1. **Introduction**

The proposed project is to construct a new two-storey museum storage facility for the regional authority to house recently bequeathed artefacts.

Some artefacts have specific storage requirements to ensure their preservation and will be housed in controlled environment storage areas (CESAs).

The facility will not be open to the public but will allow access for research and be staffed with offices and welfare facilities.

The facility will be constructed on a brown field site on the site of a former gas works which was demolished and remediated in 1972 and has remained vacant ever since. (Site plan: Appendix 1)

As the contractor's Design Manager, I will prepare a report that describes and evaluates viable options and their preferred solution for the construction of the storage building superstructure including transmission of imposed loads to a suitable substructure. I will also describe and evaluate options for the building's environmental control systems strategy required to create an energy efficient controlled environment on the ground floor and general environmental control in other areas, as well as opportunities for the incorporation of pre-fabrication and off-site construction for the development.

2. **Preamble**

Outline drawings have been provided and the project is now at technical design stage

The project has a budget of £2 million, no additional funds are available.

Since the artefacts were bequeathed, they have been in temporary storage funded by the project.

A detailed borehole survey has confirmed the findings of the historical borehole information in Appendix 2.

It is unknown to what extent materials, services and contaminants from the demolished gas works remain in the ground.

For this report, 'superstructure' refers to the frame of the building only and 'substructure' refers to the foundations. 'Imposed load' is the load of the building itself on the substructure.

The project scenario states that the building is to be steel framed, but we have deemed it prudent to evaluate this alongside other options.

3. Part A

3.1 Superstructure

The outline section drawing indicates a frame structure comprising of beams and columns.

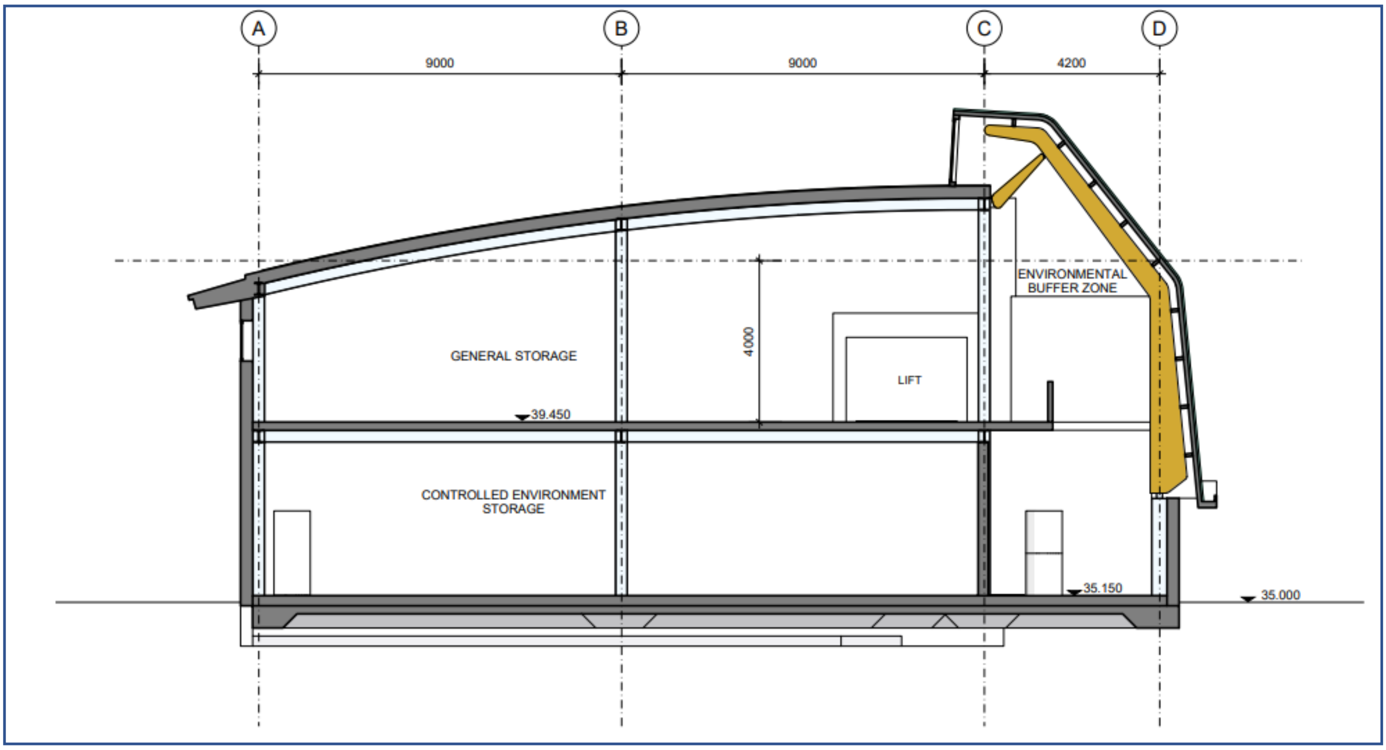


Figure 1: Section drawing

Viable material options for this design are steel, concrete and timber.

The structural designs of all potential options must comply with all parts of relevant safety codes outlined in Approved Document A (Structure) of Building Regulations 2010, which are summarised in the table below.

Frame Material	British Standard	Eurocode
Steel	BS EN 1993-1	2005 Eurocode 3: Design of Steel Structures
Concrete	BS EN 1994-1	2004 Eurocode 4: Design of Composite Steel and Concrete Structures
Timber	BS EN 1995-1	2005 Eurocode 5: Design of Timber Structures

3.1.1 Steel

Steel frame components are prefabricated off site and bolted and welded together on site. Figure 2 shows a frame similar to this design.

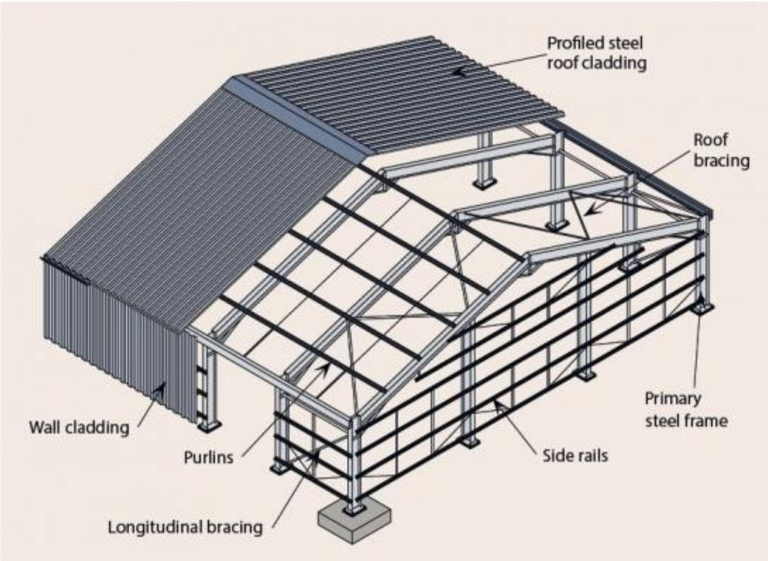


Figure 2: Steel frame

Steel frames are robust, durable, and relatively cheap which would be beneficial given the constrained project budget.

Steel offers programme efficiencies which would help this project’s time constraints. Assembly is simple so can be achieved quickly by semi-skilled operatives and can be done in most weather conditions, minimising delays.

Steel is adaptable, allowing for future layout revisions.

Steel is corrosive and is not inherently fire resistant. A tumescent protective coating can be pre-applied but will require maintenance.

Prefabrication requires the steel design to be completed prior to procurement, adding time into the programme.

Transportation of large steel columns may be complex and expensive.

3.1.2 Reinforced Concrete

Reinforced concrete is strong and completely non-combustible (an A1 fire-resistant material under EN 13501-1) It can either be poured on site or assembled using pre-cast components

Pouring is complicated by curing times as it is dependent on dry weather, potentially causing delays.

Pre-cast concrete components are easy to construct by semi-skilled operatives. Jointing is done on-site using embedded connectors or fresh concrete.

Figure 3: Pre-cast concrete frame

Transportation of pre-cast concrete is logistically difficult and expensive as components are larger and heavier than the steel equivalent.

As with prefabricated steel, there are programme implications to completing the design prior to procurement.

Concrete is generally more expensive than steel which would be a concern given budget constraints. Concrete is less adaptable than steel as the structure is difficult to modify.

3.1.3 Timber

Glued laminated (glulam) timber portal frames are fabricated off-site by specialist companies. Assembly is quick and easy and is often done by the supplier.

Figure 4: Glulam timber portal

Glulam has an excellent strength to weight ratio and is significantly more durable than steel or concrete.

Timber is sustainable and is lighter and easier to transport than steel or concrete.

As with prefabricated steel and concrete this frame requires upfront design.

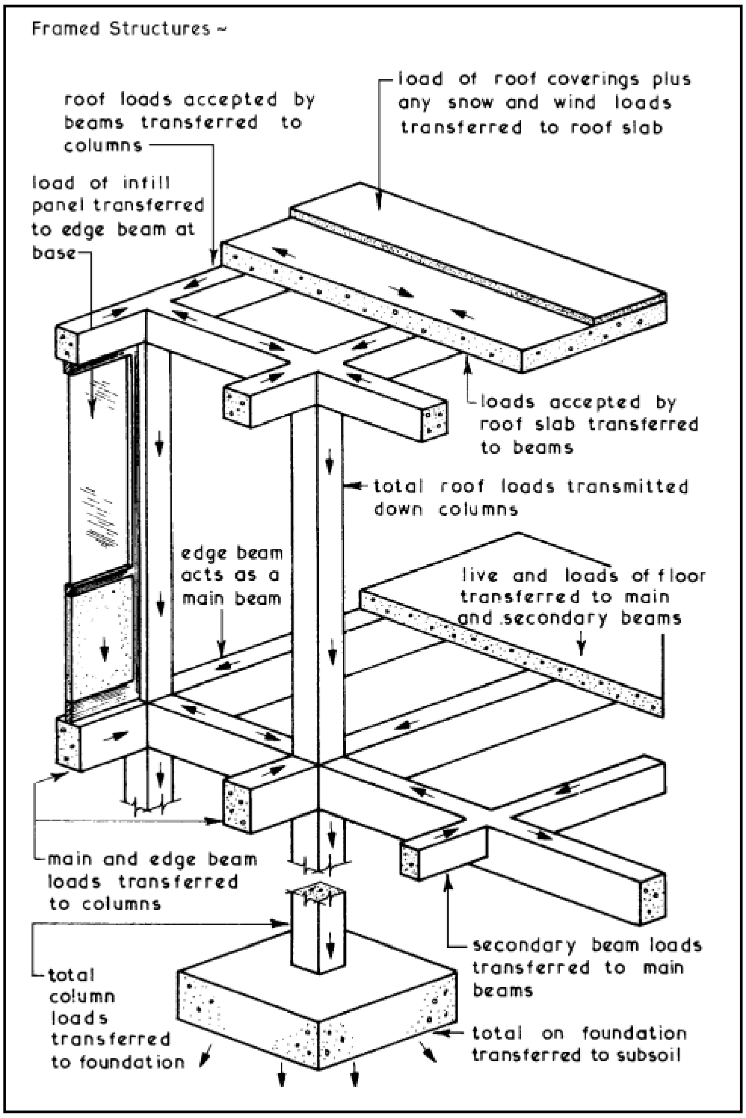
Timber frames are perceived to be susceptible to fire, however due to wood’s charring qualities, glulam frames are more fire resistant than steel.

Timber is susceptible to rot, and infestation and preservative treatment requires maintenance. This could also complicate the environmental requirements for some artefacts.

A pre-designed timber frame is much more expensive than steel or concrete which would be a concern given the project budget.

3.2 Imposed Loads and Substructure

The transmission of imposed loads from the superstructure to the substructure is summarised below.

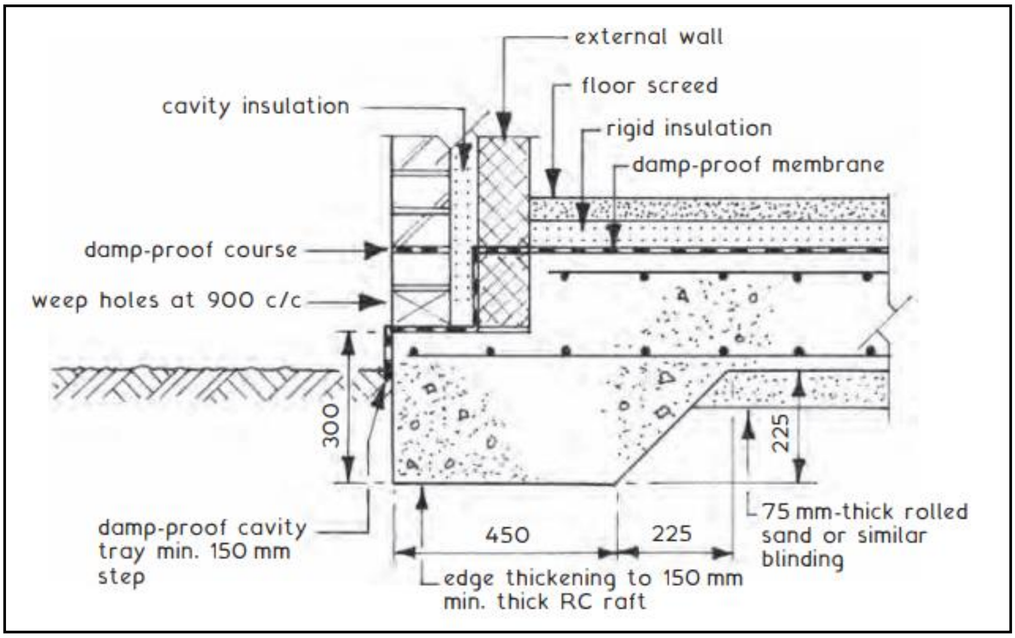


Ref 1.

The substructure must comply with the parameters for loading as set out in Approved Document A (Appendix 3)

No works below ground should commence until full ground site investigations and ground surveys to identify ground conditions and contaminations are complete, and any remedial works have been addressed.

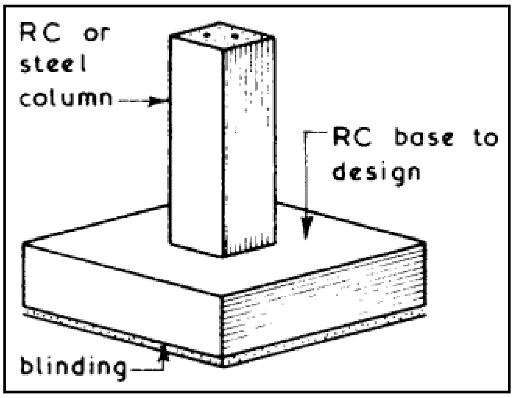
Steel is relatively lightweight, enabling simple and shallow foundations. The sectional drawing indicates a concrete floor forming a raft foundation similar to the below.



Ref 2.

Raft foundations are simple to construct and cost efficient, combining the foundation with the floor slab.

A simple pad foundation with loads directed down the main columns into pads and bolted in place would be similarly cheap and simple to construct.



Ref 3.

Soil conditions on site would support either option and neither would disturb the water table.

Concrete has a higher dead load than a comparable steel frame making a pad foundation unsuitable. A raft foundation may still be viable, but the additional load may require the foundation to be deeper, thus adding time and cost and potentially disturbing the water table necessitating groundwater exclusion.

Timber is lighter than steel or concrete so a raft or pad foundation would be suitable.

4. Part B

The facility's environmental control systems (ECS) strategy needs to provide general environmental control throughout the building and meet the specifications required for preservation of the artefacts in the CESAs, while also delivering energy efficiency and meeting the requirements stipulated in Approved Document L (Conservation of fuel and power) of The Building Regulations 2010.

4.1 HVAC

The facility’s HVAC system will control temperature, humidity, ventilation, and air filtration. HVAC will be provided by air handling units (AHU) connected to ductwork which supply air to and extract air from internal spaces.

The temperature in general areas of the facility must be a minimum of 16 degrees Celsius for staff comfort as per HSE guidelines.

The CESA temperature must be carefully controlled at 20-22 degrees Celsius. Any higher could cause aging and desiccation of organic items, while lower could cause blistering to paintings.

The optimum humidity level for the CESAs is between 45-55%RH with daily fluctuations controlled to —3%RH. Low humidity and fluctuations could cause flaking and blistering to the artefacts. Standard AHUs usually only regulate humidity within 10% RH so a specialist humidification system within the CESAs such as a steam humidifier or evaporative humidification system would be advisable.

Condair EL electric steam humidification

Figure 5: Steam humidifier

Condair ME evaporative humidification

Figure 6: Evaporative humidification system

Gaseous pollutants such as sulphur dioxide could cause damaging chemical reactions to the artefacts. Building materials including metals and woods can also cause reactions through volatile organic compounds (VOCs). As well as ensuring no damaging materials are used in the fabric of the CESAs, air in the CESAs must be sufficiently filtered to eliminate damaging particles. This could be achieved by a specialist air filtration system.

Figure 7: Air filtration system

HVAC energy consumption can be mitigated by implementing heat recovery ventilation (HRV) to recover and reuse air. Efficient heat exchangers can recover as much as ninety-eight percent of 'waste' heat, reducing energy consumption, carbon emissions and running costs.

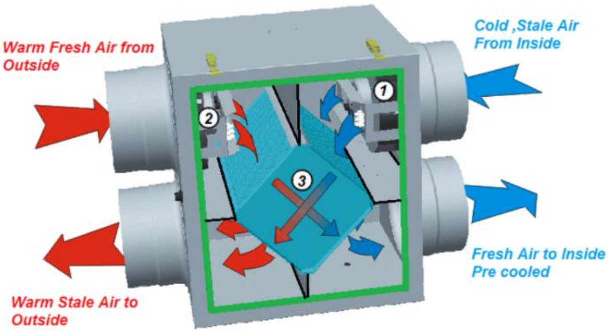


Figure 8: HRV heat exchanger

4.2 Building Fabric

The effectiveness and energy efficiency of the facility's ECS strategy is reliant on the building's thermal performance. All materials must meet the U-values stipulated in Approved Document L1(a) (see table in Appendix 4)

Some energy efficient options for consideration in the facility would include aluminium composite panel cladding and aerogel glazing.

Figure 9: Aluminium composite panel cladding *Figure 10: Aerogel glazing*

Build quality must ensure that the building is airtight and material performance is not compromised.

4.3 Lighting

Light, particularly ultraviolet (UV) radiation can cause fading of drawings and paintings. These items must be exposed to minimal light and stored inside closed units. The CESA lighting should be low level and sensor activated. Procedures should ensure limited access to these areas. There are no windows in the CESAs which will eliminate sunlight UV radiation.

LED lighting throughout the facility would ensure energy efficiency, providing approximately an eighty percent energy saving against traditional lighting. LEDs don’t include UV so would minimise light damage. LEDs last much longer than traditional lights so are cost efficient regarding replacement and maintenance.

4.4 Building Management System (BMS)

A further option is the installation of a BMS in the facility. This is a computer-based system used to monitor and control HVAC, lighting and other building services. It allows ease of control and collates data, creating alarms and alerts when when failures occur or are likely to. This would be extremely beneficial in monitoring the CESAs protecting the artefacts from any issues with the ECS. It also enables more targeted use of energy, reducing energy use, carbon emissions and running costs

5. Part C

As described above, beams for structural steel frames are prefabricated off site and this is the preferred option for the facility frame. Other options for prefabrication and OSM are considered below.

5.1 Pre-cast Concrete

Figure 11: Pre-cast concrete staircase

Pre-cast concrete products could be incorporated in the building structure including staircases and floors. They offer reduced assembly time on site as well as guaranteeing high quality due to factory production, however design specifications would need to be confirmed well in advance, potentially adding time into the programme.

The production process makes pre-cast concrete stairs more expensive than the alternatives. Due to the size, transportation may be complicated and expensive.

Pre-cast concrete floors would be suitable for a raft foundation and would offer the advantage of not requiring dry weather or curing time, as opposed to a poured concrete floor. Transportation would be less of an issue for the floor as it can be manufactured in smaller sections.

Figure 12: Pre-cast concrete floor

5.2 Prefabricated Pods

Prefabricated ‘pods’ for the offices and toilet/shower facilities on both floors of the facility could be considered.

Pods can be made to specification and come with services installed, ready to be positioned and connected on site. Bathroom pods are waterproof, and all pods can be made fire resistant to meet the building’s compartmentation strategy.

Figure 13: Prefabricated office pod

Figure 14: Prefabricated bathroom pod

Using pods can reduce on site labour and waste. All bathrooms can be installed simultaneously once the site is ready, saving time on the programme, however designs would need to be confirmed well in advance, and any changes would be costly.

5.3 Prefabricated MEP

Using BIM, mechanical, electrical, and plumbing (MEP) designs are co-ordinated to produce integrated service modules or risers, prefabricated plant modules can also be considered.

MEPs offer programme efficiencies, as work can begin before the site is ready for services. Prefabricated modules can be installed far more quickly and efficiently than multiple service engineers working simultaneously on site. The reduced scaffolding requirements also provides safety advantages. Constructing the service components in a controlled environment rather than on site ensures greater quality control and minimises snags.

Figure 15: Prefabricated integrated service ceiling module

MEP components can be cost effective in

bulk, however initial outlay on the design and manufacturing process may not be cost effective for a one-off project such as this one. Any changes require additional drawings which can slow the installation process down.

5. Conclusion

Having considered options for the facility's structure, I would recommend a steel superstructure with a concrete floor slab forming a raft foundation. Given the time and budget constraints of this project, this option offers the best balance of cost, programme, ease of construction and fire protection.

Regarding the facility's environmental control systems strategy, I would advise that incorporating HRV and a BMS would best drive energy efficiency while also supporting the building's complex requirements. I would also advise the inclusion of specialist humidification and air filtration systems into the CESAs. All lighting should be LED and building materials throughout should ensure the highest possible thermal performance of the building to maximise energy efficiency.

Regarding OSM, Prefabricated steel columns represent the best option for the frame of this building, and pre-cast concrete floor slabs represent the best option for the floor. Due to upfront design and manufacture costs other OSM elements such as the pods and MEPs could prove too costly so I would not recommend them for this project.

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Building Regulations 2010 Ventilation Approved Document F

Building Regulations 2010 Conservation of Fuel and Power Approved Document L

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Ref 1: Diagram adapted from Chudley, R & Greeno, R (2014) Building & Construction Handbook 10th Edition, Routledge, p16.

Ref 2: Diagram adapted from Chudley, R & Greeno, R (2014) p260

Ref 3: Diagram adapted from Chudley, R & Greeno, R (2014) p263

Ref 4: Table adapted from Approved Document A, p5

Ref 5: Table 4.1 adapted from Approved Document L, Volume 2, p25

Figure 1: Section drawing adapted from CIOB drawing pack

Figure 2: Photo from https://steelconstruction.info/Design#Portal_frames (12/06/23)

Figure 3: Photo from https://www.shaymurtagh.co.uk/precast-concrete-products/concrete-frame-buildings/ (12/06/23)

Figure 4: Photo from https://www.bucklandtimber.co.uk/blog/how-much-does-a-glulam-structure-cost/ (12/06/23)

Figures 5 & 6: Photos from https://www.condair.co.uk/m/0/museum-art-and-heritage-humidification-brochure-en-rt.pdf (13/06/23)

Figure 7: Photo from https://commercialairfiltration.co.uk/products/iqair-gcx-multigas (13/06/23)

Figure 8: Photo from https://www.acclaimedfurnace.com/blog/what-is-the-difference-between-an-hrv-and-an-erv/ (13/06/23)

Figure 9: Photo from https://constrofacilitator.com/aluminium-composite-panels-advantages-types-and-applications/ (13/06/23)

Figure 10: Photo from https://www.designingbuildings.co.uk/wiki/Aerogel_insulation_for_buildings (13/06/23)

Figure 11: Photo from https://floodprecast.co.uk/2020/02/advantages-of-using-precast-concrete-stairs/

Figure 12: Photo from https://www.mannokbuild.com/precast/hollowcore-flooring/(13/06/23)

Figure 13: Photo from https://www.portafab.com/modular-warehouse-offices.html (13/06/23)

Figure 14: Photo from https://www.base-4.com/how-bathroom-pods/ (13/06/23)

Figure 15: Photo from https://www.xscad.com/articles/mep-prefabrication-process-and-benefits/ (13/06/23)

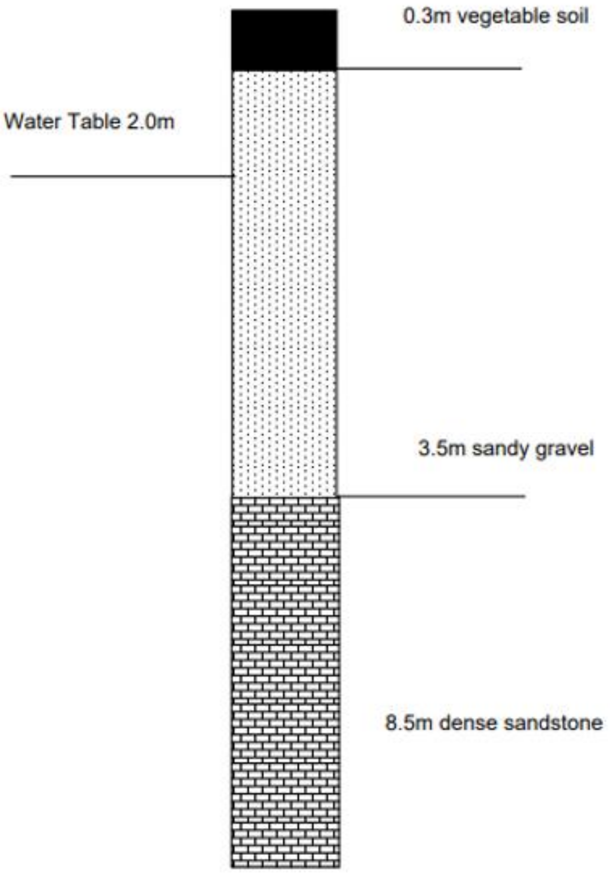
Fig 16: Site plan adapted from CIOB drawing pack

Figs 17 & 18: Historical borehole diagrams adapted from CIOB scenario

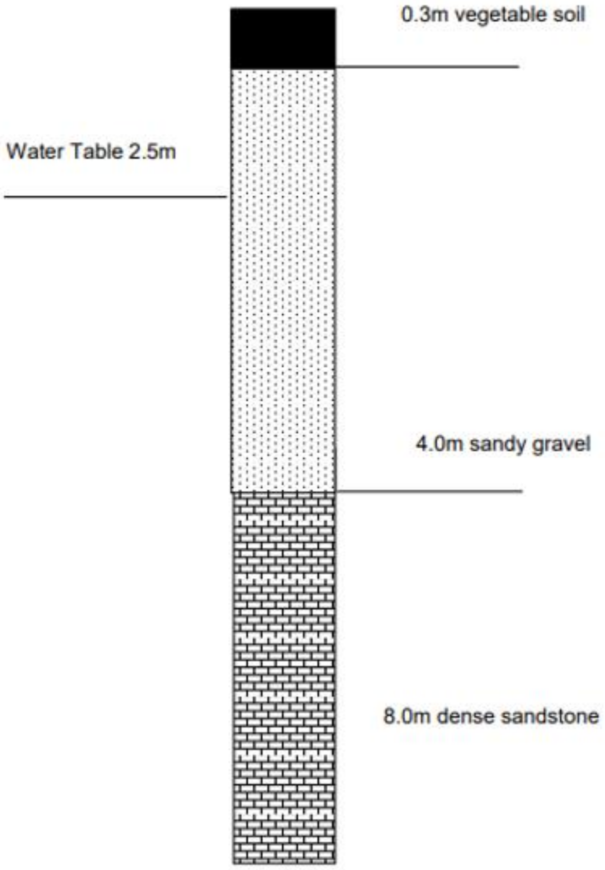
8. Appendices

8.1 Appendix 1: Figure 16 Site Plan

8.2 Appendix 2: Figures 17 & 18 Historical Borehole Records



Bore Hole Record No.1



Bore Hole Record No.2

8.3 Appendix 3: Ref 4

Requirement	*Limits on application*
Loading	
A1. (1) The building shall be constructed so that the combined dead, imposed and wind loads are sustained and transmitted by it to the ground:	
(a) safely; and	
(b) without causing such deflection or deformation of any part of the building, or such movement of the ground, as will impair the stability of any part of another building.	
(2) In assessing whether a building complies with sub-paragraph (1) regard shall be had to the imposed and wind loads to which it is likely to be subjected in the ordinary course of its use for the purpose for which it is intended.	

8.4 Appendix 4: Ref 5

Table 4.1 Limiting U-values for new or replacement elements in new and existing buildings and air permeability in new buildings

Element type	Maximum U-value[1] $W/(m^2 \cdot K)$ or air permeability
Roof (flat roof)[2]	0.18
Roof (pitched roof)[2]	0.16
Wall[2][3]	0.26
Floor[4][5]	0.18
Swimming pool basin[6]	0.25
Windows in buildings similar to dwellings[7][8]	1.6 or Window Energy Rating[9] Band B
All other windows,[8][10][11] roof windows, curtain walling	1.6
Rooflights[12][13]	2.2
Pedestrian doors (including glazed doors)[14]	1.6
Vehicle access and similar large doors	1.3
High-usage entrance doors	3.0
Roof ventilators (including smoke vents)	3.0
Air permeability (for new buildings)	$8.0m^3/(h \cdot m^2)$ @ 50Pa

NOTES:

1. Area-weighted average values, except for new windows, rooflights and doors in existing buildings.
2. For dormer windows, 'roof' includes the roof parts of the windows and 'wall' includes the wall parts (cheeks).
3. If meeting such a standard in an existing building would reduce by more than 5% the internal floor area of the room bounded by the wall, a lesser provision may be appropriate.
4. The U-value of the floor of an extension may be calculated using the exposed perimeter and floor area of either the whole enlarged building or the extension alone.
5. If meeting such a standard in an existing building, would create significant problems in relation to adjoining floor levels, a lesser provision may be appropriate.
6. The U-value of a swimming pool basin (walls and floor) calculated according to **BS EN ISO 13370**.
7. For example, student accommodation, care homes and similar uses where the occupancy levels and internal heat gains are essentially domestic in character.
8. If other performance (e.g. wind load, safety, security or acoustic attenuation) requires thicker glass to be used, an equivalent window unit with standard thickness glazing should be shown to meet the required standard.
9. The methods for calculating Window Energy Rating are set out in the Glass and Glazing Federation's Glazing Manual Data Sheet 2.3, Guide to the Calculation of Energy Ratings for Windows, Roof Windows and Doors.
10. No maximum U-value is set for display windows and similar glazing. There are no limits on the design of display windows and similar glazing, but for new buildings their impact must be taken into account in the calculation of primary energy and CO_2 emissions.
11. In buildings with high internal heat gains, the average U-value for windows can be relaxed from the values given above if this can be shown to be an appropriate way of reducing overall CO_2 emissions and primary energy. However, values should be no higher than $2.7W/(m^2 \cdot K)$.
12. U-values for rooflights or rooflight-and-kerb assemblies should be based on the developed surface area of the rooflight (U_d values), which is often greater than the area of the roof opening. Further guidance on U_d-values is given in the Building Research Establishment's BR 443 and the National Association of Rooflight Manufacturers' Technical Document NTD02.
13. The limiting value for rooflights also applies to kerbs that are supplied as part of a single rooflight-and-kerb assembly sourced from the same supplier and for which the supplier can provide a combined U_d-value for the assembly. An upstand built on site should have a maximum U-value of $0.35W/m^2 \cdot K$.
14. For external fire doorsets, as defined in Appendix A of Approved Document B, Volume 2, in new and existing non-domestic buildings, a maximum U-value of $1.8W/(m^2 \cdot K)$ is permissible.