Intended for
Crown Estate Paving Commission

Document type
Structural Review

Date
August 2021

CHESTER TERRACE
RETAINING WALL REMEDIATION STRUCTURAL REVIEW

Bright ideas. Sustainable change.

CHESTER TERRACE
RETAINING WALL REMEDIATION STRUCTURAL REVIEW

Project name	**Chester Terrace Wall Remediation – Structural Review**
Project no.	**1620012XXXX**
Recipient	**Nick Packard <Nick.Packard@cepc.org.uk>**
Document type	**Structural Report**
Version	**Rev01**
Date	**13/08/2021**
Prepared by	**Scott Brookes**
Checked by	**Jackie Heath**
Approved by	**Jackie Heath**
Description	**Structural assessment and review of current remedial strategy**

Ramboll
240 Blackfriars Road
London
SE1 8NW
United Kingdom

T +44 20 7631 5291
https://uk.ramboll.com

Revision	Date	Prepared by	Checked by	Approved by	Description
DRAFT	30/07/2021	WH/SB	SB		DRAFT 01
01	13/08/2021	SB	JH	JH	Rev01

Ramboll UK Limited
Registered in England & Wales
Company No: 03659970
Registered office:
240 Blackfriars Road
London
SE1 8NW

CONTENTS

1. INTRODUCTION

Ramboll were asked by Nick Packard of the Crown Estate Paving Commission (CEPC) to carry out a 3rd party engineering review of the assessments and recommendations made with respect to the failing retaining wall along Chester Terrace, predominantly by engineering consultants Hurst, Pierce & Malcolm (HPM).

The wall comprises a bottle balustrade surmounting a brick retaining wall, which retains a private road that is approximately 0.3-0.8m above a landscaped garden shared by the road's residents.

Ramboll's desk study review and visual site assessment was carried out by Scott Brookes (CEng, MIStructE CARE) of Ramboll, with an inspection undertaken on 2nd July 2021. Further, quantitative analysis has been carried out to allow review and comment on the historic assumptions made by HPM and to assist the client in decision making.

Our review has focussed on the existing condition of the wall, the method of analysis and tests executed to understand its performance, the potential for defect recurrence should only cosmetic repairs be carried out and alternative means of strengthening the balustrade and retaining wall not previously considered.

It is understood that the scheme currently recommended by HPM involves full re-design and reconstruction of both the balustrade, wall and foundations, and has been costed at circa £1.7 million – approximately £600k for the balustrade and £1.1m for the wall/foundations. In consideration of the proportionate cost impact of works, we understand that rates drawn from around the Crown Estate will fund works to the wall, whereas works to the balustrade will be funded by the 40No. residents of Chester Terrace, only.

2. LOCATION AND CONTEXT

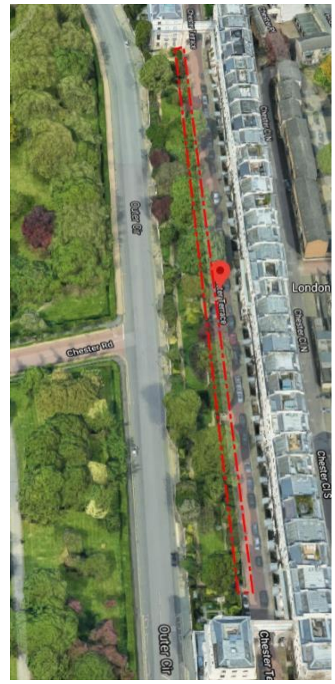

Figure 1 Chester Terrace highlighted in red © Google

Chester Terrace is a private residential road situated on the eastern edge of The Regent's Park, London, within the Regent's Park Conservation Area. The balustrade is thought to date from around mid-20th century, although the brick wall is likely older. It runs for 230 metres and delineates the road of Chester Terrace from the adjacent, lower gardens, shared by the residents of the Terrace. It runs continuously north-south down the length of Chester Terrace with 5No. inlet bays and 3No. gates along the wall's length. The level of the garden slopes downward towards the south, relative to the roadway, from 0.3m to a maximum of approximately 0.8m at the southern end of Chester Terrace.

At the lower garden side there are a series of mature trees, some in close proximity to the base of the wall. A garden pathway runs behind the line of these trees which serves as access to the full length of these gardens. According to geological surveys undertaken by Listers Geo in June 2020, the ground typically comprises 300-600mm of topsoil, underlain by made ground to 2-3m depth comprising gravelly-sandy clay and brick fragments. London clay is the underlying strata below this made ground.

Due to identified issues with the wall, including material deterioration and movement, the topside balustrade has been isolated from the pavement and adjacent road by the installation of temporary fencing. Likewise, full height heras fencing has been installed within the gardens along the pathway at the lower side towards the south end of the wall where deterioration and wall movement appears more advanced. A rudimentary scaffold buttress system has been installed along a short length of the wall at a local bay which attempts to resist further lateral movement of the wall, by overturning or sliding.

Existing services drawings via an Envirocheck survey show multiple services running along Chester Terrace as well as drainage channels running at both the topside and base of the wall connect into the wider drainage network adjacent to Regent's Park.

Figure 2 Existing Drainage Layout

Figure 3 Drain grilles roadside of the balustrade plinths

3. SCOPE & LIMITATIONS

1. The sections of wall north of the northern-most gate and south of the southern-most gate are associated with private residences and have been excluded from consideration.
2. A garden gate access key was provided by the Crown Estate Paving Commission to allow inspection
3. Ramboll's inspection was visual and tactile, only. No material condition or performance testing was carried out. No intrusive investigations (inc. trial pits) were made as part of our assessment.
4. An inspection of a similar arrangement of road and gardens at Cumberland Terrace was also made for comparative review. Successful foundation replacement was carried out here in the 1950s, along with balustrade replacement in 2010.
5. Ramboll have not carried out any cost analysis on proposed alternative approaches, but do make reference to the costs set out in historic reporting
6. A schedule of historic maintenance and upkeep was not provided for reference
7. Our understanding of the material performance of the wall, historic testing/sampling and HPM recommendations has been the reports provided to us by the CEPC: https://www.cepc.org.uk/residents/chester-terrace-resident-ratepayers-meeting/
8. HPM's calculations, which serve as the basis of their recommendations, were also provided and have been included in our review. Ramboll have carried out calculations to review the assumptions and findings of HPM's work but have not provided design calculations, considered beyond our engagement as reviewing engineers.

4. EXISTING STRUCTURE

4.1 Description

The balustrade stands at 1250mm tall and comprises a base plinth seated directly onto the retaining wall, bottles at regular centres and coping units, all of reinforced precast concrete construction. There are approximately 10-12 bottles between each die-block. It is understood from HPMs intrusive investigations that bronze pins positively tie the bottles to the coping and similarly the bottles and plinth. Plinths and copings are keyed into the adjacent unit with interlocking cast protrusions and recesses.

Figure 4 Balustrade as viewed from Chester Terrace. Note the step in coping level.

Figure 5 Balustrade as viewed from within the gardens. Note the kentledge blocks to resist lateral wall loading

The retaining wall is predominantly rendered brickwork, with only a section at the north end replaced, possibly post-bombing, with a reinforced concrete equivalent. The wall stem is between 430mm and 485mm thick. The wall footing is of mass concrete, with an inside edge assumed by HPM to align with the retaining wall's inside face.

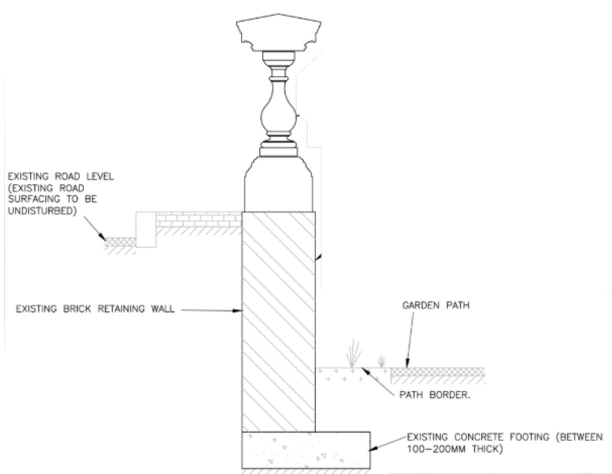

Figure 6 Existing Retaining Wall Section © Hurst, Pierce & Malcolm

4.2 Wall/Balustrade Condition

HPM and associated sub-consultants were engaged to review the wall's condition and performance in response to notable movement in the wall (bowing/leaning) and distortion/dislocation of the balustrade, which at locations is now able to be moved under light loading. Generally speaking, the wall condition was worse towards the southern end.

Identified/verified defects have been listed below, ordered by % prevalence and assigned subjective scores of structural risk and urgency:

DEFECT	**PREVELANCE (HPM)**	**STRUCTURAL RISK** (1 -lowest,5 - highest)	**URGENCY** (1 -lowest,5 - highest)
Open joints between coping stones	93%	2	3
Open joints between plinths	69%	2	3
Defective render on retaining wall	47%	1	1
Fine cracking to bottles	36%	2	3
Moving/loose bottles	35%	3	4
Cracking/separation towards base of wall	28% of bays	4	4
Balustrade able to be moved	13% of bays	4	5
Fractured/Spalled bottles	9%	3	3
Weathered bottle surface	3%	1	2

Figure 7 Open joints between coping stones

Figure 8 Dislocation of coping stones -able to be moved by hand

Figure 9 Fracturing/spalling of bottles

Figure 10 Cracking at wall low level

Figure 11 Differential coping levels

Figure 12 Banked earth at garden side

Figure 13 Stress fractures through paved pathway from tree roots

Figure 14 Scaffold buttress installed towards south end

4.3 Causes of Material Deterioration

- Thermal: cyclical expansion/contraction of the balustrade concrete along its length will generate stresses, particularly at changes in direction such as inlet bays. This has led to distortion of corner returns and displacement and cracking of coping to release build-up of stresses.
- Trees/Vegetation: Roots were recorded down to a depth of 2.2m by Listers Geo. Trees close to the wall may cause significant damage through root tendril growth, direct pressure from roots, as well as promoting desiccation of the clay- sub-strata (which has high volume change potential) local to each tree, allowing local subsidence and heave. That being said, there is no visual evidence of advanced deterioration/movement local to the trees. Furthermore, we understand the made ground (with only moderate volume change potential) extends to below 2.2m below ground level, suggesting clay desiccation may not be a primary factor.
- Construction Detailing: There are thought to be missing pins between bottles and plinth to provide positive fixity and improved resistance to overturning and sliding failure – frequency unknown. There are no movement joints allowing the aforementioned thermal ratcheting to be released. Even though there is mortar loss between plinth/rail units, the position of these open joints over bottles will resist longitudinal thermal movement. There is low cover for bottle reinforcement between7mm and 62mm) – lack of quality control on positioning reinforcement bar when casting. Low chloride content in the concrete suggests low cover depth, possibly accentuating the effects of carbonation, is the primary cause of fracturing/spalling.
- Ground Support: The made ground bearing material (to 2-3m depth) is partially granular and is known to contain brick fragments, suggesting a high likelihood of void pockets and/or washout/scour of the granular material. This may be allowing relative ground movement, causing wall level steps manifesting as undulations in the coping line and steps at the joist locations. The soft landscaping at the garden side (versus hard at the pavement), may allow localised soil saturation and softness, contributing to relative differences in earth bearing capacity on each side of the wall, promoting base rotation.

4.4 Loading

4.4.1 Balustrade

Being adjacent to a roadway, a new balustrade could be expected to be detailed to withstand peak lateral loadings from accidental vehicular impact as per BS EN 1991-1-7:2006. Given its historic construction, if retained it is at the discretion of the engineer to determine a suitable level of anticipated *actual* loading, to minimise unnecessary disruption to heritage fabric. It has been assumed by HPM that such lateral loading would be limited to that of large crowds of pedestrians (1.5kN/m) and accordingly a risk assessment approach to discount vehicular load allowances must be carried out.

4.4.2 Retaining Wall

The lateral loading applied to the back side of the retaining wall comprises:

1. Dead weight of earth under road, drainage systems, road subgrade, tarmac surfacing, road signage etc
2. Hydrostatic pressure from any water escaping the closed drainage system, through failed pipe or blocked surface gulleys
3. Applied load surcharge from Chester Terrace roadway including emergency vehicles on pavement, pedestrian use etc

A surcharge of 10kN/m^2 encompasses the worst case loading for traffic as well as surcharge from the finishes to the pavement/road.

4.5 Support/Restraint

4.5.1 Balustrade

The balustrade derives resistance to overturning and sliding failure either by the extent of coping/bottle and base/plinth concrete interface and the pressure/friction that affords and by the bronze pins providing a positive fixing and resisting through the pins' bending/shear resistance. The mortar at bed joints will provide tensile bond resistance, albeit minimal.

4.5.2 Retaining Wall

The unreinforced brickwork stem of the wall resists the lateral forces listed above through the weight of the material alone – it constitutes a gravity retaining wall. It is not clear whether the concrete stem at the northern length was similarly designed, although tensile steel reinforcement may permit it to function as a 'cantilever retaining wall', depending on its connection to the concrete footing, under.

The existing footing bears onto the made ground at a depth of 0.35-0.55 metres. Our assumption is that the retaining wall is positioned centrally to the footing width and this is less conservative than the HMP assumption shown in figure 6. This needs to be confirmed via probing or a trial hole.

4.6 Additional Analysis Recommendations

HPM have carried out quantitative analysis of the wall's performance at 4No. representative locations, varying retained height and footing size based on site measurements within trial pits.

<u>Balustrade</u>

1. Analyse against Eurocodes, not British Standards as is now the industry norm (e.g., BS6180 is used for barrier loadings)
2. Allow for load sharing between bottles/coping etc
3. As alluded to in 6.1.2 of HPM's addendum report, carry out a third balustrade analysis case, allowing for vertical pinning through full height of coping/bottles/plinth to achieve 1.5kN/m or 3kN/m linear lateral load resistance to meet contemporary requirements. Determine size of rod and comment on achievability in-situ to avoid unnecessary reconstruction of bottles in adequate condition. This would constitute a remedial solution between option 1 (cosmetic repairs) and option 2 (replacement).

Retaining Wall

1. Confirm the size of the heel of the retaining wall through trial pitting/probing, to avoid the need for conservative assumptions about the footing width. Carry out analysis ahead of time to determine required footing width threshold.
2. Change TEDDS retaining wall analysis criteria from 'cantilever' retaining wall to gravity
3. Report on the extent or factor to which the retaining wall fails at each trial pit location by 1) overturning and 2) sliding respectively, to steer remedial need at each section of wall

8.1.1 We have undertaken the analysis of the retaining walls at each of the garden side trial pit locations (See Appendix B for locations) and established that:

(a) Sliding Stability: The retaining walls have insufficient resistance to resist sliding, or lateral movement towards the garden, under application of full loading.

(b) Overturning Stability: Except for Location TP5, where there is a wider base, the retaining walls have insufficient resistance to overturning, under the application of full loading.

(c) Bearing pressure beneath the foundation: The bearing pressures beneath the foundations range between 50kN/m2 and well in excess of 200kN/m2.

5. HPM PROPOSALS

5.1 HPM Proposals

HPM has proposed four repair options within their reporting, with varying degrees of efficacy, disruption and associated cost:

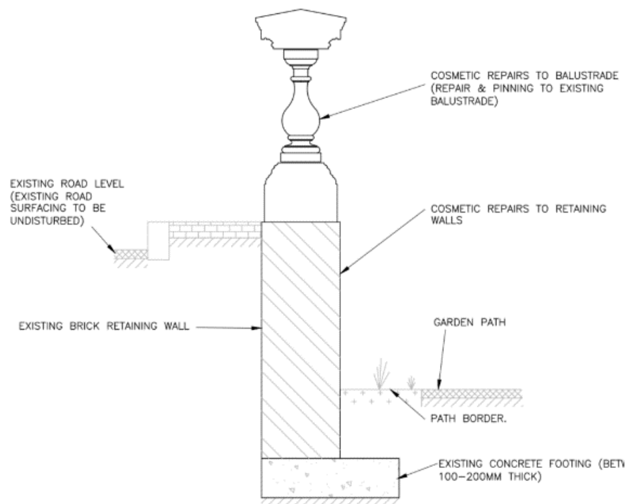

Figure 15 Section 7 -Option 1: Only cosmetic repairs to the retaining wall. No in-situ strengthening or tying of retained elements.

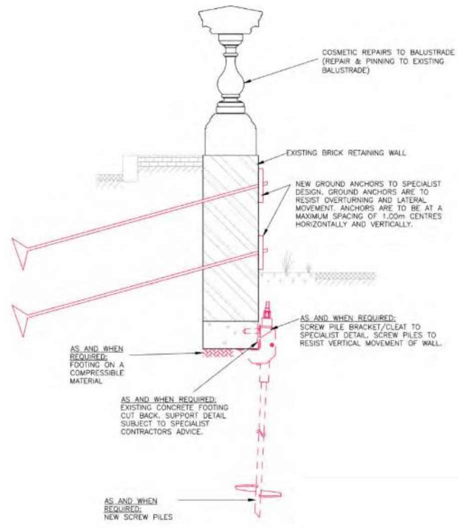

Figure 16 Section 7 -Option 4: Introduction of lateral ground anchors in the short term and screw piles reactively to address vertical movement as and when. As per HPM Option 2A.

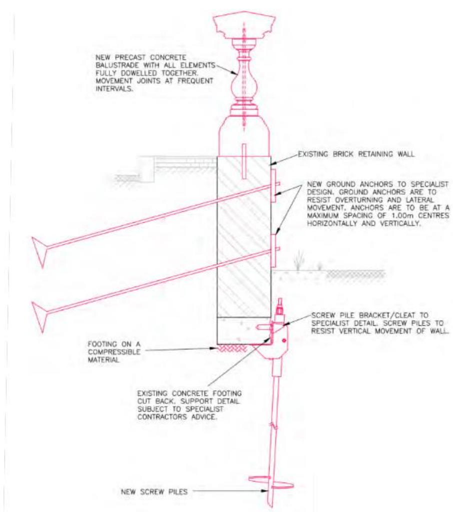

Figure 17 Section 7 -Option 5: Introduction of ground anchors to the wall and screw piles to the base concurrently. As per HPM Option 3.

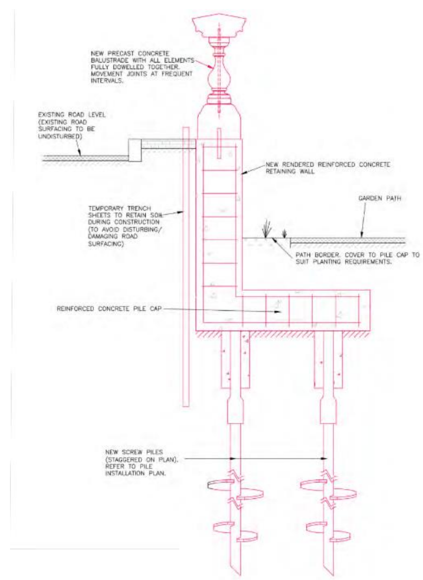

Figure 18 Section 7 -Option 6: Demolition of the existing wall and replacement with an RC retaining wall with screw piles. As per HPM Option 4

6. RAMBOLL ALTERNATIVE APPROACHES

Whilst it is agreed that the lengths of wall at the southern end of the wall, that are showing greater degrees of movement, may necessitate a fully engineered retrofit solution and/or reconstruction proportionate to HPM's options 2,3 or 4, there are nonetheless a number of alternative next steps, including further investigations to understand the nature and risk profile of the movement.

6.1 Further Investigations

Both structural and geotechnical investigations to-date have concluded through visual assessments and model analyses that a number of potential failure pathways exist for the wall, including ground failure, heave/subsidence from trees, sliding/overturning failure of the wall footing, deterioration of the brick stem and instantaneous overloading from the street.

Given this uncertainty over the primary and secondary (and potentially tertiary) causes, it would be our recommendation that targeted movement monitoring be carried out to understand the regularity, severity and nature of wall movement. By understanding whether the movement is annually cyclical, seasonal, progressive or now static, we can get closer to understanding the root cause. Furthermore, by monitoring the foundation, wall stem and balustrade independently, the source of failure can be ascertained. If the movement is cyclical, it is likely related to tree water demand. If static with instantaneous peaks, it could be road loading. If the movement is in the stem but not the foundation, it is linked to flexural performance of the brickwork rather than any geotechnical considerations.

Monitoring can be via point cloud laser scanning, which allows overlay of the whole wall in space, giving us full flexibility to check for rotation, verticality and absolute position or via installation of tell-tales or demec studs at critical junctions/cracks, to check for widening.

6.2 Phased Works

Depending on the relative importance of cost and disruption, a phased approach can be applied based on the remedial option chosen.

The wall and balustrade could be phased either by discrete section lengths or by the remediation of the wall and balustrade independently. This phasing would be dictated by urgency of the works, the extent of disruption and respective cash flow implications.

Should the work be phased by certain lengths of wall, it may be advisable to commence works at the southern end of the wall, in particular focussing on the inset section which is currently buttressed and showing significant movement. The central and north sections present significantly lower short to medium term risk, where the wall is in adequate condition and the soil retained is much lower. Accordingly, at these lengths and there is much greater flexibility in the approach taken, particularly if as part of the southern section works, a movement joint is introduced to isolate.

Alternatively, if the wall and balustrade are treated as separate remediation programme items, disruption to the topside (balustrade works) and gardens (retaining wall) can be staggered to minimise resident impact. Ideally, the wall would be the priority to avoid defect recurrence at the balustrade with continued wall movement.

6.3 Targeted Tree Management

Where large, mature trees are present, it is not uncommon for a shrinkable clay soil to be significantly desiccated to a depth of 6 m or more. However, it is likely that the levels of desiccation below about 3 m will remain at an approximately constant level as long as the tree remains in place. The design of an underpinning system to withstand the ground movements associated with the removal of the tree will, therefore, be radically different from one designed simply to provide an adequate foundation while the tree remains.

Referring to the CEPC survey drawings provided (200944) and our visual inspection, certain larger trees in close proximity to the wall hold a potential risk to the wall's performance and integrity through surcharge and ground volumetric changes, although wall damage local to trees is typically low. Specialist advice should be sought from an arboriculturist to proactively manage water demand and subsequent impact, moving forward, even after underpinning/wall reconstruction. Trees in close proximity include:

- T488 (Common Lime)
- T489 (Wild Cherry)
- T218 (Sycamore)
- T490 (Pissard's Plum)
- T491 (Glossy Privet)

6.4 Existing Balustrade with Reinforcement

Whilst there is spalling/fracturing of approximately 1/3 of all bottles, HPM's investigations and associated concrete testing tell us this correlates with poorly positioned reinforcement and low cover. Chloride tests did not show this to be critical factor at this stage, and on this basis the retention of the intact 2/3 of bottles would be by consideration of the position of the reinforcement relative to the carbonation front. At its greatest depth, the carbonation front is at 33mm, and an exercise to replace bottles where the reinforcement cover is below this threshold, could be undertaken to maximise retention in line with good conservation practice. We agree that application of a coating such as Fosroc Dekguard CP to these retained bottles would be appropriate.

Location	No. of Results	Minimum Cover, mm		Carbonation Depth, mm	
		Range	Mean	Range	Mean
Sound	12	24 to 62	42	2 to 33	12
Cracked	6	12 to 51	37	2 to 27	12
Exposed rebar	6	7 to 18	14	7 to 23	18

Figure 19 Sandberg balustraded bottles carbonation and cover testing results

To improve balustrade performance under lateral loading, positive fixity needs to be established between the coping/bottles, bottles/plinth and plinth/wall, as well as the wall itself being capable of resisting said lateral loading. This structural continuity and improved rigidity could either be achieved through vertical coring and grouting of a new full height rod, centrally positioned, which itself would resist the load, or a series of self-tapping helical ties could cross stitch across each of these interfaces. Alternatively, a new steel frame can be hidden within the concrete elements to resist full vehicle load.

6.5 Horizontal Wall Support Alternatives

The presence of existing services, as well as the coal vaults of the adjacent properties, severely restricts options for strengthening works below the road, including lateral pinning as per HPM proposals. Such anchoring works will require CCTV surveys prior to work commencing and following to confirm relative condition before and after and may struggle to get approval given the risks of damage. Furthermore, the anchors would be listed as a below ground asset and affect future servicing works below Chester Terrace. On this basis, resolving the lateral wall movement through intervention within the garden (only) should be considered.

6.5.1 Earth Works

In lieu of full wall/footing reconstruction or underpinning, a cost-effective solution to address continued bearing earth 'make ground' movement and insufficient sliding and overturning capacity, will be through the introduction of earth to the lower garden side, to lower the relative retained height, resist stem rotation and act as kentledge against toe sliding.

<u>Banked Earth</u>

By banking earth up against the wall, similar to that already seen on site but to a higher level, we can provide increased lateral resistance to overturning and sliding. This is a low cost solution, albeit does not address the potential for continued vertical made-ground movement.

<u>Mechanically Stabilised Earth</u>

Similar to banked earth, but utilising geogrids or baskets (gabions) to provide lateral restraint. Rather than a continuous bank of earth, this may comprise discrete buttresses to act as kentledge, allowing the brickwork/concrete to span horizontally between. Could be employed in the short or long term, depending on aesthetic impact.

6.5.2 King-Posts

This proposal entails the installation of new vertical- cantilevering retaining posts at regular centres in-front of the existing brickwork wall, off which it can be shored. By creating a borehole down into the clay strata, the king posts can be cast in position in good earth (not made ground) and are hence are able to provide lateral resistance. Furthermore, the king posts offer the option to re-support the balustrade on a new base plate, spanning between the posts clear of the existing wall – see Section 7.5. The newly seated bottles would remain in the same position, possibly circa 20mm higher, but not rely upon the (possibly) moving wall for support. The centres and aesthetic impact of the posts is to be confirmed with further design/analysis.

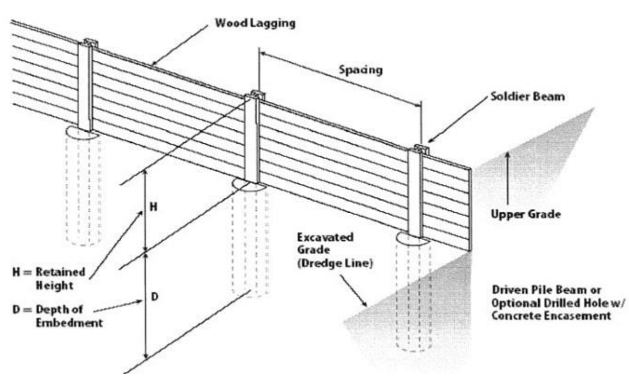

Figure 20 Representative arrangement of king (soldier) posts

6.6 Vertical Wall Support Alternatives

No permissible bearing pressure has been provided by the geotechnical assessment for the made ground and it is typically good practice to avoid giving any structural reliance such strata. The underlying London clay, typically at 2-3m depth, can be presumed to have a minimum permissible bearing pressure of 75kN/m^2, however the geotechnical consultant recommends allowing up to 125kN/m^2. It is on this basis we consider the alternative underpinning options at our disposal.

6.6.1 Traditional underpinning

Lowering the existing footing down to clay strata at circa 3m down, at current width (or splayed). HPM's analysis shows bearing stresses are in excess of 125kN/m2 typically at the southern, higher, end. It is reasonable then that a continuation of the footing at its current width will, at the northern end, address outstanding issues with regards to unpredictable long-term bearing performance of made ground. The factor of safety of the footing should be a minimum of 2, so the extent of this approach is to be determined by the retained height at which foundation stresses are equal to or less than 62.5kN/m^2.TBC by HPM. This is a low-tech, but quite disruptive option that may be applicable to certain sections, only.

6.6.2 Angled/Raked Mini-Piles

As a less disruptive in-situ alternative to HPM's screw piles or a traditional 'trench' underpinning. Raking mini-piles, cored through the existing footings and grouted in-place. This would address the vertical capacity of the footings and unpredictability of the made-ground at locations along the wall where overturning is not critical. Would be used in tandem with system to resist lateral load (ground anchors [tension] earth works [compression]) at the southern end.

Note that pile underpinning typically is required to twice the depth of a mass concrete equivalent, and consideration of future ground heave forces from felled dead or dangerous trees needs to be made.

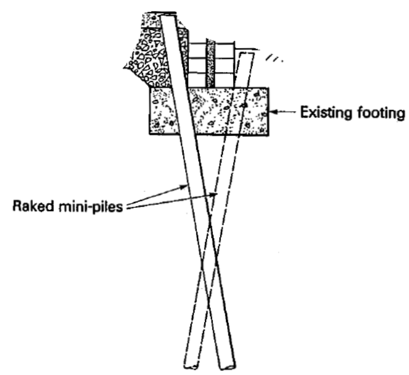

Figure 21 Raked mini piles through footing. Note unlike this diagram, our raking piles would be installed from the garden side only, at a consistent angle.

6.6.3 Grout Injection

Allow for pressure injection of grout beneath the existing footing, thereby extending it down to the clay strata. Specialist contractor to advise of efficacy in made ground of this composition. Low disruption and potential to widen the footing width.

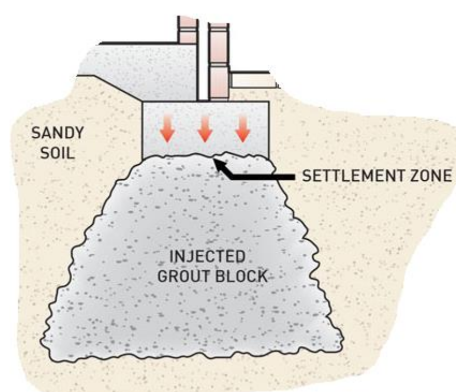

Figure 22 Typical grout injection

6.6.4 Independent Support Frame

See 6.5.2.

7. REMEDIAL OPTIONS APPRAISAL

Option No.	Origin	Remedial Solution – in order of scale of works	Cost	Site Disruption	Longevity	Notes
1	HPM	'Cosmetic' repairs (only) to balustrade and retaining wall	Low at both, but ongoing	Low – no excavation or heavy duty works required. Vegetation and trees remain in-situ.	Low (5 – 10 years) – Addresses current material issues only, not root cause of issues or structural deficiencies against current standards.	Does not address root causes and may ultimately allow wall failure if left unchecked. May be suitable at northern end of wall (only).
2	Ramboll	Targeted replacement of low cover bottles (only). In-situ pinning of all bottles to coping and plinth. Creation of movement joints to manage thermal stresses and isolate phased lengths of wall remediation. Retention, repair and strengthening of retaining wall using a combination of in-situ techniques to lower founding depth to clay strata (inc. mini-pile, grout injection) in combination with systems within the gardens to resist sliding/rotation (e.g. earthworks)	Balustrade – Moderate Wall – Low to moderate	At Chester Terrace – moderate In gardens – moderate during works, but long-term aesthetic impact	Balustrade – moderate (10 to 20 years) depending on escalation of carbonation front Wall - moderate (10 to 20 years)	Mini-piling Only applicable to lengths of wall where overturning is not critical (central and northern sections). To be employed in tandem with option 3, 4 or 5.
3	Ramboll	King-post retaining wall installation within garden, packed back to laterally support existing brick wall. Support of existing or new balustrade on new king post frame, to eliminate reliance on vertical stability of brick wall	Moderate	Low - discrete core holes through garden next to wall to allow king posts to be dropped in. Long term aesthetic impact, but able to be clad in brickwork to match	High. Assuming this arrests lateral movement and the balustrade is re-constructed on a new plate, any movement of the existing wall will be independent to the functioning of the balustrade	A low cost solution, with high aesthetic impact. Has been included as it has the potential to address both wall and balustrade, with minimal disruption.
4	HPM Option 2	Replacement of balustrade with new fully doweled equivalent, with frequent movement joints Retention and repair of retaining wall with newly introduced ground anchors Reactive installation of screw piles local to ground movement, as and when, seating the footing on a bespoke shoe/bracket. Consider RUK alternative of in-situ raking mini-piling in-lieu of screw pile, to minimise excavation of gardens during installation.	Balustrade - High Wall - Moderate (short term), increasing in long-term.	At Chester Terrace – High to allow for full balustrade reconstruction and managing ground anchor installation In gardens – moderate but ongoing and unpredictable	High (30 to 40 years) but holds outstanding risk of damage to new balustrade through wall movement (prior to reactive underpinning). Low risk of collapse so remains a structurally low risk option.	Will require joints to be formed between underpinned and non-underpinned sections to avoid damaging differential ground movement. Outstanding risk of ground anchors with services below Chester Terrace and pressure bulb interaction with coal vaults of properties on other side of street.
5	HPM Option 3	Replacement of balustrade with new fully doweled equivalent, with frequent movement joints Retention and repair of retaining wall with newly introduced ground anchors Proactive installation of screw piles concurrently with ground anchors, seating the footing on a bespoke shoe/bracket. Consider RUK alternative of in-situ raking mini-piling in-lieu of screw pile, to minimise excavation of gardens during installation.	High at both balustrade and wall, potentially matching item 6 if the full length of wall ultimately moves.	Short term high, but less so than option 6 Retention of road and footpath Mini-pile less disruptive than screw – less hazardous waste removal at top 500mm.	High (30-40 years)	Outstanding risk of ground anchors with services below Chester Terrace and pressure bulb interaction with coal vaults of properties on other side of street.
6	HPM Option 4	Reconstruction of fully pinned balustrade Replacement of retaining wall with modern reinforced concrete cantilever wall	Highest initial outlay (circa £1.7 million), but low ongoing cost.	Short term high Loss of trees and vegetation Road damage likely and loss of footpath.	Highest (50+ years)	Loss of authenticity of wall – not aligned with principles of conservation. Road use during construction will be limited to manage trench shoring surcharge

8. CONCLUSIONS & RECOMMENDATIONS

In answer to Nick Packard's original questions of his email 14th June 2021:

Is there a reasonable chance that if we put a new balustrade on the existing foundations the structure will be stable for the next 20 – 30 years?

Whilst the made ground onto which the foundations sit will indeed have consolidated over the life of the wall, given its variable and potentially voided composition there still remains a possibility for further movement. Given no monitoring has been carried out, we cannot say the rate or timing of historic movement and hence can't make comment on the likelihood of its continuation.

As such, on the basis of the made ground bearing alone, any balustrades remediation or reconstruction ahead of wall remediation holds potential for defect recurrence. That being said, whilst balustrade deterioration is typical to the full length, the severity of wall issues seems to correlate with retained height and *possibly* with proximity to certain trees. On this basis, a single remedial strategy could be adopted for balustrade (including reconstruction) and a more tailored, location specific approach for the retaining wall. Following balustrade reconstruction, lower risk areas to the northern end could be monitored to allow specification of an appropriate remedial strategy in the medium term with a low risk of balustrade defect recurrence.

There are a number of options outlined in this report that will address the wall founding and provide the existing wall with a reliable bearing, and consideration needs to be made by the client as to which route best satisfies the short- and long-term goals of the project.

Are there any other options for dealing with the moving foundations you can recommend?

As outlined in Section 6. In consideration of both HPM and Ramboll's proposals, it is recommended a targeted, tailored approach is adopted for the wall, responding to the level of short to medium term risk at certain, discrete lengths:

<u>HIGH RISK Middle/South inset bay</u>
Tree management at large local tree AND
Option 3 (king-post) OR
Option 5 (proactive re-support – screw piles or alternative in combination with horizontal shoring/nailing) OR
Option 6 (local wall replacement)

<u>MODERATE RISK – Middle Section</u>
Tree management AND
Option 3 (king post) OR
Option 4 (proactive lateral support and reactive vertical support) OR
Option 6 (local wall replacement)

<u>LOW RISK - Middle to North end</u>
Wall movement monitoring AND
Option 2 (earth works and/or in-situ strengthening) OR
Option 3 (king post) OR
Option 6. (local wall replacement)