RIDGE

BARTON HOUSE

STRUCTURAL ROBUSTNESS ASSESSMENT

BRISTOL CITY COUNCIL

July 2022

BARTON HOUSE

STRUCTURAL ROBUSTNESS ASSESSMENT

July 2022

Prepared for

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1. INTRODUCTION

1.1. Site Address

Barton House
Cotton Mill Lane
Bristol
BS5 9SL

1.2. Structural Engineering Brief

Ridge and Partners LLP (Ridge) were appointed by the Bristol City Council to carry out structural investigations to determine the robustness of the dwelling block, Barton House, Bristol. The appointment came following owners of LPS dwelling blocks, including Bristol City Council, were advised to seek professional advice regarding the safety of their assets by the Ministry of Housing, Communities & Local Government (MHCLG).

The brief was therefore to carry out an audit on the construction of the block, based on available historic information, followed by detailed intrusive investigations into selected areas of the block. The construction details of the block obtained from this audit would then form the basis of the structural assessment to determine whether the construction of the block was sufficient to resist progressive collapse in the event of accidental loading from an internal gas explosion.

1.3. Report Contents

The contents of this report relate exclusively to the construction of Barton House and its structural condition at the time of inspection. The report has been compiled following the visual inspection and a series of intrusive and non-intrusive tests conducted on a limited number of pre-selected areas of the structure.

This report documents the main findings of the investigation and the findings of the subsequent structural assessment into the robustness of the blocks against disproportionate collapse.

1.4. Limitations

Throughout the duration of the intrusive investigations the blocks remained inhabited by residents. This presented challenges to the investigation team in terms of availability of vacant flats within which intrusive investigations could be undertaken. Three suitable flats were identified, although none were available at top floor level and as such no information was uncovered with regard to the connections at roof level.

Whilst the investigative works were detailed, with multiple tests carried out in each of the three flats, it should be noted that many areas of the block were not tested and thus the assessment of the blocks can only be based on what was uncovered in the sample investigation. The investigations were also only carried out from within the flats. No works were carried out externally or in the communal areas due to H&S (Health and Safety) concerns for the residents.

All flats within the block are single (no duplex apartments), and the floor is constructed from a series of precast concrete beams. It was therefore not possible to obtain core samples from floor slabs for compressive testing.

1.5. Statement

The purpose of the Report is to advise on the construction of the LPS structure and its susceptibility to disproportionate collapse, together with those related matters specifically referred to therein and it is not intended to be used for any other purposes. The Report is for the sole benefit and may only be relied upon by the addressee, to whom we will owe a duty of care. The Report or any part of it is confidential to the addressee and should not be disclosed to any third party for any purpose, without our prior written consent of Ridge and Partners LLP as to the form and context of such disclosure. The granting of such consent shall not entitle the third party to place reliance on the Report, nor shall it confer any third-party rights pursuant to the Contracts (Rights of Third Parties) Act. The Report may not be assigned to any third party.

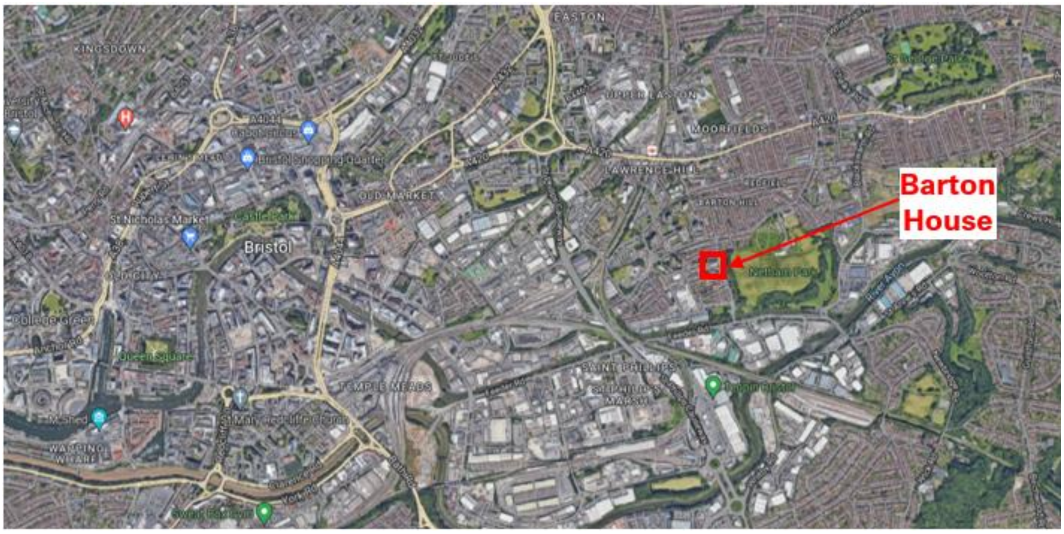


Figure 1 – Barton House Location (Google Maps, 2022)

Figure 2 – Barton House (Google Maps 2022)

2. EXECUTIVE SUMMARY

The dwelling block, Barton House, Bristol has been subjected to intrusive opening up works to confirm the condition and construction of the block, and an assessment for its robustness to resist accidental loading and its susceptibility to progressive collapse has been carried out. The intrusive investigation showed that the building was not LPS, but another form of precast system utilising in-situ concrete walls, and precast concrete beams for the floor slab. Despite not being LPS, the findings suggested that the building may be susceptible to disproportionate, progressive collapse and as such it was decided to continue with the programme of assessments.

A select number of flats were subjected to intrusive and non-intrusive investigative methods, including visual inspection, concrete testing and intrusive opening-up works. The results of the investigations were documented and used as the basis of this structural assessment.

The BRE Report 511 states that LPS blocks can be assessed under three criteria, of which a block needs only pass one. The criteria and results relating to Barton House are as follows:

LPS Criterion 1 – Adequate Ties (Reinforcement) within Joints

BARTON HOUSE – ADEQUATE TIES	
JOINT	PASS / FAIL
Flank Wall	FAIL *
Cross Wall	FAIL *
CONCLUSION - FAIL	

* The construction appears to have sufficient vertical ties due to the continuity in the in-situ wall. Whilst some horizontal ties were found, these cannot be considered effective as some were missing entirely.

LPS Criterion 2 – Adequate Strength to Resist Accidental Loads

It is believed that all flats within Barton House no longer have a piped gas supply. Historically, the building also used a district heating system which had gas boilers installed within the basement of the block, although this has also since been decommissioned. In the absence of piped-gas within the building, the BRE Report 511 states that the block must be assessed against an overpressure of $17kN/m^2$, treating each loadbearing member as a key element. The below table shows the outcome of the checks on each structural member.

BARTON HOUSE – KEY ELEMENT CHECKS (WITHOUT PIPED-GAS SUPPLY – $17KN/M^2$)	
JOINT	PASS / FAIL
Flank Wall	FAIL
Cross Wall	PASS
Floor Slabs	FAIL
CONCLUSION - FAIL	

Despite the historic strengthening works undertaken on the block, the lack of structural tie observation suggests that the block might be insufficient to resist the loads.

LPS Criterion 3 – Ability to Mobilise Alternative Load Paths

Due to the number of structural elements that fail in the event of an explosion, it is unlikely the block would be able to develop adequate load paths to prevent disproportionate collapse in its current state.

BARTON HOUSE
Unable to mobilise alternative load paths
CONCLUSION - FAIL

The conclusion is therefore that the block in its current state is inadequately robust to prevent disproportionate collapse in the event of an internal gas explosion.

Our recommendations are as follows:

To address the failings of the disproportionate collapse requirements, works are required to the block. It is likely that, if the blocks are to be retained long-term, that this will include strengthening works. The required remaining life of the block should be discussed.

A risk analysis should be carried out to determine:

- Whether the risk can be reduced to an acceptable level through risk-reduction measures for the duration of the remaining life of the blocks.
- Whether risk-reduction measures are not alone sufficient, and strengthening works are required.

If the risk analysis shows it to be required, a suitably qualified structural engineer should carry out strengthening proposals for the blocks. A cost-benefit analysis should then be carried out, accounting for the short remaining life of the blocks, to understand whether the strengthening works are suitable. Accelerated demolition programme may need to be considered following the results of the cost-benefit analysis.

3. BRIEF HISTORY OF LPS BLOCKS AND DISPROPORTIONATE COLLAPSE

On the 11th March 1968 construction was completed on a 21-storey dwelling block in Newham, East London, called Ronan Point. Two months after opening, the block of flats suffered progressive collapse to the south-east corner of the structure. A subsequent Tribunal found that the partial collapse was caused by an explosion of town gas in one of the flats. The explosion had caused the loadbearing flank wall of the flat to 'blow out', thus removing the support to the other loadbearing elements and causing further elements to fail. This event sparked a series of changes to legislation related to the design of new LPS structures and required the existing LPS building stock to be assessed.

Since this date several further documents have been produced to provide advice on the structural assessment of LPS buildings from leading professional bodies such as the Institution of Structural Engineers and the Building Research Establishment (BRE). Today the assessment process of LPS blocks is generally carried out based on the guidance provided in the BRE Report 511 – Handbook for the Structural Assessment of Large Panel System (LPS) Dwelling Blocks for Accidental Loads.

In more recent times, an investigation undertaken on the Ledbury Estate in 2017 showed that the LPS blocks were insufficiently robust to resist disproportionate collapse. Subsequent to this, the government wrote to local councils who owned LPS blocks within their housing stock to request that they be subjected to structural assessment.

4. BARTON HOUSE INVESTIGATION

4.1. Investigation Overview

The dwelling block, Barnet House located in Bristol has been assessed for its robustness to resist accidental loading from over-pressure, such as an internal gas explosion, and its susceptibility to progressive collapse. The block is believed to have been constructed by Holland Hannen and Cubitt from a form of precast concrete construction for Bristol City Council, with construction commencing in 1956.

It had been believed that the block may be of Large Panel System (LPS) construction. This was later shown not to be the case. The true construction will be commented upon in the following sections.

4.2. Investigation Methodology

In the absence of the construction details of the blocks Ridge subjected three selected flats for both intrusive and non-intrusive investigation works to determine its construction, including:

- Visual Inspection
- Concrete Reinforcement Scanning
- Concrete Testing (in-situ & laboratory)
- Intrusive Opening Up Works

4.3. Main Findings of the Investigation

The floor plan shown in Figure 3 shows the locations of the investigations undertaken within the block. Flats 60, 65 and 78 were subjected to the intrusive opening up works. Flat 91 had been selected as it was believed this may have a flank wall. However, inspection on site found that the floor slab extended the other side of the wall to form the external walkway (making this a cross wall). Therefore, only the scanning and visual inspection phase undertaken, as we required a flank wall for the investigations (78 being chosen instead).

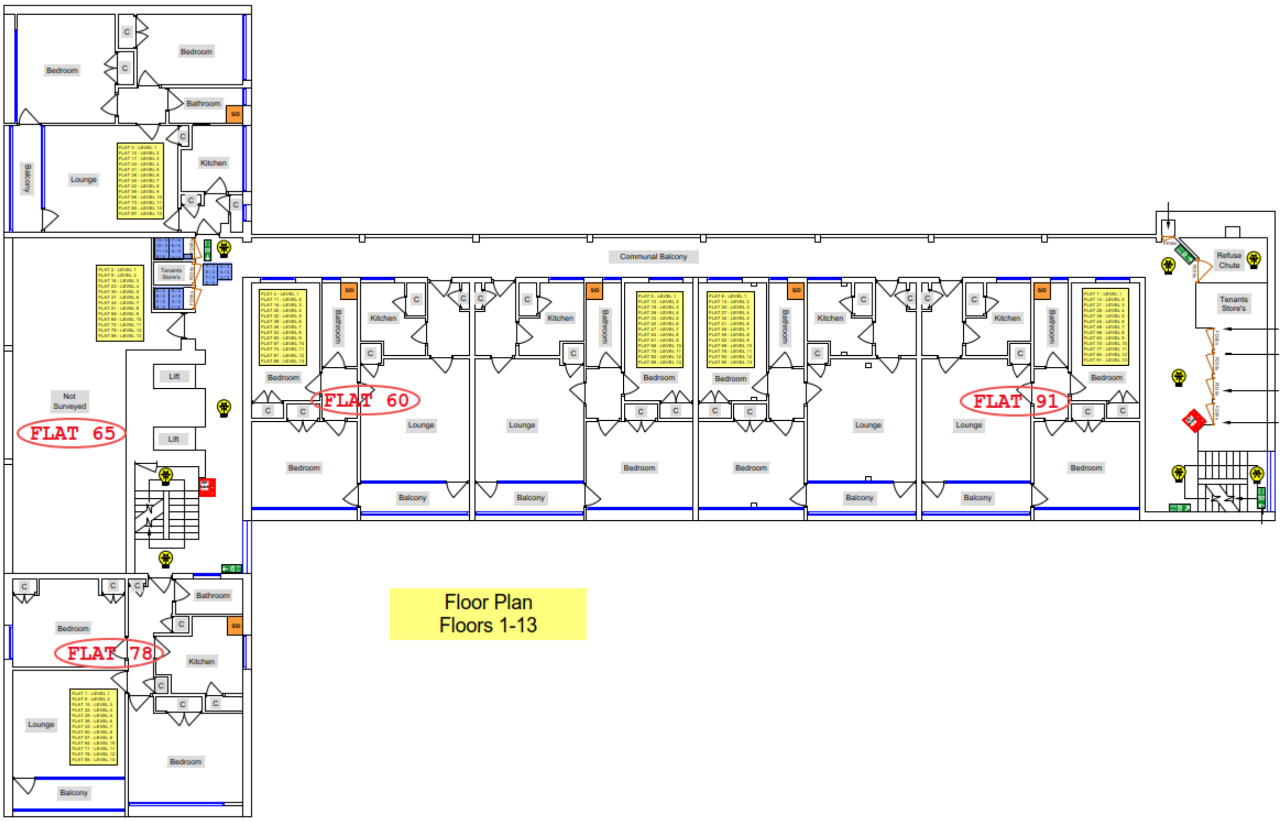


Figure 3 – Typical floor plan for Barton House showing the locations of the

It was originally believed that Barton House was construction from a form of Large Panel System (LPS). However, through the investigation works undertaken it appears that this is not the case, although the building is, in part, constructed from precast concrete members.

In an LPS block all loadbearing members are typically either large concrete floor slabs, or large concrete wall panels (sometimes precast concrete beams were also utilised). These were then lifted into position, and in-situ concrete poured into the joints to form a connection between the elements. However, at Barton House, this was not found to be the case. The loadbearing wall panels were found to be in-situ concrete members, and the floor slab was made up of a series of abutting precast concrete hollow beams.

Despite not being LPS, the precast form of the building, together with concerns over the adequacy of the details uncovered in the first flat lead Ridge to progress with the assessment as there were concerns that findings showed that the block could be susceptible to progressive collapse.

The below figures show the construction details found on site.

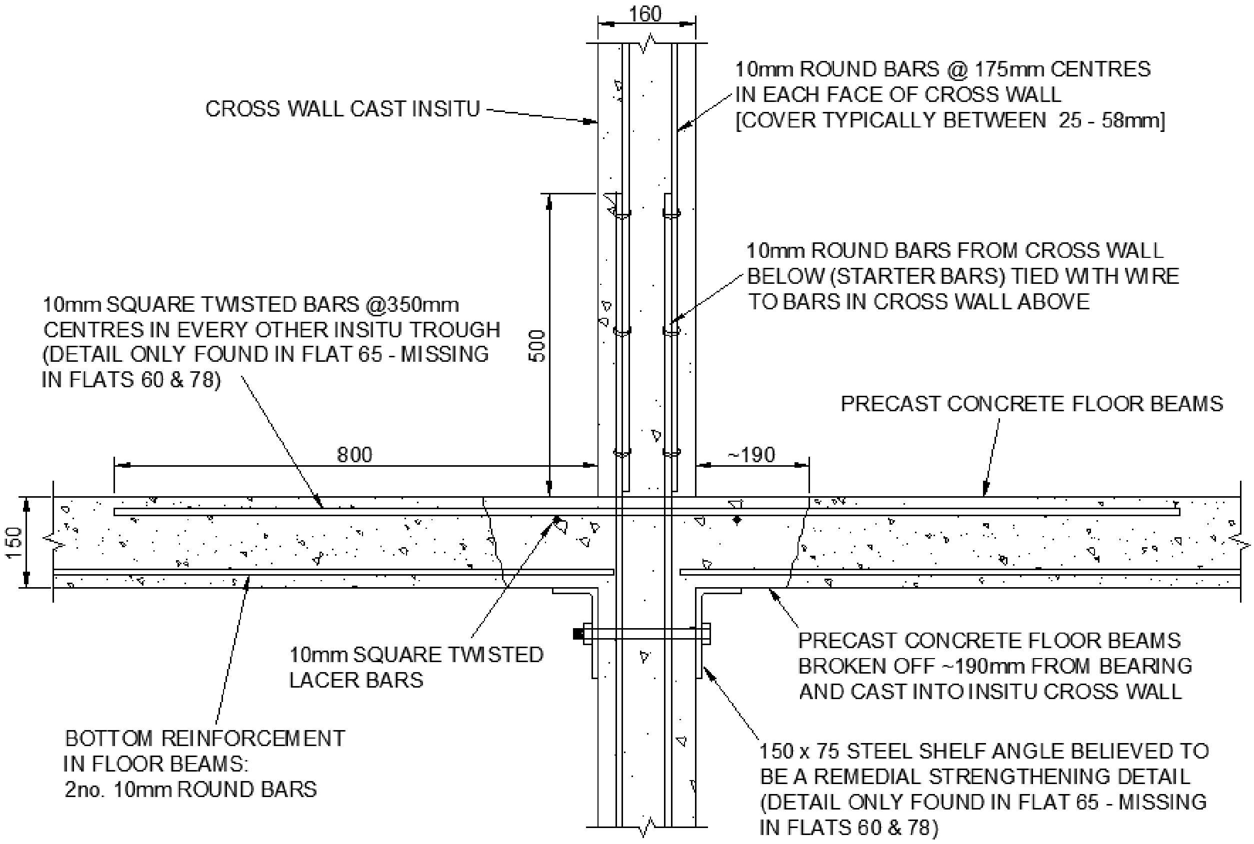


Figure 4 – Cross wall / floor slab joint

The floor beams were noted to have been broken off at their ends and had been incorporated into casting of the walls, likely to ensure a degree of homogeneity and to allow ties to be created between the elements.

The reinforcement within the columns extend from one wall into the one above, with a lap length of circa 500mm. For a 10mm diameter bar the required lap length to today's standards is 45d, ∴ 450mm. This is therefore consistent with today's standards.

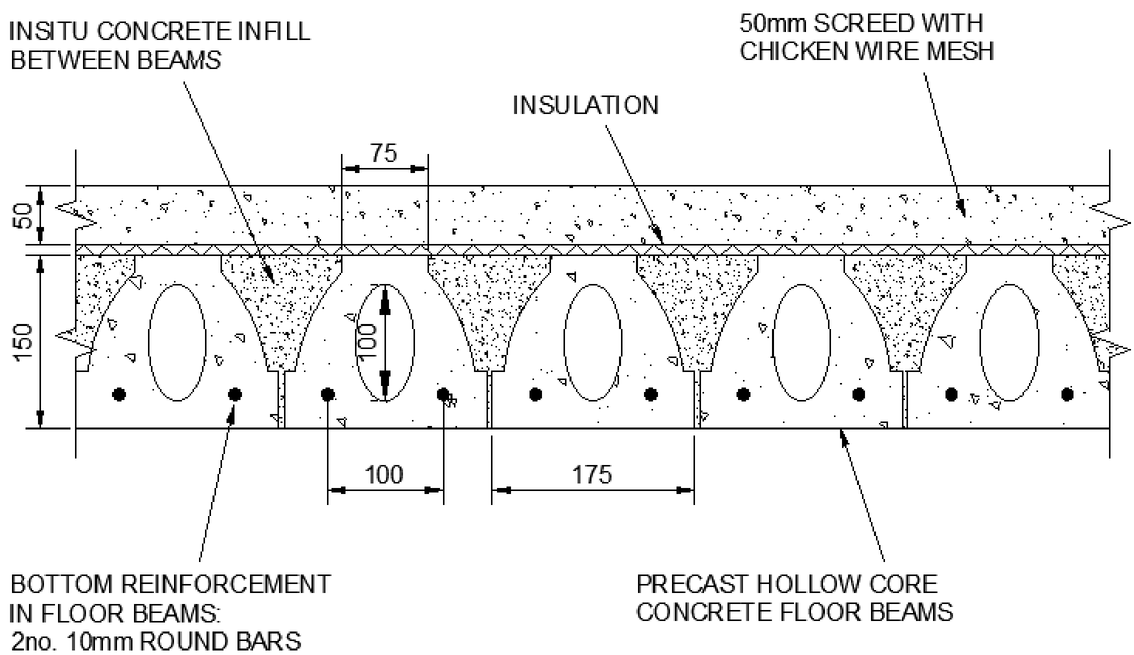


Figure 5 – Floor construction

In flat 65 it was found that there were horizontal tie bars inserted into every other grouted trough between the concrete beams. The beams were cast with a smooth face and as such friction between the ground and the precast beams is likely to be low. In the event of an internal gas explosion, it is likely that the tie bars would act sufficiently to resist disproportionate collapse.

Also, as noted prior, the horizontal ties which were found to be present in every other trough in flat 65 were not observed in the other flats investigated. In these locations, therefore, the assumptin for this assessment is that no tie have been provided during construction.

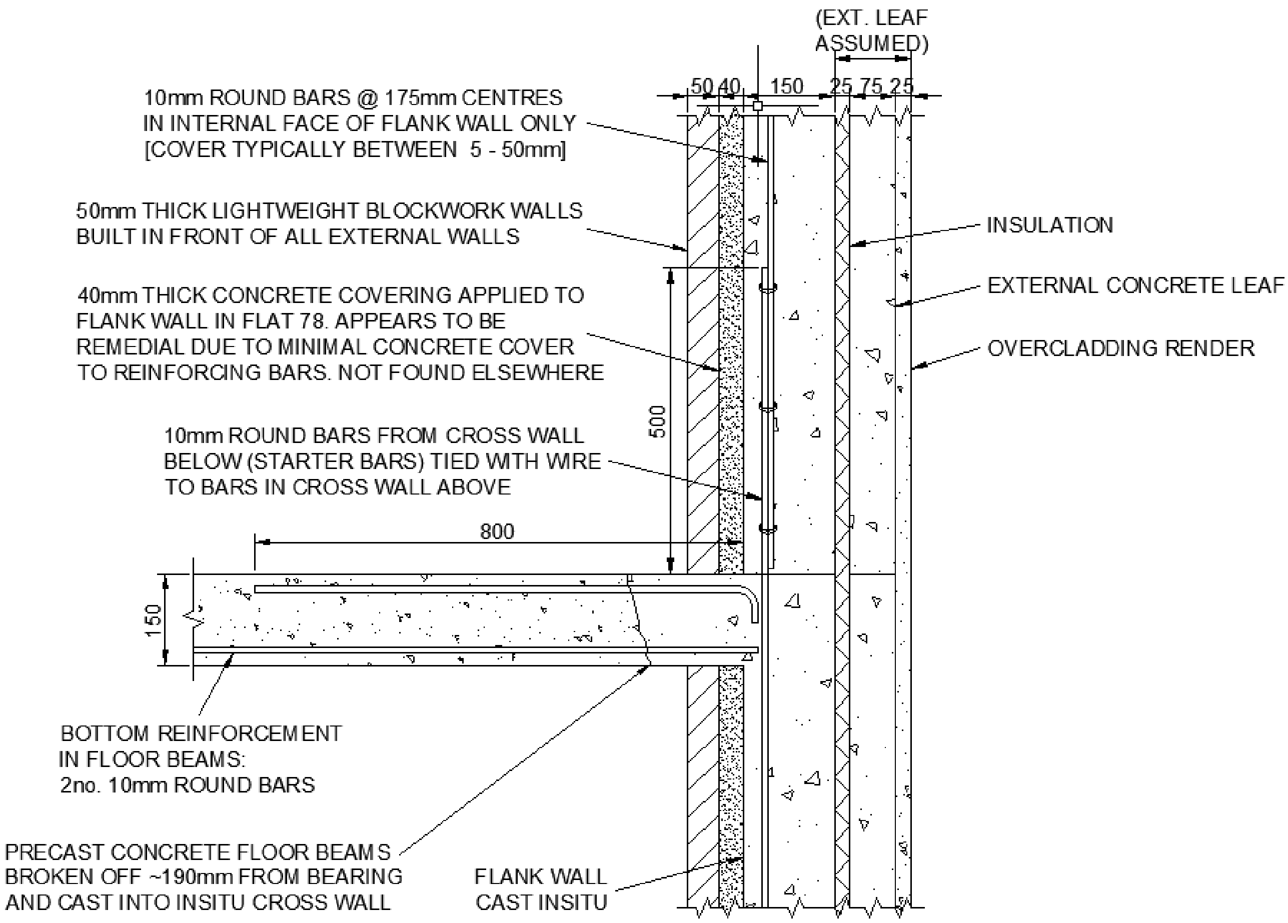


Figure 6 – Flank wall / floor slab joint

The investigations into the flank wall joint in flat 78 appear to show that the flank wall was reinforced in the internal face only, with no reinforcement in the outer face. The flank wall has an internal lightweight blockwork wall built in front of it (as did many of the cross walls whose otherside was to the exposed communal areas). However, with these flank walls it was also found that a 40-50mm layer of concrete had been roughly applied to the face of the flank wall, likely as a remedial action. It was found that the reinforcement in the two walls inspected had significantly low concrete covers (<5mm) so was likely applied for durability to prevent corrosion to the reinforcement (it is unlikely the wall would gain any additional strength from its application).

The investigation into the flank wall / floor slab joint suggested that there was no apparent effective horizontal ties provided. The connection appears to rely on a loop bar extending from the precast section into the insitu concrete. However, no lacers wrapping around were observed.

Historic Strengthening

It was also clear from the on-site investigations that the building, at some point during its history, had been strengthened with a combination of steel beams and columns. In some of the flats the cross walls / floor slab joint had been strengthened using steel angle brackets, likely to increase the bearing length on the floor slabs. However, these were noted to be missing on the cross wall in flat 78.

Figure 7 shows the floor plan in flat 65 with the locations of the strengthening works highlighted. It can be seen from the dimensions taken on site that the installed works have divided the span of the floor slab in half (roughly). Figure 8 shows the details observed of the remedial strengthening works.

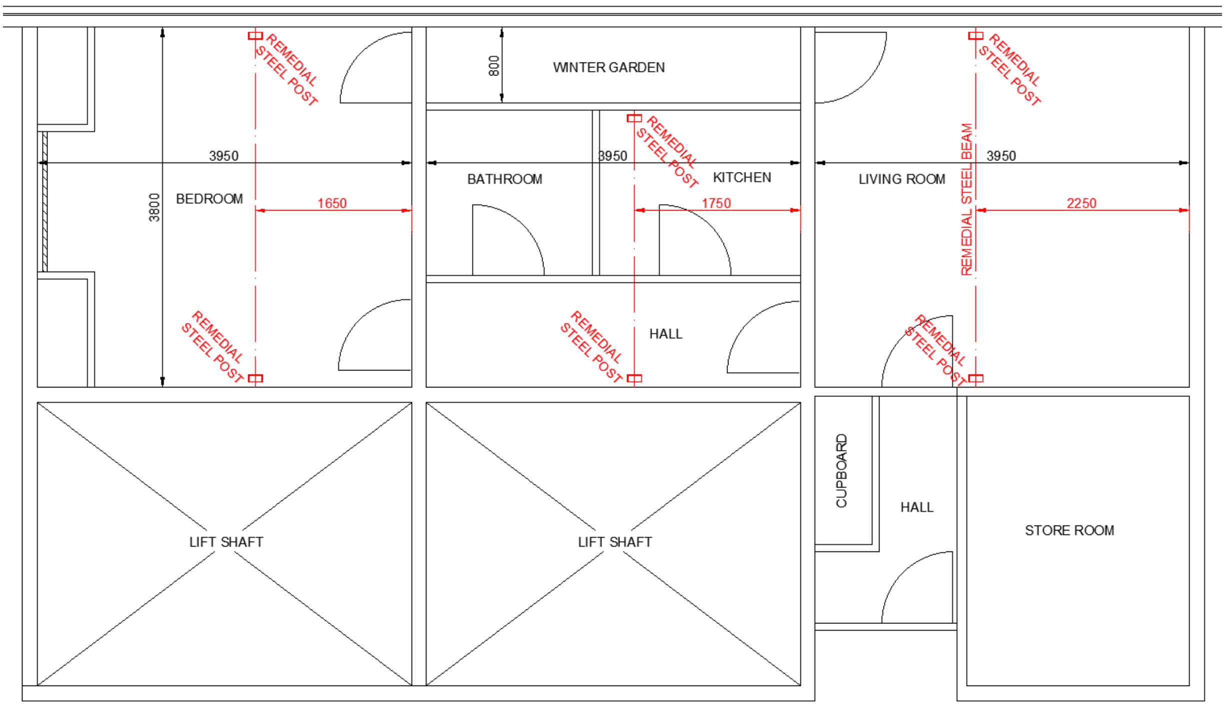


Figure 7 – Flat 65 floor plan showing location of strengthening beams and columns

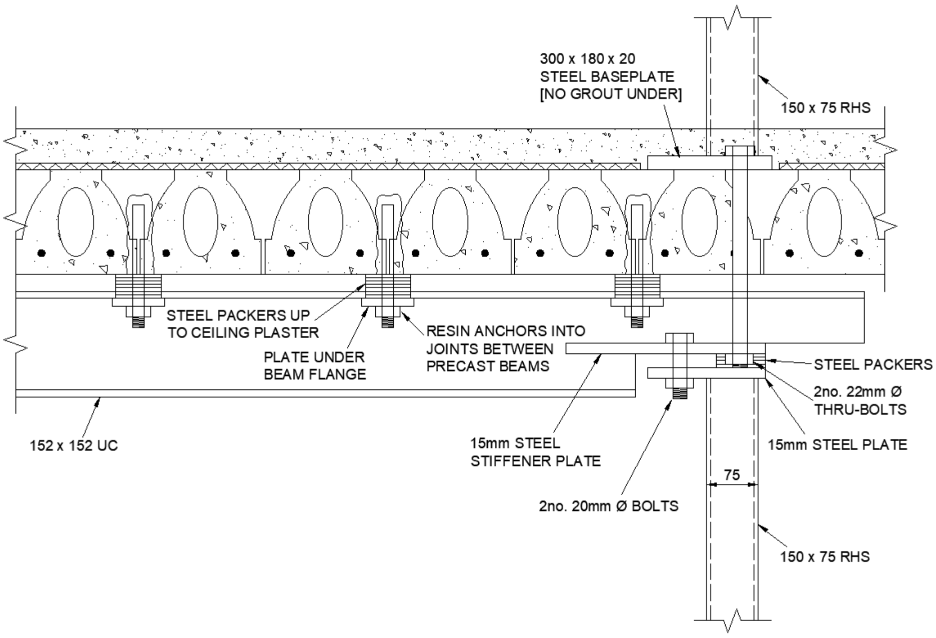


Figure 8 – Historic strengthening works to floor slabs

4.4. Concrete Testing

Carbonation

Carbonation testing is an intrusive, non-destructive testing method which determines the depth to which carbon dioxide in the atmosphere has penetrated the concrete. The cement paste in concrete generally has a pH of around 13 which creates a passive environment around the reinforcement, preventing corrosion. However, over time carbon dioxide diffuses into the concrete, which reduces the alkalinity of the concrete, subsequently losing passivity and its protection to the reinforcement within. Carbonation is not detrimental to the concrete until the passivity front has reached/exceeded the depth of the embedded steel. Once the passivity front has surpassed the reinforcement, and in the presence of moisture, the steel will begin to actively corrode and expand. This expansion creates internal pressure in the concrete and causes the concrete to crack and spall around the reinforcement. This test assesses the risk of corrosion to the reinforcement.

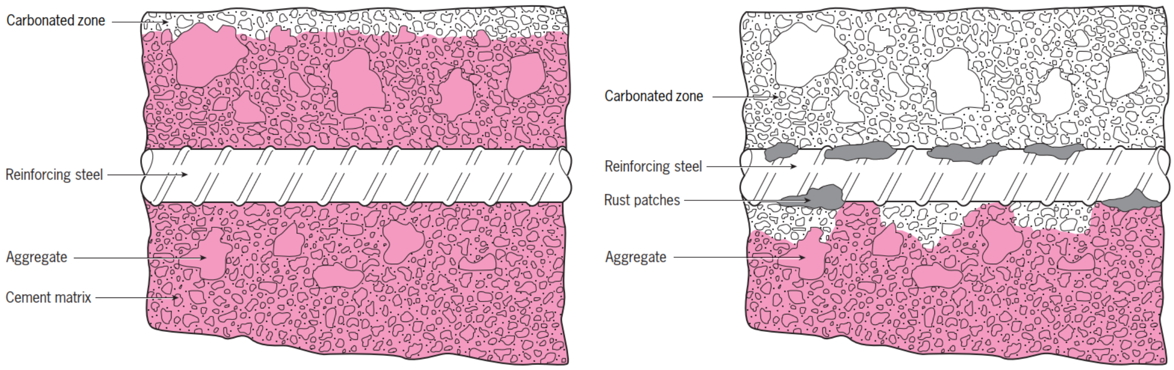


Figure 9 – (Left) Diagrammatic view of steel protected from carbonation-induced corrosion in partially carbonated concrete, (Right) Diagrammatic view of steel corroding in carbonated concrete. (BRE, 2000)

The testing was carried out by breaking out a small section of the concrete with a hammer drill. All the dust on the surface of the freshly exposed face was then removed with an air pump to prepare the surface for the testing. The indicator, phenolphthalein solution, was then applied to the freshly exposed surface using a pipette. The indicator turned pink when in contact with the concrete with a pH exceeding 9 and remained clear at a pH lower than 9. Concrete which turns pink is still providing a protective environment for the reinforcement, whereas the concrete which remains colourless has carbonated and would no longer be providing protection to any reinforcement which was located at this depth.

The results from the carbonation testing should only be used as a guide for the true depth of carbonated concrete. It has been suggested that the true passivity front extends between 5-10mm beyond the carbonation depth indicated using phenolphthalein solution. However, in areas which have high chloride content, this can be as much as 20mm beyond the indicated depth. These two limits should therefore be considered when assessing the risk of corrosion to the embedded reinforcement.

The carbonation depth was measured, from the face of the member to where the concrete turns pink, using a tape measure / callipers and recorded. The depth of carbonation recorded was then compared to the depth of the reinforcement to determine whether the passivity front had reached the reinforcement. Carbonation testing was carried out on all the anchor blocks which were safely accessible. The testing produced similar readings for the different test locations. The results of the carbonation tests are in Table 1 below.

CARBONATION TEST RESULTS					
Flat	**Test Location**	**Member Type**	**Carbonation Depth**	**Min. Cover to Bar**	**Carbonation Surpassed Reinforcement?**
Flat 60	1	Floor Slab	<5mm	14mm	No
Flat 60	2	Cross Wall	<5mm	17mm	No
Flat 60	3	Floor Slab	<5mm	30mm	No
Flat 60	4	Cross Wall	>35mm	30mm	Yes
Flat 65	5	Floor Slab	>25mm	13mm	Yes [1]
Flat 65	6	Cross Wall	28mm	22mm	Yes
Flat 65	7	Cross Wall	>35mm	26mm	Yes
Flat 78	8	Flank Wall	>20mm	5mm	Yes
Flat 78	9	Flank Wall	<5mm	22mm	No
Flat 78	10	Concrete Wall Covering [2]	0mm	N/A	No

Table 1 - Carbonation Depths

Notes:
1) Some bars in this slab were exposed during the opening up and were shown to have surface corrosion. It is not clear whether this is due to the carbonated concrete no longer affording the steel protection (active corrosion), or inadequate storage of the bars prior to manufacture (historic corrosion)
2) A concrete covering has been installed on the face of the flank walls in flat 78, likely in an attempt to remediate the significantly low concrete cover in the area. This concrete does not contain any reinforcement but will afford the reinforcement within the wall behind some protection by acting as a barrier.

In 50% of the members tested, the carbonation depth was observed to have surpassed the depth of the embedded reinforcement. In these locations, the rebar is no longer within an passive environment and may therefore no longer have sufficient protection from the concrete to prevent corrosion. The carbonation depths observed did not appear to be excessive for a structure of this age, so it likely the main issue is the low concrete cover in some areas. It was noted that the reinforcement did not have consistent cover, even within a single wall panel, suggesting there was poor quality control during construction.

Chlorides

Chloride testing was carried out by drilling the concrete with a hammer drill and the dust created collected and transferred into sealable bags. 9 no. dust samples were collected from across the three flats to be tested. The samples were then sent to Sandberg LLP's Clapham laboratory to conduct laboratory testing. The site is a UKAS accredited testing laboratory No. 0262.

Chlorides in concrete come from two sources. The first are cast-in chlorides which are present in the concrete mix at the time of casting typically from admixtures, some sources of aggregates and the cement. The second is ingressed chlorides which comes from airborne salt in the environment the concrete is exposed to. Chlorides within concrete can also take two forms; fixed chlorides (chemically/physically bound to the cement), or free (present in the pore water within the concrete).

It is the free chlorides that are responsible for the deterioration of the reinforcement. Free chlorides ingress through the concrete overtime towards the reinforcement. Once this has reached the reinforcement the free chlorides react with the protective oxide layer which forms around the reinforcement within the concrete and causes localised breakdown of this layer. This allows localised corrosion to initiate on the reinforcement.

The BRE have published a series of diagrams in Digest 444 part 2 which can be used as a part of the assessment of chloride levels in concrete members, for 25, 40 & 60 year old structures. The diagrams show the risk of reinforcement corrosion within concrete elements for the given conditions for the respective age groups. The building had been completed in 1971, meaning the property is roughly 51 years old at the time of inspection. The concrete testing results will therefore be compared against the BRE 444 diagram for a 60-year-old structure, as this best represents the structure. This diagram is shown in Figure 10.

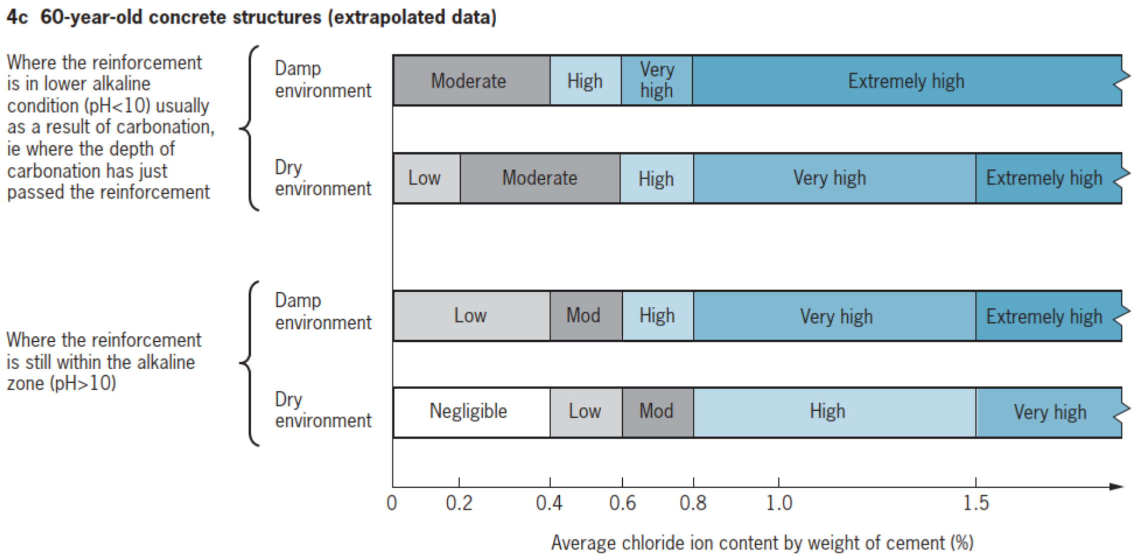


Figure 10 – Estimated Risk of Corrosion Associated with Carbonation, Chloride Content and Environment (BRE, 2000)

The testing data has been assessed based on the BRE guidance to created Table 2, showing the risk of steel reinforcement corrosion in each of the areas tested.

CHLORIDE TESTING						
	Test Location	**Member Type**	**Carbonation Reached / Surpassed Reinforcement**	**Atmosphere**	**Chloride Cl % by Mass of Cement**	**Risk of Steel Reinforcement Corrosion (BRE Digest 444 pt1)**
Flat 60	1	Floor Slab	No	Dry	0.12	Negligible
Flat 60	2	Cross Wall	No	Dry	0.12	Negligible
Flat 60	3	Floor Slab	No	Dry	0.12	Negligible
Flat 60	4	Cross Wall	Yes	Dry	0.06	Low
Flat 65	5	Floor Slab	Yes [1]	Dry	0.10	Low
Flat 65	6	Cross Wall	Yes	Dry	<0.03	Low
Flat 65	7	Cross Wall	Yes	Dry	- [1]	- [2]
Flat 78	8	Flank Wall	Yes	Dry	0.18	Low
Flat 78	9	Flank Wall	No	Dry	0.15	Negligible
Flat 78	10	Covering	No	Dry	0.03	Negligible

Table 2 - Interpretation of Sandberg Chloride Content Testing with BRE Digest 444 Part 1

Notes:
1) The laboratory testing of the sample was inconclusive
2) The risk of corrosion cannot be calculated as the testing was inconclusive, but assumed this would be at 'low' risk.

Based on the results of the testing, compared using the above diagram, suggest the following:

- The chloride contents in all concrete tested was found to be low, as is unlikely to cause accelerated rates of corrosion to the embedded reinforcement.
- All concrete members tested were found to have either a negligible or low risk of corrosion to the embedded reinforcement. As stated in the previous subsection, it appears the elements which are at the 'low' risk of corrosion are so mainly due to the low concrete cover to the rebar.
- During the opening up works some degree of corrosion (typically minor surface corrosion) was noted to the reinforcement. It is not clear whether this is due to the carbonated concrete no longer affording the steel protection (active corrosion), or inadequate storage of the bars prior to manufacture (historic corrosion)
- There was no spalling noted on any concrete element inspected, which may suggest that the corrosion noted to the bars is not active.

Cement Composition

The structural performance of concrete is greatly affected by the % content of cement, and the composition of the cement. Concrete with a low cement content, or incorrectly proportioned composition, may impact on the overall structural integrity of the structure and may provide a less protective environment to the reinforcement, leading to corrosion issues and subsequent spalling.

The full results of the chemical analysis to determine the chloride content can be seen in Appendix B, with an extract shown in Table 3. The results of the chemical analysis were then interpreted to understand the percentage weight of each chemical component against the total weight of the binder, shown in Table 4. This was then compared to the requirements from BS EN 197-1:2011 – *"Cement. Composition, specification and conformity criteria for common cements"* as a guide to determine whether the cement composition would be acceptable to today's standards, shown in Table 5.

BS EN 197-1:2011, Section 5.2.1 states that "Portland cement clinker is a hydraulic material which shall consist of at least two-thirds by mass of calcium silicates ($3CaO \cdot SiO_2$ and $CaO \cdot SiO_2$), the remainder consisting of aluminium and iron containing clinker phases and other compounds. The ratio by mass (CaO) / (SiO_2) shall be not less than 2.0." (BSI, 2011).

CEMENT COMPOSITION RESULTS				
% by weight of sample (from Appendix A)				
Flat	**Test Member**	**SiO_2**	**CaO**	**Total Cement Content**
Flat 60	Cross Wall	2.80	38.04	11.7

Table 3 - Sandberg cement composition test results

CEMENT COMPOSITION INTERPRETATION				
% by weight of cement (from Interpretation)				
Flat	**Test Member**	**SiO_2**	**CaO**	**Total (SiO_2 + CaO)**
Flat 60	Cross Wall	23.9	325.1	349.0

Table 4 - Interpretation of Sandberg Cement Composition Testing

CEMENT COMPOSITION COMPLIANCE WITH BS EN 197-1:2011 (5.2.1)		
Test Member	**Cement Consists of at least 2/3 (CaO + SiO_2)**	**The Ratio of CaO / SiO_2 > 2.0**
Cross Wall	349 > 66.6 ∴ PASS	13.6 > 2.0 ∴ PASS

Table 5 - Comparison of interpreted results with BS EN 197-1:2011

By inspection of the interpreted results, the quantities of Silica (SiO_2) and Calcium Oxide (CaO) satisfy the expected proportions for today's standards. It can be seen that the Calcium Oxide (CaO) content is shown to be considerably high, with the total SiO_2 and CaO totalling over 300% of the cement content. This indicates that there is an external source of CaO in the concrete outside of the cement. It is possible that, based on the location of the blocks being coastal, the concrete used dredge aggregate including seashells in the mix. However, it is unlikely this will have a negative effect on the adequacy of the concrete nor will it impact the effectiveness of the protection the concrete offers to the embedded reinforcement.

High Alumina Cement

As it had originally been believed that the construction of the block was LPS, it was deemed to be appropriate to undertake High Alumina Cement (HAC) testing on one of the wall panels. During the 1950's, 60's and 70's HAC was used as an alternative to Portland Cement (PC), particularly in precast concrete components, as it provided accelerated strength gains for the concrete, thus reducing construction/manufacture time. However, over time, concrete produced with HAC was prone to reductions in strength as the cement undergoes crystalline re-arrangement. HAC, when regularly exposed to water, is also vulnerable to chemical attack thus accelerating the rate of deterioration of the concrete member.

A dust sample collected from one of the cross walls was sent to the laboratory for HAC testing. The testing concluded that the concrete was produced using Portland Cement, not HAC.

Compressive Strength

In order to assess the robustness of the concrete elements forming Barton House, the characteristic compressive strength of the concrete was required. For the testing of hardened concrete, the method employed is to carry out core samples of representative areas of the block and subject the core samples to increasing compressive forces, within a laboratory, until failure.

The concrete cores taken from Barton House were from cross walls and flank walls [It was not possible to undertake core sampling of floor slabs as all flats within the block were single level (no duplex apartments) and the floors were constructed from precast, hollow beams so a solid core sample would not have been retrieved], each 100mm in diameter. These were sent to the Sandberg laboratory, and the compressive strength of each core determined. The results of the testing can be seen in Figure 11.

FLAT	SAMPLE	CORE LOCATION	COMPRESSIVE STRENGTH
Flat 60	1	Cross Wall	43.9 N/mm^2
Flat 60	2	Cross Wall	56.2 N/mm^2
Flat 60	3	Cross Wall	51.6 N/mm^2
Flat 65	4	Cross Wall	36.4 N/mm^2
Flat 65	5	Cross Wall	31.1 N/mm^2
Flat 78	6	Flank Wall	50.4 N/mm^2
Flat 78	7	Flank Wall	74.1 N/mm^2
Flat 78	8	Cross Wall	46.1 N/mm^2

Figure 11 – Compressive Strength results from the core samples taken in Barton House

Using the results obtained from the laboratory testing of each core, the characteristic compressive strength of the concrete could be determined. The calculation of the characteristic compressive strength was carried out in accordance with the method given in BS 6089:2010 – *Assessment of in-situ concrete strength in structures and precast concrete components*, and Concrete Advice No.47 – *Assessment of in-situ concrete strength using data obtained from core testing*.

The calculations, based on the core results, show that the characteristic compressive strength of the in-situ concrete walls at Barton House is **39.4 N/mm^2**.

5. BARTON HOUSE STRUCTURAL ASSESSMENT

The findings of the on-site investigations were then used in the desktop study to justify the robustness of the block.

5.1. Assessment Criteria

The block has been assessed using the 2012 BRE Report 511 titled 'Handbook for the structural appraisal of Large Panel System (LPS) dwelling blocks for accidental loads'. Despite Barton House being found not to be an LPS structure, the building does contain precast components and as such the process within this guidance document are still relevant.

The report identifies three criteria to assess LPS blocks against. The block needs only pass one of the following criteria:

- LPS Criterion 1. There is adequate provision of horizontal and vertical ties to comply with the current requirements for the relevant Consequence Class for each block as set down in the codes and standards quoted in Approved Document A – Structure as meeting the requirement set down in the Building Regulations.

- LPS Criterion 2. An adequate collapse resistance can be demonstrated for the foreseeable accidental loads and actions.
  - The block is not currently fitted with a piped-gas supply, and as such the main structural members do not need to be assessed for the enhanced overpressure of 34kN/m^2.
  - The structure shall, instead, be assessed against the reduced overpressure of 17kN/m^2 – this is the value associated to a block without a piped-gas supply, but could be subjected to an explosion from sources such as aerosols or LPG canisters etc.

- LPS Criterion 3. Alternative paths of support can be mobilised to carry the load, assuming the removal of a critical section of the load bearing wall in the manner defined for Class 2b in Approved Document A – Structure or alternatively assuming the removal of adjacent floor slabs (taking the floor slabs bearing on one side of the wall at a time) providing lateral stability to the critical section of the load bearing wall being considered. (BRE, 2012)

The following sections document the main findings of the investigation and a summary of each LPS Criterion assessment.

5.2. LPS Criterion 1 – Adequation Provision of Ties

The first stage in the assessment to determine the adequacy of the joints is to define the 'Consequence Class' of the blocks. Based on the definitions provided Building Regulations Approved Document A the block falls into Consequence Classes 2b. The block therefore requires effective horizontal and vertical ties. The details for the joints between floors and walls can be seen in Section 4.3.

The effectiveness of horizontal and vertical ties is assessed against the Eurocode document BS EN 1991-1-7:2006 Actions on Structures – General Actions – Accidental Actions.

Cross Wall / Floor Slab Joints

The assessment of the cross wall / floor slab joint has shown that:
<u>Horizontal Ties:</u> Insufficient*
<u>Vertical Ties:</u> Effective

The cross wall joint is therefore <u>**insufficient**</u> to pass the assessment for a Consequence Class 2b building.

* The horizontal ties were found to be insufficient as, although installed in some areas, they had been completely omitted in others.

Flank Wall / Floor Slab Joints

The assessment of the cross wall / floor slab joint has shown that:
<u>Horizontal Ties:</u> Insufficient
<u>Vertical Ties:</u> Effective

The flank wall joint is therefore <u>**insufficient**</u> to pass the assessment for Consequence Class 2b.

BARTON HOUSE (CONSEQUENCE CLASS 3)			
JOINT TYPE	ADEQUATE HORIZONTAL TIE	ADEQUATE VERTICAL TIE	NOTES
Cross Wall	X	√	Insufficient
Flank Wall	X	√	Insufficient

BARTON HOUSE – LPS CRITERION 1 – ADEQUATE PROVISION OF TIES
FAIL

5.3. LPS Criterion 2 – Adequate Collapse Resistance

BRE Report 511 states that as the majority of elements in an LPS dwelling block are loadbearing they must be treated as 'key elements'. Collapse resistance calculations have been carried out for the block, based on the findings of the intrusive investigations carried out on each of the main loadbearing members.

The calculations have been carried out using British Standards which have been chosen as they are akin to the design codes that the structure would have been originally designed to, rather than the modern Eurocodes.

The assessment was carried out using an overpressure of 17kN/m^2 to comply with the regulations for accidental loading for a building without a piped-gas supply. The calculations show that the structural elements that form Barton House, except for the cross walls, are insufficient to resist a loading of this magnitude.

The following table summarises the findings:

STRUCTURAL ELEMENT	BARTON HOUSE 17kN/m^2 OVERPRESSURE (PIPED-GAS SUPPLY)	NOTES
Floor Slab (Downward)	X	Inadequately Robust
Floor Slab (Uplift)	X	Inadequately Robust
Flank Wall	X	Inadequately Robust
Cross Wall	√	Adequately Robust

BARTON HOUSE – LPS CRITERION 2 – ADEQUATE COLLAPSE RESISTANCE
FAIL

5.4. LPS Criterion 3 – Alternative Load Paths

For a block to pass Criterion 3 the structure must be able to mobilise alternative load paths in the event of an explosion. In the event of an explosion with a piped-gas supply, the bounding enclosure area would be considered to be a single room within the flat. The overpressure from such an event is considered to act on all elements within this bounding enclosure simultaneously.

In the event of the explosion occurring in the rooms formed by a flank wall, this could result in the failure of two floor slabs (floor and ceiling above) and the flank wall panel. The lack of horizontal ties in the joints may also allow further slabs to 'peel' away from the walls. In this event, it is therefore unlikely that the block would be able to mobilise alternative load paths in the event of an internal explosion of this magnitude. This may lead to the disproportionate collapse of the block.

In the event of an explosion occurring in the rooms formed of purely cross walls, only the floor slabs would fail. However, the lack of ties and impact loading of the failed slabs falling on those below, could cause a 'pancake' failure as each slab below the explosion epicentre collapses down onto those below.

BARTON HOUSE – LPS CRITERION 3 – ALTERNATIVE LOAD PATHS
FAIL

5.5. Summary of LPS Criteria Checks

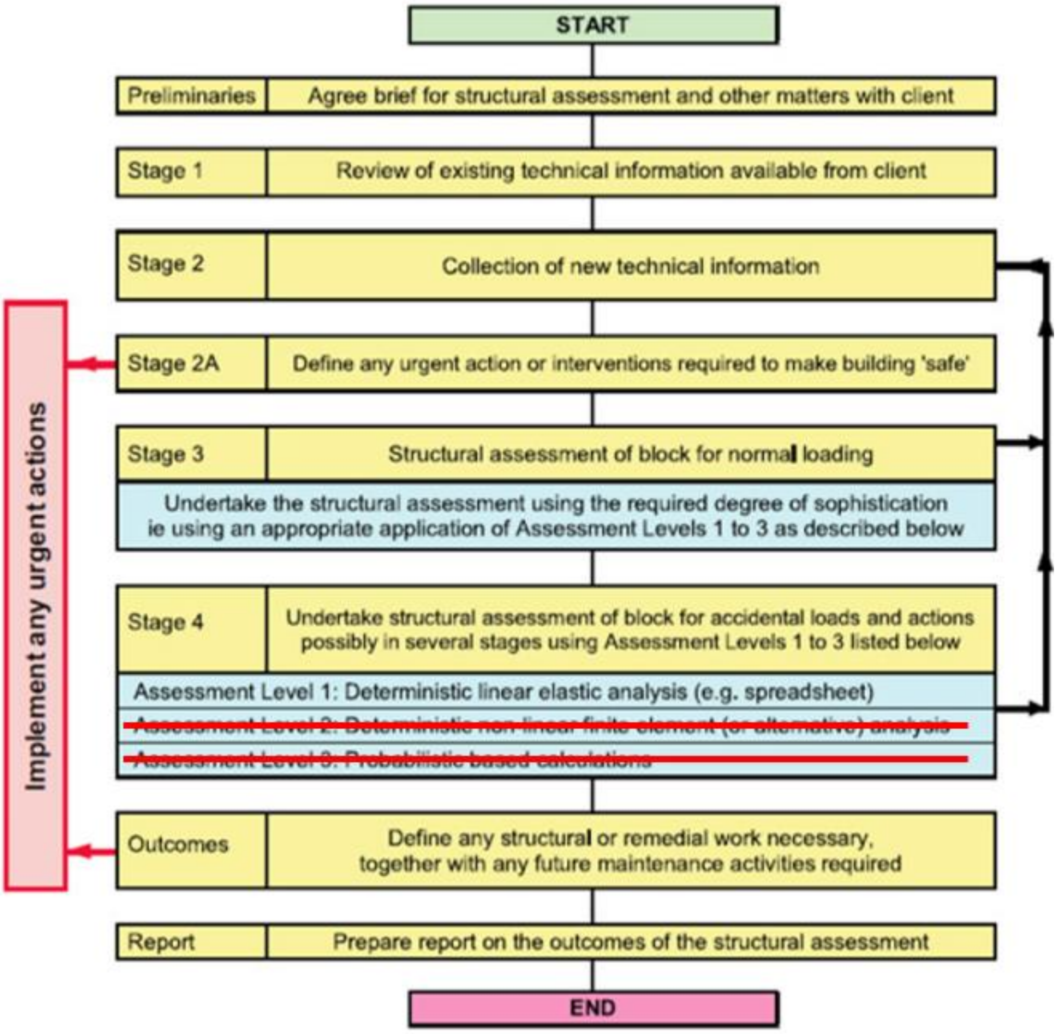
Barton House has been assessed in its current condition against the three LPS Criteria. The assessment has shown the block fails all three of the checks and is therefore inadequately robust to resist disproportionate collapse.

LPS CRITERION	BARTON HOUSE PASS / FAIL	NOTES
LPS 1	X	Inadequately Tied
LPS 2	X	Inadequately Robust
LPS 3	X	Inadequate Mobilisation of Alternative Load Paths

BARTON HOUSE – CONCLUSION
FAIL

6. CONCLUSION

To carry out the assessment of the blocks the engineers at Ridge have carried out desktop studies, on-site investigation and structural assessment calculations in the following procedure:



The outcome of the assessment is that the block in its current state is inadequate /to resist disproportionate collapse.

The concrete testing has shown that:

- Within both the precast concrete floor beams and the in-situ walls it was found that the cover to the embedded reinforcement was inconsistent, and in some areas was insufficient. However, the assessment of the carbonation and chloride content of the concrete elements has shown that the reinforcement is at either a negligible or low risk of corrosion.
- Whilst some corrosion was noted on the surface of some of the bars exposed during the opening up works, it is possible that this is historic and caused by insufficient storage during construction / manufacture rather than active corrosion. There were no areas of spalling noted within the three flats, or the other accessible areas, during the investigation which may suggest it is not active corrosion.
- The cement composition was found to be adequate.
- It was confirmed that the in-situ concrete wall did not contain High Alumina Cement (HAC)

- The in-situ concrete walls have a characteristic compressive strength of 39.4N/mm^2. The compressive strength of the floors could not be assessed as their structural form did not allow core sampling.

7. RECOMMENDATIONS

7.1. Strengthening Works / Risk-Reduction Measures

We advise that the Bristol City Council commission a risk analysis, together with a cost-benefit analysis and scheme design for strengthening works, to be carried out to determine:

a. Whether the risk of disproportionate collapse of the blocks could be acceptably reduced by risk-reduction measures; or
b. Whether strengthening works are required.

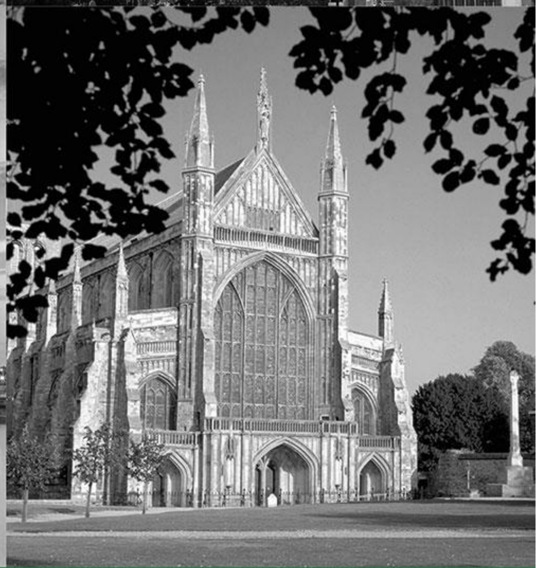
Risk reduction measures may include 'administrative' measures such as the installation of CCTV cameras with the aim of preventing gas canisters or other highly flammable objects from being brought into the blocks, installation of a fire alarm systems and an updated fire strategy,

Strengthening works may take the form of steel strapping of the floors and walls and strengthening of the joints using steel angles.

Finally, if the risk reduction measures cannot control the risk to acceptable levels, and the investment into strengthening works proves uneconomically viable, demolition may be a third option for the block.





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