London Borough of Tower Hamlets

Malting and Brewster House

Review of Structural Assessment and Proposed works

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1 Executive Summary

Arup has been appointed by the London Borough of Tower Hamlets (LBTH) to undertake a review of the structural assessments and proposed strengthening works of Malting and Brewster Houses.

Malting and Brewster Houses are 14-storey precast concrete Large Panel System (LPS) tower blocks. These systems are vulnerable to a risk of disproportionate collapse. Malting and Brewster Houses were both strengthened after the Ronan Point collapse in 1968 in accordance with the Ministry of Housing Circulars [4][5].

In the 1980s and 1990s reviews of the structural integrity of Malting House (but not Brewster House) were carried out associated with the construction of the Limehouse Link Tunnel and we understand further strengthening works were carried out at this time to all blocks.

Most recently Wilde Carter Clack (WCC) were employed by LBTH to carry out a structural assessment of the blocks in accordance with the 2012 handbook produced by the BRE and the Ministry of Housing, Communities & Local Government [2]. The assessment included some limited investigation works and based on this WCC have proposed strengthening works to the towers and have produced a tender package for these works.

Arup have reviewed the documentation available and our comments on the main findings of the investigations and structural assessment are as follows:

- WCC found that the concrete slab floors to certain areas do not meet current or previously existing standards for normal loads and require strengthening. We agree with this analysis.
- WCC concluded that the blocks do not comply with the recommendations for the prevention of "disproportionate collapse" in the 2012 guidance produced by the Building Research Establishment (BRE) and the Ministry of Housing, Communities & Local Government [2]. This means that an accidental extreme event such as a gas explosion or vehicle impact could lead to the collapse of a disproportionately large part of the building.
- To comply with the 2012 regulations and based on calculations carried out by WCC and BRE, it is proposed that the following works are carried out:
    1. Flank walls are strengthened against accidental loads and tied in to underside of leve13 (top occupied floor)
    2. New internal steel frames are installed to underside of level 13 to limit the spans of the internal reinforced concrete slabs under accidental loads (and normal imposed loads).
    3. The longer span, living room slab areas are strengthened sufficiently to resist both normal and accidental loads at all floors.
    4. The internal loadbearing walls are strengthened against accidental lateral loads at levels 11 and 12.

Generally, our review supports the work proposed. Our key comments are:

- The proposed strengthening of the living rooms slabs is a complex procedure that requires a high degree of quality control to be successful, especially as the final installed system is not examinable. We understand tests have been carried out to review constructability and quality. Close control of quality should be maintained on site.

- The extent of the strengthening of the internal cross walls is limited to levels 11 and 12 storeys based on the BRE assessment. Although these assessments do not fully comply with current codes for the design of concrete structures (BS EN 1992 1-1-2004)[13] and guidance; the BRE have based their analysis on testing and have confirmed that based on these tests the capacity is available to resist any accidental loads at the lower levels and that therefore there is negligible risk with regards to this element. The test results are not available but assuming these were carried out to comply with good practise we would have no further comment on this.

We have also reviewed briefly the following which were not covered by the WCC report and proposals:

- Central Stair Block

  The central stair block is formed from precast walls and precast stairs and slabs. Although these areas are at lower risk of most types of accidental loading (explosions etc) they are the main escape routes. A risk assessment should be carried out as a way of confirming that LBTH can manage any outstanding risks to this block in terms of disproportionate collapse.

- Fire

  We have not generally reviewed fire safety, however we have confirmed that covers to primary reinforcement to slabs found in the limited investigation works carried out are sufficient to meet requirements of modern codes for the design of reinforced concrete structures - general rules for structural fire design (BS EN 1992 1-2-2004[18]). This should be verified locally as works are carried out, since the investigation works to date have been relatively limited and lack of cover is a known issue on blocks of this type.

- Wind loads

  Wind loads are now known to be higher than are likely to have been assumed at the time of construction., however it appears the building was designed for wind loads that comply with current standards.

- Foundations

  We have not reviewed the capacity of the piled foundations in detail and it will be difficult to do so given the limited information available. The capacity under extreme wind loads is highly dependent on the ability of the raft and in situ podium to act as a spreader of the overturning loads to the piles. Our preliminary review indicates this should be acceptable, although it is not fully compliant with current codes for the design of r.c. structures (BS EN 1992 1-2-2004[13]) in that it depends on the raft concrete developing a limited tensile capacity to enable the load to be spread in the ultimate wind load case, which we know it has in reality.

Methodology

It is proposed that the flats remain in almost full occupation during the works.

Generally, the proposed strengthening works should not affect the stability of the structure if carried out competently.

A competent principle designer should be involved and the risk of any impacts or accidental loads to the structure minimised via method statements and assessments.

The contractor should be made aware of the limitations of the load capacity of the existing structure. In particular the longer span slabs which are under reinforced as existing and therefore have limited capacity for storage or equipment. All temporary works and loads should be checked by a competent engineer.

2 Introduction and Brief

This report describes the review of the structural assessments of Malting and Brewster Houses undertaken by Arup on behalf of LBTH.

Malting and Brewster Houses are 14-storey precast concrete Large Panel System (LPS) tower blocks. We understand they were built for the Greater London Council (GLC) by Taylor Woodrow-Anglian (TWA), and are believed to have been completed by 1968 although the exact dates of construction are not known. It is believed that the gas supply was removed and strengthening works were undertaken following the Ronan Point collapse in 1968. Some of the strengthening works are visible, although full details are not known. Some original drawings of the original construction are available, but investigations have found that these do not always reflect the as built construction.

The scope of the work is to perform a high-level review of the documentation from BRE and Wilde Carter Clark and any related documentation with regards to the proposed strengthening works and also a design review of the construction documentation related to health and safety. The documentation provided by the London Borough of Tower Hamlets is listed in Appendix A.

The aim of the assessment is to

- Provide a high-level review of the necessity of the proposed strengthening works and the adequacy of the works proposed.
- Assess any health and safety implications of the works (particularly with regard to the residents of the blocks) as described in the brief, with regard to the design aspects of the proposed methodologies and statements.

Arup have not reviewed the replacement of the façade or the overall fire strategy.

3 The Buildings

3.1 Description of the buildings

Malting and Brewster Houses are both 14 storeys high (above podium), with a floor to floor height of approximately 2.7m (Figure 1). Each block has a 'H-shaped' floorplan consisting of two residential towers and a lift/stair core in-between the two towers which provides access to the towers. It is likely that each of these three structures was designed to resist wind loading independently. Floor plans vary slightly between one, two and three-bedroom flats.

3.1.1 Structural form

Both blocks have standard cast in place reinforced concrete construction for the podium levels.

The tower blocks were constructed using the Taylor Woodrow Anglian (TWA) large panel precast system (i.e. they were built from factory-made precast concrete panels that were assembled together on site).

The floor slabs generally span one-way onto the internal cross-walls and the outer flank walls.

The external wall panels are supported by the cross-walls.

The approximate floor plan of one residential block can be seen in Figure 1. Floor slab panels are coloured according to their span length.

There are additional thin concrete partitions supported by the floor slabs at each level. These are likely to have been considered as non-structural.

Lateral stability against wind loading on the broad face is provided by the cross and flank walls. Lateral stability against wind loading on the narrow face is provided by the single shear wall (shown as green stability wall) with the cross walls providing torsional resistance.

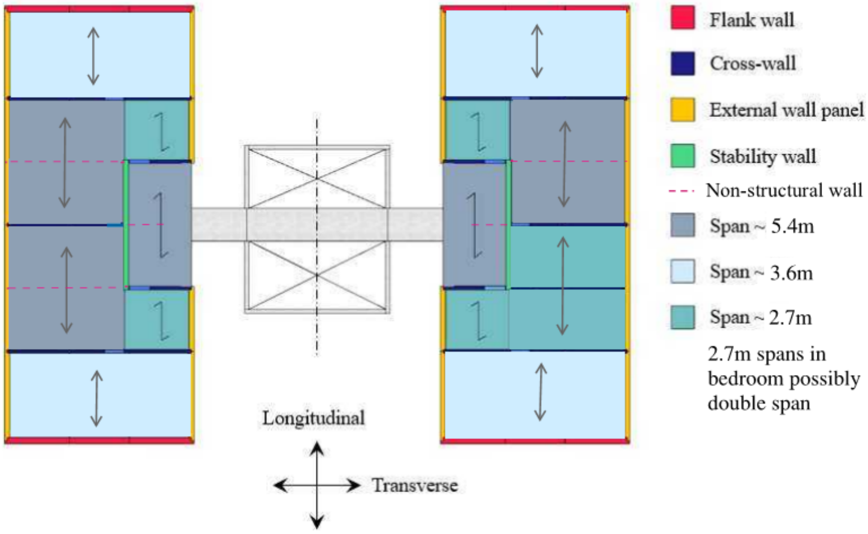

Figure 1 - Approximate floorplan of each block, illustrating the clear span dimensions..

Based on the 1990 SWK report, both blocks have piled raft foundations. The raft was designed to be approximately 900mm (3 feet) thick and relatively lightly reinforced. The piled foundations are driven piles either extending into the London clay (38 feet long noted for Malting House) or the gravel layer (24 feet long noted for Brewster House) depending on the local geology of the ground. Design drawings indicated predominantly 90-ton capacities under the tower blocks.

The stair core is made up from precast panels, floors and stairs bolted together. No drawings were available for this and this element was not assessed as part of the WCC investigations.

3.2 Summary of history of Malting and Brewster, and LPS buildings in general

Malting and Brewster Houses are located on the Barley Mow Site in The London Borough of Tower Hamlets.

The buildings were built by Taylor Woodrow-Anglian (TWA) in 1968. The TWA Large Panel System used is also known as the Larsen-Nielsen design.

Ronan Point partially collapses

In May 1968, the Ronan Point tower block, also built by Taylor Woodrow-Anglian, suffered a partial collapse as a result of a gas explosion. The damage caused by the gas explosion was considered to be more extensive (i.e. caused more parts of the building structure to collapse) than should have occurred following an event of that magnitude. In response the Ministry of Housing and Local Government issued Circulars 62/68 [4] and 71/68 [5], which effectively acted as retrospective legislation.

Circular 62/68 issued

Circular 62/68 [4] required that all LPS blocks over six storeys in height should be appraised by a structural engineer and their ability to withstand a force equivalent to a static pressure of 34kPa without incurring disproportionate collapse be assessed. If this requirement was not met, the blocks were to be strengthened or gas removed. Additionally, all new LPS blocks were to be built to these same standards.

Circular 62/68 also stated that the current wind code (CP3 Chapter V 1952) was out-dated and recommended that all LPS blocks over six storeys be reassessed in relation to their resistance to wind. It was recommended that until a revised wind code was available, designers should take note of current research papers by the Meteorological Office and the Institution of Civil Engineers [6][7].

It is believed that strengthening measures in the form of structural steel angles were adopted post-construction at Malting and Brewster Houses in response to Circular 62/68.

Circular 71/68 issued

Circular 71/68 [5] maintained that LPS blocks with piped gas should be assessed against a pressure of 34kPa. However, if the piped gas was removed, this figure could be reduced to 17kPa.

Amendment to the Building Regulations

The minimum requirements for preventing disproportionate collapse in any buildings of five or more storeys were introduced in 1970 in an amendment to the Building Regulations [8]. This is now captured in the current Building Regulations [9] by Requirement A3 in Approved Document A [3] which states:

"The building shall be constructed so that in the event of an accident the building will not suffer collapse to an extent disproportionate to the cause."

While Ronan Point was caused by a gas explosion, the current Building Regulations refer to an 'accident' in general (examples are given in Section 7.1) and therefore always apply, even if there is no gas supply in a building.

Amendment to UK wind codes

CP3: Chapter V: Part 2: 1970 [19] introduced significant changes to the national wind code in the UK, increasing design wind pressures for buildings compared to the previous code (CP3: Chapter V: 1952 [18]). This was updated again in 1972 (CP3: Chapter V: Part 2: 1972 [20]). Current codes of practice for UK building design (BS EN 1991-1-4 [12]) give similar design pressures to CP3: Chapter V: Part 2: 1972.

BRE research on LPS blocks

The BRE published several reports following the partial collapse of Ronan Point, including a report in 1985 [1], which specifically reviewed the Taylor Woodrow Anglian form of construction.

It stated: *"the conclusions drawn from the assessment of Ronan Point are likely to apply to some extent to all other TWA buildings and action is desirable to check the extent where that is not known already"*; and

"Most 'Type A' buildings are likely to have acceptable margins of safety in respect of normal loads in the H2 joints of the lower storeys if they are soundly constructed. The H2 joints in buildings of 14 or more storeys should be appraised. Consideration should be given to the appraisal of the H2 joints in other TWA buildings, having regard in particular to their height and plan arrangement."

BRE guidance on assessing LPS blocks

In 2012 BRE published the "Handbook for the structural appraisal of Large Panel System (LPS) dwelling blocks for accidental loads" [2]. This document was written in order to update the Government's 1968 guidance to consider all of BRE's subsequent research, the general development of assessment methodologies and to align with current structural design codes. The document continues to recommend that LPS blocks with piped gas should be assessed against their ability to withstand a pressure of 34kPa. However, if piped gas is not present, this figure is reduced to 17kPa.

This document is considered the current best practice guidance for the appraisal of LPS buildings.

4 Information Available and Previous Reports

4.1 Construction work and Early Strengthening

Some of the original design drawings for the Barley Mow Estate are available. including some layouts for the typical panels but no details of connections were available. The WCC investigations (see section 4.5) indicate that these do not necessarily always reflect what was built and therefore the information should be used with care.

Key points are:

- Floor panels are 180mm thick and lightly reinforced with voids at 150mm centres. The panels are tied together. The panels are supported on 44mm wide nibs at the top of the wall units and are tied into the wall unit and the adjacent floor with an in-situ stitch detail.
- Cross walls are generally 150mm thick and may have light central mesh reinforcement. In some areas ducts and recesses for services were cast into the walls (generally the central cross wall). The walls are generally levelled using two bolts at their base and tied in laterally at their top.
- Flank walls have a 152mm structural inner RC wall and 95mm outer non-loadbearing skin
- Non-loadbearing façade walls have a 102mm inner RC skin and a 95mm outer skin
- The spine wall used for lateral stability is 225mm wide and is reinforced at each end with 2 No 32mm diameter Macalloy bars. These do not appear to be prestressed and one bar drops off at each end above level 9

Angles were fixed to the base and top of the loadbearing walls units to satisfy Circular 62/68. Photos noted in the WCC report show that these have been elongated on site to ensure that the bolts have better edge distances and fixings than is usual in these situations.

4.2 Intermediate Remedial Works

Scott Wilson Kirkpatrick and SP Christie carried out a series of reviews and investigations in the late 1980s associated with the construction of the Limehouse Link Tunnel. at this stage the team clearly still had access to all drawings and the original calculations. These mainly looked at Malting House and Risby House.

The key issues that came out of this were that:

- Loadbearing walls - in many areas the walls had not been grouted properly to transfer vertical loads and levelling bolts had not been loosened and locked off. the mortar joint was also often poor quality and too thin.

- Angles restraining the flank walls were bent and loose.
- A preliminary assessment at this time wrt disproportionate collapse reached similar conclusions to the later WCC report wrt the walls, (see section 4.5). The slab design based on the drawings and calculations was considered adequate as long as the non-structural walls carried load temporarily.
- Non-loadbearing façade walls were not adequately supported laterally or vertically resulting in cracking to the panels.
- The length and design of the piled foundations could not be confirmed via integrity tests. Calculations carried out by SWK indicated that the piles to Malting House which bear on the London Clay potentially have a factor of safety of 1.5. The piles bearing on the gravel for Brewster House should have a factor of safety of 3.

The following actions were proposed. It should be noted that these were primarily to ensure robustness with regard to any settlement or movement during construction of the Limehouse Link.

- Additional wall to floor ties/angles would be installed to help restrain the wall panels in terms of disproportionate collapse (although nothing was to be done to strengthen the upper two floors where the wall panels were inadequate).
- Additional panel fixings were installed to restrain the façade panels.

These works were carried out as part of the WCC proposals in 1990 (see below).

4.3 1990 Carter Clack Assessments

Carter Clack Associates were asked to carry out a review based on the SWK reports and presented a series of options for strengthening based on different risk and design life options.

Based on this review the following remedial work was carried out, assuming that piped gas would not be installed in the blocks.

- Total soft strip.
- Removal of floor screed and reinstatement of unsatisfactory dry pack to walls with new high strength packing and grouting.
- Installation of new tie angles bolted between floors and walls.
- Tying the leaves of the outer wall panels together.
- Re-support with angles of non-loadbearing facade wall panels.
- Smoke stopping installed.

4.4 2005 WCC report

This was a superficial investigation of any visual defects.

4.5 2019 WCC Investigation and Report

In 2018 Wilde Carter Clack were asked to carry out an investigation and review of the blocks.

A desktop study and physical investigation was carried out in two apartments, one in each block which included concrete testing and also an investigation into the condition and detailing of the reinforcement in the panels where possible.

The findings generally confirmed the details of the drawings in terms of panel thicknesses and joint details, with the key exception that the reinforcement area to the floor slabs was less than shown on the drawings.

The findings are assessed in section 5, 6 and 7 below.

5 Condition of the structure of the buildings

High chloride and carbonation levels in reinforced concrete can lead to the corrosion of the reinforcement, reducing the strength of the structure. The carbonation and chloride levels in the concrete were tested at several internal locations in the buildings. In all cases, the levels measured were found to be extremely low and not a concern. In addition, all reinforcement exposed during the internal investigation works appeared to be in good condition with no significant corrosion.

The concrete was generally of high strength with test results greater than specified (as is it be expected with age effects).

Main reinforcement in the precast elements was generally found to be mild steel rather than high yield bars.

Cover to main reinforcement in the slabs was generally within code requirements of the Eurocode 2 – Design of reinforced concrete structures for both durability and fire -(BS EN 1992 1-1-2004 and BS EN 1992 1-2-2004) [13][18]. Cover to secondary bars was less than would be expected to current codes but these should not affect strength.

6 Assessment of the existing superstructure under normal loads

6.1 Vertical Loads

6.1.1 Superstructure

The key findings of the assessment were:

- The 3.6m spanning slabs were calculated by WCC to be overstressed based on the bar diameter found. The BRE independent checks (which we do not have the details of) found no immediate danger of slab failure. We would agree with the WCC assessment. Our checks indicate that generally the slabs are overstressed in bending rather than shear and therefore are unlikely to fail catastrophically.

- The 5.4m spanning slabs would also be overstressed and beyond usual deflection/crack limits under loads required by current Eurocodes[11] and we believe may be relying on the non-loadbearing partitions to limit live load movement. As noted above our checks indicate that generally the slabs are overstressed in bending rather than shear and therefore are unlikely to fail catastrophically.

- The 2.7m spanning slabs are generally within acceptable design limits under normal loading.

- The main loadbearing walls were found to be generally within acceptable load capacities for axial loads.

6.1.2 Foundations

The foundations were not assessed as part of the WCC report. SWK reviewed the foundations in 1998 based on the Cementation tender documentation and the site investigation calculations. As built drawings were not available and integrity tests carried out at this time to ascertain the length of the piles integrity tests were inconclusive.

SWK estimated that the piles into the gravel (Brewster House) would have a factor of safety of 3 and those under Malting House would have a factor of safety of 1.5. We would agree that the piles into clay have less capacity than into the gravel, although in both situations they have less than the 90 tonne capacity noted on the design drawings. However, a preliminary assessment indicates that generally there is a factor of safety greater than 1 on all normal vertical loads and there is no indication of settlement or undue movement.

6.2 Lateral Loads

6.2.1 Superstructure

The buildings need to be able to resist wind pressures acting on them, calculated using an appropriate wind code. As noted earlier many LPS blocks were designed to lower wind loads than codes introduced in the 1970s and current codes. The SWK review of the original calculations noted that the loads used were higher than those required by CP3 Chapter V and therefore would comply with current codes. A secondary check against the moments at the base of the walls also indicate that this is likely to have been the case.

For the purposes of assessing wind resistance, each building has been taken as three separate structures. The two residential blocks and the stair core.

The wind resistance of the lift and stair cores is provided by the outside walls of the lift and stair cores. The wall panels are connected to each other with bolted connections at the four corners and at the beam half-joints above the doors. These walls and the connections are likely to be sufficient to resist wind loads in all directions acting on the core, but a more detailed check should be carried out.

The two most onerous wind load cases on the residential blocks were considered by SWK i.e. wind perpendicular to the faces of each residential block. East-West winds are resisted by the flank walls and cross-walls. North-South winds are resisted by the spine/stability wall, again shown on Figure 3 with any resultant torsion taken by the cross walls.

SWK found that all the walls and their connections were found to have adequate resistance to wind loads. Arup review of the available data and checks on previous similar blocks would confirm this conclusion.

6.2.2 Foundations

The foundations were designed with the assumption that 15% additional capacity could be allowed for under wind load (up to 25% capacity was often allowed in previous codes such CP 2004 1972 or the Code of Practice No. 4 "Foundations" published by the Institution of Civil Engineers in 1954)

If simple techniques are used to assess the structure the loads would be relatively localised under the spine wall in the N-S direction and piles would be overloaded. However, a slightly more detailed assessment shows that the raft is sufficiently deep to allow for the spread of load instantaneously across the piles under the worst case loads to retain a factor of safety of 1. This requires the raft to spread the loads and the reinforcement may not be sufficient in terms of standard analysis to BS EN 1992-1-1[13] depending on the settlement that occurs in the piles under stability walls under the very short-term wind loads. However allowing for limited tension capacity of the concrete, as allowed in section 12 of BS EN 1992-1-1 as well as the reinforcement provided would provide sufficient capacity in all situations.

7 Assessment of the resistance of the existing buildings to "disproportionate collapse"

7.1 Assessment criteria defined by BRE

The BRE document "Handbook for the structural appraisal of Large Panel System (LPS) dwelling blocks for accidental loads" [2] clearly defines three assessment criteria. If the building can be proven to satisfy any one of the three criteria, then it is considered to satisfy requirement A3 of the Building Regulations [9] (which is the requirement to avoid disproportionate collapse) in accordance with Approved Document A [3]. The following is an extract from the BRE assessment guide:

"An LPS dwelling block exceeding four storeys in height (i.e. five storeys or higher) will be considered to satisfy Requirement A3 of the Building Regulations if it meets one of the following criteria:

LPS Criterion 1: There is adequate provision of horizontal and vertical ties to comply with the current requirements for Class 2b buildings as set down in the codes and standards quoted in Approved Document A – Structure as meeting the requirements set down in the Building Regulations.

LPS Criterion 2: An adequate collapse resistance can be demonstrated for the foreseeable accidental loads and actions [which is defined as 34kPa for a block with piped gas or 17kPa for a block without piped gas]

LPS Criterion 3: Alternative paths of support that 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 buildings in Approved Document A – Structure or alternatively assuming the removal of adjacent floor slabs (taking the floor slabs bearing on one side wall at a time) providing lateral stability to the critical section of the load bearing wall being considered."

7.2 Compliance with assessment criteria of Malting and Brewster Houses

LPS Criterion 1 is a prescriptive approach which defines design loads for the horizontal and vertical ties, between the structural elements in the buildings.

Although it appears that the structural elements are better tied together than in many of the LPS buildings built at this time, there is not sufficient tying action, especially vertically between wall panels, to satisfy this criterion.

LPS Criterion 2 states that in the absence of piped gas, key structural elements must be assessed for a collapse resistance under a pressure of 17kPa according to criterion 2.

According to the BRE handbook [2]:

"Collapse resistance is a measure of the ability of a structural system to resist the effects of specified accidental loads or actions occurring at or below a defined threshold.

The overpressure should be applied simultaneously to all surfaces of a single room/bounding enclosure."

The structural assessment against this criterion is concerned with the resistances of the panels themselves against this defined pressure, as well as the connections between the panels. Calculations were carried out by WCC and BRE to review this and with regards to the existing structure the following are the key issues:

- The floor slabs which span 3.6m cannot resist accidental loads either up or down (they also cannot resist normal downwards loads in usual conditions see section 6.1.1)
- The floor slabs which span 5.4m cannot resist accidental (or normal) loads up or down without relying on the support of the "non-structural" wall.
- The floors which span 2.7m can resist accidental downwards loads. The BRE also state they can take the upwards accidental blast loads but our preliminary assessment indicates they are slightly overstressed in bending in his condition. Shear/tying at ends is sufficient.
- The internal loadbearing cross walls rely on the load above to prestress them to resist lateral loads. The BRE calculations state that the walls to the top two storeys do not have sufficient prestress to resist the accidental loading and will crack. It is not clear what the assessment is based on. We would estimate that possibly up to 4 storeys may require strengthening based on simple arch theory or assuming simply supported elements with some tensile capacity.
- The flank walls will also rely on the load above to prestress them. The BRE assessment also indicated that two floors of load are required to sufficiently prestress the walls and that that they are not sufficiently well tied in to resist lateral loads. Again, our initial preliminary calculations indicate that this may be slightly unconservative but as the walls are being strengthened to deal with the lateral ties this is not an issue.
- The non-loadbearing walls were not considered in the WCC and BRE assessment but earlier checks by SWK indicate they can take temporary vertical loads from the slabs over without buckling but cannot resist any accidental lateral load.
- The strengthening angles installed in 1998 will provide lateral restraint / tying sufficient to resist the accidental load force when considered with the reinforcement detail linking slabs to their support walls This has been reviewed at upper levels where frictional resistance is limited.

LPS Criterion 3 considers whether or not alternative load paths could be mobilised in the event of removal of individual structural elements.

For the purposes of this assessment, the size of the element being removed is defined as a whole precast unit, or a wall of length 2.25H (where H is the storey height), whichever is the smaller. The largest individual precast wall units are the cross-walls adjacent to bedrooms which are approximately 5.4m long.

Owing to the structural arrangement of the building, together with the limited amount of reinforcement which could be included in any justification of alternative load paths, it is not possible to find reliable alternative load paths for all the existing floor loads.

7.3 Proposed Strengthening to achieve LPS Criterion 2

7.3.1 Proposed works and commentary

WCC have chosen to satisfy LPS Criterion 2. The proposed strategy for achieving LPS criterion 2 is documented in WCC document "Philosophy Strategy "and the calculations.

The key works proposed are:

- To strengthen the 3.6m spanning living room slabs to resist normal loads and also the accident upwards and downloads loads. The downwards loads have been taken to be both the blast loading and also a second load case based on the weight of any non-loadbearing partitions and the slab above should they collapse during any accident. The method proposed is to insert reinforcement into the voids in the slab and to grout these into place. Theoretically this works well but success will be highly dependent on workmanship. We understand that tests have been carried out on the proposed system to review constructability and result and these have been positive. We would recommend that a high level of quality control and review is maintained on site.

- To strengthen the 5.4m spanning slabs by inserting a new steel frame against the non-loadbearing partitions to support the slabs at each level, thereby reducing span from 5.4m to 2.65m- 2.7m. This means the slabs can resist downwards accidental loads (and normal loads). This new steel frame also allows the non-structural walls to be lost without risk of disproportionate collapse of the structure. Under uplift loads the slab above the explosion/accidental load will fail. This should not cause any disproportionate collapse issues as the slab below will be able to resist the load of any debris and the structural walls are stabilised by the slabs to either side of the critical span. The details at the base for this frame are not yet determined and local site investigation has been specified to confirm this detail at an early stage of the site works.

- Testing of bolts into existing reinforced concrete spine wall should be carried out to confirm capacity.

- Strengthening of the cross walls will be carried out at levels 11 and 12 to resist lateral loads. This will be carried out by using steel plates bolted and resin bonded to the walls to from a reinforcement to the wall. The strengthening will be fire protected. This means that the roof may collapse but there will be no disproportionate collapse due to the strengthening of the slabs. As noted previously the BRE assessment is slightly less conservative than simplified checks based on BS EN 1992-1-1 criteria[13]. We understand the assessments are based on test data and that the test data supports the reduction of the extent of strengthening compared to the simpler calculations.

- The flank walls will be strengthened by the installation of a new external steel frame against the flank wall which will resist lateral loads up to underside of level 13 and also ties in the wall and floors against any accidental loads. The details at the base for this frame are not yet detailed and will need to be signed off before the works begin on site allow this to be finalised.

7.3.2 Sequence of Construction

We have not reviewed any detailed proposals with regards to sequence of construction. Our understanding is:

- The buildings will generally be occupied whilst works are ongoing and residents will only be moved in a few situations.
- The works will be carried out from lower levels upwards and we understand that the lateral flank wall strengthening will be carried out simultaneously with the internal works on a floor-by-floor basis.
- As none of the works should have any impact on the stability of the adjacent elements if competently carried out then it should be acceptable for residents to remain in place.
- The contractor should be made aware of the limitations of the load capacity of the existing structure - in particular for the longer span slabs which are under-reinforced as existing and therefore have limited capacity for storage or equipment. All temporary works and loads should be checked by a competent engineer.
- We assume that internally all works on any single area or cross wall/elevation will be completed at one level before works progress to the next level. i.e. packing to new frames is fully carried out and grouting for strengthening is allowed to cure.
- Where possible the contractor should mark out any areas where they need to drill through slabs or walls to ensure that they do not drill through existing reinforcement.
- Although not part of our remit, as the blocks have a single escape route the contractor must ensure that these fire escape routes are not blocked at any time.
- We assume no hot works will be carried out on site.

8 Recommendations

8.1 Strength against disproportionate collapse of main blocks

In order to meet current reinforced concrete code requirements[13] in terms of vertical capacity and to satisfy requirement A3 of the Building Regulations [9] in terms of robustness, structural strengthening measures are required to provide the buildings with sufficient resistance against disproportionate collapse.

Arup has reviewed the indicative measures shown in the WCC report and we are generally in agreement with the proposals.

The extent of the strengthening of the internal cross walls is limited to levels 11 and 12 storeys based on the BRE assessment. Although these assessments do not fully comply with current codes for the design of concrete structures (BS EN 1992 1-1-2004)[13] and guidance; the BRE have based their analysis on testing and have confirmed that based on these tests the capacity is available to resist any accidental loads at the lower levels and that therefore there is negligible risk with regards to this element. The test results are not available but assuming these were carried out to comply with good practise we would have no further comment on this.

Some of the details remain outstanding until local site investigations can be carried.

Until the strengthening is carried out, it is recommended to undertake the mitigation measures summarised in Table 1.

Hazard	**Mitigation**
Gas explosion	There is no piped gas in the blocks. The existing ban on bottled gas (including oxygen cylinders) should be strictly enforced.
Vehicle impact	There is little risk of high speed vehicle impact because the buildings are sufficiently far away from the road and are generally protected. No mitigation required.
Fire	The cover to the main bars appears to be adequate. The team should ensure that sufficient investigation work is carried out to show that this is a general condition.
Hazards due to human errors during design and construction, or due to a lack of proper maintenance	The construction and condition of the blocks were assessed by WCC and SWK. With the exception of robustness against disproportionate collapse, the design and construction has been generally found to be satisfactory.
Unauthorised structural modifications	The reinforced concrete structural walls would be very difficult to modify. Nevertheless, a ban on any structural modifications should be strictly enforced.
Environmental hazards such as exceptionally strong winds or heavy snow on the roof	The superstructure has been reviewed for wind loads which are 3 second gusts estimated to be exceeded on the average once in every 50 years. No mitigation required
Hazards due to misuse such as overloading of a floor slab	The slabs will have been designed for residential loads (1.5 kPa). There should be a ban on any excessive loading which should be strictly enforced.

Table 1 - Hazards and mitigation measures relating to disproportionate collapse.

8.2 Stair core

The stair core has not been assessed against disproportionate collapse. As the construction is also of large precast panels the system is unlikely to fully comply with the requirements of the BRE Guidance. The core is less likely to be at risk of explosions as there is a requirement not to store or pipe gas in these areas. As they are fire escapes they should also generally be free of fire loads. They are also not inhabited spaces.

The risk therefore of any incident is very low but, as noted above, it is possible that the structure would be at risk in the unlikely event of an explosion or impact. We understand that the LBTH have been made aware of the risks and judge that these are manageable overall. We would recommend that a formal risk assessment is carried out.

8.3 Long term durability of the buildings

If the buildings are to be retained, a maintenance plan which includes proposed future assessment and inspection regimes should be formulated. The BRE outline proposed maintenance measures in their handbook [2].

9 References

[1] The structure of Ronan Point and other Taylor Woodrow – Anglian buildings, Building Research Establishment, Department of Environment, 1985

[2] Handbook for the Structural Assessment of Large Panel System (LPS) Dwelling Blocks for Accidental Loading, Stuart Matthews and Barry Reeves, Building Research Establishment, 2012

[3] Approved Document A: Structure, The Building Regulations 2010, Department for Communities and Local Government

[4] Circular 62/68, Ministry of Housing and Local Government, 15 November 1968

[5] Circular 71/68, Ministry of Housing and Local Government, 20 December 1968

[6] C. Scruton and C. W. Newberry, On the estimation of wind loads for building and structural design, Proceedings of the Institute of Civil Engineers, Volume 25, Issue 2, 1963

[7] H.C. Shellard, Extreme wind speeds over the United Kingdom for periods ending in 1963, Meteorological Office Climatological Memorandum No 50

[8] Statutory Instruments 1970 No. 109, Building and Buildings, The Building (Fifth Amendment) Regulations 1970

[9] The Building Regulations 2010, Building and Buildings, England and Wales

[10] Eurocode: Basis of structural design, BS EN 1990:2002+A1:2005

[11] Eurocode 1: Actions on structures – Part 1-1: General actions – Densities, self-weight, imposed loads for buildings, BS EN 1991-1-1:2002

[12] Eurocode 1: Actions on structures – Part 1-4: General actions – Wind actions, BS EN 1991-1-4:2005+A1:2010

[13] Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings, BS EN 1992-1-2004+A1:2014

[14] Larsen and Nielsen system, Architect and Building News, Nov 14 1962

[15] CP3: Chapter V: 1952, Code of Basic data for the design of buildings, Chapter V. Loading, Reset and reprinted 1965, The Council for Codes of Practice, British Standards Institution

[16] CP3: Chapter V: Part 2: 1970, Code of Basic data for the design of buildings, Chapter V. Loading, Part 2. Wind loads, The Council for Codes of Practice, British Standards Institution

[17] CP3: Chapter V: Part 2: 1972, Code of Basic data for the design of buildings, Chapter V. Loading, Part 2. Wind loads, British Standards Institution

[18] BS EN 1992-1-2:2004 Eurocode 2: Design of concrete structures. General rules - structural fire design (+A1:2019) (Incorporating corrigendum July 2008)

Appendix A

List of Documents Reviewed

Wilde Carter Clack, Desk Top Study on Malting and Brewster Houses, January 2018
Wilde Carter Clack, Structural Appraisal Malting and Brewster Houses, July 2018
With supporting information from;
o Martech, Internal Concrete Condition Testing
o Martech, External Concrete Condition Testing
o Socotec, Hardness Testing of Steel, Rebar to Precast Concrete Planks

Wilde Carter Clack Specification for Structural Works which includes the design of specialist
reinforcement works. November 2018
WCC Structural calculations for remedial works October 2018

· Set of Preliminary structural strengthening drawings by Wilde Carter Clack
o S.01
o S.02
o S.03
o S.04
o S.10
o S.11
o S.20
o S.21
o S.22
o S.23
o S.24
o S.26
All Status P1, tender issue 2 November 2018

Appendix A SWK report Structural Investigation on malting and Risby Houses Vol 1 August 1988
Appendix B SP Christie Interim Report Barley Mow Estate September 1988
Appendix C SP Christie Final Report Barley Mow Estate January 1990
Appendix D CCP Stage 1 Report March 1990
Appendix E CCP Stage 2 Report April 1990
Appendix E CCP Stage 2 Report April 1990
Appendix H CCP Appraisal of the Building on the Barley Mow Site January 2005

Barley Mow Estate various record drawings