

RIDGE

PROPERTY & CONSTRUCTION CONSULTANTS



Homes for Haringey

**BROADWATER FARM ESTATE
STRUCTURAL ROBUSTNESS ASSESSMENT
4 & 6 STOREY BLOCKS**

April 2018

Prepared for

Homes for Haringey
108 Gloucester Road
London
N17 6GZ

Prepared by

Ridge and Partners LLP
Partnership House
Moorside Road
Winchester
SO23 7RX



CONTENTS

1. INTRODUCTION	4
2. EXECUTIVE SUMMARY AND CONCLUSION	6
3. HISTORY OF LPS BLOCKS AND DISPROPORTIONATE COLLAPSE	11
4. THE BLOCKS ON BROADWATER FARM ESTATE	13
4.1 Brief History of Broadwater Farm Estate	13
4.2 Review of Historic Information	14
4.3 Structural Form of the Blocks	18
4.3.1. 6-Storey Blocks	18
4.3.1. 4-Storey Wings	21
5. INVESTIGATION METHODOLOGY	23
5.1 Flats and Non-Residential Areas Subject to Investigation	23
5.2 Preparatory Works	24
5.3 Non-Intrusive Ferro Scan Works	24
5.4 Interpretation of Non-Intrusive Investigation Results	26
5.5 Intrusive Opening-Up Works	27
6. FINDINGS OF INVESTIGATION	28
6.1 Overview	28
6.2 Rebar Grades	28
6.3 Overview of findings within 6-Storey Blocks	29
6.4 Overview of findings within 4-Storey Wings	30
7. LIMITATIONS OF INVESTIGATION	31
8. ASSESSMENT	32
8.1 Classification of Structure	32
8.2 Assessment Criteria	33
8.3 Assessment Discussion – 6 Storey Blocks	34
8.3.1. LPS Criterion 1	34
8.3.2. LPS Criterion 2	34
8.3.3. LPS Criterion 3	35
8.3.4. Re-assessment of LPS Criterion 2 with the Removal of the Piped-Gas Supply	36
8.4 Assessment Discussion – 4 Storey Wings	37
8.4.1. LPS Criterion 1	37
8.4.2. LPS Criterion 2	37



8.4.3.	LPS Criterion 3	38
8.4.1.	Summary of Assessment	38
9.	FURTHER OBSERVATIONS	39
10.	REFERENCES	41

1. INTRODUCTION

Ridge and Partners LLP (Ridge) was appointed by Homes for Haringey (HfH) to carry out structural investigations to determine the robustness of twelve dwelling blocks on the Broadwater Farm Estate, Haringey, London. The appointment came after the publication of a similar report in August 2017 for four LPS towers in the Ledbury Estate within another London Borough; this initial study showed that the Ledbury structure failed to satisfy the three-criteria set out in Building Regulations Approved Document A for disproportionate collapse. Owners of similar LPS dwelling blocks, including Homes for Haringey (HfH), were therefore, advised to seek professional advice regarding the safety of their assets.

This report specifically addresses the findings for the 4 & 6 storey blocks with the exception of Tangmere, which is unlike the others (and which has been reported upon separately).

The Broadwater Farm Estate is comprised of two tall high-rise blocks (each eighteen storeys above an insitu concrete podium):

- Northolt
- Kenley

and ten medium/high-rise blocks (all between four and six storeys above an insitu concrete podium):

- | | |
|--------------|--------------|
| • Croydon | • Manston |
| • Lympne | • Martlesham |
| • Debden | • Rochford |
| • Hornchurch | • Stapleford |
| • Hawkinge | • Tangmere |

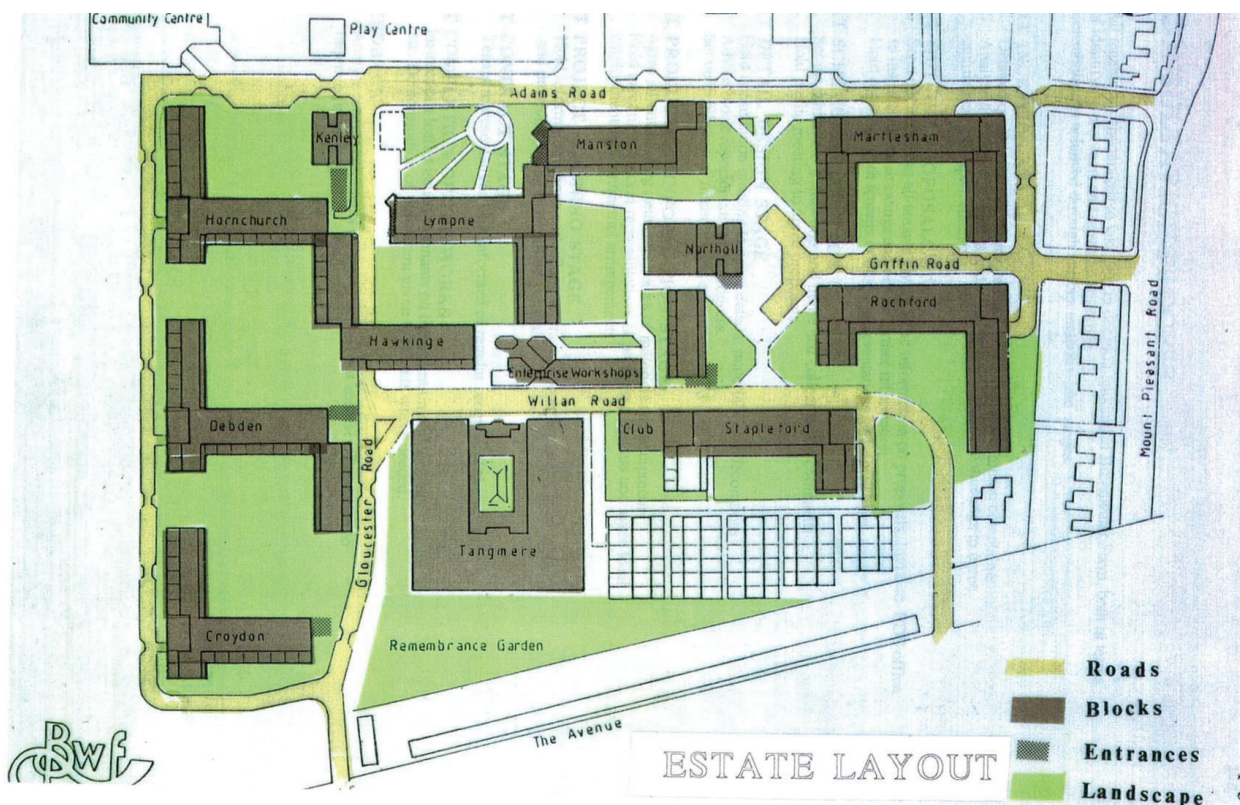


Figure 1 – Broadwater Farm Estate Layout (Haringey Council Building Design Service, 1985)

It is understood that the twelve Large Panel System (LPS) dwelling blocks were built by the Contractor, Taylor Woodrow-Anglian (TWA), for Haringey London Borough Council between 1968-1972. Northolt and Kenley have been confirmed as being constructed using the Larsen-Nielsen system. All ten of the lower rise blocks have a piped-gas supply to at least a portion of the structure (reported as having been in place since their construction). The two tall high-rise blocks do not have a piped-gas supply.

The Larsen-Nielsen system was also used by Taylor Woodrow-Anglian to construct Ronan Point, a 23-storey block of flats in Newham, London, which suffered an internal gas explosion in 1968. The explosion caused progressive and disproportionate collapse, killing four and injuring a further seventeen residents. Following the partial collapse there were a series of changes made to structural design codes and regulatory standards. Several documents have also been published by the BRE, which examine the causes of collapse and provide guidance for the assessment of structures under accidental loading. These documents have been reviewed and used to assess the LPS blocks during this investigation and are referenced as an appendix.

An archive box of information received from HfH was also reviewed for the assessment. Although much of the contents were noted as architectural, some information relating to structural elements were discovered. However, full construction drawings and calculations for the blocks at Broadwater Farm Estate appear not to have been kept by Haringey London Borough Council. [REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

In the absence of the construction details of the blocks Ridge proposed to subject each block of flats on the Broadwater Farm Estate to both invasive and non-invasive investigation works. Desktop assessments, including calculations, were then carried out to determine the robustness of the structures based on the findings.

Throughout the duration of the exploratory investigations the blocks, as a whole, remained inhabited by residents. This presented challenges to the investigation team in terms of availability of vacant flats within which intrusive investigations were undertaken.

A key criterion for the assessment of the blocks was the 'over-pressure' loading that is applied to the structure in the case of explosion. If blocks have a piped-gas supply, even to a portion of the structure, then the building is subject to an over-pressure test of 34kN/m². Buildings without a piped-gas supply, or a basement, are subject to a lower over-pressure of 17kN/m². As all lower blocks had a gas-supply to a portion of the structure it was also discussed whether the gas should be removed, if required to pass the assessment.

At the time of writing, the investigations into nine of the twelve blocks are complete where dwellings have been inspected. This report shall be updated to reflect the findings of the remaining blocks once their individual investigations have been completed.

2. EXECUTIVE SUMMARY AND CONCLUSION

The twelve dwelling blocks located on the Broadwater Farm Estate have been assessed for their robustness to resist accidental loading from over-pressure, such as an internal gas explosion, and their susceptibility to progressive collapse. The blocks were constructed from a Large Panel System (LPS) by the contractor, Taylor Woodrow-Anglian (TWA), for Haringey London Borough Council between 1968-1972.

In 1967 Ronan Point, an LPS block of similar construction to the blocks at Broadwater Farm Estate, suffered progressive collapse caused by an explosion of gas in one of the flats. This event sparked a series of changes to legislation related to the design of new LPS structures and the assessment of the existing LPS building stock. These documents have been reviewed and used in the assessment contained within this report.

In the absence of the construction details of the blocks Ridge subjected each block of flats on Broadwater Farm Estate to both invasive and non-invasive investigation works to determine its construction. The findings of these on-site investigations were then used in the desktop study to justify the robustness of the block.

The table below summarises the findings of our investigations and notes recommendations for further works relating to the 4 & 6 storey blocks (the TBA entries will be replaced upon completion of our investigations in the final version of this report):

BLOCK NAME	34KN/M ² OVERPRESSURE	17KN/M ² OVERPRESSURE	NOTES
MANSTON 6	X	✓	Gas removal required
MANSTON 4	X	✓	Gas removal & strengthening works required
CROYDON 6	X	✓	Gas removal required
CROYDON 4	X	✓	Gas removal & strengthening works required
HAWKINGE 6	X	✓	Gas removal required
HAWKINGE 4	X	✓	Gas removal & strengthening works required
ROCHFORD 6	X	✓	Gas removal required
ROCHFORD 4	X	✓	Gas removal & strengthening works required
STAPLEFORD 6	X	TBA	Cloned result pending access
STAPLEFORD 4	X	TBA	Cloned result pending access
MARTLESHAM 6	X	✓	Gas removal required
MARTLESHAM 4	X	✓	Gas removal & strengthening works required
HORNCHURCH 6	X	TBA	Cloned result pending access

BLOCK NAME	34KN/M ² OVERPRESSURE	17KN/M ² OVERPRESSURE	NOTES
HORNCHURCH 4	X	TBA	Cloned result pending access
LYMPNE 6	X	✓	Gas removal required
LYMPNE 4	X	✓	Gas removal & strengthening works required
DEBDEN 6	X	TBA	Cloned result pending access
DEBDEN 4	X	TBA	Cloned result pending access

X=Failed Test, ✓=Passed Test, TBA=To be announced

The blocks have been assessed using the 2012 BRE Report 511 titled 'Handbook for the structural appraisal of Large Panel System (LPS) dwelling blocks for accidental loads'. The report identifies three criteria to assess LPS blocks against. The blocks need 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.
 - Consequence Class 3 – Kenley & Northolt
 - Consequence Class 2b – The main 6-storey blocks of Croydon, Lympe, Debden, Hornchurch, Hawkinge, Manston, Martlesham, Rochford, Stapleford & Tangmere
 - Consequence Class 2a – The 4-storey wings of Croydon, Lympe, Debden, Hornchurch, Hawkinge, Manston, Martlesham, Rochford, Stapleford
- LPS Criterion 2. An adequate collapse resistance can be demonstrated for the foreseeable accidental loads and actions.
- 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. (Matthews & Reeves, 2012)

In the context of new build high rise design, the building regulations requires a systematic risk assessment to be undertaken for class 3 structures such as Kenley and Northolt. Whilst this is not a retrospective requirement it is good practice to consider risks to disproportionate collapse, such as vehicular impact damage which could then be mitigated using vehicular barriers for example. We recommend that HfH undertakes such a risk assessment.

The calculations for the 'key element' checks have been carried out using British Standards that are more akin to the design codes that the structure would have been originally designed to rather than the Eurocodes.

Each block was assessed separately based on the findings from the intrusive and non-intrusive investigations. The 6-storey blocks (excluding Tangmere) have been grouped together for reporting (including their) 4-storey wings. The results of the analysis are as follows:

6-Storey Blocks

- LPS Criterion 1

The joints between the loadbearing elements in the 6-storey blocks were found to possess an effective horizontal tie. However, the vertical tie in the joints was found to be insufficient. Therefore, the connections in these blocks do not pass LPS Criterion 1.

- LPS Criterion 2

The 'key elements' checks carried out on the loadbearing members in the 6-Storey Blocks show that the elements are insufficiently robust to resist an overpressure of 34kN/m² associated with a piped-gas supply. Therefore, the blocks do not pass LPS Criterion 2 with a piped-gas supply present within the block.

- LPS Criterion 3

With a piped gas supply within the flats the enclosure boundary for the explosion is assessed to be the entire flat. Therefore, an explosion of piped-gas could cause all structural elements in the source flat to fail. This could cause the surrounding members, which take bearing on the failed elements, to also fail. This may cause progressive and disproportionate collapse as no alternative load-paths could be mobilised in this instance. Therefore, the 6-storey blocks do not pass LPS Criterion 3 with a piped-gas supply.

- LPS Criterion 2 (Reassessment)

The 'key elements' check on the loadbearing members was reassessed for a reduced overpressure of 17kN/m². This reduced overpressure is associated with a block with no piped-gas supply. The checks showed that the loadbearing members were sufficiently robust to resist this loading. Therefore, the 6-storey blocks pass LPS Criterion 2 if the piped-gas supply is removed.

4-Storey Wings

- LPS Criterion 1

The joints between the loadbearing elements in the 6-storey blocks were found to possess an effective horizontal tie, but not an effective vertical tie. However, for Consequence Class 2a buildings there is no requirement in the Building Regulations for effective vertical ties in the joints and thus these blocks pass Criterion 1.

Elements of the buildings have been noted to be subject to key element design and these will need strengthening as noted in Section 8.4.1.

- LPS Criterion 2

Technically, the 4-storey wings pass the assessment as provided in BRE Report 511 as the joints satisfy LPS Criterion 1. As such no further assessment should be required.

However, the investigative works carried out in the 4-storey wings showed that the cross wall panels are unreinforced and an inherent weakness was found around the formed pockets in the flank wall

connecting the panel at the base. As the 4-storey wings have a piped-gas supply the blocks would be subject to the 34kN/m^2 overpressure in the event of an internal gas explosion. The wall panels would suffer severe failure under an overpressure of this magnitude. There is, therefore, an inherent risk of collapse in the event of an explosion with a piped-gas supply in these wings, despite the block passing the LPS Criterion 1.

Further analysis for the 17kN/m^2 overpressure associated with the removal of the piped-gas supply also showed that the wall panels would fail. However, as a risk reduction measure it is still recommended that the piped-gas supply should be removed.

- LPS Criterion 3

With a piped-gas supply within the wings the boundary enclosure has been assessed to be the entire flat. In this event two of the loadbearing walls, shown to be insufficient to resist the 34kN/m^2 overpressure, would fail. In this instance no alternative load-paths could be mobilised, potentially resulting in progressive collapse.

However, if the piped-gas supply is removed from the block the boundary enclosure would be reduced to a single room. In this case only a single loadbearing wall would fail. The floor slabs have been shown to have an effective horizontal tie and could develop catenary action, thus mobilising an alternative load-path.

However, if the explosion were to occur adjacent to the flank wall catenary action in the floor slab would not develop and no alternative load-paths could be mobilised. This could potentially lead to progressive collapse in the 4-storey wing. There is also the potential that a flank wall could be dislodged in an explosion and could strike the adjacent 6-storey main block. These elements of the buildings have been noted to be subject to key element design and these will need strengthening as noted in Section 8.4.1

Removing the gas from the 4 & 6 storey blocks will be a significant undertaking and cannot be achieved over-night, hence a phased approach to reduce risk is to be recommended.

This might comprise:

1. An immediate estate wide ban on the use of any gas cannister/bottles being used or stored within the dwellings, along with a complete ban on any other potentially explosive substances;
2. The removal of gas cookers and replacement with a non-gas source (such as electric, pending confirmation of the adequacy of in-flat electrical circuitry and block distribution systems) – both bottled gas and gas cookers should be viewed as the highest risk as they have the potential to be left on, causing a leak that might then be ignited, causing explosion and excessive pressures being applied on the structures;
3. The installation of interrupter devices linked to gas leak detectors to shut-off valves that will stem the flow of gas to boilers that serve heating and hot water in the event of a gas leak (this viewed as an interim measure until the gas boilers can be removed);
4. The renewal of gas boilers with an alternative non-gas heating/hot water source (this may also require investigation of current electrical capacity into the dwellings, blocks and estate);
5. Removal of all gas supplies in the blocks, to a point outside of the curtilage;
6. Further consideration will also need to be given to the risk from other sources of significant pressure (such as vehicle impact to panels at lower levels) and the possible effects of pressures emanating from explosions in under-croft areas, although we do note that these are open sided spaces and will

create a different pressure profile than when compared with the confined internal areas of flats; these risks will be considered in the next stages of our investigations.

It is also recommended that in due course all gas pipes are to be removed from the block to prevent these being used again in the future.

These actions will help to reduce risk pending considerations about longer term actions (this may include structural strengthening and wider option studies).

Reporting on Kenley, Northolt and Tangmere have been provided under separate cover.

3. 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.

Investigations and testing were undertaken on the remaining structure, focusing on the key structural elements and their associated joints to determine their strength. Following the investigations, the Tribunal made several recommendations. These included strengthening works required specifically on Ronan Point, but also recommended actions to be taken on other LPS structures. Existing LPS structures were required to be appraised and strengthened as required, and proposed LPS blocks were to be designed to resist disproportionate collapse.

Later that year the Ministry of Housing and Local Government (MHLG) issued MHLG Circulars 62/68 and 71/68 titled "Flats constructed with precast concrete panels. Appraisal and strengthening of existing blocks: Design of new blocks". The circulars outlined the recommendation that all blocks over six storeys (seven storeys or more) in height were to be appraised by a structural engineer to determine whether the blocks were susceptible to progressive collapse. Two methods were outlined in MHLG Circular 62/68 to prevent progressive collapse in LPS blocks. Method A was to provide alternative load paths should a critical section of a loadbearing wall be removed. Method B was to ensure the structure had sufficient stiffness and continuity to resist the over-pressure loads. For Method B the circular stated that an over-pressure of 5 lb/in² (34kN/m²) should be taken, unless actions were taken to control the risk of explosion where a reduction could be made. MHLG Circular 62/68 also stated that tensile resistance could be achieved between panels by either welding together the projecting reinforcement or by loop bars projecting from each panel which were tied together using longitudinal dowel bars.

Following the publication of the above-mentioned circulars the Institution of Structural Engineers published Report RP68/02 titled 'Notes for guidance which may assist in the interpretation of Appendix 1 to MHLG Circular 62/68'. The report included a recommendation that if the dwelling blocks did not have a piped gas supply, the over-pressure used in Method B of MHLG Circular 62/68 could be reduced to 2.5 lb/in² (17kN/m²).

In 1970 the Building Regulations were updated to include Section D17 regarding provisions to resist progressive collapse. The new section reduced the number of storeys required for an assessment to be carried out on a block to five storeys or more (a more normal Government definition of 'high-rise'), representing a reduction of two storeys from that stated in MHLG 62/68. However, the MHLG Circulars, specifically addressing LPS blocks, were not superseded by the new Building Regulations, nor changed/updated to reflect the reduced number of storeys. It is therefore believed that there was confusion over which code governed for LPS blocks. As a result, it is possible that many blocks between five and six storeys were not assessed for disproportionate collapse.

BRE Report 107: Part 2 produced in 1987 also provided non-mandatory guidance on the assessment of LPS blocks. This included methodology for inspection of the joints between elements and procedures to evaluate the findings. This report also confirmed the requirement to assess all LPS blocks over four storeys, bringing this in line with Section D17 of the Building Regulations.

The latest requirements for disproportionate collapse are defined in Building Regulations Approved Document A – Structure. This divides building usage types into consequence classes, with differing levels of assessment required for disproportionate collapse. The consequence class table can be seen in Section 8.1.

BRE have also published an additional guidance document, Report 511 titled 'Handbook for the structural appraisal of Large Panel System (LPS) dwelling blocks for accidental loads'. This report provides structural engineers with the methodology required to assess LPS blocks and summarises and documents the research the BRE have undertaken since the collapse of Ronan Point. This report has been used as the basis for our assessment of the blocks of flats at Broadwater Farm Estate.

4. THE BLOCKS ON BROADWATER FARM ESTATE

4.1 Brief History of Broadwater Farm Estate

In the 1960s Haringey London Borough Council commissioned the construction of two tall high rise, and ten lower dwelling blocks on the Broadwater Farm Estate. The twelve dwelling blocks were constructed by Taylor Woodrow-Anglian (TWA) between 1967-1972 using the Large Panel System (LPS), specifically thought to be the Larsen Nielsen system (The University of Edinburgh, 2017).

The design of the blocks saw that no habitable rooms were located on the ground floor due to the high water table in the area. The ground floor of each block was instead used as a carpark under the ten medium/high-rise blocks and a service area for the two high-rise blocks. The ground floor was constructed of an insitu concrete podium, upon which the precast units of the LPS were built up from. Another original design feature of the Broadwater Farm Estate was a series of walkways, which connected the blocks at first floor level. The walkways were subsequently demolished in the late 80s and early 90s as part of the regeneration of the estate.

In the years since construction, various remedial works and regeneration schemes have been carried out to the blocks at Broadwater Farm. These include bolting of the external non-loadbearing walls back to the slabs to reduce the movement of the walls caused by thermal expansion by way of steel angles resin fixed to the wall panel and underside of floor units, and over-cladding of the blocks with a rendered insulation system. We are also advised that firestopping works have also been carried out throughout the estate in the 1980s.

In 2006 the management of Broadwater Farm Estate was transferred to Homes for Haringey (HfH) when it was established as an Arms Length Management Organisation (ALMO) to manage all of Haringey's council housing.

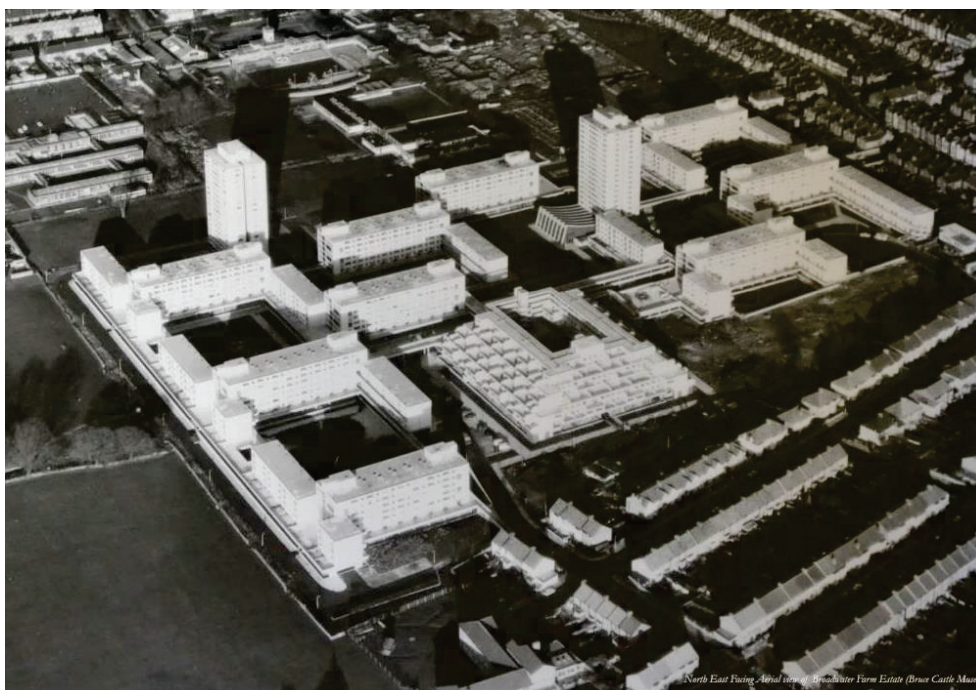


Figure 2 – Historic Aerial Image of Broadwater Farm Estate in 1975 (Coll, 2014)

4.2 Review of Historic Information

An initial desktop study was carried out using an archive box of information received from HfH. Much of the information was noted as architectural, however some structural elements were noted as outlined below:

- The structural repairs that detail bolting to be carried out to the non-structural cladding panels of the blocks between 1986 and 1987 was noted as having been provided to restrict excessive movement.
- No mention is made of reinforcing the panels to resist explosion forces from the design codes of practice.
- The edge detail observed within the information shows the external wall being supported by the wall under or flying past the slab edge. No support or restraint is offered by the hollow core structural slab to the non-structural cladding panel, other than that by the restraint cleat detailed.
- Reports outline the dry packing to structural joints as being adequate.
- Carbonation is noted as being less than 5mm at the time of survey.
- Chlorides were noted as less than 0.4%.
- Recommendations for repair to areas with minimal cover were made.
- A structural investigation into the two tall high-rise blocks, Kenley and Northolt, was carried out in 1985 to determine their robustness.

A section of the 1985 report summarising the findings from the structural investigation into Kenley states that “In regard to explosion resistance, calculations based on the working drawings confirm that the building was designed to resist a minimum equivalent static pressure of 5lbs/sq.in (34kN/sq.m) and thus complies with current building regulations. The appraisal calculations carried out covered in particular the flank walls, the middle and end bays of the floor units, and a typical internal wall.” (Building Design Partnership, 1985) However, the calculations that would justify this statement were not within the archive box of information. Without these calculations to confirm the validity of the statement it was necessary to proceed with the intrusive and non-intrusive investigations on the blocks.

On site the remedial bolting of the non-structural cladding panels back to the slab were observed in the majority of the flats. The angle is hidden behind a fire-stopping coving so is only observed if this is removed during the ‘soft strip’ works, hence why it was not seen in every flat. However, in every instance that the coving was removed this angle detail was revealed. As the coving is a fire-stopping measure, and the angle fixing is not implicit in the assessment for disproportionate collapse, the coving was not removed unless required for other opening up works to be carried out.

The fixings found consisted of 200mm long 140x75x5 steel angles with a single resin fixing into the underside of the floor slab and two resin fixings in vertically slotted holes into the non-loadbearing cladding panels, see Figure 3. These angles were located approximately midway along the external walls in each room.



Figure 3 – Hawkinge: Remedial steel angle bolted to non-loadbearing cladding panel to reduce excessive movement

Another method for fixing back the external non-loadbearing wall, thought to be an original detail, was observed in the form of a steel strap anchored with a single bolt into the top of the floor slab, see Figure 4. These steel straps were also located approximately midway along the base of the external walls in each room.



Figure 4 – Hawkinge: Strap tying base of external wall panel back to the floor slab

This steel restraint strap extends passed the end of the floor slab, running under the non-loadbearing external wall panels. The strap is tied to the wall panel by a 25mm diameter threaded bar protruding up from the wall panel below, passing through a hole in the steel strap and up into a steel 'top hat' threaded socket cast into the external wall, see Figure 5.



Figure 5 – Kenley: Threaded bar protruding from wall panel below, through hole in the strap, into a steel 'top hat' threaded socket cast into wall panel.

It is believed that an additional fixing tying the non-loadbearing external wall back to the main structure exists within the cross wall insitu joint, and was part of the original construction of the block. BRE Report 63 shows this detail, see Figure 6, which was confirmed by the opening up works to be present in Flat 42 Kenley, see Figure 7. Being of similar construction it is, therefore, assumed that this detail is also present in all blocks.

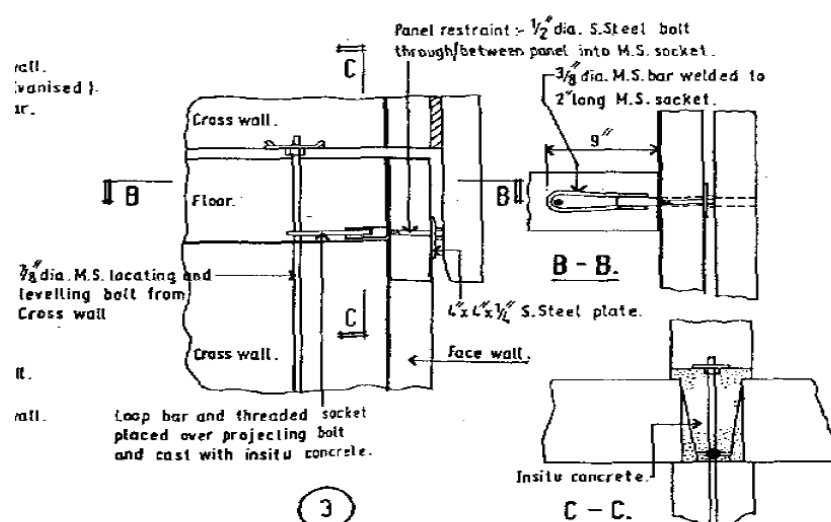


Figure 6 – Extract from BRE Report 63. Non-loadbearing cladding panel connection details. (Department of the Environment, 1985)



Figure 7 – Flat 42 Kenley - Threaded bar found within insitu cross wall joint tying the non-loadbearing cladding panel back to the main structure

The archive information contained no construction drawings or calculations for the blocks. Subsequently Ridge requested archive searches from:

- [REDACTED]
- [REDACTED]
- [REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

4.3 Structural Form of the Blocks

4.3.1. 6-Storey Blocks

Excluding Tangmere, there are nine 6-storey dwelling blocks on Broadwater Farm Estate. The main blocks are rectangular in plan with smaller, four-storey wings connected at 90° to the ends via external walkways. Main corridors serving the flats run centrally through the block at intermediate levels, from which are flats on both sides. The flats are split diagonally over two levels with the kitchens and living rooms stacked along one elevation and the bedrooms stacked along the alternate elevation. Stairs up to the second-floor lead to a corridor which crossed over the main corridor to rooms above the flat opposite. The flats had a floor to ceiling height of circa 2.4m.



Figure 8 – Example of 6-storey dwelling block (Hawkinge)

These blocks are constructed from an insitu concrete podium slab at deck level with the floors above constructed from a style of Large Panel System (LPS). It is understood that these medium/high-rise blocks also use the Larsen Nielsen System form of LPS construction (The University of Edinburgh, 2017). This form of construction involved the use of precast concrete panels, which were manufactured on the land adjacent to the site, then craned into place and assembled. Reinforcement extended from the panels into the joints between the elements and were tied together. The joints between the elements were then cast using insitu concrete and a dry-pack mortar used for final bedding of the precast loadbearing wall panel above. An example of the insitu joint between the cross walls panels and floor slabs can be seen in Figure 9. The exterior of the blocks have been over-clad; this conceals the LPS nature of the block externally and the joints internally are concealed by finishes.

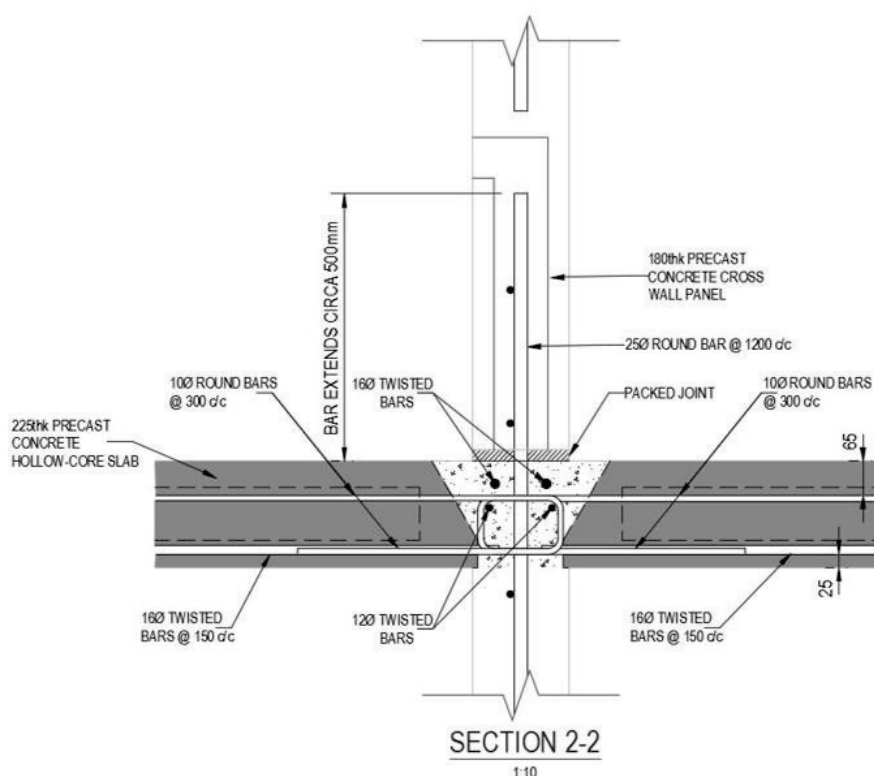


Figure 9 – Example of insitu joint between precast concrete units (Cross Wall to Floor Slab)

The precast concrete hollow-core floor slabs were one-way spanning onto the internal cross walls and, in the end flats, the outer flank walls. Excluding the flank walls the outer walls of the block were non-loadbearing and as such were not designed to support loading from the structure other than their own self weight and the cladding. These wall panels are stacked upon each other and tied back to the cross walls by means of a bolt and a loop bar around the grout bar and also using steel straps which were bolted into the floor slabs. Internal concrete partition walls were also found to be present within the flats. These walls were built off the floor slabs, and do not have structural joints like the cross walls. The internal walls are fixed back to adjacent cross/internal walls with bolts fixed into cast-in threaded sleeves in the partitions. The flat layout for Manston can be seen in Figure 10 as an example.

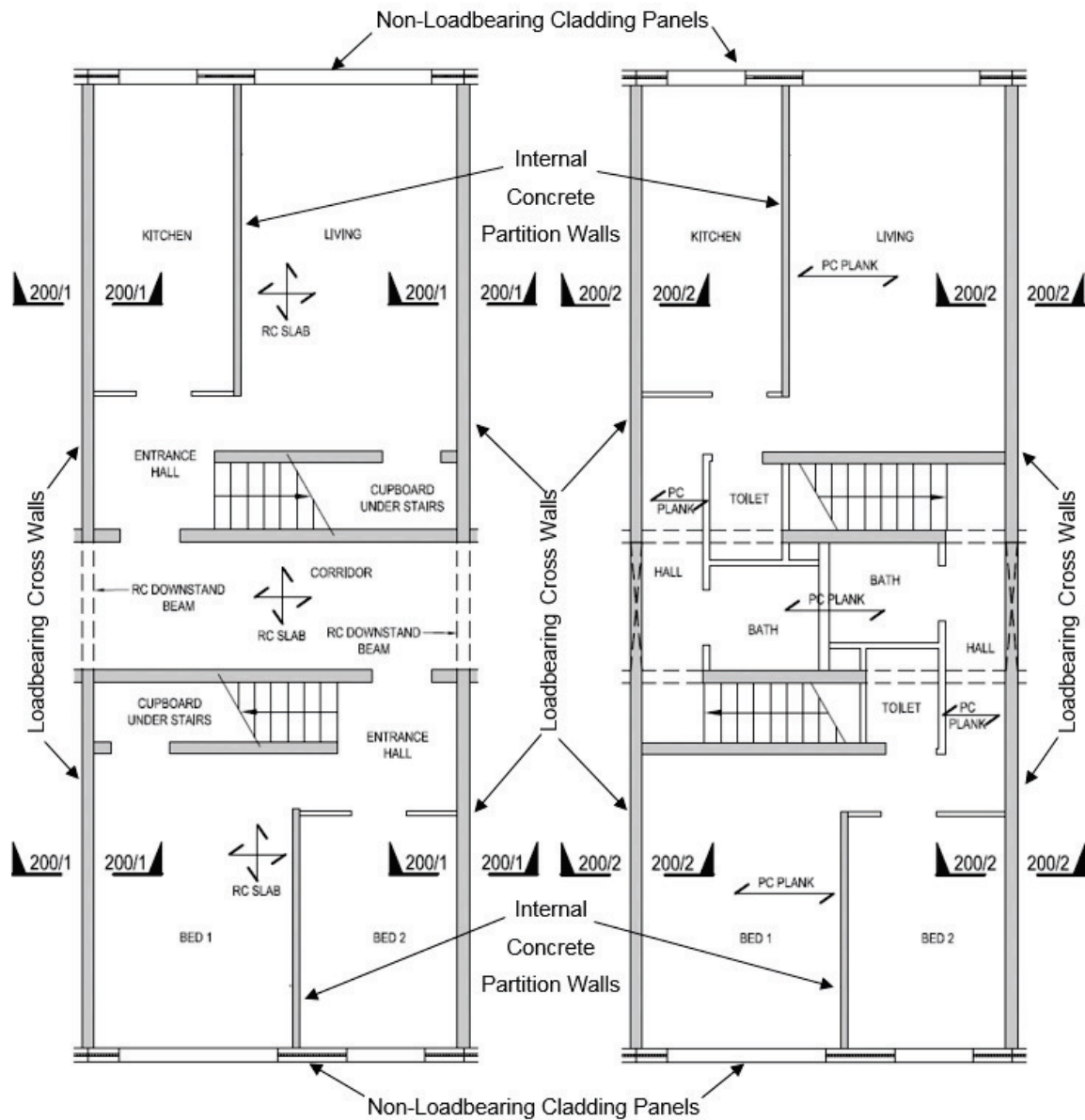


Figure 10 – Example of floor plan of duplex flat in 6-storey dwelling block (Flat 2 Manston)

4.3.1. 4-Storey Wings

Each of the nine 6-storey blocks (excluding Tangmere) have either one or two 4-storey wings connected to them. These flats are accessible from the main 6-storey block by an external walkway. The flats within the 4-storey wings are either single level or duplex, with a floor to ceiling height of around 2.4m.

The wings are constructed from an insitu concrete podium slab at deck level with the floors above constructed from a style of Large Panel System (LPS). They were constructed from precast concrete panels, which were manufactured on the land adjacent to the site. The joints between the elements were cast using insitu concrete and a dry-pack mortar used for final bedding of the precast loadbearing wall panel above.

However, through the exploratory investigation carried out on these wings it was determined that the design of the wings was inherently different to the 6-storey main blocks. For example, the cross wall panels were found to be unreinforced, and the vertical elements of the connections between members in the insitu joint varied from that seen in the 6-storey block. The tie detail between the floor slabs and the cross walls did not contain a vertical element at the base of the cross wall panel and the flank wall panels contained a vertical element which was cast into grout within a formed pocket.



Figure 11 - Example of 4-storey wing (Hawkinge) – All flats in this block are single level

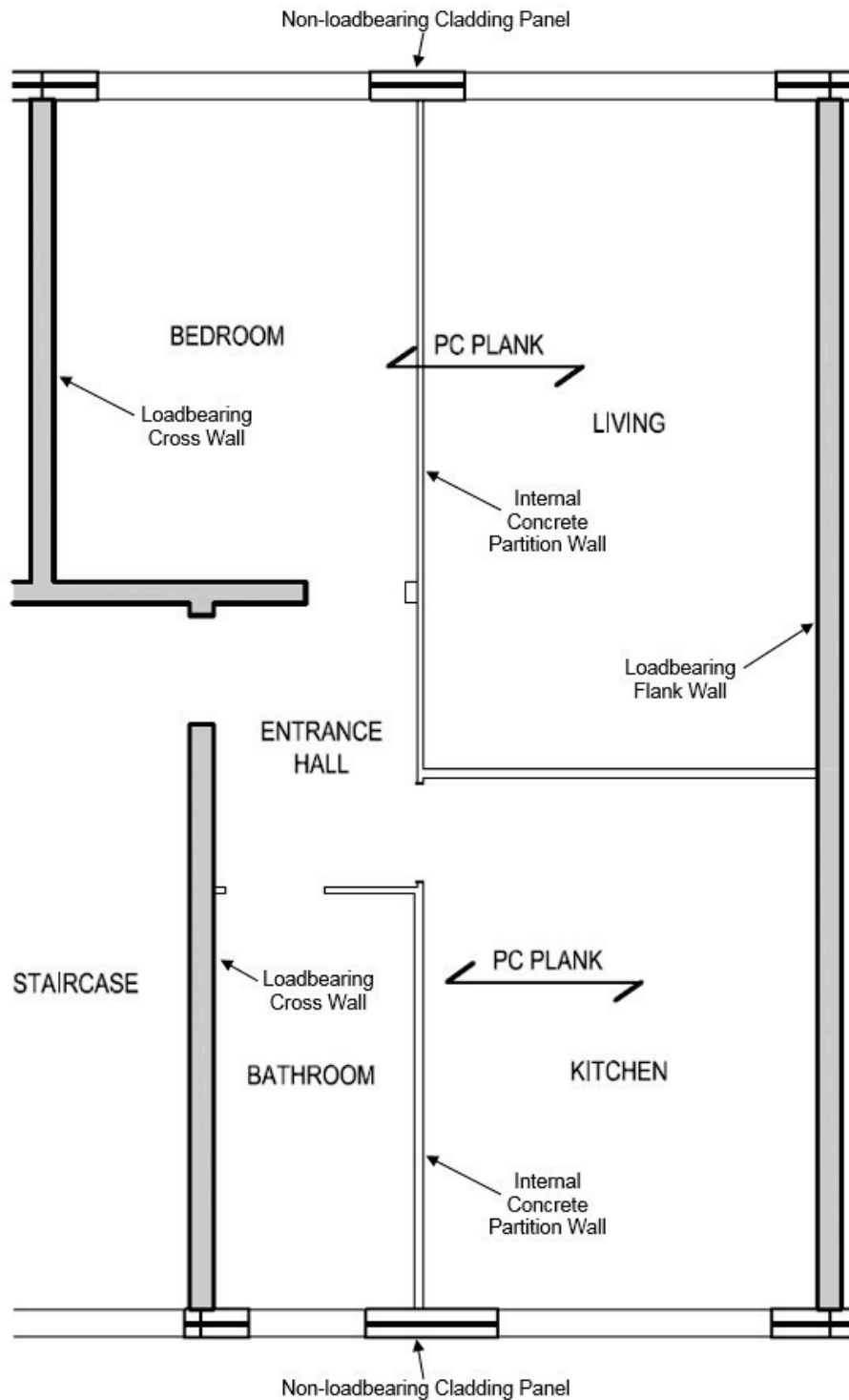


Figure 12 – Example of floor plan in 4-storey wing (Flat 36 Hawkinge)

5. INVESTIGATION METHODOLOGY

5.1 Flats and Non-Residential Areas Subject to Investigation

The first stage of the investigative works was to carry out an initial assessment on the vacant flats and non-residential areas to determine whether they were suitable for investigation. Flats were only selected if additional information could be obtained from them, for example if the flat contained a structural element not found within other selected flats in that block.

To date, the following flats and non-residential areas were identified as suitable for investigation in the 6-storey blocks and the 4-storey wings:

- Manston:
 - Flat 2 (6-storey block, Deck level & 1st floor duplex flat)
 - Flat 51 (6-storey block, 4th & 5th floor duplex flat)
 - Drying Area (6-storey block, 4th floor non-residential area)
- Hawkinge:
 - Flat 14 (6-storey block, Deck level & 1st floor duplex flat)
 - Flat 36 (4-storey wing, 3rd floor flat)
 - ESO Lodge (6-storey block, 1st floor non-residential area)
- Croydon:
 - Flat 40 (4-storey wing, 4th floor flat)
 - Drying Area (6-storey block, 5th floor non-residential area)
- Rochford:
 - Flat 43 (4-storey wing, Deck level & 1st floor duplex flat)
 - Drying Area (6-storey block, 1st floor non-residential area)
- Martlesham:
 - Flat 86 (6-storey block, 4th & 5th floor duplex flat)
 - Drying Area (6-storey block, 4th floor non-residential area)
- Lympne:
 - Flat 70 (6-storey block, 4th & 5th floor duplex flat)
 - Drying Area (6-storey block, 1st floor non-residential area)
- Hornchurch:
 - Drying Area (6-storey block, 1st floor non-residential area)
- Debden:
 - Drying Area (6-storey block, 1st floor non-residential area)
- Stapleford:
 - Drying Area (6-storey block, 1st floor non-residential area)

5.2 Preparatory Works

'Soft strip' works were undertaken in the vacant flats that were identified to be suitable for the investigation, this included removal of the timber floors on top of the precast concrete floor slabs and the fire-stopping material above the windows, in order to allow a detailed visual inspection of the joints to take place.

Prior to the preparatory works commencing Homes for Haringey carried out an assessment in the flats for asbestos. Relevant precautionary measures were taken as advised by the HfH surveyor and health and safety team.

A strategy was also put in place by HfH for the eventuality where additional material potentially containing asbestos was exposed during the breaking out works. During the breaking out works the use of dust suppression was to be used, in the form of dampening down the area with water, with appropriate personal protective equipment. Should a potential source of asbestos be exposed the works were to be immediately stopped, the area to be dowsed with water and the room evacuated. Once the area was vacated the senior asbestos surveyor for HfH was to be informed. The room would then be cleared by the asbestos removal operative and subject to an environmental air test.

During the breaking out works material suspected of containing asbestos was discovered in several flats/communal areas within the "dry-pack" at the base of the wall panels. The agreed procedure was followed in each instance.

5.3 Non-Intrusive Ferro Scan Works

The load bearing walls within each of the flats were identified. In general, the walls with the least services (pipes/wires etc.) were selected for scanning works.

The critical areas, in terms of assessing the blocks against disproportionate collapse, are around the insitu joints between the main structural elements. As such, the non-intrusive scanning works were focussed on the cross walls, flank walls, and floor slabs (and where applicable the corbels and R.C. beams) close to the intersection of these members.

The scanning works were carried out on 600mm x 600mm grids using a HILTI PS250 Ferro-magnetic scanner. The data was then transferred onto a HILTI PSA 100 tablet for viewing and review of the scans. Examples of the scan data can be seen in Figure 13 and Figure 14.

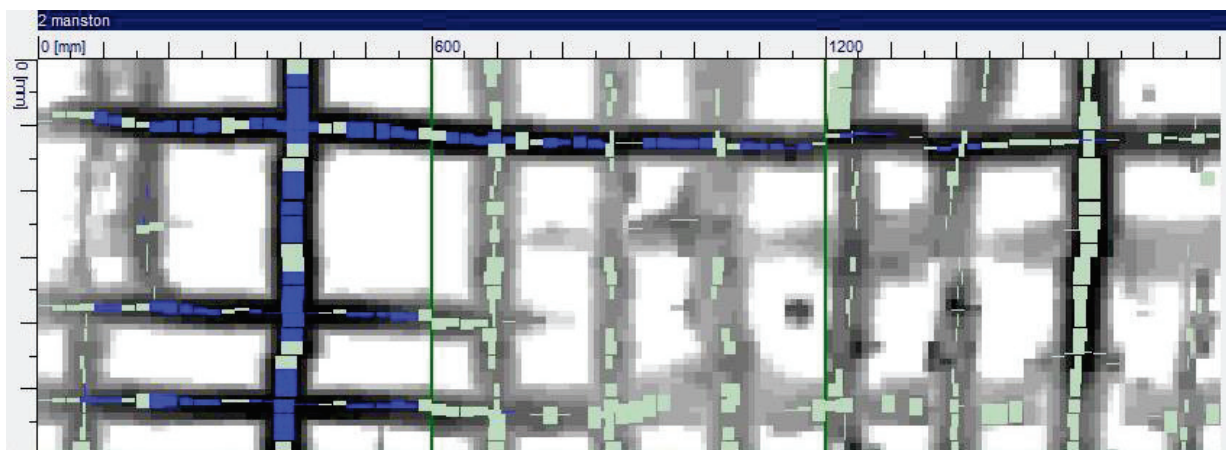


Figure 13 – Example of Three Wall Scans taken in Flat 2 Manston. The scans clearly show small diameter bars at regular 150mm c/c with two distinctively larger diameter link bars at approximately 1200mm centres. Two clear lateral bars are shown to extend the full width of the three scans, whereas the middle lateral bar appears to only be present in the first scan. It should also be noted the difference in clarity between the link bar in scan 1 compared to scan 3. This was a common occurrence throughout the scanning with some link bars being harder to identify.

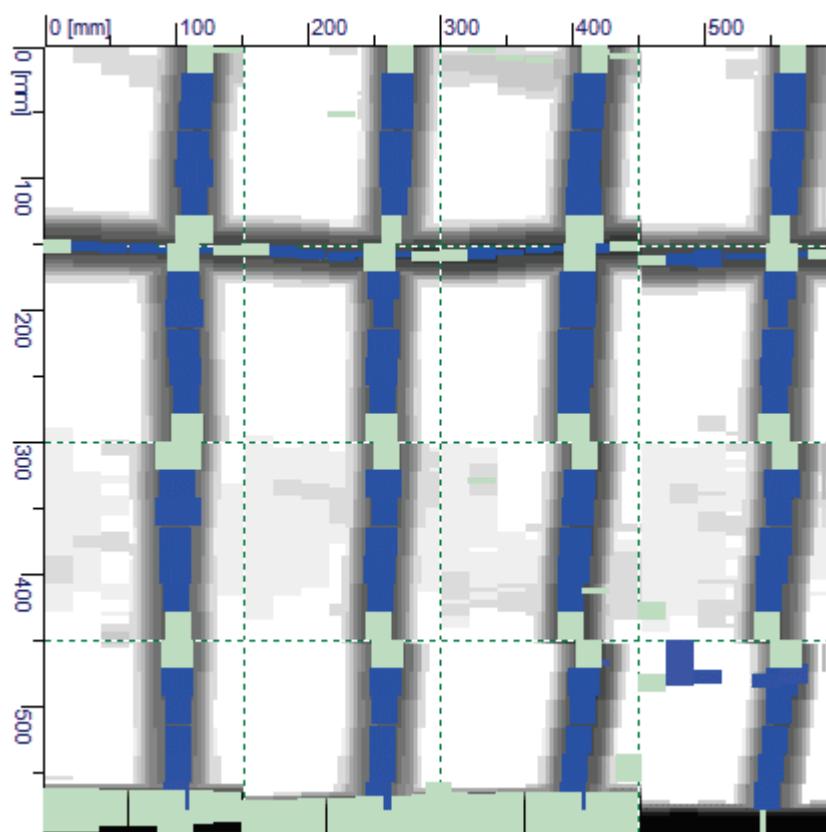


Figure 14 – Example of Ceiling Scan Data taken in Flat 2 Manston. Scan shows bars at close regular centres at the base of the slab.

The HILTI PS250 was then set to the cover-meter function and the walls and slabs re-scanned to determine the cover to the reinforcement bars (rebar). The location and cover of the rebar was marked up onto the walls. A detailed interpretation of the information obtained through these two non-invasive investigation methods was undertaken to identify areas required for further investigation and breaking out works.

5.4 Interpretation of Non-Intrusive Investigation Results

The results from the Ferro scan mapping and the cover-meter mark-up on the walls were then compared. The combination of the two sets of data enabled the engineers to identify the areas known to be critical in the investigation of structural adequacy for disproportionate collapse. In particular, the location around the 25mm link bars typically provide the information required to determine whether the structure possessed effective vertical and horizontal ties.

Once the areas of interest were identified the engineers marked-up the walls to indicate to the contractor where the intrusive opening up of localised pockets was to be carried out.

An example of the walls marked-up with the information obtained from the two sets of scans can be seen in Figure 15.

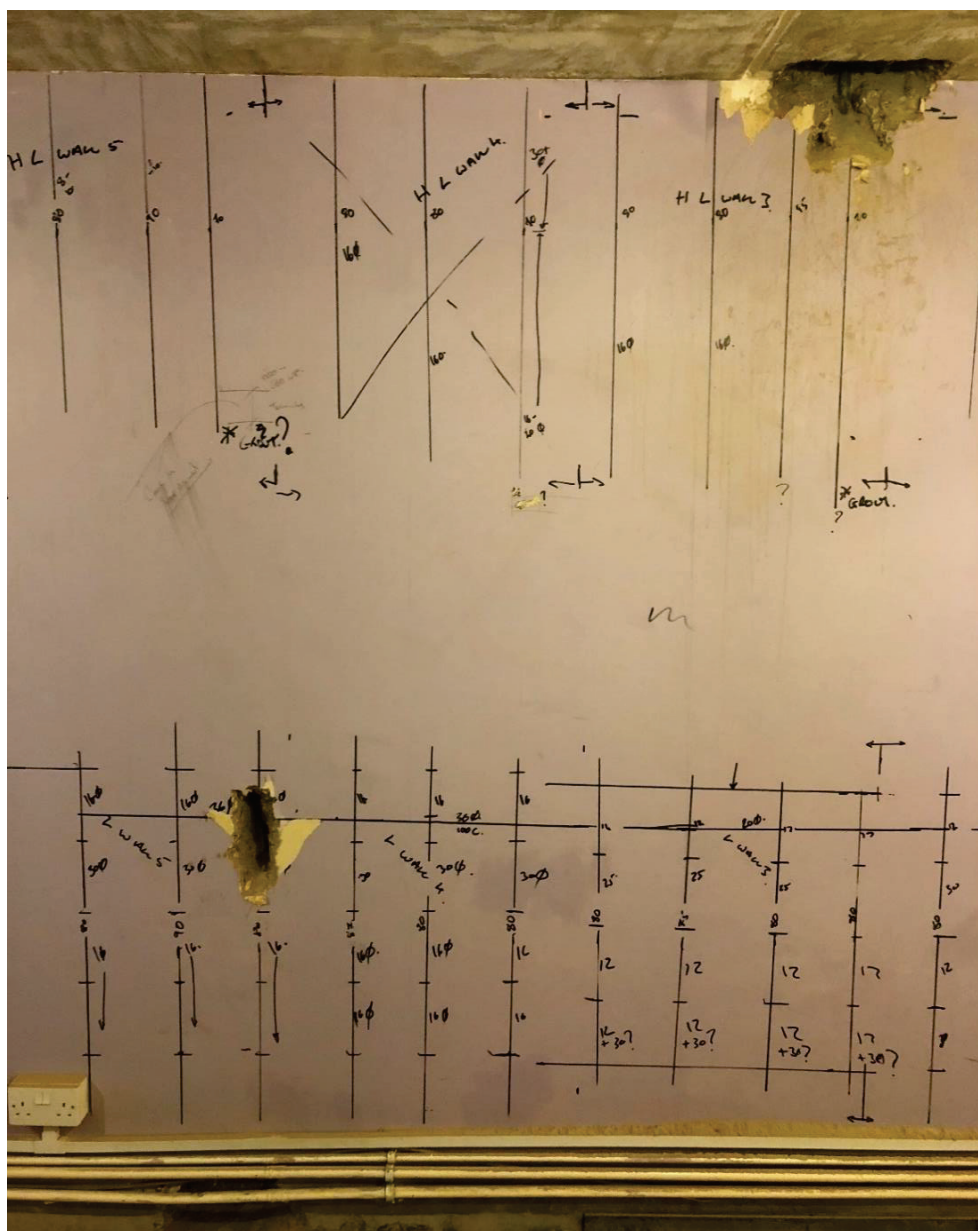


Figure 15 – Wall of Flat 2 Manston marked-up with the results from the two scans. The information obtained then used to identify areas for further investigation using intrusive methods.

5.5 Intrusive Opening-Up Works

For the intrusive investigation Ridge arranged for a contractor to carry out the opening-up works under the supervision of an engineer. Having previously identified the areas of interest to the investigation using the non-intrusive methods the contractors carefully broke out pockets in the concrete, where required, using HILTI electromechanical concrete breakers.

Once broken out, the pockets were visually inspected by the engineer to validate the results from the Ferro Scanning works and to understand the reinforcement details and ultimately the construction of the block.

These details were measured and recorded to enable calculations to be produced to assess the adequacy of the elements to resist accidental overpressure loading.

Initially, several pockets were made in each flat to aid in the understand of how the blocks were constructed. During the investigation many similarities were found between the blocks in the way the panels were connected within the insitu joints. These similarities were observable in the scanning data. This allowed the amount of intrusive opening up works to be progressively scaled back. Intrusive opening up works were only carried out in the later flats to verify any discrepancies found within the scan data.

6. FINDINGS OF INVESTIGATION

6.1 Overview

A combination of intrusive and non-intrusive investigations have been carried out within select flats in blocks assessed to date. The aim of this section is to compare the results of similar blocks to find common details, and to highlight any discrepancies.

Nine blocks on the estate are 6-storey rectangular blocks with between one and three 4-storey wings attached to the ends. However, as the wings are below five storeys in height the current Building Regulations treat these differently to the main blocks, further details can be found in Section 8. Therefore, these 4-storey wings will be assessed independently to the main blocks.

6.2 Rebar Grades

Assessing the age of the structures it is likely that the rebar within all twelve of the dwelling blocks conformed with BS 1478:1964. The three rebar types noted in this code are:

- MR = Round Mild Steel
- HR = Round High Yield
- HS = Square High Yield

Opening up works of the precast units and the associated joints showed that plain round bars, ribbed bars, and twisted square bars were used in the construction of the block. As it was not possible to determine whether the plain round bars were mild steel or high yield bars without record information this report will consider them to be type 'MR' with a characteristic yield strength of 250MPa. The ribbed bars were 'HR' type bars with a characteristic yield strength of 450MPa. The twisted square bars were likely 'HS' type bars with a characteristic yield strength of around 450MPa.

6.3 Overview of findings within 6-Storey Blocks

Generally, the construction comprised of 8" thick hollow core slabs spanning between 7" centrally reinforced pre-cast cross walls with vertical link bars at approximately 4' centres. The span direction was noted to change for the last span to each end of the block and the slabs span from the corridor to the flank wall. The flank walls are a 6" reinforced concrete panel with a single layer of reinforcement toward the rear of the panel, a corbel supports the precast concrete plank just below floor level.

The non-structural cladding build-up was noted to be a 6" lightly reinforced internal panel, 25mm polystyrene insulation and an external 75mm concrete panel. The cladding to the non-load bearing east and west elevations is vertically stacked and restrained by the structure only at each level.

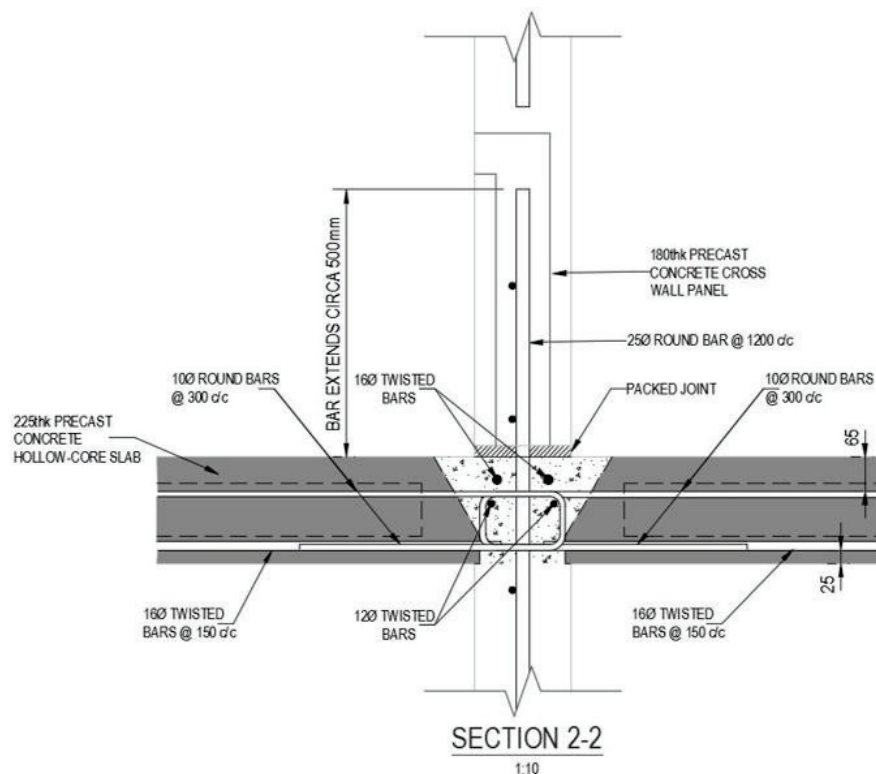


Figure 16 – Example of insitu joint between Cross Walls and Floor Slabs

6.4 Overview of findings within 4-Storey Wings

Generally, the construction comprised of 8" thick hollow core slabs spanning between 7" pre-cast cross walls that were found to be largely unreinforced. The flank walls are a 6" reinforced concrete panel with a single layer of reinforcement toward the rear of the panel, a corbel supports the precast concrete plank just below floor level.

The non-structural cladding build-up was noted to be a 6" lightly reinforced internal panel, 25mm polystyrene insulation and an external 75mm concrete panel. The cladding to the non-load bearing east and west elevations is vertically stacked and restrained by the structure only at each level.

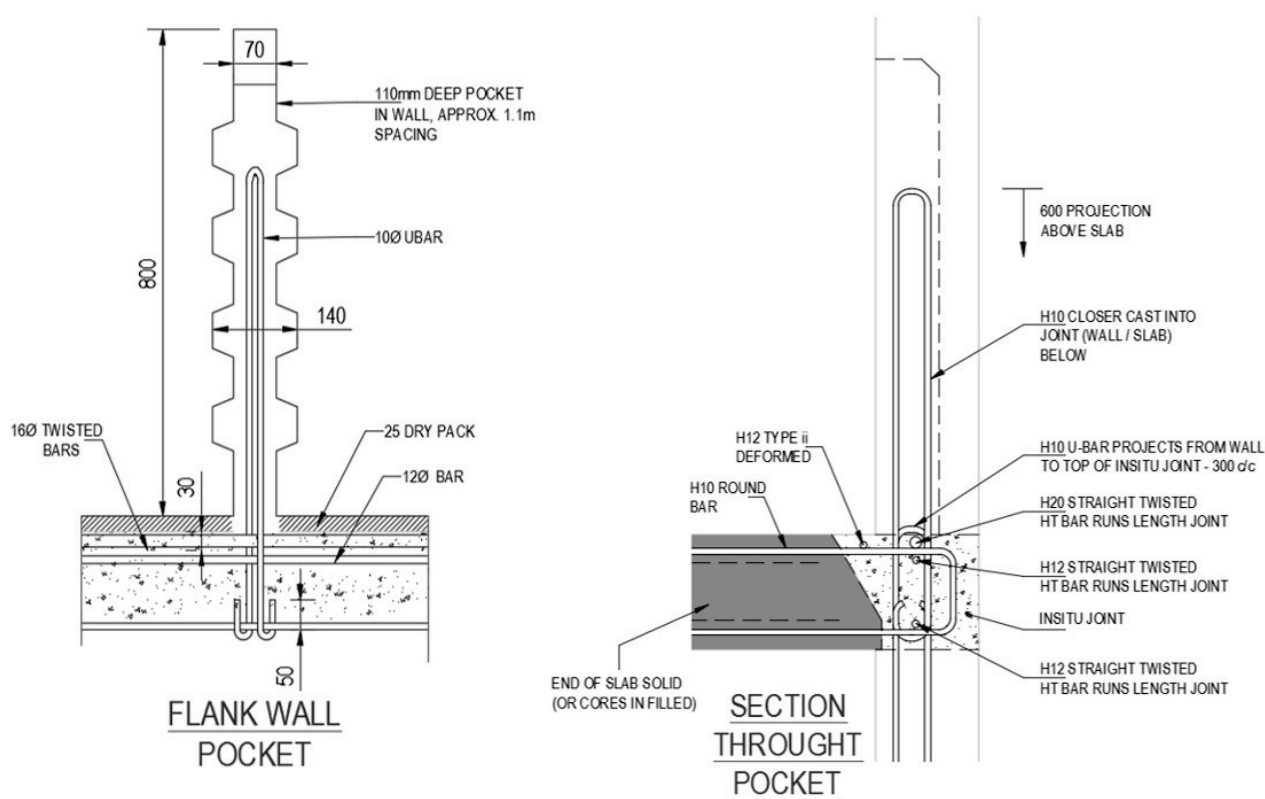


Figure 17 – Example of insitu joint between Flank Walls and Floor Slab

7. LIMITATIONS OF INVESTIGATION

As part of the investigation into the robustness of the block of flats at Broadwater Farm Estate Ridge carried out a review of the historic information held by Homes for Haringey. It was noted that much of the information held was architectural and contained no construction drawings or calculations for the blocks. Ridge also requested archive searches from the original contractor, consulting engineer and Hornsey Town Hall (known to have held the drawings historically). However, at time of writing no additional information has been provided. In the absence of the construction details more breaking out work was required to understand the construction of the building before the robustness assessment could take place.

The investigation was also affected by the presence of asbestos in the ceiling coatings and within parts of the structure. This caused delays to the project timescales as this had to be stripped out prior to the breaking out works.

Whilst the investigation on each block was detailed, with multiple wall and floor scans and several subsequent pockets opened up, it should be noted that there is the possibility for lack of continuity between the joints in the same block. As the investigations were only carried out on one or two of the flats per flat and the communal drying areas there is the possibility that other joints, not included in this investigation may contain imperfections, may be a product of poor workmanship, have missing bars, damaged/corroded rebar etc. Without checking every joint in the block, it is impossible to provide 100% certainty that all joints have been constructed correctly. A full assessment of every joint in the blocks would not be practical and thus the assessment of the blocks can only be based on what was uncovered in the sample investigation.

8. ASSESSMENT

8.1 Classification of Structure

The Building Regulations 2010 Approved Document A divides buildings into consequence classes depending on their purpose and number of storeys using Table 1.

Consequence Classes	Building Type and Occupancy
1	Houses not exceeding 4 storeys
	Agricultural buildings
	Buildings into which people rarely go, provided no part of the building is closer to another building, or area where people do go, than a distance of 1.5 times the building height
2a Lower Risk Group	5 storey single occupancy houses
	Hotels not exceeding 4 storeys
	Flats, apartments and other residential buildings not exceeding 4 storeys
	Offices not exceeding 4 storeys
	Industrial buildings not exceeding 3 storeys
	Retailing premises not exceeding 3 storeys of less than 2000m ² floor area in each storey
	Single-storey educational buildings
	All buildings to which members of the public are admitted which contain floor areas exceeding 2000m ² but less than 5000m ² at each storey
2b Upper Risk Group	Car parking not exceeding 6 storeys
	Hotels, blocks of flats, apartments and other residential buildings greater than 4 storeys but not exceeding 15 storeys
	Educational buildings greater than 1 storey but not exceeding 15 storeys
	Retailing premises greater than 3 storeys but not exceeding 15 storeys
	Hospitals not exceeding 3 storeys
	Offices greater than 4 storeys but not exceeding 15 storeys
	All buildings to which members of the public are admitted which contain floor areas exceeding 2000m ² but less than 5000m ² at each storey
	Car parking not exceeding 6 storeys
3	All buildings defined above as Consequence Class 2a and 2b that exceed the limits on area and/or number of storeys
	Grandstands accommodating more than 5000 spectators
	Buildings containing hazardous substances and/or processes

Table 1 - Disproportionate Collapse Consequence Classes (Department for Communities and Local Government, 2010)

The two blocks, Kenley and Northolt, are both eighteen stories above an insitu concrete ground floor service area. These blocks are, therefore, within consequence class 3 'All buildings defined above as Consequence Class 2a and 2b that exceed the limits on area and/or number of storeys'

The remaining blocks (excluding the wings) on Broadwater Farm Estate are six-storey buildings, with an insitu ground floor car park below. These blocks are, therefore, within the 2b (upper risk group) consequence class 'Hotels, blocks of flats, apartments and other residential buildings greater than 4 storeys but not exceeding 15 storeys'.

Attached to the main six-storey blocks are four-storey wings. These wings are within the 2a (lower risk group) consequence class 'Flats, apartments and other residential buildings not exceeding 4 storeys'

8.2 Assessment Criteria

BRE Report 511 – Handbook for the Structural Assessment of Large Panel System (LPS) Dwelling Blocks for Accidental Loading provides guidance on how to determine whether an LPS block complies with the Building Regulations for disproportionate collapse. The report identifies three criteria for assessment, of which the blocks need only pass one:

- 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 (see Section 8.1) 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.
- 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. (Matthews & Reeves, 2012)

8.3 Assessment Discussion – 6 Storey Blocks

8.3.1. LPS Criterion 1

To meet Criterion 1 for a Class 2b building the joints between slabs/panels in the block must have adequate provision of horizontal and vertical ties.

Assessment of the cross wall joints exposed during the intrusive investigation revealed that there were 10mm diameter U-bars at 12" centres protruding from the edges of the precast floor slabs. The U-bars from the adjacent floor slabs were joined within the joint with 2no. 12mm diameter lacer bars. This connection constituted the horizontal tie in the joint. This connection method is highlighted in MHLG Circular 62/68 as an acceptable horizontal tie connection.

The vertical tie in the cross wall joints consisted of 25mm bars at 4' centres cast into the top of each panel and dry packed into the bottom of the panel above. The investigative works have also shown that these bars are not continuous in the wall panels. The bars extend circa 500mm up into a grout pocket cast into the bottom of the cross wall panels. Another bar is then cast into the panel above the grout pocket. This connection method is not sufficient to provide an effective vertical tie. In the event of a failure of a cross wall, the floor above which would have originally been taking bearing on the failed wall, would be reliant on hanging from the vertical bars protruding down from the wall above. These plain round bars are grouted into the walls and would offer little tensile resistance due to the minimal bond a smooth bar achieves. A pull-out failure of the bars would therefore be likely, causing the floor to fall away from the wall above.

As the joints do not provide an effective vertical tie it is deemed that the cross wall joints within the six-storey blocks investigated to date do not comply with Criterion 1.

Flank Wall Joints - The investigations into the flank walls with associated corbel detail (located within the drying areas of each block) are ongoing. This will be reported on in a later revision of this document.

8.3.2. LPS Criterion 2

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.

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 Eurocodes.

The bending moment resistance was identified to be the critical check for the floor slab. The slab contains 16mm bars at 6" centres in the bottom, and unreinforced in the top. Uplift is, therefore, the most onerous case.

In the cross walls the likely failure mechanism was identified as local shear splitting failure around the 25mm link bars as these bars are the only reinforcement to extend into the joint. Diagrams of this failure can be seen in the extracts from fib Bulletin 43 in Figure 18 and Figure 19.

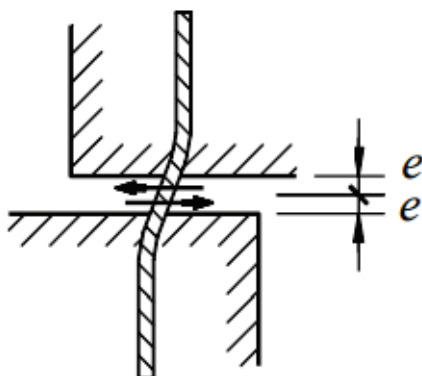


Figure 18 – Shear transfer by dowel action with double fixation (fib, 2008)

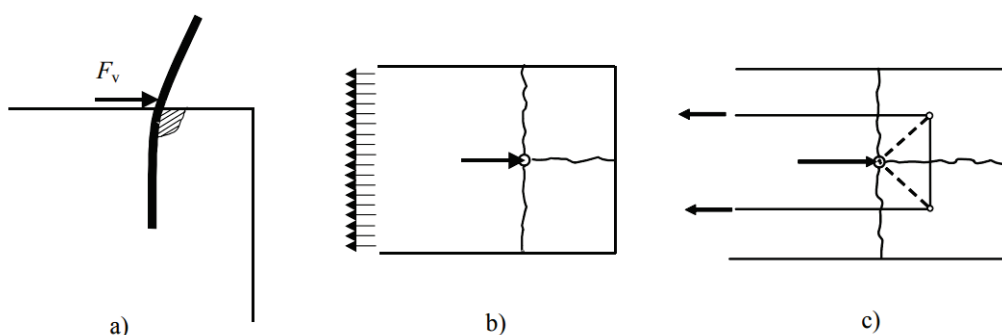


Figure 19 – Splitting effects around dowel pin loaded in shear, a) shear force acting on dowel bar indicating area of concrete under dowel subject to high stress concentration, b) potential planes of cracking, c) strut and tie model for design of splitting reinforcement – no splitting reinforcement found within wall panels.

An initial assessment was carried out using an over-pressure of 34kN/m^2 to comply with the regulations for accidental loading for building with a piped-gas supply. The calculations show that the structural elements that form the 6-storey blocks are insufficient to resist a loading of this magnitude.

The investigations into the flank walls with associated corbel detail (located within the drying areas of each block) are ongoing. The robustness of these element will, therefore, be reported on in a later revision of this document.

8.3.3. LPS Criterion 3

For a block to pass Criterion 3 the structure must be able to mobilise alternative load paths in the event of an explosion. If a single wall were to fail it is likely that the building would be able to mobilise alternative load paths and the floor slab above would go into catenary action. However, BRE Report 511 states that “the over-pressure should be applied simultaneously to all surfaces of the single room / bounding enclosure within which the explosion is considered to occur” (Matthews & Reeves, 2012). In this instance the bounding enclosure was deemed to be the entire flat for a piped-gas supply, to conform with BRE 511 Clause 5.4.3 – Multi-room Explosions as the continual flow of gas from the mains supply could readily spread into adjacent rooms.

The calculations carried out for the Criterion 2 assessment demonstrate that the structural bounding enclosure suffers complete failure under the 34kN/m^2 over-pressure loading. This could result in a disproportionate collapse event for the block as all support is removed or compromised.

As such, the block does not pass the LPS Criterion 3.

8.3.4. Re-assessment of LPS Criterion 2 with the Removal of the Piped-Gas Supply

Following the failure of the three LPS Criteria with a piped-gas supply, further calculations were, therefore, carried out to assess the block of flats for a reduced over-pressure of 17kN/m^2 . This over-pressure would relate to a block without a piped-gas supply. However, as the 6-storey blocks had a piped-gas supply at time of investigation this would have to be removed to comply with the regulations.

The calculations carried out show that the structural elements were sufficiently robust to resist the 17kN/m^2 overpressure except for the slab in uplift. In the uplift condition our analysis showed that in order to develop the full stresses the slab would engage the dividing wall between the kitchen and living room which would provide benefit to the slab in this instance reducing the stress within the slab.

The resulting stress is likely to only cause a localised failure of the slab central to the room below in the uplift condition, the floor slab below was analysed for the loading from the failed floor slab above and was found to be able to resist the load. The building therefore passes criterion 2 as progressive collapse is resisted. The calculations were carried out for a single room explosion to conform with BRE 511 Clause 5.4.2

8.4 Assessment Discussion – 4 Storey Wings

8.4.1. LPS Criterion 1

The four-storey wings are subject to the requirements associated with the consequence class 2a.

To satisfy LPS Criterion 1 a class 2a structure needs only effective horizontal ties within the joints. In the four storey wings investigated to date the joints have U-bars protruding from the ends of each slab at circa 12" centres. The U-bars from the two adjoining slabs are also tied together using transverse lacer bars. This connection is highlighted in MHLG Circular 62/68 as an acceptable horizontal tie. The structure, therefore, passes LPS Criterion 1, and as such can be considered compliant with Building Regulations 2010 for disproportionate collapse.

However, it is noted in Approved Document A – Structure of the Building Regulations that an alternative approach to that stated in LPS Criterion 1 is to check that the floor area at any storey at risk of collapse upon the notional removal of any nominal length of loadbearing wall does not exceed 15% of the floor area in that storey or 100m², whichever is smaller, and does not extend further than the immediate adjacent storeys. Where this limit is exceeded the elements should be designed as a 'key element'.

In some of the 4-storey wings there are only 2 flats per storey. In these blocks the removal of a flank wall would result in 50% of the total floor area in each storey at risk of collapse indicating that these should be assessed as 'key elements' and therefore subject to the over-pressure highlighted in LPS Criterion 2. Such an assessment may require strengthening works to the critical wall and floor elements to resist the required over-pressure.

Furthermore, site observations have noted the flank walls in some instances are constructed immediately adjacent to the taller 6-storey buildings. The failure of these wall panels under an over-pressure load may not only result in the collapse of the 4-storey wing, but also that of the adjacent taller building, and are therefore subject to the 'key element' design highlighted above.

8.4.2. LPS Criterion 2

The investigative works carried out in the 4-storey wings showed that the cross wall panels are unreinforced and an inherent weakness was found around the formed pockets in the flank wall connecting the panel at the base. As the 4-storey wings have a piped-gas supply the blocks would be subject to the 34kN/m² overpressure in the event of an internal gas explosion. The wall panels and floor slabs would suffer failure under an overpressure of this magnitude. There is, therefore, an inherent risk of collapse in the event of an explosion with a piped-gas supply in these wings, despite the block passing the LPS Criterion 1.

A further check was, therefore, carried out on the floor slab for the reduced overpressure of 17kN/m² associated with the removal of the piped-gas supply. However, in the absence of top reinforcement in the floor slabs, the slabs were also shown to fail in uplift under the 17kN/m² overpressure.

The cross wall panels within the four storey wings investigated to date have were found to be unreinforced. The cross walls are, therefore, not sufficiently robust to resist the overpressure associated with an internal gas explosion, even if the piped-gas supply was to be removed.

The base connection of the flank wall panels was within formed pockets. These were deemed inadequate to resist an overpressure of 17kN/m² given the lack of lateral reinforcement in the pocket, variable quality and

compaction of the grout within the pocket and poor adhesion of the grout to the precast element given the un-scabbled smooth edges.

Considering the findings above, a suitable method of calculation to assess the adequacy of the connection is impractical. As such, empirical testing would need to be considered to determine the capacity of the connection to resist the overpressure associated with an internal gas explosion.

Therefore, although the four storey wings have been shown to comply with LPS Criterion 1 the structure does fail the 'key element' checks for certain locations. This does, therefore, indicate that the building could potentially suffer progressive collapse in the event of an internal explosion.

8.4.3. LPS Criterion 3

It is shown in the calculations for the Criterion 2 assessment that all floor slabs and wall panels fail under the 34kN/m² and 17kN/m² over-pressure loads. As such, under this overpressure criterion the block will be unable to mobilise alternative load paths. The four storey wings, therefore, fail the LPS Criterion 3 under the 34kN/m² overpressure associated with a piped-gas supply.

This failure is likely to propagate up the building causing progressive and disproportionate collapse. As such, the block does not pass the LPS Criterion 3.

8.4.1. Summary of Assessment

The four storey wings technically pass the assessment, given the adequate horizontal tie for class 2a structures, for disproportionate collapse as set out in BRE Report 511. However, elements of the buildings have been noted to be subject to key element design and these will need strengthening as noted in Section 8.4.1.

Notwithstanding the above an assessment of the building, under 34 kN/m² loading from the piped gas supply shows that these blocks could suffer a disproportionate collapse event and therefore we would recommend the removal of piped gas from this block type in line with the actions being carried out on the other blocks on the Broadwater Farm Estate.

However, calculation shows even with the removal of the piped-gas supply, there is still an inherent, albeit significantly reduced, risk of progressive collapse in the 4 storey wings should a 17kN/m² overpressure event occur. Strengthening will significantly help to mitigate this risk.

9. FURTHER OBSERVATIONS

During the investigation into the robustness an observation was noted that the reinforcement found within the joints does not effectively deal with the stresses known to be present in joints of this construction. The forces and stresses present in the joints can be seen in the extract from fib Bulletin 43 in Figure 20.

For example, U-bar reinforcement is normally found to the bottom of the wall panels, the base of the wall panels investigated did not have such reinforcement. However, from our observations on site there were no obvious signs of structural distress from the lack of the appropriate joint reinforcement, this is most likely due to the low stresses contained within the joints of the current structural configuration.

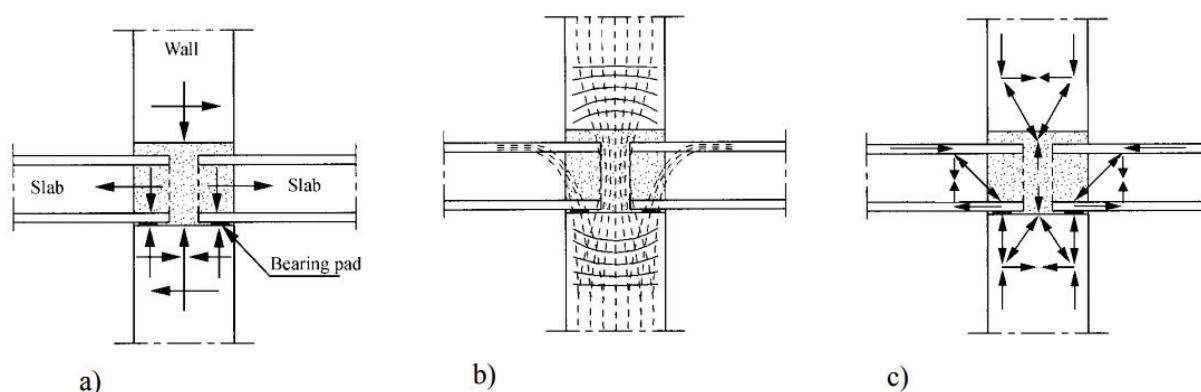


Figure 20 – Slab-wall connections, a) forces, b) simplified stress analysis, c) strut-and-tie model (fib, 2008)

Throughout the investigation cracks were found to be a common occurrence in the loadbearing wall panels. The majority of cracks were vertical cracks running the entire height of the wall, and all the way through the thickness of the panel. There are a number of likely causes for the cracking within the panel which are thermal, shrinkage, poor curing or construction related damage. The cracks observed are not thought to affect the load bearing adequacy of the structure.

A sample of the cracks found during the investigation can be seen in Figure 21.



Figure 21 – Examples of cracking in loadbearing wall panels in various flats across Broadwater Farm Estate

Another observation was that the non-loadbearing external wall panels are vertically stacked, and fixed back to the main structure primarily to reduce lateral deflections in the panels. In the event of an explosion in one of the flats the non-loadbearing external wall panel, and its fixings back to the structure, would be insufficient to resist the 17kN/m^2 overpressure. This would cause the panels to 'blow out' and fall away from the structure.

As these panels are vertically stacked if the explosion were to occur in the lower floors this may result in a 'domino effect', with the panels above progressively losing their support and potentially falling to the ground. Although this would not be deemed to be disproportionate collapse as no floor area would be at risk of collapse with the removal of these panels (unless struck by the falling debris) there is the potential to cause considerable collateral damage, injury or loss of life.

10. REFERENCES

- BSI, 1997. *BS 8110-1:1997 Structural use of Concrete - Part 1: Code of practice for design and construction*, s.l.: s.n.
- Building Design Partnership, 1985. *Final Report on Structural Investigations at Broadwater Farm Estate - Stage 1: Northolt and Kenley*, s.l.: s.n.
- Building Design Partnership, 1986. *Addendum Report For Broadwater Farm Estate Stage 1: Northolt and Kenley*, s.l.: s.n.
- Coll, D., 2014. *President's Medals - The Broadwater Farm Estate and the Social Production of Space*. [Online]
Available at: http://www.presidentsmedals.com/showcase/2014/I/1421_11115927091.jpg
[Accessed 19 01 2018].
- Concrete Society, 2016. *Concrete Advice 19 - Historic Reinforcing Bars and Steel Fabric*, s.l.: s.n.
- Currie, R. J., Armer, G. S. T. & Moore, J. F. A., 1987. *BRE Report 107 Part 2 - The Structural Adequacy and Durability of LPS Dwellings*, s.l.: s.n.
- Currie, R. J., Reeves, B. R. & Moore, J. F. A., 1987. *BRE Report 107 Part 1 - The Structural Adequacy and Durability of LPS Dwellings*, s.l.: s.n.
- Department for Communities and Local Government, 2010. *The Building Regulations 2010: Approved Document A - Structure*, s.l.: NBS.
- Department of the Environment, 1985. *BRE Report 63 - The Structure of Ronan Point and other Taylor Woodrow-Anglian Buildings*, s.l.: s.n.
- fib, 2008. *Bulletin 43 - Structural Connections for Precast Concrete Buildings*, s.l.: International Federation for Structural Concrete (fib).
- Haringey Council Building Design Service, 1985. *Broadwater Farm Estate Action*, s.l.: s.n.
- Matthews, S. & Reeves, B., 2012. *BRE Report 511 - Handbook for the Structural Assessment of Large Panel System (LPS) Dwelling Blocks for Accidental Loading*, s.l.: BRE.
- Ministry of Housing and Local Government, 1968. *MHLG Circular 62/68*, s.l.: s.n.
- Ministry of Housing and Local Government, 1968. *MHLG Circular 71/68*, s.l.: s.n.
- The University of Edinburgh, 2017. *Tower Block - Broadwater Farm*. [Online]
Available at: <http://www.towerblock.eca.ed.ac.uk/development/broadwater-farm>
[Accessed 07 12 2017].

