Possible solution to past AM examination question

# Question 1 - April 2014

## School building

by Dr Peter Gardner

The information provided should be seen as an interpretation of the brief and a possible solution to a past question offered by an experienced engineer with knowledge of the examiners' expectations (i.e. it's an individual's interpretation of the brief leading to one of a number of possible solutions rather than the definitive "correct" or "model" answer).

# Question 1. School building

## Client's requirements

1. A two storey school building is required for a new town. See Figure Q1.
2. The school building is to provide 24 classrooms located on two levels, equally divided either side of a hall and administration facilities. The classrooms are to be accessed from a central corridor at each level.
3. Columns are only permitted around the perimeter of the building and on the wall lines of the central corridor.
4. The internal clear floor height to all areas, except the hall, is to be 2.8m with a 200mm clear service zone under the structure.
5. An external enclosed staircase is required at each end of the central corridor.
6. The building is to be clad in a flat composite cladding system and the roof is clad with composite profile sheeting.

## Imposed loading

7. Roof 0.75kN/m$^2$
   Floors 3.00kN/m$^2$
   Imposed loading includes allowances for finishes, services and partitions.

## Site conditions

8. The site is level and located on the outskirts of the new town.
9. Basic wind speed is 40.0m/s based on a 3-second gust; the equivalent mean hourly wind speed is 20.0m/s.
10. Ground conditions:

| | |
|---|---|
| Ground – 1.0m | Top soil and fill |
| 1.0m – 2.0m | Soft clay, C = 10kN/m$^2$ |
| 2.0m – 6.0m | Stiff clay, C = 100kN/m$^2$ |

No ground water was encountered.

## Omit from consideration

11. Detailed design of the external staircases as they do not contribute to the overall stability.

## 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 the solution. (20 marks)

b. After completion of the design and before construction, the client asks whether theatre lighting and possible scenery could be hung from the hall roof increasing the general imposed loading on the roof to 2.0kN/m$^2$. Explain how this could be achieved using sketches as necessary to illustrate your solution. (10 marks)

## SECTION 2 (70 marks)

For the solution recommended in Section 1(a):

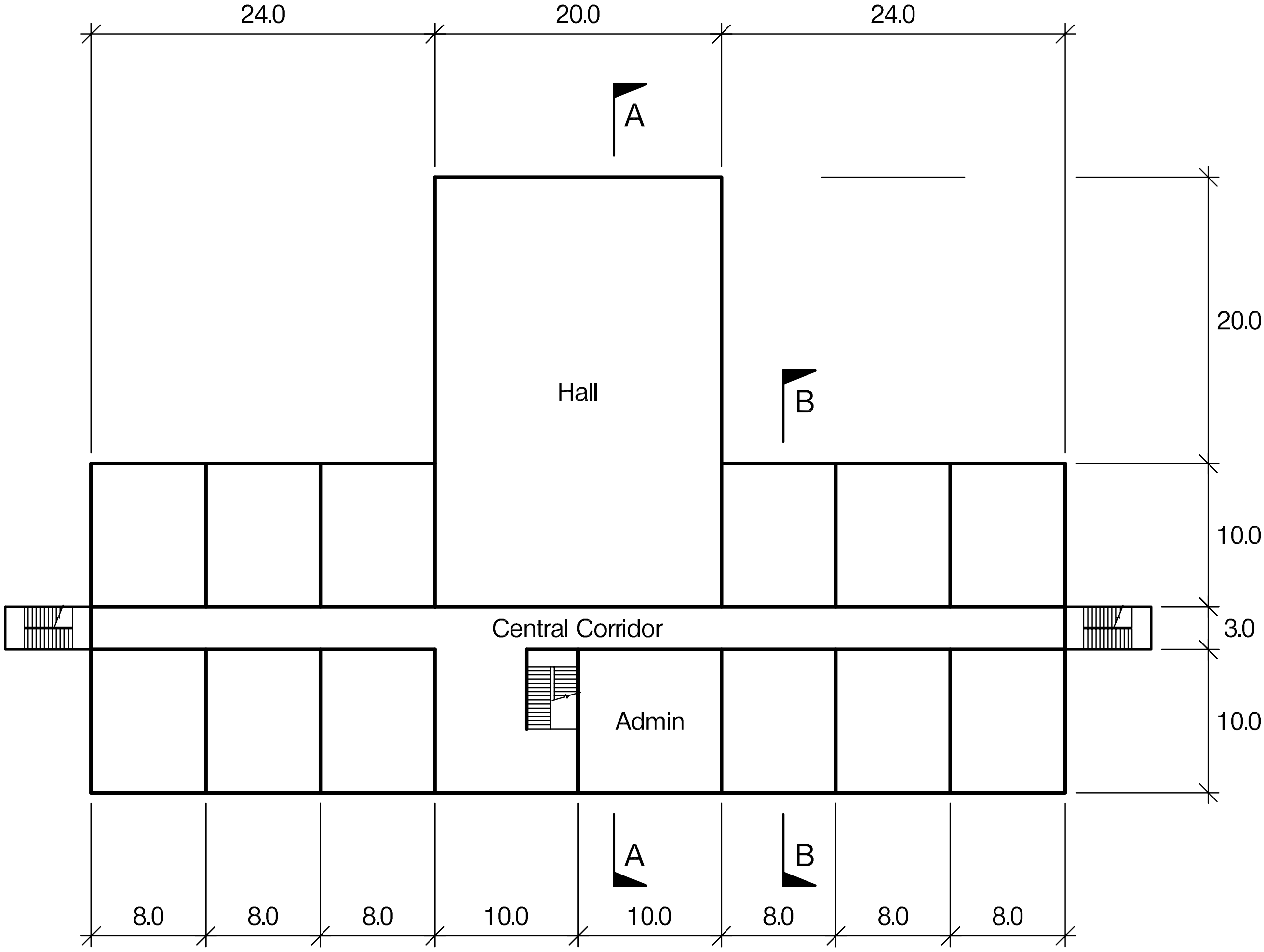
c. Prepare sufficient design calculations to establish the form and size of the principal structural elements including the foundations. (30 marks)

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 roof at eaves level.

   (ii) A perimeter column at ground floor level. (30 marks)

e. Prepare a detailed method statement for the safe construction of the building. (10 marks)

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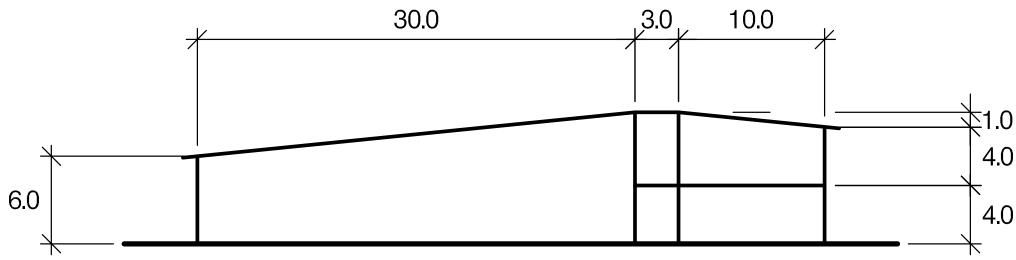
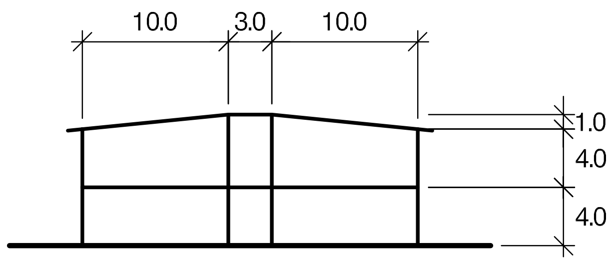



SECTION A - A




SECTION B - B

NOTE: All dimensions are in metres

FIGURE Q1

## School Building

This question relates to a two-storey school building containing twenty-four classrooms, a hall and associated admin and distribution areas. The question is relatively straightforward with a few issues that need consideration but it doesn't contain anything of any particular complexity.

Summary of the brief

- Symmetrical school building providing 24 classrooms on two levels, either side of a hall.
- Columns are only permitted around the perimeter of the building and on the wall lines of the central corridor.
- The internal clear floor height to all areas except the hall is 2.8m with a 200mm clear service zone under the floor structure.
- An external enclosed staircase is provided at each end of the central corridor.
- The building is clad in flat composite cladding and the roof is clad with composite profile sheeting.
- The site is level and located on the outskirts of a new town. The wind speed is commensurate with this location.
- The ground profile consists of one metre of topsoil and fill, a further metre of soft clay both on top of four metres of stiff clay. No groundwater is encountered and there is no mention of the soil below 6m.

Appraisal of the issues

Columns are only permitted around the perimeter of the building and on the wall lines of the central corridor. There is the option to provide one or two rows of columns along the central corridor.

The hall roof needs slightly more consideration. The roof is mono-pitch and beams can span either north-south or east-west. East-west seems the most logical direction for the roof beams as they only need to span 20m, the only complicating factor is the supporting elements in line with the classrooms, as columns cannot be positioned to provide direct support to the roof beams (see restriction on column positions). A beam spanning 10m to pick up roof beams (see figure 1) seems the most logical arrangement. Spanning the roof beams north-south has the advantage that they can rest on columns positioned along the central corridor but has the disadvantage that they span 30m instead of 20m (see figure 2). Either way, steel lattice beams would be appropriate (portal frames wouldn't provide any particular advantage over trusses).

There is no restriction on using the external elevations for stability but the brief suggests that the external staircases should not contribute to the stability system (see brief, point 11). Therefore vertical and horizontal bracing could be used to stabilise the whole building. Particular attention must be given to the stability of the hall. Moment frames would be unnecessarily complex and offer no advantage (as they are more flexible than a braced solution).

As stiff clay exists at two metres, pads at this level are the most logical foundation solution. Piles would be an alternative but offer no particular advantage because the stiff clay is only two metres below the surface. As there is one metre of topsoil and fill, and a further metre of soft clay, an engineered suspended ground floor slab should be proposed (this would be more cost effective than improving the soil just to support the floor slab).

<u>Proposed scheme</u>

Steel or concrete could be used for this building but I've selected a steel frame with a concrete first-floor. It should be a straightforward matter to frame-up the main structure with columns positioned on the corners of the classrooms and around the hall perimeter to support the hall roof beams. See figures 1 and 2 for the plan layout.

The storey height is 4m (from diagram in the question) and the clear internal height is 2.8m, with 200mm required as a service zone. This leaves 1.0m for the structure, which based on a simple span depth ratio should demonstrate there is adequate room for floor beams spanning 10m or 13m, however this will ultimately be confirmed by your calculations.

The decision regarding using one or two lines of columns comes down to a balance between shorter spans and two lines of columns compared with one line of columns but longer floor beams. Despite the adequate structural zone my judgement is that two rows of columns and beams spanning 10m would offer the most appropriate solution.

The floors could be constructed using a variety of different approaches but composite beams or precast floor planks supported on steel beams would be appropriate. The disadvantage of composite construction, from an examination point of view, is that once selected they must be designed as one of the principal elements.

The hall roof would be constructed of 20m span lattice girders spaced at 5m centres supported on universal columns. As transfer beam spanning 10m would be required to support the roof truss adjacent to the classrooms (see figure 1).

Stability would be provided by vertical bracing around the perimeter with the concrete first-floor acting as a diaphragm to transfer lateral loads to the bracing. Horizontal bracing in the roof provides the same load transfer at the upper level. See figure 1 & 2 for suggested locations.

The foundations could be pads on the clay at 2m although piles would be an alternative. The ground floor slab should not be supported by the topsoil and fill. There are a variety of options but I've selected a suspended ground floor slab with the option of intermediate support.

Section 1b

The scenario presented in section 1b relates to the client asking whether theatre lighting and scenery could be hung from the school roof which significantly increases the imposed load. The design has been completed but construction has not started. Clearly the most obvious consideration is the increased loading on the roof, and the associated columns and foundations, requiring a redesign of all these elements.

However discussion should also be offered relating to the fixing points for the lighting and scenery and it's important to include the implications of how the loads are distributed. If the client requires flexibility in positioning the lighting and/or scenery, secondary structural elements would be needed. The lighting and scenery will also impose significant point loads that need to be taken into account in the design. It is also possible that the lighting and scenery would affect clearance in the hall. All these issues can be discussed as part of your answer to this section.

Summary

This is a relatively straightforward question but it's important that the issues mentioned above are adequately dealt with in your proposal. Particular attention should be given to the size and layout of the hall roof, overall stability (and particularly in relation to the hall structure), and the issues surrounding the ground floor slab potentially resting on poor soil.

If the proposed structural arrangement is clearly set-out and all of the issues are adequately addressed, with reasons given for each of the design decisions, it should be possible to achieve a good pass mark.

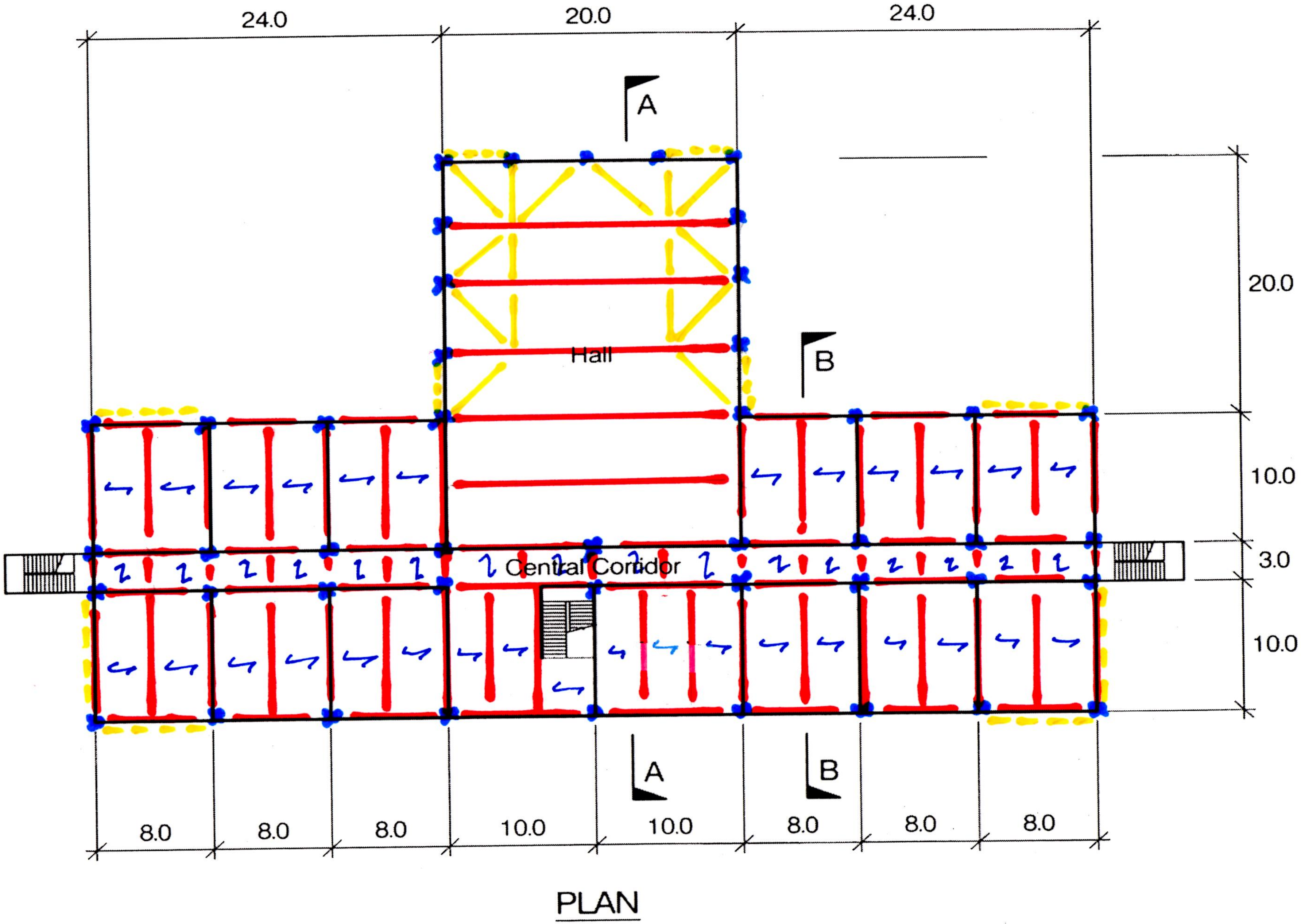



Figure 1. First floor plan and option one for the hall roof.

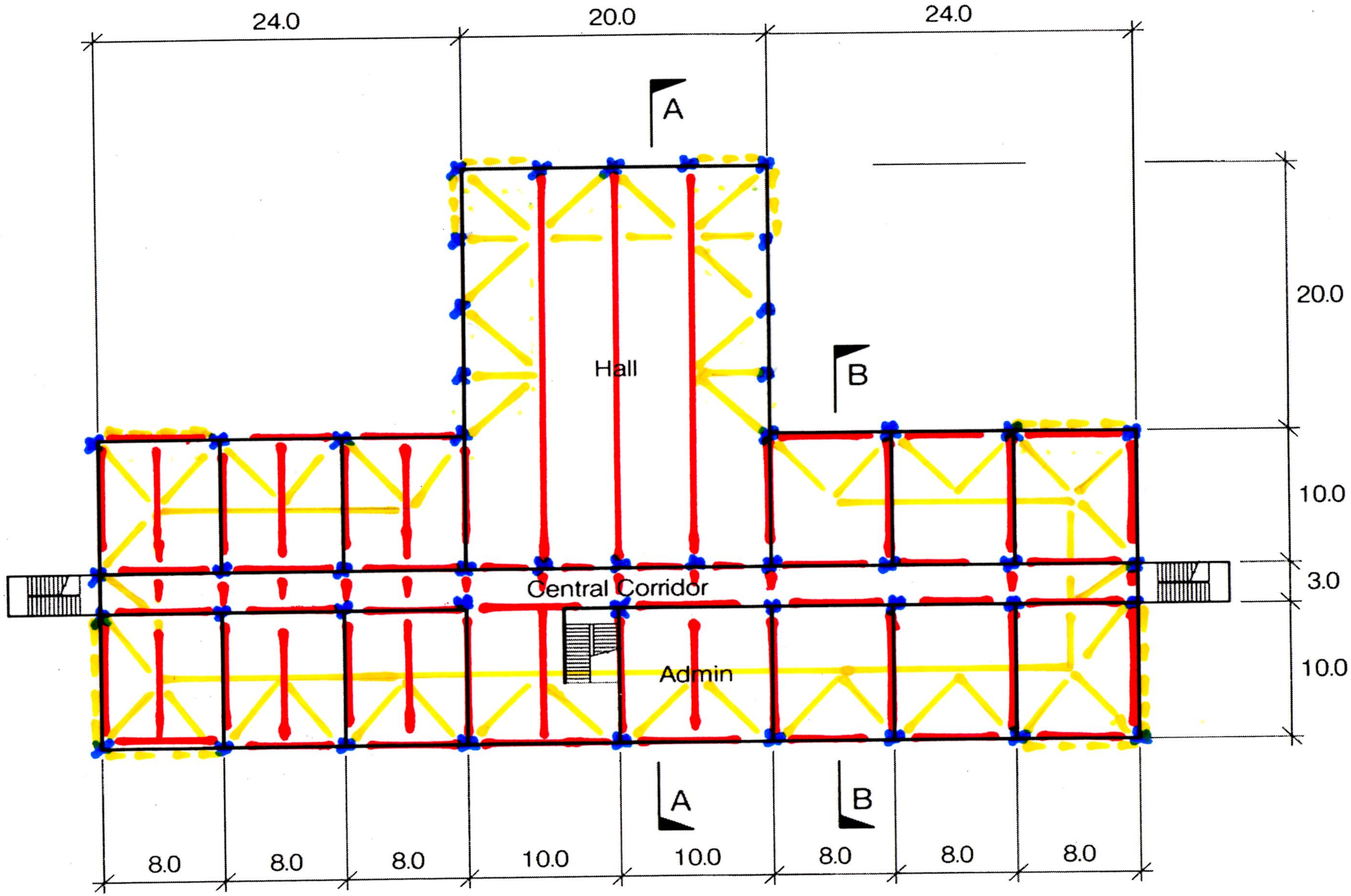



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Figure 2. Roof plan and option two for the hall roof.