Structural Engineer's Appraisal

Covent Garden Car Park
Warwick District Council

Issue Number P02
02.08.2022

Document History

Issue	Date	Comment	Author	Chk'd
P01	11.07.22	Draft Issue	OLJ	LEW
P02	02.08.22	Final Issue	OLJ	GGM

Contents

1.0 Reference and Instruction

1.1	PE Report Reference	:	R001OJ – 220236- 17.2 Covent Garden Structural Engineer Appraisal– Issue 01
1.2	Client	:	Warwick District Council
1.2.1	Address	:	Riverside House Milverton Hill Leamington Spa CV32 5HZ
1.2.2	Telephone Number	:	n/a
1.3	Inspected Property	:	Multi-storey car park Covent Garden Russell Street Leamington Spa
1.4	Instruction		
1.4.1	On behalf of	:	Warwick District Council

1.5 Brief

- To carry out a structural analysis following a previous site report identifying potential overstressing of structural members including cracking at beam and column interfaces and hairline vertical cracking to the beams as identified in report reference R001-NCC-210467.
- Obtain dimensions of the structure, arrange for concrete investigations and carry out a ferrous scan to establish reinforcement details of the structural elements to provide enough data to allow for a structural analysis of the car-park.
- Provide recommendations based on the results of the structural analysis.

2.0 Scope of Investigations and Report

In accordance with the aforesaid instructions, the following investigations have been undertaken:-

(a) A measured survey of typical primary structural members
(b) A ferrous scan of primary structural elements
(c) Intrusive investigation to confirm results of ferrous scan.

The investigations and this report are confined to technical assessment of the load bearing elements of the structure. Whilst every endeavour will be made to provide a positive and helpful report we are unable to predict the future behaviour of the structure or its components. Guarantee cannot therefore be given that the property will be free from future damage or that existing defects will not suffer from further deterioration or lead to damage.

This report is not to be used for any other purpose or by any third party and is not to be taken as a specification for remedial action or works. However, if the recommendations included within this report are to be subsequently taken forward to detailed design / scheduling and / or construction; before any work can commence, there is a duty on designers, within the definition of the Construction (Design and Management) Regulations 2015, to ensure that Clients are aware of the specific duties they are required to carry out under the provisions set out in the CDM Regulations. HSE's Client Guidance document INDG 411 which can be found on www.hse.gov.uk sets out clear and concise guidance as to the role the Client plays in a project, and also what is expected of other disciplines involved in the project.

The report is not a "Building Survey" as defined by RICS and is therefore not concerned with general building defects and/or damage, other than those relating to the load bearing elements.

No breaking out or opening up of the building fabric was undertaken at that time and no part of the property which was not readily accessible, or which was covered or otherwise concealed, was inspected. Absence of report on any such part is not to be taken that it is free from defect. Such unexposed parts may contain problems and special arrangements would need to be made for these areas to be investigated (where practicably possible) if confirmation were to be required about their condition.

Drains were not inspected or tested.

Foundations were not uncovered.

Enquiries with local or statutory authorities have not been carried out. Whilst attention may be drawn to any apparent breaches of statutory requirements relative to the buildings or site, the absence of any such comment does not imply compliance with such requirements. The building and associated structures have not therefore been assessed for compliance with the Building Regulations, for example, Approved Document B – Fire Safety.

3.0 The Site

3.1 O.S. Grid Reference	:	SP 316661
3.2 Topography	:	Ground levels fall by in the region of 1-3m from the East to the West elevations of the car park and falls in the region of 1m from the South to North elevations. Walls to floors at ground level and level 1 are partially retaining.
3.3 Substrata/Geology	:	Reference to British Geological Survey data, indicates: No superficial deposits but the site overlies Bromsgrove Sand foundation.

4.0 Assessment of Findings

4.1 Current Damage and Frame Geometry

The structure is a 9-level multi-storey car park, constructed c 1960. Its construction comprises an in-situ reinforced concrete frame supporting in-situ concrete slabs at each floor level with access ramps between levels. There are two brick/block stair cores at either end of the car park.

Each structural deck is formed by in situ concrete slabs 140mm thick, spanning between 760 x 255mm primary down-stand concrete beams at approximately 4525mm centres. The beams span 15.9m between concrete columns.

There are cracks in the column heads which would appear to have resulted in the original columns being strengthened with newer column located in the same plane as the primary beams. This was perhaps carried out after overstressing of the structure was identified at some time in the past. There are also cracks located in the down-stand beams caused by overstressing.

Stability is achieved via masonry shear walls positioned either side of the ramps, around the stair cores and along the central spine of the structure.

External wall details comprise 230-300 mm thick concrete parapets 665-750mm high and faced with a pre-cast aggregate concrete panel. At all levels metal handrails 220mm have been built off the top of the parapets.

Level 1 is situated partially below ground level retained by brick retaining walls 1.8 m high, forming the perimeter of the external face.

A movement joint runs through the centre of the upper decks from the east to the west elevation.

Concrete access ramps ascending to the upper decks near to the north and south elevations and descending ramps located near to the centre of the car park are formed using the same reinforced in-situ slab detail as the main decks.

No as-built drawings have been made available.

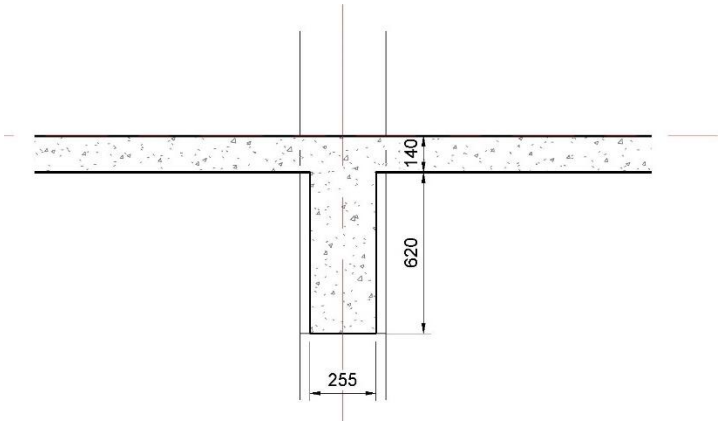

Figure 1 - Flanged Beam Section

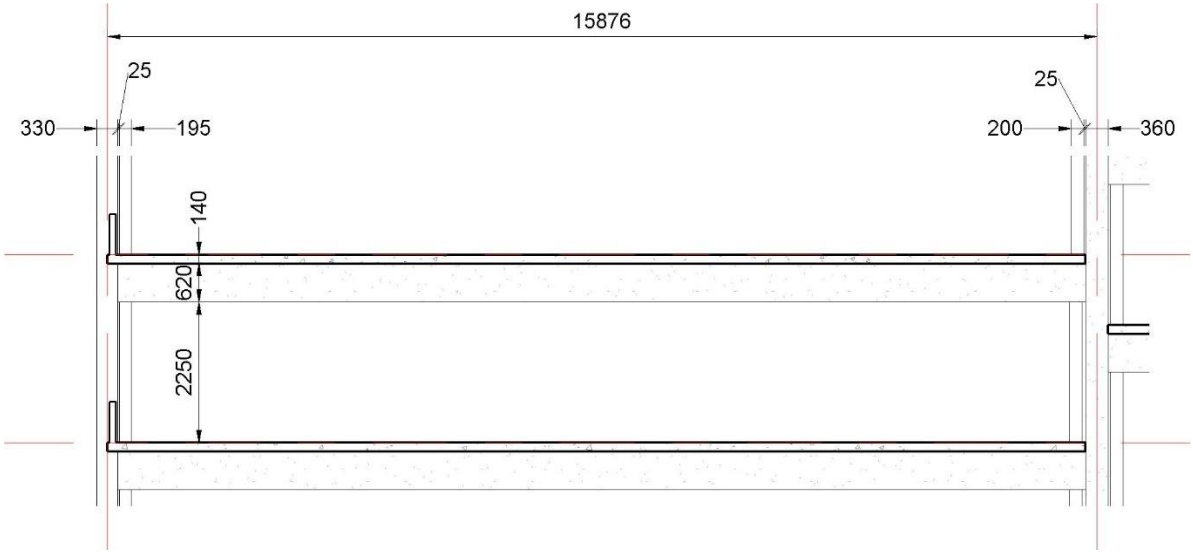

Figure 2 - Flanged Beam Elevation

4.2 Reinforcement Size and Type

4.2.1 Beam

Figure 3 - Beam Bottom Reinforcement

Figure 3 shows shear links running from top to bottom of image and flexural reinforcement left to right of image. Shear links are 8mm smooth round bars, Flexural reinforcement is 30mm square twisted bar.

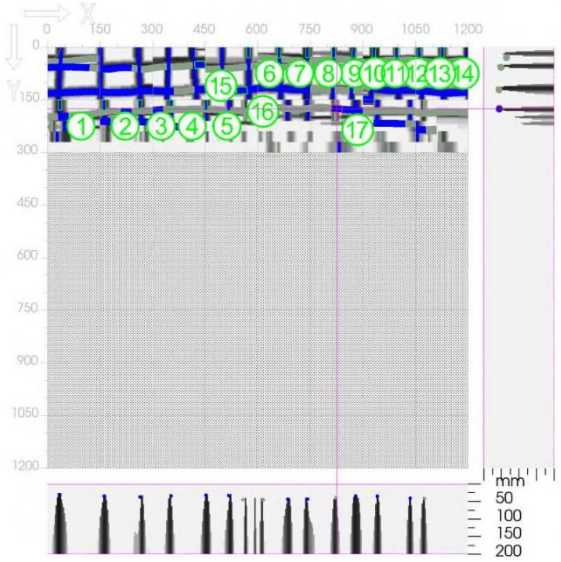

Figure 4 - Ferrous Scan Beam Soffit

Figure 4 shows shear links, bars 1-14 at approximately 100mm spacing. 3 number flexural reinforcement bars 15,16 and 17.

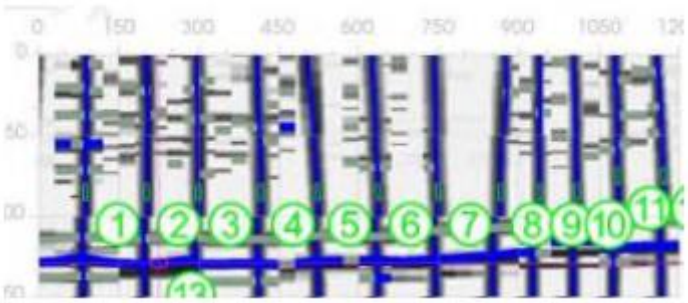

Figure 5 - Ferrous Scan Beam Face

Figure 5 shows shear links, bars 1-14 at approximately 100mm spacing. Bar 13 flexural reinforcement, only one flexural reinforcement bar is visible due to the plane from which the ferrous scan is taken.

4.2.2 Slabs

Figure 6 - Slab Soffit Reinforcement

Figure 6 shows 9mm square twisted primary reinforcement running top to bottom of the image. 7mm square twisted secondary reinforcement running left to right

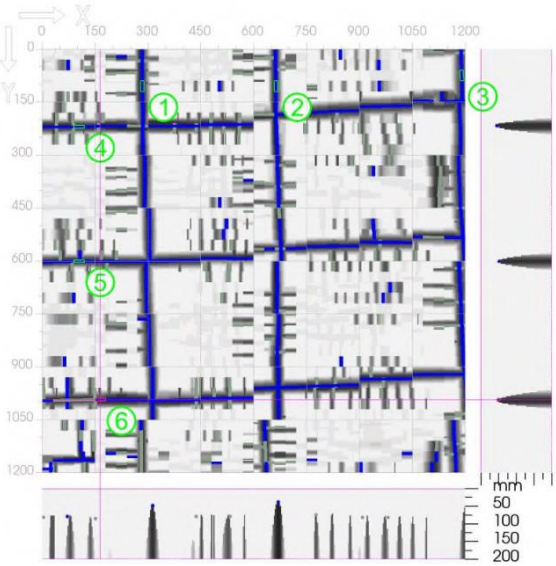

Figure 7 - Ferrous Scan Slab Soffit

Figure 7 shows primary and secondary slab reinforcement within the slab soffit at 450mm spacing in both directions.

Figure 8 - Slab Soffit Reinforcement

4.3 Reinforcement Grade

Samples of reinforcement could not be taken to determine the grade of reinforcement without compromising the integrity of the structure. Table 2 however reports the historic yield stresses of various bar types and sizes during the period when the car park was constructed. The following reinforcement grades are likely present in various building components

Building Component	BarType	Reinforcement Yield Stress
Slabs	Square Twisted	455N/mm²
Beams – Flexural	Square Twisted	415N/mm²
Beam – Shear	Plain Round	250N/mm²

Table 1 - Covent Garden Car Park Reinforcement Grades

Plain round mild steel bars	
Code	Yield
BS 785: 1938 and BS 785: Part 1, 1967	36,000 psi (250 N/mm^2) for bars up to 1^1/$_2$ inches (38 mm)
BS 4449: 1969, 1978 and 1988	250 N/mm^2
Cold worked deformed bars	
Code	Yield
BS 1144: 1943	70,000 psi (485 N/mm^2) for bars less than ⅞ inch (10 mm) 60,000 psi (415 N/mm^2) for bars over ⅜ inch (10 mm) 54,000 psi for twin twisted bars
BS 1144: 1967	66,000 psi (455 N/mm^2) for bars up to ⅝ inch (16 mm) 60,000 psi (415 N/mm^2) for bars over ⅝ inch (16 mm) 72,000 psi (495 N/mm^2) for 72 Grade ribbed bars with rolling mark
BS 4461: 1969	460 N/mm^2 for bars up to 16 mm 425 N/mm^2 for bars over 16 mm
Hot rolled deformed bars	
Code	Yield
BS 785: Part 1, 1967	60,000 psi (415 N/mm^2) for medium tensile bars 70,000 psi (485 N/mm^2) for high tensile bars
Not covered by Standard	80,000 psi (550 N/mm^2) for Lancs 80 bars from Lancashire Steel Co.
BS 4449: 1969	410 N/mm^2 for all sizes
BS 4449: 1978	460 N/mm^2 for bars up to 16 mm 425 N/mm^2 for bars over 16 mm

Table 2 - Specified Yield Stresses - Historic Approaches to the Design of Concrete Buildings and Structures

4.4 Cover

British Standard BS8500 recommends cover to reinforcement requirements dependant upon the exposure class of the structure. Current regulations generally require more cover than buildings built in the 1960 and 1970s.

Modern car park structures built to BS8500 require a minimum of 40mm and those designed to BS EN 1992 : 2004 require 45mm of cover. 30mm for decks and columns and 25mm to soffits is more typically found on historic structures.

The lower the concrete cover the greater the reinforcement is at risk of corrosion over time from carbonation and in the case of car parks chlorides.

4.5 Concrete Compressive Strength

Compressive Stregnth			
Core Ref	Location	Structure	Result (N/mm2)
C1	GL 9 C LvL 4-5	Column	27.0
C2	G14 C Lvl 5	Column	41.7
B1	G14 A-B Lvl 5	Beam	25.9
B2	G14 G9 D-E Lvl 6	Beam	32.4
S1	G14-15 D-E Lvl 6	Slab	37.5

Table 3 - Concrete Compressive Strength

Five number concrete core samples were taken throughout the structure to measure the compressive strength of the concrete. The measured strengths ranged from 25.9 to 41.7 N/mm^2, corrected cube strength 26.1 to 41.6 N/mm^2. For the purposes of our analysis a strength of 30N/mm^2 has been assumed.

4.6 Design Analysis

Car parks designed to current standards are required to support the dead loads applied which are generally the self-weight of the structure and imposed loads which in accordance with BS EN 1991-1 recommends a uniformly distributed load of 2.5kN/m² for car parks. There are also factors of safety allowances which need to be included.

Assumptions in our design analysis:

- Concrete strength 30 N/mm² based on concrete samples taken.
- Concrete properties are consistent and do not vary across the car-park footprint.
- Reinforcement strengths – as table 4.3
- Concrete cover to reinforcement as measured on site.
- Design carried out to BS EN 1991 and BS EN 1992.

Our analysis confirms that the structure does not have the capacity to support the loadings applied when designed to current standards. The primary beams fail in bending exceeding the tension capacity of the reinforcement.

Our analysis has confirmed that the beams have sufficient capacity to only carry an imposed load of 0.629kN/m², approximately 64kg/m², spread uniformly over the deck and that includes safety factors which would otherwise be allowed for.

4.6.1 Beams

PICK EVERARD Halford House Charles Street Leicester, LE1 1HA	Contract/ Job Covent Garden Car Park Structural Analysis			Job No. 220236	
	Part of works Flanged Beam Design			Sheet No. 1 of 2	Rev. 1
	Drawing No.	Calcs by/ Date MM 05.07.22	Checked by/ Date OLJ 11.07.22	Approved by/ Date	

The following calculations are to assess the load carrying capacity of the existing structural beams at Covent Garden Car Park, Leamington Spa. The analysis has been carried out without material or loading safety factors. The significance of the exclusion of these factors is reviewed in the Conclusions and Recommendations of this report.

The flanged beams are of the follow proportions 760mm deep x 255mm wide, spanning 15876mm. Additional extensions to the columns have been added to the columns, this has reduced the beam length to 15576mm

Ref.	Calculations					Output
Effective flange width:						
Beff,1	bi	=	2255 mm			
	lo	=	15576 mm			2008.6 mm
Check:						
Beff,1 less than	0.2 * lo	=	3115 mm			OK
	bi	=	2255 mm			OK
Beff, 2	bi	=	2272 mm			2041.9 mm
	l0	=	15876 mm			
Check:						
Beff 2 less than	0.2 * lo	=	3115 mm			OK
	bi	=	2255 mm			OK
beff	bw	=	255 mm			
	beff1 + beff2					4050.5 mm
	beff	=				4305.5 mm
Loads						
w	Live	=	2.85 kN/m		equililant UDL = 0.63 kN/m²	
	Dead	=	19 kN/m	Total load	= 22 kN/m	
	L	=	15.88 m			
M	M=		wL^2/8			662.6334132 kNm
	bf	=	4306			
	cover	=	25			
Max bar size across twisted profile		=	42			
	d	=				714 mm
	fck	=	30			
k	M/(bf d^2 fck)					1.0063E-02
From lever-arm curve, Figure 7.1						
ia						0.95
Z	d*ia	=				678.3 mm

Ref.	Calculations	Output
Depth of stress block	s = 2(d-z)	71.4
	fyk = 415	
As	M / 0.87 fyk Z	0.002705728
	Area of steel required:	2705.728181 mm2
	Area of steel provided following investigation: 2700 mm2	

4.6.2 Slabs

PICK EVERARD Halford House Charles Street Leicester, LE1 1HA	Contract/ Job Covent Garden Car Park Structural Analysis			Job No. 220236	
	Part of works Continuous Slab design GL 13 - 14, level 2			Sheet No. 1 of 2	Rev. 1
	Drawing No.	Calcs by/ Date MM 05/07/22	Checked by/ Date OLJ 11/07/22	Approved by/ Date	

The following calculations are to assess the load carrying capacity of the existing structural slabs at Covent Garden Car Park Leamington Spa. The analysis has been carried out without material or loading safery factors. The significance of these is reviewed in the Conclusions and Recommendations of this report.

The slab is of the following proportions :15.88m x 4.510 m, 140mm thick

Ref.	Calculations	Output
Known Values	fck = 30 N/mm2	Plan dimensions of slab
	fyk = 415 N/mm2	15.88 x 4.510 m
	Qk = 0.6 KN/m2	W x L
	Gk = 3.36 KN/m2	D = 0.14 mm
	Density 24	
Ultimate load (for 1m width slab)	F = (1.35*Gk + 1.5*Qk) * 4.510 m * 1m	F = 24.52 kN
Servicability load	F = Gk + Qk	F = 17.86 kN
Using table 8.1 coefficiencts, assuming end supports ae pinned, moment at middle of end span =		
Strength	M= 0.086FL	M = 9.5089 kN m
Service	M= 0.086FL	M = 6.927 kN m
Bending reinforcment		
	d = 110 mm 0.11 m	b = 1000 mm
	k = M/(b d^2 fck)	= 3E-08 0.0262
Lever arm curve - fig 4.5		
	la = 0.96 = 0.95	
	z = la * d	z = 104.5 mm
As		
Strength	As = M / 0.87 fyk Z	As = 252.03 mm2/m
Service	As = M / 0.87 fyk Z	As = 183.6 mm2/m
	Area of steel provided 9mm² twisted bar	As,prov 180 mm2/m

PICK EVERARD Halford House Charles Street Leicester, LE1 1HA	Contract/ Job Covent Garden Car Park Structural Analysis			Job No. 220236
	Part of works Continuous Slab design GL 13 - 14, level 2			Sheet No. 2 of 2 / Rev. 1
	Drawing No. 0	Calcs by/ Date MM 05/07/22	Checked by/ Date OLJ 11/07/22	Approved by/ Date

Ref.	Calculations	Output
Known Values	Fck = 35 N/mm2	Plan dimensions of slab
	Fyk = 500 N/mm2	15.88 x 4.510 m
	Qk = 2.5 KN/m2	W x L
	Gk = 3.36 KN/m2	D = 0.14 m
	Density 24 KN/m3	
Ultimate load		
(for 1m width slab)	F = (1.35*Gk + 1.5*Qk) * 4.510 m *1m	F = 37.37 kN
Servicability load	F = Gk + Qk	F = 26.43 kN
Using table 8.1 coefficiencts, assuming end supports are pinned, moment at middle of interior span =		
Strength	M= 0.063FL	M = 10.618 kN m
Service	M= 0.063FL	M = 7.5092 kN m
Bending reinforcment		
	d = 110 mm	b = 1000 mm
	0.11 m	
	k = M/(b d^2 fck)	= 3E-08
		0.0251
Lever arm curve - fig 4.5		
	la = 0.96	
	= 0.95	
	z = la * d	z = 104.5 mm
As		
Strength	As = M / 0.87 fyk Z	As = 233.58
Service	As = M / 0.87 fyk Z	As = 165.19
	Area of steel provided 9mm² twisted bar	As,prov 180 mm2/m

5.0 Conclusions & Recommendations

When designed to current codes of practice the car-park can support a uniform distributed load of only 0.629kN/m², approximately 64kg/m², spread uniformly over the deck.

A typical car would impose a load of at least 90kg/m² spread uniformly across the deck which would indicate that the car-park is significantly under designed. This would explain why additional columns have been added and perhaps explain why cracking has appeared in beams.

Whilst the car-park is not in imminent risk of collapse, damage will deteriorate in the future if left unattended. It should also be noted that with larger SUV's and heavier electric cars now in general use loadings are likely to increase rather than decrease.

The following options could be considered going forward:

1. Make no structural or operational changes to the car park and close it. **Costs – Security provision.**

2. Restrict weight to the car-park. Limit access by vehicle height and increase parking bay widths. Include regular monitoring of structural behaviour, carry out concrete repairs, apply carbonation coating and deck coating. **Costs in the region of £1,600,000 - £2,500,000 Every 10-15 years and lost revenue from reduced capacity.**

3. Strengthen structure with the addition of columns along the length of the primary beams. Carry out concrete repairs, carbonation coating and deck coating. The introduction of additional columns along the line of the primary beams will reduce the parking bay widths. **Costs likely to be greater than £2,500,000 and lost revenue due to reduced capacity.**

4. Demolish and rebuild. **Costs £7,315,000 - £10,010,000, 50 year design life assuming similar capacity, costs to be reduced for lower capacity.**

5.1 Reduce vehicle height - Option 2 and 3

Reducing vehicle height will reduce the risk of heavily loaded vehicles entering the carpark, the upper limit to be set at 1650-1700mm.

5.2 Increase parking bay width - Option 2

The parking bay widths are approximately 2400mm, it is recommended that the parking bays are increased in width to approximately 4500mm. This equivalent to the spacing of the primary beams, this action is intended to reduce the density of the car parking, reducing the load on the car park.

5.3 Monitor structural behaviour – required for Option 2

It is recommended that the deflection and crack widths on the existing structure are monitored before any measures are implemented, whilst the car park is in service and then periodically every 6months thereafter, to monitor any initial improvement or future creep.

5.4 Concrete repairs, carbonation coating and deck coatings – Option 2 and 3

Refurbishment costs to deal with Concrete repairs, carbonation coatings and deck coating are likely to range between £1,500,000 and £2,500,000 depending on specification. Works are likely to require renewing every 10-15years.

5.5 Structural strengthening – Option 3

The existing structure could be strengthened with the introduction of columns to the end of the parking bays on the same 4500mm grid as primary structure, shown in Figure 9

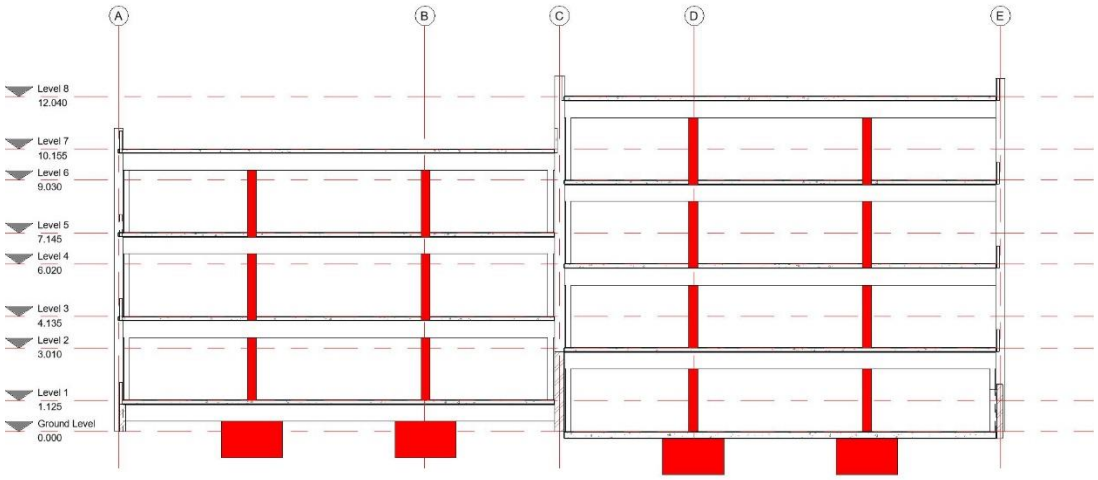

Figure 9 - Proposed columns and foundation in red

The concrete decks and ramps could be strengthened with the addition of carbon fibre to the soffit.

5.6 Demolish and Rebuild – Option 4

New build cost in the region of £19000 to £26000 per car parking space. The current capacity of the carpark is 385 spaces which equates to £7,315,000 to £10,010,000 for a similar capacity, depending on specification. Demolition costs are likely to be in the region of £66.84 pre m², equating to £830,000. Figures are based on SPONS 2022, an area of 12430m² and 385 parking spaces.

6.0 Status of Report

This report does not provide a warranty or guarantee as regards the structural adequacy and condition of the building. It provides a considered professional opinion based on a limited visual inspection and no liability shall attach to us except to the extent that we have failed to exercise reasonable skill, care and diligence in the provision of our services.

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