Bristol City Council – Strategic Partnership

Barton House Structural and Structural Fire Review

Reference:

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Job number 297880-00

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Contents

Tables

Figures

Executive Summary

Arup, as part of the Strategic Partner team with Arcadis, has been commissioned by Bristol City Council:

1. to carry out a high-level review of the overall methodology and subsequent conclusions described in the Structural Robustness Assessment by Ridge dated 02 February 2024 (ref 5013240-RDG-XX-XX-DOC-9902) ("second Ridge report"); and
2. to conduct a structural fire assessment of the primary elements of structure in Barton House to assess the risk of disproportionate collapse.

1. Review of the Second Ridge Report

Following our review of the second Ridge report, Arup agrees with Ridge's overall conclusion that states: "*it is suggested that the building is at relatively low risk of disproportionate collapse and therefore Barton House would behave adequately during an accidental event."* This conclusion is subject to the proposed works currently being carried out in the building, as described in the second Ridge report.

2. Structural Fire Assessment

Arup has also reviewed the additional measures recommended by Ridge (to lower the risk of disproportionate collapse at Barton House) to identify if any additional fire specific measures are required. Arup recommends that applied fire protection, designed and installed by suitably competent persons, to the steel frames identified as necessary to enhance robustness is provided. Arup also recommends that suitably competent persons inspect the subdividing walls in the common area storerooms to see that the specified resistance to the spread of fire between storerooms can be achieved.

If these recommendations are adopted in addition to those provided by the second Ridge report, Arup considers there is a low risk of disproportionate collapse of structure in Barton House in the event of a single dwelling or storeroom fire.

Arup has conducted a structural fire assessment of the primary elements of structure in Barton House. We conclude that the external and internal walls have an adequate level of structural fire resistance. However, we identified that the slabs have a lower period of fire resistance than recommended for a stay put evacuation strategy. To address both this hazard and the increased risk of structurally significant fires due to the Expanded Polystyrene Insulation ("EPS") rendered finish system, we recommend that a simultaneous evacuation strategy and common fire alarm initiated by means of detecting a fire anywhere within a flat is adopted. Such a system is described in National Fire Chiefs Council (NFCC) guidance Appendix A.

Bristol City Council will need to continue managing the risks associated with EPS until such time as it is removed, or Barton House is decommissioned.

Bristol City Council will need to consider this assessment in discharging their roles as Responsible Person and Principal Accountable Person under the Regulatory Reform (Fire Safety) Order 2005 and Building Safety Act respectively.

1. Introduction

1.1 Appointment and scope of work

In July 2022 Ridge & Partners LLP ('Ridge') produced a report for Bristol City Council entitled Barton House – Structural Robustness Assessment ("first Ridge report").

In September 2023 Arup, as part of the Strategic Partner team with Arcadis, was provided with a copy of the first Ridge report by Bristol City Council. Arup were asked to review it to identify examples of hazards that might lead to an increased risk of progressive collapse due to the inadequate structural robustness identified by Ridge. The intention of this was for Bristol City Council's information in their considerations of how they would manage the risk while they implemented the next steps for the building and its occupants.

Arup prepared a Technical Note dated 11 October 2023. Based on the reported structural survey information presented in the first Ridge Report, Arup agreed with Ridge's conclusion that the building was at risk of disproportionate collapse. Arup recommended a follow-on piece of work to identify threats, vulnerabilities and potential mitigations which could be used by Bristol City Council to develop a pathway to address the disproportionate risk of collapse. Bristol City Council instructed Arup to undertake this work and attend Bristol Archives to search for relevant historic information on Barton House.

In November 2023, Bristol City Council convened a risk workshop with Arup to consider other possible hazards to the building robustness and potential mitigations, including those related to fire safety. Due to the reported lack of robustness ties as outlined in the first Ridge report, during a risk workshop held between Bristol City Council and Arup a substantial risk for which there was no apparent reasonable mitigation was identified. This was in the event of a fully developed fire in an apartment which caused a localised structural element to fail, the reported lack of robustness in the building could result in a progressive collapse of structure. Arup also advised Bristol City Council that the measurements of concrete reinforcement cover identified by Ridge in certain locations in their 2022 report potentially indicated a lower duration fire resistance than recommended by codes at the time of construction.

In our letter dated 10 November 2023 Arup strongly recommended that '*to improve confidence that the existing survey information more widely reflects the 'as built' situation in the building, that further survey work be undertaken immediately.'* Following this advice Bristol City Council asked Ridge to lead further structural investigations and draw conclusions on the adequacy of the structure against disproportionate collapse. As part of these further investigations, Bristol City Council asked Arup to:

1. Peer review Ridge's structural investigations and their conclusions on structural robustness. As part of this role Arup also had an opportunity to comment on the investigations and assessments undertaken;
2. Considering item (1) advise on the likelihood of disproportionate collapse as a result of a single dwelling fire; and
3. Undertake a structural fire resistance assessment of the existing structure of Barton House using further measurements of concrete cover obtained in the structural investigations.

1.2 Purpose of this report

The purpose of this report is to firstly set out the conclusion of Arup's review of Ridge's report on structural robustness and secondly the method of Arup's structural fire safety assessments, discussions of the implications of their outcome and conclusions and recommendations for Bristol City Council. This has been set out as follows:

- Section 2: sets out the conclusion of our peer review of the second Ridge report.
- Section 3: sets out our advice regarding the risk of disproportionate collapse due to fire considering our conclusion in Section 2
- Section 4: presents our analysis of the structural fire resistance of Barton House using the original drawings, additional structural survey data provided by Ridge. An assessment of the adequacy of the structural fire resistance with regard to the evacuation strategy at Barton House is made.
- Section 5: sets out our conclusions and recommendations for Bristol City Council.

As Arup have undertaken this scope of services since November 2023, we have provided interim reporting to Bristol City Council setting out our findings and recommendations as they developed.[1]

This report is intended for use by Bristol City Council to assist in carrying out their statutory duties for Barton House.

1.3 Limitations

The structural fire assessments detailed within this report are based upon the reference information set out in Section 1.4. Arup have not carried out any independent structural surveys of Barton House. Arup have been provided with the opportunity to observe site investigations overseen by Ridge for the purpose of carrying out their structural robustness assessment; further Arup have been provided with interim survey information by Ridge which aligns with our own observations. Arup have referred to this information in addition to our independent review of historical record drawings when carrying out our structural fire assessment.

The assessments conducted are relevant to Barton House only.

Specific analysis of structural fire performance and recommendations on how to reduce any consequential risk are relevant to Barton House only.

Arup's peer review of the second Ridge report as set out in Section 2 is a review of the appropriateness of the method of assessment, and of the adequacy and proportionality of the conclusions and recommendations. It is not a detailed 3rd party check nor verification of the accuracy of calculations or reporting.

[1] Letter *'Barton House: Structural Fire Safety',* 10 Nov 2023; Technical Note: *Structural/Fire Summary*, 11 Dec 2023; Technical Note: *Structural/Fire Summary* Rev 02, 13 Dec 2023; Letter: *Structural Fire Safety (DRAFT)*, 03 Jan 2024

1.4 Reference information

Table 1 details the specific reference information Arup has been provided with or have sourced independently to carry out our peer review and structural fire assessment.

In addition to specific information set out in Table 1, we have relied on relevant byelaws, regulations and technical standards in force both at the time of construction and currently. Where these have been relied upon, they have been referenced directly in the text.

Table 1 Barton House reference information

Document reference	Description	Date	Produced by
5013240 - Bristol City Council - Barton House – Robustness Assessment	Structural robustness assessment for Barton House building	July 2022	Ridge
Barton Hill Redevelopment Block A: Original Architectural drawings	Architectural plans, elevations and sections	1956-1957	J Nelson Meredith
Barton Hill Redevelopment Block A: Original structural drawings	Reinforced in-situ concrete details and sections, pre-cast concrete layouts, sections and details	1956-1957	Clarke Nickols & Marcel
5013240-RDG-XX-XX-DOC-9902 Barton House - Structural robustness assessment	Structural robustness assessment for Barton House building	09 February 2024	Ridge

2. Peer review of Ridge structural robustness assessment

Arup has carried out a peer review of the most recent structural investigations, subsequent methodology and conclusions described in the Ridge report *Barton House - Structural robustness assessment* (the "second Ridge report"). Arup has also had an opportunity to comment on proposed structural surveys, observe the site surveys, review proposed methods of analysis, review report drafts and meet with Ridge to discuss their conclusions.

As noted above, Arup's review focused on the methodology and approach adopted by Ridge in its investigations and the adequacy and proportionality of its conclusions and recommendations. We did not undertake a detailed third-party check nor verify the underlying data or calculations. However, we also observed some investigation works carried out on site at Barton House between November and December 2023. Based on these activities, Arup's comments on the second Ridge report are as follows:

- We agree with Ridge's proposals to use the 1970s installed steel frames in strategic locations, working in combination with the robustness ties observed during the recent structural investigation, to locally enhance the building's robustness where required.
- We also agree with the proposed 'Critical Steel Frame Locations' shown in Appendix C of Ridge's report, and the conclusion that, once the proposed works as described in the second Ridge report are complete, "*it is suggested that the building is at relatively low risk of disproportionate collapse and therefore Barton House would behave adequately during an accidental event."*
- With regards to the eastern and western store areas, it is stated that for the flank walls adjacent to stores *"Accidental exposure to this wall panel is not considered to be significant and as such disproportionate collapse is unlikely. It is proposed that store doors are vented to avoid accumulation of dangerous gases and that all mobile gas cylinder storage is banned."*. We agree with this statement and please refer to our recommendations for limiting the potential for fire exposure in Section 3.

3. Risk of disproportionate collapse due to fire

Ridge has recommended certain measures are taken to lower the risk of disproportionate collapse during an accidental event in Barton House. As set out in Section 2 of this report, we agree with Ridge's recommended additional measures. Arup has also considered where there are any fire specific measures that need to be carried out to address the risk of disproportionate collapse due to fire. In summary:

- Ridge identify the 1970s era steel frames in selected locations as necessary to achieve adequate collapse resistance (LPS criterion 2). It is therefore recommended that in all locations identified by Ridge the steel frames are provided with suitable applied fire protection to achieve 90 minutes load bearing fire resistance. The applied fire protection should be designed and installed by suitably competent persons.
- For flank walls adjoining the west and east core storerooms, Ridge conclude that exposure of the flank wall to an accidental event is likely to be limited due to internal subdivision of the storerooms. Ridge further recommend reducing the hazard within the storerooms by banning the storage of mobile gas cylinders and providing vents in the storeroom doors. Should all of Ridge's recommended measures be acceptable and be feasibly implemented by Bristol City Council, we further recommend that:
    - The subdividing storeroom walls are inspected to confirm they are of adequate construction and thickness to likely achieve 30 minutes integrity and insulation fire resistance. The existing walls should also be checked for any openings between storerooms and any identified openings fire stopped by certified products. Guidance on the likely fire resistance of existing construction can be found in BR 128 *Guidelines for the construction of fire-resisting structural elements*.
    - Where door vents are to be located in a door which are required by the Barton House fire risk assessment to have fire resistance, we recommend that grilles/vents that achieve a minimum of 30 minutes integrity fire resistance (or higher) are installed. Note this recommendation is to ensure that measures adopted against disproportionate collapse do not inadvertently reduce the level of fire protection along escape routes.

Where these recommendations are adopted in addition to those provided by the second Ridge report it is our assessment that there is a low risk of disproportionate collapse of structure in Barton House in the event of a single dwelling or storeroom fire.

4. Structural fire assessment

4.1 Method of assessment

In this section, we have set out our assessment of the structural fire resistance of the primary load bearing elements of structure for Barton House.

The assessment is conducted in three stages:

a. The structural fire resistance requirements and recommendations at the time of construction is established;

b. A calculation of the likely structural fire resistance of the existing primary structural elements is carried out; and

c. The potential structural fire resistance is then compared with the relevant period of fire resistance from the time of construction.

4.2 Barton House

Barton House opened in 1958[2]. Structural and architectural drawings obtained by Arup from the Bristol City Archive are dated 1957-1958. It is likely that construction was in this period, with design preceding that circa 1956. A more precise date for the design and construction of Barton House has not been established.

Figure 1 is view of Barton House from the (a) time of construction[3] and (b) an exterior view of Barton House today[4].

Figure 1 External views of Barton House

(a)

(b)

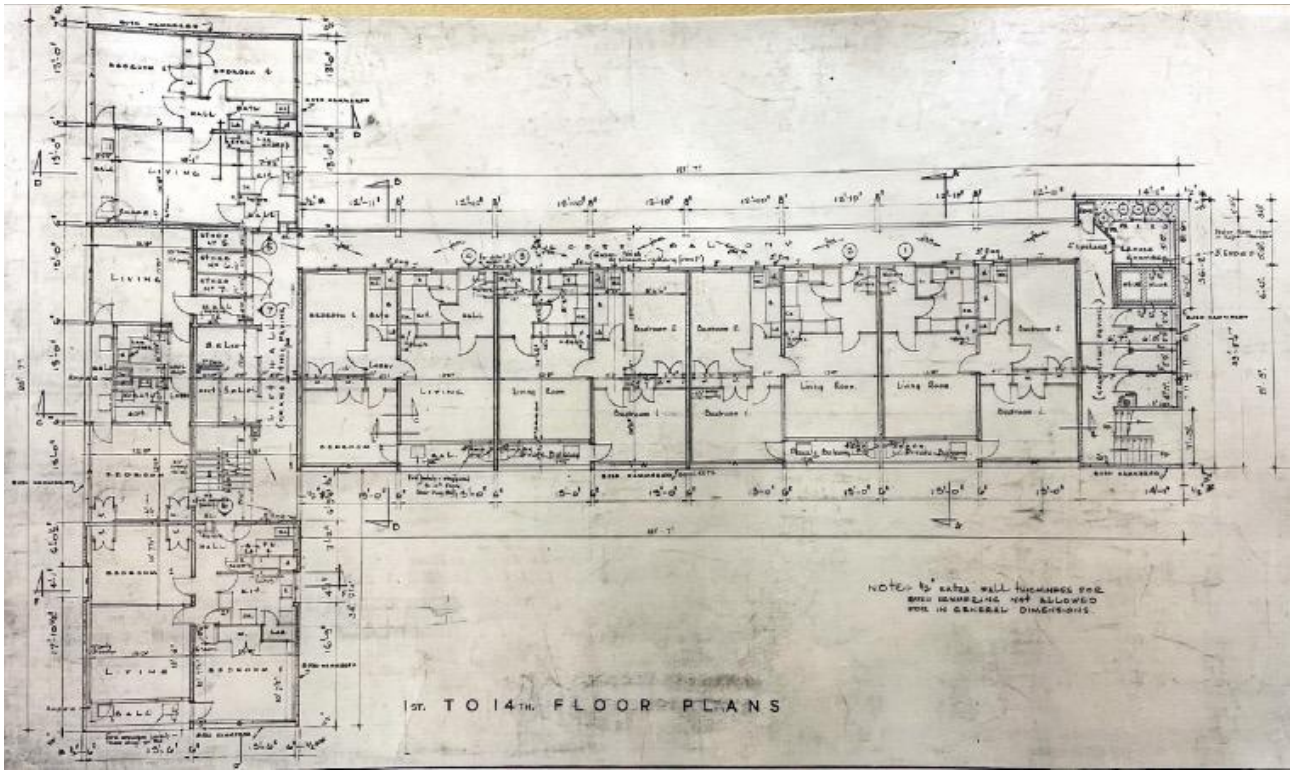
[2] Bristol Evening Post, June 23, 1953

[3] Official Architecture and Planning, Vol. 21, No. 12 (December 1958), pp. 559-561 (3 pages). https://www.jstor.org/stable/44128191 [accessed 11/01/2024]

[4] Barton House problems less severe than first thought, Bristol council says | Bristol | The Guardian [accessed 13/02/2024]

Barton House consists of a non-residential ground floor (plant room, community room and caretakers' accommodation) and fourteen floors of residential dwellings. It contains 98 dwellings with 7 dwellings per floor. Dwellings have either 1 or 2 bedrooms. The height to topmost storey has been estimated from elevation drawings provided by Bristol City Council as ~37m (121ft). The internal arrangement of a residential floor is set out in Figure 2 per the original drawings. The arrangements are the same at each above ground level. Flats are accessed from two un-enclosed stairs at opposite ends of the building by a balcony on one side which is open to the external air.

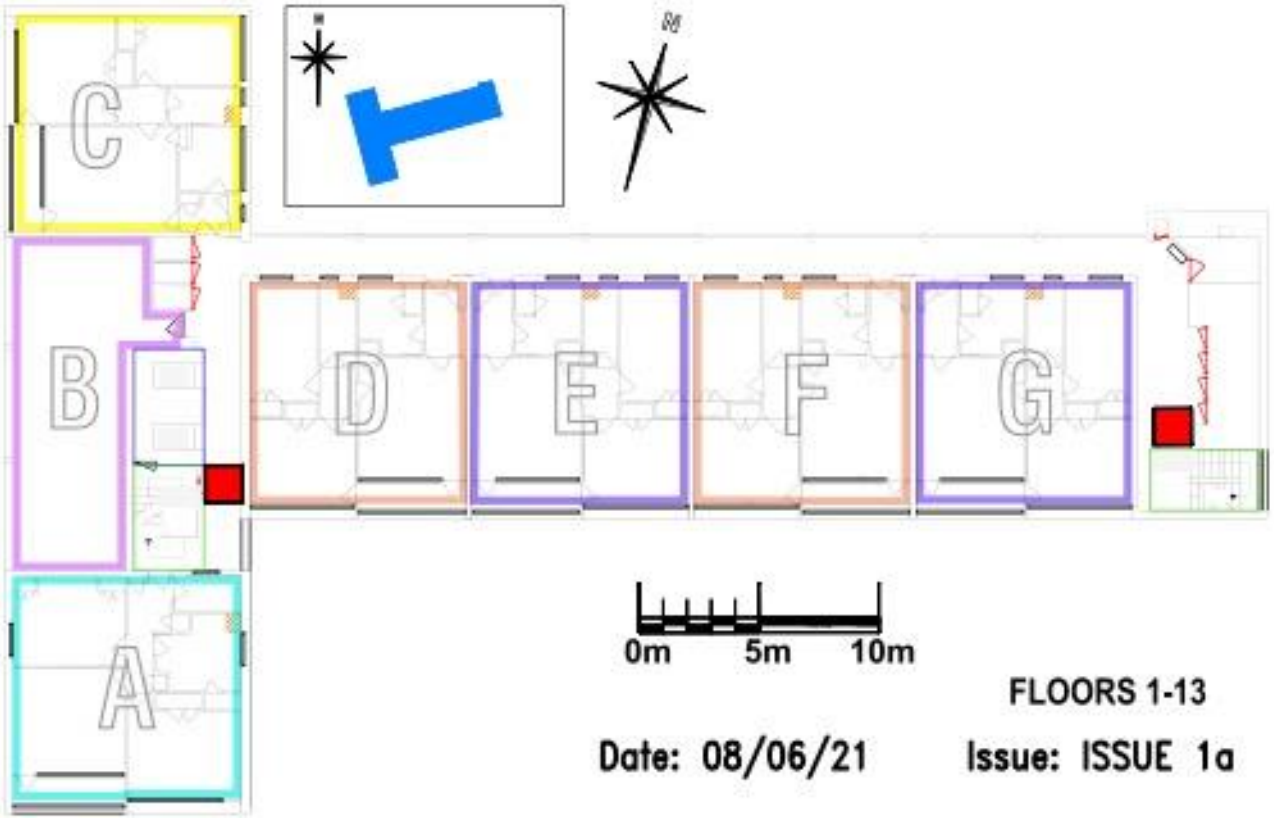
Figure 2 Typical Residential Floor Layout (Levels 1-14) original drawings[5]



[5] Bristol City Archives

Figure 3 illustrates the residential floor layouts as drawn in 2021. These plans were provided to Arup by Bristol City Council. Bristol City Council have advised that no major alterations to the internal flat layouts or common areas have been undertaken.

Figure 3 Typical Residential Floor Layout (Levels 1-14) 2021 drawings[6]



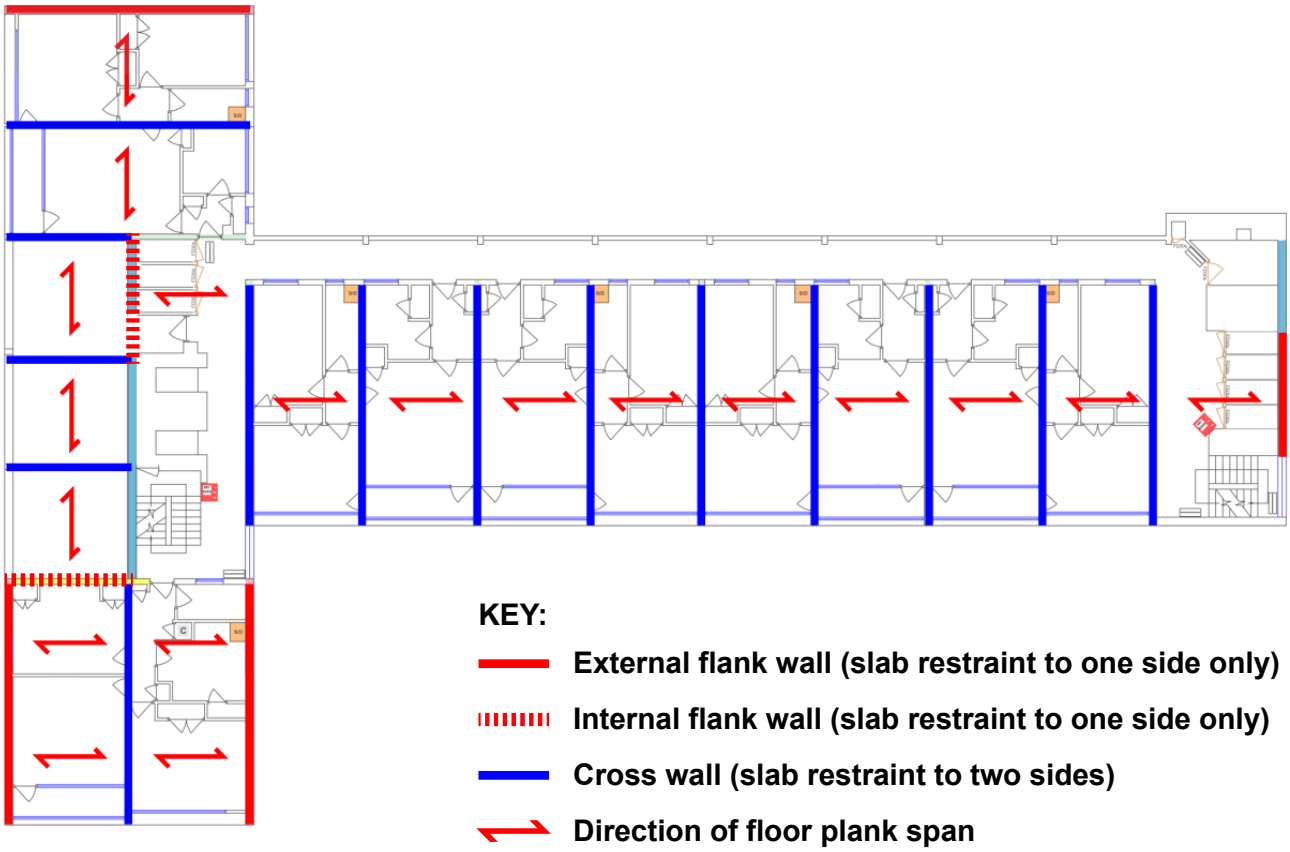
In comparing the two sets of plans, the most significant change to layouts is the provision of windows to the individual flat balconies. Arup also understand from Bristol City Council that Barton House was reclad with an EPS rendered system circa 2008.

[6] Provided by Bristol City Council to Arup

4.3 Barton House Primary Structure Levels 1 – 14

The primary load bearing elements of structure, i.e. those that are essential to the stability of the building, are the floor slabs and the internal and external loadbearing walls. The location of these elements is indicated in Figure 4.

Figure 4 Location of primary elements of structure reviewed in this assessment

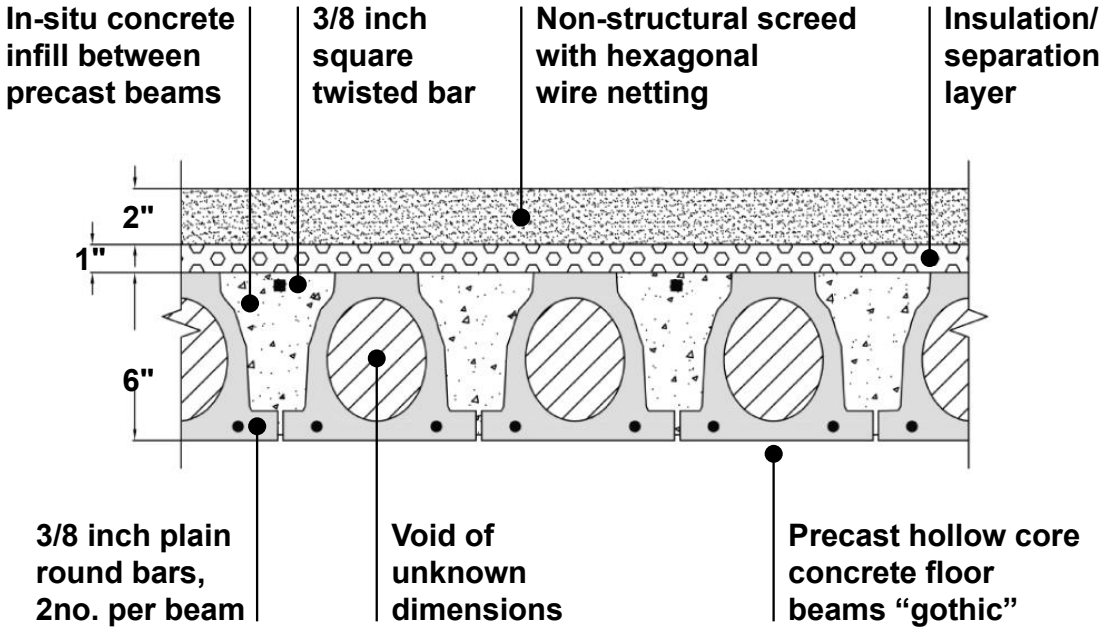


Arup's understanding of the structure of Barton House is built up from a combination of the record drawings and site survey information obtained by Ridge and observed by Arup. The relevant details of the structure, as considered in the structural fire analysis are summarised below.

4.3.1 Floor slabs

Figure 5 is an illustration of the observed geometry and construction of the floor slabs. The floor beams are comprised of proprietary 'gothic' precast reinforced concrete beams with internal hollows. Conservatively a large void diameter of 100mm x 75mm spaced every 100mm has be assumed. The precise void geometry is not known; an estimate has been included to ensure the effects on heat transfer through the slab are represented. There are 2 No. bottom plain round reinforcing bars of 3/8 inch diameter (approx. 10mm) in each precast beam. These beams are set next to each other with unreinforced cast in-situ concrete poured between them. An unknown insulation material (observed by Ridge to be ~1" or 25mm) is overlaid and then a non-structural screed of 50mm thickness.

Figure 5 Observations of hollow core floor slab construction [excerpt from second Ridge report]



The original drawings specified ½" (13mm) cover to slab reinforcement. Our observations from the site survey carried out indicates that the bottom concrete cover to the reinforcement varied from 10mm -15 mm; this aligns with Ridge's reported observations their second report.

A non-structural wet applied plaster finish was observed to the underside of the floor slabs. Bristol City Council have advised Arup they believe the plaster finish is original and was hand applied. No testing to establish the specific material has been carried out. Arup observed the depth pf plaster finish being measured as 8-9mm thick. As this finish is hand applied variation in thickness is to be expected. No detailed survey of the plaster finish thickness has been carried out.

The floor slabs are supported by internal cross walls (Section 4.3.2) or by a 'flank' wall (Section 4.3.3).

From Arup's inspection of the original drawings and survey of the end support conditions, the floors appear to have been designed as simply supported.

4.3.2 Internal Cross walls

Figure 6 is an illustration of the observed geometry and construction of an internal cross wall. The internal cross walls are either in-situ reinforced concrete or made from precast reinforced concrete panels 'stitched' together with in-situ reinforced concrete 'columns' (depending on their location). Regardless of their construction, these walls are consistently 6 inches (approximately 150mm) thick.

In some locations an additional blockwork layer was observed adjacent to the internal cross walls. The block work wall is believed to be from the time of construction as it is described in the original Architectural plans. The blockwork walls are shown in plans only between dwellings and is not therefore present for all internal cross walls. This is consistent with Arup's site observations. The presence of the blockwork wall has not therefore been considered in this structural fire assessment as it is not present for all cross walls.

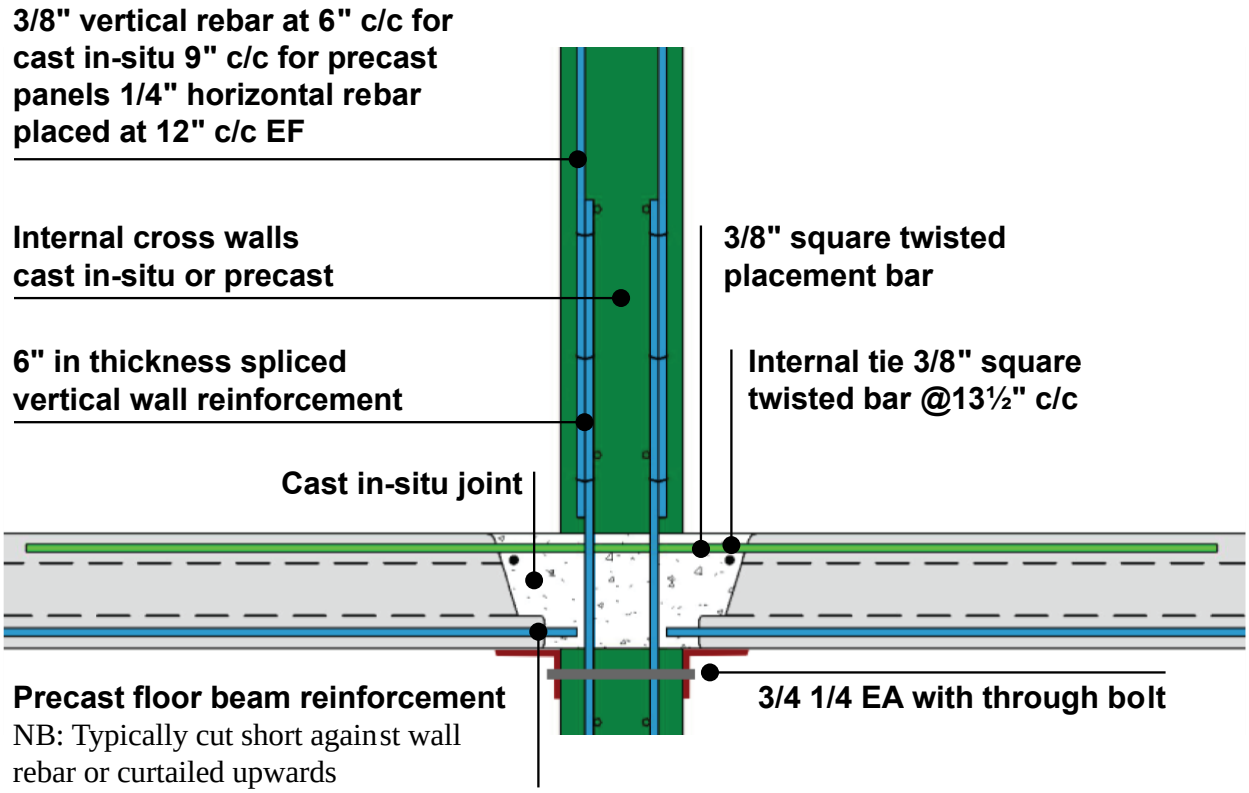
Floor slabs are supported at each end by the internal cross walls. The support between slab and wall appears to have been formed by breaking the ends of the precast gothic beams to expose the bottom

reinforcement which was then recast in-situ with top reinforcement bars between the beams and the cast in-situ wall below (or over the precast wall panels below). The top reinforcement bars are continuous through the wall to the slab on the other side. The top reinforcement appears to be provided as a structural tie. No top reinforcement is evident in the precast gothic beams.

The original drawings specify cover to steel reinforcement above ground to be 1" (~25mm); therefore, indicating an intent to provide ~25mm of cover to the steel reinforcement in cross walls. Arup observed surveys of the cross walls and measurements 25-35mm concrete cover. In some locations measurements as low as 5mm were observed; in these locations a 40mm thick shotcrete layer to affected area was observed. This aligns with Ridge's site survey information as reported in their second report.

The additional 40mm of shotcrete increases low cover from 5mm to 45mm. Therefore, the minimum cover to cross wall steel reinforcement is taken as 25mm.

Figure 6 Observed construction of internal cross wall [excerpt from second Ridge report]



Steel shelf angles are evident in Figure 6. The original structural drawings indicate that these were likely to be temporary supports during the original construction; it is Arup's understanding that these are not relied upon for slab support in the permanent case. These shelf angles have therefore not been included in our assessment.

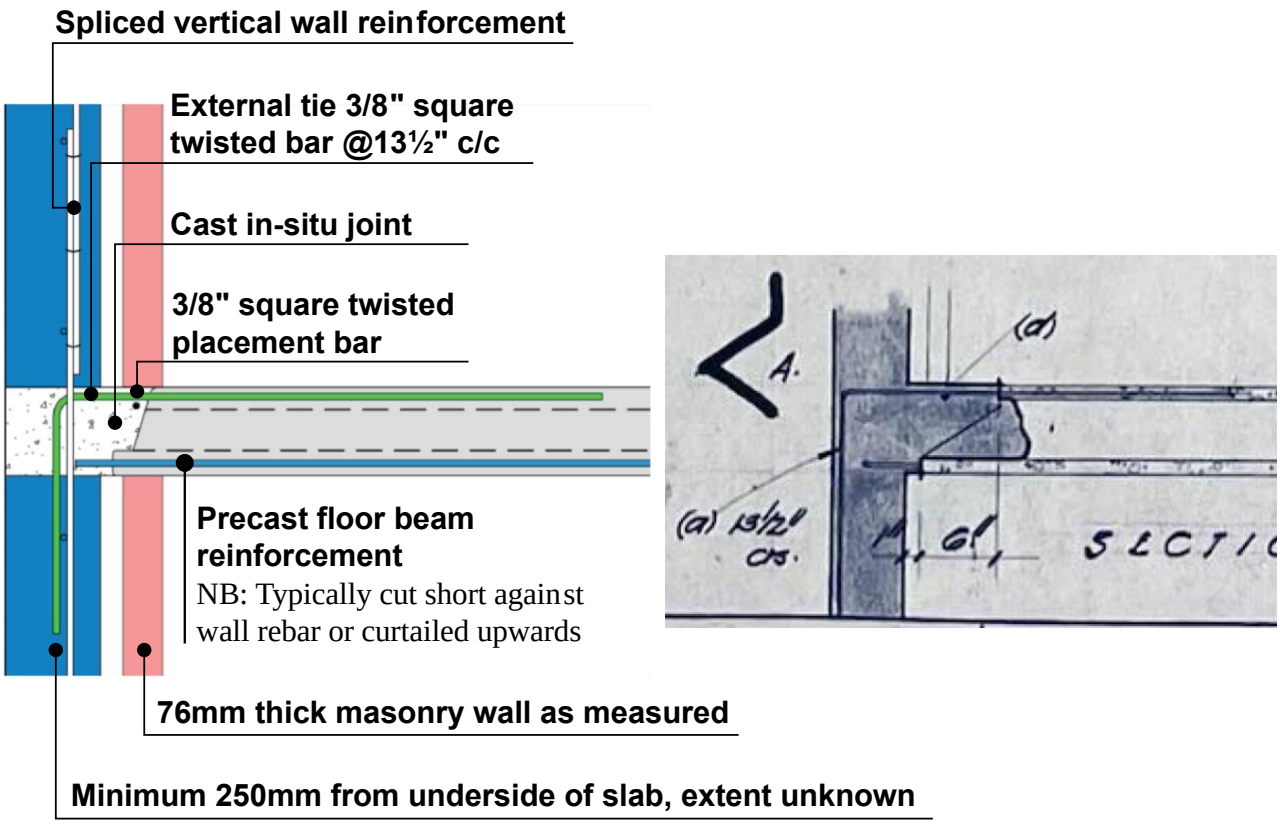
4.3.3 External flank walls (and internal flank walls supporting slabs on one side only)

Flank walls are external walls supporting a slab on one side only. As illustrated in Figure 4 there are also two locations where an internal wall supports a slab on one side only and these have a similar construction to the external flank walls in terms of support of the slabs.

Floor slabs are supported by the flank wall in a similar manner to the cross walls; the key difference is that the top reinforcement bar at the flank walls is an angled bar as illustrated in Figure 7.

The external flank walls are in-situ reinforced concrete, generally 6 inches (approximately 150mm) thick (in some locations an extra ½ inch thickness has been added to allow for a 'bush hammered' finish but this is not considered to contribute to the structural thickness of the wall). The internal flank walls (See Figure 4) are in-situ reinforced concrete, 6 inches (approximately 150mm) thick.

Figure 7 Observed construction of external flank wall detail (left) and as intended from record drawings (right) [excerpt from second Ridge report]



The original drawings specify cover to steel reinforcement above ground to be 1" (~25mm); therefore, it is believed the original intent was to provide ~25mm of cover to the steel reinforcement in flank walls. Typical cover measurements exceeded the 25mm intent in the record drawings. By exception some locations of low cover were observed (as described for internal cross walls); in these instances, a 40mm shotcrete layer was observed on the inner face of the flank wall.

In our analysis a minimum cover to flank wall steel reinforcement is taken as 25mm.

A lightweight blockwork wall was observed in front of the flank walls; these are present for each flank wall surveyed and appear on original drawings. Ridge describe the thickness of this blockwork wall as 76mm (3") in the second Ridge Report which aligns with the record drawings. The presence of this wall provides additional protection to the flank wall in the event of a fire; this has been included in our assessment.

4.4 Legislation, regulation and codes of practice

To establish the required fire resistance for the elements of structure in Barton House we need to establish the relevant regulations and codes of practice at the time of construction.

Table 2 sets out relevant regulations and codes of practice for structural and fire safety design at the time of construction of Barton House and in the immediate aftermath.

Table 2 Relevant building and fire safety regulation and codes of practice at the time of construction of Barton House

#	Barton House	Regulation	Fire safety code of practice	Concrete structural code of practice
1948			CP3 Chapter IV (1948) Code of Functional Requirements of Buildings. Precautions Against Fire. Houses and Flats of not more than two storey(s)	
1953		Bristol City and County Building Byelaws 1953		
1957	Construction			CP114 (1957) The structural use of reinforced concrete in buildings
1958	Opened			
1962			CP3 Chapter IV (1962) Code of Basic Data for the Design of Buildings. Precautions Against Fire. Part 1 Fire Precautions in flats and maisonettes over 80ft in height	
1965		The Building Regulations 1965		

It is not known which regulations and codes of practice were employed by the designers or enforcing authorities at the time of construction. Therefore, a review of each of the relevant regulations and codes of practice has been undertaken. Their provisions are then compared with the design of Barton House to establish the likely basis of design.

4.5 Required structural fire resistance at the time of construction

4.5.1 Bristol City and County Building Byelaws 1953

At the time of the construction of Barton House the relevant regulations prescribing the fire resistance requirements for structures was the Bristol City and County Building Byelaws 1953. This does not set out any requirements regarding arrangements for means of escape.

Byelaw 45 and its subjoined Table set out the fire resistance of floors, columns, beams and certain walls. In a domestic building exceeding 50ft [15.24m] in height, fire resistance of 1 hour was required for structure.

4.5.2 Local Authority: Means of Escape in Case of Fire

At the time of construction of Barton House, design requirements for means of escape were not specified alongside the fire resistance requirements set out in the building byelaws. It is possible that guidance was published separately, for example, in London guidance was published as the LCC Means of Escape in Fire (1954). Searches have been made of historic archives including the Bristol Archive, which holds the relevant byelaws from the time of construction. However, no record of such a code of practice for Bristol has been identified.

4.5.3 CP3 Chapter IV Part 1 Fire Precautions in flats and maisonettes over 80ft in height (1962)

Although CP3 Chapter IV Part 1 (1962) was published after the construction of Barton House, it was not uncommon at that time for buildings to be constructed using the recommendations set out in draft codes; therefore, the layout of Barton House has been compared with the provisions of CP 3 Chapter IV (1962).

It is important to note that CP3 Chapter IV Part 1 (1962) was the first design standard for residential blocks of flats which set out directly that high rise residential buildings should be designed so that occupants not on the floor of the dwelling fire may remain safely in the building. This is the evacuation strategy that became known as ‘stay-put’ (bold included for emphasis):

*“**The assumption should no longer be made that buildings must be evacuated if a fire occurs and high residential buildings should, therefore, be designed so that the occupants of floors above a dwelling which is on fire may, if they choose, remain safely on their own floor**. It may be necessary to evacuate the floor on which the fire occurs, and in some circumstances those floors which are in the immediate vicinity of the fire, but the occupants of these floors should be free to reach safety in any other part of the building via the staircase.”*

CP3 Chapter IV Part 1 (1962) provides recommendations for three stages of means of escape:

a) Stage I: internal planning of flats and maisonettes

b) Stage II: escape routes from flats or maisonettes to main staircases

c) Stage III: main staircases in blocks of flats

CP3 Chapter IV Part 1 (1962) makes specific recommendations for the fire resistance of structural elements which are of particular importance or additional to those set out in byelaws or regulations:

“It should be noted that the grade of fire resistance recommended below for some parts of the structure may be in excess of that required in byelaws or regulations. Where this is so the view is held that a larger factor of safety is desirable than is provided by the byelaws or regulations.”

Clause 303 requires *“the fire resistance of columns and load bearing walls, and of beams and floors which are essential to the stability of a building in the event of a fire should not be less than one-and-a-half hours”*

Therefore, the recommended period of fire resistance to support the means of escape arrangements set out in CP3 Chapter IV Part 1 (1962) is 90 minutes.

We have compared the means of escape arrangements at Barton House with those set out in CP3 Chapter IV Part 1 (1962). The features of Barton House analysed in this comparison are illustrated in Figure 8. The original arrangement of Barton House aligns with CP3 Chapter IV Part 1 (1962) as follows:

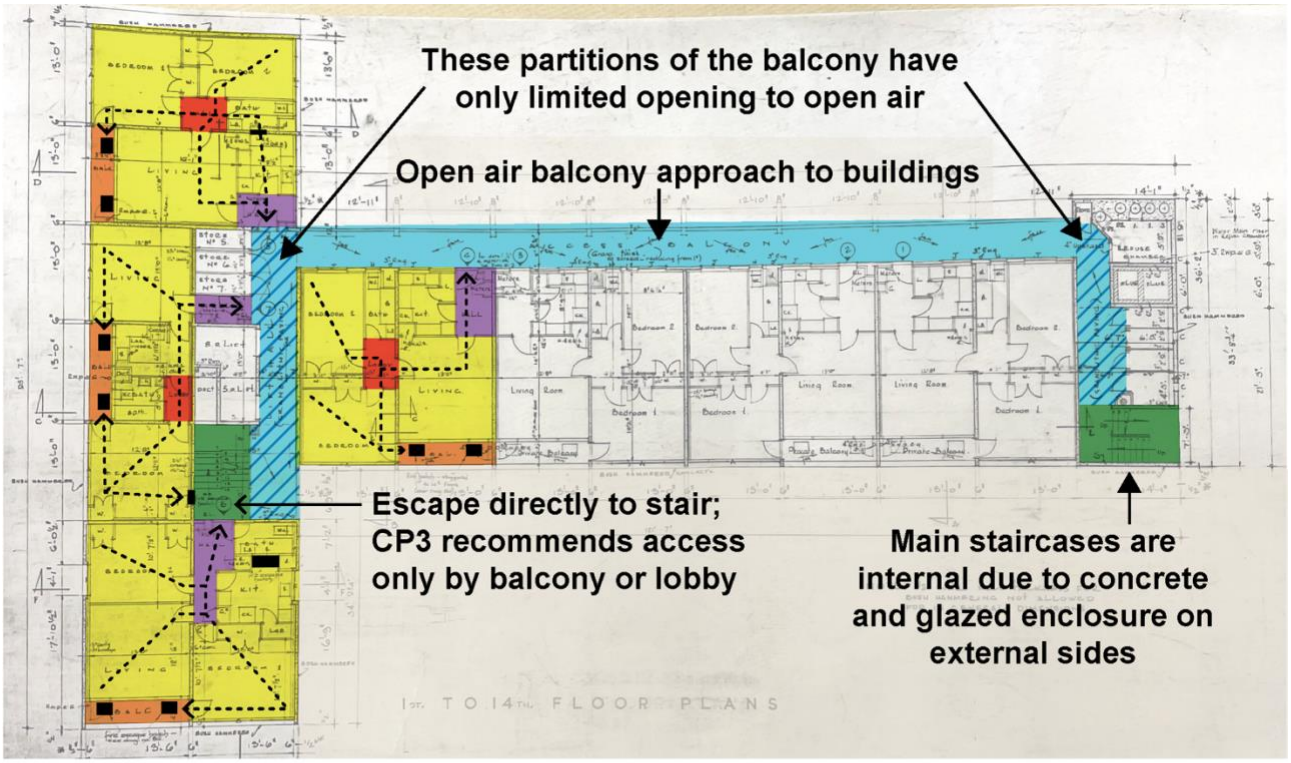
a) **Stage I (internal planning of flats):** Flats were planned with a private entrance hall with no fire risk. Bedrooms are accessed through the lounge; these bedrooms are separated from the lounge by an inner hall and an alternative dwelling exit by means of a vertical fire hatch located in the residential balconies. In flats where bedrooms do not have a window to the balcony approach[7] to the escape staircases further escape hatches were planned providing an alternative means of reaching the balcony approach or a main staircase. The provision of the inner hall and alternative exits align with Clause 206 a.ii of CP3 IV 1962 which stated *"if necessary to pass from one bedroom to another in order to reach the alternative, the bedrooms should be connected by…. Inner hall which is cut off by a self-closing door from any other part of the flat"*. Although it should be noted that CP3 IV 1962 does not specifically describe the use of fire hatches.

b) **Stage II (escape from flats to main staircases):** Escape from the common areas of Barton House is by the external balcony approach to one of two remote staircases. As escape from each dwelling is by the balcony approach to one of two stairs the design aligns with Clause 207 a.ii of CP3 IV 1962 which stated *"alternative exits from each dwelling are considered to be necessary. A balcony on one side leading to main staircases at opposite ends will provide two such exits."*

c) **Stage III (main staircases):** The main staircases do not align with the recommendations as CP3 IV 1962 (Clause 208, 306) recommends they are enclosed throughout their height and having fire resistance of not less than one hour. The staircases in Barton House are not enclosed or separated from balconies by fire resisting construction throughout their height. Nor do they appear to be external stairs as glazing is present to both staircases.

[7] Balcony approach is defined in CP3 IV 192 as *"A design in which each dwelling is approached externally by means of a balcony".*

Figure 8 Comparison of means of escape provisions with recommendations of CP3 IV 1962



KEY:

- Stage I escape: Dwelling
- Stage II escape: Balcony approach
- Stage III escape: Main staircases
- Entrance hall
- Bedroom lobby/hall
- Residential balconies
- Fire escape hatch

4.5.4 Discussion

The applicable building byelaws required a minimum grade of fire resistance of one hour for Barton House as it was a domestic building greater than 50ft.

However, it appears likely that the principles of stay put and the arrangements of means of escape set out in CP3 Chapter IV (1962) were applied at Barton House.

CP3 Chapter IV (1962) was the first code of practice to detail an evacuation strategy in this way and set purposeful design recommendations for what is now referred to as stay-put evacuation.

It made clear that a higher period of fire resistance than that required by byelaws was needed as "*a larger factor of safety is desirable than is provided by the byelaws or regulations".*

Therefore, in our professional opinion the higher performance of 90 minutes was the appropriate period of fire resistance for Barton House using the codes of practice at the time.

It should be noted that today the required period of fire resistance for a residential building greater than 30m is 120 minutes.

4.6 Assessment of structural fire resistance

4.6.1 Method of Assessment

The period of fire resistance of reinforced concrete elements of structure of existing buildings can be determined using the following approaches:

1. By reference to historical sponsored fire resistance testing for the specific construction. Sponsored fire resistance testing is carried out by the manufacturer or proprietor. This method is appropriate for proprietary forms of construction such as the precast beams provided by Gothic Construction Limited[8] for Barton House. Records of fire resistance tests are limited from this period; records published in 1960[9] have been reviewed however no relevant test records were identified for Gothic pre-cast beams.
2. By reference to the rules for fire resistance design in structural codes of practice at the time of construction. This method may be applied to the loadbearing walls only.
3. By calculation using methods of analysis set out in current codes of practice – this method may be applied to both the floor slabs and wall construction.

In our assessment we have used the third method of assessment which is applicable to all critical elements assessed.

The assessment conducted is based on resistance to a single dwelling fire. This is the basis of design as set out in the legislation and codes of practice at the time of construction of Barton House and currently.

The 'standard temperature-time'[10] curve is used to define the heat exposure to the structure. It is the standard method of defining heat exposure in the determination of load bearing fire resistance. The current standard temperature-time curve is the same as that in use at the time of construction.

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[8] https://www.jstor.org/stable/44128191 [accessed 11/01/2024]

[9] Sponsored Fire-Resistance Tests on Structural Elements, H.M Stationery Office (1960)

[10] BS EN 1991-1-2:2002 Eurocode 1: Actions on structures. General actions - Actions on structures exposed to fire (incorporating corrigenda March 2009, November 2012 and February 2013)

4.6.2 Floor slabs

A 2D thermal response analysis of the floor slabs was conducted to determine the temperature affected depth of concrete and bottom reinforcement. Heating was applied to the underside of the slab and an ambient temperature condition to the top surface. The analysis was conducted based on a depth of cover range of 10-15mm consistent with the site survey findings.

A structural analysis of the slab acting as a simply supported floor was then performed. This established a likely fire resistance period of 55-70 mins, accounting for the measured variation in concrete cover.

Arup have been asked by Bristol City Council to review whether the plaster finish to the floor slabs could make a contribution to their fire resistance. Our review of the potential contribution is set out in the below sub-section.

Contribution of plaster finish to floor slab fire resistance

A plaster finish to the underside of the floor slabs was observed. Arup observed this plaster finish during the site surveys and measurement of its depth on two occasions. Arup observed the depth of plaster finish being measured as 8-9mm. The plaster finish is believed by Bristol City Council to be hand applied; variability in the depth of plaster should therefore be expected.

No specific material testing of the plaster material has been carried out. Bristol City Council have informed Arup they believe the plaster material to be the original finish applied at the time of construction.

Arup have reviewed technical standards from the time of construction and more recent standards for guidance regarding the contribution of applied plasters to the fire resistance of concrete slabs.

The code of practice for reinforced concrete at the time of construction CP114 1957 makes reference to *"board, plaster or spray treatments"* providing additional protection but stops short of setting out specific rules for how they can be applied.

Guidance on fire resistance of proprietary structures at the time[11] (1960) also notes applied finishes can provide protection but warns that some will fail early:

"Plaster in its many forms is a useful fire-protection material which also provides a finished surface when applied direct to a background or when used on metal lath. On a solid base, normal plasters make only a limited contribution to the fire-resistance of the constructions of which they form part, even when the surface is specially prepared. When applied to metal lath the usefulness of the plaster as fire protection is likely to be terminated only if the fixings fail. It should be noted that when applied metal lath the thickness of the plaster is measured from the outer face of the lath. Plasters made with lightweight aggregates such as exfoliated vermiculite and perlite have exceptional insulating properties and, when used on the appropriate background their adhesion is high."

More recent guidance in BR 128 'Guidelines for the construction of fire-resisting structural elements Rev 2' (1988) includes specific guidance whereby an equivalent thickness of concrete may be replaced by the various named protection.

[11] Sponsored Fire-Resistance Tests on Structural Elements, H.M Stationery Office (1960)

It sets out 5 different forms of directly applied protection (a) mortar, (b) gypsum, (c) lightweight plaster, (d) sprayed lightweight plaster and (e) vermiculite slabs. The use of this guidance is subject to the following specific conditions:

1. **Material properties**: *"The appropriate thicknesses will depend on the precise properties of the material selected and reference should be made to the manufacturer"* – in the case of Barton House the specific material type and properties are unknown.
2. **Key/bond:** *"Direct application of plaster or sprayed fibrous material, or the provision of a fire protecting ceiling under the floor, are some of the ways in which improvements can be made. It is important to ensure adhesion of the coating where it is directly applied. In the case of plaster protection, adequate key and bond may have to be provided by combing the surface of the concrete but this will depend on the plaster type used."* – in the case of Barton House it is not possible to identify whether any surface preparation was made to provide key and bond.
3. **Lightweight plaster:** *"Recent changes made in the formulation of premixed lightweight plasters and work completed on the revisions to BS 476: Part 8 and the British Standard Codes of practice concerning concrete, masonry and timber constructions has necessitated revising both the text and tables of the 1982 edition which is now withdrawn"* The guidance set out is relevant to recent changes in the formulation of premixed lightweight plasters, therefore this cannot apply to Barton House which was constructed some 30 years before the publication of BR128.

Due to the uncertainty around the material performance of the existing plaster finish we have not included its thickness or an equivalent thickness as per BR128 guidance in our calculation of fire resistance above (this Section 4.6.2).

In terms of the potential significance of the plaster, if it could be established that the material present was for example a gypsum plaster with appropriate key and bond, the plaster finish could be considered to provide an additional ~6mm of cover to the concrete reinforcement. This would increase the estimate of fire resistance of the floor slabs from 55-70min to 70 - 85min.

4.6.3 Internal Cross Walls

The 2D thermal response analysis of the internal cross walls was carried out under two scenarios: (a) heating from both sides and (b) heating from one side only. The former represents the case of a fire affecting an internal dwelling cross wall and the latter a fire affecting a cross wall between dwellings. The former is the worst-case scenario as it results in the greatest depth of heat affected concrete and reinforcement. The analysis was conducted using the minimum observed depth of cover 25mm.

A structural analysis of the strength and stability of the wall was performed. This established a likely fire resistance period of 86-120 mins, for the range depending on whether the exposure is from either two sides or one side respectively.

4.6.4 External flank walls

The 2D thermal response analysis of the external flank wall was conducted for observed minimum cover of 25mm and included the presence of the lightweight blockwork. Our analysis established that the thickness of this construction in front of the flank wall provides sufficient insulation to prevent any significant strength loss of the steel reinforcement or concrete for the duration of the applied 120-minute heat exposure.

Therefore, the external flank walls (including the adjacent blockwork construction) can be considered to achieve a period of fire resistance in excess of 120 minutes.

4.6.5 Summary of Results

Element of construction	Estimate of load bearing fire resistance (minutes)	Additional comment
Floor slabs	55 – 70 min	The presence of a wet applied plaster may increase the fire resistance duration if it is sufficiently robust to remain in place. Insufficient information regarding the material and its adhesion is available to rely definitively on it for protection, and therefore it has been ignored. The range represents the range of measured cover to the reinforcement.
Cross walls	86 – 120 min	The lower bound represents exposure from one side in the case of a cross wall between dwellings and the upper bound represents exposure from two sides in the case of a crosswall within a dwelling
External Flank Walls	>120 mins	The performance of the external flank wall is greater than the cross walls due to the presence of the lightweight blockwork wall and cavity airvoid.

4.6.6 Further surveys of structural cover and finishes depth to floor slab bottom reinforcement

On 20th December 2023 Arup was provided with further survey data for the floor slabs in Barton House, based on extensive scanning carried out in 6 flats (2 rooms per flat) on different floors (See Table 1).

These additional surveys provide data on the combined depth of concrete cover to reinforcement and plaster finish. We have set out in Section 4.6.2 our reasons for excluding the plaster finish layer from the fire resistance calculation for the floor slabs. Arup understand that:

- No breakout of the slab underside was carried out to directly measure reinforcement cover in these additional surveys. This is Arup's recommended method to verify measurements.
- The depth of plaster finish was not measured during these scans. The plaster finish is believed to be hand applied and therefore variability in its depth of application is to be expected. Arup have observed only two physical measurements of the plaster thickness; this is insufficient to determine the likely variability of the plaster finish. Therefore, the thickness of concrete cover to the reinforcement cannot be derived from the data with confidence.

Therefore, there is significant uncertainties associated with the additional scan measurements. We believe confidence in the additional measurements is not sufficient to revise our assessment of fire resistance periods for the structure.

As part of our review, we have reviewed the data and its implications for the minimum depth of cover to likely to be expected per beam. If it could be established that the variation in the plaster finish from the measured 8-9mm was low the obtained data provides further evidence that our assessment of fire resistance of the floor slabs in the range of 55-70min is reasonable. It does not indicate that the fire resistance of the beams and therefore slab achieves or exceeds 90 min.

4.6.7 Implication of the findings

The fire resistance of the floor slabs and in some instances the walls is less than the 90 minutes fire resistance standard recommended for a stay put evacuation strategy. This means that in the event of a single dwelling fire there is an increased risk of local structural failure compared to a structure which would achieve at least 90 minutes fire resistance. This is separate from the risk of disproportionate collapse which we address in Section 3.

The fire resistance is, however, commensurate with building byelaws in place at the time of construction for buildings which we understand did not rely on stay put evacuation, i.e. 60 minutes.

To address this identified risk at Barton House, there are two potential options:

- The first is to increase the fire performance of the existing structure. For example, this can be achieved by applied fire protection to the slab soffits or fire protection to all the existing steel frame goal posts (i.e. not just the flank wall steel frames as recommended Ridge in their Jan 2024 report to enhance robustness). Note that this option would require further structural fire assessment work to be undertaken.

- Alternatively, a simultaneous evacuation strategy initiated by means of reliably detecting the outbreak of fire anywhere within a flat (i.e. detection in all rooms) followed by automatic building wide alarm. This performance standard is set out in the National Fire Chiefs Council publication *Guidance to support a temporary change to a simultaneous evacuation strategy in purpose-built blocks of flats* Version 4 (2022) Appendix A.

Arup understands from Bristol City Council that the façade of Barton House contains combustible Expanded Polystyrene (EPS) as part of a render finished insulation system; the fire safety hazards associated with this system have not been assessed by Arup. The risk management of the EPS will need to continue to be managed by Bristol City Council until such time as it is removed, or the building is decommissioned.

Arup have considered the hazard associated with the EPS render finished insulation system only in the context of its impact on the likelihood of the development of structurally significant fires in Barton House. A structurally significant fire is one that can heat the structure to such a degree that its strength and/or stability is impacted. An uncontrolled external fire involving the EPS which causes multi-dwelling fires is significantly more extreme than the single dwelling fire for the structure that we have assessed (as set out in the legislation and codes of practice at the time of construction of Barton House and also currently). The presence of EPS therefore further increases the risk associated with the identified lower period of fire resistance of the structure.

Based on our assessment of the structure and the hazard presented by the EPS with regards to the potential impact on the structure for a fire spreading via the façade, it is our opinion that a simultaneous evacuation strategy initiated by means of detecting a fire anywhere within flats (i.e. detection within all rooms) will provide a greater reduction in risk level than increasing the fire performance of the existing structure. The inclusion of such a system also aligns with the NFCC guidance for buildings with combustible external wall insulation systems where an all-out evacuation strategy is adopted.

It is Arup's understanding that at the date of issuing this report that Bristol City Council intend to pursue the option of a simultaneous evacuation strategy initiated by means of reliably detecting the outbreak of a fire anywhere within a flat followed by an automatic building wide alarm for Barton House.

5. Conclusions and recommendations

Arup has carried out both a peer review of the second Ridge report, and a high-level review of Ridge's methodology used for their robustness assessment for Barton House. From our own observations and peer review, we are in agreement with Ridge's conclusion that once the proposed works as described in the second Ridge report are complete, "*it is suggested that the building is at relatively low risk of disproportionate collapse and therefore Barton House would behave adequately during an accidental event.*"

We also agree with the principle of strategically relying on the 1970s installed steel frames, acting in combination with the robustness ties observed during the recent structural investigation, to locally enhance the building's robustness in locations identified in Appendix C of the second Ridge report.

To lower the risk of disproportionate collapse in the event of a single dwelling or storeroom fire we recommend, in addition to Ridge's recommendations that the following are undertaken:

- In all locations identified by Ridge the steel frames are provided with suitable applied fire protection to achieve 90 minutes load bearing fire resistance. The applied fire protection should be designed and installed by suitably competent persons.
- The common area storeroom subdividing walls are inspected to confirm they are of adequate construction and thickness to likely achieve 30 minutes integrity and insulation fire resistance. The existing walls should also be checked for any openings between storerooms; any identified openings require being fire stopped by certified products. Guidance on the likely fire resistance of existing construction can be found in BR 128 *Guidelines for the construction of fire-resisting structural elements*.
- For recommended door vents in common area storerooms, where these are to be located in a door which is required by the Barton House fire risk assessment to have a fire resistance, it is recommended that grilles/vents that can achieve 30 minutes integrity (or higher) fire resistance are provided. Note this recommendation is to ensure that measures adopted against disproportionate collapse do not inadvertently reduce the level of fire protection along escape routes.

To address the identified lower period of load bearing fire resistance of the structure than recommended by CP3 IV for a stay put evacuation strategy *and* the increased risk of structurally significant fires due to the EPS rendered finish system, it is recommended that a simultaneous evacuation strategy initiated by means of detecting a fire anywhere within a flat is adopted. Such a system is described in National Fire Chiefs Council (NFCC) guidance Appendix A.

Bristol City Council will need to continue the risk management of the EPS until such time as it is removed, or Barton House is decommissioned.

Bristol City Council will need to consider this assessment in discharging their roles as Responsible Person and Principal Accountable Person under the Regulatory Reform (Fire Safety) Order 2005 and Building Safety Act respectively.

5.1 Obligations under the Regulatory Reform (Fire Safety) Order 2005 and Building Safety Act

To meet obligations under relevant fire safety legislation, if Bristol City Council decide to re-occupy Barton House:

- The Responsible Person should: include this assessment and the recommendations for methods of mitigating the identified risk in their fire safety risk assessment; and review their procedures for serious and imminent danger, including the necessity for Personal Emergency Evacuation Plans (PEEPs).

- The Principal Accountable Person should consider this assessment and the recommendations for methods of mitigating the identified risk in the preparation of their safety case; including sharing with any person(s) appointed to assist them in preparation of the safety case.