# RIDGE

PROPERTY & CONSTRUCTION CONSULTANTS

Homes for Haringey

**BROADWATER FARM ESTATE**
**STRUCTURAL ROBUSTNESS ASSESSMENT**
**TANGMERE (6 STOREY ZIGGURAT) REPORT**

April 2018

Prepared for

Homes for Haringey
108 Gloucester Road
London
N17 6GZ


Prepared by

Ridge and Partners LLP
Partnership House
Moorside Road
Winchester
S023 7RX

[redacted]

RIDGE

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# 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 Tangmere block which is of Ziggurat form and which is unlike the other 6 story blocks (that have 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
- Lympne
- Debden
- Hornchurch
- Hawkinge
- Manston
- Martlesham
- Rochford
- Stapleford
- Tangmere

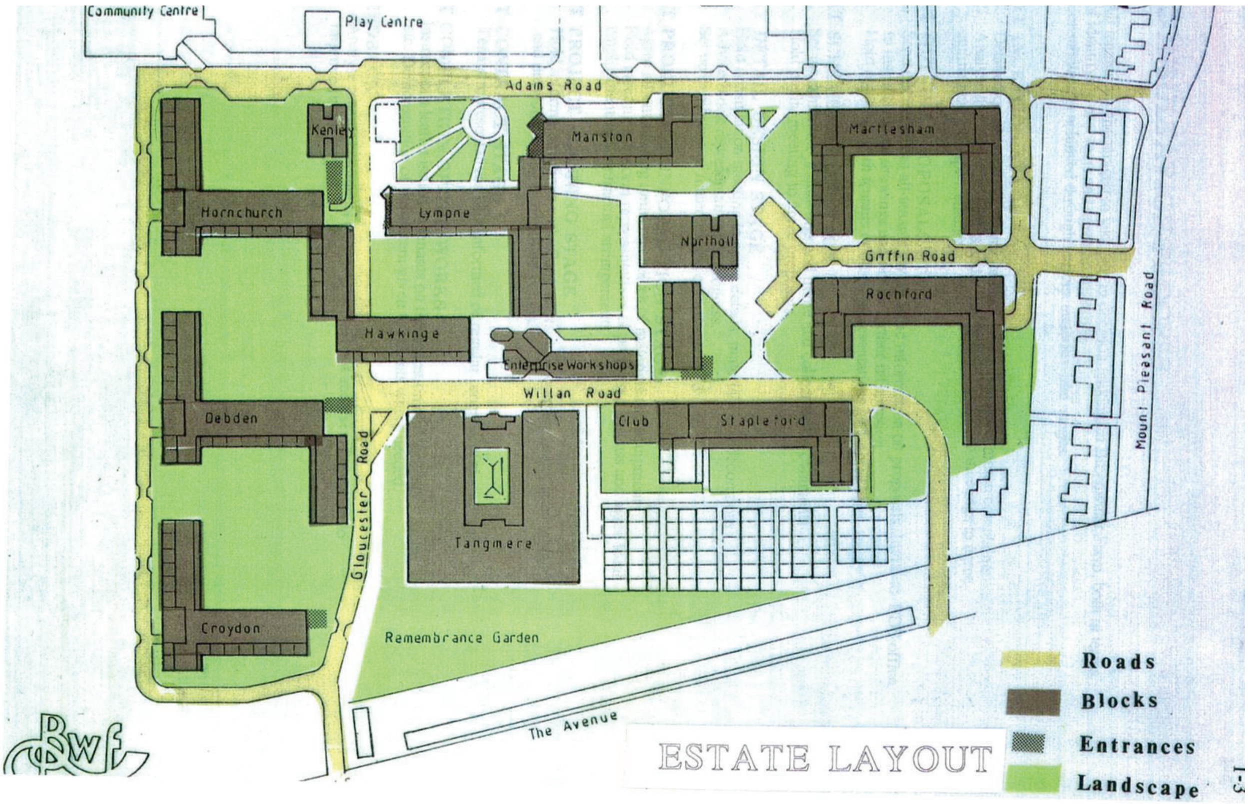


*Figure 1 – Broadwater Farm Estate Layout (Haringey Council Building Design Service, 1985)*

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. Subsequent archive search requests made to [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/m$^2$. Buildings without a piped-gas supply, or a basement, are subject to a lower over-pressure of 17kN/m$^2$. 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 in the 6-storey Tangmere (ziggurat) block and notes recommendations for further works:

| BLOCK NAME | $34KN/M^2$ OVERPRESSURE | $17KN/M^2$ OVERPRESSURE | NOTES |
|---|---|---|---|
| TANGMERE | X | X | Gas removal & strengthening works to be considered within full options appraisal. |

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 2b – Tangmere

- 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)

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.

The results of the analysis are as follows:

## Tangmere

- LPS Criterion 1

  The joints between the loadbearing elements in Tangmere were found to possess an effective horizontal tie. However, the vertical tie in the cross wall joints were found to be insufficient. Therefore, the connections in this block does not pass LPS Criterion 1.

- LPS Criterion 2

  The ‘key elements’ checks carried out on the loadbearing members in Tangmere show that the elements are insufficiently robust to resist an overpressure of 34kN/m$^2$ associated with a piped-gas supply. Therefore, the block does 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, Tangmere does 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/m$^2$. This reduced overpressure is associated with a block with no piped-gas supply. The checks showed that only the cross wall panels were sufficiently robust to resist this reduced loading. The flank wall panels near the top of the block have been shown to fail in flexure and the floor slabs also fail in flexure for both uplift and downward loading under the 17kN/m$^2$ overpressure.

- Summary of Assessment

  The assessment has shown that Tangmere fails to satisfy all three of the LPS Assessment Criteria, even with the removal of the piped-gas supply. Therefore, in its current state a disproportionate collapse event is likely in the event of an internal explosion.

As an initial response, we would recommend the removal of the piped-gas supply from Tangmere as part of a risk reduction measure. The removal of the gas from the block 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.

In conjunction with the removal of the gas supply we would recommend that strengthening design options are considered in order to comply with the LPS Criteria as part of a full options study.

## 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 $lb/in^2$ ($34kN/m^2$) 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 $lb/in^2$ ($17kN/m^2$).

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.

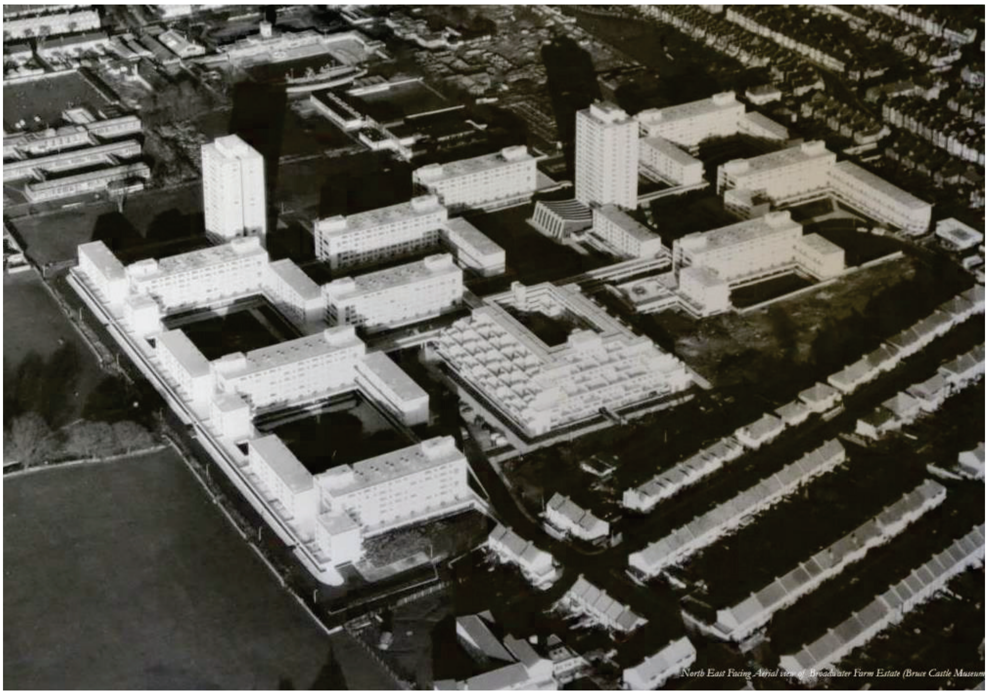

*Figure 2 – Historic Aerial Image of Broadwater Farm Estate in 1975 (Coll, 2014)*

## 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.

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

- [redacted] (who acquired the original Contractor, Taylor Woodrow Construction, in 2008)
- [redacted] (the original Consulting Engineers)
- Hornsey Town Hall (the archive box of information received from HfH included a report by the Building Design Partnership produced in 1985, which stated that approximately 1500 drawings were held on microfiche in Hornsey Town Hall). An email was sent to Haringey London Borough Council to determine whether these were still held there.

Vinci Construction replied to the Ridge request for an archive search. Unfortunately, as Taylor Woodrow did not design the blocks of flats at Broadwater Farm Estate they did not hold any of the construction drawings for the site. However, they did provide Ridge with the names of the original architect, C.E. Jacob of Haringey Town Hall, and consulting engineer, Clarke Nicholls Marcel.

Clarke Nicholls Marcel have since confirmed that they retain the original drawings for the twelve LPS blocks at Broadwater Farm Estate. However, at the time of writing these drawings had not yet been received.

[redacted]

## 4.3 Structural Form of the Blocks

### 4.3.1. 6-Storey Ziggurat Block (Tangmere)

Tangmere is a 6-storey dwelling block on the Broadwater Farm Estate. Tangmere is of a different design to the other blocks on the estate, and as such has been considered separately. The block is 'U-shaped' in plan and was built in a ziggurat form, with each successive floor recessed back from the floor below. The main entrance to the building is via the concierge, within which is a lift shaft which services each floor and a stairwell that encompasses the lift shaft. The stair core is internal up to deck level with the upper levels open. Main corridors running along the inner edge of the U-shaped block serve the flats on each level. The flats within Tangmere are a mix of single storey, duplex, and some flats were converted into three-storey dwellings following the past closure of retail units.  The flats have a floor to ceiling height of circa 2.4m.  The HfH offices are also located on the ground floor of this block (within a converted under croft).

*Figure 3 – Tangmere (External view)*

*Figure 4 – Tangmere (Internal courtyard view)*

Although Tangmere is of a different design to the surrounding blocks, it does share similarities in its construction.  The block was constructed using a style of Large Panel System (LPS) atop an insitu concrete podium slab.  It has also been suggested that Tangmere also uses the Larsen Nielsen System (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.

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. Tangmere also possesses several elements not found within the other blocks, including precast concrete beams and columns supporting flats at high level.

The ziggurat configuration of Tangmere creates a more complex disproportionate collapse mode compared to the simpler rectangular blocks elsewhere on the Broadwater Farm Estate.

The floor layout for Flat 119 Tangmere can be seen in Figure 5 as an example. The floor plans for all the flats subjected to the investigations have been appended to this document for reference.

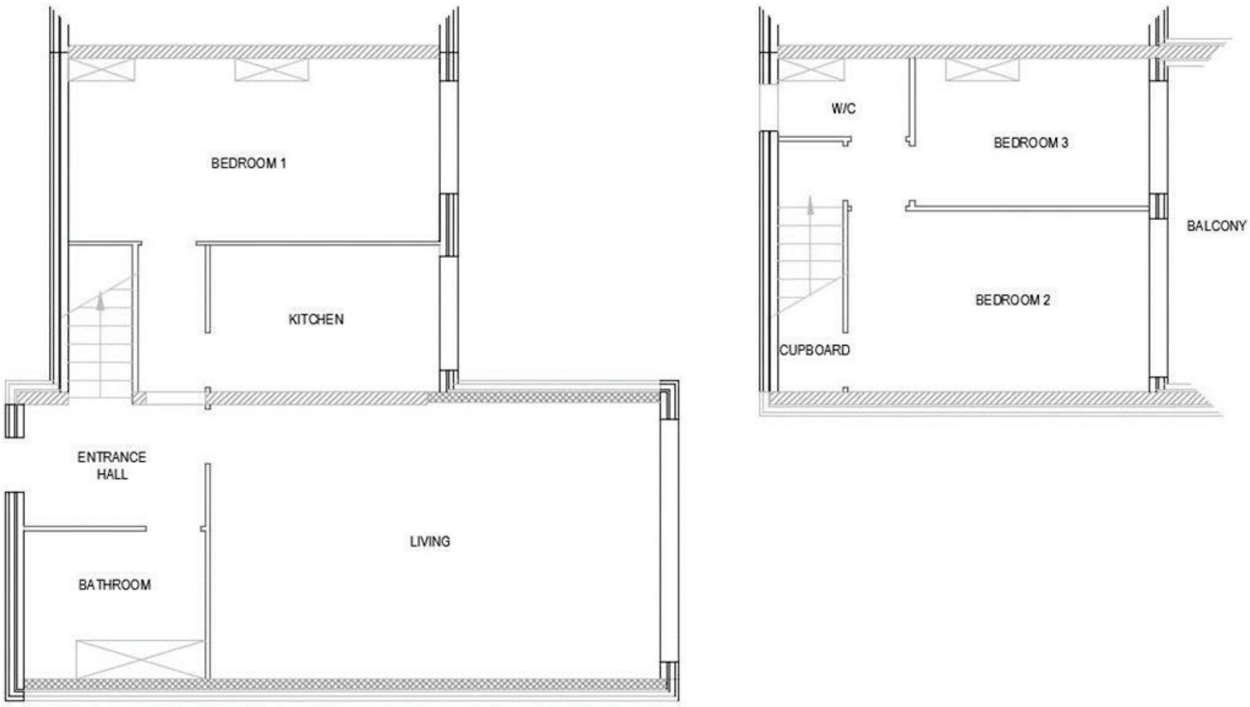


*Figure 5 – Example floor plans in 6-storey ziggurat block (Flat 119 Tangmere)*

In addition to the structural issues identified above, and outside of our current scope of works, we have noted several significant problems in Tangmere:

- The block is significantly affected by damp, most likely caused by water ingress and cold bridging resulting in black mould and mildew on the walls;
- Poor airflow within the communal corridors, caused by the installation of the new fire compartmentalisation measures; and
- Surface water penetration is a known historic problem, which is associated with detailing associated with the original design and construction of the block. The surface water drainage on the roof to the

terraces is poor. The form of the building lends itself to the physical build-up of water and without very regular maintenance to the entire surface water drainage system, there is significant likelihood of degradation of the structure over time.

# 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 ziggurat block:

- Tangmere:
  - Flat 96 (6-storey ziggurat block, 4th floor flat)
  - Flat 119 (6-storey ziggurat block, 4th & 5th floor level duplex flat)

## 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 6 and Figure 7.

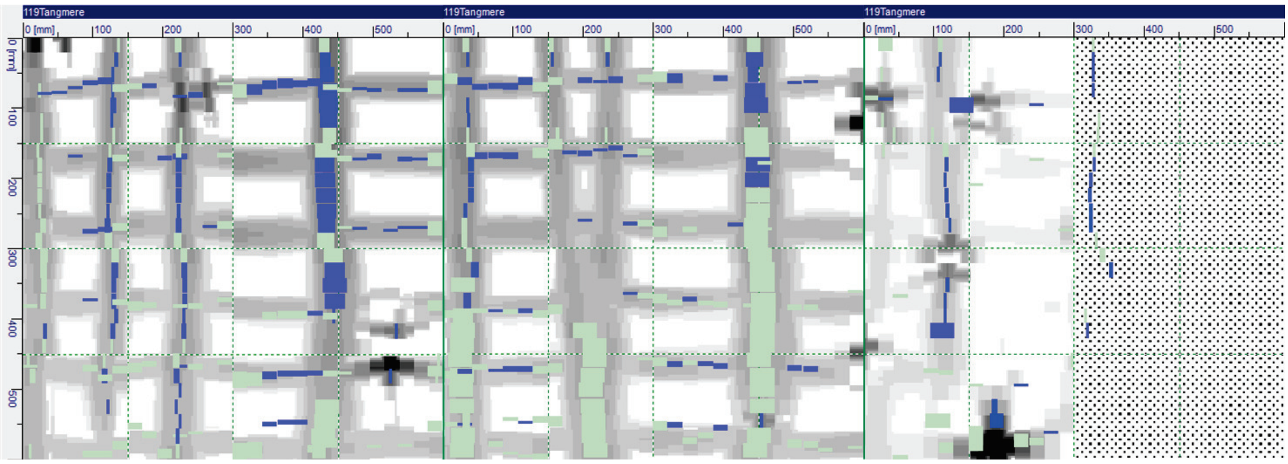


*Figure 6 – Example of Three Wall Scans taken in Flat 119 Tangmere. The scans clearly show small diameter bars at close regular centres with two distinctively larger diameter link bars at approximately 600mm centres. Lateral bars at circa 100mm centres are shown to extend the full width of the three scans. It should also be noted the difference in clarity between the bars in scan 1&2 compared to scan 3. This was a common occurrence throughout the scanning with some link bars being harder to identify.*

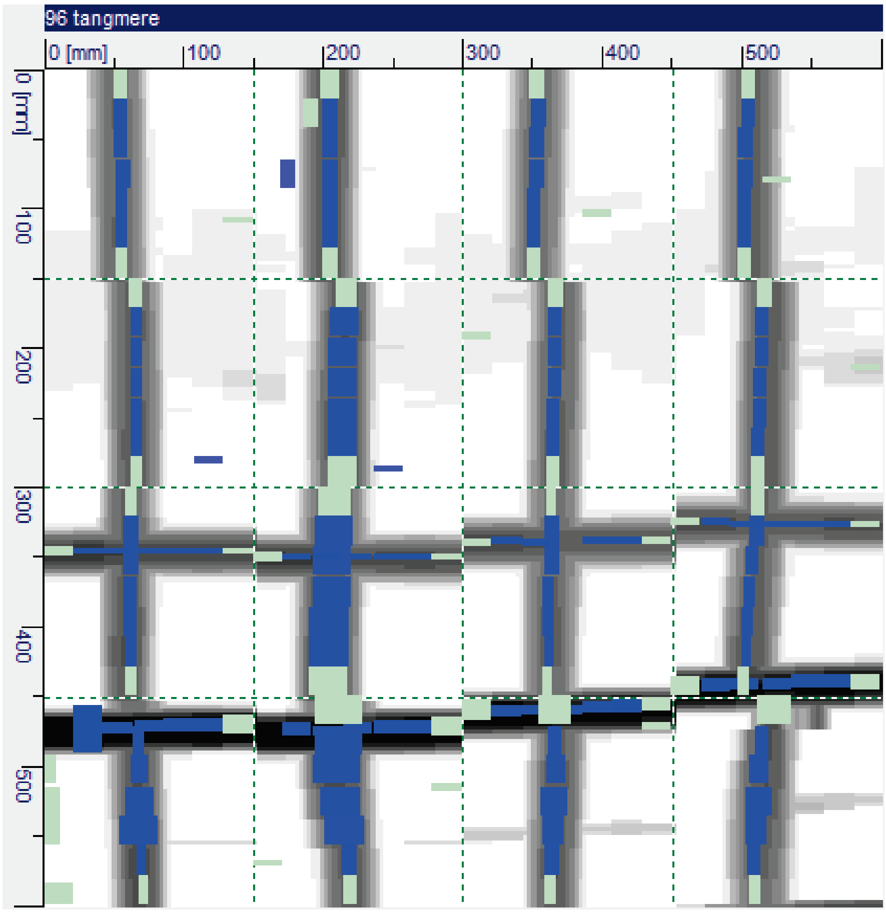


*Figure 7 – Example of Ceiling Scan Data taken in Flat 96 Tangmere. Scan shows bars at close regular centres at the base of the slab.*

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 20mm 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 8.

*Figure 8 – 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.

Tangmere is said to be the ‘flagship’ building of the Broadwater Farm Estate. Tangmere is built in a ziggurat form, with each successive floor stepping back from the one below. This design is unique in comparison to the other blocks on the estate.

## 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 Ziggurat Block (Tangmere)

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 flank walls are a 6“reinforced concrete panel with a single layer of central reinforcement, 25mm polystyrene insulation and an external 75mm concrete panel, link bars were found at 2’ centres.

Movement joints were also observed in the block, formed by back-to-back cross wall panels with a small cavity between.

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. Unlike the other 11 blocks on the estate the non-loadbearing cladding panels are not vertically stacked due to the ziggurat form of the building.

## 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 |
| | Car parking not exceeding 6 storeys |
| 2b Upper Risk Group | 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)*

Tangmere is a six-storey building, with an insitu ground floor car park below. Tangmere therefore falls 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*'.

## 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 Ziggurat Block (Tangmere)

### 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 20mm bars at 4’ centres cast into the top of each panel, extending up into the insitu joint and the wall panel above. The link bar from the panel below connected to the link bar in the upper panel using a steel box-section inside a formed pocket in the wall panel to which both link bars were bolted to. 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 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. Therefore, the connection does not satisfy LPS Criterion 1.

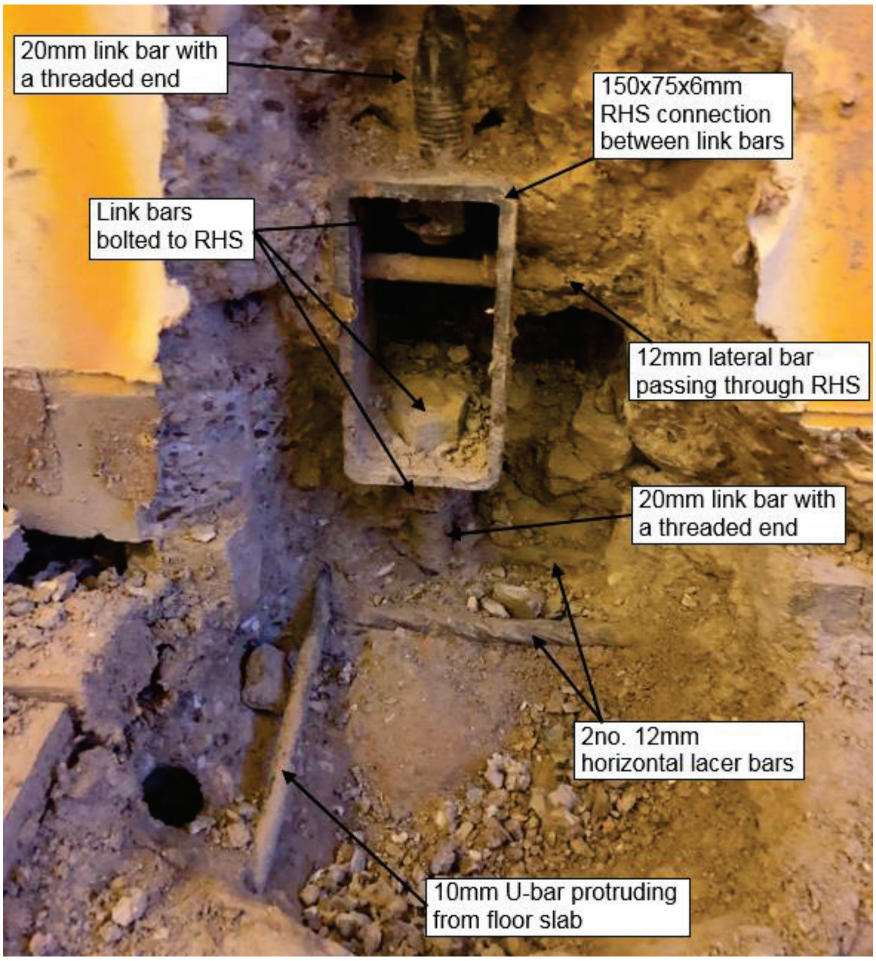


*Figure 9 – Link bar connection in cross wall panel*

In one of the flank walls subject to the investigative works in Flat 119, Tangmere it was found that the vertical tie in the joint consisted of 20mm bars at 2' centres cast into the top of each wall panel extending up through the insitu joint into a grout pocket in the bottom of the panel above. These bars were found to extend circa 500mm up into a grout pocket. Due to the reduced spacings of these link bars the connection has been shown to be an effective vertical tie. This flank wall connection, therefore, passes LPS Criterion 1.

However, the opposite flank wall which was supported on a precast concrete beam contained no bars which extended down into the insitu joint. As such there was no vertical tie in this connection, and thus does not satisfy LPS Criterion 1.

As not all of the joints provide an effective vertical tie it is deemed that Tangmere does not comply with LPS Criterion 1.

### 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. At the time of inspection Tangmere had a piped-gas supply to the block. Therefore, to comply with the regulations for accidental loading an initial assessment was carried out using an over-pressure of 34kN/m$^2$.

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.

For the 'key elements' check on the floor slabs the flexural resistance was identified to be the critical check. The slab contains 12mm mild steel bars at 6" centres in the bottom, and unreinforced in the top. The assessment showed that the slab failed in flexure under the 34kN/m$^2$ overpressure in both uplift and downward loading.

The assessment carried out on the flank wall panels identified the flexural resistance of the panels to be the critical check. The wall panels contained 10mm mild steel bars at 6'' centres placed centrally in the panel. The assessment showed that the flank wall panels failed in flexure under the 34kN/m$^2$ overpressure.

In the cross walls the likely failure mechanism was identified as local shear splitting failure around the 20mm 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 10 and Figure 11.

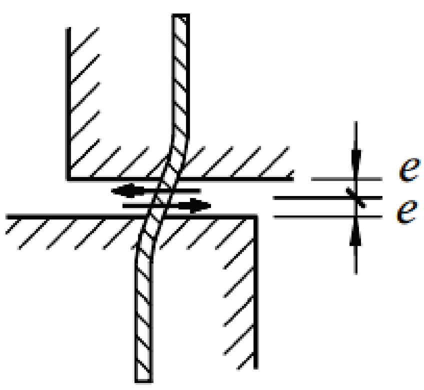


*Figure 10 – Shear transfer by dowel action with double fixation (fib, 2008)*

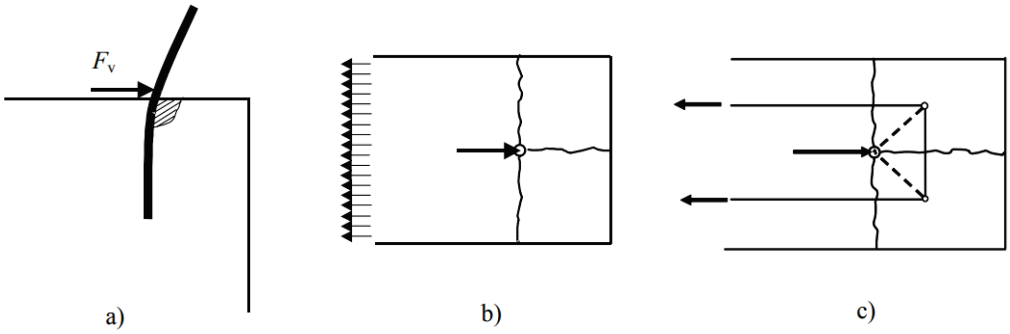


*Figure 11 – Splitting effects around dowel pin loaded in shear, a) shear force acting on dowel bar indicating area of concrete under dowel subject to high stress concentration, b) potential planes of cracking, c) strut and tie model for design of splitting reinforcement – no splitting reinforcement found within wall panels.*

The calculation for shear splitting failure of the cross walls around the grout bars was carried out in the assessment for the 6-storey blocks. The wall panels were shown to fail under the 34kN/m$^2$ overpressure. Therefore, by inspection the cross wall panels in Tangmere will also not be sufficiently robust to withstand the loading.

### 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 Tangmere had a piped-gas supply at time of investigation this would have to be removed to comply with the regulations.

The 'key element' check carried out for the floor slab show that the flexural resistance of the slabs are insufficiently robust to resist the reduced overpressure in both uplift and downward loading.

The flank wall calculation also show that the reinforcement provided within the panels, even when utilising the tensile capacity of the concrete itself, is insufficient to resist the 17kN/m$^2$ overpressure. However, it is also appreciated that the compressive stresses induced in the concrete from the structure above will benefit the flank wall panels lower in the structure. However, the flank wall panels in the upper floors, subject to less vertical loading, will be susceptible to flexural failure.

The calculations undertaken on the cross wall panels in the 6-storey blocks were shown to be adequate for an overpressure of 17kN/m$^2$. The central reinforcement in the 6-storey cross wall panels is identical to that in Tangmere, but there is a difference in the detailing of the link bars in Tangmere which utilises a box-section to connect the link bars with lateral bars to engage the surrounding concrete. This connection will reduce the shear stress significantly around the link bars. Therefore, the cross wall panels in Tangmere can be considered adequate by inspection.

In summary, in the event of an internal explosion of magnitude 17kN/m$^2$ the floor slab and, in the case of a flat near the top of the block, the flank wall fails. It is therefore likely that a disproportionate collapse event will happen. The failure mode will likely take one of the two forms:

1) Failure of roof and floor slabs will lead to 'pancaking' of the structure to and through deck level.
2) Failure of the flank wall, roof and floor slabs will lead to a progressive event that will result in collapse of successive floors and flank walls in a downward and diagonal direction to and through deck level.

Following the results of the investigations we would recommend that strengthening proposals for Tangmere are looked into in order for the block to resist a 17kN/m$^2$ internal explosion; this should then inform a wider options study, as the costs of strengthening are likely to be significant as will the disruption to each flat (full decanting can be anticipated).

## 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 12.

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.

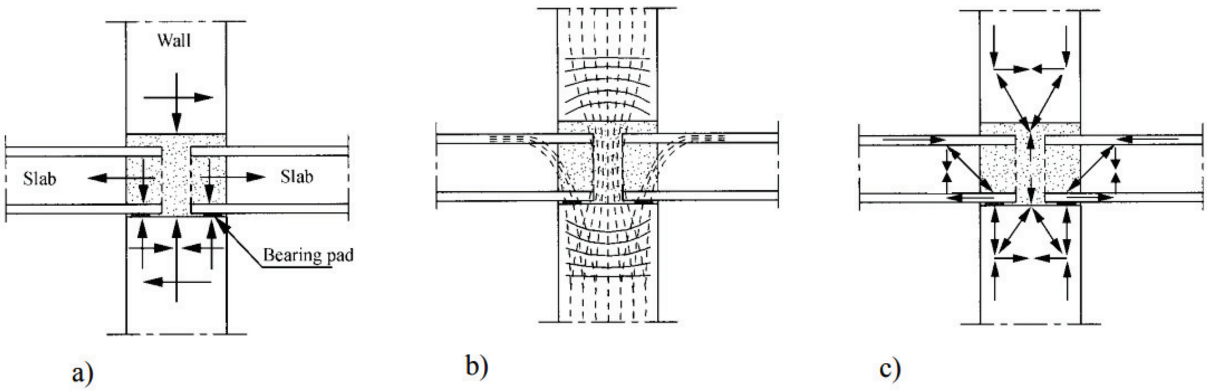


*Figure 12 – Slab-wall connections, a) forces, b) simplified stress analysis, c) strut-and-tie model (fib, 2008)*

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.

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