Collaboration in Conservation
Chichester Festival Theatre: a case study

15th June 2018

Definition

collâ’bor|āte *v.i.* Work jointly (*with*, or abs.) esp. at literary or artistic production

Working together

Collaboration in Conservation is Constructive

E S S E N T I A L

S U C C E S S

Our heritage

SNC·LAVALIN

FAITHFUL GOULD
Member of the SNC-Lavalin Group

Chichester Festival Theatre: a case study

SNC·LAVALIN

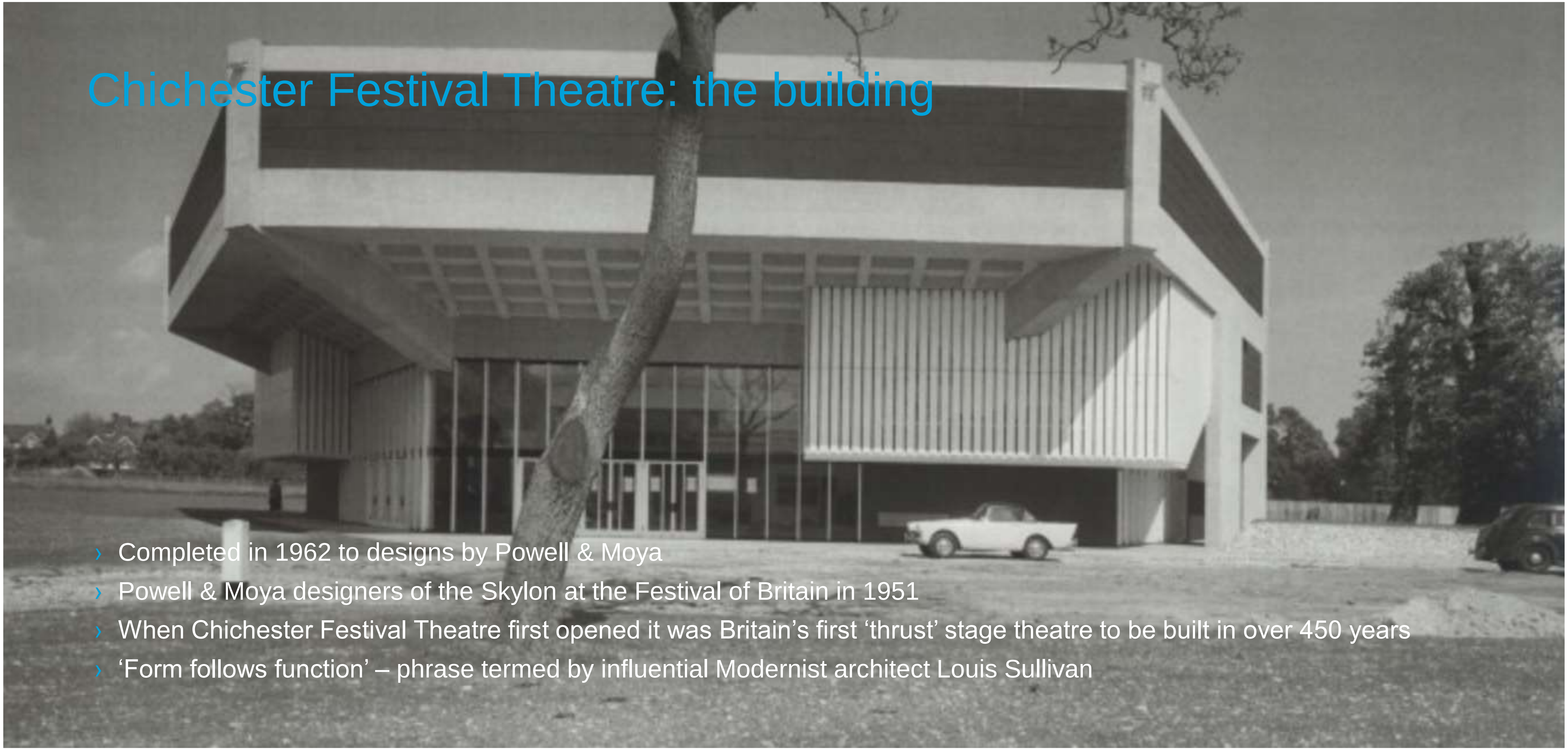
FAITHFUL GOULD

Member of the SNC-Lavalin Group

The Building

SNC·LAVALIN

FAITHFUL GOULD
Member of the SNC-Lavalin Group



Chichester Festival Theatre: the building

- Completed in 1962 to designs by Powell & Moya
- Powell & Moya designers of the Skylon at the Festival of Britain in 1951
- When Chichester Festival Theatre first opened it was Britain's first 'thrust' stage theatre to be built in over 450 years
- 'Form follows function' – phrase termed by influential Modernist architect Louis Sullivan

SNC·LAVALIN

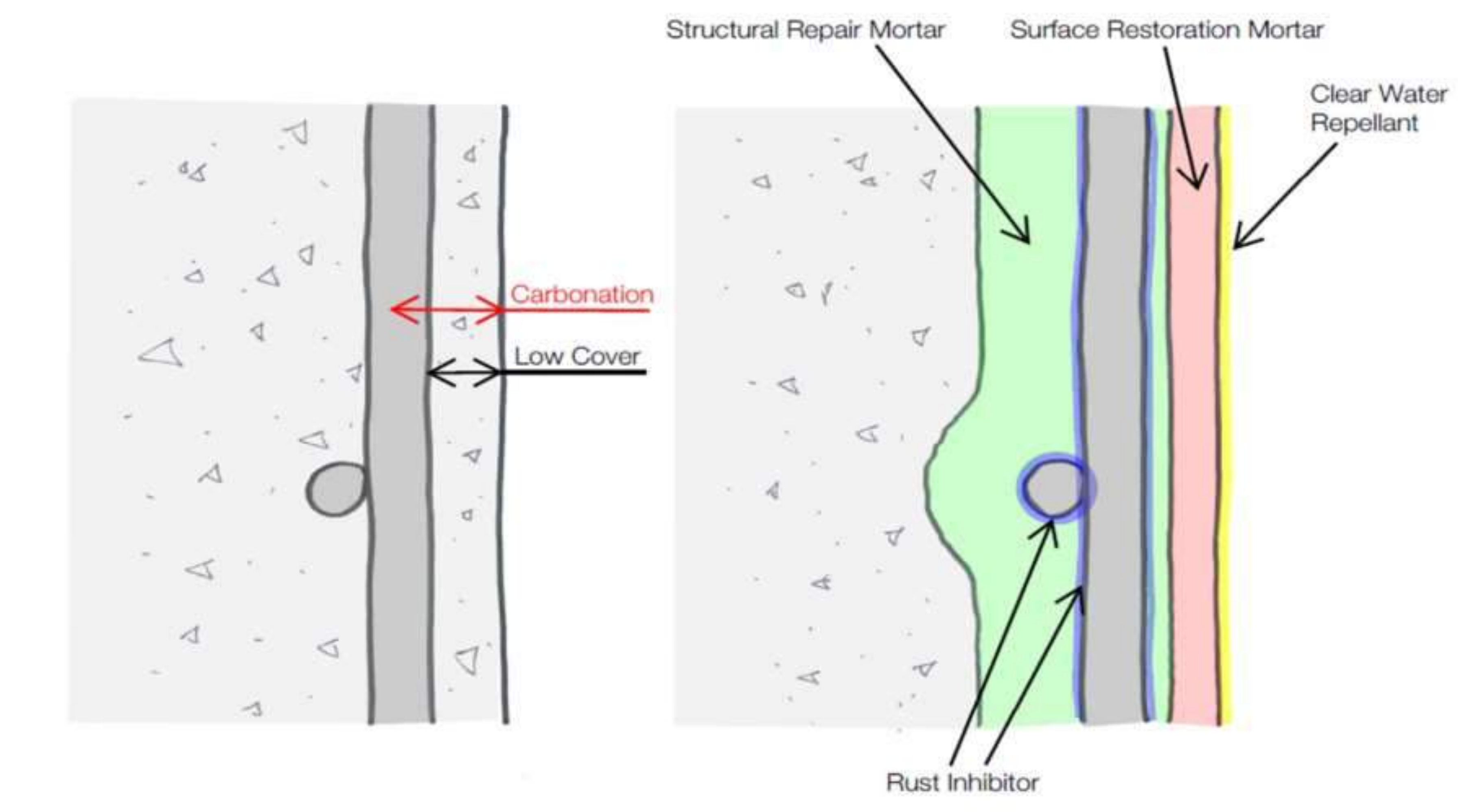
FAITHFUL GOULD
Member of the SNC-Lavalin Group

Project scope

SNC·LAVALIN

FAITHFUL GOULD
Member of the SNC-Lavalin Group

Concrete repair approach



Concrete repair

Concrete repair

Concrete repair

Concrete repair

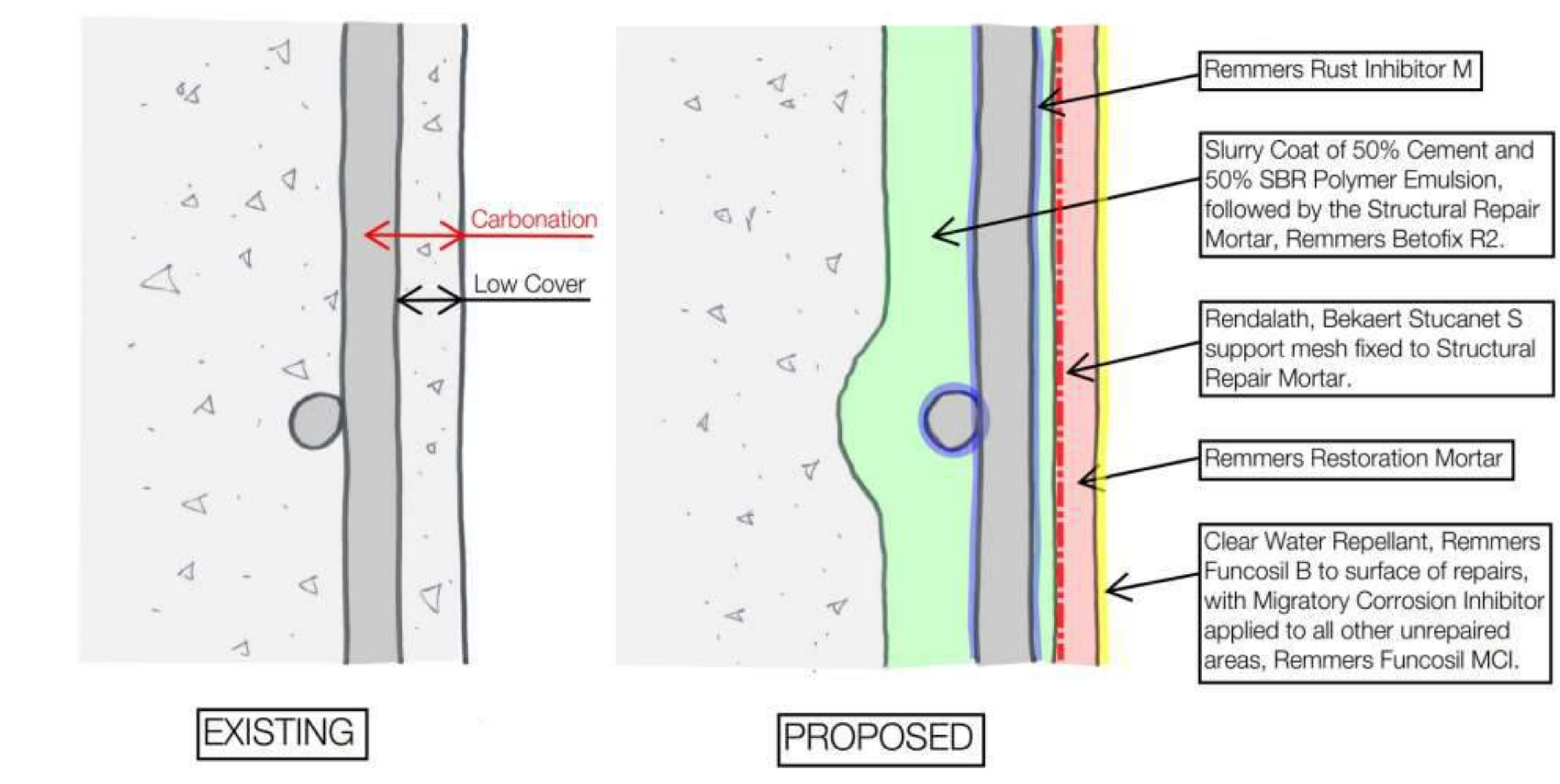
Concrete repair

SNC·LAVALIN

FAITHFUL GOULD
Member of the SNC-Lavalin Group

Testing of concrete repair

Revised concrete repair approach



Concrete repair (second attempt)

Concrete repair (second attempt)

SNC·LAVALIN

FAITHFUL GOULD
Member of the SNC-Lavalin Group

Concrete repair (second attempt)

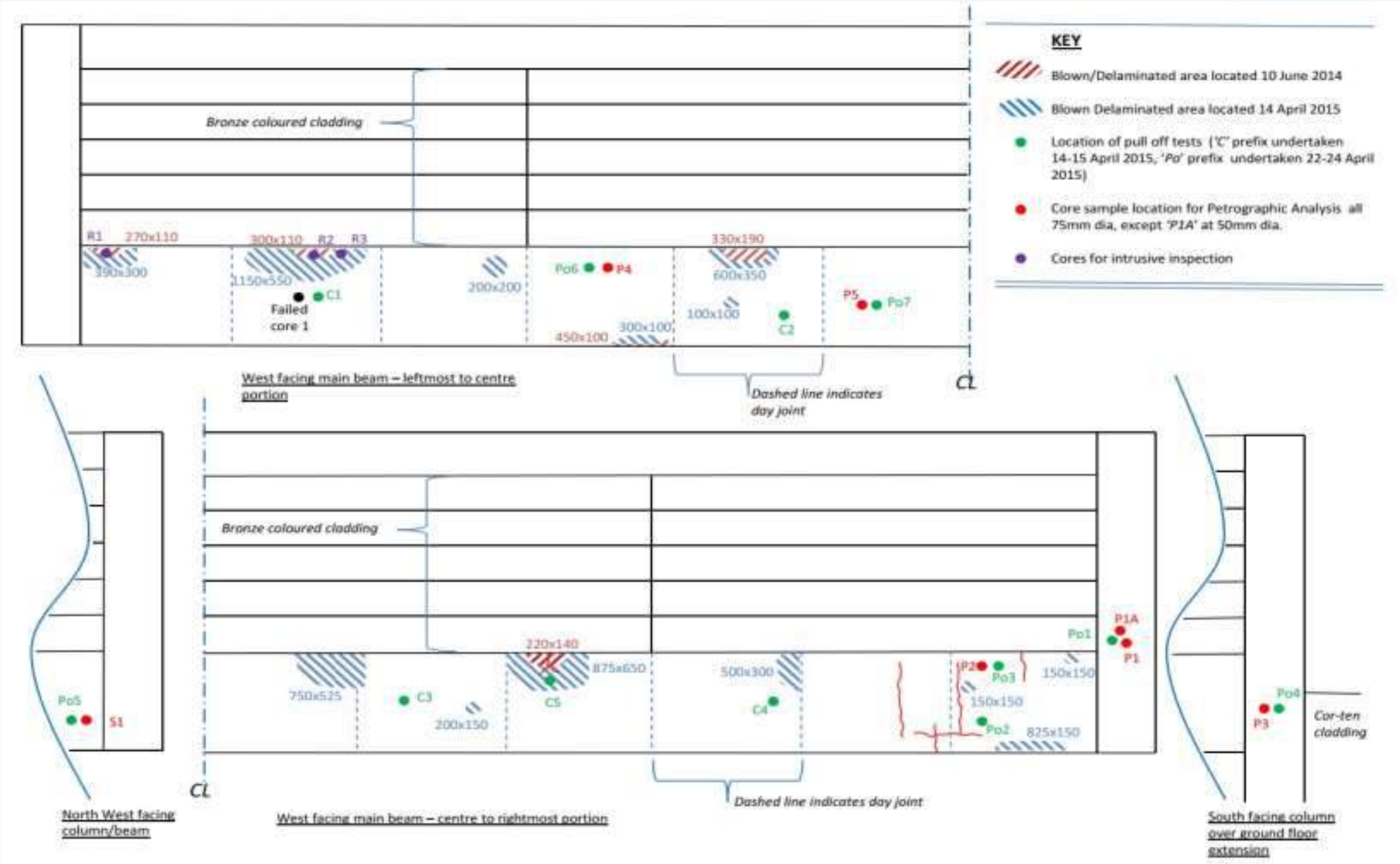
Testing of concrete repair (application two)

Testing of concrete repair (application two)





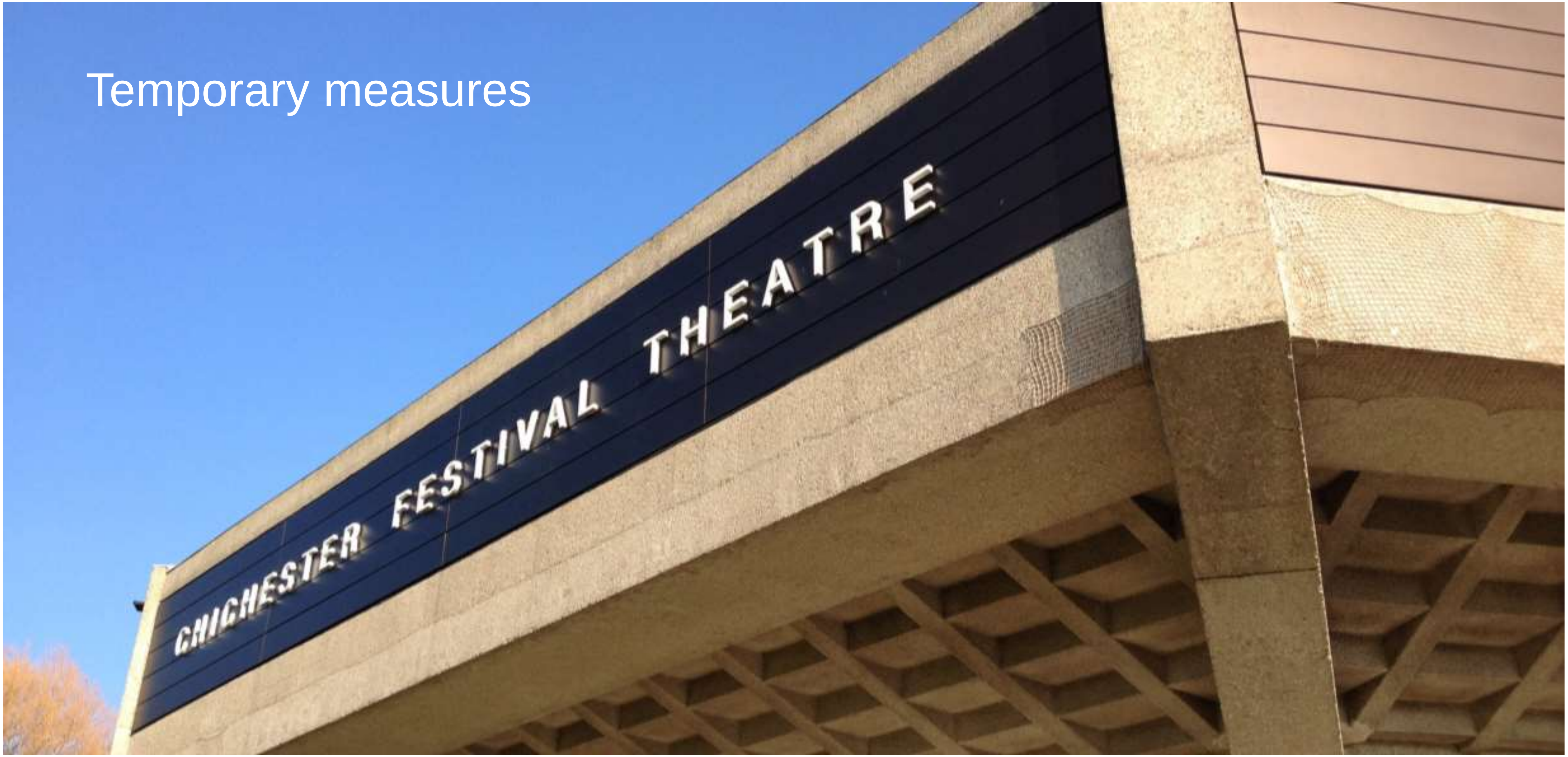

Testing of concrete repair (application two)



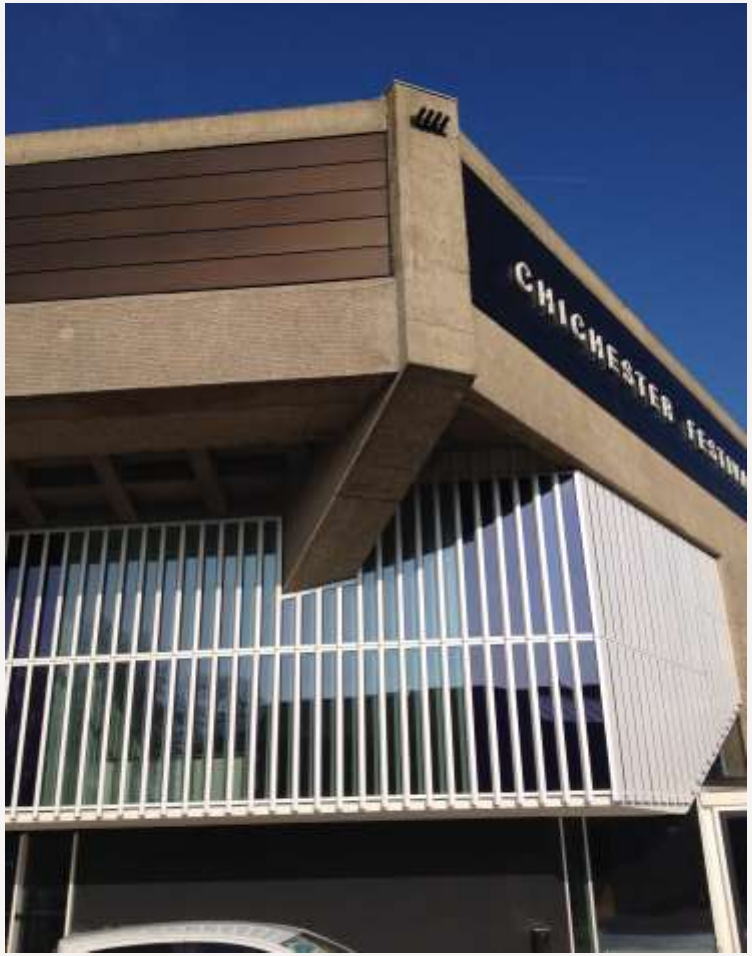
SNC·LAVALIN

FAITHFUL GOULD
Member of the SNC-Lavalin Group

Temporary measures



Temporary measures



Options appraisal

Options appraisal

The purpose of this study is to identify feasible and viable repair options to address those areas of problematic concrete, which will not adversely affect the aesthetic values that are inextricably part of the special interest and importance of the building.

This study identified and considered the following approaches to the repair of the failing concrete:

- Like for like repairs
- Pre-cast concrete panels
- Render
- Various types of cladding including glass fibre reinforced concrete cladding panels

This study has evaluated the aforementioned repair solutions against set criteria. The criteria used to evaluate the repair solutions included the deemed advantages and disadvantages, the conservation implications of using such a repair, foreseeable risks associated with each repair type, their suitability in various locations on the building, and the estimated costs associated with the application of each repair.

'Like for like' repairs follow accepted conservation principles and after being evaluated against the criteria mentioned above, generates persuasive reasoning for its use and implementation.

Trials & Experimentation

SNC · LAVALIN

FAITHFUL GOULD
Member of the SNC-Lavalin Group

Collaboration

Triton Building Conservation

Geoff Engering
Managing Director

Triton Building Conservation

Lee McAlpine
Contract Manager

Triton Building Conservation

Julian
Site Foreman

Chichester Festival Theatre

Simon Parsonage
Finance Director

Jeremy Bragg
Client Project Manager

Price & Myers

Ben Scott
Associate Engineer

2 | CONTRACTOR APPOINTMENT

Concrete composition research

Triton Building Restoration (TBR) impressed at the initial selection process and had also been initially recommended to CFT by Historic England based on the work they had carried out for Faithful+Gould at the Grade II* 'modernist' Congress Theatre in Eastbourne.

TBR were appointed and the experimentation process restarted.

1 | EXPERIMENTATION ACTIVITY

Concrete composition research

Petrographic results carried out during the 'Renew' project provided an indication of the proportion of cement, sand and aggregate within the existing concrete structure.

Additional extensive research undertaken by Triton Building Restoration uncovered the details of the construction company used during the original build and even spoke to a number of their operatives involved in the project. The original specification was obtained and a series of visits were made to local quarries.

Consultation with Tarmac identified that they held the extraction licenses for the types of aggregate required for the concrete mixes we wanted to replicate.

The aggregates used in the building of Chichester Festival Theatre, were originally locally sourced, and therefore of flint gravels and quartz-rich sands, like the Tarmac marine dredged aggregates. The Tarmac marine gravels have a similar range of colours, being predominantly white, black or pale brown, depending on the degree of weathering on the surface patina of the flints.

NAB 351 (area circled in orange) is the location of aggregate found to be the most suitable and similar to the original aggregate used.

2 | EXPERIMENTATION ACTIVITY

The test rig

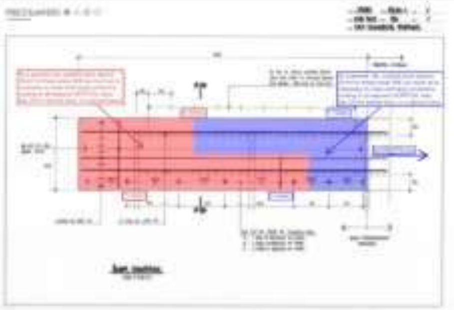


Fig.1 Price & Myers rig design

Fig.2 Reinforcement cage for rig replicating the formation and density of reinforcement found on site

Fig.3 Rig reinforcement

Fig.4 Completed rig with concrete removed to selected areas to expose reinforcement behind replicating site conditions as closely as possible

2 | EXPERIMENTATION ACTIVITY

The test rig (continued)

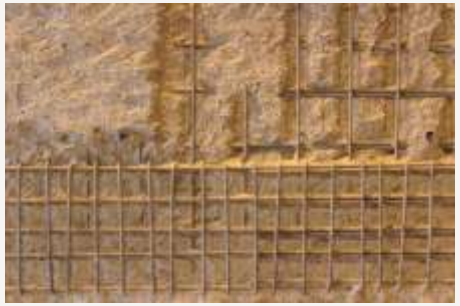


Fig.5 Close up of rig with reinforcement and concrete

The team agreed that the best way to carry out the repair trials was to build a replica of one of the main concrete beam elevations, and recreate conditions on site.

Price & Myers subsequently designed and detailed a reinforced concrete testing rig, approximately 10m long and 1.3m high. It was only half the length of one of the main beam elevations due to the practicality of storing it. However, it represented the full height of the beam and also afforded the option of using both sides to allow for a good number of test panels.

Price & Myers detailed the steel reinforcement in the testing rig to replicate as much as was reasonably possible, the existing reinforcement in the main beam elevations. This included replicating the variations in cover, distribution and density of reinforcement to the building. Price & Myers also made Triton aware of the locations of the existing post-tensioned cables in the existing beams which need to be avoided during the repairs, so specific exclusion zones to avoid these cables were applied to the testing rig.

To provide additional stability to the rig during the trial process, steel bracing was retrospectively added to the supporting frame.

3 | EXPERIMENTATION ACTIVITY

Concrete mix sampling

3 | EXPERIMENTATION ACTIVITY

Concrete mix sampling (continued)

Fig.1 Selection of sample panels prepared for comparison against internal wall within theatre

Fig.2 Four shortlisted sample panels

Fig.3 'Box 20' positioned against in situ concrete surfaces

Fig.4 Close up of 'Box 20' against backdrop of insitu concrete

A total of 38 initial 'biscuit' samples were prepared off site and transported to Chichester Festival Theatre for comparison against a pre-determined section of concrete wall. The selection of constituent materials was informed by the previous detailed desktop research.

Each panel had subtle variations in cement, aggregate, sand and respective proportions. Even different cement manufacturers were used as their products can differ in colour. Each panel was formed within a timber mould, the surface brushed off to remove laitance and expose the aggregate, and then given a quick hydrochloric acid wash to remove cement deposits from the aggregate. This surface treatment was used for the biscuit samples only and not intended as a surface treatment for the actual repairs.

The purpose of the 'biscuit' samples was to identify the concrete mix that most closely resembled the in-situ concrete.

An internal wall of the theatre was selected due to it being readily accessible as well as being well lit by natural light. Parts of the wall had also been an external wall previously with resulting weathered concrete similar to the concrete found on the areas to be repaired. The wall also had an area that had formerly had a lean- to structure which had internalised a part of the concrete and prevented the weathering of this area.

The wall therefore presented an opportunity to compare both weathered and un-weathered concrete surfaces and respective mixes. Four sample panels were selected with two for each of the weathered and un-weathered areas.

4 | EXPERIMENTATION ACTIVITY

Test panel strategy

With the test rig built and a concrete recipe mix passing initial 'aesthetic' scrutiny we needed to agree an experimentation strategy. We needed to consider the test panels we wanted to cast and the various technical criteria that we wanted to examine.

Using the internal sample wall as reference we noted the residual surface marking of formwork shuttering used during the original build (refer to Fig.1 in Experimentation Activity: Three). We noted the replication of this shuttering pattern upon those original external surviving concrete surfaces.

This panelled effect was deemed an important part of the overall aesthetic as well as being an important indication of construction processes. It is our understanding that the 20m long concrete structural components being repaired had been formed in two pours with a horizontal and centrally located 'day joint'. An attempt to replicate the original construction techniques used together with the presentation of a horizontal 'day joint' was prioritised.

We determined that the size of these shuttered panels (approx. 1250 x 650mm) as seen in the above mentioned photograph would provide a good reference for our initial sample panels.

Whilst our desire was to cast as large a panel as the test rig would allow, it was agreed that the smallest panel size that could end up being used for the repair strategy (depending on the results of the experimentation) should be used to assess the various test criteria. Using smaller panels to determine various technical details and suitability also had the benefit of controlling costs during the experimentation process.

Reinforcement was a key consideration in the development of the trials. To provide a mechanical bond between the repair and the existing concrete backing, it was decided that a steel mesh should be fixed back to the existing concrete, and cast as an integral part of the sample panels. Threaded rods are to be resin bonded into the exposed concrete surface, with a mild steel mesh physically fixed to the rods using toothed washers. During the works the mesh will be stainless steel to mitigate corrosion. However, to reduce costs a mild steel mesh was used as part of the repair trials.

Once various criteria (defined against the subsequent experiment activities) had been challenged and we were collectively happy that these had been satisfactorily met and discharged our intention was to move from small test panel up to a 5m long panel and carry out relevant testing on the larger panel. Should these fail or the results prove inconclusive we would reduce the length of panels accordingly.

5 EXPERIMENTATION ACTIVITY

The first test panel

Fig.1 First panel. N.b. tide mark and difference in colouration

Fig.2 Side view of panel and interaction with test rig

Fig.3 Close up of panel and interaction between concrete and insitu reinforcement to side abutting panel 3

Fig.4 Close up of panel and interaction between reinforcement mesh and concrete substrate

Fig.5 Close up of surface of concrete prior to surface treatment

5 EXPERIMENTATION ACTIVITY

The first test panel (continued)

Criteria considered during the casting of the first panel was as follows:

- Reinforcement
- Concrete mix
- Formwork
- Insertion of concrete into formwork
- Aggregate distribution
- Abutment detail with insitu concrete at base of rig

Formwork for this panel used marine plywood (single sheet 18mm) fastened to the substrate using stainless steel threaded rod inserted into female anchors set within the test rig fabric. The rod was covered with ‘polypipe’ to act as a slip plane when the concrete set allowing the threaded rod to be removed. Bolts were used to fasten the formwork in place.

The selected concrete mix was mixed by hand and inserted into the formwork. The mix was agitated into position by hammering the formwork.

Observations

There was a noticeable tidemark within the mix. It was later established that two different mixes had been used creating the difference in colour.

The surface had frequent voiding and pitting raising concern over the compaction of the concrete. Alternative techniques were trialled in successive panels to determine their effectiveness.

Unevenness within the panel was identified and this was found to be due to the formwork and number and positioning of fixings.

Fixings for formwork were positioned within a zone that on site must be avoided due to the presence of sensitive structural reinforcement.

The distribution of aggregate within the panel could not be determined until surface preparation was undertaken.

The marrying of new and old concrete upon the base of the rig was shown to be possible
where fixings in formwork had provided sufficient restraint. Additional fixings were identified as being required.

6 EXPERIMENTATION ACTIVITY

Test panel two, three and four

Fig.1 Panels 1-4 with shuttering in situ on panel 4

Fig.2 Oblique view of cast panels

Fig.3 Close up of day joint between panels 1 and 2

Fig.4 Oblique view of first four panels

6 EXPERIMENTATION ACTIVITY

Test panel two, three and four (continued)

PANEL 2

Criteria under consideration

- Insertion of concrete into formwork
- Horizontal joint between panels
- Aggregate distribution
- Sloping head detail

Additional fixings were used to fix the formwork. The formwork for the upper panel used the bottom panel for support and guidance.

The concrete was mixed by hand, poured, and poked and the shuttering agitated with a hammer.

Observations

There was cracking noted to the surface of the concrete where the formwork had been overtightened after the concrete had started to cure. A larger ‘polypipe’ sleeve was used compared to the first panel.

Less surface pitting was noted compared to the first panel.

The horizontal joint between panels was deemed to be good with the exception of deflection found within the formwork.

The head detail was run in by hand and was found to have been applied after the main panel had set, this being deemed a poor detail.

PANEL 3

Criteria under consideration

- Insertion of concrete into formwork
- Continuation of horizontal day joint
- Vertical joint

The concrete was applied as per panel 2 but tamped using a BS rod in lieu of the poking.

6 EXPERIMENTATION ACTIVITY

Test panel two, three and four (continued)

Observations

A noticeable reduction in surface voiding and pitting.

Good continuation of horizontal day joint and good adherence at vertical joint.

Formwork to base of panel out of alignment with first panel with further fixings required. Note that the lack of depth to the rig makes the fixing of the shuttering to the soffit face difficult.

PANEL 4

Criteria under consideration:

- Refinement of shuttering
- Head details

The concrete mix and application process was as per panel three. The shuttering was strengthened by using an additional ply sheet to increase the thickness of the formwork.

Observations

Good consistency was achieved with neat joint detailing. The sloping head details was run by hand and was effective.

Abrasion of the surface will confirm the adequacy of aggregate distribution and overall completion of the mix.

Cube Testing

Results from these early panels produced results (lower than desired) in the region of 15 to 20N/ mm² after 28 days.

These comprehensive strength results necessitated a review of the concrete mix used for the first four panels

7 EXPERIMENTATION ACTIVITY

Panel five

Fig.1 Panels one to five

Fig.2 Objective view of panel five

7 EXPERIMENTATION ACTIVITY

Panel five (continued)

PANEL 5

Criteria under consideration:

- Concrete mix
- Insertion of concrete mix into formwork

The shuttering was as per that used for panel four in contrast to the previous panels, a vibrating poker was used to ensure maximum impression of the concrete and distribution within the formwork.

The proportion of cement was increased to 1.5 measure in an attempt to determine whether this positively impacted composite strength results.

Observations

Although not immediately noticeable from thetest panel, the corresponding 'biscuit' samplecreated for the mix had a noticeable 'yellow ochre' colouration. When taken to CFT and considered against the comparison wall it was not felt to be an acceptable match.

Cube testing of the mix provided slightly improved compressive test results, but still not to an anticipated level.

8 EXPERIMENTATION ACTIVITY

Surface preparation to panels one to five

Fig.1 The panels were each divided into three sections using chalk

Fig.2 View of the panels being sub-divided

Fig.3 Ply-board was used to assist in restricting abrasives straying into the other sub-divided areas of the panels

Fig.4 Washing down residual traces of abraded concrete and aggregate with clean water

SNC·LAVALIN

FAITHFUL GOULD
Member of the SNC-Lavalin Group

8 EXPERIMENTATION ACTIVITY

Surface preparation to panels one to five (continued)

Fig.5 Complete surface preparation trials

Fig.6 Abrasive preparation of 'biscuits' for comparison on the site

Fig.7 Additional 'biscuit' samples with abraded surface for comparison on site at CFT

SNC·LAVALIN

FAITHFUL GOULD
Member of the SNC-Lavalin Group

8 EXPERIMENTATION ACTIVITY

Surface preparation to panels one to five (continued)

The surface preparation trials were important for two reasons:

1. They allowed us to determine the distribution of aggregate and whether there was any viability depending on the different approaches to applying the concrete.
2. They allowed us to experiment with various abrasives to determine and identify the various finishes that could be obtained and whether these provided a close match to those found on site.

Two primary aggregates were used namely crushed glass and aluminium silicate. These abrasives were used with two types of specialist equipment provided by Restorative Techniques with different pressures and nozzle sizes tested to establish various abraded finishes that could be achieved.

The aluminium silicate abrasive was found to provide the best results. It was also noticeable that the best surface finishes were obtained on these panels that had longest to cure.

The results from the cube testing caused concern over the suitability of the concrete mix and led to the revised recipe used in panel five.

It also led to the reconsideration of some of the earlier 'biscuit' samples prepared and whether these might be more appropriate to provide higher compressive strength results.

Selected 'biscuit' samples were prepared using the aluminium silicate abrasive ready for comparison on site.

The aluminium silicate was used effectively to clean down reinforcement on the rig. It was agreed that this would provide an effective and thorough technique to prepare reinforcement ahead of repairs on site.

9 EXPERIMENTATION ACTIVITY

Concrete mix sampling (Part II)

Fig.1 Alternative 'Biscuit' Samples with abraded surface for comparison against wall at CFT

Fig.2 A close up of the internal concrete at CFT. A repetitive patterning is visible, suggestive of a percussive form of finishing

The compressive test results from the cube tests carried out on the early panels marked a change in approach to the repair mix, aesthetics and conservation philosophy.

Whereas our focus had formerly been on creating a concrete mix that closely resembled the cleaned but weathered external concrete, it was evident that the addition of building sand to provide the required colouration to the mix, affected the performance of the concrete mix during cube testing.

9 EXPERIMENTATION ACTIVITY

Concrete mix sampling (Part II) (continued)

We therefore decided to place greater onus on closely replicating the original concrete mix, resolving that this was an 'honest' approach to the repair of the concrete.

Whilst 'biscuits' nine and ten were deemed a good match to the cleaned and weathered concrete located on the selected internal comparison wall, the abraded finish was not.

The on site identification that percussive techniques had been used originally helped inform the next surface preparation techniques to be tested.

10 EXPERIMENTATION ACTIVITY

Core and hammer testing

Fig.1 Core testing carried out to applied panels

A collection of different physical tests, both invasive and non-invasive were carried out on the trial repairs. The testing was carried out for two main reasons. Firstly, to identify any problems with the concrete repair trial panels, both in terms of the concrete mixes used for each panel, as well as the structural integrity of the concrete repair panels themselves.

Secondly, to build up an objective record of knowledge from the testing of the trial panels and compare that knowledge with non-invasive testing of the actual panels applied to the building.

The second reason is of importance as our aim is to prevent unnecessary disturbance to the newly applied repair panel by invasive testing, but seeking the confidence that the repairs have been successfully applied through non-intrusive testing.

Fig.2 Additional cores were taken to determine the quality and bond between panels

10 EXPERIMENTATION ACTIVITY

Core and hammer testing (continued)

75mm diameter cores were taken. The cores and corresponding holes were inspected for voiding, cracking and general structural integrity. Almost all of the cores exhibited good compaction of the concrete through its full thickness, with little or no voiding in most areas.

Additionally, although not as consistent a test as the standard concrete cube test, some of the cores were crushed to give a further indication of the concrete strength. Test results generally correlated with the results obtained in cube testing.

The cores were also used for pull-off tests to check the adherence of the repair panels to the parent concrete. Unfortunately, due to the nature of the build up of the repair panels with the new and existing steel reinforcement, many of the cores delaminated during the coring process. Those that were able to be pulled off returned relatively low results for adherence. This was thought to be attributable to the damage caused by the coring process. The new steel reinforcement being installed to provide a mechanical bond means that to a larger extent the compromised results from the pull-off tests can be disregarded.

The applied panels were also tested for voids by hammer testing the surface and listening for a change in tone of the sound produced. No voids were identified in any of the panels tested on site.

Hammer testing will be the test used to assess the integrity and any voiding of the repair panels cast onto the building.

11 EXPERIMENTATION ACTIVITY

Core and hammer testing (continued)

The results from cube and core testing of the panels and alternative mixes were not producing the desired results. We, therefore, made a more in depth and forensic assessment of the consistent parts of the concrete mix, how the mix was being prepared and applied, the quality control measures that were being implemented and the consistency in mixing and application.

The amount of water being used in the mix was scrutinised. Water had been added by volume, one part cement to one part water. It was determined that greater accuracy was required in the measurement of water content. Rather than referring to volume, weight of water compared to weight of cement was critical. A water/cement ratio of between 0.55 to 0.60 was stipulated.

The change in the method of measurement of water content made profound changes to the mix and how this responded during compressive strength tests.

It was also evident that accuracy and thoroughness in mixing was of paramount importance. Differences in the quality of mixes produced by different operatives was observed.

Consistency in how mixes were formulated was, therefore, identified as being critical to the success of the trials and to the repair works on site.

The trials demonstrated that working practices have a direct impact on the suitability of the concrete mixes being produced. There is no room for any complacency from site operatives.

The following mix was suggested and trialled which produced good results:

- One part blue circle cement
- Two parts sharp sand
- One part 10mm aggregate
- Two parts 20mm aggregate

Sand and aggregate was sourced from Nab 351 Blashford coastal marine deposits.

12 EXPERIMENTATION ACTIVITY

Test panels six and seven

Fig.1 Panel six cast onto test rig with formwork present on panel seven

Fig.2 Corner of panel six illustrating voiding caused by run off of water from mix

Fig.3 Bush hammering trial

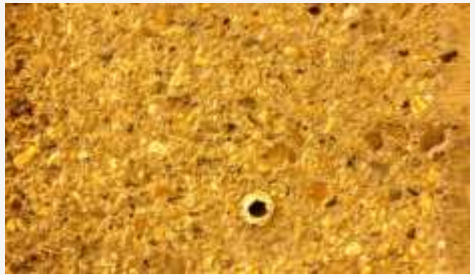


Fig.4 Surface finish achieved by bush hammering

12 | EXPERIMENTATION ACTIVITY

Test panels six and seven (continued)

Panels six and seven were the first to be applied at the intended larger of 5000 x 650 mm dimensions to be employed on site. Shuttering was as per the previous panels but increased in size and included four 17mm thick marine ply panels adhered to the internal face of the shuttering. These additional panels were inserted in an attempt to recreate the shuttering pattern found on the building. The concrete mix was inserted into the formwork using the same approach and technique as panel five.

Following our review of the mix proportions and mixing technique adopted, the revised mix was used with the proportions of sand, aggregate, cement and water.

Bush hammering to a small part of the face of panel six was undertaken.

Observations

The revised concrete mix performed well within the formwork with operatives reporting no issues in terms of workability, caused by the reduced water content.

Voiding was noted to the bottom corner of panel six. It was evident that this had been caused due to leaching of the water from the mix. It was agreed that the shuttering for panel seven, subsequent panels and the site works, would require the perimeter of the shuttering sealing to prevent water loss. A non-staining *Arbo* sealant was used which prevented any further loss of concrete and resulting voiding.

Initial observations of panels six and seven were very positive.

The 'bush' hammering trial produced results that closely resembled those found on site. The expressed joints between shuttering panels, visible when the shuttering was removed, were removed by the 'bush' hammering process.

13 | EXPERIMENTATION ACTIVITY

Core and hammer testing

Fig.1 Core testing of panels six and seven

Physical tests were carried out as per 'Experiment Activity: Ten'. Results demonstrated that there was minimal voiding within those cores tested and that results were consistent with those found in earlier panels. The increase in panel size has not led to any concerns of problems being identified by testing performed.

The positive results meant that we were able to apply a further two 5000mm x 650 mm panels to demonstrate consistency in application and workmanship.

14 | EXPERIMENTATION ACTIVITY

Test panels eight and nine (final panels)

Criteria under consideration:

- Consistency in application
- Bush hammering

The shuttering was formed as per panels six and seven, with the exception of an increased gap left between the joints of the 17mm marine ply shutter lining panels to determine whether this would assist in expressing the joints after 'bush' hammering.

We were also keen to explore whether the length of time that panels were allowed to cure, would impact upon the ease of manipulating the surface and the surface finish results.

Observations

The casting of panels eight and nine demonstrated both a consistency and accuracy in installation and in the operatives' workmanship.

The bush hammering trials demonstrated that the earlier during the curing process that the surface was prepared, the easier the process was. Appropriateness and quality of surface finish results were not affected by the hardness of the concrete.

It was agreed that bush hammering could be undertaken shortly after the shuttering had been removed, but no earlier than three days after each panel had been cast.

Bush hammering could not be used on those small areas where repairs had been made to shuttering fixing holes, as this led to their disturbance and eventual failure.

It was determined that hand applied repairs needed to be hand finished to obtain a closely matching surface finish.

SNC·LAVALIN

FAITHFUL GOULD
Member of the SNC-Lavalin Group

Implementation of concrete repairs

Access and working platform

Removal of previous repairs

Removal of previous repairs

Change Footer here: Insert > Header and Footer (delete if none)

Removal of previous repairs / preparation of concrete surfaces






Removal of previous repairs / preparation of concrete surfaces

Preparation of reinforcement

Preparation of reinforcement

Setting out

Setting out

Installation of reinforcement and form-work

Installation of reinforcement and form-work




Concrete mix constituents

Concrete mix

Concrete panel installation

Concrete panel installation

Concrete panel installation






Concrete panel installation

Change Footer here: Insert > Header and Footer (delete if none)

Concrete panel installation

Concrete patch repair (vertical surfaces)

Concrete patch repair (vertical surfaces)




Concrete patch repair (vertical surfaces)

Concrete patch repair (vertical surfaces)

Concrete patch repair (soffit)

Concrete patch repair (soffit)

Concrete patch repair (soffit)

Concrete patch repair (soffit)






Completed results

Completed results

SNC·LAVALIN

FAITHFUL GOULD
Member of the SNC-Lavalin Group

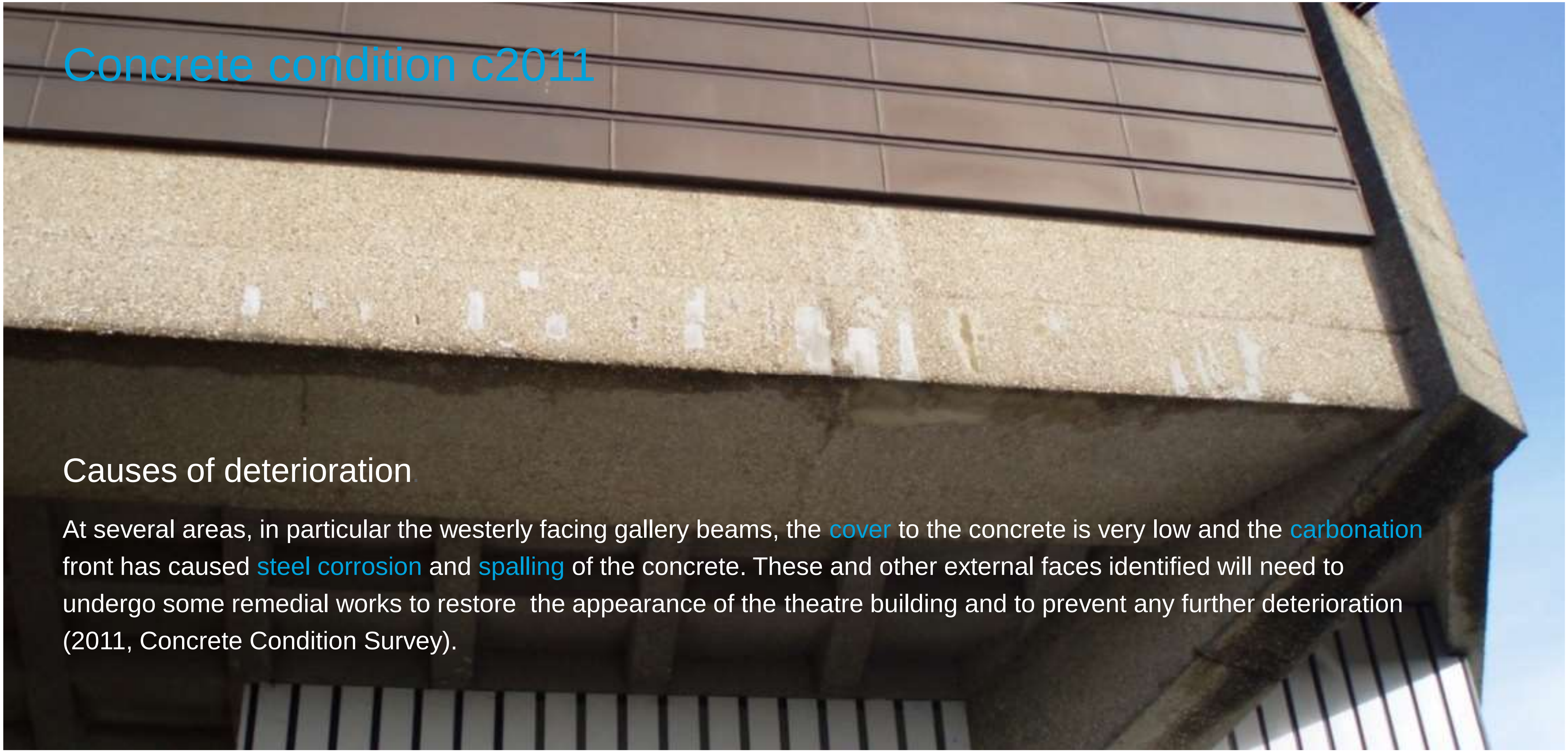
Questions

Concrete condition c2011

SNC·LAVALIN

FAITHFUL GOULD

Member of the SNC-Lavalin Group



Concrete condition c2011

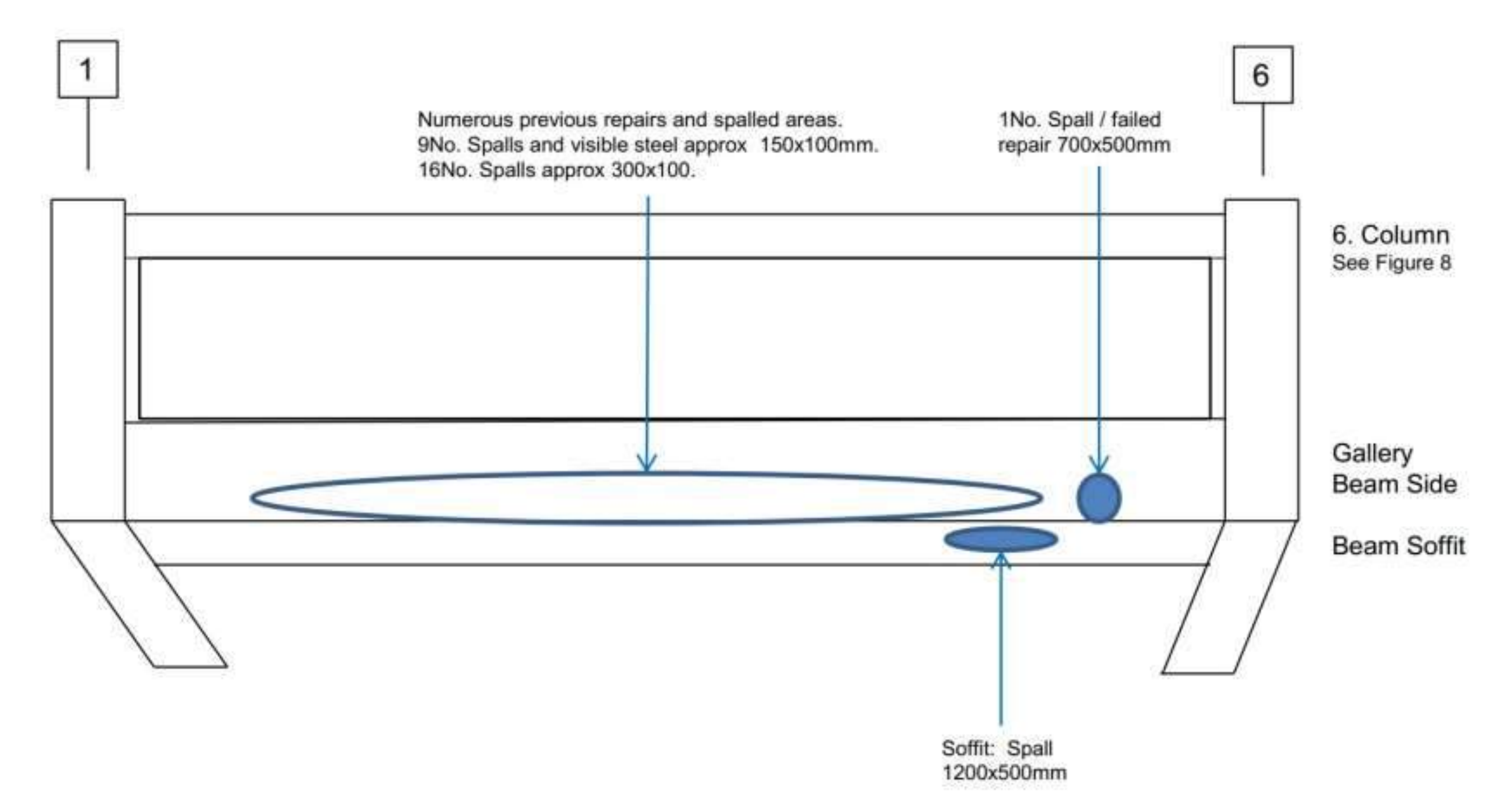
Causes of deterioration

At several areas, in particular the westerly facing gallery beams, the cover to the concrete is very low and the carbonation front has caused steel corrosion and spalling of the concrete. These and other external faces identified will need to undergo some remedial works to restore the appearance of the theatre building and to prevent any further deterioration (2011, Concrete Condition Survey).

SNC·LAVALIN

FAITHFUL GOULD
Member of the SNC-Lavalin Group

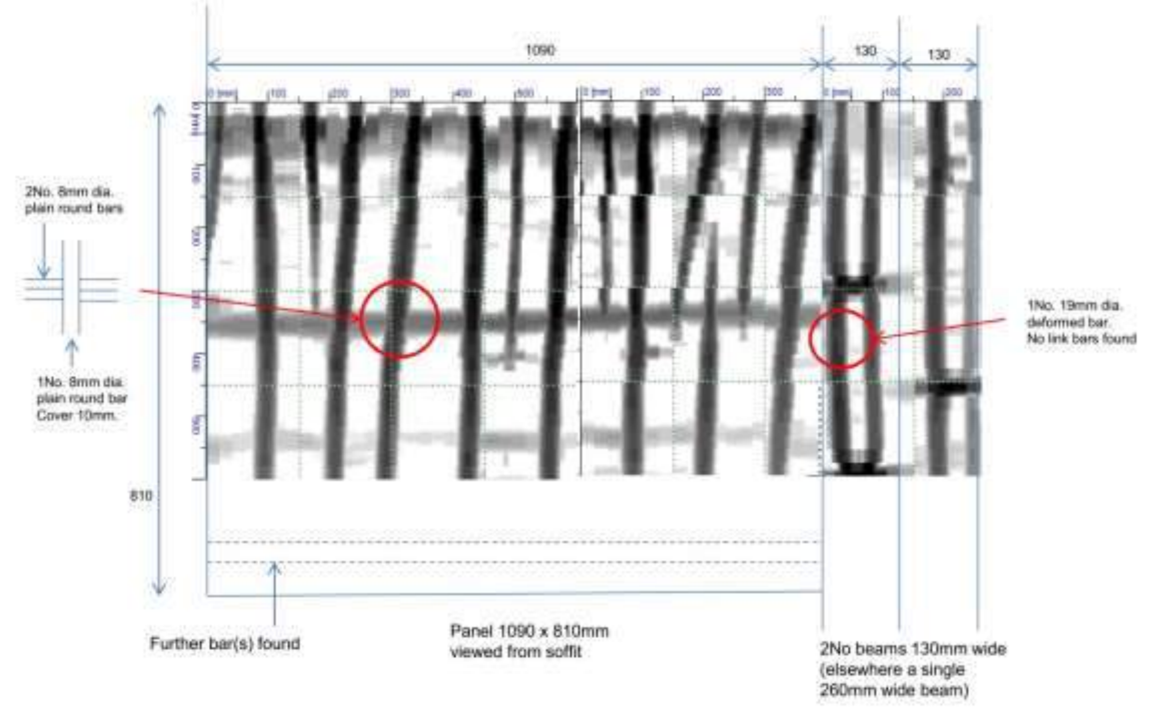
Concrete condition c2011



SNC·LAVALIN

FAITHFUL GOULD
Member of the SNC-Lavalin Group

Concrete condition c2011



Core No.	Location	Density (Kg/m³)	Compressive Strength (N/mm²)
Loc 1	Internal horizontal beam at back of stage	2280	50.7
Loc 2	Internal horizontal beam at back of stage	2270	49.8
Loc 3	External beam (suggested trial area)	2260	49.4
Loc 4	External beam (suggested trial area)	Microscopic Examination	
C1	Elevation 1-6 Gallery beam side	Microscopic Examination	
C2	Elevation 6-5 Wall	Not extracted - excessive steel encountered during drilling	
C3	Elevation 2-1 Gallery beam side	2300	58.4
C4	Elevation 2-1 Gutter beam	2290	54.6
C5	Elevation 3-2 Lower beam	2290	50

Concrete condition c2011

There is a simple “rule of thumb” that can be used to determine the expected depth of carbonation of good quality concrete: the depth of carbonation in mm should roughly equal the square root of the age of the structure in years.

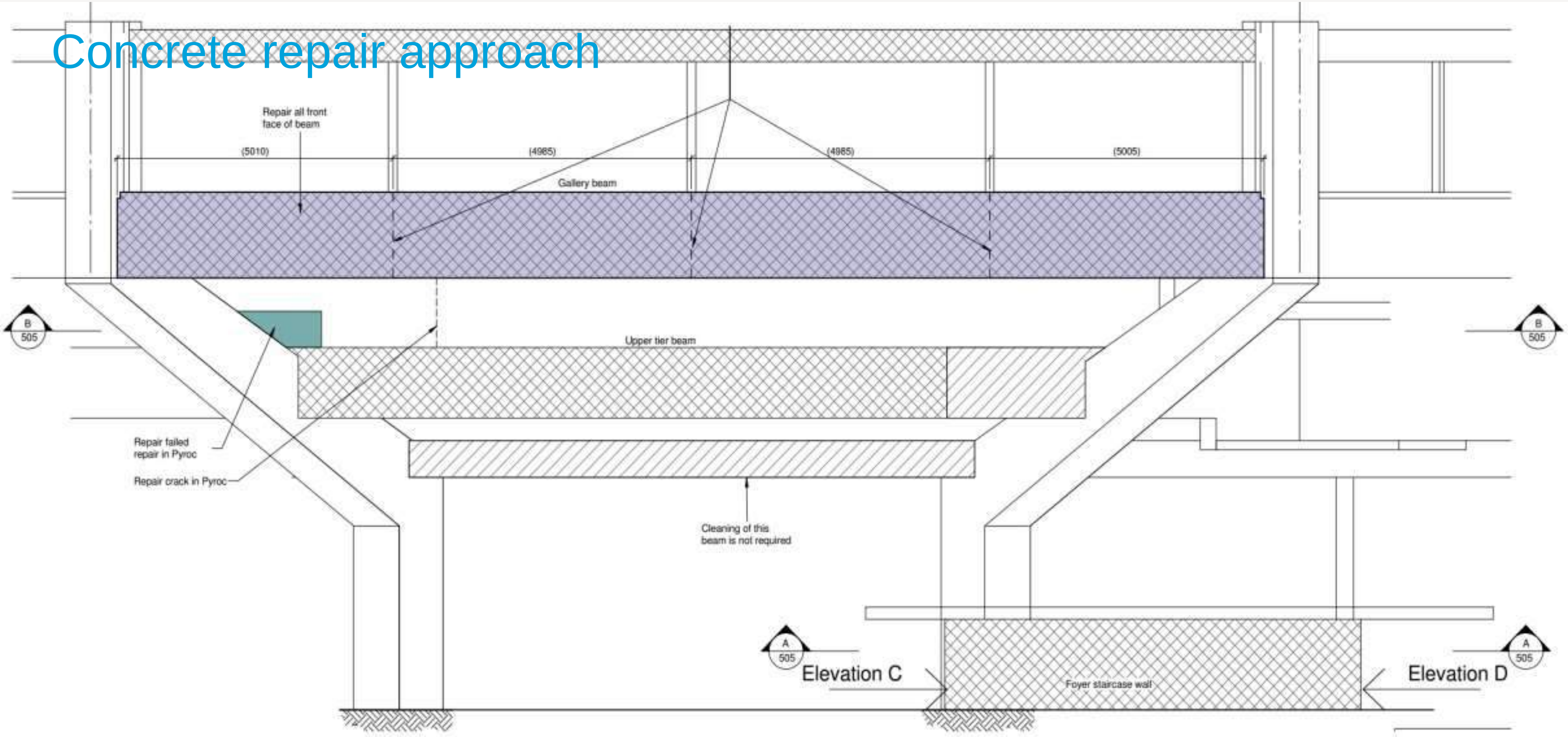
Concrete used in the construction of the theatre is of variable quality, based on the depths of carbonation observed (less than 1mm up to 30mm).

With the theatre some 50 years old, a depth of carbonation in the region of 7mm would not be unreasonable.

Depths of carbonation significantly exceeding this criterion were found in about one third of the areas examined.

(2011, Condition Survey Report)

Concrete repair approach



SNC·LAVALIN

FAITHFUL GOULD
Member of the SNC-Lavalin Group

Further testing of previous repairs

Table 1 – Comparison of the petrographic examination findings with the materials specified in the Schedule of Repair Materials provided on page 10 of the repair specification (included in Appendix C)

Specified material (outer to inner layers)	17752/L1	17752/L2
Remmers Funcosil B1 waterproofing agent	Evidence of water beading at most surfaces suggests likely addition of waterproofing agent. Sopme areas were observed to be a different colour and did not bead water at the surface.	Evidence of water beading at surface suggests likely addition of waterproofing agent.
Restoration Mortar with addition of 10 mm "Golden gravel" (60:40 aggregate to cement)	Consistent with Remmers Restoration Mortar with medium (0.5 mm max) sized fine aggregate and the addition of a well rounded chert gravel as specified. Petrography suggests a high microporosity.	Consistent with Remmers Restoration Mortar with medium (0.5 mm max) sized fine aggregate and the addition of a well rounded chert gravel as specified. Petrography suggests a high microporosity.
Stucanet Stainless steel mesh	Consistent with galvanized steel. Majority of double wire fixings absent. Aperture differs from specification.	Consistent with galvanized steel. Majority of double wire fixings absent. Aperture differs from specification.
"Tight Coat", Remmer Restoration Mortar with 10 % SBR emulsion	Consistent with Remmers Restoration Mortar with medium (0.5 mm max) sized fine aggregate. Petrography suggests a high microporosity.	Consistent with Remmers Restoration Mortar with medium (0.5 mm max) sized fine aggregate. Petrography suggests a high microporosity.
Ronacrete SBR primer and cement slurry	Where present, appears consistent with a modified cement slurry material.	Consistent with a modified cement slurry material.
Remmers BetoFix R2 repair mortar	Consistent with Remmers Betofix R2.	Consistent with Remmers Betofix R2.

Further testing of previous repairs

What were the conclusions of the petrographic testing undertaken by RSK?

It is likely that a combination of these factors resulted in a failure of the repair system within the “tight coat” layer, causing the outer restoration mortar to delaminate.

- The failed area of the repair system appeared to be inconsistent with the repair specification
- In both samples the outer restoration mortar application was observed to be too thick
- Within the failed sample, the applied “tight coat” appears to have been poorly compacted, suggesting that the mix was not firmly pressed back into the “tight coat” to ensure aggregate interlock with the Rendalath mesh
- The repair system exhibited common secondary deposits (calcite and ettringite) suggesting a moderate degree of leaching and fluid movement through the system during or subsequent to installation
- Some evidence to suggest a material substitution was made with respect to the utilized mesh material. In addition, within the failed area the mesh appears to have been installed inconsistently with the repair specification