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Limiting Capacities of Drainage Stacks in Single Stack System

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Investigations were carried out to find the inter relationship of vacuum developed, the flow rate and the diameter of the stack. Equation was found out for expressing the inter relationship of peak negative pressure, flow and diameter of the stack. Recommendations for limiting capacities of single stack have been given.

A drainage stack that takes discharge from all types of sanitary appliances and that is not aided by vent pipes is called as single stack and such a drainage system as single stack system. In any drainage pipe when the water flows down the stack it reaches a steady state of flow in a short height of drop forming an anular cross section with central air-core. The water flowing down exerts a drag force on the central air core. The depletion of air due to drag, if not fully supplemented by the air from the top of the stack or by any other source will cause a partial vacuum in the stack. Normally the water inlet point of the stack offers some resistance to the flow of air and thus helps the creation of vacuum. In single stack system the hydraulic flow is limited to such an extent that the vacuum developed is always within the safe range, to prevent any serious damage to the water seal. Thus the vacuum tolerated depends on the depth of seals used. Normally a maximum of 40-mm of water gauge is tolerated when the minimum depth of seals is 50 mm. A 40 mm negative pressure is reported to cause a loss of 25 mm seal in practice. A residual of 25 mm deep seal is taken as safe.

The British recommendations for single stack system based on their experiences are shown in Table I.

From Table I it is seen that in case of 100 mm dia. stack the hydraulic load recommended is consis-

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TABLE I

Diameter of stack	Number of groups of appliances in each floor	Appliances in each group	Recommended height of the stack in number of floors
100 mm	1	Sink, basin bath, & W. C.	10
	2		5
125 mm	1	Basin, bath and W. C.	15
	2		12
150 mm	1	--do--	25
	2	--do--	25

tant and hence where there are two groups of appliances on each floor the height of the stack allowed is only half that of the stack with one group in each floor. But in cases of 125 mm and 150 mm dia. stack the consistancy in the recommendations of hydraulic loads is not there, as these recommendations only show the positions to which the single stack has been successfully tried in field. Therefore these recommendations lack theoretical and rational support.

Even in India the past works carried out at Central Building Research Institute were in the same lines but for Indian practices. These works showed that the single stack system could be employed in buildings upto four storeys high. But for employment of this system in taller building in India there is some sort of diffidence. The trial and error method is time consuming and costly. The data given in Table I, though very valuable, give very little help for design of single stack system in different conditions, for reasons already mentioned. Therefore there is a greater need for basic data on the relationship of the hydraulic load and the diameter of the stack.

The earlier investigations carried out in U.S.A. in the past has shown that as the water flows down the stack it soon attains a terminal velocity in a short height of the stack. At terminal velocity the acceleration due to gravity and retardation due to dynamic friction will be equal and opposite. The following equation for terminal velocity has been derived and verified in the investigation

$$V = 3.0\,(Q/D)^{2/5} \qquad (1)$$

Where

V_T —Terminal Velocity

Q —Flow in gpm (U. S. gallans)

D —Diameter of stack in inches

It is already stated that the vacuum is caused by the water flowing down the stack. Hence vacuum developed also can be expressed as a function of V_T i.e. function of Q/D. With this objective a project was taken up at CBRI recently to investigate the inter relationship of vacuum developed, the flow rate and the diameter of the stack.

Details of Test Set-up

A mock-up construction with ground and four floors is fitted with a transparent stack of 100 mm diameter. The stack is provided with cross junctions at each floor level. The discharging appliances such as W.Cs, wash basin and sink are located on the fourth floor platform. At all the lower floors one W.C. or water seal trap of Indian type W.C. is located on either side of the stack. The branch connecting pipes are of 100 mm diameter and of 0.5 meter length. The junctions at all the floors were of Asbestos Cement. The connection between the junction and the transparent stack of PVC were made by Galvanized Iron Couplers Thirty centimeters above and below the junctions 2 mm dia holes were made for pneumatic pressure observations. Similar test holes were made at the mid points of each floor height. All these holes are normally kept closed excepting the concerned one during observations.

Hydraulic loads and observations

To produce various load effects the appliances were discharged independently or in combination. The discharge rate curves of all the appliances were plotted earlier itself. The peak rate of flow was also noted for these appliances, as given in Table II—A

TABLE II—A

Type of appliance	Peakrate of flow through each appliances	Number of appliances connected to stack at fourth floor
W. C. bowl	112 1/min	3
Sink	65 1/min	1
Wash basin	30 1/min	1

From the various combinations of discharges of these appliances the following loads (to the nearest five) were produced on the stack.

1. 110 1/min
2. 140 1/min
3. 175 1/min
4. 225 1/min
5. 250 1/min
6. 290 1/min
7. 340 1/min

Each load was repeated until the maximum negative pressure (vacuum) developed was recorded at all the test observation holes along the height of the stack. The maximum of three observations was taken as the reading at each point. Thus for each hydraulic load the maximum pressure diagrams of the stack were plotted for each load. Figure 1 shows a typical pressure digram of the stack.

Analysis of Pressure Digrams

The study of pressure digrams of the stack for various hydraulic loads

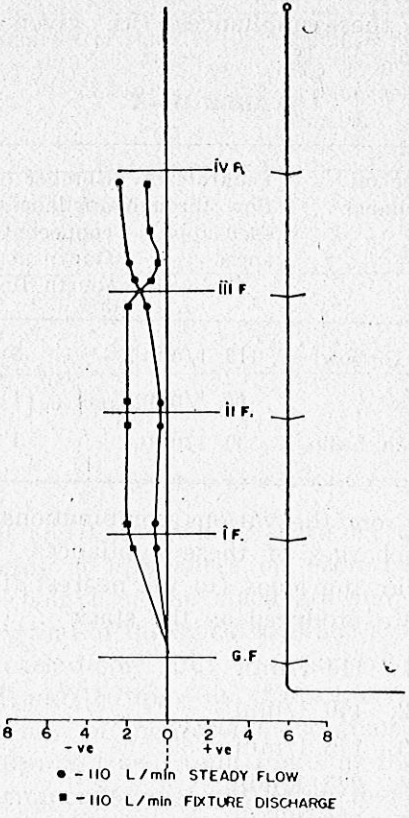

Fig. 1

reveals that in all cases the peak negative pressure occurs somewhere just on floor (3 meters) below the point of inlet of discharge load. A considerably high negative pressure also develops just below the point of inlet. The negative head gradually decreases from the point of inlet, but suddenly increases to peak negative head at the end of about 3 meters drop, forming a kink as shown in Fig. 1.

This type of behaviour is seen only with fixture discharge loads. In case of steady flow loads (by continuous pumping of water) the peak negative pressure develops just below the point of inlet. This differential behaviour under steady flow and under fixture discharge conditions can be explained for the reason that in case of fixture discharges it takes little fall before reaching steady flow stage. In the initial stage when the water enters the stack from the branch the velocity rapidly increases to terminal velocity. The flow condition is also turbulent when it enters the stack, occupying almost the entire cross sections of the stack. The flow condition rapidly changes to steady flow in the form of an anular ring, by the time it passes down by one floor height. In the initial stages when the flow changes from turbulent to anular ring, the release of air to the central core slightly reduces the negative pressure. But as soon as the terminal velocity is reached and the flow becomes steady the water flowing down exerts a drag force on the central air core and drags it down; causing a sudden increase in the negative pressure to its peak value. Therefore the fixture discharge loads in the stack produce three zones of turbulent, transition and steady flows (Fig. 1). But in cases of steady (continuous) flow loads the earlier zones of turbulet and transition are absent

In both the cases from the point of occurrence of the peak negative pressure, the negative pressure steadily reduces to zero lower in the ground floor zone and further steadily increases to a positive pressure at the foot of the stack. The extent of positive pressure developed depends on the radius of the bend at the foot of the stack and on the number of bends and length of the horizontal drain. The work done abroad have shown that large radius bends (about 3 times the diameter) or 2 number of 135° bends are adequate to keep the positive pressure within the limit of 40 mm (1.5 inches) of water gauge. Therefore in the present investigations attention has been given to only peak negative pressures.

Inter-relationship of Peak negative pressure, flow, and diameter :

In single stack system the peak negative pressure, which is most critical, should be kept within the limits It is already said that the critical position occurs where the water just starts flowing down in the form of steady anulɑr ring at terminal velocity. Hence it can be said that the peak negative pressure developed is a function of terminal velocity.

i.e. $h = \theta (V_T)$ ... (2)

where h=peak negative pressure

But $V_T = \theta (Q/D)$ from equation (1)

$\therefore$ $h = \theta (Q/D)$ (3)

The above expression (3) is in confirmation of the known facts that for a given stack as the flow increases the peak negative pressure developed increases and also that for a given flow the peak negative pressure reduced as the diameter of the stack employed increases, due to the availability of larger anular ring (π D). To put the expression (3) in the form of a regular equation, one more fact has to considered that when the flow is absent the negative pressure developed is also zero. Therefore the following equation (4) can be used for expressing the inter relationship of peak negative pressure, flow and diameter of the stack.

$\therefore$ $h = C\ (Q/D)^n$ ....(4)

The values of peak negative pressures observed for various hydraulic fixture discharge loads are given in the Table II—B

TABLE II—B

Diameter of stack (D in ~~inches~~ mm)	Hydraulic load Q (1/min)	Q/D	Peak negative pressure h (in cms)
100	110	1.1	1,6
100	140	1.4	2.14
100	175	1.75	2.80
100	225	2.25	3.6
100	255	2.55	4.1
100	290	2.90	4.8
100	340	3.40	8.0

From the above table values of Q/D and 'h' are plotted as shown in Fig. 2. This figure also clearly shows that h is a power function of (Q/D) confirming the equation (4).

An attempt was made to statistically fit the equation (4) for the data in Table II and the final expression is given below.

$h = 1.33\ (Q/D)^{1.34}$ ... (5)

The following Table III shows the validity of the above equation (5), which is fairly good.

TABLE III

Observed Q/D	Observed h (in cms)	Calculated 'h' from equation (5) in cms.
1.1	1.6	1.51
1.4	2.4	2.09
1.75	2.80	2.81
2.25	3.60	3.97
2.55	4.10	4.66
2.90	4.80	5.54
3.40	8.00	6.85

Recommendations for Limiting Capacities of Single Stack

For any predetermined permissible limit of negative pressure, a corresponding permissible Q/D value can be taken from the Fig. 2. Considering a negative pressure of 40 mm ($1\frac{1}{2}''$) of water gauge, the permissible Q/D value is 2.5 from Fig. 2. Therefore in any single stack system the hydraulic fixture discharge load in litres/minute should not exceed 2.5 times the diameter of the stack in mm. However, in these cases it is essential that all floor traps and W.C. traps connected to the stack should have a minimum of 50 mm deep water seals. For interpreting these results in the form of permissible height of the stack expressed in number of storeys, the National Bureau of Standards of U.S.A. and Building Research Station of U. K. give certain guide lines.

Both recommendations are based on the principle of assigning certain weightage for various appliances depending upon their frequency of use and rate of discharge. How-

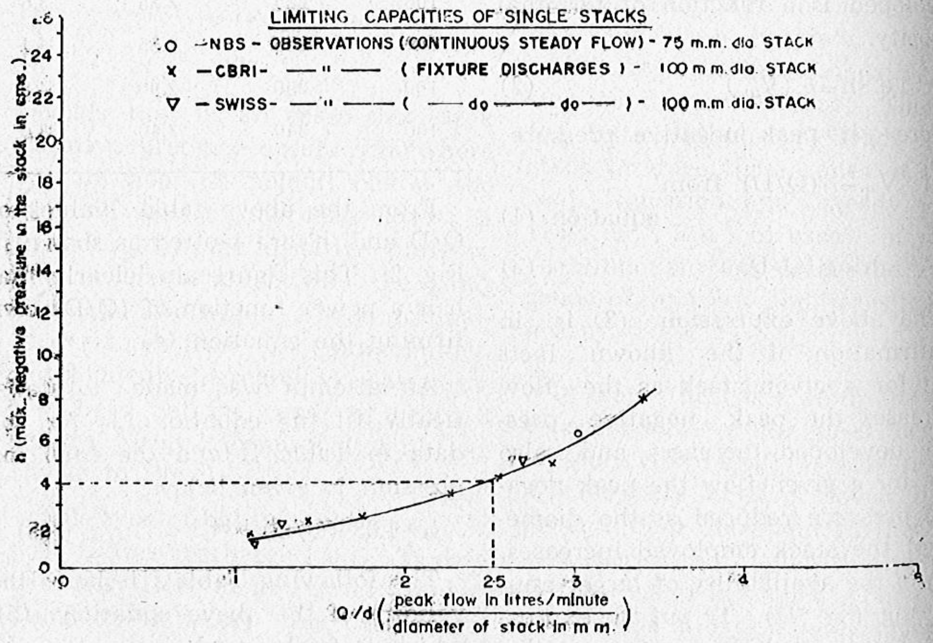

Fig. 2

ever, these recommendations vary in their weightage numbers of appliances due to the variations in the frequencies and discharge rates considered. The Table IV shows the limiting capacities of stacks expressed in terms of permissible number of storeys.

TABLE IV

Diameter of stack in mms	Permissible flow Q in l/min.	Permissible number of storeys	
		Recommendation A	Recommendation B
100	250	9	11
125	315	15	20
150	375	23	29

In the above table the recommendation A is based on the NBS guide lines for converting flow into equiplent number of groups of appliances with one group at each floor. A single group consisting of a water closet (flush-valve operated) a bath tub or shower stall, a wash basin and a domestic sink. The recommendation B is based on the BRS guide lines for converting flow into number of storeys, assuming that at each storey there is a group of appliances of 3 gallon W.C. bath, basin and sink. These interpretations have to be taken with considerable reservations for use in India, as the frequency of use of appliances considered by them may not suit our conditions. However until further extensive surveys are carried out and the data on frequency of use are established the recommendation A, which is more conservative can be used. In recommendation A it is assumed that a W.C. is flushed once in every five minutes, whereas in B it is once in 19 minutes. Another built in safety of this principle, common to both recommendations, is the assumption that the peak use of all types of appliances occur simultaneously, whereas in practice there would be considerable differences of time between the peak use of W.Cs baths, sinks etc.

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