THE ARCHITECTURAL DESIGN OF THE ARMENIAN GENERAL BENEVOLENT UNION SECONDARY SCHOOL IN BEIRUT WITH STRUCTURAL DESIGN OF THE AUDITORIUM

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THE ARCHITECTURAL DESIGN OF THE ARMENIAN GENERAL BENEVOLENT UNION SECONDARY SCHOOL IN BEIRUT WITH STRUCTURAL DESIGN OF THE AUDITORIUM

by

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P R E F A C E

The idea of having a modern secondary school for the Armenian community of Beirut was not a novelty, but due to lack of funds the actual carrying out of such an idea was posponed for many years.

A donation of an important sum was made for this purpose in 1949. Immediately thereafter, a committee was set up to find a lot for the school, and to draw up the specifications.

The committee fulfilled its obligations by purchasing a lot of land near the Grand Serail, beside the Armenian Church, and drawing up the specifications for the school.

This presentation is an attempt to meet the specifications and design the school after a thorough study of the problem.

Particular attention is given to the orientation and ventilation problems, which constitute two vital elements for buildings in Beirut, and as our engineering science progresses, the importance of such studies is being further realized.

S P E C I F I C A T I O N S

The School shall be composed of:-

1. Twelve classrooms
2. An auditorium for 800 people
3. One assembly hall for 300 students
4. One library
5. Physics and chemistry laboratories
6. A drawing room
7. A Gymnasium
8. Principal's room
9. Secretary
10. Guest or waiting room
11. A room for teacher-in-charge
12. Teachers' room
13. Music room
14. One dining hall
15. Stores
16. Gate-man's room
17. A shade
18. Toilet room
19. Two playgrounds.

I. SITE

Since the lot of land has already been purchased, no criteria for an ideal school-site shall be enumerated, yet the following comment seems to be necessary. The plan of the lot and a free hand perspective of it and its surroundings are sketched below to give a clearer picture, and to serve as a reference for the statements made hereafter.

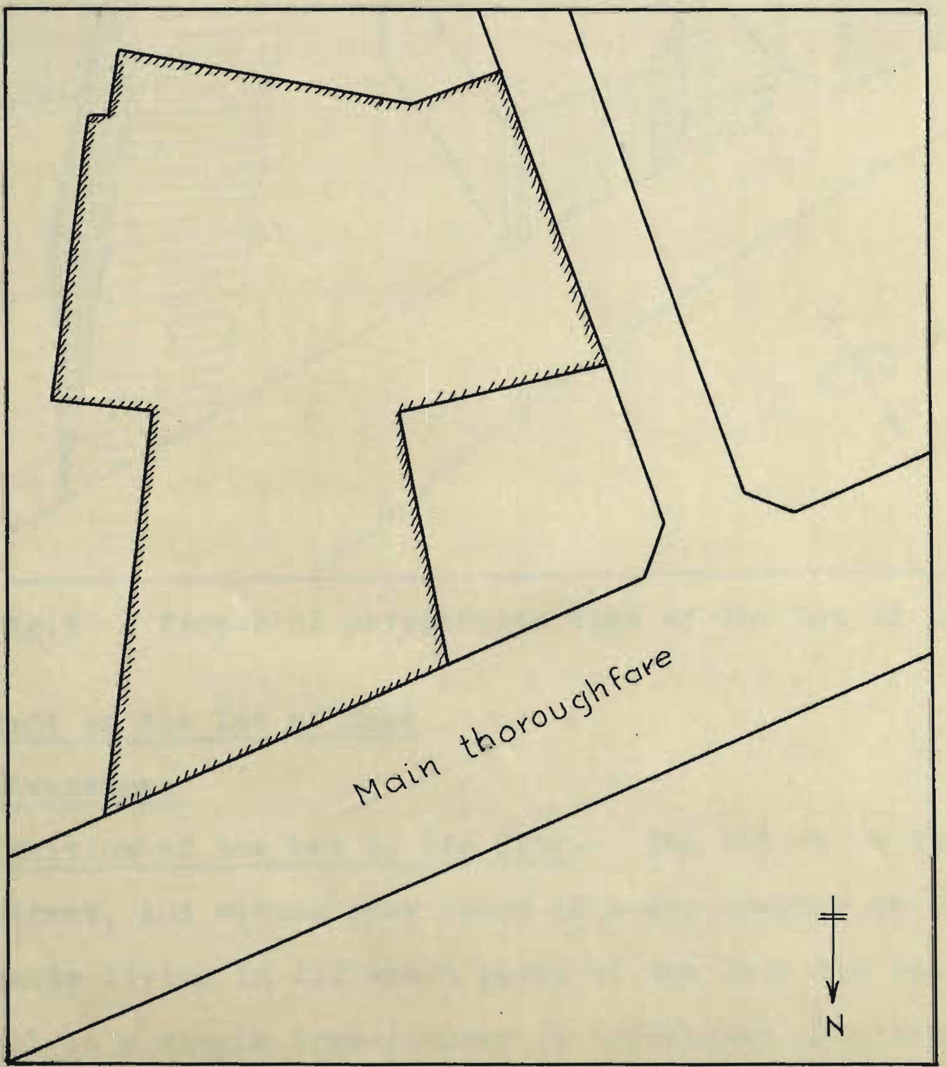


Fig. 1. Plan of the Plot

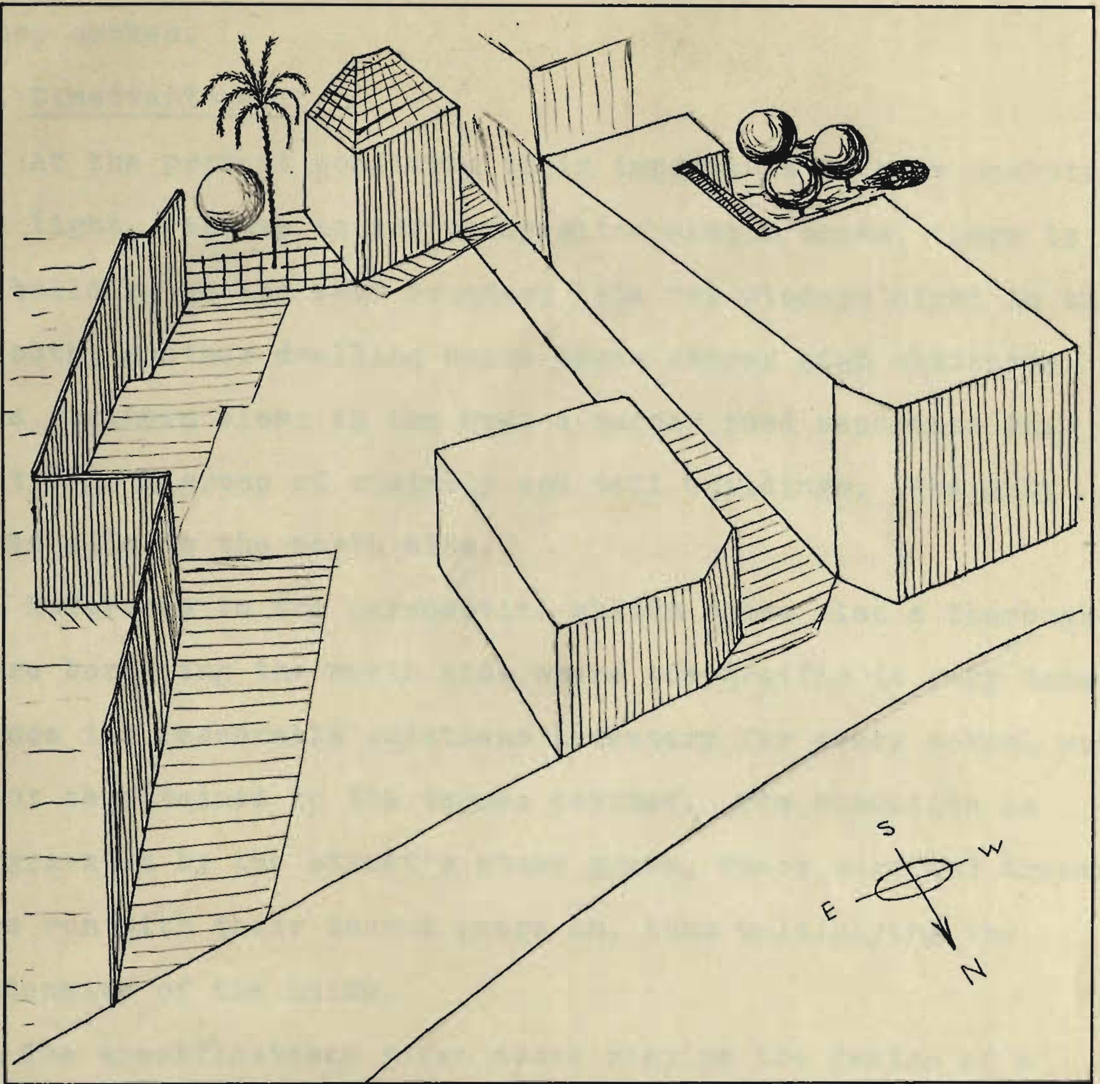


Fig.2 A free-hand perspective view of the lot of land

Comment on the lot of Land

A. Advantages

1. Position of the Lot in the City.- The lot is in the center of Beirut, and within easy reach to every quarter of it. Students living in different parts of the city can reach the school in a single tram-journey (a tremendous advantage), and always in less than half-an-hour's time.

2. It is at an elevated position, free from factory or work-

shop smokes.

B. Disadvantages:

1. At the present condition it is impossible to have unobstructed light, because as the perspective sketch shows, there is a building on the east boundary line two storeys high; in the south, another dwelling house three storey high obstructs the southern view; in the west a narrow road seperates the lot from a group of unsighty and tall buildings. The only free side is the north side.

2. Reference to the perspective sketch shows also a thoroughfare bordering the north side where the traffic is very dense, hence the reasonable quietness necessary for every school cannot be attained to the degree desired. The situation is aggravated by the street's steep grade, where cars and trucks are run with their second gears on, thus multiplying the intensity of the noise.

3. The specifications given above require the design of a school for 300 to 350 students, together with an auditorium for 750 to 800 people. But even the total area of the lot fails short of the minimum requirements for playgrounds needed for such a school.

4. Because of the obstruction on the south-western side the natural ventilation of the school shall suffer a great deal.

5. The boundary lines of the lot are extremely irregular.

The above disadvantages are very serious and should be remedied in some way or another. The following considerations intend to get around the difficulty, but never attain ideal conditions.

II. GENERAL CONSIDERATIONS FOR AN APPROXIMATE LAY-OUT

1. Position of the building in the lot of land for minimum noise. It is of utmost importance that the building be as far away from the main thoroughfare as possible, to have minimum noise originating at the street. Fig. 3 on page 5 indicates the place where the building should approximately be located to satisfy this condition. Furthermore, this arrangement will have the advantage of avoiding the serious danger of discharging the children directly into the busy thoroughfare.

2. Position of building in the lot for maximum light. To have maximum of light the building should be as far away from the south and the east borders as possible. Fig. 4 on page 5, shows the area of the land which meets the first and second conditions as much as it is practicable.

3. Shape of the building. The above two considerations make it necessary to give a rectangular shape to the building (school proper) instead of the more commonly used shapes, such as U, L, or H. The addition of the auditorium, far larger than that required for the school, will make the shape of the whole a rather T-shape structure.

4. Number of storeys. The specifications require too much on a too little lot. A rough estimate shows that a minimum of three storeys are necessary to meet the requirements.

5. Orientation of the building for light and ventilation. This problem deserves a much more careful study than it is generally recognized in this part of the world.

Generally speaking, for ordinary type of building, whether

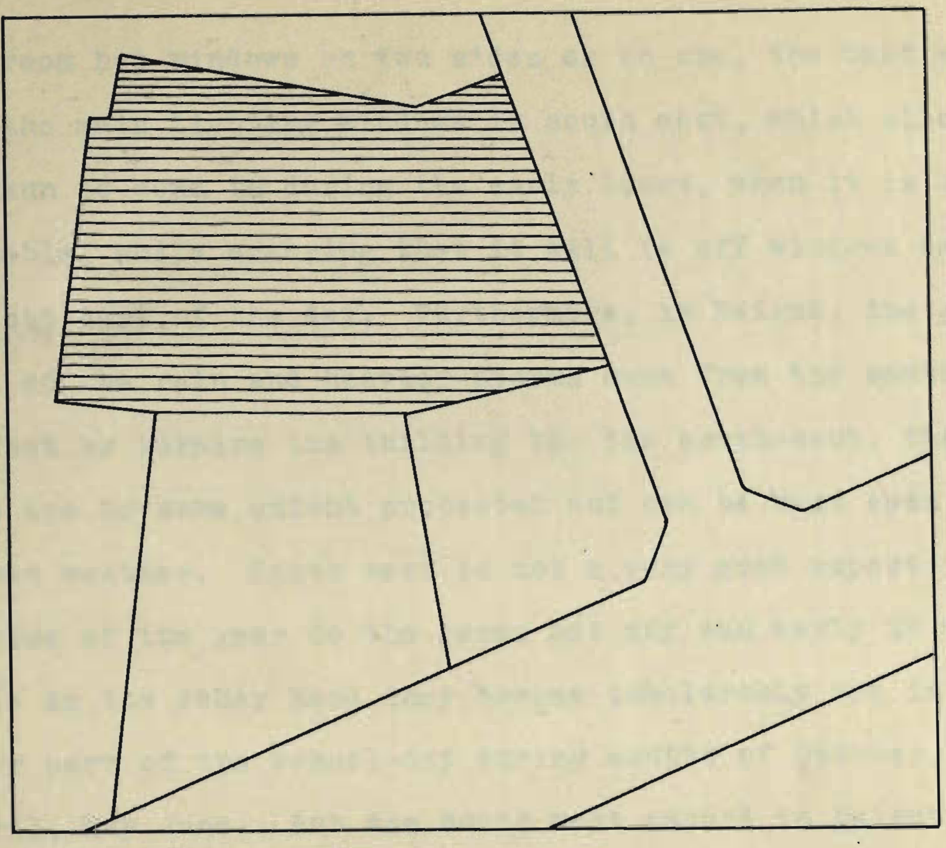


Fig. 3 Position of the building for minimum noise

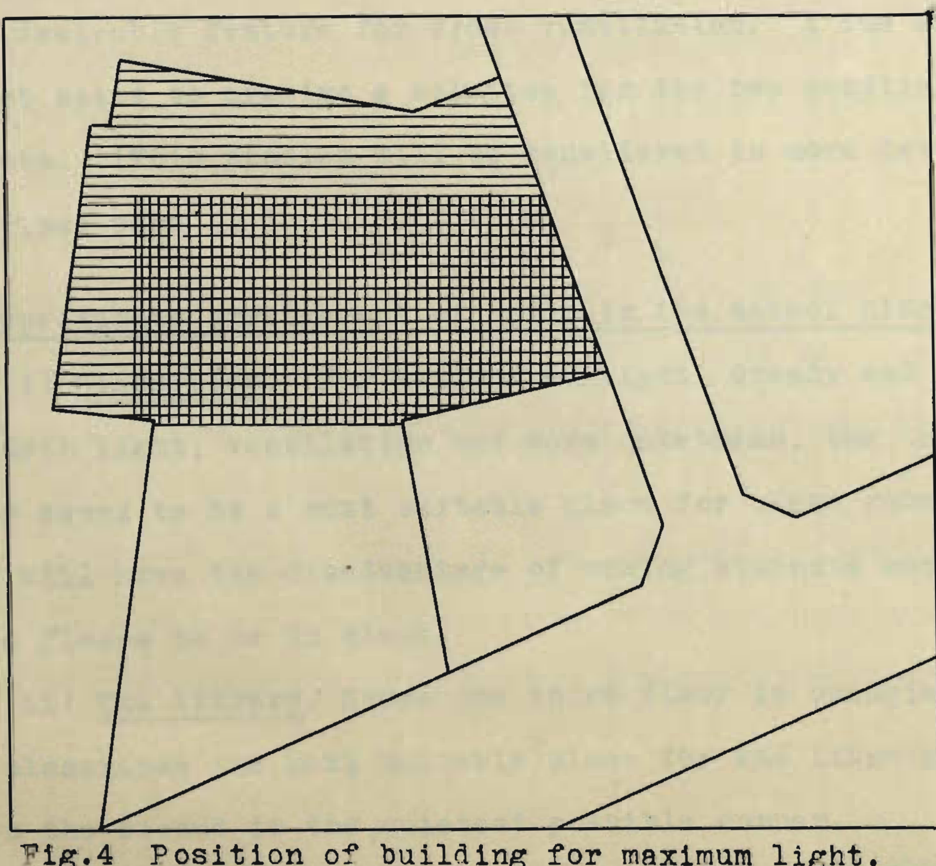


Fig.4 Position of building for maximum light.

the room has windows on two sides or on one, the best aspect for the main lighting windows is south east, which allows the sun to come in during the early hours, when it is most valuable, while ensuring that it will be off windows before the hot part of the day. Furthermore, in Beirut, the greater part of the rain and heavier storms come from the south west, so that by turning the building to the south-east, the openings are to some extent protected and can be kept open more in wet weather. South west is not a very good aspect; at no time of the year do the rooms get any sun early in the day, while on the other hand they become intolerably hot in the later part of the school-day during months of October, November April, May June. But the south west aspect in Beirut, has the advantage of full exposure to the prevailing winds, a most desirable feature for cross ventilation. A due south aspect seems to promise a solution for the two conflicting aspects. (This problem will be considered in more details later, see page 13)

5. Approximate arrangement of units in the school plan.

i) Classrooms.- For maximum sunlight, steady and unobstructed north light, ventilation and more quietness, the third floor seems to be a most suitable place for class rooms. This will have the disadvantage of making students ascend three floors to be in class.

ii) The library. Since the third floor is occupied by the classrooms the next suitable place for the library will be on the second in the quietest possible corner.

iii) Laboratories. a) Chemistry. Steady north skylight which is desirable for any chemistry laboratory, suggests a location for itself on the second floor and on the northern side.

b) Physics lab. will be next to it because these two laboratories naturally have much in common.

iv) Administration. A seperate quarter for the administration seems to yield a more convenient result; a place somewhere on the second floor will give a better control over the school, will offer a better reception for visitors, at the same time being away from noise.

III. ACTUAL PLANNING OF THE SCHOOL

A. Third Floor.

1. Classroom is the fundamental unit of the school organization, in fact the reason for its existance , hence a lengthy study will be devoted to its design.

a. Size and Shape of the class unit. The area required by the classroom was established from the fact that the number of the students in each class shall not exceed 30, and shall not fall short of this number by more than 6 per cent. This is so, because the administration shall limit the number of students in each class to thirty for petagogic reasons; moreover, the school being free of charge will have too many applicants, and hence a selection will ensure the best students with no chance of being dropped or having to repeat the year.

Therefore the number of the students will not be reduced in any class by more than 6 per cent.

The followings are the areas alloted per student in different countries

U. S.A. ....1.75 to 2.8 sq.m. (19 to 3o sq.ft.)

England ....1.50 to 1.8 sq.m. (16 to 20 sq.ft.)

France .... 1.25 to 1.5 sq.m.

Germany .... 1.45 to 1.7 sq.m.

In the present project 1.65 sq. m. per student was decided upon, so that seperate seats could be used, and better isolation could be achieved by having more space between each student. This tends to decrease the amount of infectious illnesses. Hence total area required 30 x 1.65 = 49.4 sq.m. 7 x 7 m. is selected. The reasons for selecting a square shape are the followings:-

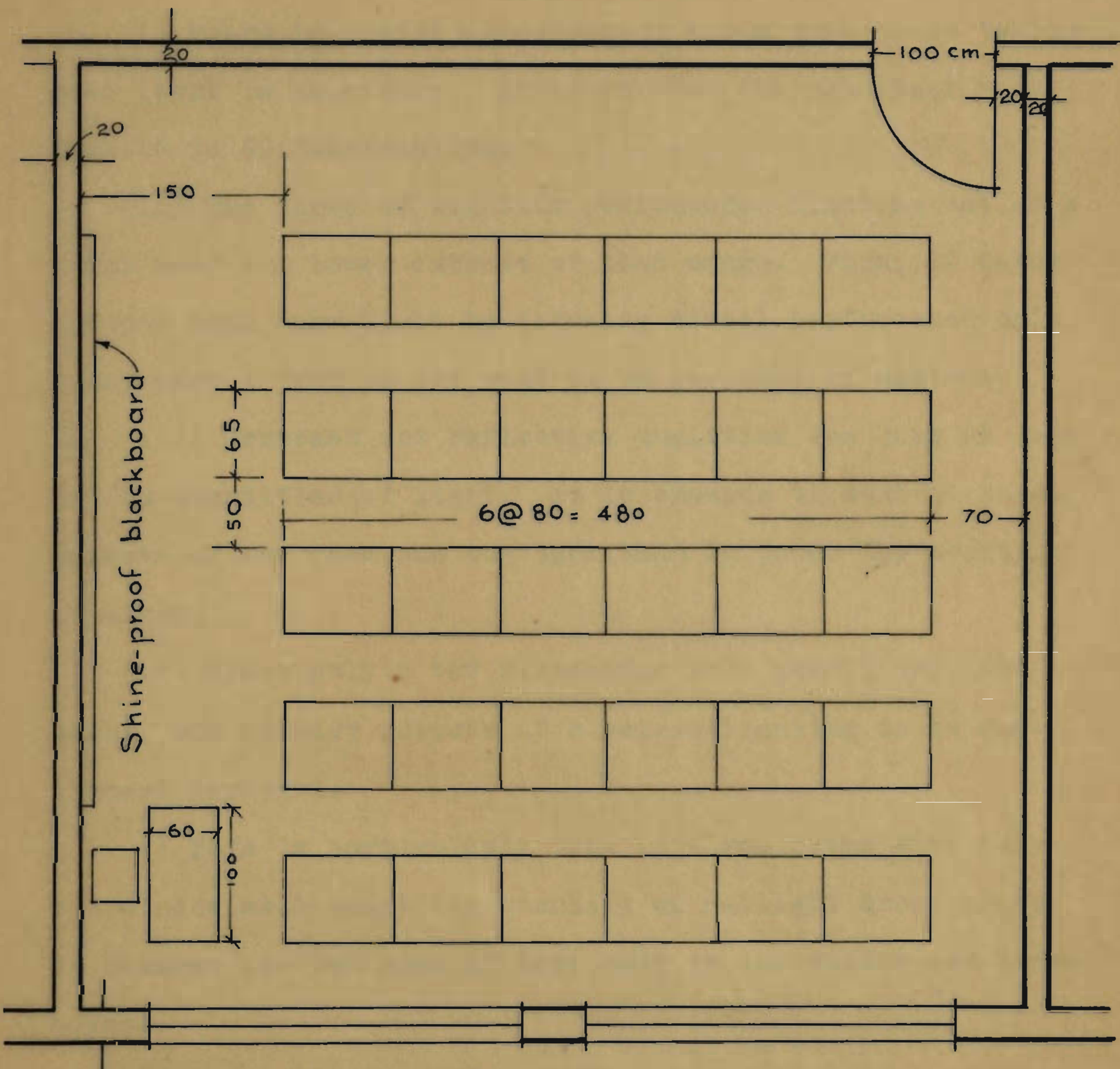
i) It has the shortest periphery of any straight line geometrical shape, hence cheapest in cost.

ii) Subdivides itself neatly into a main recitation area of rectangular shape up forward, and near the wall opposite the windows, plus a rear rectangle (both narrow) for activity spaces.

iii) The teacher can have a better control over the class because the back row students are not as faraway as in a rectangular shape class.

iv) Consumes least façade and hence it is suitable for the project.

v v) In a square room the day's walking may be several



TYPICAL 7X7m CLASS UNIT

miles shorter for the teacher.

b. Daylighting has been a subject complex and controversal; but the following facts stant out:-

i) There is a wide disagreement among experts as to how much light is necessary. Estimates for the same task vary from 12 to 40 foot-candles.

ii) The curve of lighting performance flattens out at a point near the lower extreme of that range. Thus, it takes 130 per cent more light to increase visual performance only 5 per cent - from 90 per cent to 95 per cent of maximum.

iii) Contrast and reflective qualities are just as important as quantities of light. It is cheaper to control these aspects of the room and the task than to boost the quantity of light.

iv) Since only a few classrooms in a school are used at night, the primary purpose of electric lighting is to supplement daylight.

v) This is particularly true in class rooms with only one window wall where the quantity of daylight drops sharply between the two rows of desk next to the window and those beyond.

For good lighting of the class the window area required is specified as 25 per cent of floor area (20per cent in older specifications). Floor area 7 x 7 = 49 sq.m. @25% = 12.25 sq. m. of window area required. Actually provided 6.6 x 2.6 = 17.1 sq. m.

This excess is fully justified (although more expensive) when the ventilation problem is considered.

c. Control of sunlight in the classrooms. It was decided after careful study of the mean daily temperature of Beirut, (the mean being 30 years normal) that direct sun rays in the classrooms after 9:00 am. between April 15 to November 10 were undesirable. Hence a shade casting cantilever slab over the windows was necessary to accomplish this end. Shots were taken by the candidate on November 10, 1950, and April 15, 1951 for finding the inclination and azimuth of the sun rays. On April 15 at 9:00 a.m. the sun was 47°-50' above the horizon, and azimuth angle was 68°. According to this data the length of the shade casting cantilever slab was determined graphically as being 100 cm. (See fig.5).

d. Natural ventilation. This is a vital problem for this part of the world, and in general it has never been given the necessary attention.

This subject of natural ventilation is so important in its bearing upon the whole theory and practice of ventilation that it will be well to give a brief account of some of the experiments which Dr. Leonard Hill has carried out. The following account is taken from his report *.

"According to the usually accepted ideas of ventilation, the evil effects of a crowded and ill ventilated room are due to the fact:-

a) That the air becomes impoverished of oxygen

*"Ventilation and the Effect of Open Air upon Respiratory Metabolism

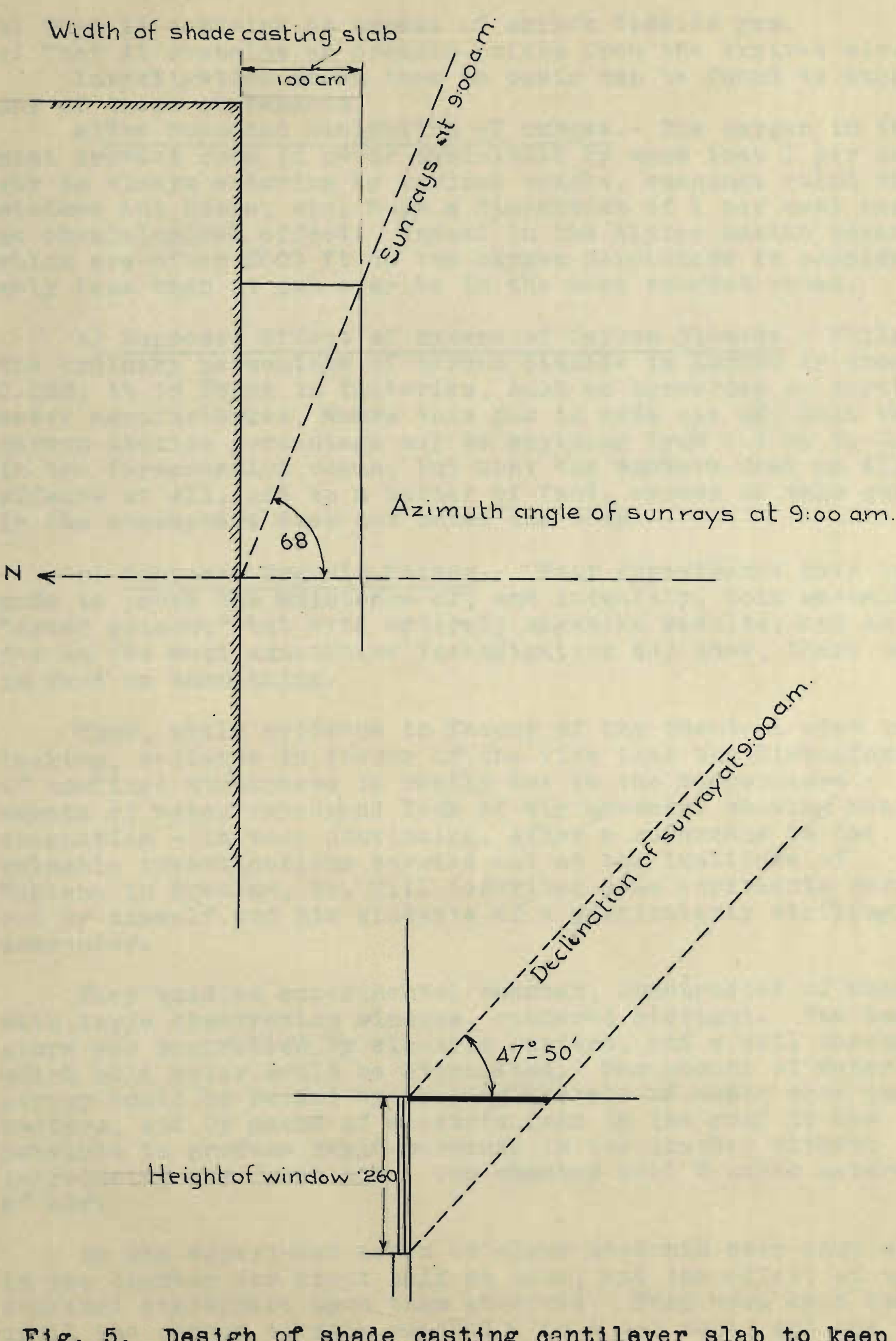


Fig. 5. Desigh of shade casting cantilever slab to keep sun rays out of classrooms between April 15 to November 10.

b) That it contains an excess of carbon dioxide gas.
c) That it contains an organic poison from the expired air.

Investigation shows that no basis can be found to support any of these statements.

a) The Supposed Diminution of Oxygen.- The oxygen in the most crowded room is never diminished by more than 1 per cent; air is always entering by various cracks, openings round the windows and doors, etc. Such a diminution of 1 per cent has no physiological effect. Indeed in the Alpine health resorts, which are often 5000 ft up the oxygen percentage is considerably less than it can ever be in the most crowded rooms.

b) Supposed Effect of Excess of Carbon Dioxide.- While the ordinary percentage of carbon dioxide in London is about 0.038, it is found in factories, such as breweries or aerated water manufactories, where this gas is made use of, that the carbon dioxide percentage may be anything from 0.9 up to 2.5 in the fermentation rooms, but that the workers feel no ill effects at all, and as a matter of fact, excess of this gas in the atmosphere does not enter the body.

c) Supposed Organic Poison.- Many experiments have been made to prove the existence of, and indentify, this so-called "crowd poison," but with entirely negative results, and as far as the most exhaustive investigation can show, there is in fact no such thing.

Thus, while evidence in favour of the chemical view is lacking, evidence in favour of the view that the disconfort of confined atmosphere is really due to the temperature - excess of water vapour and lack of air movement causing heat stagnation - is very convincing. After a reference to the valuable investigations carried out at the Institute of Hygiene in Breslaw, Dr, Hill describes some experients carried out by himself and his students of a particularly striking character.

They used an experimental chamber, constructed of wood with large observation windows, rendered airtight. The temperature was controlled by electric heaters, and a coil through which cold water could be circulated. The amount of water vapour could be raised by placing vessels of water over the heaters, and by means of electric fans in the roof it was possible to produce rapid currents in the chamber without introducing any fresh air. The chamber held 3 cubic meters of air.

In one experiment seven or eight students were shut within the chamber for about half an hour, and the effect of the confined atmosphere upon them observed. They were kept there until the carbon dioxide reached 3 to 4 per cent, and the oxygen had fallen to from 17 to 16 per cent. The wet-bulb termometer rose meanwhile to about 82° F. to 85° F. and the dry bulb to a degree or two higher. The students went in chatting and laughing, but by and by, as the temperature rose, they ceased talking and their faces became flushed and moist. Some tried to light a cigarette to relieve the monotony and were puzzled by their matches going out - due, of course to the diminution of oxygen which they had not noticed, although it had fallen below 17 per cent. Their breathing was slightly deepened by the high percentage of carbon dioxide which rose to 3 to 4 percent. Their disconfort was relieved to an astonishing extent by putting on the electric fans in the ceiling, and as long as the air was kept in rapid motion the occupants were to a very marked degree less affected by this air containing 3 to 4 per cent of carbon dioxide and only 16 to 17 per cent of oxygen.

A particularly remarkable feature of the experiment should be noted: by means of a face mask and tube one student inside breathed nothing but air from outside, while by a similar arrangement a student outside breathed nothing but the vitiated air inside. The occupant of the chamber found no relief from breathing the fresh air from outside, while the other student, being himself outside, felt no disconfort from breathing the vitiated air inside. The cumulative evidence ~~evidence~~ may be considered to show convincingly that heat stagnation is the cause of the disconfort, and the unpleasant symptoms that are felt in overcrowded and ill-ventilated rooms".

In conclusion it may be considered that the admission of fresh air diverted as far as possible by various devices yet avoiding too strong a direct draught, will give that which is required.

Now, keeping the above in mind, and the impossibility of having windows on both sides of the classrooms because of limitted space, the candidate deviced the followings as a solution to the problem at hand.

i) Since a south-west orientation for maximum exposure of windows to the prevailing winds in Beirut is not advisable, for reasons given on page 6,it was decided to have projections coming out of the wall to act as wind traps. For economic purposes it was found that these projections or fins could advantageously be the legs of concrete bents which will form the framework of the structure connected by slabs of the different floors.

ii) To have cross-ventilation which is essential, specially for places where high relative humidity prevails, such as Beirut, it was decided to have transom type windows placed against the ceiling overlooking the corridor. Since the wind velocity in Beirut is in general 1.6 to 3.3 meters per second (4.7 miles per hour) or more, this arrangement will ensure a constant draught across the classroom, thus providing the 300 cu. ft. per minute of outside fresh air. 10 cu. ft. per minute per student was taken because this amount will take care of the 400 B.th.u. of heat which the human body should get rid of in order to feel confortable, and at the same time keep classroom atmosphere at a relative humidity 2 per cent more than the outside air.

To avoid disturbance in the classrooms due to noises in the corridor a low ceiling for the corridor 2.60 meters high was devised as a prevention against noise entering from the corridor to the classroom through the transom windows. Fig. 6 will make the whole arrangement clearer.

iii) <u>Design of window frames</u>. It was said a while ago that a constant draught was necessary across the classroom, yet this draught should take place above the head level of the seated students, in order to avoid its detrimental effects. To achieve this purpose, window frames as shown in fig. 7 shall be used.

1 iv) <u>Shine proof Blackboards</u>. A small detail as it may

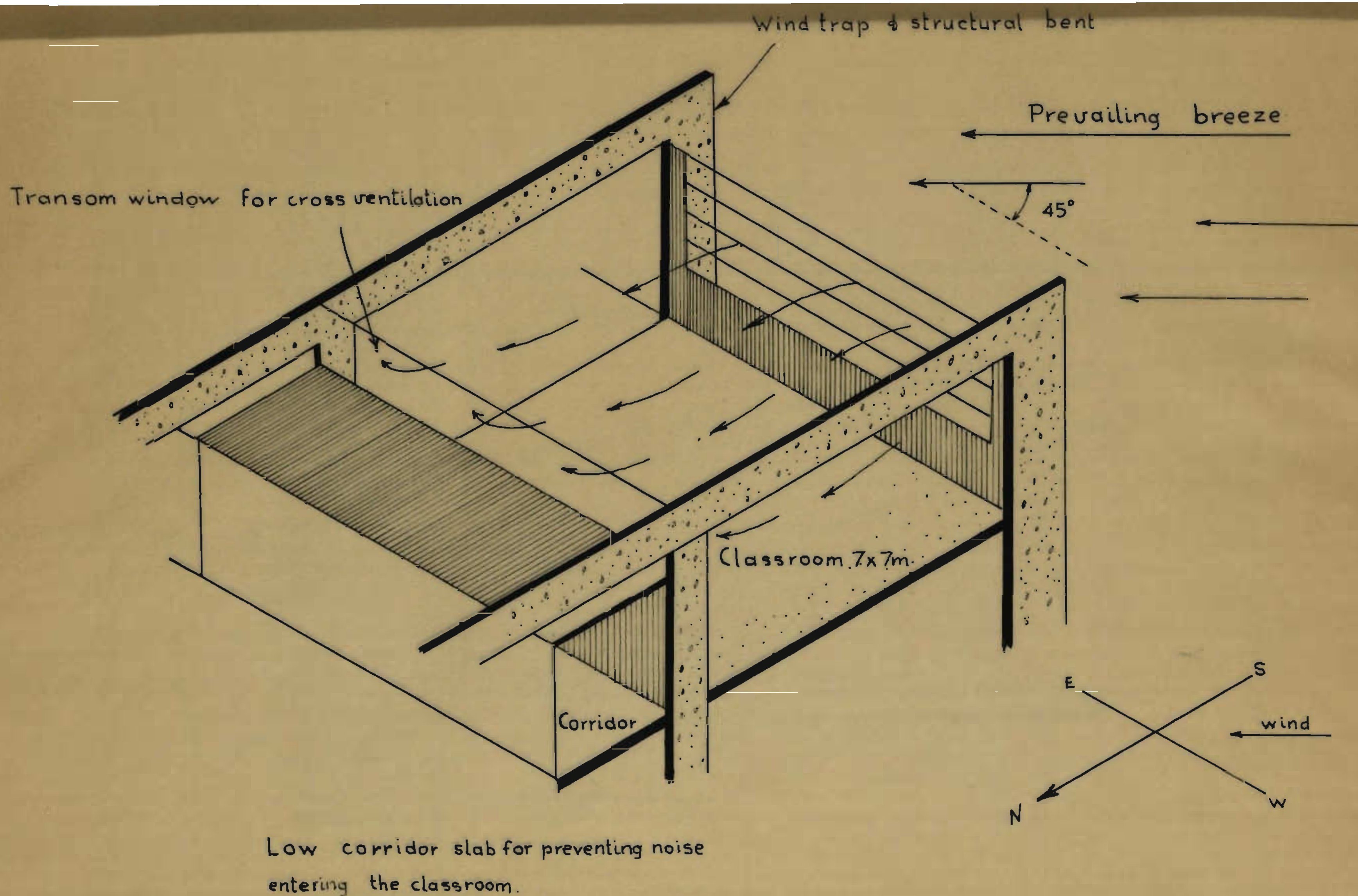
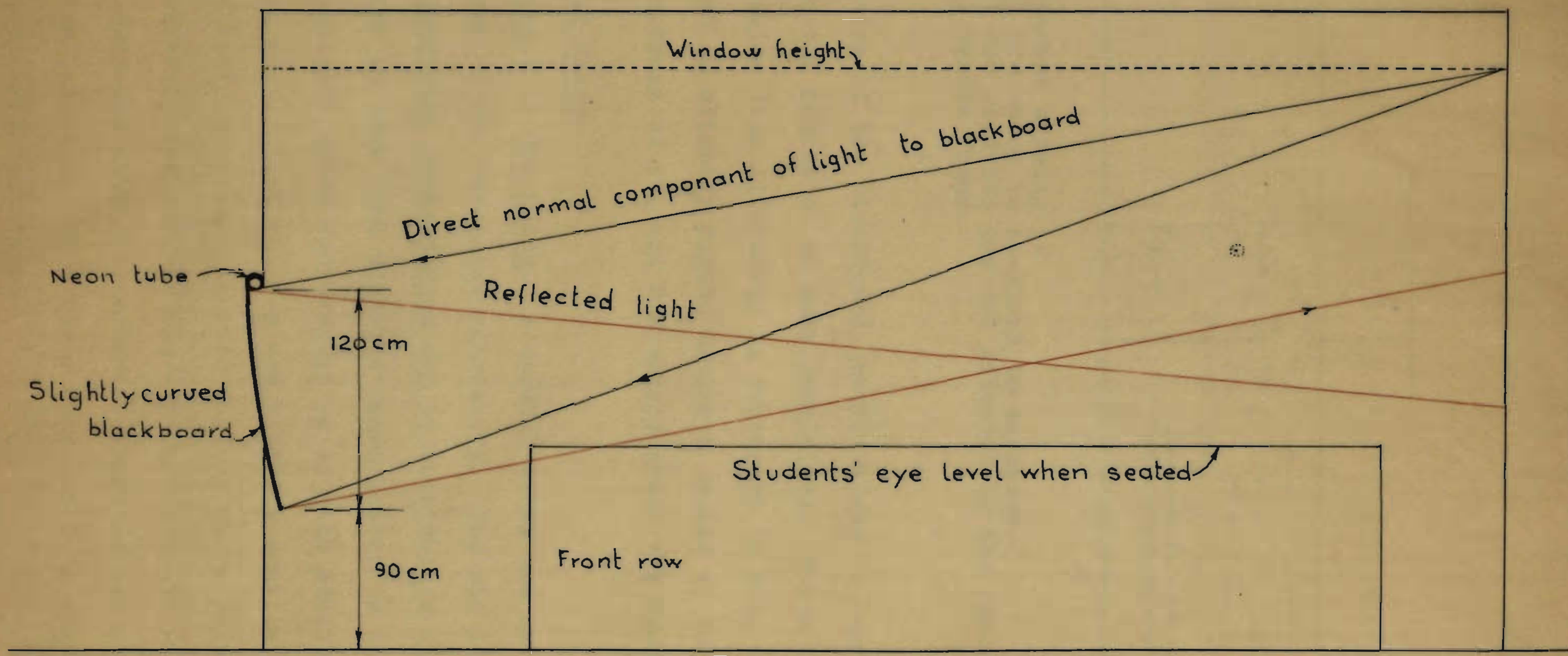


DIAGRAM 6 SHOWING CROSS VENTILATION ARRANGEMENT



SKETCH SHOWING DESIGN OF SHINE PROOF BLACKBOARD

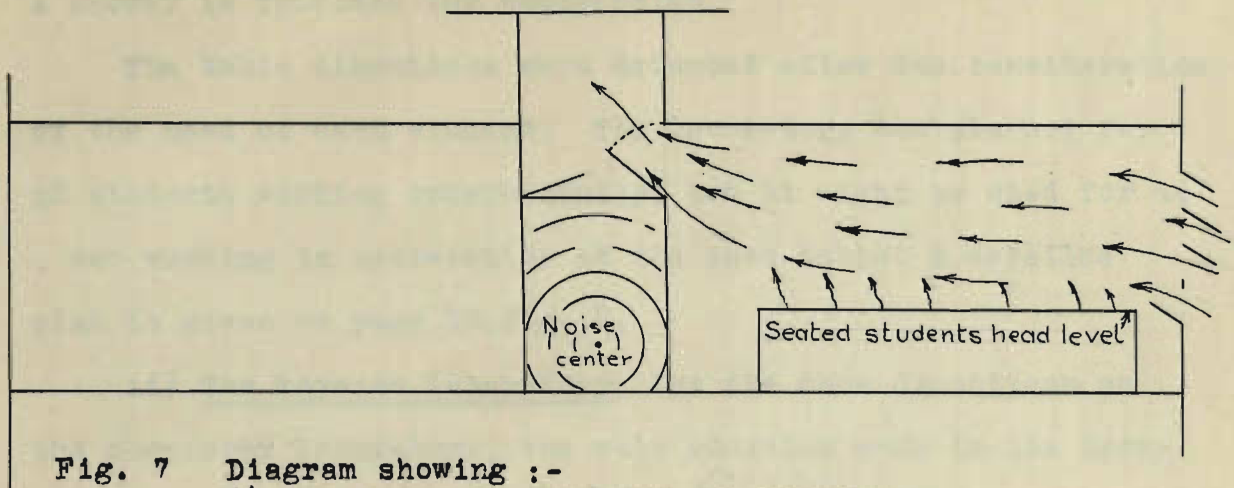


Fig. 7 Diagram showing :-
i) How noise is confined to corridor
ii) How students are not affected by the draught
iii) Window frame.

seem the shining of the blackboard, nevertheless is important, because it is the source of so many complaints. Hence a design overcoming this difficulty is presented in fig. 8 . The blackboard is slightly curved having a center of curvature 5.2 meters in front of it, and 2.2 meters above the floor.

B. Second Floor

1. Laboratories.- i) Chemistry. A careful study was devoted to the planning of the chemistry laboratory. The old idea that physics and chemistry laboratories can be combined is utterly wrong. Keeping in mind that students learn better in the laboratories , adequate space was devoted to it with additional windows facing west. This will ensure a better ventilation which is absolutely necessary in such a place where poisonous gases are constantly present. Hoods were provided to take care of H_2S (hydrogen sulfide), Ammonia, fluorine gas etc. Adjacent to the laboratory is a store which will be used for keeping the necessary chemicals.

A shower is provided for emergencies.

The table dimentions were selected after due consideration of the need of each student. The laboratory was planned for 22 students working independently, but it might be used for 44 , two working in coorenation at the same table. A detailed plan is given on page 18,fig. 8.

ii) The Physics laboratory has the same dimentions as the chemistry laboratory, the only addition made is the dark-room for photometry experiments and photography.

2. The Library was placed in the eastern corner of the second floor, there being more quiet than other parts of second or first floor. It was planned to accomodate for 36 students reading at the same time.

3. The Teachers'-room was planned for fifteen teachers. Twelve seperate tables are provided for teachers where they can make individual study and corrections. A long table at the center of the room is provided, around which the weekly meetings of teachers may take place. See fig.9 on page19.

4. Drafting room. The two requirements for drafting rooms i.e., steady north skylight and necessary amount of it, governed its design. The room shall be furnished with neon tubes to supplement daylight during overcast winter days.

5. Administration.- This quarter was planned to be an almost completely seperate unit. A seperate door gives access to it.

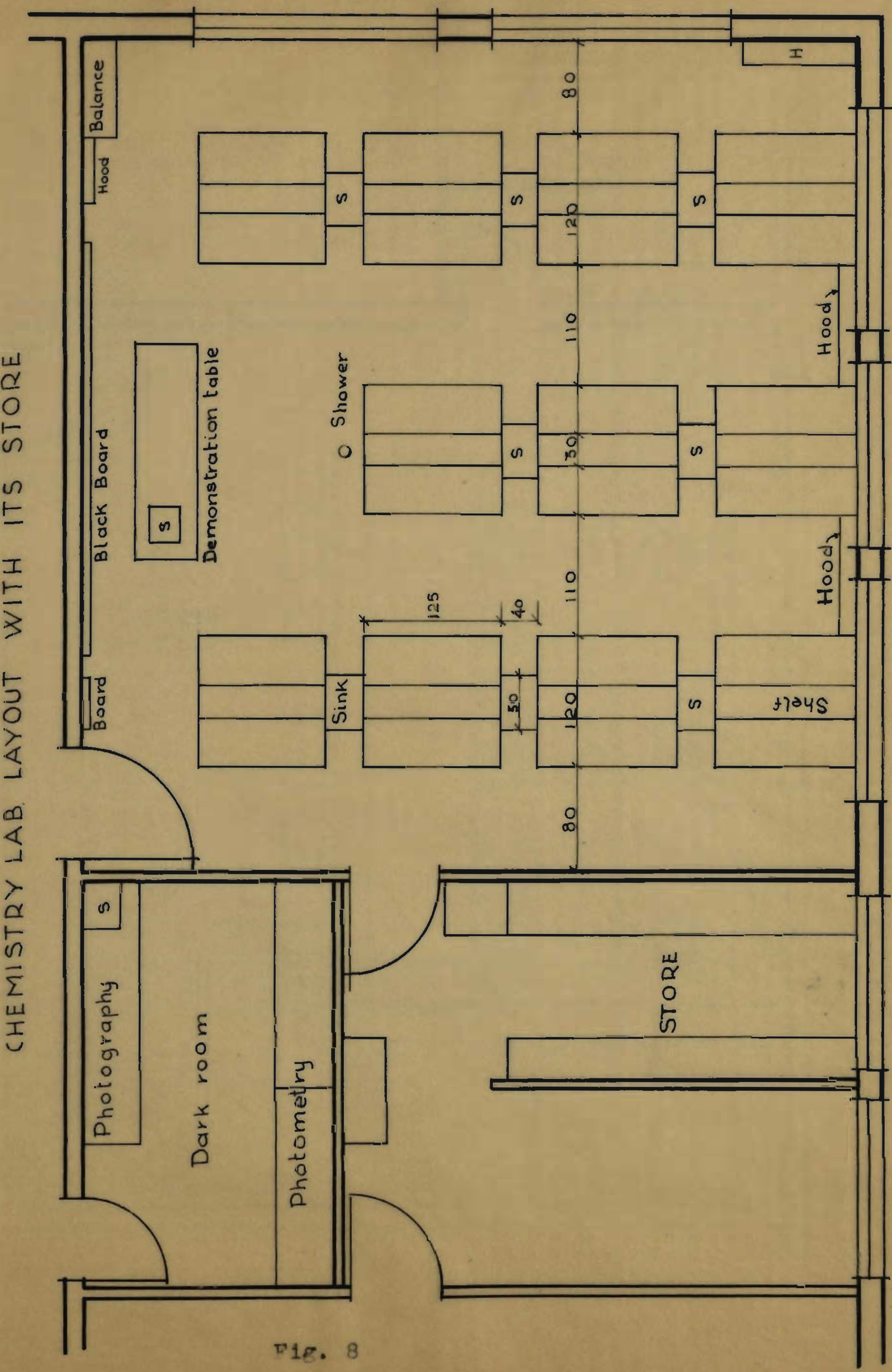

CHEMISTRY LAB LAYOUT WITH ITS STORE
Balance
Hood
Black Board
Board
Demonstration table
S
O Shower
Sink
125
40
50
80
120
110
30
Hood
Hood
Shelf
H
STORE
Photography
Dark room
Photometry

Fig. 8

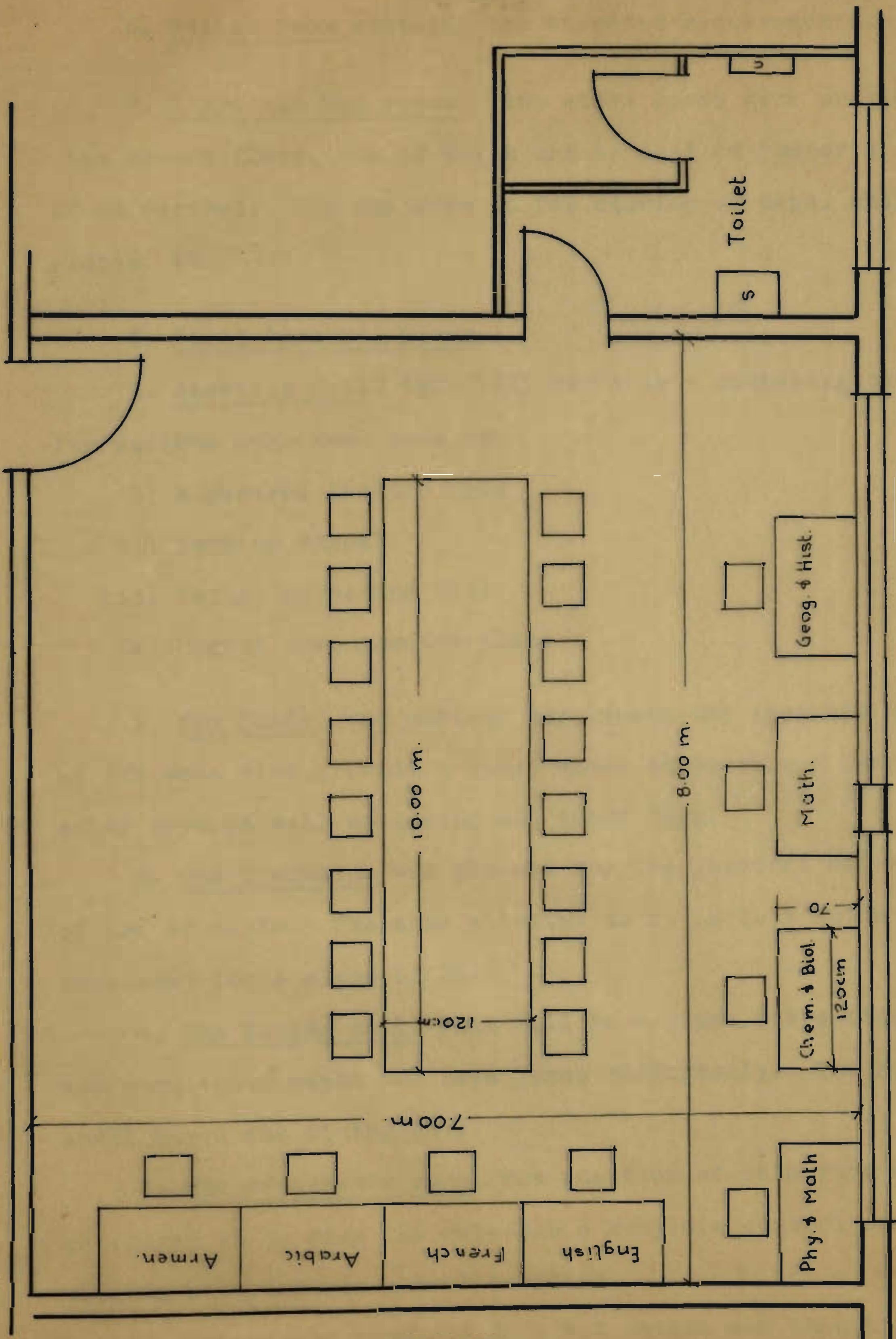

Toilet
TEACHERS' ROOM
8.00 m.
10.00 m.
120cm
7.00 m.
Geog. & Hist.
Math.
Chem. & Biol.
120cm
Phy. & Math
English
French
Arabic
Armen.

Fig. 9

6. Toilet room contains the standard requirements.

7. Store and Map rooms. two store rooms were provided on the second floor, one of which can be used as doctor's clinic if so desired. The map room is for storing of maps, charts, globes etc.

C. First (ground) Floor.

1. Assembly Hall. This will serve as a gathering place for various purposes such as:

i) A general lecture room

ii) Morning Chapel

iii) Social gathering hall

iv) Urgent announcement place

2. The Shade was made to supplement the Assembly Hall, at the same time provide a place where students can play on rainy days as well as during hot sunny days.

3. The Gymnasium was planned for the physical education of the students. The area allotted to it is that which is necessary for a class of 30.

4. The Dining hall. This will be a place where students can warm their meals and have lunch confortably. The kitchen shall serve the dining hall.

5. The gate-man's room. The position of this room was so chosen as to give the gate-man a complete control over the persons entering the school building.

6. Stair-case room. 4.20 x 7.0 meters was thought as sufficient for serving the building effieiently.

THE AUDITORIUM

A. ARCHITECTURAL DESIGN OF THE AUDITORIUM

It will be seen that the school was designed for 300 pupils, yet the specifications require an auditorium for 800 people. Obviously, this is much more than that required for the school, the purpose being the desire of having an activity center for the community. Hence this auditorium at the same time is supposed to be :-

i) a theatre where shows can be produced

ii) a movie-theatre

iii) a concert hall

iv) a lecture hall

v) and a place for various other gatherings .

1. Area Required. Auditorium specifications for floor was met by selecting 0.6 sq. m. per person. Consequently, the area needed would be 0.6 x 800 = 480 sq. m.

2. Proportioning of width to depth. Much difficulty was experienced in the determination of the width and depth of the auditorium, because of two conflicting requirements, namely - i) the hall as a movie-theatre required a ratio of depth to width as large as possible; ii) the hall required a ratio of depth to width as small as possible as a theatre, concert hall or lecture room. Moreover, the following facts had to be considered:-

a) The horizontal angle of polychromatic vision(no eye movement) is approximately 40°. (See fig. 10)

b) The horizontal angle to the center line at which objects onstage, upstage of the curtain line cease to bear the intended relationship to other objects onstage and to the background is approx. 60°. (See fig.11)

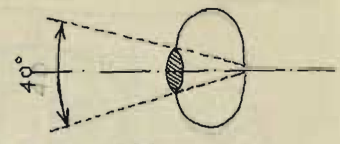


Fig. 10

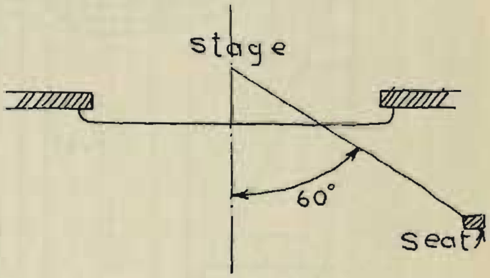


Fig. 11

c) The horizontal angle to the projection sheet at which distortion on the screen becomes substantially intolerable is 60° measured to the far side of the projected image. (See fig 12)

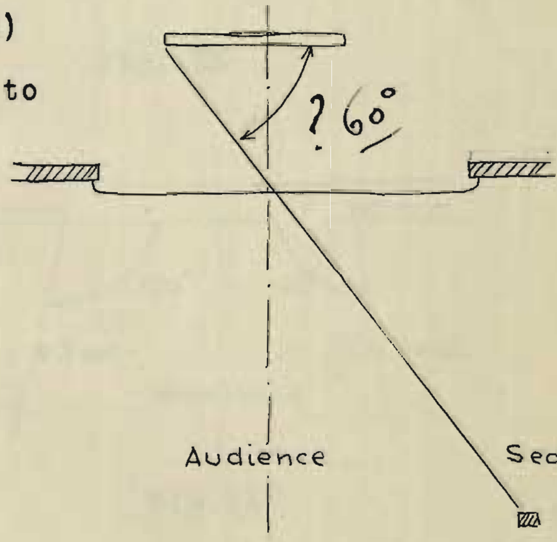


Fig. 12

d) Judged by the audiences ability to recognize shapes, and confirmed by free audience choice of seats, the following is the order of desirability of locations.

i) a front center (except where the screen is close to the front row).

ii) middle center;

iii) middle sides;

iv)front sides;

v) rear center;

vi) rear sides; (See fig. 13)

e) Audiences will not choose locations beyond a line approximately 100° to the curtain at the side of the proscenium. (See fig. 14).

f) The vertical angle beyond which ability to recognize standard shapes falls of very rapidly is approximately 30°.

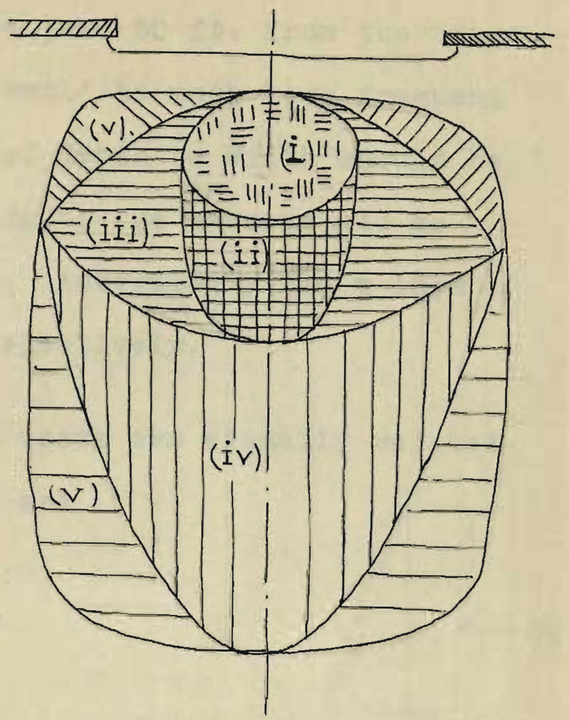


Fig. 13

Now, there were many formulas for the determination of the relationship between depth of house, width of house, and width of screen or proscenium. The following was judged as more suitable for this particular case: "Depth equals 1.25 to 2.35 times house width , where house width is 2.5 to 3.5 times screen width". A ratio of 1.6 was chosen for the following reasons:

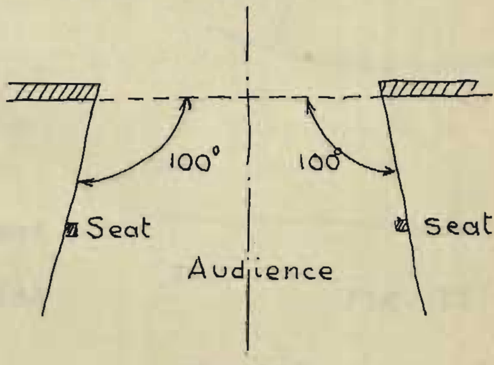


Fig.14

Normal human vision can perceive a minimum dimention or seperation equal to one minute of visual arc, or this means that at 50 ft. 0.175 in. Details of actors' make up and facial expressions are not plainly

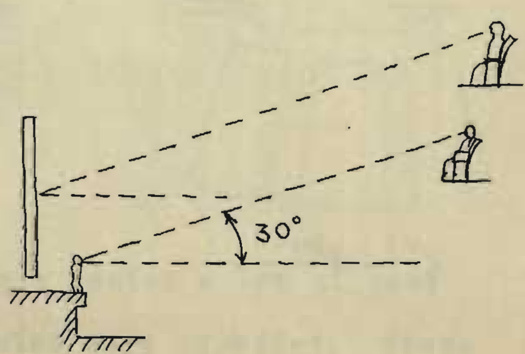


Fig. 15

recognizable at a distance of more than 50 ft. from the stage. Since motion picture performance would be much less frequent than other performances, a ratio of depth to width should be as small as possible, without going to the extreme, so as not to harm the movie performance. Accordingly 21m x 13½m was chosen as length and width respectively.

3. Seating. Occupants of all seats are visually related to the performance when the seats are oriented towards stage. This necessitated curving the rows of the seats. The center of the curvature was located on the center of the auditorium approximately the depth of the house behind proscenium. (See Fig. 16)

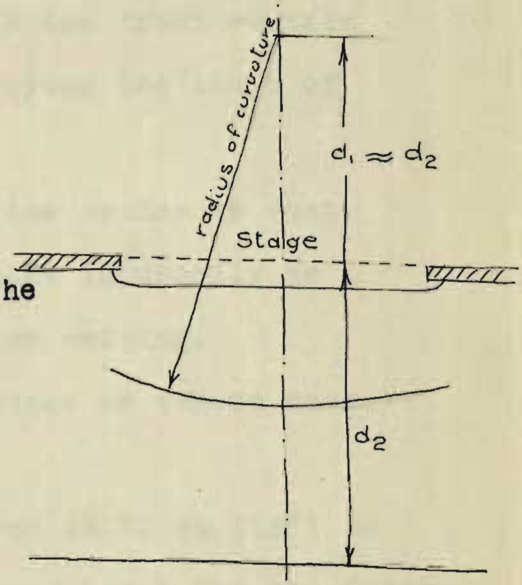


Fig. 16

4. Seat Stagger. To provide best visibility from any seats, staggering of seats was necessary. This was accomplished by non uniform placement of seats of varying width in succeding rows, and by curving the aisles.

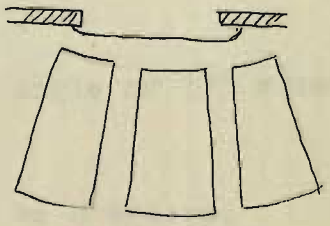


Fig. 17

5. Aisles. Since a center aisle wastes a lot of best desirable seating area two side aisles were provided. These were made radial because they were the best and slightly curved to achieve seat staggering. Aisle width was made 90 cm. near

the stage and 140 cm. at the exit.

6. Section of the floor. The lowest seat in the orchestra was located such as to enable the spectator just see the stage floor. The floor slope was made 6 per cent.

7. Balcony section. In determining the section of the balcony the followings were taken into consideration:

i) the highest seat in the balcony must be on a line which is not more than 30° to the horizontal at the front curtain at the stage floor, if it is not to be beyond the limit of reasonable distortion.

ii) The seated spectator at the back of the orchestra must be able to see the top of the screen, which is usually as high as any significant portion of a stage setting.

iii) Each spectator must see the whole stage or screen over the head of those in front of him.

iv) A point 111.5 cm (3' - 8") below, and 45.75 cm (18") in front of the eye position will be the floor level for the front row.

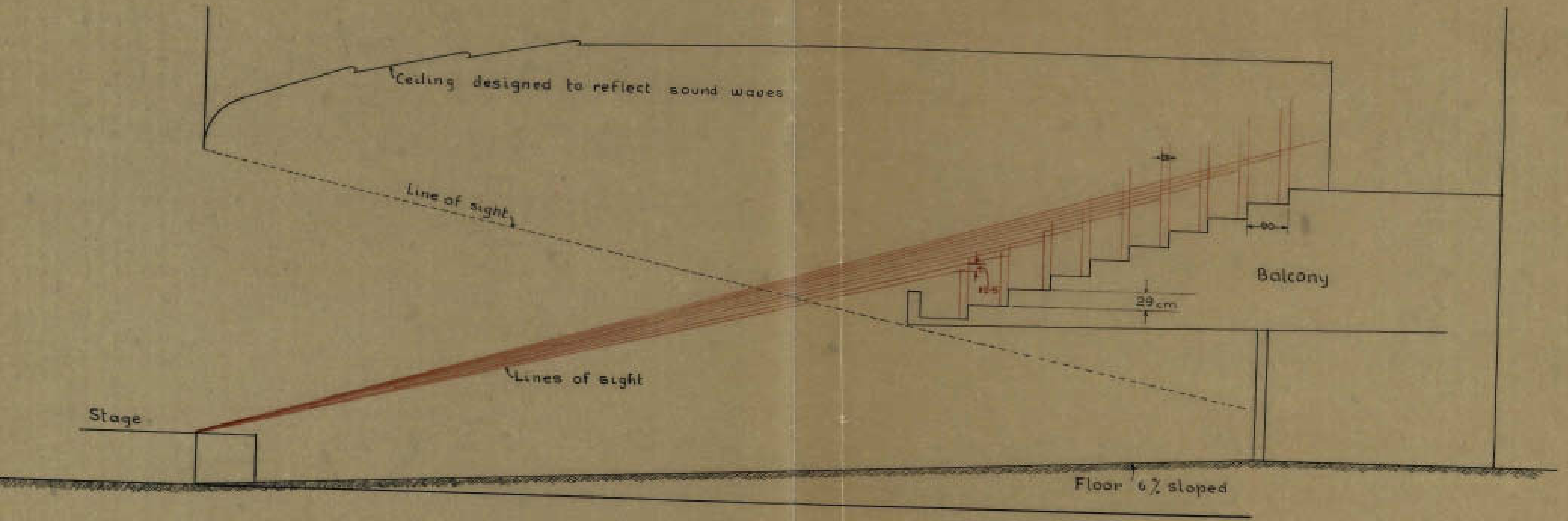
A graphical solution which has met the above conditions is given in fig. 18. Results obtained were:-

i) Highest seat in the balcony made an angle of 17° with the horizontal.

ii) Maximum balcony projection came to be 8 meters.

iii) Floor level difference between succesive rows 29 cm.

The third result was checked by trigonometric solution and was found to be 28.7 cm. Fig. 19 gives a complete solution.



Ceiling designed to reflect sound waves
Line of sight
Lines of sight
Stage
Balcony
29 cm
Floor 6% sloped

Fig. 18

$\tan \theta_1 = 4.35/1630 = 0.26687$

$\tan \theta_2 = \dfrac{320 \text{ plus } 115\ 12.5}{1630} = 0.27454$

Total height at a distance 16.75

$0.27454 \times 16.75 = 4.5985$

Therefore difference of elevation 28.7

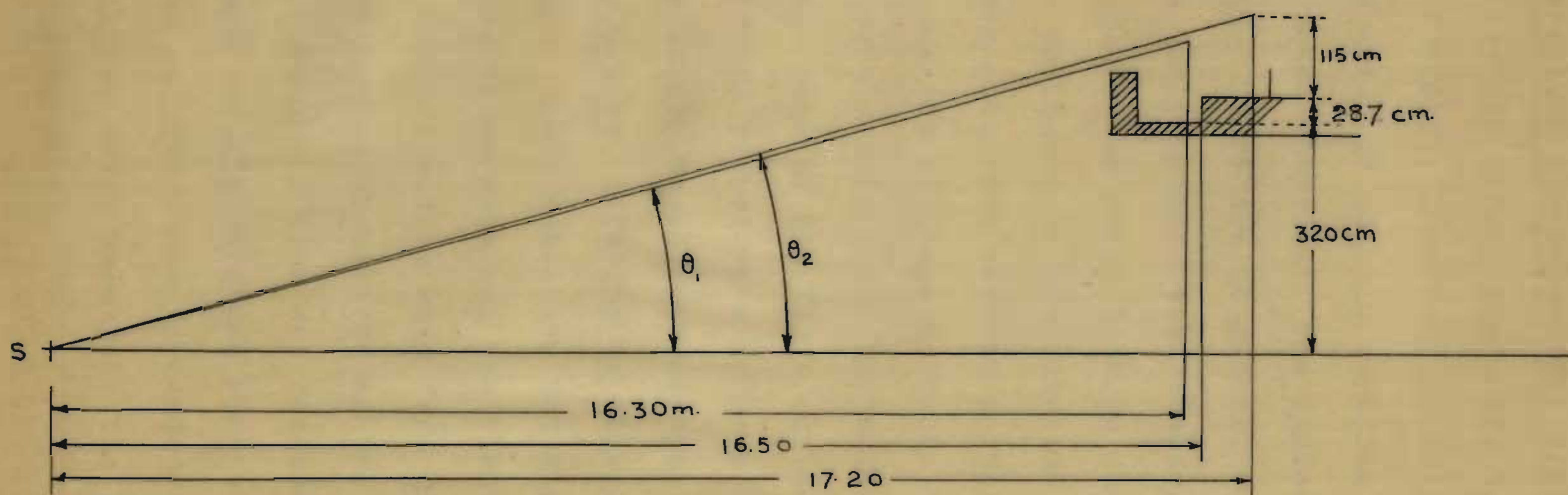


Fig. 19

Trigonometric solution for finding thedifference of level between each row of seats in the balcony.

8. General considerations for acoustical treatment. The audience wants to hear the actor, the orchestra, the instrumental solist, the audible componant of motion picture etc., as they naturally are. If all the surfaces in the hall are made very soft and sound absorbant, the audience can hear practically nothing. There are no echoes.

Since ceilings are the principal distribution surface, they were planned to reflect the sound back to the audience, but in a manner that it would not be concentrated in certain spots, nor reflected back and forth between parallel surfaces, not to get to the audience out of phase with the direct wave. Moreover, since sound travels only about 330 meters per second in air, the length of the path of the first reflected wave shoud not exceed that of the direct wave by more than 15.25 meters, otherwise the audience would hear everything twice.

a. Design of the ceilings. Refering to fig. 20 it will be seen that the reflected sound waves are not distributed uniformly over the entire floor area but the first reflected wave reaches the floor about 9 meters away from the stage, and they become more and more concentrated as the back of the hall is approached. This was done so, because as one moves away from the stage the direct sound wave energy becomes less and less, and reinforcement is needed for good audibility. These reflected waves were made the reinforcing elements to the direct sound waves.

b. Design of side walls. The position of the side walls

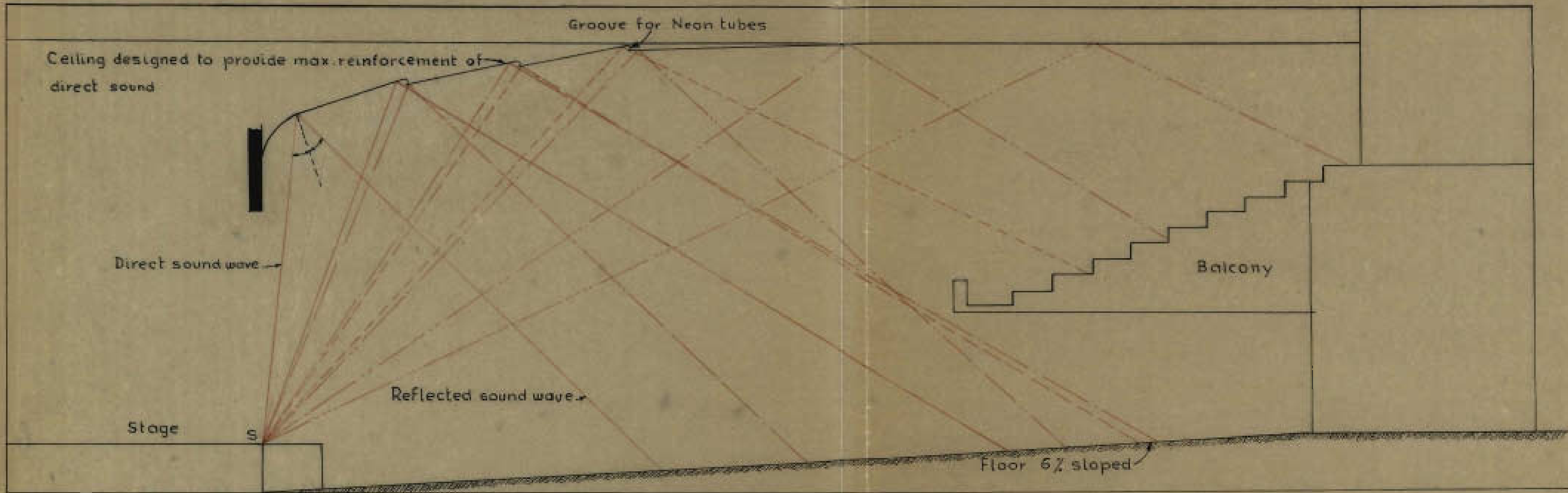

Groove for Neon tubes
Ceiling designed to provide max. reinforcement of direct sound
Direct sound wave
Reflected sound wave
Balcony
Stage
S
Floor 6% sloped

Fig. 20

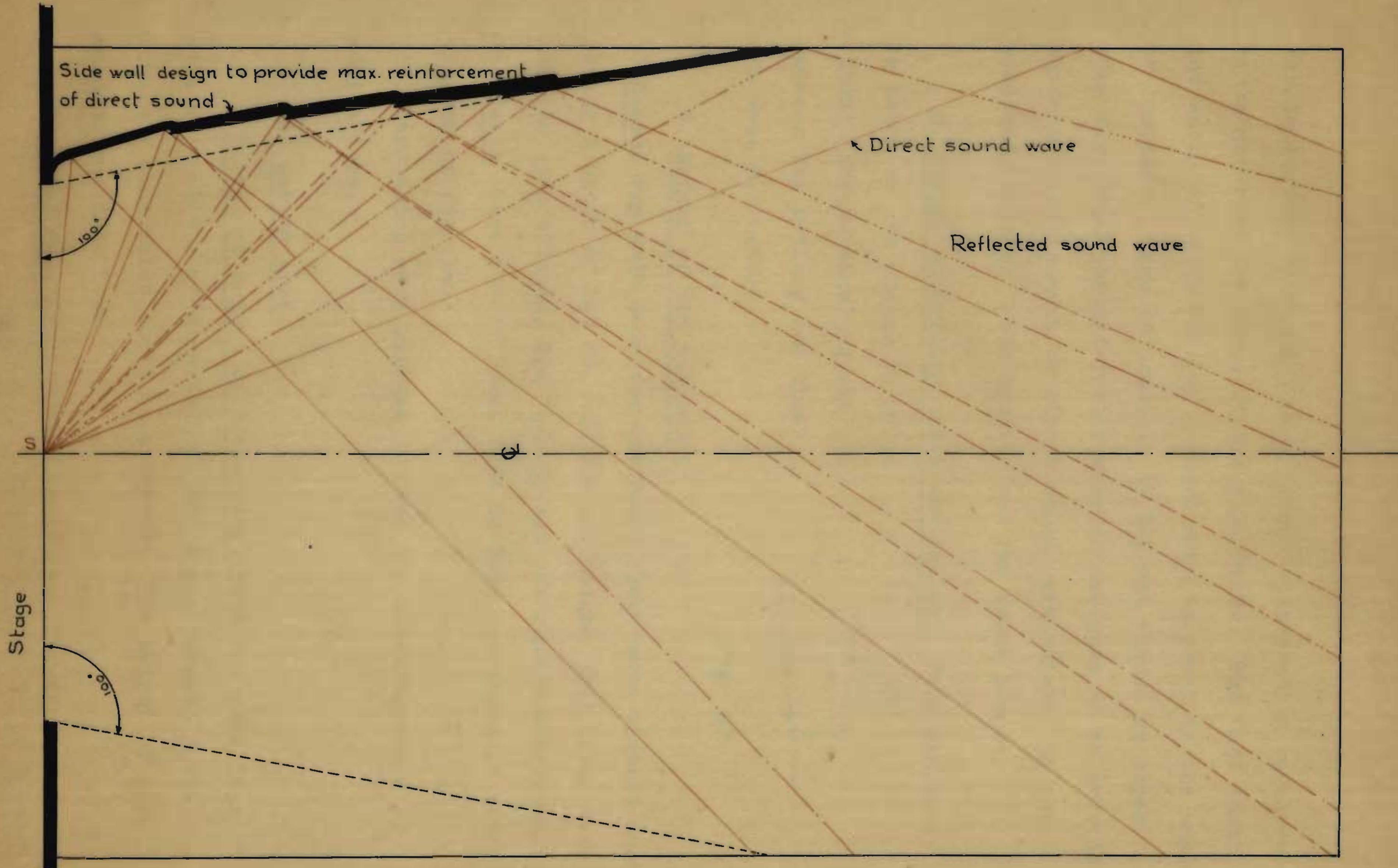

Side wall design to provide max. reinforcement
of direct sound
Direct sound wave
Reflected sound wave
S
Stage
100°
100°

Fig. 22

was determined by sight lines. Sound distribution requirements governed the shape of the side walls. The fact that the angle of reflection of a sound wave is equal to the angle of incidence, made it possible to lay out shapes on paper. (See fig. 22). The side walls were so designed as to provide maximum reinforcement of direct sound particularly in the spectator portion, most remote from the sound source.

c. Design of ceiling under the balcony. This was made as shown in the sketch to avoid echos; the vertical height between the ceiling and floor was made 2.6 meters.

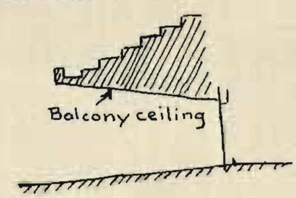


Fig. 23

9. Safety of the audience.

i) Doors. Two exit door fot the first floor were planned each having a width of 140 cm, and 2.4 cm. height The doors were made to open outside. The balcony has the same door arrangement.

ii) Seats were put at 90cm. back to back, as shown in the diagram of fig. 24.

iii) Lavatories were planned to meet the specifications of auditoriums.

10. Acting Area.

a. Width and height of proscenium. This was made 10 m wide so that the requirement of 100^{o} angle between curtain line and side walls could be achieved. The height of proscenium was made 5.8m.

b. Backstage. Two dressing rooms, one for men and another for women were planned with mirrors, sinks, and a toilet room.

c) Store. A rather large room was provided for storing stage accessories.

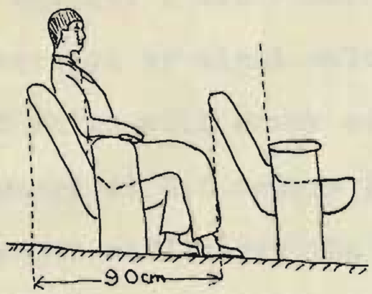


Fig. 24

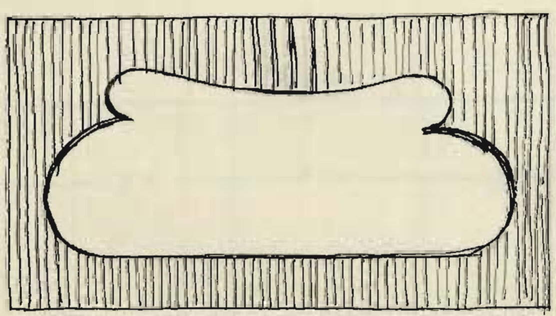


Fig. 25. Sketch showing the proscenium.

B. STRUCTURAL DESIGN OF THE AUDITORIUM

Balcony Design

Live load as specified by typical American building codes for Auditoriums and theatres with fixed seats is 50 - 80 lbs./ sq. ft. (245 - 390 kg./sq.m.). The whole load will be carried by eight columns. Two girders will be used,one of which will serve as a balustrade. Five cantilevers spaced at 2.5 meters parallel to the direction of the hall length will carry the balcony slab load. It will be assumed that 1/3 of the load will be carried by cantilever action and 2/3 by the girders.

Fig. 26 gives the general arrangement adopted.

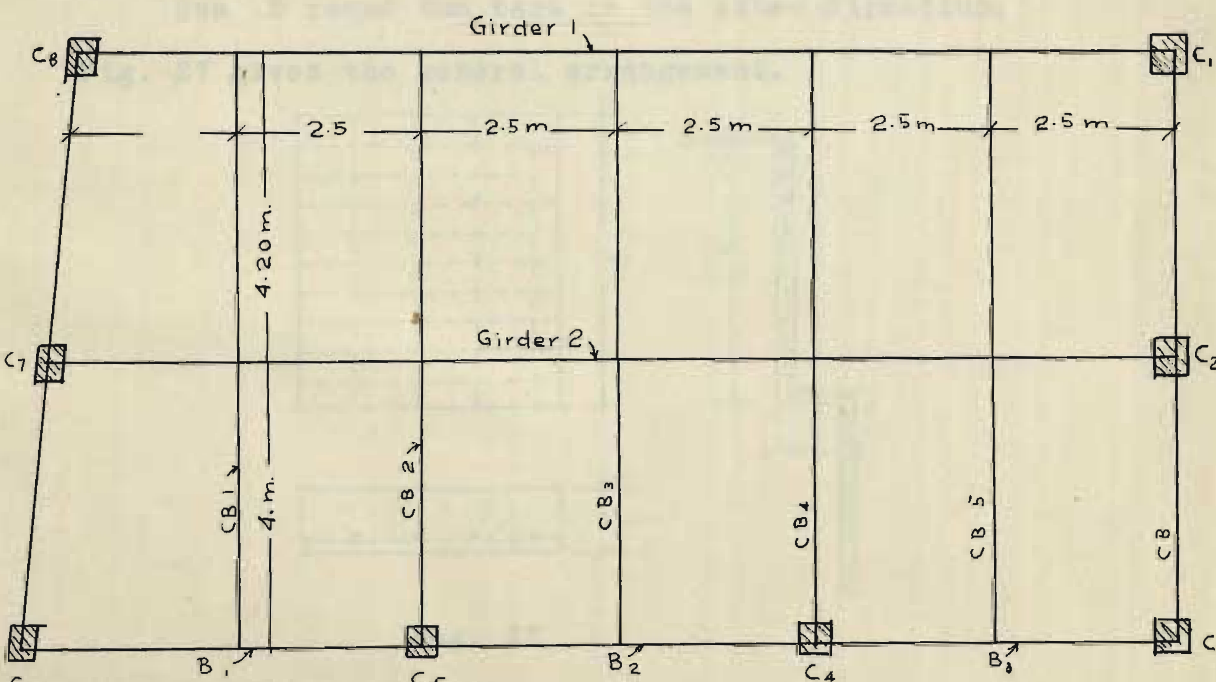


Fig. 26

It is assumed $n = 12$; $f_s = 1200 kg/cm^2$ (18 000 psi); $f_c = 50$ (710 psi)

Design of Slab.

It is assumed that the slab is supported in one direction only, i.e. in the direction parallel to the width of the hall. Assume 9 cm slab

$$\begin{array}{lll} & D.L. = & 216\ kg/m^2 \\ & L.L. = & 384\ kg/\ sq.m \\ Total & & \overline{600}\ kg/sq.m \end{array}$$

No tiling shall be used.

Supposing partially fixed ends,

$$M = 1/10(600 \times 2.5^2) = 375\ kg.m.$$

$$d = 0.367 \times \sqrt{375} = 7.1\ cm \quad \text{plus } \tfrac{3}{4}\text{" insulation (1.9cm)}$$

$$= 9\ cm \quad (3.5")$$

$$A_s = 0.694 \times 7.1 = 4.92\ sq.\ cm/meter$$

Use 10 round 8 mm bars / meter (5/16" at 2.5"centers)

Use 5 round 8mm bars in the other direction.

Fig. 27 gives the general arrangement.

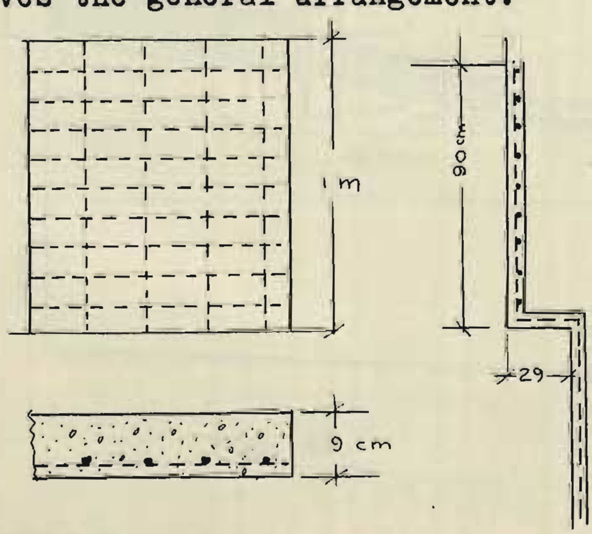


Fig. 27

Design of Cantilever Beams

In the design of cantilever beams it is assumed that one third of the load in a strip of 5 meters in width is is carried by the cantålever. Univormely distributed load 5 x 300 kg/ meter. @ 1/3 = 1000 kg/ meter. Assume 600 kg./ m the average weight of cantilever. @ 1/3 -= 200kg/m

1000 plus 200 = 1200 kg/m.

M = 4x1200x8 = 48,000 kg.meter

$d = 0.4\sqrt{\frac{48000}{0.4}}$ = 120 cm plus 5 cm insulation

= 125 cm. overall (49.5")

$A_s = \frac{48,000}{1200x.87x1.20}$ = 38.4 sq.cm.

Use 8 round bars 25m.m. (8 round 1" at 4" centers)

Use 8mm round stirrups.

Fig. 28 gives detailed arrangement of the cantilåver beam.

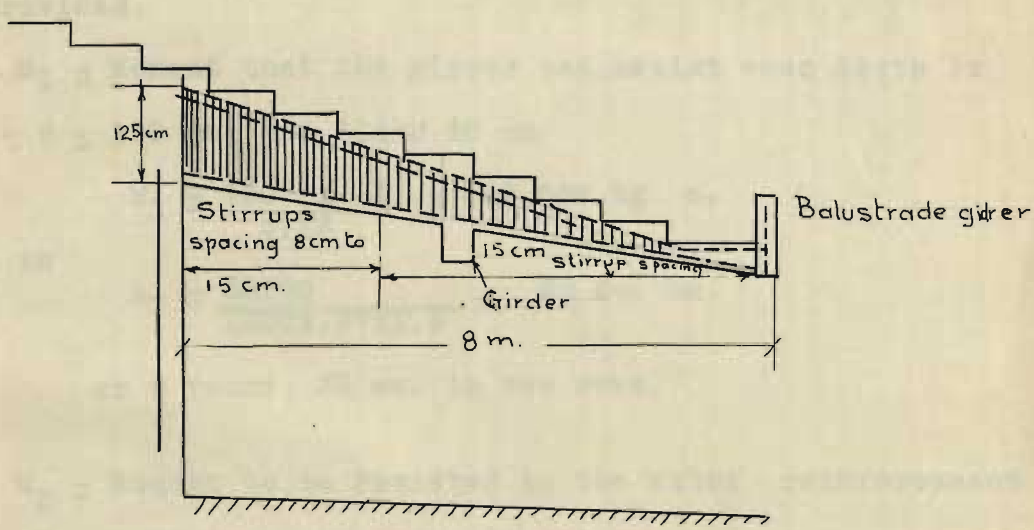


Fig. 28.

Design of Girder G_2

Uniform load = 4 x 600 = 2400kg/m

It is assumed that only 2/3 of the load will be carried by the girder, therefore:-

2400 x 2/3 = 1600 kg. / m

Moment due to uniform load

$$M_u = 1/10 \times 1600 \times 15.5^2 = 32,000 \text{ kg.m.}$$

Moment due to concentrated loads of cantilever beams

$$M_c = 4250 \times 15.5/2 = 32,000 \text{ kg. m.}$$

Moment due to D.L. of girder, assuming girder dimentions as 140 cm x 50 cm.

$$M_d = 1/10 \times 1680 \times 15.5^2 = 33,6000 \text{ kg. m.}$$

Total Moment M = 97,600 kg. m.

$$d = 0.4\sqrt{\frac{97680}{.5}} = 175 \text{ cm.}$$

For clearance purpose depth will be made 138 cm and reinforcement for compression, as well as extra tension will be provided.

M_1 = Moment that the girder can resist when depth is 138 - 8 = 130 cm, and width 50 cm

$$M_1 = \frac{130^2 \times .5}{0.16} = 53,000 \text{ kg. m.}$$

with an

$$A_s = \frac{53000}{1200 \times .87 \times 1.3} = 39 \text{ sq. cm.}$$

or 8 round, 25 mm. in two rows.

M_2 = Moment to be resisted by the extra reinforcement

$$97,600 - 53,000 = 44,600 \text{ kg. m.}$$

hence,

$$A_{s2} = \frac{44600 \times 100}{1200 \times (130-8)} = 30.0 \text{ sq. cm}$$

Use 6 round 25 mm (6 round 1")

Total tension reinforcement

8plus 6 = 14 round 25 mm. (14 round 1")

in two rows.

The required compression reinforcement will be

$$A_s' = 30 \times \frac{1 - k}{k - (d'/d)} = 30 \; \frac{1 - 0.333}{.333 - 8/130} = 74 \text{ sq.cm.}$$

Use 14 round 25mm bars (14 round 1") in two rows.

No bars will be bent up because the compression reinforcement is equal to tension reinforcement

The diagonal shear will be taken care of by stirrups 14 mm.(9/16") spaced at 10 cm 1/3 of the span on both sides. In the middle third of the span, stirrup spacing will be made 15 cm.

Fig. 29 gives details of the arrangement adopted.

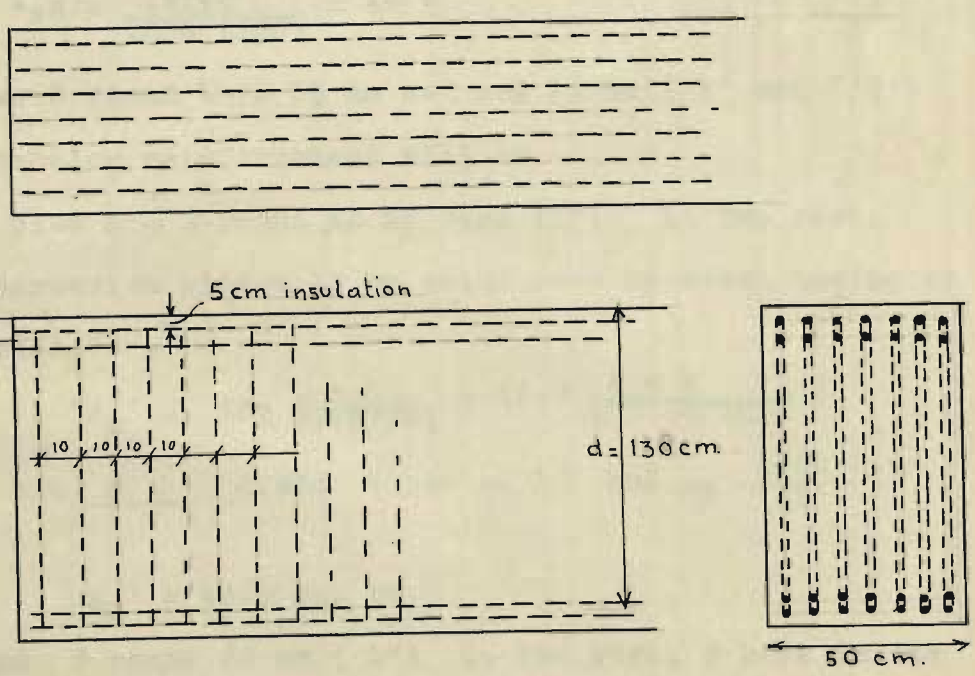


Fig. 29.

<u>Desigh of Balustrade Girder G_1 .</u>

Load 2x600= 1200 kg/m. Assume D.L. 720 kg/m (100x40cm)

Moment $M = 1/10 \; (1920 \times 15.5^2 = 46{,}000$ kg. m

Moment due to cantilevers $M = 1940$ kg. m

Total Moment 47940 kg. m

$$d = 0.4\sqrt{\frac{47940}{0.4}} = 150 \text{ cm.}$$

Clearance requirements limit the depth to 115 overall, therefore the girder should be reinforced for compression too.

Moment M to be resisted = 47,940 kg.m.

A girder of 115x40 cm can resist M_1

$$M_1 = \frac{40x107^2}{0.16x100} = 28,800 \text{ kg m.}$$

Moment to be resisted by the extra reinforcement

$$M_2 = 47,940 - 28,800 = 19,140 \text{ kg. m.}$$

The amount of additional steel needed to resist this moment

$$A_{s2} = \frac{19140}{1200\ (100)} = 16.8$$

Use 3 round bars 25 mm and one 16 mm (1" and 7/8")

Total tension reinforcement will be

5 plus 3 = 8 round 25 mm bars (1") in two rows.

The compression side will be reinforced by steel having an area of A_s'

$$A_s' = As_2 \frac{1 - k}{k-(d'/d)} = 16.8 \frac{1 - k}{k - (8/107)} =$$

But $k = \frac{n}{n + r}$ = 0.333 since n = 12, and $r = \frac{1200}{50}$

Hence $A_s' = 43.5$ sq. cm.

Use 9 round 25 mm (1") in two rows, 5 bars in the upper row, and 4 in the lower row.

Bars will not be bent, since $A_s = A_s'$. Diagonal stresses will be taken care of by 14mm. stirrups spaced as in G_2.

Fig. 30 gives details of the arrangement.

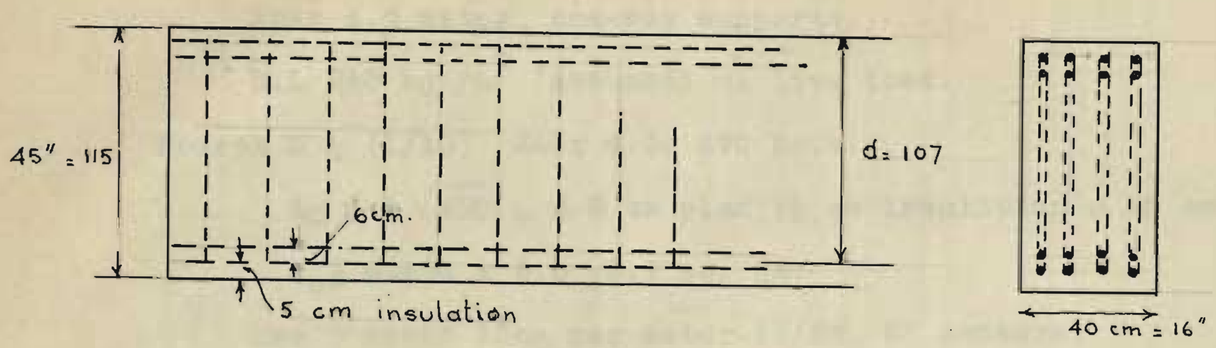


Fig. 30.

Design of Beam B_1 (Beams B_2 , B_3 are similar)

Moment due to concentrated load

$$M = 2000 \times 2.75 = 5500 \text{ kg.m}$$

Moment due to uniform load

$$M = (1/10)(900 \times 5.5^2) = 2700 \text{ kg. m.}$$

Total moment M = 8200 kg. m.

$$d = 0.4\sqrt{8200/.4} \doteq 56 \text{ cm plus 4 cm insulation} = 60 \text{ cm}$$

$$A_s = \frac{8200}{1200 \times .87 \times .56} = 14.7 \text{ sq. cm}$$

Use 6 round 18 mm ,(3/4")

6mm stirrups will be used, spacing being 12 cm (3") throughout the beam length, because of the concentrated load.

Fig. 31 gives details of the arrangement adopted.

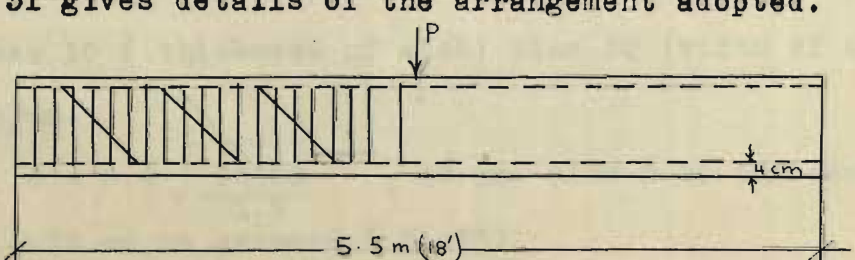


Fig. 31

Design of Roof.

Span 4.5 meter, one-way supports.

D.L 240 kg./m^2 (assumed) no live load.

Moment M = (1/10) 240x 4.5= 490 kg.m.

d= 0.4 $\sqrt{490}$ = 8.5 cm plus $1\frac{1}{2}$ cm insulation = 10 cm (4")

A_s = 0.694 x 8.5 =5.9 sq. cm.

Use 8 round 10mm per meter (3/8", 5" centers)

also, 5 round 10mm /meter in a direction perpenticular to the first bars, for temperature and shrinkage. Every other bar will be bent up to provide for the negative moment.

Design of Beams to support the Slab.

Beams will be spaced 4.5 meters center to center.

Span of beam 15.0 meters (50 ft.)

Uniformly distributed load coming from slab

240 x 4.5 = 1080 kg. per meter

D.L. of beam; assuming beam dimention as 55x30 cm.

.55x.30x1x 2400 = 400 kg./m.

Total uniformly distributed load will be 1480 kg./m.

M =(1/12) 1480x15^2 = 28,000 kg.m.

The beam will be designed as a T-beam. Hence the part of slab which resists compression will be taken as 2 times 8 times 10 (thickness of slab) plus 30 (width of stem) = 190 cm.

$$d = 0.4\sqrt{\frac{28000}{1.9}} = 49$$ cm. plus 6 to the center of bars = 55 cm,as assumed.(21.7")

Check for shear; $V = \frac{7.5x\ 1480}{55x30}$ = 6.5 kg./ sq.cemtimeter.

Therefore o.k.

$$A_s = \frac{28,000}{1200x.87x.5} = 54 \text{ sq.cm}$$

Use 8 round 25 mm (1") in two rows and

4 round 22 mm (7/8") in one row.

To provide for negative moment, bars will be bent up at one-third of the span.

Fig. 32 gives all the details.

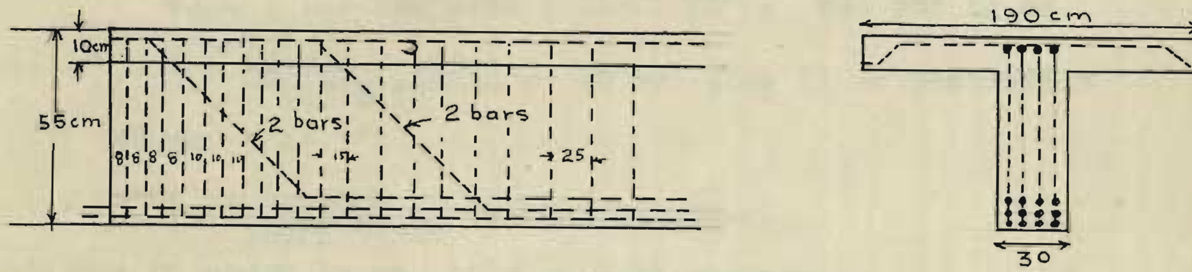


Fig. 32.

A bracing will be used at the support between the column and the T-beam, so that a fixed condition may be attained.

<u>Design of Columns</u>

Loads on C_1 (or C_2)

13680 plus 1000 plus 10(.50x.75) 2400 = 45 Tons.

Loads on C_4

45 plus 2.8 = 61 tons

Loads on C_4

45 plus 3.25 x 8 = 71 tons.

<u>Design of Column C_4.</u>

Load 61 tons; cross section required

$$A = \frac{61,000}{50} = 1220 \text{ sq. cm.}$$

Use 30 x 40 cm. (11.8" x 15.7")

@ 2 per cent steel 22.2 sq. cm

Use 6 round 16 mm (5/8") bars

Foundation footing

$$\frac{61000 \text{ plus } 1500}{\text{allowable soil pressure}} = \frac{62500}{w}$$

Suppose w to 3 kg./ sq. cm. , then area required for footing

$$A = \frac{62500}{3} = 20833 \text{ sq. cm.}$$

Choose 150 x 140 cm. (59"x55")

$$M_{x-x} = 1.5\ (30 \text{ plus } 1.2x55)\ 55^2 = 435\ 000 \text{ kg cm.}$$

$$d = \frac{(20833 - 1220)}{140 \times 15} = 29 \text{ cm. plus } 11 \text{ cm insulation}$$

40 cm. (15.7")

$$A_s = \frac{435000}{1200x.87x29} = 14.5 \text{ sq. cm.}$$

Use 10 round 14 mm (1/2" @ 5.5" centers.)

Same arrangement will be used for the other direction.

Fig. 33 gives details of the footing.

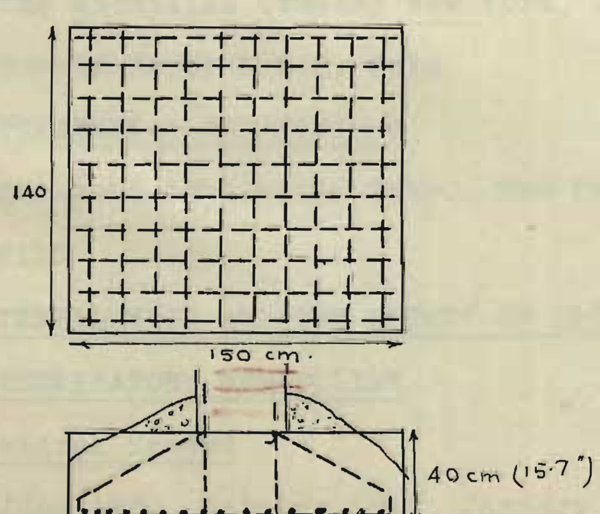


Fig. 33. Footing

BIBLIOGRAPHY

1. Sir Felix Clay

MODERN SCHOOL BUILDINGS

B.T.Batsford Ltd., London, 1929

2. C.G.Stillman & R.Castle Cleary

THE MODERN SCHOOL

The Architectural Press, London 1949

3. R.W.Sexton

SCHOOLS

Architectural Book Publishing Co.,Inc., New York 1939

4. W.K Harrison & C.E.Dobbin

SCHOOL BUILDINGS OF TODAY AND TOMORROW

Architectural Book Publishing Co.Inc.,New York 1931

5. J.J. Donovan

SCHOOL ARCHITECTURE

The Macmillan Company New York, 1921

6. Harold Burris-Meyer & E.C. Cole

THEATRES & AUDITORIUMS

Reinhold Publishing Corp., New York, 1949

7. Dr. L. Hill

VENTILATION AND THE EFFECT OF OPEN AIR UPON THE RESPIRATORY METABOLISM

8. Architectural Record

June 1950, October 1948, January 1948.

9. The Architectural Forum

October 1949, June 1949, July 1948.