Annex A – NHS Update Meeting Paper for Ministerial Working Group on Building and Fire Safety (December 2022 but rescheduled for January 2023)

REINFORCED AUTOCLAVED AERATED CONCRETE (RAAC) – NHS POSITION

Purpose

1. This note is to inform the Working Group of the proposed programme of survey works to identify the extent and condition of RAAC in buildings in the NHS Scotland estate.

Background

2. RAAC is a lightweight, reinforced and aerated form of concrete that was commonly used in buildings from the mid-1960s to the mid-1980s. RAAC is mainly found in roofs, although occasionally in floors and walls. RAAC is less strong than traditional concrete and there have been problems as a result, which could have significant consequences.

3. RAAC elements are primarily found in roof construction however they have been discovered in wall and floor constructions. Concerns that had arisen with roof planks include:

- Rusting of embedded reinforcement leading to cracking and spalling of the AAC cover;
- Cracking, of varying degrees of severity, thought to be associated with moisture and temperature related movements in the planks;
- Excessive deflections due to creep;
- Floor and roof planks tending to act independently, rather than as a single structural entity.

4. There is a risk of structural failure of RAAC planks. Failure can be gradual or sudden, if sudden, there is no warning. Structural failure can be caused by several mechanisms and it is now recognised that RAAC is considerably less robust than structural concrete and ages much less well. Because RAAC planks were most commonly used in roofs, sudden failure can be dangerous and could potentially result in death or injury. It should however be noted that, at present, reported failures of RAAC are few and far between.

5. The Standing Committee on Structural Safety (SCOSS), alerted Health Facilities Scotland (HFS) to the issue in May 2019. The Alert was produced after the collapse of a school roof in 2018.

6. A recent BBC report notes that NHS England have discovered at least 34 buildings with RAAC elements across 16 of their NHS Trusts and have earmarked £685 million to deal with these risks. The Department of Health and Social Care (DHSC) has also publicly committed to eradicating RAAC in the NHS estate by 2030. There have been a number of high-profile news reports showing propping of roof structures within clinical areas. There is no similar commitment in NHS Scotland and no funding has been earmarked to deal with any issues identified.

Current Situation

7. HFS have commissioned a survey team to establish the extent of RAAC across the NHS Scotland Estate and the condition it is in. This has proved a complex tendering process as there as there are many variables and a wide geographical area. HFS are engaging with colleagues in DHSC to learn from their experience.

8. This survey process will begin with a desktop exercise to establish the extent of physical surveys required. Once the physical survey programme is established, appropriate access will be arranged. Surveys will be visual in nature and will provide an extent and a risk rating on the condition of any RAAC discovered.

9. It is expected that there will be a significant portion of the NHS Scotland estate which will require to be surveyed and it is likely that RAAC will be present in some areas. It is also likely that some areas will require remedial works.

10. The survey team has been procured with a remit to provide an indication of the potential cost to rectify each instance of RAAC which is found to be defective and/or measures to be undertaken to ensure its continued safety. The surveys are programmed to complete in financial year 2023/24.

Recommendation

11. Ministers are asked to note the advice within this paper and that action is being taken to determine the extent and risk of RAAC in the NHS estate. Further updates on the NHS RAAC survey will be provided to the Ministerial Working Group over the next year. Health Infrastructure Officials will share learning with colleagues.

Health Infrastructure, Investment and PPE Division
December 2022

Annex B – Slightly amended NHS Update Meeting Paper for Ministerial Working Group on Building and Fire Safety (December 2022 but rescheduled for January 2023)

REINFORCED AUTOCLAVED AERATED CONCRETE (RAAC) – NHS POSITION

Purpose
1. This note is to inform the Working Group of the proposed programme of survey works to identify the extent and condition of RAAC in buildings in the NHS Scotland estate.

Priority
2. Routine

Background
3. RAAC is a lightweight, 'bubbly' form of concrete that was commonly used in buildings from the mid-1960s to the mid-1980s. RAAC is mainly found in roofs, although occasionally in floors and walls. RAAC is less strong than traditional concrete and there have been problems as a result, which could have significant consequences.

4. RAAC elements are primarily found in roof construction however they have been discovered in wall and floor constructions. Concerns that had arisen with roof planks include:
- Rusting of embedded reinforcement leading to cracking and spalling of the AAC cover;
- Cracking, of varying degrees of severity, thought to be associated with moisture and temperature related movements in the planks;
- Excessive deflections due to creep;
- Floor and roof planks tending to act independently, rather than as a single structural entity.

5. There is a risk of structural failure of RAAC planks. Failure can be gradual or sudden, if sudden, there is no warning. Structural failure can be caused by several mechanisms and it is now recognised that RAAC is considerably less robust than structural concrete and ages much less well. Because RAAC planks were most commonly used in roofs, sudden failure can be dangerous and could potentially result in death or injury. It should however be noted that, at present, reported failures of RAAC are few and far between.

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9. This survey process will begin with a desktop exercise to establish the extent of physical surveys required. Once the physical survey programme is established, appropriate access will be arranged. Surveys will be visual in nature and will provide an extent and a risk rating on the condition of any RAAC discovered.

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Alan Morrison
Deputy Director Health Infrastructure, Investment and PPE 8 December 2022

[not in scope of the request] – text

Annex C – July 2022 email from Scottish Government official to Fife Council and Falkirk Council

From: [redacted 11.2]@gov.scot
Sent: Friday, July 8, 2022 10:56:28 AM
To[redacted 11.2]@fife.gov.uk>; [redacted 11.2]@falkirk.gov.uk
Cc: [redacted 11.2]@gov.scot; [redacted 11.2]@gov.scot
Subject: Reinforced Autoclaved Aerated Concrete (RAAC)

CAUTION: This email originated from outside of the organisation. Do not click links or open attachments unless you recognise the sender and know the content is safe.

Hello [redacted 11.2] and [redacted 11.2],

We are contacting you in your respective roles on the SHOPS and ADES Resource networks.

The Scottish Fire and Rescue Service has approached the SG in relation to Reinforced Autoclaved Aerated Concrete (please see the below SFRS article).

We understand that the expectation is that the hazard identification will form part of the normal workplace risk assessment regime under Health and Safety legislation. Therefore, do you know if there has been any work done to identify schools with RAAC in Scotland?

Please get in touch if you have any questions, and thank you in advance for your help.

SCOTTISH
FIRE AND RESCUE SERVICE
Working together for a safer Scotland

Failure of Reinforced Autoclaved Aerated Concrete (RAAC) planks

Reinforced Autoclaved Aerated Concrete (RAAC) was used in the construction of hospitals, schools and other public buildings from the 1960s to the 1980s. This material has a lifespan of approximately 30 years and can also be weakened by water ingress. However, in some cases, it has not been replaced after this time.

RAAC has been found in approximately 48 UK hospitals, where it has been used and is still in place. RAAC is mainly used in the construction of flat roofs but has also been found in walls and floors. There are also concerns that it has been used in other buildings. It is difficult to identify unless it has been highlighted in Site-Specific Risk Information.

Organisations have started remedial works to prolong the life of affected structures until they can be replaced. This includes the use of support props and the addition of new wooden or steel beams to support the originals and load bearing structures.

Hazards to consider include:

- Structural collapse affecting hospital services, including oxygen supplies
- Prevalence of asbestos in buildings of this age
- Unknown performance in a fire, although the likelihood of structural collapse increases if RAAC is exposed to heat and water

Our Protection Policy and Reform Unit (PPRU) is working to raise awareness of this issue among fire protection teams and is planning a joint action with National Operational Learning. We are also working with those across sectors to identify these premises where possible, and relay that information to FRS who have these premises in their areas.

The Standing Committee on Structural Safety has published an article highlighting the Failure of Reinforced Autoclaved Aerated Concrete (RAAC) planks

Further information can also be located at CROSS, who now have a theme page on RAAC at Structural safety of reinforced autoclaved aerated concrete (RAAC) planks | CROSS (cross-safety.org).

For more information refer to Partial or structural collapse: Fires in buildings

Annex D – Meeting paper for a Structural-Safety Group meeting that took place in May 2020 that a Scottish Government official was invited to

SS/20/12.1

Structural-Safety

Structural-Safety
c/o The Institution of Structural Engineers
47-58 Bastwick Street
London
EC1V 3PS
United Kingdom
www.structural-safety.org
structures@structural-safety.org

FAO [redacted 11.2]
Ministry of Housing, Communities and Local Government
2nd Floor South West
Fry Building
2 Marsham Street
London
SW1P 4DF

21.05.2020

Dear [redacted 11.2]

Advice on the need for research on RAAC planks in existing building stock

I am writing in connection with the need to carry out research into the use of Reinforced Autoclaved Aerated Concrete (RAAC) in our building stock. The role of Structural-Safety is to gather and share information on concerns and events that affect structural safety, and to issue alerts and give advice on how such matters should be approached to help prevent future occurrences.

In late 2018, we received a report from the LGA about the partial collapse of a school roof made from RAAC. This was a sudden failure and it was fortunate that there were no injuries or worse. In May 2019, we issued an Alert on Failure of RAAC Planks to warn of potential problems with this material. As a consequence, several other reports of a similar nature were received, including reports of other failures, and it became obvious that there had been wide-spread use of such roofs in public sector buildings.

A Study Group was established under the leadership of The Institution of Structural Engineers to consider the scale of the problem and to investigate ways of ensuring continued safety to the users and occupants of the affected buildings. What became apparent is that there are many asset owners who do not know they have such roofs or the threat that they may pose, and also that the industry lacks detailed codes or other reference documents which allows it to reliably assess RAAC materials in their present state.

Input to the Study Group from consulting engineers and practitioners has revealed that there are large buildings, in use, that could be at risk. Some of these are hospitals and the scale is daunting. For one hospital alone, the estimated cost of replacing the roof, including disruption, is £750m, and for a group of hospitals in the same area could be £5bn.

The Study Group decided that research was needed and worked with BRE to develop a research programme to address the issue.

Structural-Safety

This was discussed at a recent meeting of the Structural-Safety Expert Panel, where BRE presented their proposal for new research to examine the behaviour of RAAC planks and the ways in which they can fail. There is no doubt that age is a factor and most of the roofs have been in place for 40 to 60 years.

Structural-Safety fully supports the BRE research proposal and believe it will be a valuable contribution to what is emerging as a major potential risk to the fabric of a significant part of our national asset base. The proposal is attached to this letter and it is understood that BRE could start the work immediately.

We strongly recommend that BRE are commissioned to do the work as soon as possible so that the results can be used to help in finding ways to manage this very important safety concern. It is only by understanding the current capacity of RAAC planks that proper judgements can be made over continued building usage and / or the implementation of remedial measures.

Should you have any queries or wish to discuss the matter please let me know and we will be pleased to assist.

Yours sincerely

For Structural-Safety

[redacted 11.2]

[redacted 11.2]

[redacted 11.2]

[redacted 11.2]@structural-safety.org
Tel [redacted 11.2]

Assessing RAAC construction

A parametric investigation in support of asset management decisions

1 Introduction

The total number of properties constructed with Reinforced Autoclaved Aerated Concrete (RAAC) is not known. The development of RAAC material for structural purposes started in early 1930's in Sweden and was first introduced to the UK in the late 1950's. It developed into a popular form of construction in the UK between 1960-1980 due to each component's low weight and ease of construction. It has been mainly used in walls and roofs and sometimes in floors.

The products qualities and the wide range of spans available enable the units to be integrated into a range of building types including public buildings, specifically hospitals and ambulance stations, testing laboratories, schools, police stations and other small industrial units from the 1950s through to the 1980s. Since roofs and intermediate floors are generally shrouded by false ceilings, the presence of RAAC units has sometimes not been identified.

RAAC is a type of concrete more akin to mortar than traditional concrete, comprising a cement paste in combination with silica agent, ground blast furnace slag or pulverized fuel ash. The material is extremely lightweight as the strength and drying shrinkage is achieved by using high-pressure steam during the curing and manufacturing process. Typical properties of this material can be found in the following publications:

1. *Siporex Autoclaved Aerated Concrete Building Products*, Siporex publication, April 1972;
2. *History of Autoclaved Aerated Concrete, The short story of a long lasting building material, (April 2014), W. van Boggelen*;
3. IP10-96 : Reinforced autoclaved aerated concrete planks designed before 1980, BRE, 1996;
4. IP07-02 : Reinforced autoclaved aerated concrete panels - test results etc., BRE, July 2002;
5. BR445 - Reinforced autoclaved aerated concrete panels - review of behaviour and developments in assessment and design, 2002, BRE;
6. Autoclaved aerated concrete; moisture and properties, 2nd International Conference on autoclaved aerated concrete, Wittmann F H (editor), Vol 6, Elsevier, 1983;
7. Autoclaved aerated concrete; properties, testing and design. RILEM recommended technical practice. RILEM Technical Committees 78-MCA and 51-ALC. London, E & FN Spon, 1993;
8. The structural use of Aerated concrete, ISE, Jan. 1961.

Whilst the total number of existing UK buildings incorporating this material is not known, we have included below an example of the scale of RAAC component use and its impact in hospital construction in some areas of the UK. The practitioners research group, which has informed this proposal, know of at least 9 schools in Suffolk that have buildings on their respective estates that incorporate RAAC roof panels. In the East and South East more detailed information is available for five regional hospitals, which are known to have been constructed with RAAC roof and loadbearing wall panels. It is estimated that a total of circa 8,000 roof panels and 8,000 wall panels have been used in each of these hospitals.

The two regional hospitals in the Midlands constructed with RAAC roof panels and nonloadbearing RAAC wall panels, have about 15,000 roof panels per hospital. In one hospital the floor panels were also of RAAC.

In many RAAC applications the research group advises that failsafe supports have been introduced to manage potential risks in a property. The financial impact of these assuring works is marked. The support works to roof panels in just one of the hospitals mentioned above has been budgeted at circa £70m. Even more costly are the works to enable the replacement of RAAC panels in the roof, which for one of the hospitals, has been budgeted at (~) £750m. If these conditions and associated costs are extrapolated to all 7 sites, the assuring works would amount to circa £500m. The costs to replace the seven assets would amount to £5.25b. With such marked financial impact, RAAC asset owners are left in a difficult, if not untenable situation, where the funds as well as the practicalities of re-building assets (many of which are in full operation) are unattainable.

The work proposed here is aimed at addressing the needs of the consulting profession advising RAAC asset owners. The work is led by, and in support of, practitioners. This study will generate performance assessment background information to aid decision-making and ensuring high-risk assets are being identified swiftly and assertively, enabling assurance work to be prioritised and budget-constrained works to be deployed in an effective and targeted manner.

1.1 Recent events

SCOSS issued an alert in May 2019 in relation to the then recent failure involving a flat roof constructed using reinforced autoclaved aerated concrete (RAAC) planks. The roof was associated with a school building. It was reported that there was little warning of the sudden collapse. The exact failure mechanism and the factors initiating the failure are not known. However, the mode of failure appeared to occur close to the supports rather than the central section of the units.

As a direct result of this collapse there was a growing realisation within the engineering community that there was an urgent need to :

• gain a better understanding of the in-service behaviour of RAAC planks, and
• to obtain a clearer understanding of the primary factor(s) that led to the initiation of the failure and its associated mechanism(s).

More insight and information would enable consulting engineers to adapt and expand the assessments of RAAC roofs constructed using these products and in turn advise building owners appropriately on the ongoing safety and in-service considerations.

1.2 Identified issues with RAAC

A number of issues have been identified with historic RAAC construction. These issues include excessive in-service deflection leading to ponding of rainwater and distress to certain types of rainwater membranes and finishes, transverse and longitudinal cracking of the units, different levels of serviceability between adjacent units, rusting of embedded reinforcement leading to cracking and spalling of the units, and more recently the complete failure/collapse of a small number of roof units.

More in-depth review of these issues are presented in the following documents:

• BR455 - Reinforced autoclaved aerated concrete panels - review of behaviour and developments in assessment and design, BRE, 1992;
• Causes of defects in gas concrete reinforced elements (In Czech) Skokanek Z, Stavivo, 1984, v62(10), 404-17;
• Investigation of long time deflection of reinforced aerated concrete slabs, CIVIDINI B,
proceedings of the RILEM International Symposium of Autoclaved Aerated Concrete, moisture and properties, held at Lausanne March 1982, pp 267-81;
• Expanded and aerated concrete. Anchorage of the reinforcement and creep of reinforced concrete slabs. Schaffler H, Deutscher Auschuss fuer Stahlbeton, Heft 136, Berlin, Ernst & Sohn, 1960, 59pp.

The issues have been widely documented and match the experience of practitioners and have informed the scope of the proposed research.

These include a variety of behaviours and phenomenon, including ghosting adjacent certain reinforcing bars, localised corrosion of the reinforcement particularly in wall panels bordering areas of high relative humidity and where water ingress has/is occurring, debonding of rebar coatings and/or failure of the AAC to bond with the coating etc. An example of ghosting is shown in the image included below.

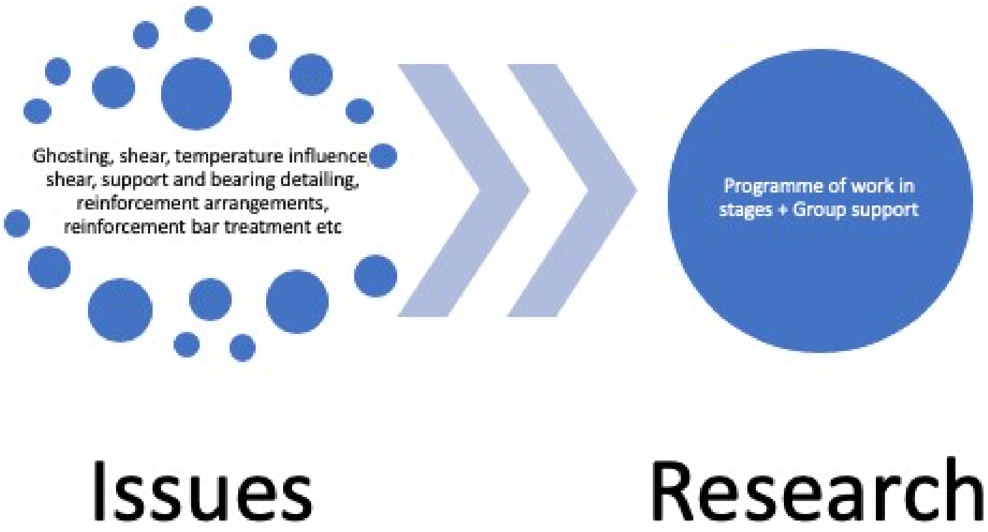
An example of ghosting associated with a reinforcing bar in a wall panel

1.3 Outline of proposed work

The sheer number of potential issues, the outcome of research undertaken to date and the most recent site-base findings require a parametric approach to developing practical guidance to support RAAC asset management review and decision-making.

The RAAC Learning Group has been set up to facilitate exchange and collaborative research on these issues. This group consists of specialist consulting engineers that have been involved in the assessment of RAAC roof planks and wall panels, the IStructE, SCOSS, local authority partners, an AAC manufacturer and BRE.

One direct outcome of the discussions held between the group members to date has led to the development of a parametric load testing programme to address the issues outlined in this proposal. The primary aim of the test programme is to investigate what factors influence the performance of these units with increasing in-service age, including typical durability challenges and detailing considerations.

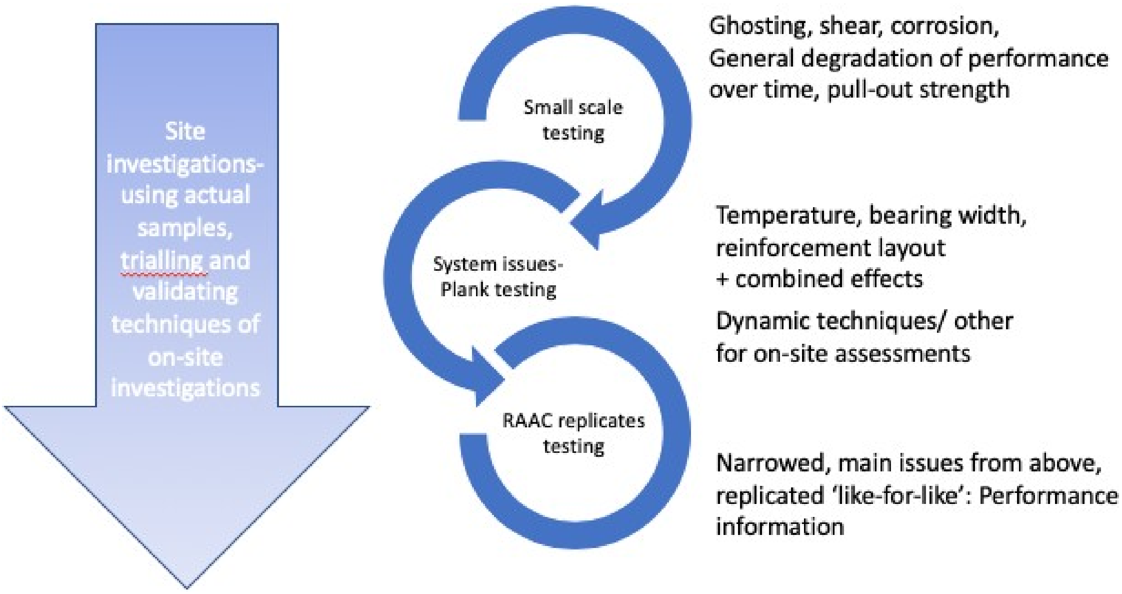


The continued input, steer and support of the group as well as SCOSS being a key component in developing the understanding of the relative importance of impacts on the performance of these units.

With the scarcity of typical and relevant test samples for investigation a scaled testing programme is being proposed. The test results are being supplemented by numerical modelling to complement the findings and to ensure the practical implementation of the experimental testing programme- into the future. The approach is parametric in order to investigate particular aspects of potential performance-influencing parameters, by narrowing issues per test and sample set-up. This is to help isolate and quantify performance influences, narrowing overriding, critical issues and enhancing insight and learning potential.

2 Proposed research stages

The following programme stages are envisaged, noting for each stage the main, potentially performance affecting, issues. The scale of samples to be tested is aligned with the issue being investigated, namely small-scale testing where material issues are being reviewed and larger plank testing for investigating global system, interacting performance factors. The fullscale bespoke RAAC plank testing is reserved for the final stages of testing, as some of the main performance factors have been confirmed and quantified. The design of these planks is intended to incorporate the 'worst-case' combination of issues where possible.



As much as possible, site material will be sourced and tested, aligned with the programme shown here. An additional key aspect of the work is to trial non-destructive assessment techniques, such as dynamic testing and radar technology. This study is aimed at creating a database of benchmark results established on material with 'known' defects, so as to aid future on-site investigations and analysis of findings on RAAC buildings in practice.

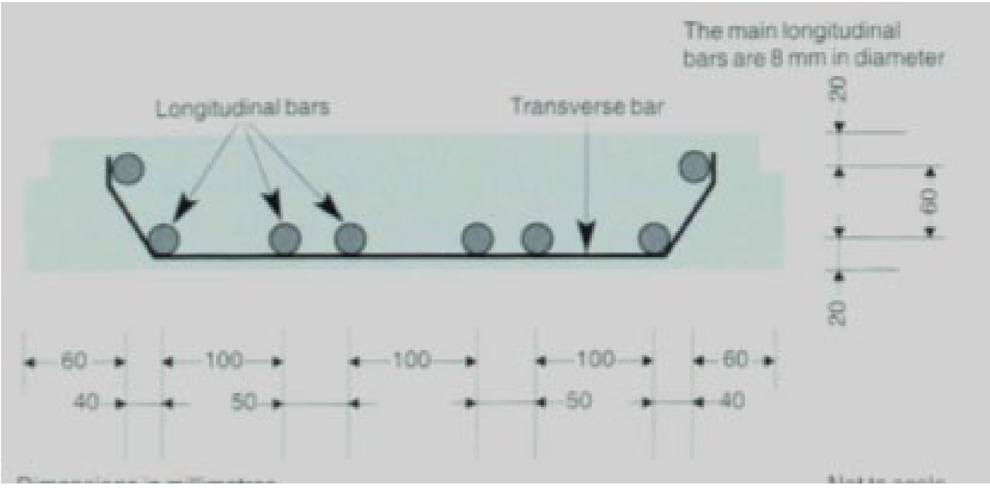
2.1 Assessment in stages

The number of possible permutations of material properties, geometric parameters and reinforcement provisions on the sensitivity to and, mode of failure of the roof planks are vast. It would therefore be financially prohibitive, overly time consuming and impractical to explore each of the possible permutations in representative samples and repeated tests.

BRE have therefore endeavoured to develop load testing programmes (as developed in conjunction with the RAAC Learning Group) that will seek to explore the possible material and geometric factors that might, possibly in combination, have a controlling influence on the structural behaviour exhibited, specifically at the supports, by RAAC plank structures.

Following small-scale investigations on actual RAAC planks recovered from site and to restrict the number of possible permutations of contributing factors, it is proposed to adopt one ‘design’ of RAAC/replica roof plank in Phase 2 of the programme.

This design is proposed to be a 100mm deep plank with a span of a 2.4m and longitudinal reinforcement provisions as shown in the figure included below. This design is consistent with the one adopted for the 1995 testing programme undertaken by BRE (refer IP7/02), ensuring alignment between the 1995 and the proposed 2020 testing programmes. It is hoped that this will maximise the use of both programmes in support of the practitioners’ requirements.



Vertical section through proposed specimen roof plank – 1995 BRE load tests

Whilst a number of possible alternative loading strategies could be adopted, it is acknowledged that the use of more than one loading strategy would double or treble the number of planks that would be required. Being mindful of the need to restrict variations to ensure cost efficiencies, it is proposed to utilise a single loading strategy up to component failure, see section 5.1.

Consideration could, however, be given to exploring the appropriateness of adopting a second loading strategy for a few selected plank types should the RAAC Learning Group members consider this to be appropriate and if sufficient funds can be secured. Influences on performance by thermal exposure variations will also be explored in this part of the programme. Bespoke heating panels, such as the example shown below for a previously completed piece of work, will be employed to create a temperature differential within the planks and ascertain associated performance patterns.

Typical heating array panel

2.2 Small-scale and plank testing

BRE proposes to extract small-scale samples from RAAC planks made available from currently identified demolition sites. In the currently identified sites floor and roof planks and wall panels appear to be available. Non-destructive testing will be completed on the units prior to removal of samples and before the planks/panels will be mined for small-scale samples for testing. Strength testing will be conducted using the pull-out testing method which is repeatable and can be reliably undertaken on relatively small samples. These tests will be supplemented by shear testing of other samples. Multiple samples will be extracted from units to quantify, where possible, impact of corrosion patterns, reinforcement bar treatments and 'ghosting' in RAAC of that period.

Where feasible, BRE will be using full-scale planks for testing under laboratory conditions - especially where small-scale material testing information has been completed to guide on inservice conditions of the planks through life. This will be dependent on the state of planks available from identified sites and the total number of planks available. The process of review has begun to inform this proposal. The total number of potential sample planks will need to be confirmed once the detailed work starts. A provision has been included in the costings to cover this aspect.

In this stage of the programme, BRE will also test manufactured test samples, in small and replicate scale, which incorporate specific defects in order to determine and verify typical drops in performance. The material used in the fabrication of the test planks will seek to replicate (as far as this is possible/practical to achieve) the low compressive strength/modulus of AAC.

2.3 Replica RAAC plank testing

Through the contacts of the RAAC Learning Group the manufacture of RAAC test planks, incorporating specific defects, will be sourced. These test planks will be made of modern RAAC but will include specific defects. This stage of the work will be completed last. This will enable lessons learnt and the key/critical physical characteristics derived from previous stages of the programme, to be combined and incorporated into a series of specimens, leading to the greatest influence on performance.

The ‘base’ design of the RAAC roof plank will be identical to that adopted in the previous part of the programme (matching BRE’s research from 1995).

Figure 1 presents a diagrammatical representation of how we envisage the various aspects of the proposed testing phases will relate to one another and the positioning of the associated project milestone reviews.

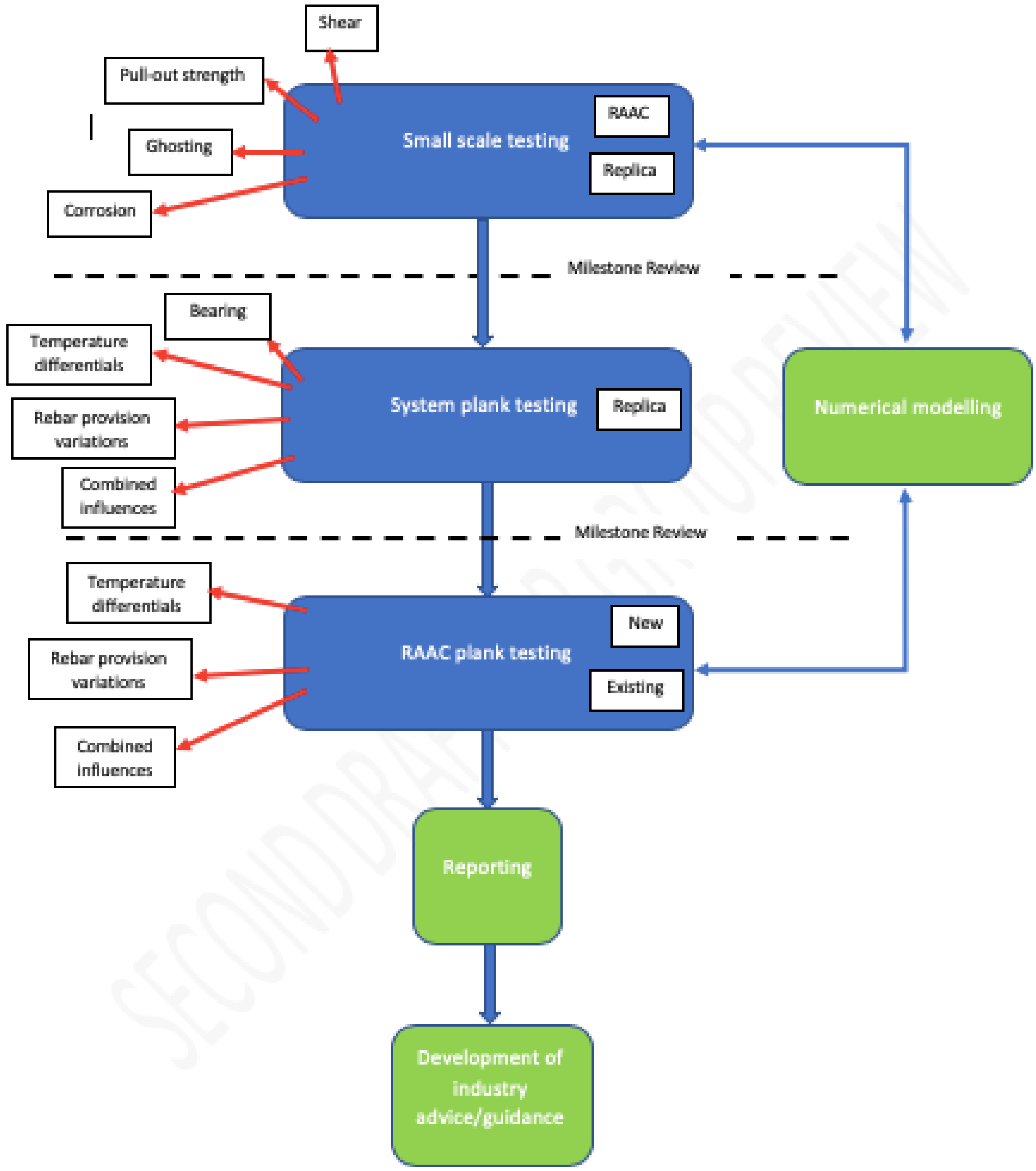
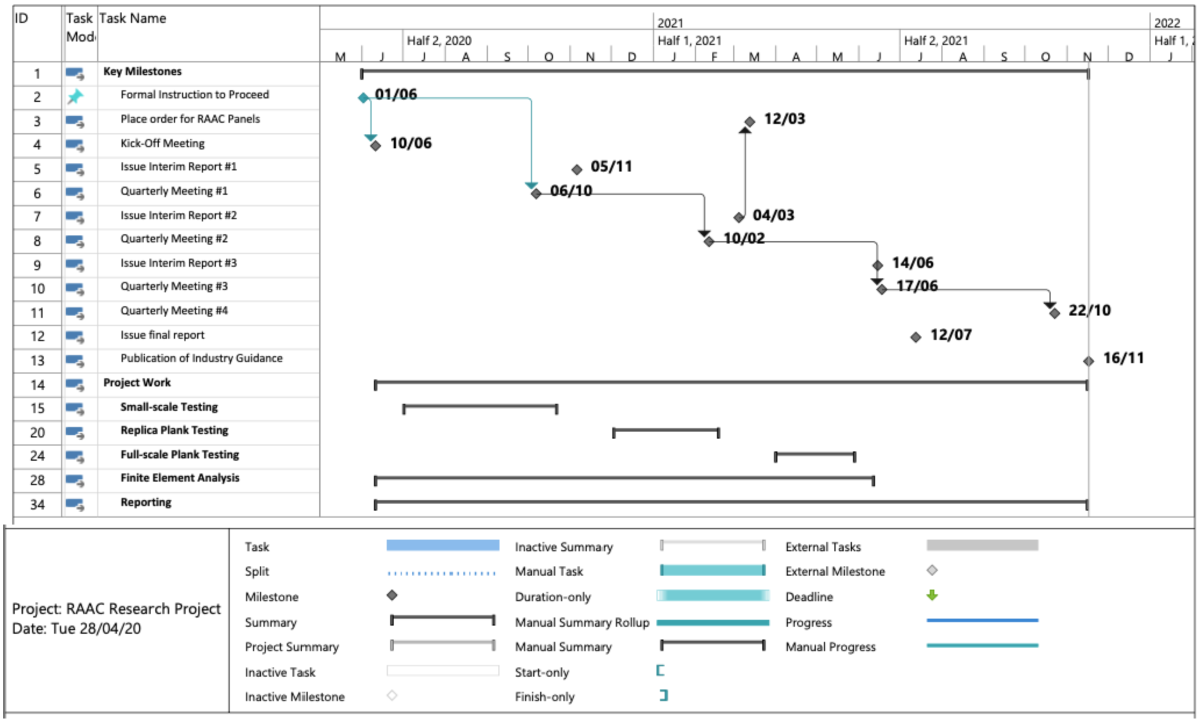


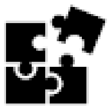
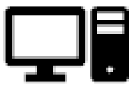
Figure 1 : Proposed scope of testing and modelling and project timeline

The overview below shows the various stages of the project, approximate timelines for meetings and milestone reviews, including lead times advised by the AAC supplier.



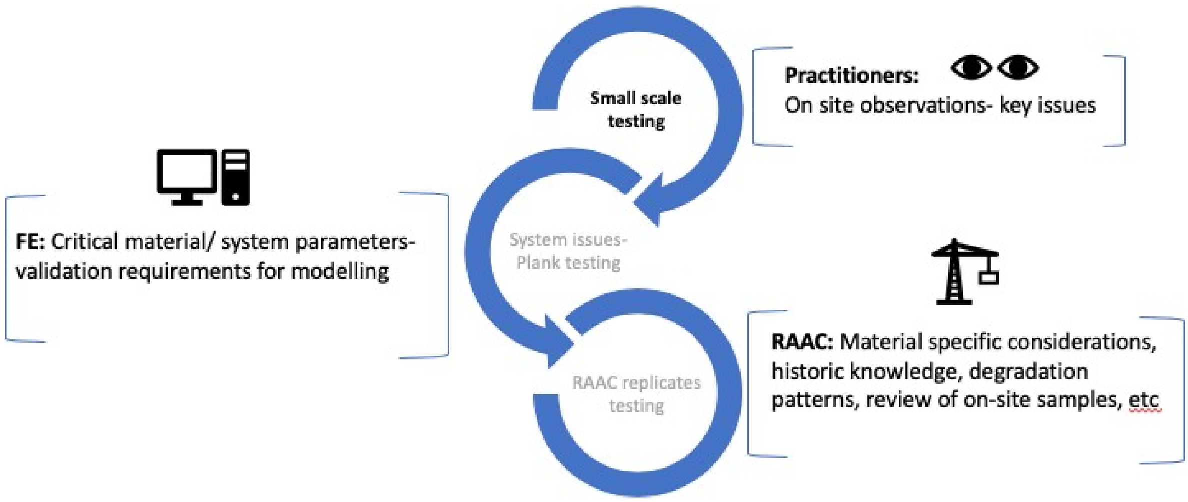
3 Proposed Task Groups

We propose that a series of task groups are established with respective roles being aligned to particular work specialities/experience/expertise of the RAAC research group members (and others as appropriate and require). These groups will be responsible for a series of agreed tasks (refer proposed tasks set out in the table below) and to provide input on an as required basis into one or more of the other groups.

Group	Role(s)	Organisation(s)
Funding organisation	To provide adequate funding to support research/dissemination programme.	MHCLG
Research support group 	To provide testing/laboratory facilities. Fabrication/preparation of small-scale units. Responsible for managing and undertaking testing programme. Reporting results of laboratory testing.	BRE
Practitioners group 	Collation of key observations from previous/current sites at which RAAC units are present and for any new sites that are visited over the course of the project. Development of recommendations for industry guidance on assessment strategy for consulting engineers. Liaison with building owners to source examples of existing RAAC roof units. Coordination of sourced RAAC roof units and transport to BRE.	Consulting engineer practices, UK AAC company
Finite element modelling group 	Determination and collation of critical material and behavioural requirements. Development of modelling technique(s) to replicate small-scale behaviour of AAC and full-scale behaviour of RAAC units.	Wilde Carter Clack, UK AAC company
RAAC materials group 	Sourcing examples of existing RAAC roof units. Sourcing product supplier/manufacturer, liaison and coordination of production of full-scale RAAC test planks/ specimens. Fabrication of full-scale RAAC test planks/specimens.	UK AAC company Benelux based AAC company

The organisations listed are welcome to provide input into one or more of the other groups as required.

An example of the envisaged phasing and interaction of the various strands of input is shown below.


Small scale testing
Practitioners:
On site observations- key issues
FE: Critical material/ system parameters- validation requirements for modelling
System issues- Plank testing
RAAC: Material specific considerations, historic knowledge, degradation patterns, review of on-site samples, etc
RAAC replicates testing

4 Testing

4.1 Small-scale and plank testing

The small-scale testing will, in the first phase, specifically be focussing on identifying issues from existing RAAC planks as located from site. A number of potential RAAC sites have been identified where planks are awaiting imminent removal. The sites currently available appear to have wall panels but only a few roof panels. This will be further investigated but it is assumed all planks/panels can be used in some form in support of this project.

The small-scale work will look for examples of the effects of corrosion, ghosting and reinforcement detailing. On-site NDT testing will be undertaken prior to samples being extracted to map specific effects and calibrate techniques available to practicing engineers in the field. A range of non-destructive tests on recovered materials/planks as well as manufactured planks are proposed. This will allow an assessment to be made as to the efficacy of the methods for identifying defects within structures, as well as reinforcement bar location and extent. Some of the NDT methods proposed include GPR, cover meter and corrosion potential (half-cell) testing. The results will be compared and correlated to the eventual results of the destructive testing and breaking out of samples.

In addition, we propose to explore the impact of different coatings on the bond strength between the reinforcement and surrounding AAC. This will be reviewed as the material from site becomes available and the permutations of influencing factors are better understood.

Coupon material testing will have to be considered in addition to support FE modelling efforts. A moderate budget has been allowed for this and will be delivered by sub-contract. An existing supply chain partner of BRE is able to assist as required.

A series of full-scale loading tests would be undertaken on a small number of roof planks that can be recovered from site. This testing will be maximised as much as possible but will be restricted by the number of planks available and their condition. The supporting smallscale testing is equally important in this phase to link material properties, levels of carbonation, corrosion etc. to the actual behaviour of units under applied loading. The pattern and impact of cracking in these panels will be a key factor to consider and performance impacts will be captured.

In this stage BRE will also manufacture small-scale as well as full-scale single test planks that incorporate specific, confirmed ‘defects’. It is proposed that these test planks and smallscale samples will be manufactured at BRE using cementitious fine aggregate mix with low compressive strength and modulus. It is proposed to adopt a single design mix, after a small series of trials to assess suitability, with a single characteristic compressive strength similar to that of ‘standard’ / historic RAAC units.

Note: We appreciate that samples obtained from in-service RAAC will have a range of compressive strengths. It will therefore be necessary to arrive at a research group

consensus to what may be deemed to be a representative strength value for the testing programme.

Whilst we acknowledge that it will not be possible to replicate the holistic behaviour of AAC in the manufactured samples, we will endeavour to produce a relatively weak cementitious product that is friable, and which has a broadly similar ‘structural’ performance to that of AAC.

The properties/geometries of the cementitious units that could be varied (assuming that a single plank length/unit depth and longitudinal reinforcement provision are utilised) is currently proposed to include:

- Compressive strength;
- Modulus;
- Support bearing width/length;
- Support material type;
- Termination of longitudinal reinforcement relative to end of plank;
- Termination of longitudinal reinforcement relative to lip of bearing;
- Position of end transverse bar position relative to end of the plank;
- Position of end transverse bar position relative to lip of bearing;
- Distance of end transverse bar relative to immediately adjacent transverse bar.

4.2 Potential additional material small-scale testing scope

Corrosion of reinforcement is known to have occurred in RAAC roof planks where water ingress has been evident or where planks are located above/adjacent rooms where the relative humidity was known to be high. It has been postulated by some, that corrosion of the embedded reinforcement can have a detrimental effect upon bond strength. However, others have argued that corrosion can have a positive affect by virtue of the fact that the corrosion products extend outwards away from the surface of the reinforcement and into the pores of the surrounding small closed cells. As these cells are surrounded by cell walls composed of a fine siliceous aggregate bound together by calcium silicate hydrate, it has been argued that this process assists the reinforcement to ‘grip’ onto the surrounding matrix thereby enhancing the bond strength between the two materials.

Depending on findings of the initial stages of the programme, the impact of low levels of corrosion on the bond strength of reinforcement embedded in specimens might require additional work on a suite of dedicated small-scale prism specimens.

Pending research group input and findings from the first phases of work as well as observations made on site, specimens can be exposed in a number of high concentration chloride salt baths with varying submersions regimes. The specimens will also be subjected to different wetting/drying cycles. At the end of each of the respective exposure regimes, the test prisms would be removed, dried to a constant weight. The prisms would then be subjected to pull-out tests to determine the bond strength (and shear, if required).

This work is currently not included in the main programme (or costings) and can be costed separately upon request.

4.3 Structural behaviour: Plank testing

The full-scale plank testing will adopt the following key parameters which can affect the structural system behaviour:

- Single characteristic compressive strength (see above);
- Single percentage moisture content (to be agreed but associated with a dry internal environment);
- Bearing width (test set up) – 20mm, 40mm & 50mm (likely upper and lower bounds with one intermediate value consistent with minimum recommendations);
- Bearing type – steel and concrete beam (two common types used in practice);
- Presence/absence of end transverse bar and its position (if present) relative to the lip of the bearing (7No. alternative configurations from a total of 22 No. considered configurations).

We have currently selected a combination of these variables which has resulted in a total of 50 No. test planks.

4.4 Proposed designs of plank specimen

The currently proposed test plank designs/configurations are listed in the accompanying spreadsheet (Annex A).

4.5 Replicate RAAC specimen

Through the RAAC Learning Group a potential supplier of modern-day RAAC planks has been identified. The supplier will be manufacturing planks as well as associated test prisms.

Depending on the outcome of previous stages of the work the following material properties will be varied in the final stage of testing:

- AAC density;
- AAC compressive strength;
- Moisture content;
- ACC composition;
- Reinforcement size;
- Reinforcement strength.

Other properties/geometries that will be varied in line with previous findings (assuming that a single plank length/unit depth and longitudinal reinforcement provision are utilised) and will include a selection from the following:

- Support bearing width/length;
- Support material type;
- Termination of longitudinal reinforcement relative to end of plank;
- Termination of longitudinal reinforcement relative to lip of bearing;
- Position of end transverse bar position relative to end of the plank;
- Position of end transverse bar position relative to lip of bearing;

- Distance of end transverse bar relative to immediately adjacent transverse bar.

In this final stage of testing following parameters will be chosen, as 'worst' case scenario

- AAC density (fabrication) – either 500 & 700 kg/m3 (informed by previous findings);
- Bearing width (test set up) – 20mm, 40mm & 50mm (as identified in previous stage
- Bearing type – steel and concrete beam (as identified as worst case in previous stage);
- Presence/absence of end transverse bar and its position (if present) relative to the lip of the bearing (worst-case scenarios identified from previous stage)

We have currently selected a combination of the variables listed in 4.3 above which has resulted in a total of 50 No. test planks (with planks now twinned to provide supporting data).

Note: It is recommended to test a duplicate of each test plank to provide a degree of repeatability per test configuration. This will be finalised depending on the number of variables carried through to the final stage of testing.

Test prisms will be required alongside each of the RAAC replica planks will so that certain physical characteristics of the test planks can be determined. These will feed into FE modelling and cover density, moisture content, compressive and E modulus. We propose that at least two sets of test prisms will be fabricated for each of the tests.

At this point it is considered too difficult to pre-condition the replica RAAC test plank (and RAAC test prisms). For this each test plank and prism would need to be fully carbonated prior to being tested. This is considered impractical at this stage. However, this aspect can be revisited at a later stage once initial testing of existing RAAC results have become available.

5 Load testing

5.1 Static load testing

For the system testing, test planks and RAAC replica, as well as RAAC whole planks removed site, a 1/4 point static loading configuration will be used, matching BRE's method used in the 1995 test programme.

Medium-duration (7 weeks) testing of RAAC panel loaded with panel design load during the first series of 1995 tests

Displacement transducers will continuously monitor the mid span and end bearing displacements whilst high level and bearing level videos will record the behaviour of each test plank during the loading cycle and up to failure.

The majority of testing will be completed in short duration. However, depending on available of RAAC planks removed from site medium-duration (21 weeks) loading in a dry internal environment will be endeavoured. In order for this to render meaningful insights, at least two planks (ideally more) will need to be available.

5.2 Dynamic load testing

[redacted 10(5)(e) (confidentiality of commercial or industrial information)]

5.3 Thermal testing

[redacted 10(5)(e) (confidentiality of commercial or industrial information)]

Note 1 : Anecdotal reports have suggested that heat generated within the upper regions of concrete hollow core roof planks arising from solar radiation (during periods of hot weather and in the presence of a bitumen based roof covering) had induced hogging of the planks. It is not clear, however, whether this behaviour also occurs in RAAC units.

Note 2 : The recent collapse of RAAC roof slabs at a school occurred over the w/e of the 7/8th July 2018. During this 2-day period the ambient air temperature reached a maximum of circa 32 degC (London City Airport Met station). A web-based review of literature has suggested that with an external shade temperature of circa 32degC, the temperature of roof units underlying a bitumen-based membrane could reach between 60 and 88 degC

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6 Factors/behaviours currently not considered

The currently proposed testing programme has not considered/incorporated the following loading configurations and/or long-term behaviours, primarily due to cost considerations. These include:

1. Asymmetrical loading;
2. Cyclic/fatigue loading;
3. Long term thermal/moisture cycling;
4. Pure shear loading;
5. Corrosion modelling – refer to previous sections of this proposal for qualifying comments.

7 Numerical modelling

A programme of numerical modelling will be undertaken by the finite element modelling group at various stages during the research programme, with the results of the modelling runs being compared to, and calibrated with, the behaviour of both the small scale samples and full-scale RAAC planks (independent of source).

We anticipate that by using this feedback process the group will be able to improve the accuracy of the numerical modelling such that it will be possible to evaluate the sensitivity of specific features (i.e. discrete and intermittent ghosting/voiding) within the AAC with a reasonable degree of confidence. It should also be possible to explore the influence of specific details in the construction that for practical or financial reasons, could not be practically replicated within the laboratory. This approach will also allow the team to theoretically explore a series of 'what-if' scenarios with relatively minimal physical effort. One example being the study of the influence of moisture content on the behaviour of a 'test' plank or small-scale sample given a range of parameters.

Numerous research papers[1] have explored the role and accuracy of the finite element technique in the modelling of closed foamed materials (i.e. metal foams). The research studies have shown that it is possible to make 'sensible predictions on strength behaviour with reasonable accuracy…from local to global failure'.

8 Approximate project timelines

Below the approximate timeline in which the various stages of the work are to be completed- a detailed plan is included in Annex B. Whilst a start date is yet to be confirmed and depends on timeline approval, the durations of the various work stages as well as anticipated milestone reviews and research group review and input stages are representative of anticipated overall time requirements.

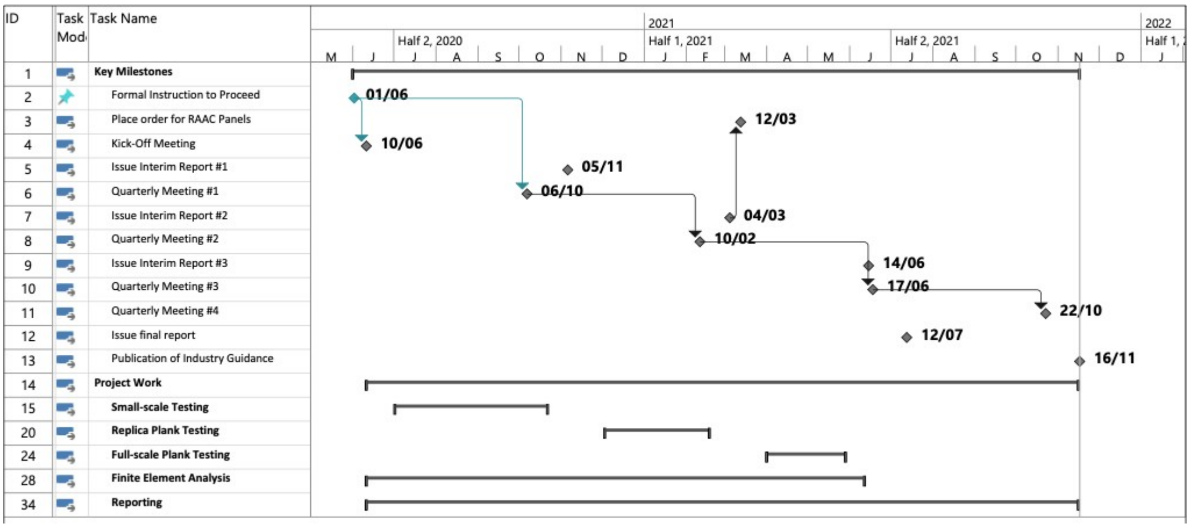
The stages are spaced and aligned with delivery to ensure maximum possibilities for exchange, enabling research group, wider industry and SCOSS input at various times.

It is important to note that the programme has been designed to enable a wide range of characteristics to be investigated, the outcome of relative importance of each at this point not known. Adjustments to the timelines as well as input to the final design in larger scale testing will be adjusted to follow through on phase 1 findings etc.

The input of the research groups and sub-expertise panels will be a key component of the work and pivotal in designing both the programme and the design of the test samples.

This has been given ample time and whilst the outcome of the work is highly anticipated and called for by all experts in this field, it is important to stress that the output and the relevant of the work will be directly linked to the thoroughness and confidence of the experimental programme outcomes. A regular report on progress to date, issues identified, conclusions drawn and outstanding requirements has been added to enable in-depth review and also to mobilise resources by the practitioners and modelling partners to input flexibly and in alignment with requirements as they develop.

BRE will be acting as project management to ensure all these strands are coordinated and communication is allowing for meaningful exchange on issues as well as reach consensus on best steps forward.



9 Outline budget

A draft budget has been developed for the following categories so as to guide on costs per stage and by type of input. This is a draft budget at this stage to guide on approximate effort. Detailed proposal (s) will be prepared, including detailed test plans, run of tests and confirmation of available material for small-scale and on-site plank testing.

[redacted 10(5)(e) (confidentiality of commercial or industrial information)]

The costings include approximate budgets for set-up of the test samples, materials, measurement, NDT and load testing as well analysis of results and writing of summary reports. The budget also includes provision for liaison with all partners as required and facilitating/ hosting technical meetings and exchange on subject matters as required.

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Annex A Plank test panel details: Extract

[redacted 10(5)(e) (confidentiality of commercial or industrial information)]

Annex B GANTT chart

[redacted 10(5)(e) (confidentiality of commercial or industrial information)]

Annex E – Meeting paper for a Structural-Safety Group meeting that took place in May 2020 that a Scottish Government official was invited to

LOG OF RUNNING TOPICS *(updated 15 July 2020) CONFIDENTIAL* **SC/20/01.3**

This log schedules current topics which are being dealt with by SCOSS.

ID	Topic	Progress	Action/ Status
A21	Balconies	A draft has been developed by APM about the safety of balconies in general. There have been many collapses world-wide and CROSS-AUS and CROSS-US are being involved so that this will be our first International Alert. The draft has been shared and comments and case studies will be forthcoming. The intention is to publish the Alert this year.	AS/AM **HIGH**
A23	Failure of RAAC (reinforced autoclaved aerated concrete) roof slabs	CROSS was notified in late 2018 of the partial collapse of a school roof formed from RAAC planks and a SCOSS Alert was published in May 2019. There have been other reports and an RAAC Learning Group has been established by PM with the support of Government departments; LGA, DfE, NHS and MHCLG to monitor and manage the topic. Research support is being provided by BRE. The Topic, having achieved the required result of alerting industry, will now be removed from this list although updates will be given as progress is made.	PM **MEDIUM**
B13	Pedestrian bridge collapse in Miami	In 2019 a pedestrian bridge in Miami collapsed and the first authoritative review of this has been published by OSHA (Occupational Safety and Health Administration): https://www.osha.gov/doc/engineering/pdf/2019_r_03.pdf NTSB (National Transportation and Safety Board) then published an Accident Report published in October 2019: https://www.ntsb.gov/investigations/AccidentReports/Reports/HAR1902.pdf There are important lessons to be learned from this event and SW and VP volunteered to write a SCOSS Alert. Meantime Andy Hermann, CROSS-US and past-president of ASCE, is chair of a panel writing a report about the collapse for ASCE. This is expected to be available to us by the autumn and we will then be able to use it to prepare an Alert.	SW/VP/AH **HIGH**
C9	Fire safety in tall timber buildings	This Topic was raised in May 19 (see minutes from group meeting on 01.05.19 for details). Since then the Timber Frame Fire Working Group has been established. NG and LB are members so they will represent Structural-Safety as the work evolves.	LB/NG **HIGH**

E10	Unexpected consequences from escalation in scale	An Alert prepared by APM on Effects of Scale was published in November 2018. There may be important consequences arising from this so an IStructE panel have been briefed and are taking the work forward. APM is liaising with IStructE and SCI and SCOSS will be kept informed.	AS/APM **MEDIUM**

ID	Topic	Progress	Action/ Status
E12	Assessment of LPS (large panel structure) buildings	There has been engagement with the LGA (local Government Association) and MHCLG on the risks associated with LPS buildings for three years and advice has been given. There was a meeting with some owners of such buildings in January 2020 at which the concerns on structural and fire safety were raised by AS and BRE. MHCLG/LGA need to be reminded that this problem will not go away.	AS/APM/TJ **HIGH**