NHS National Services Scotland

Reinforced Autoclaved Aerated Concrete (RAAC) in NHS Estate: Management and Monitoring

Scottish Health Technical Note

SHTN 00-05

Version 1.0 - July 2025

NHSScotland Assure
Quality in the healthcare environment

Contents

1. Purpose

Introduction

1.1. In 2019, Standard Committee on Structural Safety (SCOSS) published ‘Failure of Reinforced Autoclaved Aerate Concrete (RAAC) Planks’ SCOSS Alert, May 2019 which identified concerns about the structural safety of this form of construction. NHSScotland has responded to concerns about the integrity of RAAC by commissioning a programme of discovery via NHSScotland Assure.

1.2. This has led to RAAC being found in NHS buildings belonging to many NHS boards. Figure 1.1 shows a typical example of RAAC roof planks above a suspended ceiling in a healthcare facility. This guidance has been written to provide structural engineering information to NHS boards about RAAC, how to monitor and safely manage it once found, and when to seek advice from professionals.

1.3. The purpose of this Guidance is to provide a rational, evidence-led basis with which to respond to RAAC user concerns, concurrent with its safe monitoring and management.

1.4. It has been structured with some background information about RAAC, its properties and behaviour, before describing the risk factors that result from those properties and behaviour. Finally, it presents methodologies for assessing and managing risk.

Figure 1.1 - RAAC planks supported on steel trusses

1.5. This document is aimed at NHSScotland Estates and Facilities Directors for action, Directors of Health and Safety for action and to Estates and Facilities Managers for information. It is intended to provide background information on the underlying rationale and context for the proposed methodologies. It also includes examples of real buildings to assist the reader in their understanding of this document.

RAAC discovery

1.6. A process of locating RAAC within the NHSScotland estate, known as Discovery, has been undertaken. It began with a desktop study to identify where properties with a high, medium or low likelihood of containing RAAC were located to better inform the urgency of surveying one property over another. NHS boards provided a list of properties to be surveyed in each of their estates, and this formed the property survey list in the RAAC Phase 1 Discovery Survey Programme commissioned by NHSScotland Assure. The sequence of visits was based on a combination of likelihood and location.

1.7. Likelihood was determined according to the number of characteristics a property had that were consistent with RAAC being present, albeit such characteristics are not unique to buildings containing RAAC. For this reason, a high, medium or low category defined how likely a building was to contain RAAC relative to other properties, rather than being a prediction of likelihood in absolute terms.

1.8. At the completion of Discovery, each NHS board received a set of reports stating which of their inspected properties contain RAAC and where no RAAC was found. The reports also provide layout plans, photographs, information about the condition of the observed RAAC, recommendations for further investigation and locations where remedial action is required. Information about mitigating and managing structures with RAAC has also been provided.

NHS board responsibility

1.9. It is the responsibility of individual NHS boards to implement the recommendations that have been made in Discovery Reports and to make plans for managing RAAC in the longer term. It is also their responsibility to manage and maintain their properties in accordance with good practice and relevant legal/ statutory requirements. This document does not change or alter a NHS boards legal/ statutory obligation.

1.10. NHS board estates and staff who have responsibility to maintain and manage the estate, are not expected to perform structural engineering inspections and appraisals to assess the condition of RAAC, however they are expected to employ competent and qualified Structural Engineers, experienced in the assessment of RAAC, to carry out this work on their behalf. They are also expected to ensure that any findings or recommendations from the Structural Engineer's work is implemented.

1.11. Similarly, NHS boards are expected to consider the implications for RAAC if alterations or amendments to buildings are being considered. In most cases this should be done in consultation with a Structural Engineer.

1.12. This Guidance provides NHS boards with relevant information to support their response to RAAC, including informing their decision-making on ongoing monitoring, communications and safe management.

2. Introduction to RAAC

General background

2.1. At the conclusion of World War II, the need to re-build UK cities quickly was influenced by a scarcity of construction materials and skilled labour. This made alternative materials, manufactured off-site in the controlled environment of a factory, more attractive. Reinforced Aerated Autoclaved Concrete (RAAC) was one of the systems that emerged to fill this need, although as a material it had been in existence since the 1930s. Figure 2.1 and Figure 2.2 show historical images of RAAC being installed.

Figure 2.1 - Installation of a RAAC plank (Cover, ‘Autoclaved Aerated Concrete Roof and Floor Units Handbook 2’, Aerated Concrete Ltd, October 1977)

Figure 2.2 - Installation of a RAAC plank (page1, ‘Autoclaved Aerated Concrete Roof and Floor Units Handbook 2’, Aerated Concrete Ltd, October 1977)

2.2. Notwithstanding this, it is worth noting that in the 1930’s conventional reinforced concrete was still in its infancy, with the first codes and standards being published in the early twentieth century. Much was still to be learned about concrete technology.

2.3. RAAC was to become increasingly popular in the 1960’s and 1970’s, especially for roof structures, primarily because manufactured planks are lightweight and therefore easy to install, but also because Autoclaved Aerated Concrete (AAC) is a better insulator than conventional concrete.

2.4. There were some early concerns about excessive deflection, which have been attributed to high span to depth ratios that would not be acceptable today as well as general concerns around the manufacture of precast concrete emerging towards the end of the 1960’s. The issues were sufficiently obvious at the time that it would be unusual to find an installation of this kind today, at least not without modification.

2.5. There was limited guidance on the use of RAAC in contemporary design standards such as Code of Practice (CP) 116-2:1969, CP 110:1972 and British Standard (BS) 8110-1985, therefore design was mostly based on testing by manufacturers. Contemporary guidance documents issued by manufacturers in the 1960-70’s provide evidence of load testing and quality control (see Figure 2.6); however, site observations indicate that this was not always implemented successfully. Some of the issues that have arisen from this are described in this document.

2.6. In the 1990’s the integrity of RAAC was called into question after several school roofs were investigated by the Building Research Establishment (BRE) however, more recently interest in RAAC has been rekindled after a section of roof collapsed at a school in 2018. More information about this can be found in a Standard Committee on Structural Safety (SCOSS) Alert dated May 2019. While no single issue was deemed to be responsible for the collapse, it was clear that manufacturing and erection tolerances were significant factors, which exacerbated the effect of other issues.

2.7. Following BRE’s commission to investigate the behaviour of RAAC in the 1990’s, especially for roof structures, several technical reports were published based on their findings. This research provides the foundation for guidance published by the Institution of Structural Engineers (IStructE), the most recent of which is ‘Reinforced Autoclaved Aerated Concrete (RAAC) Investigation and Assessment - Further Guidance’, The Institution of Structural Engineers (IStructE), April 2023.

2.8. As a result of those concerns Loughborough University was commissioned by NHS England in 2022 to conduct new tests concluding in May 2023, however at the time of writing this document, it is not clear whether these tests will result in any update to the most recent IStructE guidance.

Characteristics of AAC

2.9. AAC is a form of lightweight concrete formed from materials containing lime and silica (calcareous and siliceous). It is a fine-grained material, without coarse aggregate, that has either chemically or mechanically induced bubbles, which give it a foam like appearance. The autoclaving process is used to cure and harden it.

2.10. AAC is like ordinary concrete, in the sense that it is weak in tension and strong in compression, however its compressive strength, which would be in the range of 2-5 kilopascal (kPa), is much less than modern concrete (30-40 kPa). That said, a better comparison would be with ordinary concrete from the same era as RAAC, where the difference is much less. When the concrete design code CP 114: The Structural Use of Reinforced Concrete in Buildings (1965 edition) was first introduced three grades of concrete were available, with permissible compressive strengths ranging from 6.9-10.4 kPa. This is not vastly different to the strength of RAAC. It was not common to use stronger concrete until the modern era.

2.11. A feature of AAC that is perhaps more important than absolute strength is the absence of coarse aggregate. Without aggregate interlock it has a lower shear strength and bond stress (<1kPa) and may be more vulnerable to failure due to cyclical and creep effects, though the latter characteristics are less well understood. This tends to manifest initially as additional deflection or cracking.

2.12. The coefficient of thermal expansion for AAC is often taken to be $8x10^{-6}$ $^{o}C^{-1}$, which is lower than standard concrete ($10x10^{-6}$ $^{o}C^{-1}$) and lower than steel reinforcement ($12x10^{-6}$ $^{o}C^{-1}$). This means that temperature changes introduce internal stresses to reinforced AAC, due to differential expansion and contraction.

2.13. Another characteristic of RAAC, shown in Figure 2.3, is the ‘shadow effect’ which occurs when gas bubbles, due to the foaming process, form voids around the reinforcing bars. The size of the voids is thought to depend upon the bar diameter and will tend to reduce the bond between AAC and embedded reinforcement. Figure 2.4 below also shows the variability in voids throughout the AAC.

Figure 2.3 - Shadow effect around reinforcement (page 4, ‘Reinforced Autoclaved Aerated Concrete (RAAC) Panels Investigation and Assessment’, IStructE, February 2022)

Figure 2.4 - Variability of AAC (page 4, 'Reinforced Autoclaved Aerated Concrete (RAAC) Panels Investigation and Assessment', IStructE, February 2022)

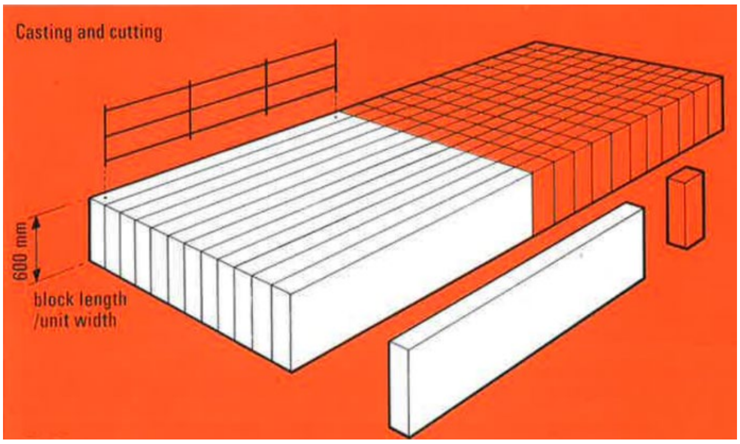
2.14. The porous nature of AAC means that water can easily penetrate the surface and saturate it. This was known when RAAC planks were manufactured and for this reason a cementitious latex coating was applied to the reinforcement.

Manufacturing of RAAC

2.15. RAAC was manufactured in a factory in several stages. In the first instance moulds were partially filled with slurry which then expanded to fill the moulds due to the formation of hydrogen bubbles. As the slurry set the hydrogen would diffuse and be replaced with air. Before the setting process began, strips of welded steel mesh were inserted into the slurry, which would eventually reinforce the finished RAAC planks.

2.16. Once the slurry had become sufficiently hard the moulds were removed, and the resulting cake was cut into standard rectangular shapes by a wire cutting machine. The individual planks were then placed into autoclave ovens to harden (refer to Figure 2.5 below).

Figure 2.5 - Casting and cutting of RAAC (page 2, 'Autoclaved Aerated Concrete Roof and Floor Units Handbook 2', Aerated Concrete Ltd, October 1977)



2.17. After hardening units were milled along the edge to standard profiles. Floor, roof and cladding generally had chamfered edges, while partitions tended to have square edges.

2.18. RAAC planks were also load tested to ensure that their capacity was known and could be reliably specified (Refer to Figure 2.6).

Figure 2.6 - Load testing of RAAC (page 4, ‘Autoclaved Aerated Concrete Roof & Floor Units Handbook 2’, Aerated Concrete Ltd, October 1977)

2.19. The two primary manufacturers were Siporex Ltd and Durox Building Units Limited, who were based in Motherwell in Lanarkshire and Linford in Essex respectively.

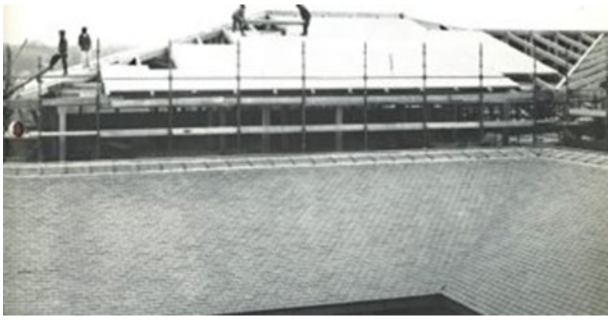
Where is RAAC found?

2.20. RAAC can be found in buildings that were constructed between 1950 and 1995, although the period between 1960 and 1980 is most common. Although floors were sometimes made of RAAC, it is more often found in roofs. Indeed, if RAAC is absent from the roof it is unlikely to be found in the floors. Few RAAC floors have been observed on the NHSScotland estate during the Discovery process.

2.21. As shown in Figure 2.7 roofs formed with RAAC planks tend to be flat, albeit an incline of less than 5 degrees qualifies for this description. For this reason, installations frequently have a timber furring to create a mild fall towards the roof gutters. The type of structure used to support RAAC panels is normally in the form of masonry walls, hot rolled steelwork, concrete down-stand beams or prefabricated trusses. Occasional RAAC planks are used in combination with in-situ concrete. Most often this is seen where there is a plant room found on the roof. Figure 2.8 shows that there have also been instances of RAAC being installed on a pitched roof.

Figure 2.7 - Flat roof installation of RAAC

Figure 2.8 - Pitched roof installation of RAAC (page 19, 'Autoclaved Aerated Concrete Roof & Floor Units Handbook 2', Aerated Concrete Ltd, October 1977)



2.22. RAAC can also be found in facades. Sometimes it forms the inner leaf of a cavity construction with panels fixed back to a steel frame at regular intervals. On other occasions there is a single outer leaf made of RAAC panels stacked from ground level and spanning horizontally between steel columns. Contemporary literature shows an option to stack planks vertically; however, this has not been observed on the NHSScotland estate during the Discovery process.

2.23. Non-loadbearing partitions made of RAAC are occasionally discovered, however many examples will have been removed during building refurbishments.

How RAAC works

Roof planks

2.24. RAAC planks are normally supported at either end by an underlying primary frame and are discontinuous at these points. Structural Engineers call this a simply supported structure, which is a common architype.

2.25. When the planks are loaded, they begin to bend in the middle with the top surface becoming squashed, and therefore experiencing compressive stress, and the bottom surface becoming stretched, and therefore experiencing tensile stress. Like ordinary concrete, AAC is stronger in compression than tension and for this reason steel reinforcing bars are placed longitudinally into the bottom of each slab.

2.26. Tensile stresses are transferred from the AAC into the reinforcement via the effect of friction at the interface between materials. This is known as bond stress. The magnitude of bond stress is limited by the smoothness of the cementitious-latex coating applied to the reinforcement to protect it from corrosion. If the tensile load becomes too large the bond breaks down and slippage occurs between the AAC and reinforcement. This manifests in the form of excess deflection in the plank and associated cracking on the plank soffit.

2.27. To prevent this from occurring, transverse bars are welded to the tensile reinforcement to anchor them in place. This is especially important in the end zone where the anchorage stresses are highest. Distress or defects that diminish the effectiveness of the transverse bars are therefore important, although the onset of failure is usually ductile due to the deflection progressively increasing (Refer to Figure 2.9 and Figure 2.10 below). A ductile failure is a type of failure seen in malleable materials and is characterised by extensive plastic deformation. This usually occurs prior to the actual failure of the material. Ductile materials deform plastically, slowing the fracture process and allowing more time to correct problems. They are also more forgiving, and any error in the design process does not result in catastrophic failure.

Figure 2.9 - Reinforcement recovered from RAAC plank (page 6, 'IP 10/96 - Reinforced Autoclaved Aerated concrete planks designed before 1980', BRE, December 1996)

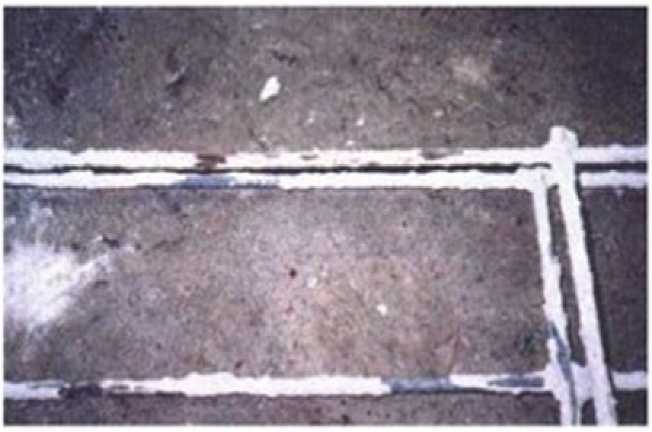
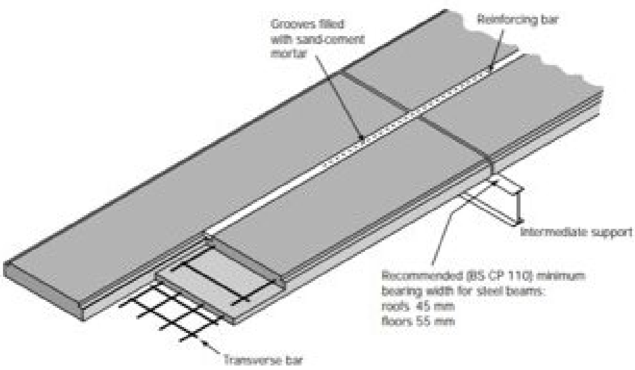


Figure 2.10 - Typical configuration of RAAC reinforcement (page 1, 'IP 10/96 - Reinforced Autoclaved Aerated concrete planks designed before 1980', BRE, December 1996)



2.28. While bending is maximal in the middle of a simply supported plank, shear forces are greatest at the supports. If the supports are too narrow, or if the reinforcement does not extend beyond the face of the support, full depth cracks can form quickly leading to brittle failure. Brittle failure refers to the breakage of a material due to a sudden fracture. When a brittle failure occurs, the material breaks suddenly instead. This effect is exacerbated because RAAC has no coarse aggregate, which would otherwise improve the material interlock either side of a crack.

2.29. Distress or defects in the vicinity of the bearings are more important than within the body of the material because failure tends to be brittle rather than ductile.

2.30. That said, the original designers did attempt to improve the robustness of RAAC construction by inserting continuity reinforcement into grooves located in the joints between planks. These were intended to pass over the supports and tie planks together. The joints were then filled with sand/ cement mortar. It is not clear how successful this was as the bond around the bars was unlikely to be well formed.

2.31. The infill mortar was also intended to bond planks together so that the roof would function as a horizontal diaphragm capable of transferring horizontal (lateral) load through the structure and into the vertical stability elements, for example steel bracing or core walls. It is assumed that this was successful as RAAC buildings are not known for being laterally unstable, although adjacent planks are known to behave independently of one another. The presence of systemic cracks between the mortar and RAAC planks would suggest that the ability of the structure to behave as a diaphragm has been diminished and its capacity should be carefully assessed.

2.32. RAAC planks are lightweight and therefore straps and clips were used to provide a positive connection to the primary structure, which were intended to resist wind uplift. Examples can be seen in the contemporary details shown in figures 2.15 - 2.25. The absence of such straps and clips to provide resistance to uplift should also be carefully assessed, especially if roof finishes were to be reduced in weight. The parts of the building considered most at risk of uplift are at the edges and corners of the building where wind loads are highest.

Cladding

2.33. The most common form of cladding observed is formed of horizontal planks stacked from ground level and tied back to a primary steel structure at either side.

2.34. The planks span horizontally between vertical supports, with maximal bending at mid span, using the same mechanism as the roof planks, albeit the most important loading is applied laterally by the wind. Since the wind can apply both positive and negative pressure, two layers of reinforcement are present; one in either face. Figure 2.15 below shows an example of a load and span table used for determining RAAC wall unit thicknesses.

Figure 2.11 - Thickness of RAAC wall units, given load and span (page 11, 'Autoclaved Aerated Concrete Wall & Partition Units Handbook 1', Aerated Concrete Ltd, September 1977)

Unit thickness mm	Unit length (c/c supports) mm 2 400	3 000	3 600	4 200	4 800	5 400	6 000
	Permissible wind loads kN/m²						
125	2.00	1.50	1.00				
150	2.50	2.25	1.75	1.50	1.25	1.00	
175	2.75	2.50	2.00	1.75	1.50	1.25	1.25
200	3.25	2.75	2.25	1.75	1.50	1.50	1.50
225	3.75	3.25	2.75	2.00	1.75	1.75	1.50
250	4.25	3.50	3.00	2.25	2.00	1.75	1.75

2.35. Two distinct types of horizontal cladding panel have been observed in contemporary literature, namely Siporex and Durox. The former is characterised by flat bearing surfaces, while the latter has a tongue and groove arrangement.

2.36. The tongue and groove detail has an advantage over the alternative because it provides a mechanism for sharing load between planks. This is beneficial if a plank is cut or damaged. Without the tongue and groove, friction is the only means of load transfer. This implies that defects near the top of a wall may be more important than defects near the bottom, where frictional forces will be greater.

2.37. It follows that observations related to the location of distress and the type of planks that have been used are important. It is also important to note whether planks have moved relative to each other. Relative horizontal displacement could indicate an absence of friction or a cracked tongue. Relative vertical displacement, due to settlement of the support, could suggest that the tongue and groove have become disengaged or more importantly flat surfaces are no longer in contact and cannot generate friction.

2.38. Lack of verticality, in the form of bulges or leans, would also be important observations as they are likely indicative of ties at the supports being compromised.

2.39. Where RAAC cladding has been observed externally on the NHSScotland estate there has been a paint coating applied to the external surface, which is assumed to provide an additional layer of protection against water penetration. Since RAAC is porous the integrity of the coating is important, as is the integrity of the latex coating applied to the reinforcement.

2.40. No information is provided about cladding in IStructE or BRE guidance documents therefore a Structural Engineer should use their professional engineering knowledge and judgement to determine the integrity of cladding panels. Figure 2.12 and Figure 2.13 below show examples of RAAC cladding.

Figure 2.12 - External RAAC cladding panels

Figure 2.13 - Internal view of RAAC cladding panel

Non-loadbearing partitions

2.41. Non-loadbearing partitions made of RAAC are not common. This is likely because most buildings containing RAAC date to the 1960s and 1970s and will have been refurbished several times since then. When this happened floor plates would have been reconfigured and the RAAC partitions would have been replaced with modern alternatives. Nevertheless, examples have been found amongst brick, block and metal stud partitions, sometimes within the same length of wall. This suggests that there has been a partial rather than full refurbishment.

2.42. RAAC partitions are essentially full height structures that span vertically from floor level to the soffit above. They are restrained at the head by a metal channel fixed to the slab soffit. It is essential that the toes of the channel are long enough to accommodate deflection of the floor slabs. To facilitate their installation after the building was constructed, RAAC partitions were made slightly short and are therefore supported at the base by timber packers and dry pack. Lateral support is provided by the floor screed cast either side of the partition. For this reason, removal of the floor screed may have structural implications.

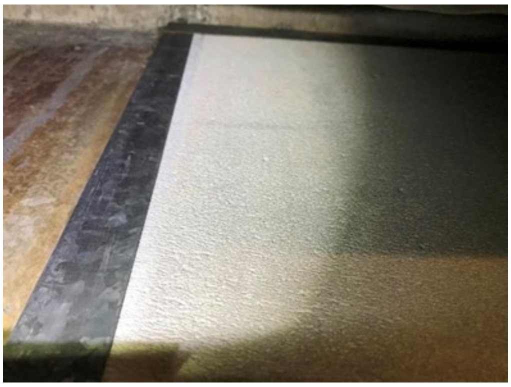
2.43. Plank edges were manufactured square with the gaps between planks filled with mortar, although long runs of wall (> 6m) were jointed to accommodate movement. At these locations edge tracks were normally installed and at corners 6mm dowels were used to pin units together.

2.44. By convention 75mm thick planks were made up to 2.75m high and 100mm thick planks were made up to 3.75m high, with those more than 3m having two layers of reinforcement.

2.45. Self-evidently partitions should have been installed plumb and openings large enough to compromise their ability to span vertically should be avoided.

2.46. No information is provided about non-loadbearing partitions in IStructE or BRE guidance documents therefore a Structural Engineer should use their professional engineering knowledge and judgement to determine the integrity of non-loadbearing partitions. Figure 2.14 below shows an example of a RAAC non-loadbearing partition looking at the vertical Face of the partition.

Figure 2.14 - Non-loadbearing RAAC partition



Contemporary details

2.47. The details shown in Figure 2.15 to Figure 2.28 below have been taken from contemporary literature published by Aerated Concrete Ltd and Siporex in the 1970’s and show roof details, cladding, details and non-loadbearing partition details. They show how original designers intended RAAC planks to be manufactured and installed. Significant deviations from these details are worth investigating as they could suggest an unusual load-path that needs to be understood, or the presence of latent defects, dating to the original construction.

Roof details

Figure 2.15 - Roof units anchored with Sheffield clips (page 10, 'Autoclaved Aerated Concrete Roof and Floor Units Handbook 2', Aerated Concrete Ltd, October 1977)

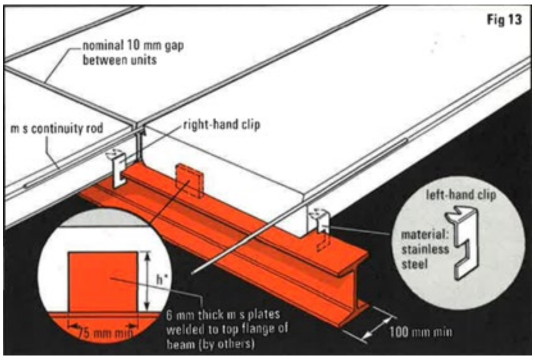


Figure 2.16 - Roof units tied to cast-in stirrups (page 11, 'Autoclaved Aerated Concrete Roof and Floor Units Handbook 2', Aerated Concrete Ltd, October 1977)

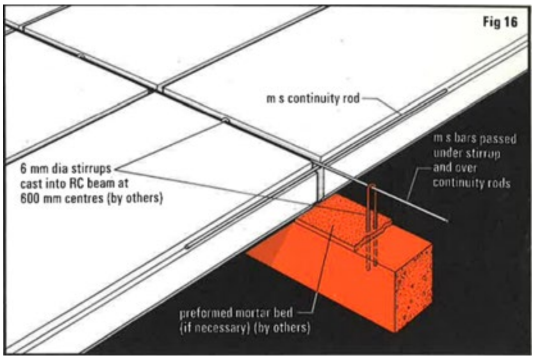


Figure 2.17 - Edge fixing for severe uplift conditions (page 10, 'Autoclaved Aerated Concrete Roof and Floor Units Handbook 2', Aerated Concrete Ltd, October 1977)

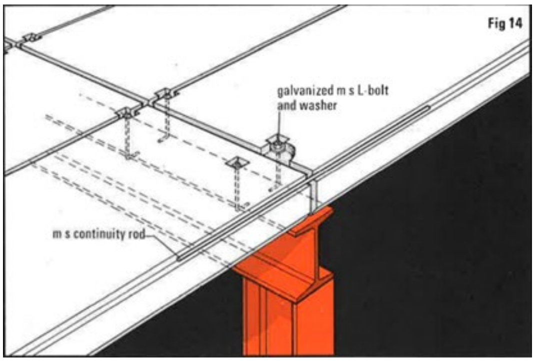


Figure 2.18 - Roof units strapped to timber beam (page 11, 'Autoclaved Aerated Concrete Roof and Floor Units Handbook 2', Aerated Concrete Ltd, October 1977)

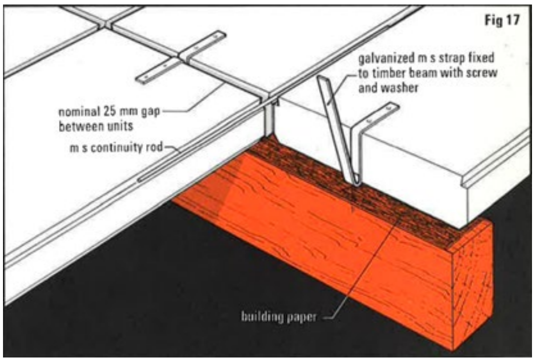


Figure 2.19 - Roof units strapped to RSJ (page 10, 'Autoclaved Aerated Concrete Roof and Floor Units Handbook 2', Aerated Concrete Ltd, October 1977)

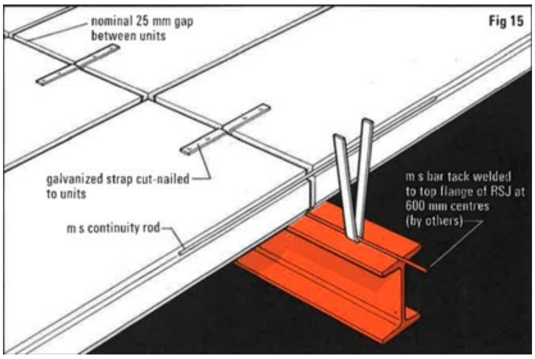


Figure 2.20 - Roof units strapped to cavity ties (page 11, 'Autoclaved Aerated Concrete Roof and Floor Units Handbook 2', Aerated Concrete Ltd, October 1977)

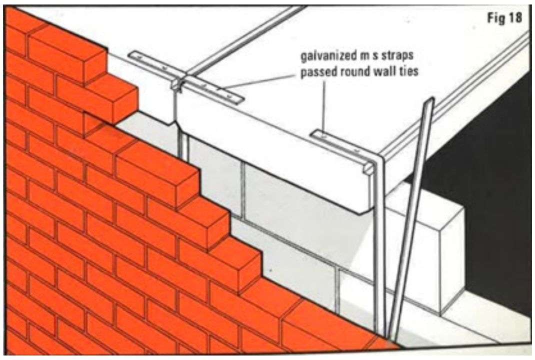


Figure 2.21 - Openings and holes up to 600mm wide (page 9, 'Autoclaved Aerated Concrete Roof and Floor Units Handbook 2', Aerated Concrete Ltd, October 1977)

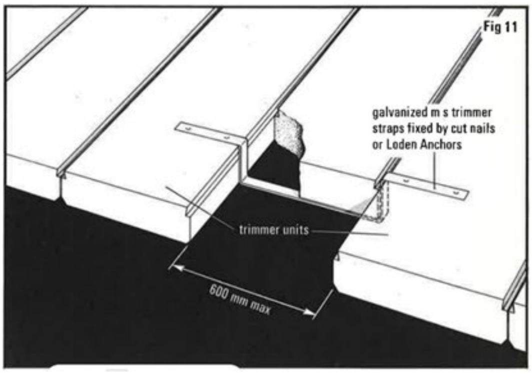


Figure 2.22 - Openings and holes up to 1200mm wide (page 9, ‘Autoclaved Aerated Concrete Roof and Floor Units Handbook 2’, Aerated Concrete Ltd, October 1977)

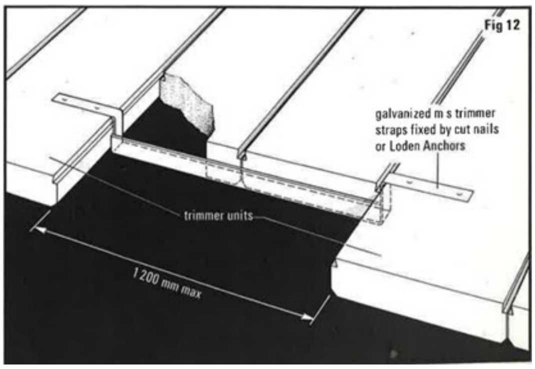
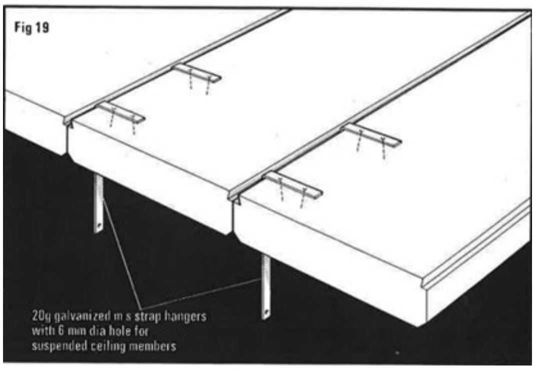


Figure 2.23 - Straps to support suspended ceiling for RAAC panels (page 12, ‘Autoclaved Aerated Concrete Roof and Floor Units Handbook 2’, Aerated Concrete Ltd, October 1977)



Cladding details

Figure 2.24 - Siporex and Durox horizontal wall units (page 4, ‘Autoclaved Aerated Concrete Wall and Partition Units Handbook 1’, Aerated Concrete Ltd, September 1977)

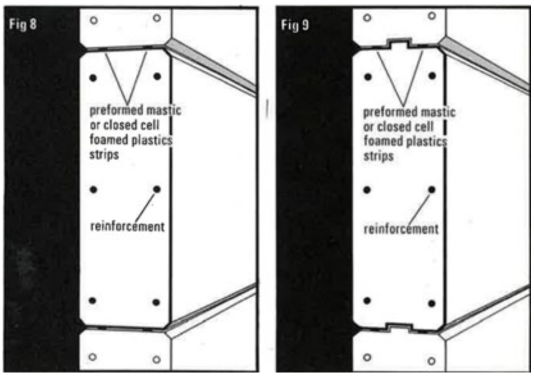


Figure 2.25 - Horizontal unit; window support and corner fixings (page 18, ‘Autoclaved Aerated Concrete Wall and Partition Units Handbook 1’, Aerated Concrete Ltd, September 1977)

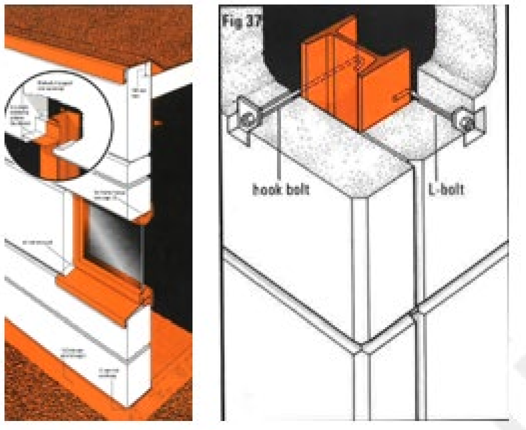


Figure 2.26 - Steel frame horizontal unit fixing (page 18, ‘Autoclaved Aerated Concrete Wall and Partition Units Handbook 1’, Aerated Concrete Ltd, September 1977)

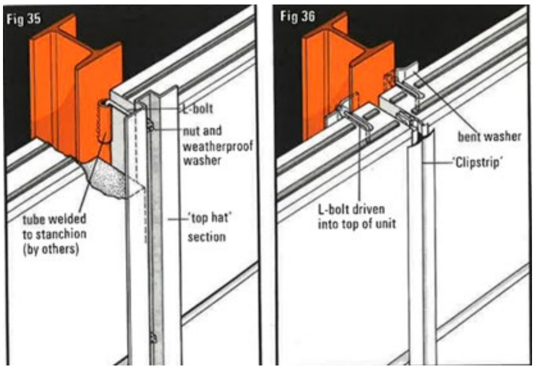
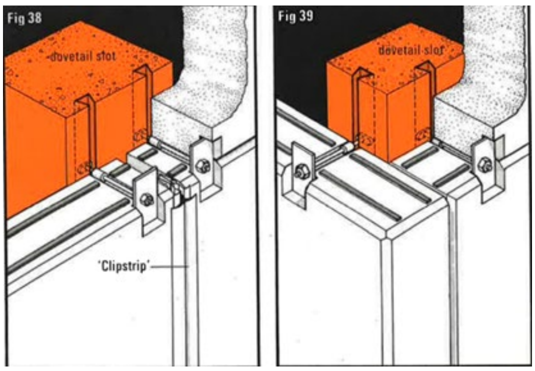
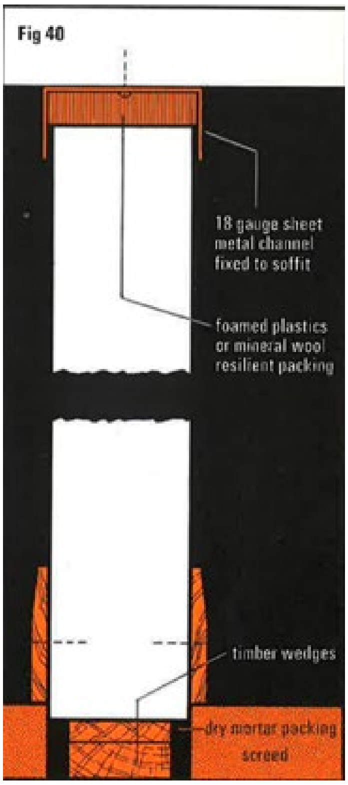


Figure 2.27 - Concrete frame horizontal unit fixings (page 18, ‘Autoclaved Aerated Concrete Wall and Partition Units Handbook 1’, Aerated Concrete Ltd, September 1977)



Non-loadbearing partitions

Figure 2.28 - Non-loadbearing partition (page 19, ‘Autoclaved Aerated Concrete Wall and Partition Units Handbook 1’, Aerated Concrete Ltd, September 1977)



3. Risk factors

3.1. To make an assessment on whether an existing structure is safe, it is important to understand how the designer intended it to behave and whether there are any factors present that either interfere with the intended behaviour or create the conditions for future interference. The following chapter discusses some of the more common factors and how they might be appraised.

End bearing

3.2. Pre-cast planks are supported at both ends by either a beam or a wall. The width of the support, known as the bearing, is important because an accumulation of manufacturing and installation tolerances, or thermal movements, could result in the intended bearing being narrower than intended. It could also mean that reinforcing bars may not extend over the bearing.

3.3. A narrow bearing has the effect of concentrating load over a small area, which leads to locally high stress. In the absence of adequate reinforcement, this could lead to a brittle failure. Brittle failure, as implied by the name, is not preceded by deformation and can happen quickly, albeit there is usually an event that triggers it.

3.4. It is for this reason that maintaining the integrity of bearings is a key objective of building maintenance. They should be kept dry and free from distress. Figure 3.1 below shows an example of an end bearing showing signs of distress.

Figure 3.1 - Distressed end bearing

3.5. Contemporary design documents suggest that the minimum bearing width was intended to be 45mm for roofs and 60mm for floors, however current guidance requires that 75mm be provided. It is understood that 75mm is intended to include the minimum bearing plus an allowance for tolerance. It is thus a nominal figure.

3.6. That said, assuming the guidance is intended to encompass both floors and roofs, there is an arithmetic difference between the tolerance when applied to each such as floors would encompass a tolerance of 15mm (75-60) and roofs 30mm (75-45). A Structural Engineer must determine the extent of bearing they deem to be acceptable for each individual scenario.

Cracks and spalls

3.7. It is important to understand the difference between a crack and a spall, and to know why they occur.

3.8. Spalls happen when concrete breaks from the surface of a structure in a direction perpendicular to that surface. In some cases, the newly exposed surface will itself spall with the effect becoming progressive.

3.9. The three most common causes of spalling can be placed into three categories. The first two are related by water penetration and the other tends to be a form of damage.

3.10. When water persistently penetrates Autoclaved Aerated Concrete (AAC) it will migrate towards the soffit under gravity. If the volume of water penetrating from above exceeds the amount that can escape from the soffit, then a spall can start to form. This is usually preceded by staining. It follows that an impermeable coating on the soffit, such as an emulsion paint, is likely to make spalls worse than they would otherwise be.

3.11. A more aggressive form of spalling occurs when water penetration causes corrosion of embedded reinforcing bars. When steel corrodes the resulting rust expands to become many times thicker than the parent steel. This places a great deal of pressure on the surrounding concrete. Since the primary reinforcing bars are placed into the bottom of the AAC, expansive corrosion results in a spall on the soffit.

3.12. A third form of spalling is caused by accidental damage, for example, cutting a large diameter hole from above can cause the soffit of a Reinforced Aerated Autoclaved Concrete (RAAC) plank to spall, especially if a percussive drill is used. Another example would be the use of an inappropriate fixing to support a load from the underside of a plank, which subsequently suffers a pull-out failure.

3.13. Spalls can be problematic because they reduce the cover to the reinforcement and diminish the bond between the steel reinforcement and AAC, such that load transfer cannot occur. Occasionally, if corrosion has occurred, a loss of material from the reinforcing bars can also become important.

3.14. While different types of cracks exist, most are caused by excess tension, which can result from a variety of effects, for example, bending stress, thermal expansion, or drying shrinkage. Tension cracks imply movement has occurred perpendicular to the internal surfaces of the crack.

3.15. Shear cracks occur when surfaces slip past each other, but they are less common and tend to be characterised by uneven contact surfaces.

3.16. Cracks can be important because they could indicate that the capacity of the structure is insufficient, though this is not always the case. Another important factor is whether a crack will allow moisture to penetrate and cause expansive corrosion.

3.17. In the case of both cracks and spalls, their significance is ultimately governed by how they influence the structural load path. Both kinds of distress, when found near a support, are potentially important, while remote from supports they may be of less concern.

3.18. Another relevant factor is whether distress is live or dormant. If, for example, the underlying cause of a crack or spall no longer exists, and the damage was caused by a singular event, then the crack might be dormant and will not become worse. Conversely, if a crack were caused by chronic moisture penetration, then the distress may become worse until an intervention is made.

3.19. Thus, knowing both the location and cause of distress are important to decide whether it is of material importance to the structural load path. Figure 3.2 below shows an example of a type of distress known as a spall.

Figure 3.2 - Soffit spall

Low cover

3.20. Some planks were manufactured with the reinforcement placed too close to the outside of the cross section (see Figure 3.3). This issue is known as having low cover and it tends to manifest in one of two ways. In some instances, the reinforcement is directly visible and in others there is a distinct discolouration of the soffit (refer to Figure 3.3) corresponding to the location of the reinforcement. The latter phenomenon results from a differential rate of drying as the AAC cures.

Figure 3.3 - Soffit discolouration indicating low cover

3.21. There are several reasons why low cover could be important. The first is reduced fire resistance, because the reinforcing bars have less protection from heat. This is not necessarily problematic, because RAAC is usually found in roofs, which ordinarily do not need to be protected from fire, albeit this is not always the case. Where doubt exists the advice of a Fire Engineer or Architect should be sought.

3.22. The second reason relates to the durability of the concrete. Though AAC is more porous than standard concrete mixes, low cover further reduces the amount of protection afforded to the reinforcing bars and increases their susceptibility to the causes of corrosion. That said, tensile reinforcement is found at the internal (underside) face of RAAC roof planks, which means that to become wet the roof finishes would need to have failed, and water must have penetrated through the full depth of the cross section. If water penetration is prevented, this cannot happen. An alternative, sometimes overlooked but equally risky, mechanism could occur if the RAAC were in a room where the air was moist, for example in a laundry or shower area.

3.23. Another reason low cover could be detrimental is the potential for an impaired or reduced bond between reinforcement and AAC. This would reduce the load-bearing capacity of a RAAC plank by allowing slippage of the reinforcement to occur. This is likely to manifest itself initially in the form of excess deflection and cracking on the soffit. If these symptoms are not present, then it may be inferred that, although less than intended, the plank capacity has nevertheless proved sufficient to support the loads applied thus far. Therefore, providing the load is not increased, the capacity should continue to be sufficient.

Deflection

3.24. All structures deflect when subjected to load, however if deflection becomes too pronounced it can point towards an underlying structural problem and it can also create an adverse feedback loop, where the underlying issue becomes progressively worse.

3.25. This effect is most often found in flat roofs, because excess deflection causes rainwater to pond at mid-span, this in turn leads to additional load, which increases deflection.

3.26. Standing water on the roof is also unhelpful because it will find flaws in the roof covering and penetrate the structure. Not only does a saturated structure weigh more it may also lead to other forms of distress, which are discussed in other sections of this document.

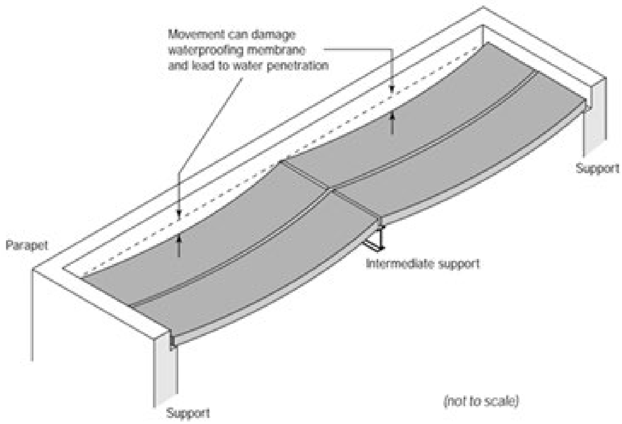
3.27. Notwithstanding the direct effect of adverse feedback loops, excess deflection could suggest that the bond between tensile reinforcement and AAC has diminished. In such circumstances anchorage of the longitudinal reinforcement via transverse reinforcement, located at the end of a plank, is crucial. It is for this reason that the absence of transverse bars, or distress to them, is considered structurally significant.

3.28. Excess deflection can be identified either by the absolute deflection of a plank or local deflection relative to its neighbours, an example of which is shown in Figure 3.4. An overall deflection of L/100 (length of span divided by 100) is considered the upper limit and a differential deflection greater than 20mm is potentially problematic.

Figure 3.4 - Differential deflection between RAAC planks

3.29. Where excess deflection occurs next to static elements of the structure, for instance, adjacent to a parapet of gable wall, the roof finishes are vulnerable to splits and tears, which have the potential for water to penetrate (refer to Figure 3.5 below). Another example would be above primary beams that provide support to deflected planks.

Figure 3.5 - Risk to finishes from deflection (page 3, 'IP 10/96 - Reinforced Autoclaved Aerated concrete planks designed before 1980', Building Research Establishment (BRE), December 1996)



Water penetration

3.30. AAC is a porous material and therefore water penetration is more important than with other forms of concrete. There are several implications to this. Firstly, the embedded reinforcement is more vulnerable to corrosion. Secondly, it is believed that saturated AAC can soften over time and become less stiff and strong. Thirdly, saturated AAC has an increased self-weight, which reduces its ability to support imposed loads.

3.31. For these reasons, it is important to maintain roof and wall finishes to minimise the opportunity for water to penetrate. Figure 3.6 and Figure 3.7 below show common issues in relation to water.

Figure 3.6 - Chronic water penetration to slab soffit

Figure 3.7 - Water ponding on roof

Alterations to roof and floor planks

3.32. Alterations to an existing structure are important when they interfere with the intended structural load paths. The most common reason for this is when new service penetrations are required, although this is not the only reason. During installation planks were sometimes cut short to fit on a ledger angle so that a change in roof level can be formed. Similarly, planks were sometimes trimmed in width to fit a non-standard gap between a wall and the adjacent roof structure.

3.33. The first issue, associated with the creation of new service penetrations, is that too many longitudinal reinforcing bars may be cut, such that the residual cross-section cannot resist bending forces around the opening. The second is the potential for cutting the transverse reinforcement, which means that the longitudinal bars may not be adequately anchored. This can reduce the capacity of a plank significantly. These issues can be expected to happen in a ductile fashion and will normally give some warning in the form of cracking and often excess deflection.

3.34. A third issue may arise if a penetration is too close to the support, as this may cause shear failure at the plank end due to there being inadequate reinforcement at the bearing. This is an important form of failure, as it may be brittle and could occur rapidly. For this reason, penetrations near the end of a plank must be considered carefully.

3.35. Alterations conducted during or after installation of planks are commonly observed to have been carried out in a rough manner causing damage to the residual cross section. Self-evidently this will influence the plank capacity and therefore damage must be assessed like other cracks, based on how they affect the load path.

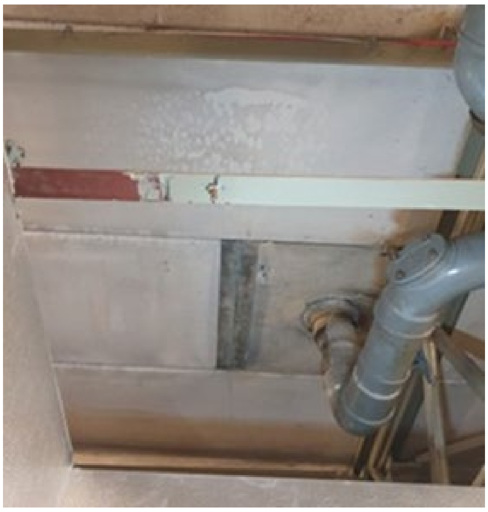
3.36. An effective way to tell whether a service penetration was made before or after a plank was installed is to look for evidence of folded plate straps at the free end of the cut plank. These were commonly placed into joints between planks and used to transfer load laterally to planks either side of an opening. This is important for three reasons. Firstly, adjacent planks must carry more load. Secondly, the straps were often narrow, providing a bearing for the cut plank less than 75mm wide. Thirdly, although installed at the time, the suspended plank may have been site cut, rather than being manufactured to be the correct length. Figure 3.8 to Figure 3.11 show common issues found around penetrations and where panels have been cut.

Figure 3.8 - Service penetration in the end of RAAC plank

Figure 3.9 - Edge of RAAC plank site cut to fit outturn dimension

Figure 3.10 - RAAC plank cut short to sit on shelf angle has cracked bearing

Figure 3.11 - RAAC plank cut short and supported on folded strap



Over-loading

3.37. There are several ways in which roof structures can be overloaded, however some of them are more obvious than others. For example, it is common for buildings to need new or additional plant, and an unoccupied area of roof may appear like a good location. Similarly, new services, and sometimes ceilings, are often added to the soffit of a structure. Indeed, there are examples of suspended ceilings installed below existing plasterboard ceilings to conceal new service installations from view. Self-evidently such arrangements add new load to an existing roof and have the potential to exceed the existing capacity.

3.38. Over-loading can also result from excess roof deflection because it creates the conditions for ponding of water, or the accumulation of snow, especially if the deflected shape exceeds the roof fall. This can become a self-reinforcing effect if the additional weight of water causes further deflection, which in turn causes increased ponding.

3.39. A less obvious, but related, effect can occur if water penetrates the roof finishes and becomes trapped in AAC’s pores. This will cause the weight of the associated RAAC planks to be greater than assumed. Several mechanisms that promote water penetration have been suggested in previous sections of this document.

3.40. Nevertheless, for the reasons outlined above, care must be taken to ensure that imposed loads are not intentionally increased, due to modern fit-out requirements, or unwittingly due to the condition of the existing structure and fabric. Maintenance of a dry structure is important. Figure 3.12 below shows an example of a soffit crack caused by plant loading.

Figure 3.12 - Soffit cracks caused by plant loading above

Moisture movement

3.41. As with conventional concrete, moisture is lost from AAC as it dries, and this is responsible for the occurrence of shrinkage. Swelling can also occur if the AAC becomes wet, albeit the magnitude of swelling is considered smaller.

3.42. Since RAAC planks tends to be reinforced more heavily on the soffit than they are near the top, shrinkage and swelling tend to happen differentially across the section. In theory this has the potential to induce an upward deflection and local cracking. It may therefore be suggested that this could eventually cause fatigue.

3.43. A possible mitigation to this effect results from the fact that the induced deflection is predominantly upwards, which means that the weight of the plank must be overcome before this can occur. This in turn implies the need for a significant moisture movement, and by inference, significant fluctuations in environmental conditions.

3.44. For this reason, maintaining a dry environment is crucial, which emphasises the importance of keeping roof finishes, gutters and rainwater pipes in good condition and free from debris/ blockages.

Thermal effects

3.45. The coefficient of thermal expansion for AAC is often taken to be $8x10^{-6}\ {}^{o}C^{-1}$, which is lower than standard concrete ($10x10^{-6}\ {}^{o}C^{-1}$) and lower than steel reinforcement ($12x10^{-6}\ {}^{o}C^{-1}$). This means that ambient temperature changes can introduce internal stresses, due to differential expansion and contraction, of the reinforcement relative to the AAC.

3.46. This is not a straightforward mechanism to understand, because planks do not react to ambient temperature change instantaneously. Rather, a temperature gradient will initially form across the section, which will become uniform over time, albeit a subsequent change in ambient temperature, such as occurs between day and night, may reverse this process.

3.47. Thus, in roof planks, the potential exists for a cyclical process of upward and downward deflections that could eventually lead to fatigue cracks forming.

3.48. It is for this reason that the make-up of roof finishes is important. A darker covering will absorb more daylight than a lighter one and a well-insulated roof will take longer to warm and cool. It follows that changing either of these factors may either reduce or worsen the potential of thermally induced cracks.

Creep

3.49. Creep occurs when the strain in a material increases over time, while the stress to which it is subject remains constant. In practical terms it may be thought of as time-dependant deflection caused by a long-term reduction in material stiffness.

3.50. All concrete behaves this way; however, AAC is especially vulnerable when it is wet. Indeed, its elastic modulus, or ‘stiffness’ has been estimated to reduce by 20% if it becomes saturated. The rate of creep is also known to increase if the magnitude of stress is increased.

3.51. In RAAC planks there are several locations that are influential in relation to creep. Compressive stress at the centre of a plank, which is generated by flexure (the action of bending or curving) and in the reinforcement, anchorage zones via the transverse bars.

3.52. Notwithstanding the underlying mechanisms and influences relating to creep, the potential effects of additional long-term deflections are like elastic deflections, which are discussed in previous sections of this report.

4. Risk assessment

Risk categories

Floor and roof plank condition

4.1. The tables shown below in Figure 4.1 are extracted from the Institution of Structural Engineers (IStructE) Reinforced Aerated Autoclaved Concrete (RAAC) Manual. They are useful because they provide a consistent basis for evaluating the risk associated with floor and roof panels made of RAAC. They also communicate something about the condition of the structure, and whether action should be taken, to the non-technical reader.

4.2. Figure 4.1 relates to the overall condition of the structure. They deal with distress; the importance of its location; and its relation to observed deflections. While not explicitly stated, the proximity of distress to the support is considered important, because associated failure could be brittle and sudden. Similarly, higher deflection is rated more onerously because it implies the reinforcement bond may be distressed.

4.3. The difference between the tables reflects the absence or presence of water, as this has the potential to exacerbate existing issues, or create the conditions for future distress. Thus, the difference is intended to reflect chronic water penetration rather than temporary wetting or minor dampness at the concrete surface.

4.4. While both tables are based on sound structural logic, which considers potential failure mechanisms, they both provide a simplified model that can lack nuance. For instance, they have nothing to say about the type of distress that has been observed and what relevance that may have.

4.5. The importance of this becomes evident by considering the potential implications of cracks caused by flexural stress, those caused by water penetration, and those caused by accidental damage, perhaps due to impact.

4.6. In the case of accidental damage, providing the structure is currently stable and serviceable, its integrity may well be secure if the event that caused it was an isolated incident. Of course, this assumes that the RAAC location does not make it inherently susceptible to future damage.

4.7. Similarly, if the observed distress is due to water penetration, the causes of which have been addressed, there is no reason for the integrity of the relevant plank to become worse, providing it is currently stable and serviceable.

4.8. Distress due to flexure of a plank may be more difficult to judge because it could be caused by loads that are excessive, or it could be the result of cyclical drivers such as thermal effects, or it could be a combination of such factors. Nevertheless, it is important to understand whether the observed distress is dormant and if so, what might cause it to become live.

4.9. Ongoing inspection and monitoring are the mechanisms by which nuances, such as those noted above, are considered. This is why the risk categories used in Figure 4.1 correspond to specific requirements.

4.10. The green category implies the need for ongoing triennial inspection, while the 'amber' category implies the need for ongoing annual inspections. The 'red' category means that action should be taken, albeit this does not necessarily imply strengthening.

4.11. If monitoring were to identify an adverse trend, inspections should become more frequent, especially if a change to the risk category were necessary. Indeed, if the category changed from 'amber' to 'red', emergency action may become necessary. An experienced Structural Engineer should be consulted at the point an adverse trend is established.

Figure 4.1 - Panel condition matrices (Tables 3 and 4 IStructE Manual)

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

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

Bearing condition

4.12. The table below (see Figure 4.2), which deals specifically with support bearings, is also extracted from the IStructE RAAC Manual. It introduces a new category, 'red critical' that is intended to convey the need for immediate intervention because of the potential for brittle failure. This is discussed further in section 3 of this document.

Figure 4.2 - End bearing matrix (table 2 IStructE RAAC Manual)

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

4.13. That said, as noted in section 2, the requirement for bearings to be 75mm wide is based on a minimum bearing plus a tolerance. Different values for roof and floor planks are not provided, as is found in contemporary design documents. The new requirement seems to imply that planks that are compatible with the original design requirements, and may have survived for 50 years, are no longer acceptable. Indeed, the current IStructE Guidance states that:

‘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’.

4.14. Given the stated reason for introducing a 75mm requirement is to provide tolerance for inaccuracies in the manufacturing and erection process, providing the minimum value is demonstrated to have been achieved, and the correct placement of reinforcement has been verified, the tolerance could be said to have fulfilled its purpose. The guidance does not currently address this point and although the document states the required 75mm bearing width is a ‘minimum’, it is the responsibility of a qualified Structural Engineer to determine the adequacy of the end bearing condition.

4.15. When it is not clear whether an existing bearing is greater than 75mm, but there is good access to the slab soffit, it is likely simpler to augment the bearing than it is to intrusively investigate its make-up. This may be done by introducing ledgers, as shown in Figure 4.3 and Figure 4.4.

Figure 4.3 - Augmented bearing to steel support

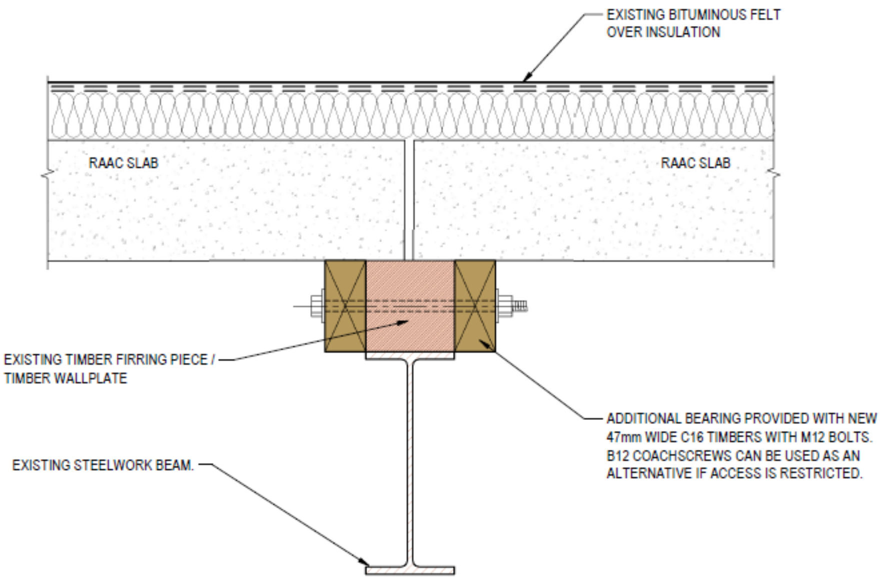
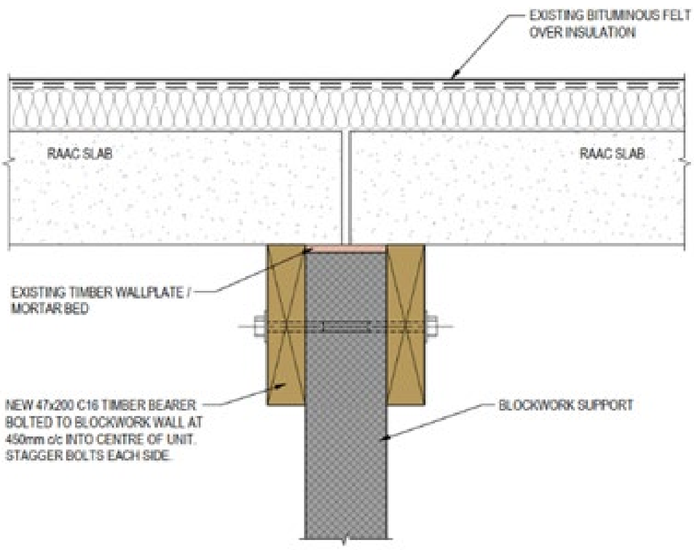


Figure 4.4 - Augmented bearing to block wall support



4.16. Alternatively, if access to the soffit is not clear, then intrusive measurements from above, encompassing a representative number of locations, becomes more reasonable. The question then arises as to what should be done if the measured bearing is found to be less than 75mm.

4.17. A strict reading of the guidance would suggest that the bearing ought to be enhanced, however this may have serious implications for a live hospital, especially if found in a critical service location. In certain instances, a more nuanced assessment, considering factors included but not limited to those listed below, in combination with a mitigation strategy, may prove viable. An experienced and competent Structural Engineer will make a judgement on whether end bearing require enhancement based on some, or all, of the following considerations:

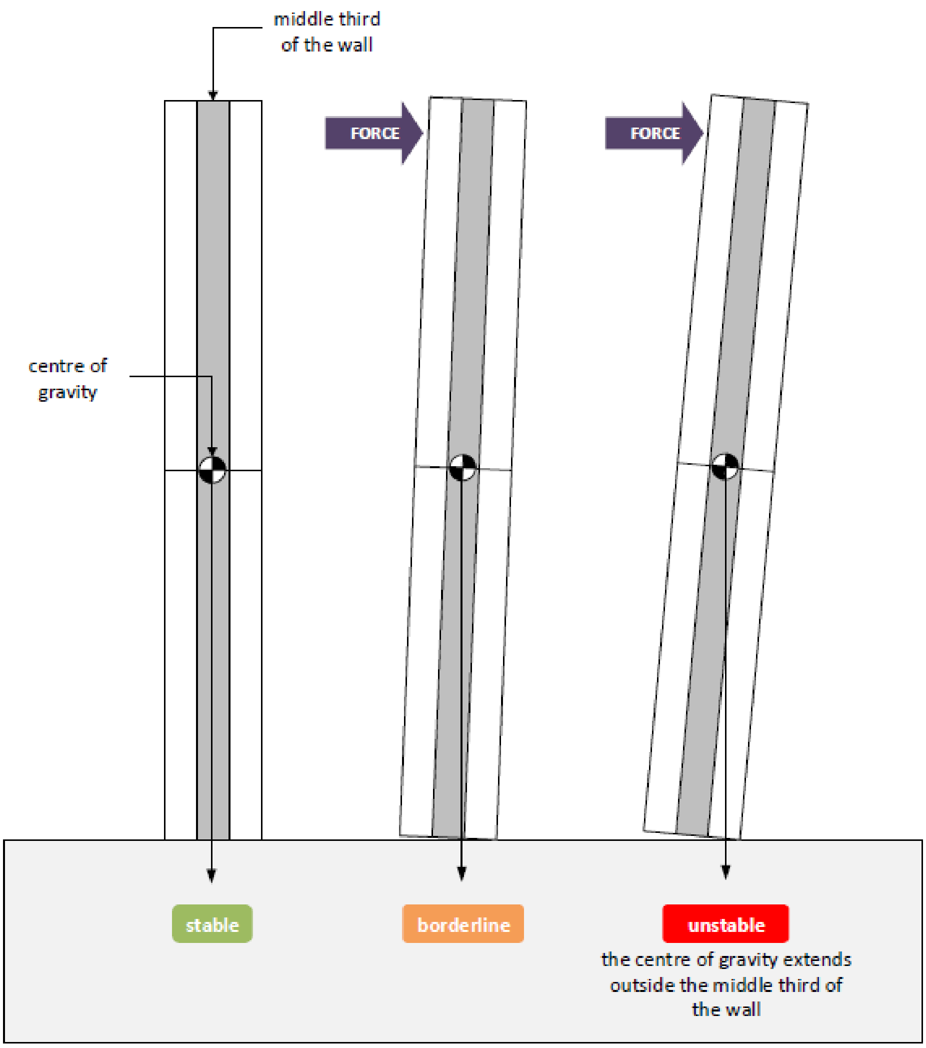
- has the minimum bearing stated in contemporary design documents been achieved or exceeded?
- are there longitudinal bars extending beyond the face of the support?
- are there transverse bars in the plank end zone?
- are the joints between planks properly filled with grout and is there evidence of cracking or separation in the joint?
- are there reinforcing bars placed in the joints between planks that extend over the support?
- are there cracks or spalls within 500mm of the support on either the top or bottom surface?
- have post installation openings modified the plank end?
- is there evidence of chronic water penetration?
- has the plank exceeded normal deflection limits?
- are the top and bottom surfaces of the Autoclaved Aerated Concrete (AAC) solid or are they soft or friable?
- does the plank carry permanent loads, such as plant?
- how are services below the slab supported? Are they post fixed using drilled anchors or are they suspended from straps set into the joints between planks?
- does the distribution and number of soffit fixings have the appearance of being adequate?
- if present are the drilled soffit fixings likely to have compromised the soffit reinforcement?
- what is the condition of the roof coverings?
- what is the colour of the roof coverings and is a layer of insulation present?
- do the rainwater goods appear to be working correctly; is there evidence of standing water on the roof?
- is the occupancy below the planks likely to generate a humid internal environment?
- what is located below the planks and what is the likely consequence of failure?
- how hard would it be to remove obstructions below the soffit, to make enhancements, and what would the implications be?
- is there a suitable management and mitigation strategy in place and can it be maintained over time?

Wall planks

4.18. The ‘panel condition matrix’ and ‘support condition matrix’ contained in the IStructE guidance, and reproduced in Figure 4.1 and Figure 4.2 above, is specific to RAAC planks acting as suspended floor and roof panels. While neither is applicable to wall panels that are stacked vertically and span horizontally, similar categories may be applied to their construction. For a wall stacked from ground level the key factors are whether the wall is plumb and whether it is fully restrained. The extent to which distress is problematic depends on whether it compromises either the vertical or horizontal load paths.

4.19. An accepted rule of thumb for Structural Engineers when they assess the vertical stability of solid walls is to maintain their centre of gravity within the middle third of their thickness. It is proposed that walls out with this limit be classified as ‘red’. That said, the presence of hooks tying the planks laterally to supporting columns, mitigate this risk by enabling them to span horizontally.

Figure 4.5 - Middle third concept diagram



4.20. A horizontal penetration within a plank, or other distress, could theoretically compromise a wall’s ability to span horizontally. Contemporary design documents show that the Durox system adopted a ‘tongue and groove’ detail between planks, which would provide an alternative load path to distribute load to adjacent planks either side of an opening (see Figure 4.5).

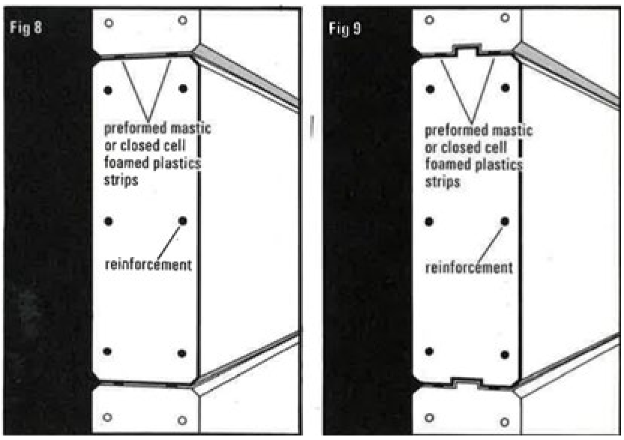
4.21. It follows that, in the presence of openings or distress, the integrity of the ‘tongue’ is important. A differential displacement between adjacent planks would indicate the ‘tongue’ had failed and any vertical separation could indicate disengagement between the ‘tongue and groove’. Observations of this nature in conjunction with large penetrations or cracks would imply a ‘red’ category. If the tongue remains intact, then ‘amber’ category would be more appropriate. Figure 4.6 shows distressed RAAC cladding panels.

4.22. Conversely, the Siporex system did not have a ‘tongue and groove’ detail and would therefore be more vulnerable to distress near the top of a wall, where there would be less weight acting on joints and therefore less friction between panels. Evidence of differential displacement between planks or vertical separation, in combination with a large penetration or cracking, would be classed in the ‘red’ category, especially near the top of a wall. In the absence of displacement or separation the ‘amber’ category may be appropriate, providing the height of wall above the penetration is sufficient to generate frictional resistance.

4.23. Where there is general evidence of weathering, in the form of minor cracking and or crazing (development of a network of fine random cracks or fissures on the surface of concrete caused by shrinkage of the surface layer), planks would be classified as ‘amber.’ That said, where there is evidence of chronic water penetration, in the form of expansive corrosion and spalling, then the issues described above are of greater importance and the ‘amber’ category would increase to ‘red.’

Figure 4.6 - Distressed cladding panels

Figure 4.7 - Siporex and Durox cladding panels



Non-loadbearing partitions

4.24. As with wall planks, the IStructE guidance does not address non-loadbearing partitions, however some of the same factors that apply to cladding are also applicable to partitions. For instance, breaching the middle-third rule (when designing a rectangular cross section, the ratio of width to depth should be no greater than 3:1 and the depth should be at least one-third the width of the section) would lead to a ‘red’ category classification.

4.25. If the means of lateral restraint has been compromised, either at the top or bottom of a partition this would also lead to a ‘red’ category classification. Examples of this would be a large service penetration at the wall head, as shown in Figure 4.8 below, or an absent floor screed at the base of the wall. Another example would be if the head track were damaged, or the down-stand legs were too short to accommodate floor deflections.

4.26. A deep spall with exposed reinforcement, or lateral cracks over the full width of a plank, would also be important, especially near to a restraint. These scenarios would also merit a ‘red’ category classification.

4.27. If the vertical joints between planks have cracked, an ‘amber’ category would be appropriate. An ‘amber’ category would also be given to partitions that carry lightweight services, albeit this could become ‘red’ if the services were especially heavy, or if there were other defects present, like cracking or spalling. Figure 4.8 and Figure 4.9 show issues with partition planks that could effect the category given to a panel.

Figure 4.8 - Alteration to an internal partition

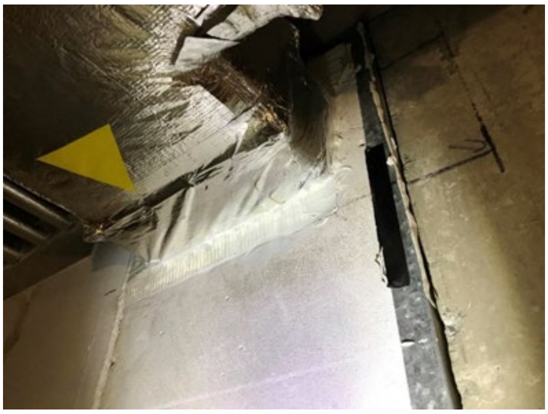


Figure 4.9 - Cracked infill joint between partitions

Minor and major distress

4.28. To correctly implement the risk category tables extracted from the IStructE RAAC guidance it is important to define what is meant by ‘major’ and ‘minor’ distress. This will always require an element of subjective judgement; however, the following definitions are offered in the guidance.

‘*Major cracking/ spalling: defined where a panel exhibits large/ deep cracks that may be accompanied by spalling and in some cases by 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*.’

4.29. The guidance also notes that:

‘*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.*’

4.30. These supplementary observations are important because they correctly identify that the importance of a crack is not necessarily defined by its size or depth. It is also important to know the underlying cause, whether it is live or dormant, whether the location is relevant to the load path, whether there are alternative load paths, whether the surrounding material is sound and so forth. Some additional factors relevant to this discussion are found in section 3 of this document.

4.31. Nevertheless, since nuance can exist when cracks and spalls are inspected, a Structural Engineer experienced in the appraisal of RAAC may downgrade or upgrade the status of a crack based on risk assessment of all the relevant factors.

4.32. Appendix A provides examples of defects, damage and distress of RAAC panels, classified according to tables 3 and 4 of the IStructE Manual.

Forms of occupancy

4.33. While the risk categories presented in the IStructE document are useful because they provide a consistent method of assessment, they say nothing about the consequences of failure. It is for this reason that it is helpful to consider the form of occupancy and their sensitivities in locations where RAAC is found.

4.34. It is self-evident that an external storeroom that is accessed infrequently by small numbers of staff does not pose the same level of risk as a 24-hour public entry space, or critical care ward, that is in constant use. Furthermore, if the sort of person using the space was a trained individual, for example a member of the local property and estates team, they would be more informed about how to use the space than an ordinary member of the public.

4.35. Another factor would be whether there are any hazards that result from the form of occupancy. An example of this would be one that creates a humid internal atmosphere, perhaps due to plant or equipment. A laundry or physiotherapy pool may fit this category. A more generic example would be locations where post installation holes or soffit fixings are more likely to be found, for example in a plant room.

4.36. A further consideration is the unstated assumption that the risk posed by RAAC, which may never manifest, exceeds that posed to patients by closing, even temporarily, healthcare facilities. Whilst a Structural Engineer is not qualified to quantify healthcare risks it is a relevant factor for NHS boards to consider in their own evaluation of risk.

Forms of mitigation

4.37. Though a building may contain RAAC planks assigned to different categories, mitigations can be used to manage the associated risks. Using this approach the overall risk in a building may be less than that posed by individual planks without the benefit of mitigation.

4.38. The intention of any mitigation measure is to prevent existing distress from becoming worse, by controlling the loads that are supported, maintaining the systems responsible for keeping the structure dry, and re-appraising the use of the relevant spaces.

4.39. Most of these considerations are incorporated into sections 5 and 6 of this document, along with some additional factors. It is recommended that each NHS board prepares a bespoke strategy for each of their buildings that contain RAAC, based on the factors outlined.

5. Maintenance requirements

5.1. Under UK health and safety regulations, such as those covered in the Workplace health, safety and welfare. Workplace (Health, Safety and Welfare) Regulations 1992. Approved Code of Practice and guidance L24, all NHS boards should create and maintain a bespoke management and monitoring strategy for all properties containing Reinforced Aerated Autoclaved Concrete (RAAC) to ensure safety of staff and visitors. It should include plans for:

- inspection and maintenance of the building fabric enclosing RAAC
- managing the use of the space containing RAAC
- inspection and monitoring the condition of RAAC

5.2. The strategy should be a live document that is updated by the NHS board annually or when circumstances change (whichever occurs first). Some generic information was issued along with RAAC Discovery Reports and is expanded upon below.

Rainwater goods

5.3. A number of mitigation measures can be applied to the rainwater goods of a property such as:

- clean rainwater goods to ensure that they are free flowing. For example, channels gutters, inlets, hoppers and rainwater pipes
- where not present fit wire guards to rainwater inlets to prevent debris from being washed into rainwater pipes. These should be inspected and cleaned to remove blockages
- ensure that rainwater goods are free from distress and do not leak water into the building fabric. Eroded pointing in brickwork or surface staining to cladding are normally a good indicator that this is occurring
- inspect and clear the below ground surface water network to ensure that it is free flowing and does not back-up water into the rainwater pipes
- ensure that rainwater goods are correctly sized and that there are sufficient inlets to drain the roof, especially in locations that are easily obstructed or where the existing falls may be inadequate
- make sure that rainwater goods are adequately fixed and that there is no evidence of corrosion or detachment. Where necessary replace defective fixings
- where possible use asymmetric gutters with the lower edge placed furthest from the building. In the event of overflow this will help to push water away from the building
- manage vegetation within the vicinity of the building to ensure that potential blockage from leaves and twigs is avoided. This would include pruning mature trees that may overhang low-rise buildings and removing fallen leaves, especially in autumn
- bird guano can block rainwater outlets. Where this has become problematic mitigation measures should be taken in consultation with appropriate pest/ vermin control experts

Roof and wall coverings

5.4. A number of mitigation measures can be applied to the roof and wall coverings of a property such as:

- remove all vegetation from the roof surface noting where it has grown, as this may indicate locations that are not free draining. Where the cause is self-evident make alterations, as necessary, for example removing obstructions or adding drainage inlets as required
- identify and investigate excess deflections, which may be indicative of underlying structural issues, and may allow ponding to form. Also consider whether the existing falls are adequate. Action to be taken as required
- identify areas of distress that could be responsible for allowing water to penetrate the building fabric. Focus on those that could be difficult to drain, where standing water has previously been identified, and existing penetrations where seals and flashings may be compromised
- repair all splits and tears and investigate locations characterised by bubbles and softness under foot, as these may indicate latent issues that need repaired. Flaws are commonly found in the following locations:
    - areas that are most frequently trafficked such as circulation routes
    - locations where roof planks span parallel to a wall, gable or parapet
    - over beams supporting RAAC planks, especially where the planks have deflected excessively
    - beneath heavy plant placed directly on top of roof coverings
- consider whether wear to existing surfaces on circulation routes can be mitigated by adding a protective layer. The implication of any additional weight would need to be considered before doing so
- consider whether routes can be identified to avoid areas that are most vulnerable to tear. For instance, local to penetrations and where prior patch repairs have been made
- look for evidence of deterioration due to sunlight and consider solar protection, paint or chippings, albeit the latter should not be added without first considering load implications
- replace existing coverings that have exceeded their useful design life and establish a long-term plan for replacing those which are currently serviceable before they become problematic
- do not permit persistent ponding or standing water on roofs, because water is likely to find weaknesses in the finishes that allow it to migrate into the structure. If, in the short term, it is not possible to resolve the underlying issue that is causing ponding, then brush standing water into channels and gullies to keep the roof clear

Internal environment

5.5. A number of mitigation measures can be applied to the internal environment of a property such as:

- consider whether internal environmental conditions could be wet and might cause persistent dampness or condensation to form. This may be due to the use of a space or the equipment within it. For example, water heaters, steamers used for cleaning, rehab pools, showers, plantrooms etc. It could also be due to spaces being exposed or unheated
- remove impermeable coatings from the soffit of planks, for example emulsion paint, because this will trap moisture. If paint is to be used ensure that it is breathable so that moisture vapour can escape. For similar reasons, where planks are supported from the façade avoid using impermeable coatings to the supporting walls
- conduct a risk assessment of how the space beneath a roof is currently used and consider whether changes would be practical or beneficial. For instance, improving ventilation, insulation, heating, moving equipment or replacing it with modern versions that are less onerous and so on

RAAC roof and floor planks

5.6. A number of mitigation measures can be applied to RAAC roof and floor planks as follows:

- inspection of RAAC planks is expected to be conducted by a Structural Engineer experienced in the assessment of RAAC. It should include the following structural issues:
  - bearings should have a full and even support and be free from cracks, spalls, chronic water penetration, and reinforcement corrosion. It has been assumed that where the reinforcement does not extend beyond the face of the support remedial work has been conducted to extend the bearing
- where the deflection of a plank appears excessive, either relative to its neighbours or overall, take measurements for comparison with prior results. A relative deflection of 20mm or greater and an overall deflection of L/100 could be considered problematic. The magnitude and extent of deflection should be compared over time:
  - chronic moisture penetration should be diagnosed, and the underlying cause addressed. In affected areas the Autoclaved Aerated Concrete (AAC) should be tap tested, for evidence of friability, and penetrated with a knife, for evidence of softening
  - the presence of reinforcement corrosion should be investigated. Some surface corrosion is tolerable, however corrosion at depth should be addressed, especially in the presence of excess deflection. The magnitude and extent of corrosion should be compared over time
- cracks and spalls should be diagnosed and monitored over time to determine whether they are dormant or live. Remedial action should be taken if distress is already critical or if it continues to become worse
- significant penetrations, and the straps often used to support them, should be monitored for evidence of ongoing distress. Observations shall be compared to those from prior inspections. It is assumed that where remedial action was merited, based on initial inspections, this has already been carried out

- following inspection planks shall be categorised by the Structural Engineer in accordance with section 4 of this document. If a change in category is, at some future point, required then this should be brought to the attention of the NHS board so that action can be agreed
- maintenance shall include:
    - ensuring that water-resisting finishes and rainwater goods function correctly, as noted above
    - ensuring that seals around penetrations remain watertight
    - ensure that roof spaces remain appropriately ventilated

RAAC cladding panels

5.7. A number of mitigation measures can be applied to RAAC cladding panels as follows:

- inspection of RAAC facades is expected to be conducted by a Structural Engineer experienced in the assessment of RAAC. It should include the following structural issues:
    - the integrity of fixings that attach cladding panels to the primary structure. Fixings should be free of corrosion and the AAC sub-base should be free from cracks and spalling
    - there should be contact between adjacent panels to ensure the transfer of load, especially in the vicinity of penetrations. Where the contact surfaces have a tongue and groove finish the profile should be fully engaged and free from distress
    - cladding panels should be plumb with their centre of gravity remaining inside the middle third of their thickness over the height of the façade
    - cracks and spalls in cladding panels should be identified, diagnosed and repaired, especially those which pass through the cross section or are located near to fixings or penetrations
    - evaluate openings in planks, especially where there is evidence of distress of a lack of contact with adjacent planks
- following inspection cladding panels shall be categorised by the Structural Engineer in accordance with section 4 of this document. If a change in category is, at some future point, required then this should be brought to the attention of the NHS board so that action can be agreed
- maintenance shall include:
    - ensuring that seals around penetrations remain watertight
    - repairs to rainwater pipes and hoppers so that they do not leak into the façade, especially in locations where the internal structure could be in contact, or proximity to the façade
    - ensuring that finishes, including water resistant coatings, are not distressed or failing, especially at seals and joints
    - ensuring that, where present, ventilation is clear and functioning correctly

Non-loadbearing RAAC partitions

5.8. A number of mitigation measures can be applied to non-loadbearing RAAC partitions as follows:

- inspection of non-loadbearing RAAC partitions is expected to be conducted by a Structural Engineer experienced in the assessment of RAAC. It should include the following structural issues:
    - the head of each panel must be engaged in a head track securely fixed to the soffit of the floor above. The toes of the track must be of sufficient length to provide lateral restraint to the panel and to accommodate movement due to occupancy loads acting on the floors
    - floor screed at the base of a partition must be intact and in contact with the partition thereby providing lateral restraint at its base
    - the gaps between units should be filled with mortar and be free from cracks
    - partitions should be plumb with their centre of gravity remaining inside the middle third of their thickness over their full height
    - cracks and spalls should be identified, diagnosed and repaired, especially those which pass through the cross section or are located near to the lateral restraints
    - penetrations through partitions should be carefully assessed, especially when they are within 500mm of lateral restraints. Where necessary supplementary support should be provided
    - the location and orientation of partitions should be considered in relation to the type of loads that they are likely to experience:
        - partitions that may experience crowd loading, for instance on an escape route, are at more risk than partitions that divide two rooms, especially if the direction of travel is perpendicular to the orientation of the partition
        - rooms or corridors trafficked by wheeled vehicles are at greater risk of impact loading. Impact loading from vehicles may be averted by low level barriers bolted to the floor
    - where there is doubt about the efficacy of a partition, load testing may be the most appropriate method of determining its capacity, however a more practical solution may be replacement
    - alterations to partitions to distribute building services, especially routing of IT cabling, which tends to be done by IT rather than building trades, must be carefully controlled. Nevertheless, regular inspection should also be used to identify whether ad hoc penetrations have been made without permission

Leak schedules

5.9. A leak schedule may be created as follows:

- maintain a leak schedule that provides a record of locations where water penetration has occurred and the actions that have been taken to address it. The schedule shall be used to inform maintenance work and to provide an objective record of its efficacy
- ensure that all staff, especially maintenance staff who are more likely to visit less accessible locations, know how to report any leaks, cracks or other potential defect issues and to whom they should make such reports. This may require an education programme to be developed by the NHS board

Load limitations

5.10. A number of mitigation measures can be applied to the loading on RAAC panels as follows:

- restrict access to roofs to essential maintenance staff only. Consider maintenance activities well in advance and ensure that maintenance activities do not increase the loads currently supported - including maintenance equipment which may only be required for a short duration
- do not add new plant to roofs and consider whether it is practical to locate existing plant in other areas. Alternatively consider options to spread loads over a greater area
- if possible, reduce the dead load on roofs by removing chippings and replacing them with an appropriate solar reflecting coating. An architect may need to be consulted about the impact of such a change
- ensure that standing water is not permitted to persist on the roof, as ponding will increase loading. Similarly, if standing water penetrates the finishes, it may saturate the AAC causing it to become heavier
- the use of designated walkways, combined with signage, are another way to control the movement people and equipment, although education will be required to ensure that the work force understand why restrictions have been created and why it is important to follow them

Adverse weather

5.11. Mitigation measures can be applied during periods of adverse weather as follows:

- ensure the building remains serviceable through regular maintenance of rainwater goods and roof coverings with ad hoc re-inspections after periods of particularly inclement weather. Repair storm damage and remove obstructions accordingly

Minor repairs

5.12. A number of mitigation measures can be implemented in the form of minor repairs such as:

- patch repairs to roof coverings and rainwater goods should be made timeously to ensure that they do not become worse or create the conditions for distress to the underlying primary structure
- executing minor repairs should not normally involve significant increases in load to the existing roof, however there may be circumstances where this is not the case. For

example, if scaffolding were needed to gain access to a higher level. In such circumstances, advice should be obtained from a Structural Engineer

Major repairs and alterations

5.13. Major repairs and alterations may be difficult to carry out, because this invariably means increasing the load carried by the existing structure. The availability of comprehensive documentation for the loading criteria originally used to design RAAC panels is in most cases limited, and even if that information does exist, it is not always clear that the relevant units will have retained that capacity. As shown in earlier sections of this document, there are many reasons why the original capacity may have been diminished and it is imperative that a competent and experienced Structural Engineer makes an assessment, on each individual panel, by understanding how the designer intended it to behave and whether there are any factors present that either interfere with the intended behaviour or create the conditions for future interference.

5.14. It is also very difficult to back calculate the capacity of RAAC without completing a comprehensive programme of intrusive works, which will cause some distress to existing planks. This will require access to soffits, which may be difficult, due to their location or due to servicing below. These factors may also affect the viability of using temporary propping from within the spaces below.

5.15. Two alternative approaches are:

- load testing of the relevant planks. This can be done from above without disrupting operations below, however conducting such tests could only take place if the bearings had been demonstrated to achieve the IStructE's recommendations
- temporary structures. It may be possible to provide temporary structures that bridge between primary supports, such as steel beams and walls, and thereby avoid loading the RAAC planks. Such areas could be used to land materials on a roof, or as platforms to work from

5.16. The introduction of new penetrations does not necessarily increase the existing load on a roof or floor, but it would diminish the capacity of the affected planks. For this reason, in all but the simplest cases, additional support will be required. It is also important that methods of cutting planks do not use percussive tools to avoid spalling of soffits.

5.17. In each proposed case, an experienced Structural Engineer should be consulted before making major changes or alterations to a RAAC structure.

Record keeping

5.18. NHS boards should keep an up-to-date record of all inspections and maintenance work, which may be used to help diagnose future issues and plan work. Records should include, but not be limited to, the following information:

- a schedule of planned maintenance and inspection work
- a record of all ad hoc maintenance and inspection work
- a leak schedule
- reference to inspection reports provided as a result of national survey programmes or through surveys commissioned by the NHS board
- all records shall include a description of the general location of work using naming conventions and reference codes used within inspection reports
- all records shall include a description of the specific location of completed works within a property marked on existing drawings
- the date work was conducted and a summary of the weather conditions
- reference may also be made to the following documents, which provide useful information about the maintenance of buildings and the keeping of records:
    - ‘Appraisal of Existing Structures [3rd ed]’, IStructE, October 2010
    - ‘Guide to Surveys and Inspection of buildings and associated structures,’ IStructE, June 2008
    - ‘Defects in Buildings,’ Property Services Agency, 1989

6. Monitoring and inspection

6.1. The recommendations found in this section of the document overlap with the requirements for inspection and maintenance, however they are specifically intended to address annual and triennial inspections, which are expected to be conducted by Structural Engineers experienced in the assessment of Reinforced Autoclaved Aerated Concrete (RAAC).

Deflection measurements

6.2. One way of assessing deflections is to carry out digital surveys of planks. A digital survey can be conducted from either above or below floor or roof level depending on accessibility to the underside of the planks. The primary purpose of a digital survey will be to overlay new deflection data with prior survey information to identify changes. The method of monitoring and measuring deflections in RAAC planks should be determined by a competent and experienced Structural Engineer.

6.3. If, through monitoring or inspection of RAAC, panel deflection has increased to the extent that an area of the floor or roof will change risk category, then this should be brought to the attention of a Structural Engineer experienced in the appraisal of RAAC. The Structural Engineer may instigate an intrusive investigation, increase the frequency of surveys or suggest remedial work to be carried out.

6.4. Should deflections reach ¾ of the permitted maximum (span/100), then the NHS board should convene an emergency committee meeting on site to decide what, if any, action is required to prevent the maximum from being reached. It is recommended that representatives of the NHS board, estates department and where appropriate, the relevant hospital disciplines working within the affected spaces, should form the committee. A Structural Engineer experienced in the appraisal of RAAC should also be present.

6.5. A range of measures will be available to the committee, from closing the space to continued monitoring at an increased frequency. Action will be decided based on an objective risk assessment that considers the current risk category, diagnosis of the underlying issue, the expected effect of available mitigations, the potential consequences of failure and how success will be measured.

6.6. It is recommended that NHS boards with RAAC in their buildings make contingency plans, which could be implemented at short notice, that describe how they would provide a Structural Engineer with access to clinical areas, or areas with other forms of restriction.

6.7. It is also recommended that committee members be identified in advance so that the emergency meeting may be convened quickly.

Panel condition

6.8. The general condition of RAAC planks identified as being at risk shall be assessed from the ceiling void, for instance, where planks have been cut, chronic water penetration has been identified, excess deflection is present, or where prior distress has been observed.

6.9. Each location observed must be positioned on a general arrangement drawing. Some locations may be in places that are difficult to access, such as clinical locations, therefore NHS boards will need to plan carefully for the required inspections.

6.10. The risk category for planks in each location will be indicated by colour coding. If, in the opinion of the Structural Engineer, the condition of a plank has worsened to the extent that an area of the floor or roof will change risk category, then this should be brought to the attention of the NHS board so that remedial action can be agreed. The Structural Engineer may instigate an intrusive investigation, increase the frequency of surveys or suggest remedial work to be conducted.

6.11. If any location is perceived to pose a critical risk, then a procedure, like that used to appraise deflections that have reach ¾ of the maximum, shall be adopted.

Bearing condition

6.12. Bearings will be inspected in locations identified as being at risk by a Structural Engineer qualified in the assessment of RAAC. This includes the circumstances described in Figure 4.2; however, emphasis will be placed on locations where a bearing width less than 75mm has been accepted for pragmatic reasons.

6.13. It has been assumed that where reinforcement did not extend beyond the face of the support, remedial action has already been undertaken to extend the bearing. Bearings that have undergone enhancement will also be re-inspected to ensure the enhancement is working as intended.

6.14. A change to the risk category of bearings, especially if the change implies critical status, as determined by the Structural Engineer, will be brought to the attention of the NHS board so that appropriate action can be agreed. A plank reaching a critical status will be the subject of the emergency process described above.

Record keeping

6.15. In section 5 of this document general requirements have been provided for record keeping. NHS boards shall supplement these requirements with accurate records of the risk category and deflection characteristics assigned to RAAC planks that have been inspected.

Appendix A Examples of defects

A.1 Examples of defects, damage and distress of Reinforced Autoclaved Aerated Concrete (RAAC) panels, classified according to tables 3 and 4 of the Institution of Structural Engineers (IStructE) Manual, which deals with the general condition.

Table A.1 - Examples of defects, damage and distress

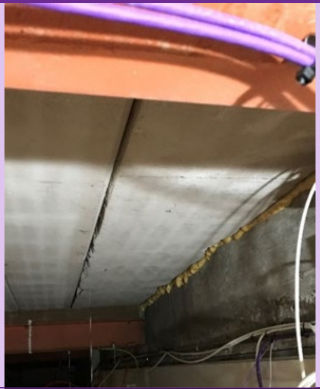
Example Image	Observations	RAG Rating
	• water penetration collecting in voids around reinforcement and creating efflorescence on the soffit. The location is close to support, however deflection is not excessive and there is no cracking or spalling, although the conditions exist for expansive corrosion of the reinforcement and increasing the plank weight • strictly speaking the IStructE classification is Amber, because there is no distress, but due to the extent of penetration, there is a reasonable expectation of distress forming. Red may be more appropriate	Amber
	• water penetration close to the support, causing efflorescence, and erosion, to the soffit • deflection is not excessive • the conditions exist for expansive corrosion of the reinforcement and increasing the plank weight	Red

Example Image	Observations	RAG Rating
	• a soffit fixing has been pulled from slab causing a spall. Although close to support, the plank is dry, has no flexural cracking or excessive deflection and no reinforcement is visible • providing the action is not repeated, the damage should not become worse	Amber
	• a deep spall, with reinforcement exposed, can be seen • the plank is dry, has no flexural cracking or excessive deflection, suggesting the spall is not stress induced • the end of the support strap is located next to the spall, which implies an uncontrolled installation of the plank that has been cut short • providing the action is not repeated, the damage should not become worse, albeit the spall should be repaired to protect the reinforcement	Red
	• a large penetration in the middle of a plank, although remote from the supports • while spalled at edges, probably due to the method used to cut the hole, there are no flexural cracks. The plank is dry and deflection is not excessive • although the damage is unlikely to be repeated, the capacity of the plank has been materially diminished	Red

Example Image	Observations	RAG Rating
	• water penetration close to the support, causing efflorescence and cracking on the soffit, probably due to expansive corrosion • reinforcement is locally visible • the deflection is not excessive	Red
	• opening in slab, remote from the support, carried on the adjacent plank using folded plate straps. The adjacent plank has been cut near the bearing for the folded plate straps. The adjacent plank has been cut near the bearing for the folded plate straps • no flexural cracks are seen but the slabs' flexural capacity has been diminished • planks are dry and deflection is not excessive	Red
	• minor cracking near the middle of planks due to the weight of air handling plant placed on top • plank is dry and deflections are not excessive • the air handling plant could be moved or spread over more planks	Green

Example Image	Observations	RAG Rating
	• spalled soffit near support, likely caused by rough handling during installation, but otherwise sound when tested • longitudinal and transverse reinforcement visible and present over support • dry and no excessive deflection	Red
	• major crack at the plank bearing, probably caused by a modification intended to shorten the plank so that it could bear onto a ledger (made of an inverted tee) fixed to the primary steelwork	Red (critical)
	• plank end cut short to make room for a rainwater pipe. The cut plank is supported on a folded metal strap. A second strap supports the in-situ infill • the plank is dry, the deflection is not excessive and there is no cracking or spalling	Amber

Example Image	Observations	RAG Rating
	• minor cracking that begins near the support and is due to the weight of air handling plant placed on top • plank is dry and the deflection is not excessive • the air handling plant could be moved or spread over more planks	Amber
	• the plank forming gutter has been modified to fit between the façade and the nearest supporting beam. This has caused spalling to the inside edge. Post installation there is no reason for this damage to be repeated • the plank is dry, there are no stress induced cracks or spalls, and the deflection is not excessive	Amber
	• the soffit of this plank, which forms a roof gutter, has been heavily damaged with percussive tools and reinforcement is exposed to view. The damage is close to the support, although the plank is dry and there are not any cracks induced by stress. The plank has not deflected excessively • given the location, and the position of rainwater pipes out of picture, it is likely that the damage was caused by an attempt to create a new rainwater outlet, which was abandoned in progress	Red

Example Image	Observations	RAG Rating
	• the end plank has lost its bevelled edges and has rough edges. This implies that it has been modified, probably because it did not fit the out-turn dimension to the adjacent wall • the plank is dry, does not have cracks or spalls and has not deflected excessively • there is also discolouration on the plank soffit that appears to correspond to the position of reinforcement within the plank. This is discussed in the example below	Amber
	• discolouration on the plank soffit corresponds to the position of longitudinal and transverse reinforcement. Shallow cover likely caused differential curing relative to neighbouring concrete. Fire resistance will be reduced, although roofs are seldom compartment floors. Low cover is not unique to RAAC; it is often present in conventional concrete until the 1980's • the plank is free from cracks and spalls, has not deflected excessively, and is dry	Green
	• approximately two thirds of the plank width have been removed near mid span. The hole edges have spalled, due to the method of cutting, but cracks induced by stress are not evident. The plank is dry and does not appear to have deflected excessively • nevertheless, the capacity of the plank has been materially reduced	Red

Example Image	Observations	RAG Rating
	• more than two thirds of the plank width have been removed near the support. The hole edges are neatly cut, and there are two straps framing the hole. The magnitude of their contribution is not clear, as bolts in RAAC have limited capacity, but spalling and cracks induced by stress are not evident. The plank is also dry and does not appear to have deflected excessively • nevertheless, the capacity of the plank has been materially reduced	Red
	• the planks are dry and are not cracked or spalled, however they have deflected differentially, although not by much. This could be a difference in manufacturing or something else going on. For this reason, it would be sensible to monitor movements	Amber
	• chronic water penetration is evident near the plank supports, suggesting a significant failure of the roof coverings and rainwater goods. This does not appear to have resulted in expansive corrosion, cracking/ spalling, but the conditions now exist for that to happen. If the planks become saturated generally, the weight of the planks could also become important • the planks have not deflected excessively and have not spalled • strictly speaking the IStructE classification is Amber, because there is no distress, but due to the extent of penetration, there is a reasonable expectation of distress forming. Red may be more appropriate	Amber

Example Image	Observations	RAG Rating
	• a modification at the head of an existing non-loadbearing partition prevents it spanning vertically from floor to soffit, as intended. There is a vertical track tying the right-hand edge to the adjacent column and the butt joint to the left is filled and is intact. The partition remains plumb and is inferred to be spanning horizontally • since its stability relies on the integrity of an unreinforced joint it would be better to restore restraint at the top of the partition	Red
	• there is lots of surface damage, probably due to old fixings, and water damage, due to the surface coating being compromised. There are several openings that influence the ability of planks to span horizontally between steel columns, although the wall remains plumb, and the horizontal joints remain tight. No out of plane slippage can be seen between planks. Corrosion of embedded fixings is a risk if water penetration continues. Distressed areas are a debris risk and ought to be fixed	Red

Abbreviations

AAC: Autoclaved Aerated Concrete

BRE: Building Research Establishment

BS: British Standards

CP: Code of Practice

IStructE: Institution of Structural Engineers

kPa: kilopascal

RAAC: Reinforced Autoclaved Aerated Concrete

SCOSS: Standard Committee on Structural Safety

Glossary

Bearing - The point of contact between the end of a Reinforced Autoclaved Aerated Concrete (RAAC) plank and a supporting structure. For instance, a steel beam or brick wall.

Bond stress - Bond stress is a form of stress that exists at the interface between two structural components, when load is shared between them. For instance, at the surface of a steel reinforcing bar embedded within Autoclaved Aerated Concrete (AAC).

Brittle - A brittle material is one that fractures suddenly when its design strength is exceeded. Brittle failures are undesirable because they give little warning.

Creep - Deflection that increases with time, but without any increase in the applied load. It is caused by the stiffness of a material changing with time.

Damage - Damage to a structure is an impairment to its integrity or performance that has been caused by accident, or malicious intent. For instance, a collision or impact. Cracks, spalls, excessive deformation, water penetration, instability and so on could all be the result of damage.

Dead load - Loads resulting from the self-weight of materials from which a structure is made and the permanent fixtures that it carries. The dead load of a roof would include the self-weight of water-resisting finishes, insulation, RAAC planks, steel beams, suspended services and ceilings.

Defect - A defect in a structure is a type of shortcoming that is present because of its design, manufacture or erection such as it is the result of an inherent flaw that has been present from the outset. Cracks, spalls, excessive deformation, water penetration, instability and so on could all be caused by a defect.

Design strength - The design strength of a material is its maximum (ultimate) strength divided by a factor of safety that accounts for natural variability in its properties.

Distress - Distress is a term that describes a loss of integrity or performance of a structure resulting from its use, exposure to the environment, or lack of maintenance. For instance, if the protective membranes on a roof are not maintained the underlying structure is vulnerable to water penetration. Cracks, spalls, excessive deformation, water penetration, instability and so on can all be forms of distress.

Ductile - A ductile material is one that undergoes irreversible deformation, rather than sudden fracture, when its design strength is exceeded. For this reason, ductile behaviour is preferred to brittle behaviour.

Feedback loop - A feedback loop occurs when the cause of an action is reinforced by its own effect. For instance, a deflected roof slab may collect water, which increases the weight to be carried by the slab, thereby causing more deflection. Feedback loops are especially detrimental when their effects cannot be controlled and continue to the point of failure.

Imposed load - Loads carried by a structure that are transient. For instance, the weight of occupants, furniture and equipment.

Shear stress - Shear stress is a form of stress that acts parallel to the surface of a material. It is normally the result of equal, but opposite, forces being applied. The maximum shear stress in a structure is normally found at the supports.

Spall - A spall occurs when the surface of a structure fractures and breaks free from the body of the structure. Spalling is normally a local effect.

Span - The span of a structure is the distance between two supports. For instance, walls or steel beams located at either end of a RAAC plank.

Strain - Strain is a measure of how much a structure will stretch or compress, relative to its original length, when load is applied. Structures that exhibit low strains are normally said to be stiff.

Stress - Stress is the intensity of a force. It is a measure of how much force is applied to a given area. High stress can result from a large force, or a small area, or a combination of the two.

Support - Supports are elements of a structure that carry one or more other elements. For instance, a wall or steel beam may carry one or more planks of RAAC.

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