The Institution of
StructuralEngineers

Reinforced Autoclaved Aerated Concrete (RAAC) Investigation and Assessment – Further Guidance

April 2023

1 Introduction

In 2019, SCOSS published a safety alert ‘Failure of Reinforced Autoclaved Aerated Concrete (RAAC) Planks’ which identified concerns about the structural safety of this form of construction.

In February 2022, the Institution of Structural Engineers (IStructE) published supporting guidance titled Reinforced Autoclaved Aerated Concrete Panels – Investigation and Assessment. This guidance provided further information for the assessment of RAAC panels.

This report provides further guidance on the critical risk factors associated with RAAC panel construction. It includes a proposed approach to the classification of these risk factors and how these may impact on the proposed remediation and management of RAAC.

This report has been written by members of the IStructE RAAC Study Group to assist with the approach to RAAC assessment amongst the structural engineering community. It is intended to be adopted by structural engineers who will be responsible for quantifying, appraising and providing reasoned assessments of RAAC panel construction on a case-by-case basis using their own engineering judgement.

It is recommended that a reader familiarises themselves with the 2019 SCOSS Alert the previous IStructE report and the references in Section 8.

This report focuses on roof panels but can be used for the assessment of floor panels. The discussion of load bearing or non-load bearing wall panels are not covered in the scope of this report.

The Institution of Structural Engineers and the Study Group which produced this Guide have endeavoured to ensure the accuracy of its contents. However, the guidance and recommendations given should always be reviewed by those using the Guide in light of the facts of their particular case and any specialist advice. Users should also note that the Institution periodically updates its guidance through the publication of new versions (for minor alterations) and new editions (for more substantial revisions) - and should ensure they are referring to the latest iteration. No liability for negligence or otherwise in relation to this Guide and its contents is accepted by the Institution, its servants or agents. Any person using this Guide should pay particular attention to the provisions of this condition.

2 Surveys

2.1

Guidance produced by the IStructE in February 2022 provided advice on the form and scope of surveys to be adopted for RAAC panel installations. This identified the need to survey the panels for:

- Measurement of deflections
- Recording of cracks and defects
- Recording evidence of water leaks
- Hammer tap testing for signs of debonding concrete
- Recordings of panels cut after manufacture
- Recording of any alteration or penetration through panels after construction

Also, recent experience has emphasised the significance of the end bearing and the investigation of the end bearings is now required to assess the structural risks.

RAAC panels present highly individual results when surveyed with adjacent panels often exhibiting varied deflections, cracking, etc. Given this variance in RAAC panel construction it is recommended that all panels are visually assessed.

2.2

Deflection measurement of panels can assist in the assessment of panels performance. The measurement of each panel deflection will allow the greatest level of assessment. However, where this is not possible, measurement of deflection of a representative sample should be undertaken. A minimum recommended sample size should be proportional to the size and scale of the building or structure being assessed but should typically not be less than 10% of the total number of panels.

The panels selected should provide a representative sample including:

- Structural spans
- Panel width and depth (if known)
- Increased loading resulting from roof access
- Loading from a supported plant or machinery
- Different internal environments, for example, any dry, damp or humid areas
- Areas where there could be an accumulation of external load factors including a build-up of water or drifting of snow

The measurement of any panels affected by past or current water leaks would also be of assistance in accessing any detrimental impact of any leaks.

The span of panels should be recorded together with their mid-span deflection.

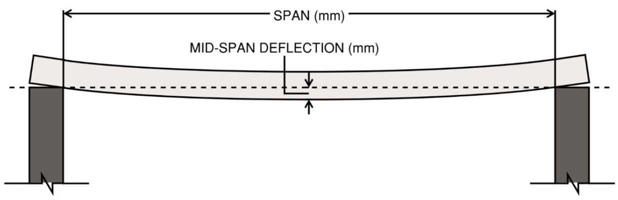


Figure 1 - Deflection schematic (not to scale)

2.3

Non-destructive testing techniques, such as the use of covermeters, provide insight into reinforcement location. However, more expensive radar techniques may not yield reliable test results due to equipment tolerances; particularly when in the presence of foil backed insulation or covering. If used, the specialist survey companies should be consulted to ascertain the tolerances of equipment for given construction forms prior to commissioning surveys.

2.4

The specification of intrusive investigation works for RAAC panels should be carefully considered. Intrusive surveys can be undertaken to record:

- Panel bearing lengths
- Position of transverse anchorage reinforcement at bearings
- Panel thickness
- Reinforcement quantities and diameter

Intrusive investigations will result in damage to panels. The location and extent of the trial areas should be carefully selected by the engineer. Any such investigations should be kept to the minimum size given the disruptive nature of any works that may impact on panel structural capacity. The engineer should assess the condition and capacity of panels ahead of the investigation works and consider the need for temporary propping or support.

Investigations should be undertaken using hand tools with small diameter non-percussive drilling only if needed. Investigations may include localised drilling to estimate depth of bearing, opening using hammer and chisel. All trial holes should be made good with a suitable proprietary repair mortar and all waterproofing or protective finishes made good to prevent further degradation of the panels.

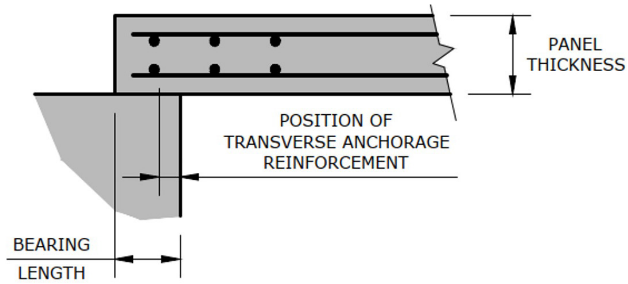


Figure 2 – End bearing configuration

Locations for intrusive investigation should provide a representative sample from around the building or structure. This should include any variation in span or support arrangements. The number of locations selected needs to be sufficient to gain an understanding of the original design intent for the panels and the range of manufacturing or construction installation tolerances.

3 Risk factors

RAAC presents a number of risks associated with the original construction form including the materials used, design intent, manufacturing control and construction / installation control. Further risks are presented through the in-service conditions including uncontrolled modifications, changes in loading regime, poor maintenance and ageing.

These are described below.

3.1 End bearing

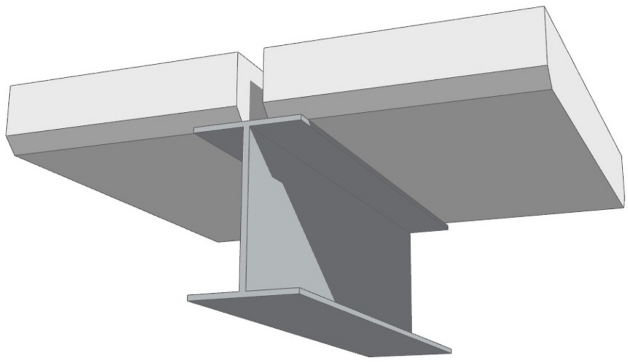
Poor bearing is a significant risk to the integrity of RAAC roof panels.

The codes of practice associated with the design of RAAC from the 1950's to 1980's were CP114 Reinforced Concrete in Buildings and CP116 Structural Use of Precast Concrete. These codes recommended minimum end bearings of only 45mm for roof panels and 60mm for floor panels. In practice, construction tolerances could have resulted in reduced bearing lengths.

To anchor longitudinal reinforcement, RAAC panels require transverse reinforcement over the bearing support. As noted by testing undertaken by the BRE (BRE IP 10/96), absence of transverse reinforcement at the end bearing can substantially impact on panel performance. The inspection of several buildings has identified that with short bearing lengths there is a risk that this critical anchorage reinforcement can be absent over the support face, presenting an increased risk of panel failure.

For this reason, a minimum as built bearing length 75mm is now considered to be necessary. Any bearing less than 75mm would be considered substandard and present an unacceptable risk to panels from shear failure or slippage and remedial actions are recommended.

Narrow or short bearing lengths may be identified through visual inspection; for example, where panels span from either direction onto a narrow steel beam or masonry wall less than 100mm. These shared bearings on narrow beams or supports can therefore present risks of inadequate bearing length.



Sub-standard bearing on 100mm beam

Figure 3 – End bearing condition

However, in many instances visual inspection alone may be inadequate. Numerous examples have been found of panels having short bearing lengths (<75mm) even when supported on wide steel or concrete beams. Therefore, it is recommended that the bearing length is verified. Intrusive surveys are the only effective method for identifying the bearing length and the position of transverse anchorage reinforcement.

3.2 Anchorage reinforcement

RAAC floor and roof panels require transverse reinforcement to anchor the longitudinal reinforcing bars. This is particularly critical at bearings where transverse bars are needed over the supports as discussed in the previous section.

Where transverse anchorage reinforcement is absent the longitudinal bars will have significantly reduced tensile capacity and there is an increased risk of failure. The mode of failure is still being assessed by academic research, however sudden brittle shear failure is considered possible.

It is not possible to ascertain poor anchorage of reinforcement from visual inspection, therefore intrusive survey techniques are required.

3.3 Cut panels

Cut panels can be created from the manufacturing process where longer panels may have been cast and cut down to create shorter panels or where panels were trimmed at the time of the original construction for building services or other small penetrations.

Original construction techniques used narrow steel trimmers or hangers supported by adjacent panels to form openings in roofs. These steel hangers often have narrow bearing support and have been installed some distance from transverse reinforcement. Therefore, cut panels supporting on hangers present inadequate bearing conditions and poorly anchored longitudinal reinforcement.

Figure 4 – Photo of hangers

Depending on the span of the panel being supported these conditions may present high risk of panel failure.

Cut panels can be identified through visual inspection, where supported on hangers or where panels are visibly narrower or shorter than adjacent panels. However, visual inspection is difficult where panels have been cut as part of the manufacturing process and intrusive surveys may be required.

Cut panels should be identified in all instances. The length of the cut panel, support conditions and defects should be noted.

3.4 Cracking

Cracking and spalling can be a visible indicator of excessive deflections, water ingress, mechanical damage or reinforcement corrosion. It is recommended that all visible defects are recorded during a visual inspection. Where applicable, this should be supported by crack measurement and location for assessment and future review.

It is recommended that cracking and spalling is recorded as either major or minor as defined below:

- Major cracking/spalling: defined where a panel exhibits large/deep cracks that may be accompanied by spalling and in some cases exposed reinforcement
- Minor cracking/spalling: defined where a panel that exhibits small cracks on its surface. These are commonly transverse across the panel width and usually expected to be seen at the centre of the panel

Cracking close to the supports (circa within 500mm) is of significant particular concern because it could be representative of shear cracking. Cracking close to a bearing should be recorded and cracks across the full width of a panel are considered more serious than cracks local to the edges

3.5 Builder's works/building modifications

Builders work that was not part of the original construction can result in panels being cut or drilled for new services.

Sometimes new trimming beams may have been installed but the designers of the trimming may not have been aware of the impact of the loss of transverse anchorage reinforcement at the bearing and therefore the support provided to cut panels may be inadequate.

In some instances, small diameter core holes may result in longitudinal or transverse reinforcement being cut or damaged or mechanical damage to the RAAC panels both of which will weaken RAAC panels presenting a risk of failure as with cut-panels or inadequate bearing lengths.

Note: While fixing into RAAC are outside of the scope of this report, care is needed with fixings due to the low strength nature of the AAC and fixings have been known to pull out. Where critical or heavy services are fixed into RAAC these should be checked.

3.6 Water ingress

Prolonged water ingress can impact on RAAC. Water ingress can saturate RAAC panels giving risk to a potential increase in panel weight. Water ingress has also been noted as adversely impacting on the material strength and is likely to lead to unseen corrosion to the reinforcement.

The increase in weight and loss of material strength adversely impacts on the panel strength and load-carrying capacity.

The corrosion of reinforcement will, over time, lead to spalling of the surrounding RAAC panel resulting in falling debris and potential for loss of panel capacity. The corrosion of reinforcement may also impact on the bond between RAAC and embedded reinforcement, which may adversely impact panel strength.

It should be noted that due to the open nature of the AAC matrix significant levels of corrosion can occur before spalling of the cover concrete occurs. The corrosion can therefore be well established before there are obvious external signs.

Water penetration is normally evident through visual inspection. It can be noted where a panel is showing signs of staining, salt crystallisation or corrosion/spalling.

Water ingress may also be noted through adjacent elements, such as finishes or masonry where salt crystallisation or staining may also be evident.

Water ingress presents a significant contributing risk. Therefore, any panels with water ingress should be recorded and the significance assessed.

3.7 Deflection measurements

There are several factors that may result in high deflections of RAAC panels. RAAC panels which are exhibiting high deflections may increase the risk of water ponding and increases in loading and / or lead to a change in bearing stresses. Both factors being potential failure risks.

The deflection of RAAC panels can often be noted visually, however measurement is required to ascertain accurate deflection data. The deflection of panels should be recorded and the data should be used to classify the deflection of each panel as follows:

- Deflection equal to panel span/100 or greater
- Deflection between span/100 and span/200
- Deflection between span/200 and span/250
- Deflection equal to panel span/250 or less

The differential deflection between adjacent panels should also be recorded, particularly where this is significant. Deflections exceeding 20mm between panels being considered significant.

3.8 Adverse or changes in loading

Poor roof drainage can result in the build-up of water on flat roofs which can be further exacerbated by vegetation build up. These situations can result in elevated and prolonged loading of panels. Changes in roof level can also lead to drifting of snow and locally increased loading.

Any areas where additional loading associated with a change or use, new suspended or supported building services equipment, changes in ceiling or roof finishes should be considered potential adverse loading.

Changes in loading regime beyond that which the structure was originally intended could overload the panels above the original design load allowances.

Any increase in loading could significantly impact on the RAAC installation, particularly when combined with other risk factors; such as poor bearing or water ingress.

4 Assessment of risk

It is recommended that the surveys information is used to assess a risk classification for the panels/building. The below RAG (Red, Amber, Green) risk rating approach is proposed as set out below.

Red risks have been split into High risk and Critical risk. The application of qualified and experienced engineering judgement is required to assess when a Critical risk exists. Critical risks may exist where multiple risks exist for example major cracking and adverse loading conditions. The use of the building may also be a factor in the assessment. **Depending on condition Critical risk areas may need immediate action. Final selection and urgency of mitigation measures to be determined in conjunction with the building owner/occupants.**

Assessment category	Risk category	
Red	Critical risk	Requires urgent remedial works which may include taking out of use or temporary propping to allow the safe ongoing use of a building. Depending on the extent, this may be part or all of the building. Combined with awareness campaign for occupants including exclusion zones.
	High risk	Requires remedial action as soon as possible. Combined with awareness campaign for occupants, which may include exclusion zones, signage, loading restrictions and the need to report changes of condition, eg, water leaks, debris, change in loading, etc.
Amber	Medium risk	Requires inspection and assessment on a regular basis, eg, annually. Combined with awareness campaign for occupants, which may include signage, loading restrictions and the need to report changes of condition, eg, water leaks, debris, etc.
Green	Low risk	Requires inspection and assessment occasionally, say three year period depending on condition. Combined with awareness campaign for occupants, which may include signage, loading restrictions and the need to report changes of condition, eg, water leaks, debris, etc.

Table 1 – Risk categories

4.1 Determination of risk

It is recommended that observations of the defects within the panels should be used to categorise the panels in a particular building. The following tables provide guidance on typical RAAC panel defects and the proposed risk category associated with that defect.

The presence of water within RAAC panels is of concern and therefore a panel with observed historic water ingress has an elevated risk level. Therefore, alternative tables are presented below for panels that have been subject to long term water ingress and a separate table for panels which have remained dry.

These tables are non-exhaustive and the matrices approach is an initial recommendation. It is expected that the structural engineer will assess each case individually and use their judgement to aggregate the risks, based on the local conditions to determine an appropriate risk category.

4.1.1 Support condition

Support / bearing condition	Risk category
Bearing investigated and found to lack required transverse reinforcement	Red (critical)
Cut or modified panels, including where cut panels are supported on proprietary hangers	Red (critical)
Bearing <75mm with transverse anchorage reinforcement	Red
>75mm with transverse anchorage reinforcement	Green

Table 2 – Support/bearing risk category

4.1.2 Panel construction

The panel condition is a function of cracking, deflection, and water ingress.

Where water ingress is observed it may be difficult to ascertain the period and therefore the impact that this may have had on the panel strength. Therefore, all water ingress is considered Red / Amber risk.

Risk assessment if water ingress is observed				
Deflection	Major cracking or spalling	Minor cracking/ or spalling within 500mm of support	Minor cracking or spalling away from the supports	No visible defect
Deflection >span/100	Red	Red	Red	Red
Span/100<deflection<span/200	Red	Red	Red	Red
Span/200<deflection<span/250	Red	Red	Amber	Amber
Deflection<span/250	Red	Red	Amber	Amber

Table 3 – Risk category with water ingress

Risk assessment if NO water ingress is observed				
Deflection	Major cracking or spalling	Minor cracking/ or spalling within 500mm of support	Minor cracking or spalling away from the supports	No visible defect
Deflection >span/100	Red	Red	Red	Red
Span/100<deflection<span/200	Red	Red	Amber	Amber
Span/200<deflection<span/250	Red	Amber	Green	Green
Deflection<span/250	Red	Amber	Green	Green

Table 4 – Risk category with NO water ingress

5 Remediation

Remedial action should be undertaken on any panels assessed to be Red (High or Critical risk) condition, with planned remedial action determined for Amber (Medium risk) condition panels.

In some instances, it may be appropriate to apply remedial action only to the affected panels. Alternatively, depending on the remedial works, this may be applied to all panels within the building being assessed.

The response to Red (High or Critical risk) panels should be considered as time dependent. In some instances, immediate exclusion zones or the introduction of temporary propping to allow the safe ongoing use of a building may be recommended.

In all instances, the ongoing use of buildings with RAAC panels identified to be in a Red (High or Critical risk) category should be risk assessed.

Engineers undertaking the risk assessments should be aware of the approach being developed for the management of high risk buildings under the Building Safety Act.

Remediation strategies may include:

- The addition of secondary supports or beams at the end bearing to provide an increased effective bearing length. This is applicable to panels with short bearings length and misplaced transverse anchorage bars. This strategy will not be suitable for cut panels with no transverse anchorage reinforcement
- Positive remedial supports to actively take the loading from the panels. This could include the addition of new timber or lightweight structures to support the panels directly
- Passive fail safe supports to mitigate catastrophic failure of the panels if a panel was to fail. Such as a secondary structure designed to support the panels
- Removal of individual panels and replacement with an alternative lightweight solution
- Entire roof replacement

6 Management strategy

A management strategy should be applied to Amber (Medium risk) and Green (Low risk) RAAC panels. This should be developed by the building occupant/owner.

It is expected that panels presenting a Low or Medium risk will deteriorate over time, but precise details of the mechanism that causes this, or the rate at which it will occur is not yet known.

The management strategy should consider the current condition of the RAAC panels and include:

- Monitoring plans for RAAC panels and inspection regime
- Risk assessment details
- Areas for proposed future remediation
- The assumption on degradation of RAAC panels that have informed the plans – this should be informed by the structural engineer, based on site conditions
- The management strategy should also include plans for reducing the risks associated with RAAC panels
- These should include plans for limiting:
    - Applied operational loads, for example no-walk zones on RAAC roofs, maintaining roof drainage and removal of ponding water
    - Applied fixed loads, for example, restricting new or removal of existing building services equipment
    - Durability risks, for example reducing humidity in plant or kitchen spaces, re-roofing including insulation laid to falls

An awareness campaign should be implemented so that all occupants are aware of the concerns about RAAC. This should provide reassurance that measures are being undertaken, but also help involve occupants in the management. Occupants should be encouraged to notify the responsible person if conditions change, for example, if leaks are detected, debris is found, or adverse loading noted.

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