdiagnosis or simple oversight. It does not create potential fault lines at transitions between material types or properties. The appropriate method for complete stabilization of the plaster is Consolidation. This process stabilizes the exiting plaster in-situ; no plaster is removed for this process, thus there would be no additional loss of the murals and less inpainting required. Once the hard work of removing the insulation and cleaning the back of the plaster is complete (a requirement for any realistic remediation approach), the consolidation process is relatively quick, meaning the time difference between a localized approach and full treatment is probably negligible.

I recommend complete stabilization of the entire ceiling using a method HPCS refers to as Plaster Consolidation.

Plaster Consolidation

This treatment involves strengthening the existing plaster ceiling system by penetrating it with an acrylic-based consolidation agent specifically designed for this purpose. The process creates a new strong, yet flexible, bond between the plaster and laths. Missing lugs and keys are replaced with a thickened and filled adhesive with the same acrylic base as the consolidant.

This process is carried out entirely from the attic and would only require workers in the occupied space of the cathedral for monitoring during application. Full scaffolding is required for access to the face of the ceiling during the work to monitor the surface conditions. The results of the consolidation process would also be virtually unperceivable from the floor as well: the ceiling would appear unchanged and yet be fully stabilized.

The patented products involved are no-VOC acrylic emulsions with a similar base to latex paint. HPCS is the inventor, developer and sole practitioner in Canada of the consolidation process and has applied it to dozens of buildings across Canada and over 100 in North America with a one hundred percent success rate.

The concept of plaster consolidation recognizes that “as built” plaster on wood lath ceilings in a nineteenth century building was a loosely suspended system of heavy plaster hung mechanically by keys and lugs as described above. The set plaster hung loosely from the wood lath and because it was suspended, moved gently with the to-and-fro caused by wind loads and other subtle building movements.

The consolidation process converts the plaster from a suspended system to an adhered system with the plaster strengthened and bonded to the lath with a flexible adhesive. Flexibility is important to maintain the plaster system’s inherent ability to absorb some building micro-movement. In this case the application would be from above since there is ready access to the back of the plaster in the attic. The back of the ceiling is cleaned, and all broken lugs and keys are removed by hand in the exact manner as in the testing procedure. The low-viscosity consolidation agents are spray-applied to the back surface of the ceiling and are readily adsorbed by the plaster and thoroughly coat the laths. All missing lugs and keys are then ‘re-built’ with a thickened and filled variant of the consolidation agent. The lug and key replacement material coalesces to new, light-weight acrylic lugs and keys that bond perfectly to the consolidated plaster.

This process does not address cosmetic surface defects on the ceiling face. Any existing cracks or surface defects would have to be addressed separately from the face if such repairs are necessary. The best time to do so would be after the plaster is consolidated and there is no risk of cosmetic work on the surface dislodging loose plaster.

Figure 14: Initial application of consolidation agent. (Notre Dame Cathedral, Ottawa)

Figure 15: Missing lugs and keys are replaced with a lightweight, thickened variant of the consolidation agent.

One of the tangential benefits of HPCS's consolidation process is that in addition to preserving the original ceiling and making it strong and stable for the foreseeable future, the attic will be thoroughly cleaned of decades worth of debris, sand, and dust. The sprayed on acrylic consolidant further acts as a dust 'lock-down' in the attic.

Temporary Plaster Support System

In this case it will be necessary to install a temporary support system for very delicate areas of the ceiling were there is very high key loss. For example, the plaster is in such poor condition at test location 3 and 11 that it must be supported before it is consolidated. There are most certainly other areas that will also require support. HPCS has developed a specialized tool for gently supporting fragile plaster called Micro-Jacks™. Micro-Jacks are small screw jacks that work with standard tube and clamp scaffolding to provide gentle and highly adjustable support for decorated plaster ceilings while stabilization work is performed. Installation is simple and the jacks can be removed within a couple days of the consolidation treatment. The jacks have non-abrasive contact pads and can be dialed in to provide the minimum required support, or even re-align deflecting plaster if the conditions allow. The supported ceiling area is still fully visible for monitoring during treatment. Areas with more than 50% key loss should be supported prior to consolidation treatment.

Insulation Removal and Replacement

All the insulation must be carefully removed prior to beginning the consolidation process. A specialty contractor with the right experience and equipment should be contracted to undertake this job before remediation of the ceiling plaster can begin. The work is not highly skilled labour, but care is required, and the work crew must be conscientious. Traversing the attic must be done carefully as the ceiling is easily damaged by a misplaced foot. Ideally the work should be overseen by a Conservator.

After the plaster consolidation work is complete a qualified contractor should install new insulation. The client should seek guidance from an appropriate authority regarding the type and amount of new insulation required for the space.

Addressing Previous Repairs

As noted above, we found many old repairs of varying quality, and we know there are many more based on a visual inspection of the ceiling from floor level. Some of the old repairs should be carefully cut out and replaced, while others won't require any attention. The course of action for each repair will depend on its current stability, expected long-term stability, and the materials used for the repair. At this time the amount of work cannot be accurately quantified.

Cosmetic Surface Repairs

From the floor the ceiling appears to be in reasonably good condition with some visible cracks and peeling. The cracks don't pose any challenges. Once the plaster is consolidated, they are simply cosmetic repairs. Only the cracks that have opened enough to be visually distracting should be addressed. The peeling will require further investigation to determine how much of it is paint, and how much is finish coat plaster. Some, or possibly all of the peeling material might be failing repair work. It isn't possible to tell from the floor if there is any largescale delamination of the finish coat of plaster. I would expect there to be more obvious signs of this type of failure if it was a systemwide condition of the original plaster. Access to the face of the ceiling is required to learn more and develop an action plan.

Decorative Plaster Cornice

The nave has an extruded plaster cornice embellished with dentils running the perimeter of the ceiling. No access was available during our visit, so the cornice was not inspected. Its condition is unknown. There are not obvious visual indications of problems. It should be properly inspected when scaffolding is in place for the ceiling.

Cost Estimate for Plaster Consolidation

The estimated cost for HPCS to carry out the plaster consolidation work at St Ninian's is in the order of $300,000. There would be related costs in addition to the plaster consolidation work such as insulation removal and replacement, and scaffolding. A full deck scaffolding is required for the work to ensure the safety of the murals and to install temporary supports for very delicate areas while work is carried out in the attic. Addressing previous repairs that require replacement, and other cosmetic work on the face such as crack filling is excluded from this estimate.