Possible solution to past AM examination question

Question 2 - April 2012

Aircraft Maintenance Hanger

by Dr Peter Gardner

Question 2. Aircraft maintenance hangar

Client's requirements

1. A maintenance hangar is required by a regional airport to cater for large aircraft. See Figure Q2.
2. A clear column-free area of 40.0m by 40.0m is required, with additional space for a workshop and office. Clear headroom is required of 8.0m height over a 40.0m by 24.0m area, and 12.0m height over a 40.0m by 16.0m area next to the entrance doors in order to accommodate the aircraft tailfin. A services zone 1.0m high, including an allowance for overhead cranes, is also required above the clear headroom. See Figure Q2.
3. The hangar is to be clad in lightweight insulated metal panels and glazing.
4. The aircraft entrance to the hangar is to be 38.0m wide and 12.0m high, closed with two sliding doors. The weight of these doors is to be supported in a channel at ground level, and the doors are to be guided horizontally in an inverted channel at roof level.
5. Generous external space is available. The client would like an attractive and iconic structure within a reasonable budget.

Imposed loading

6. Roof — 2.5 kN/m²
   Overhead cranes attached to roof — Two point loads, each of 100kN, to be considered acting anywhere on the main roof elements.
   Ground floor — 20.0 kN/m²
   The roof and floor loadings include allowances for finishes, services including the overhead crane beams, and partitions.

Site conditions

7. The site for the hangar is level and open. The airport is served by main roads and a canal.
8. Basic wind speed is 40 m/s based on a 3 second gust; the equivalent mean hourly wind speed is 20 m/s.
9. Ground conditions:
   Ground level – 1.0 m — Topsoil
   1.0 m – 25.0 m — Sandy gravel with N increasing linearly with depth from 15 to 30.
   The highest recorded ground water level is 4.0 m below ground.

Omit from consideration

10. Design of the overhead crane beams, the stairs to the office and the hangar doors.

SECTION 1 (30 marks)

a. Prepare a design appraisal with appropriate sketches indicating a viable structural solution for the proposed scheme. Indicate clearly the functional framing, load transfer and stability aspects of the scheme. Justify the reasons for your solution. (20 marks)

b. After the roof has been made weather-tight and the doors have been installed there is a heavy snowstorm and the main doors jam because deflection of the roof causes the top channel to press on the doors. Explain to the client how this could be resolved, using sketches to illustrate your solution. (10 marks)

SECTION 2 (70 marks)

For the solution recommended in Section 1(a):

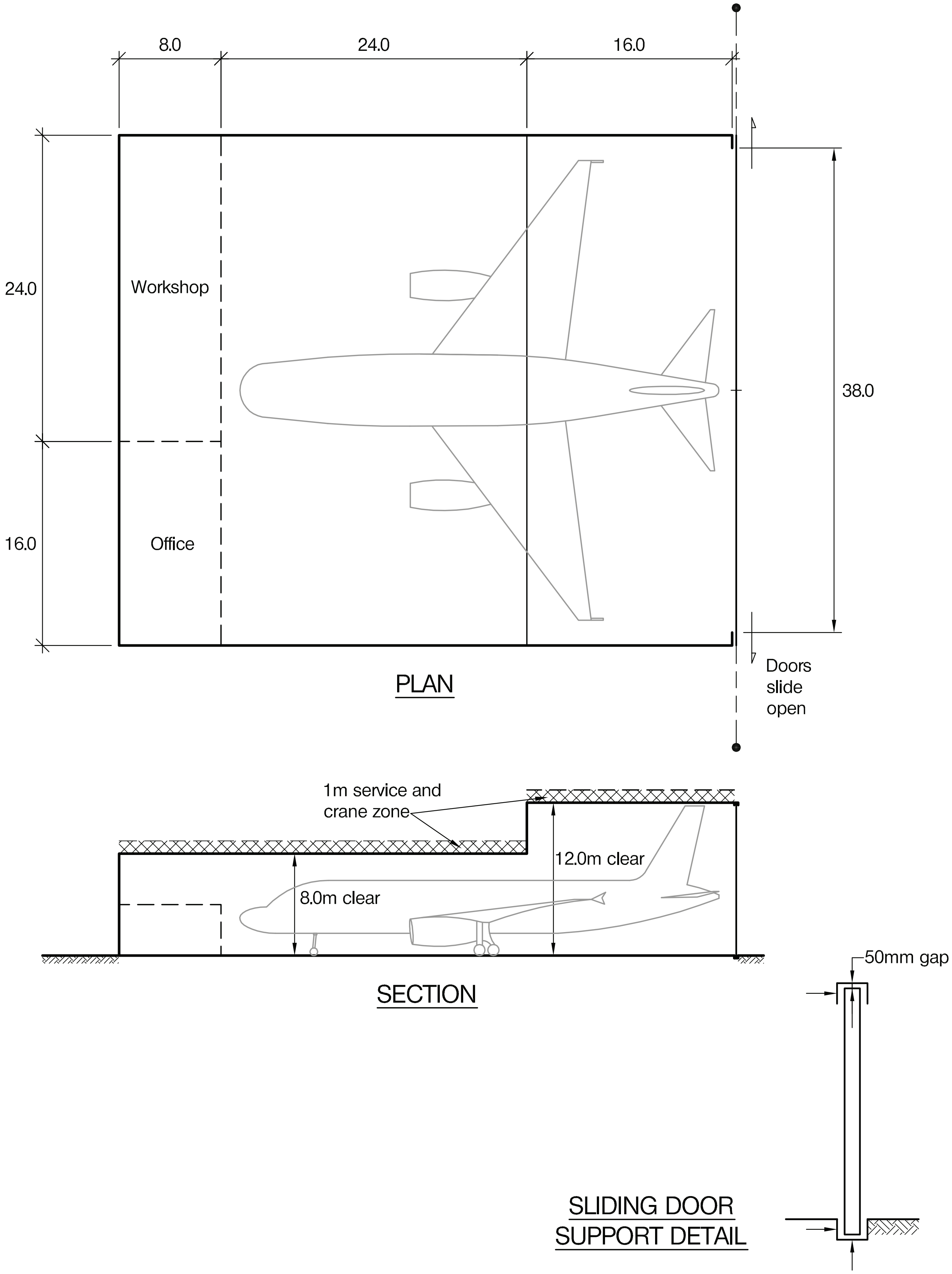
c. Prepare sufficient design calculations to establish the form and size of all principal structural elements including the cladding support structure and foundations. (30 marks)

d. Prepare general arrangement plans, sections and elevations to show the dimensions, layout and disposition of the structural elements for estimating purposes. Prepare clearly annotated sketches to illustrate details of:

   (i) The connection between a main column and primary roof structural element.

   (ii) A typical perimeter foundation, ground floor and main column connection at ground floor level. (30 marks)

e. Prepare an outline programme and method statement to minimise construction time. (10 marks)



NOTE: All dimensions are in metres except as noted

FIGURE Q2

Aircraft Maintenance Hangar

Introduction

This question relates to a maintenance hangar for a large aircraft. The geometry and layout is relatively straightforward but this is a large building with a 40m clear span. Although initially potentially daunting, the simplicity of the layout could well make this an attractive question.

The brief

- The requirement is for a large column-free building to be used as a maintenance hangar for aircraft. The overall internal dimensions are 40m x 48m. The proportion of the building that accommodates the aircraft is to be column free, and this section has two clear-height requirements: 8m over the majority of the building and 12m over the section that houses the tail. An additional space allowance in the roof of 1m is required to accommodate services and overhead cranes.

- There is no restriction on the structure outside the specified envelope.

- The client has indicated an attractive and iconic structure would be desirable subject to a "reasonable budget".

- The hangar is clad in lightweight insulated metal panels and glazing.

- A large door 38m long and 12m high consisting of two sliding panels is required. The weight of these doors is supported on runners at ground level.

- Two point loads each of 100kN need to be accommodated anywhere in the main roof (overhead cranes).

- The ground floor has an imposed load of 20kN/m^2.

- The ground consists of topsoil for the first metre and then sandy gravel with an N value increasing with depth. Groundwater is possible up to 4m below ground level.

Design appraisal

Clearly, with a 40m span roof, this is a large building. No columns are allowed within the 40m x 40m area that houses the aeroplane. Columns are presumably permissible in the remaining 8m of the building that houses the workshops and offices. It may be simpler to use the same roof structure over the whole building, however a slightly more efficient (and thus cheaper) structure could be provided if full-height columns were installed in the office and workshop area.

Although glazing is present there is no indication of large areas of glass. However, this is a long span roof which needs to carry a large point load at mid span, therefore significant structural members will be required.

The requirement for two 100kN point loads that can act anywhere on the roof elements, effectively means a 200kN point load must be carried at the centre point of the main roof trusses. This is slightly curious as cranes that can "pick-up" anywhere are usually supported on tracks that run along the length of a building, so although the load can be anywhere, it's transmitted back to the structure at the eaves level of the principal columns. However in this case we are specifically told the roof must support the load. This could be accounted for by fixed-position cranes, where the client needs the flexibility to locate them anywhere in the structure. Travelling cranes generate a significant lateral load, but if we are assuming these are fixed cranes, only nominal lateral load need to be taken into account. There will be a dynamic effect in relation to the vertical loads.

It should be apparent that the doors will create a dominant opening in terms of wind, and therefore various combinations of dead, imposed, crane and wind loads should be combined to establish maximum loads on all the principal members.

The weight of the doors is supported by the ground, with a 50mm gap in the top guiding channel to allow for deflection. It should be noted that the top of the doors will produce a significant horizontal load at roof level. The doors are 12m high, so the horizontal load is applied at the level of the clear vertical space, but depending on exactly how the service and cranes zone is formed, it is probable that the bottom of the roof members are at 13m. How this horizontal load is transmitted into the building structure therefore needs to be considered.

The doors are formed by two panels which when open would significantly project outside the building envelope. This would require a structure to support the top guiding rail and also to resist the horizontal load at 12m. The question specifically allows candidates to omit the design of the crane beams and the hangar doors, but it's left to interpretation whether the doors support structure needs to be included in your solution.

Stability can be provided by either traditional bracing; vertical cantilevers or portal frames depending on the exact structural arrangement that is chosen (see figures 1 and 2).

The ground consists of topsoil for the first metre which clearly cannot be used for any foundation or to support the ground floor slab. Below the topsoil is sandy gravel with improving capacity with increasing depth. Groundwater has been encountered at 4m. Because the capacity of the sandy gravel increases with depth, a judgement needs to be made regarding the level of any foundations (pads or piles) based on estimations of the ground bearing pressure. It would probably not be practical to construct pad foundations below 4m (combination of depth and groundwater).

The ground floor has to accommodate a high uniformly distributed load, which needs to be specifically designed for, probably with piles into the sandy gravel. There is also the possibility of very high point loads from the aircraft wheels and also by the loads from the crane being lowered onto the ground, but because the question specifically gives a uniformly distributed ground floor load it would be unreasonable to expect you to design for additional [unspecified] point loads.

Design options and proposal

Main frame

Although the building has to provide a clear span of 40m, there is no restriction on construction depths outside the space required to accommodate the aircraft. It should therefore be apparent that there are a number of options available to provide a steel framed building structure. The crane load provides a large central point load which will have a significant impact on the type of structure selected.

The main structure could be formed with simply supported roof trusses spanning 40m, a 40m x 48m space frame, lattice portal frames or a cable stayed roof. A simply supported roof truss would not be the most elegant solution, nor would it be particularly "attractive and iconic", but it would be by far the easiest to design (especially under exam conditions). For this reason it is probably the best scheme to actually propose, but all the other options can be discussed in the design appraisal (see figure 1).

Stability

Although the building is large there are no restrictions in three elevations to inhibit the provision of bracing to stabilise the building, although there is limited space in the door elevation. Assuming simply supported roof trusses have been proposed, traditional diagonal bracing could be used in three sides and the roof. By utilising the 1m strip available on either side of the door in addition to the construction depth, bracing can also be provided in the door elevation (if necessary the additional external door support mechanism will could be used to stabilise the door elevation). The stability system should be adapted if one of the other principal roof forms has been proposed.

Foundations

The post practical option is probably piles taken to an appropriate depth in the sandy gravel, to support the columns and the ground floor slab (and the door track).

Section 1b

The scenario presented is that after the roof has been constructed there is a heavy snowstorm and the main doors have jammed because the roof has deflected which has caused the top channel to bind on the doors. You are asked to explain how this issue could be resolved.

The first thing that strikes me is that this should not have happened, as the designer should have anticipated that the roof over the door would deflect. The initial detail allows for a 50mm gap between the door guiding channel and the top of the door to allow for exactly this situation. This is going to be an embarrassing and costly problem.

The starting point should be some serious investigation to establish why this problem has arisen. There seems to be three possibilities: the building has deflected more than 50mm, the gap of 50mm was not provided as designed or the snowstorm was heavier than could reasonably have been anticipated in this area (or was allowed for in the design!).

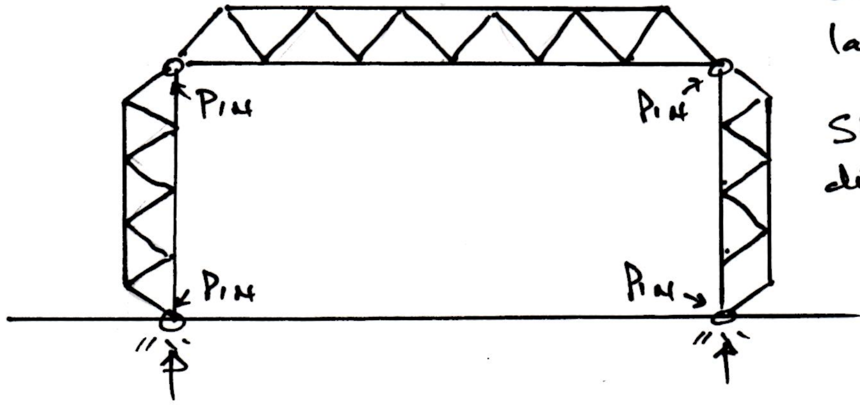
The outcome of this investigation would then establish what needs to be done to prevent a recurrence. As the building has been constructed, and any remedial work is likely to be significant in nature, this is going to have a big impact in terms of disruption and will undoubtedly cost a lot to correct. The first and third causes are design issues but the second is a construction problem.

It would also be important to establish if the cranes were in use at the time the doors jammed, as this would either provide a relatively simple solution (ie ensure there is not crane use, when there is snow on the roof and when the doors need to operate), but conversely, if the cranes were not operating when the doors jammed, their concurrent use would make this problem even worse!

There are various options, each of which results in disruption and significant additional cost. The most practical of which is to provide additional support for the beam over the doors in the form of diagonal "knee braces". This would keep the critical floor heights for the tail and the wings but would significantly stiffen the door beam and thus reduce deflection. Although this is a horrendous scenario if it occurred in real life, in this case it provides lots to discuss and could result in a very full answer (but care would need to be taken not to spend too long on a relatively small proportion of the available marks).

Summary

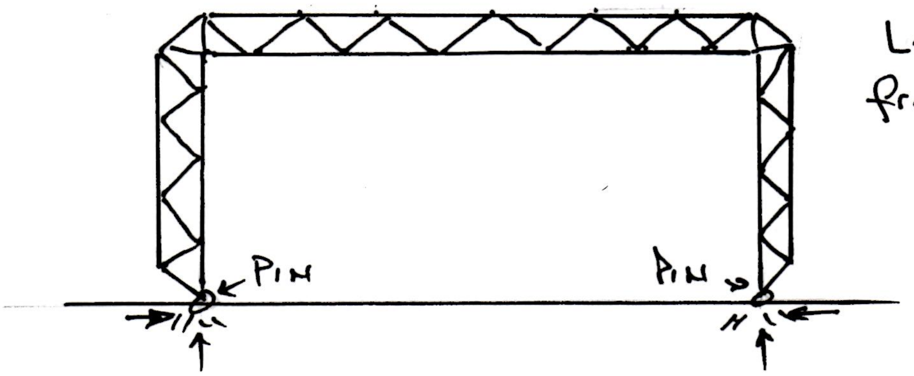
This is a large building but with relatively simple geometry and no particularly problematic elements in the brief. A relatively straightforward design solution can be proposed consisting of simply supported trusses and traditional diagonal bracing. As long as the implications of the large door, the point loads on the roof and the high uniformly distributed load on the ground floor are taken into account it should be possible to provide a complete solution in the allocated time.



Simply supported lattice trusses.

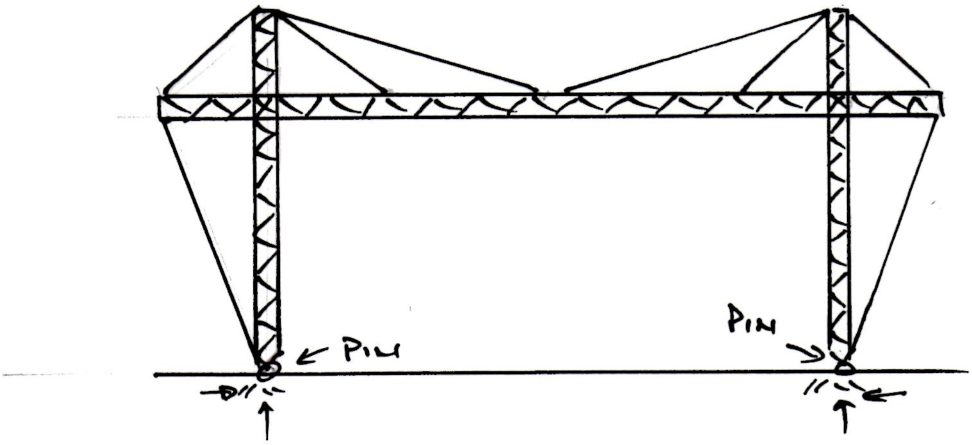
Stability via diagonal bracing

OPTION 1



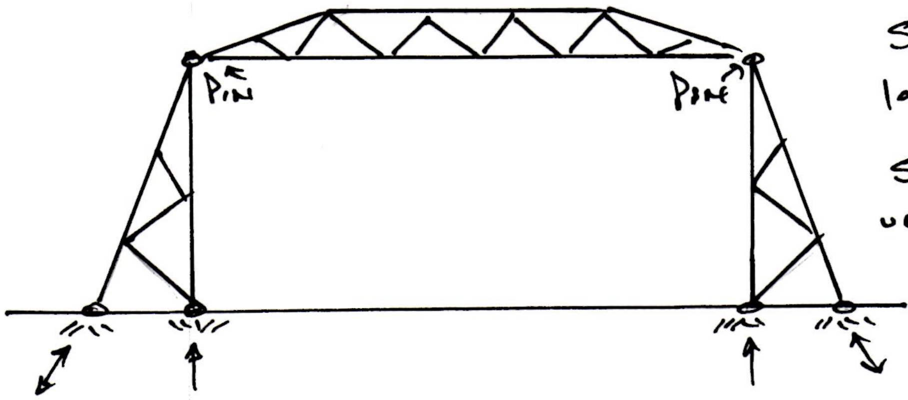
Lattice portal frame.

OPTION 2



Cable stayed lattice frame

OPTION 3



Simply supported lattice truss

Stability via vertical cantilevers

OPTION 4.

FIGURE Q2-1

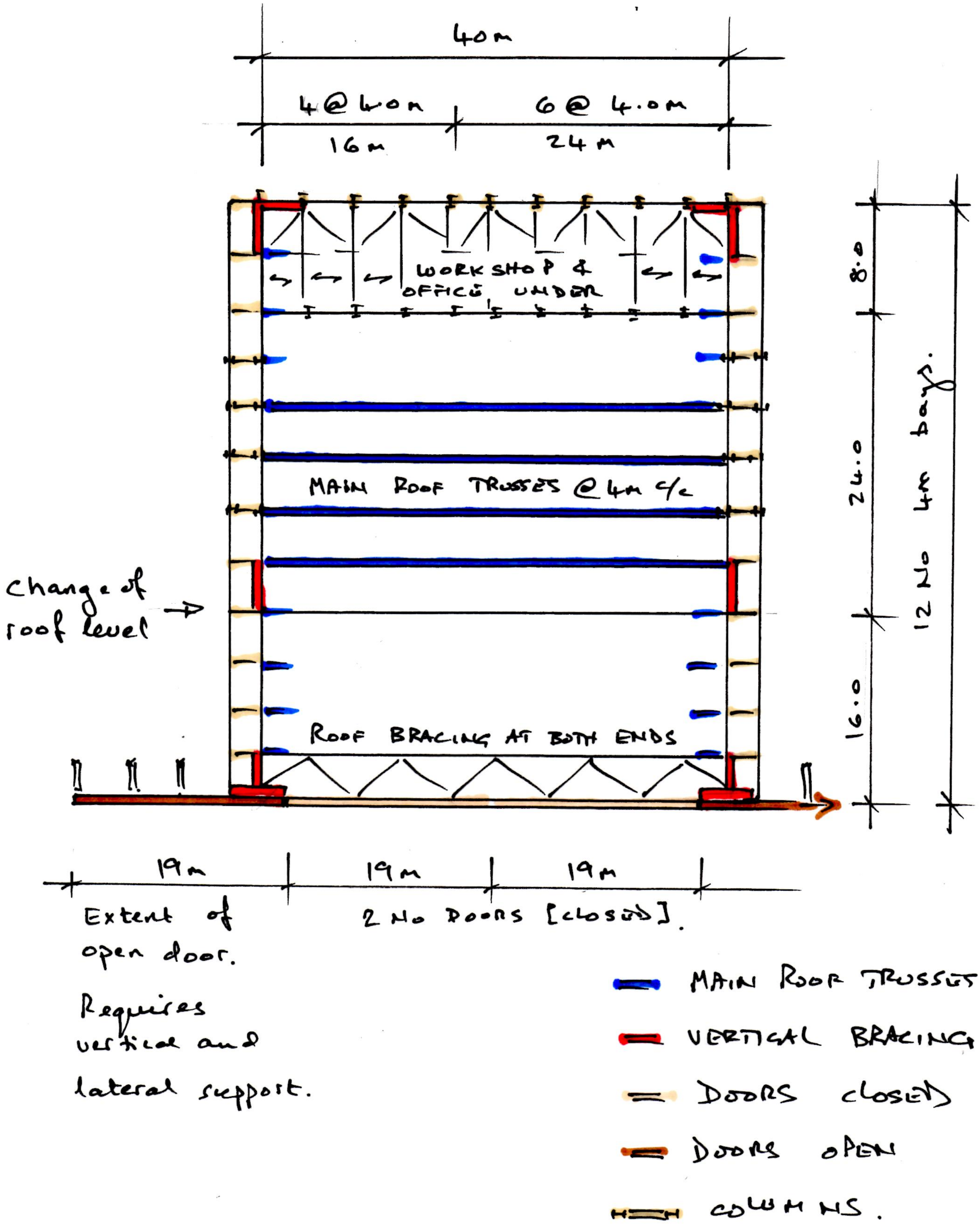

40m
4 @ 4.0m
16m
6 @ 4.0m
24m
WORKSHOP & OFFICE UNDER
MAIN ROOF TRUSSES @ 4m c/c
Change of roof level
ROOF BRACING AT BOTH ENDS
8.0
24.0
16.0
12 No 4m bays.
19m
19m
19m
Extent of open door.
2 No DOORS [CLOSED].
Requires vertical and lateral support.
MAIN ROOF TRUSSES
VERTICAL BRACING
DOORS CLOSED
DOORS OPEN
COLUMNS.

FIGURE Q2 - 2