Mech. Engg. Res. Bull.
Vol. 14 (1991), pp 8-23

Static Pressure Distributions for Cross Flow on Rectangular Cylinders

A. M. Tito Islam*
A. C. Mandal*

ABSTRACT

Static pressure distributions on a group of rectangular cylinders for a uniform cross flow is presented. The effect of side ratios and longitudinal spacing on pressure distribution is taken into consideration. Non-dimensional parameters, e.g. lift and drag coefficients are also presented which are calculated from the measured pressure distributions.

INTRODUCTION

A study of cross flow on a group of rectangular cylinders has considerable practical significance. Recent engineering problems regarding wind loads around a group of skyscrapers, chimneys, towers etc. require detailed investigation of flow patterns and aerodynamic characteristics on bluff bodies. For designing a group of tall buildings, knowledge of the effect of wind loading on a single tall building is insufficient because the interference of the neighbouring buildings in a group makes the nature of wind loadings different from that on a free-standing building. Apart from wind loading problems, concentration of high rise buildings in a locality can produce environmental problems like unpleasant wind conditions near ground level (e.g. blowing dust off the ground), too high wind load on people, too high wind speed in streets and passages or stagnation of air in certain areas causing air pollution.

Till now extensive research work has been carried out on an isolated bluff body. Study on bluff bodies which interfere with each other is also an important one. M. Hayashi, Akirasakurai & Yujiohya (1986) made experimental investigation into the wake characteristics of a group of flat plates. P.W. Bearman and A.J. Wadcock (1973) described the flow characteristics around two circular cylinders displaced in a plane normal to the free stream. However, study concerning the flow over group of rectangular cylinders, is not enough.

It is expected that when more than one bluff body is placed in a uniform flow, the surrounding flow and vortex shedding patterns would be different from those on a single body, because there would be interference in the flow by one body on the other depending on the arrangement or spacings of the bodies. The present study is an experimental investiation and it is confined to determination of pressure distributions on a group of rectangular cylinders with change in side dimension as well as longitudinal spacings.

NOMENCLATURE

A	Area
H/D	Side ratio of cylinder
C_D	Drag Coefficient
L_l	Longitudinal Spacing
C_L	Lift Coefficient
L_t	Transverse Spacing
C_p	Pressure Coefficient
P	Local Static Pressure
D	Width of Cylinder
P_o	Free Stream Static Pressure
F_D	Drag Force
U_o	Free stream velocity
F_L	Lift Force
H	Breadth of Cylinder
α	Angle of attack
ρ	Density of air

EXPERIMENTAL SET-UP AND PROCEDURE

The experiment was carried out in an open circuit subsonic wind tunnel with a test section of 457.2mm x 457.2mm (18 inch x 18 inch) cross section. Twelve cylinders of rectangular cross section were considered for the study. The cylinders were made of perspex. Four sets of cylinders were used with three identical ones in each set. The cylinders spanned 457.2mm each and their side dimensions were: width D=30mm for each, breadth H=37.5mm, 45mm, 52.5mm and 60mm. Each rectangular cylinder was tapped on two adjacent sides to measure pressure distribution. Flexible tubes of 1.6mm outer diameter were used for connecting the tappings to the limbs of a multimanometer. Water was used as the manometric liquid.

Three rectangular cylinders, each of side dimension D=30mm and H=37.5mm having side ratio H/D=1.25 were placed in the staggered form as shown in figure 1. These were so positioned that the 30mm side of each of the cylinders was kept normal to the approach velocity direction. Initially the cylinders were mounted in such a way that the transverse spacing between the downstream cylinders and the longitudinal spacing between the front and downstream cylinders were 1D. Since the top downstream cylinder (T) and the bottom downstream cylinder (B) were symmetrically placed, the pressure distribution were measured on the bottom cylinder only.

The transverse spacing (L_t) was kept constant at 1D while the longitudinal spacing (L_l) was changed to 1D, 2D, 3D, 5D and 7D. At zero angle of attack mean pressure distribution were measured for each of the above mentioned five sets. Pressure was measured simultaneously for both the upstream and downstream cylinders.

Pressure distributions for the cylinders with side ratios of 1.5, 1.75 and 2.0 were measured in a similar manner.

The flow velocity in the test section was maintained constant at 18.3m/sec. The Reynolds number based on the side dimension D=30mm was 3.45×10^4. The turbulence intensity of the tunnel was approximately 0.33%.

For the present analysis, the pressure coefficient is defined as,

$$C_p = \frac{P - P_o}{\frac{1}{2}\rho U_o^2} \quad (1)$$

The drag and lift coefficient are defined respectively by the following equations,

$$C_D = \frac{F_D}{\frac{1}{2}\rho A U_o^2} \quad (2)$$

$$C_L = \frac{F_L}{\frac{1}{2}\rho A U_o^2} \quad (3)$$

The C_p, C_D and C_L values were determined by numercial integration using Simpson's rule.

RESULTS & DISCUSSIONS

The pressure distribution around the upstream cylinder with side ratio of H/D = 1.25 for varying longitudinal spacing L_l, keeping the transverse spacing constant at L_t = 1D are shown in figure 2. It is observed from this figure that for each longitudinal spacing L_l, the pressure distributions on the top and bottom surfaces are symmetrical. It may be noted that at L_l = 7D, the pressure on the back, top and bottom surfaces are the lowest. As the upstream cylinder is brought closer to the downstream cylinders the pressure tend to increase on all these surfaces upto the spacing L_l=1D. Due to the proximity of the cylinders, the flow becomes turbulent. This leads to the exchange of momentum between the fluid particles causing rapid pressure recovery on the top, bottom and back surfaces of the upstream cylinder. With the increase in distance (L_l) this effect is minimised. At L_l = 7D it becomes negligible and the pressure distributions at this distance approaches to those on an isolated cylinder [Islam et al(1990)].

The figures 3, 4 and 5 show the C_p-distributions on the upstream cylinder for the side ratios (H/D) of 1.5, 1.75 and 2.0 respectively. For the constant transverse spacing of 1D between the downstream cylinders, more or less similar pattern of C_p-distributions are observed on the upstream cylinder for various side ratios (H/D).

The Cp-distributions on the bottom downstream cylinder with side ratio of H/D = 1.25 for varying longitudinal spacing (L_l) keeping the transverse spacing constant at L_t = 1D is shown in the figure 6. It is observed from this figure that when L_l=1D the value of C_p rises close to unity on the front surface near the bottom corner. For the spacings of L_l = 2D and 3D the pressures on the front surface are negative and show a rising tendency towards the bottom corner. For larger longitudinal spacings the pressures on the front surface are positive but they differ much from those on the front surface of an isolated cylinder. When the downstream cylinder is closer to the upstream one, the front face of that cylinder remains in the wake region, which is the cause of negative pressure on the front face. However, for spacing L_l = 1D the bottom corner of the downstream cylinder does not fall in the wake

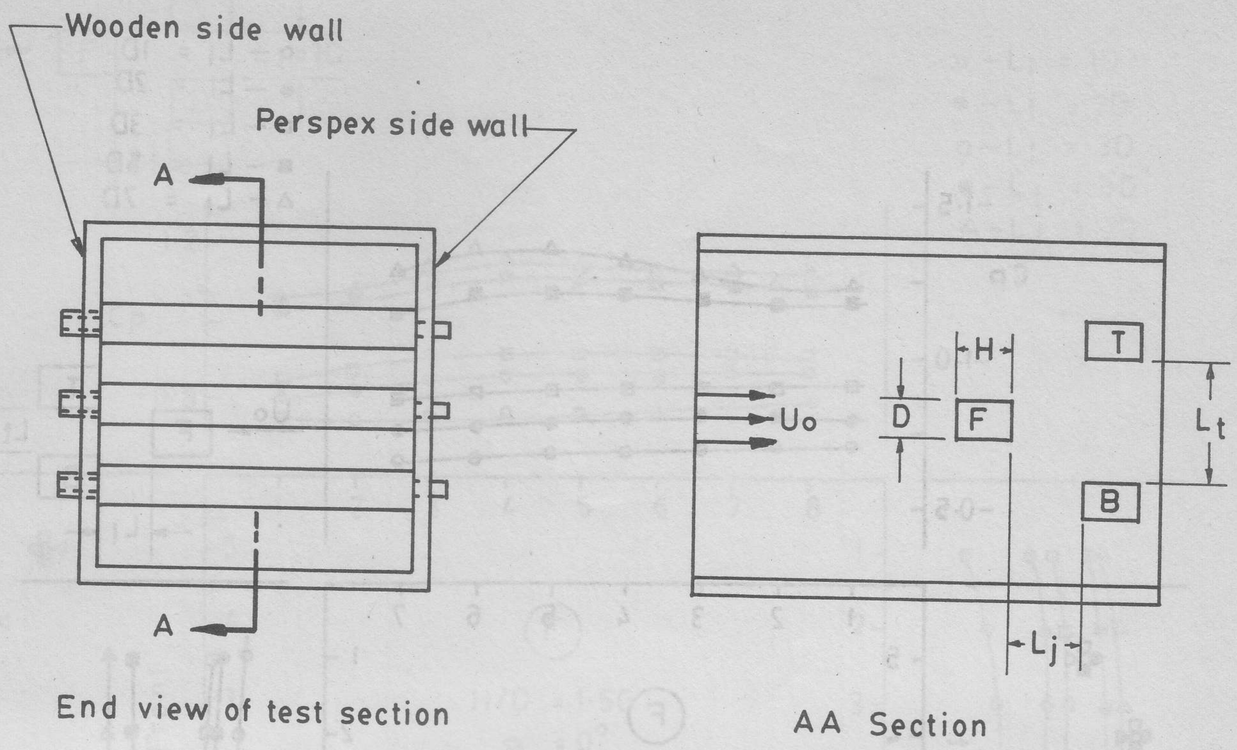

Figure 1 : Tunnel test section showing the position of cylinders in staggered form

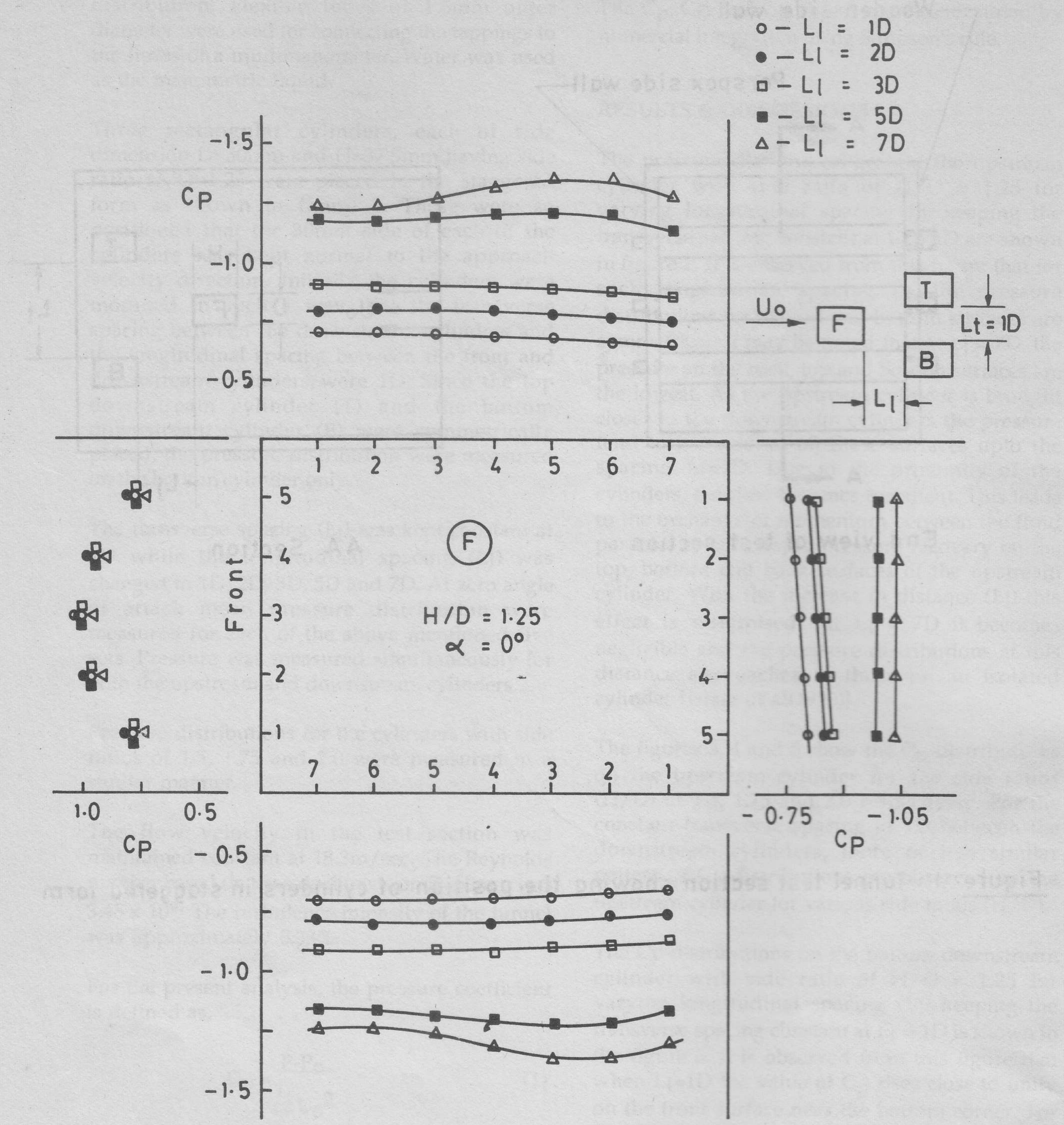

Figure 2 : Effect of longitudinal spacing (L_l) on CP-values for upstream cylinder with side ratio (H/D) of 1.25 keeping tranverse spacing (L_t) constant at 1D

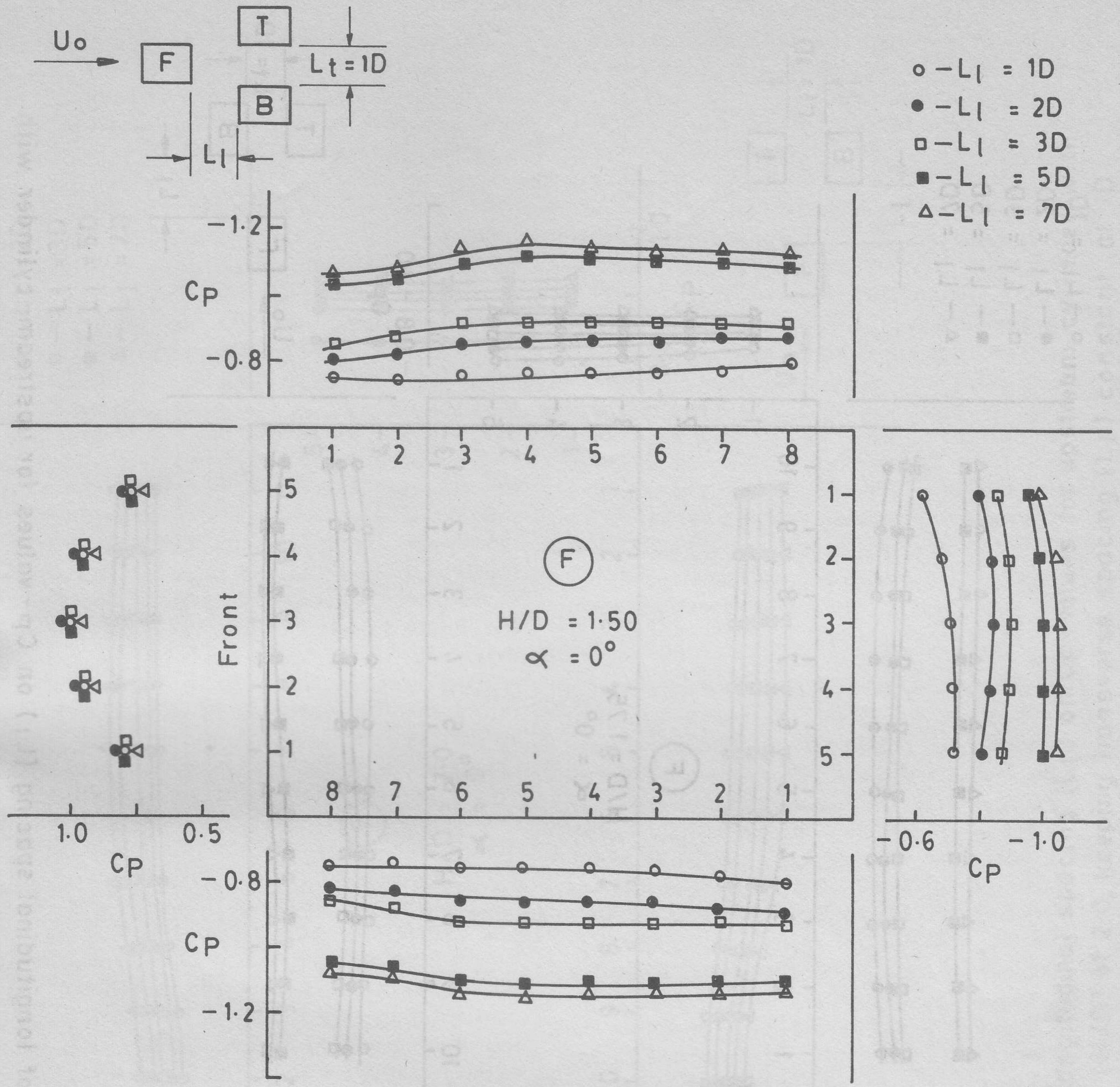

Figure 3: Effect of longitudinal spacing (L_l) on C_P-values for upstream cylinder with side ratio (H/D) of 1·25, keeping transverse spacing (L_l) constant at 1D

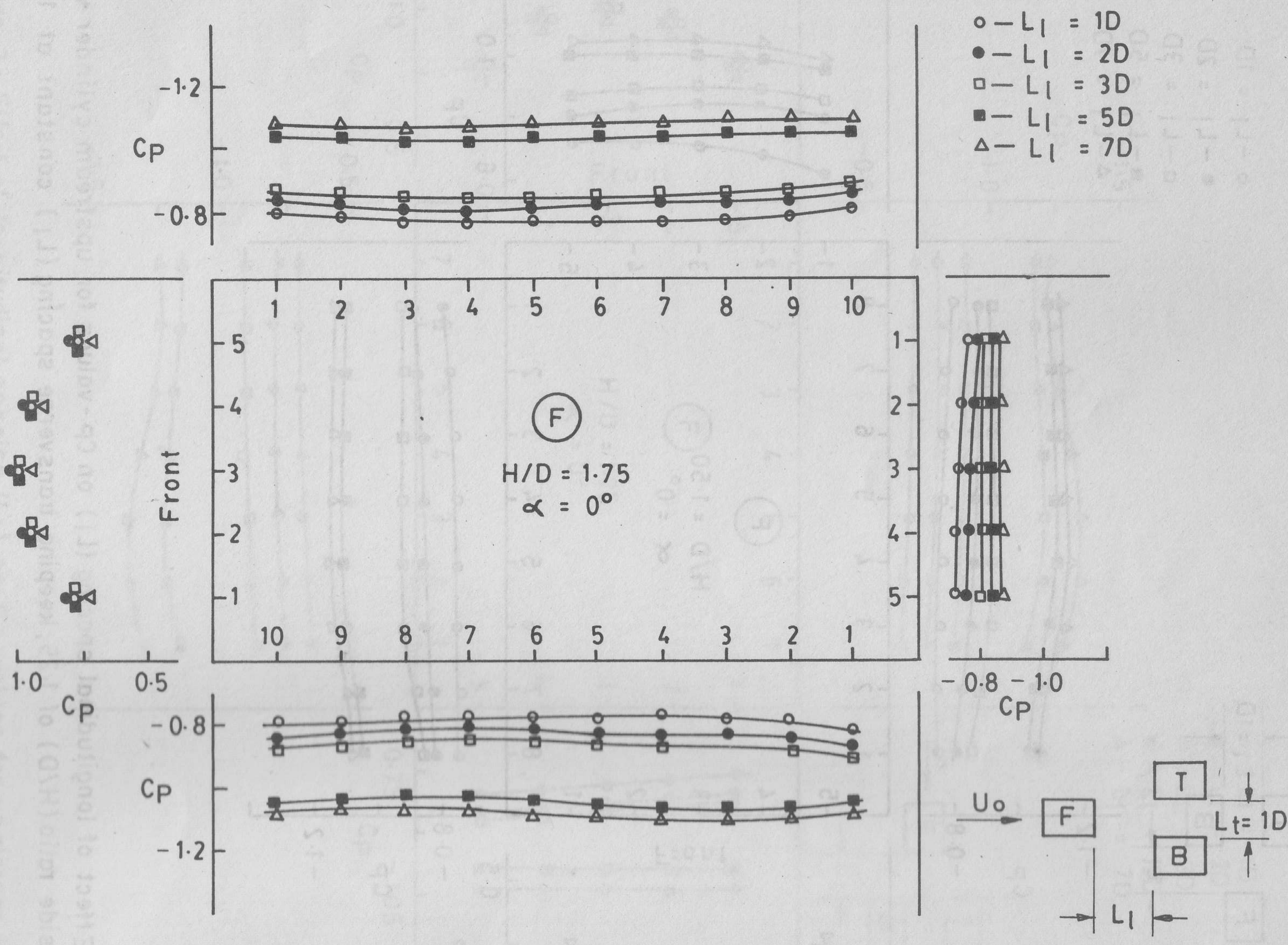

Figure 4 : Effect of longitudinal spacing (L_l) on Cp-values for upstream cylinder with side ratio (H/D) of 1·75, keeping tranverse spacing constant at 1D

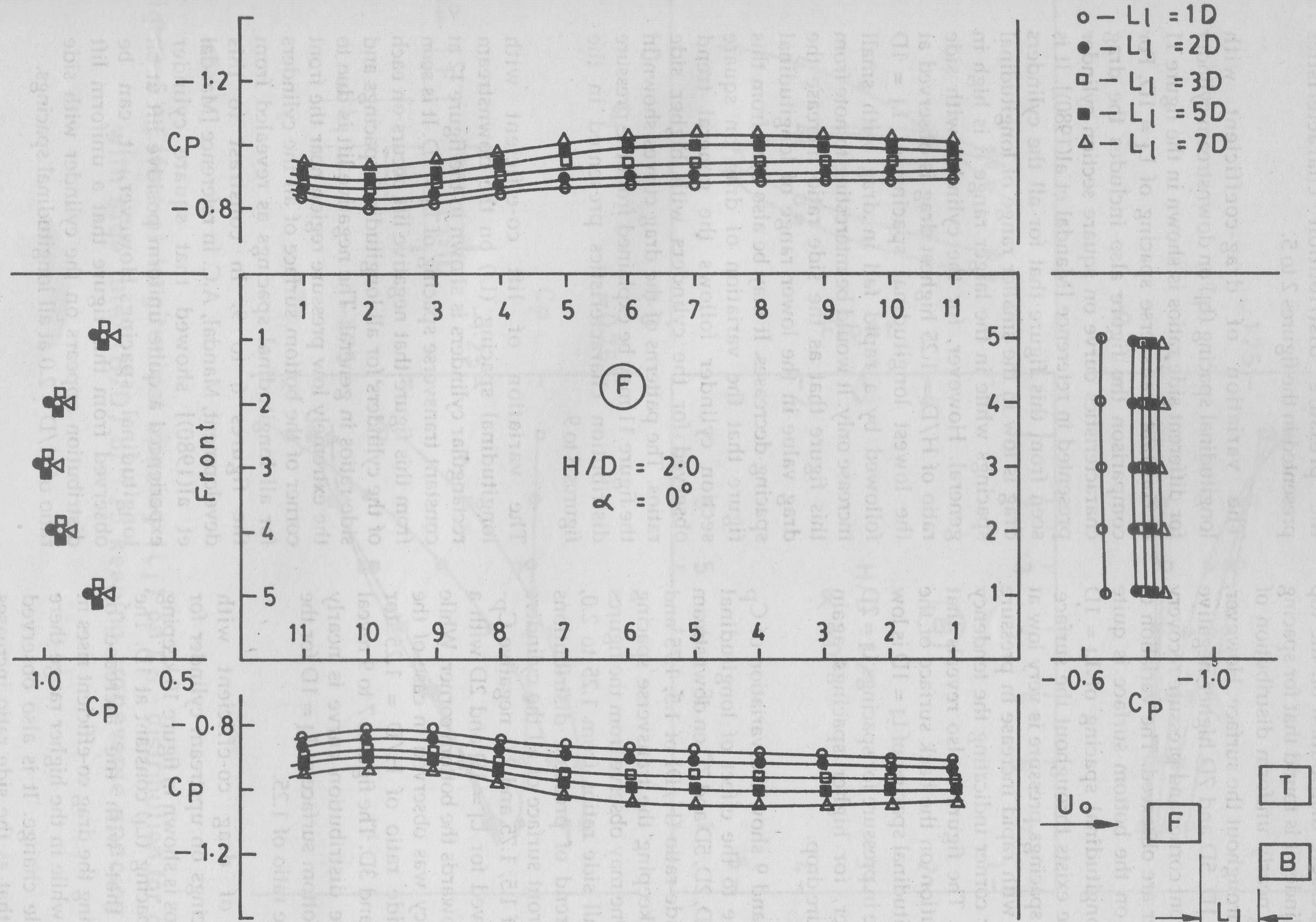

Figure 5 : Effect of longitudinal spacing (L_l) on Cp-values for upstream cylinder with side ratio (H/D) of 2·0, keeping transverse spacing (L_l) constant at 1D

region of the upstream cylinder and thus a stagnation point is established near that corner.

Observing the pressure distribution on the top surface of the cylinder it is found that for spacing L_l = 2D and 3D nearly uniform distribution of pressure occur throughout the surface. However, for spacing L_l = 1D, 5D and 7D higher negative pressure at the front corner and pressure recovery at the rear corner are observed. The variation of C_p-distribution on the bottom surface is quite different. For longitudinal spacing of L_l = 1D uniform pressure exists throughout the surface. While for larger spacings pressure is very low at the front corner with rapid increase in pressure towards the rear corner indicating the tendency of reattachment. The figure 6 also reveals that pressure distribution on the back surface of the cylinder for longitudinal spacing of L_l = 1D is low followed by a rise in pressure for spacings L_l = 2D and 3D.However, for higher spacings again there occur pressure drop.

The figures 7, 8 and 9 show the variation of C_p distributions due to the effect of longitudinal spacings of L_l = 1D, 2D, 5D and 7D on downstream cylinders with side ratio (H/D) of 1.5, 1.75 and 2.0 respectively keeping the transverse spacing constant at 1D. One may observe from the figures 6 to 9 that for all side ratios from 1.25 to 2.0, nearly similar trend of pressure distributions appear. On the front surface of all the cylinders with side ratio of 1.5, 1.75 and 2.0, negative C_p-values are observed for L_l = 1D and 2D with a rise in pressure towards the bottom corner. While the same tendency was observed in case of the cylinder with side ratio of H/D = 1.25 for distance L_l = 2D and 3D. The figures 7 to 9 reveal that the pressure distribution curve is nearly uniform on the bottom surface at L_l = 1D for the cylinder with side ratio of 1.25.

The variation of drag co-efficient with longitudinal spacings on upstream cylinder for different side ratios is shown in figure 10 keeping the transverse spacing (L_t) constant at 1D. The figure reveals that with the increase of longitudinal spacing the drag co-efficient rises in the lower range, while in the higher range there is not appreciable change. It is also observed from this figure that as the side ratio increases the drag decreases in general. The variation of drag co-efficient with longitudinal spacing on square section cylinder presented in reference [Mandal et al(1980)] is also shown in this figure for comparative study. It is observed from this figure that in the higher range of longitudinal spacing the cylinder with side ratio of 1 experience maximum drag. The pattern of the curves in this figure 10 may be explained from the pressure distribution characteristics presented in the figures 2 to 5.

The variation of drag-coefficient with longitudinal spacing (L_l) on downstream cylinder for different side ratios is shown in the figure 11 at constant transverse spacing of L_t = 1D. For comparison the figure also includes the drag characteristics curve on square section cylinder presented in reference [Mandal et al(1980)]. It is seen from this figure that for all the cylinders drag is low in the smaller range of longitudinal spacings while in the larger range it is high in general. However, for the cylinder with side ratio of H/D = 1.25 highest drag is observed at the lowest longitudinal spacing of L_l = 1D followed by a rapid fall in drag with small increase only. It would be interesting to note from this figure that as the side ratio increase the drag value in the lower range of longitudinal spacing decreases. It may be also seen from this figure that the variation of drag on square section cylinder follows the general trend observed for the cylinders with higher side ratios. The patterns of the drag curves shown in the figure 11 may be explained from the pressure distribution characteristics presented in the figures 6 to 9.

The variation of lift co-efficient with longitudinal spacing (L_l) on the downstream rectangular cylinders is shown in the figure 12 at constant transverse spacing of L_t = 1D. It is seen from this figure that negative lift occurs on each of the cylinders for all longitudinal spacings and side ratios in general. The negative lift is due to the extremely low pressure region near the front corner of the bottom surface of all the cylinders for all longitudinal spacings as revealed from the figures 6 to 9. In constrast to this development, Mandal, A.C. in reference [Mandal et al(1980)] showed that square cylinder experienced a quite uniform positive lift at all longitudinal spacings.However, it can be observed from this figure that a uniform lift distribution appears on the cylinder with side ratio of H/D = 2.0 at all longitudinal spacings.

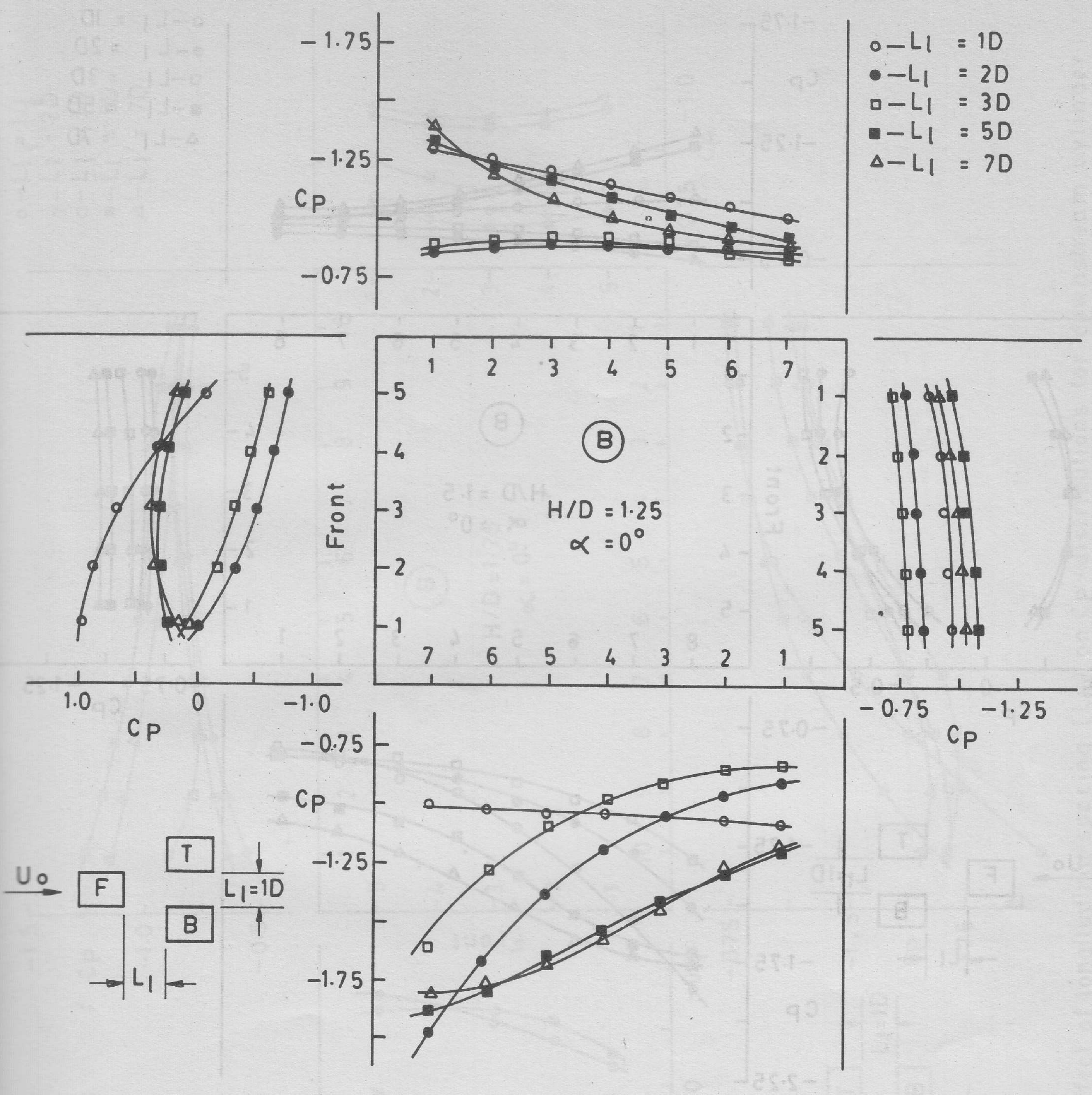

Figure 6 : Effect of longitudinal spacing (L_l) on C_P - distribution for downstream cylinder with side ratio (H/D) of 1.25 keeping transverse spacing (L_t) constant at 1D

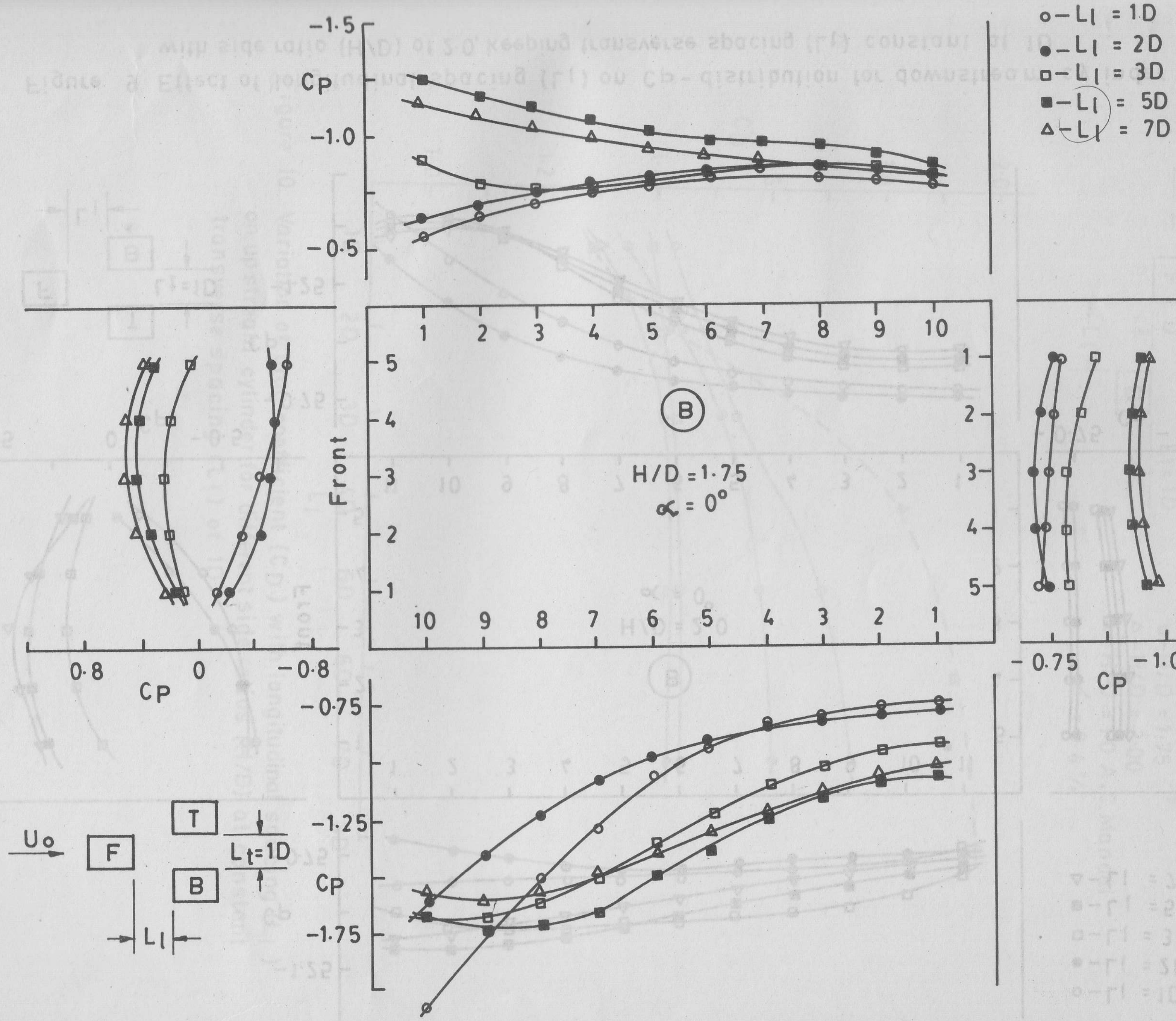

Figure 8 : Effect of longitudinal spacing (L_l) on Cp-distributions for downstream cylinder with side ratio (H/D) of 1·75, keeping tranverse spacing (L_t) constant at 1D

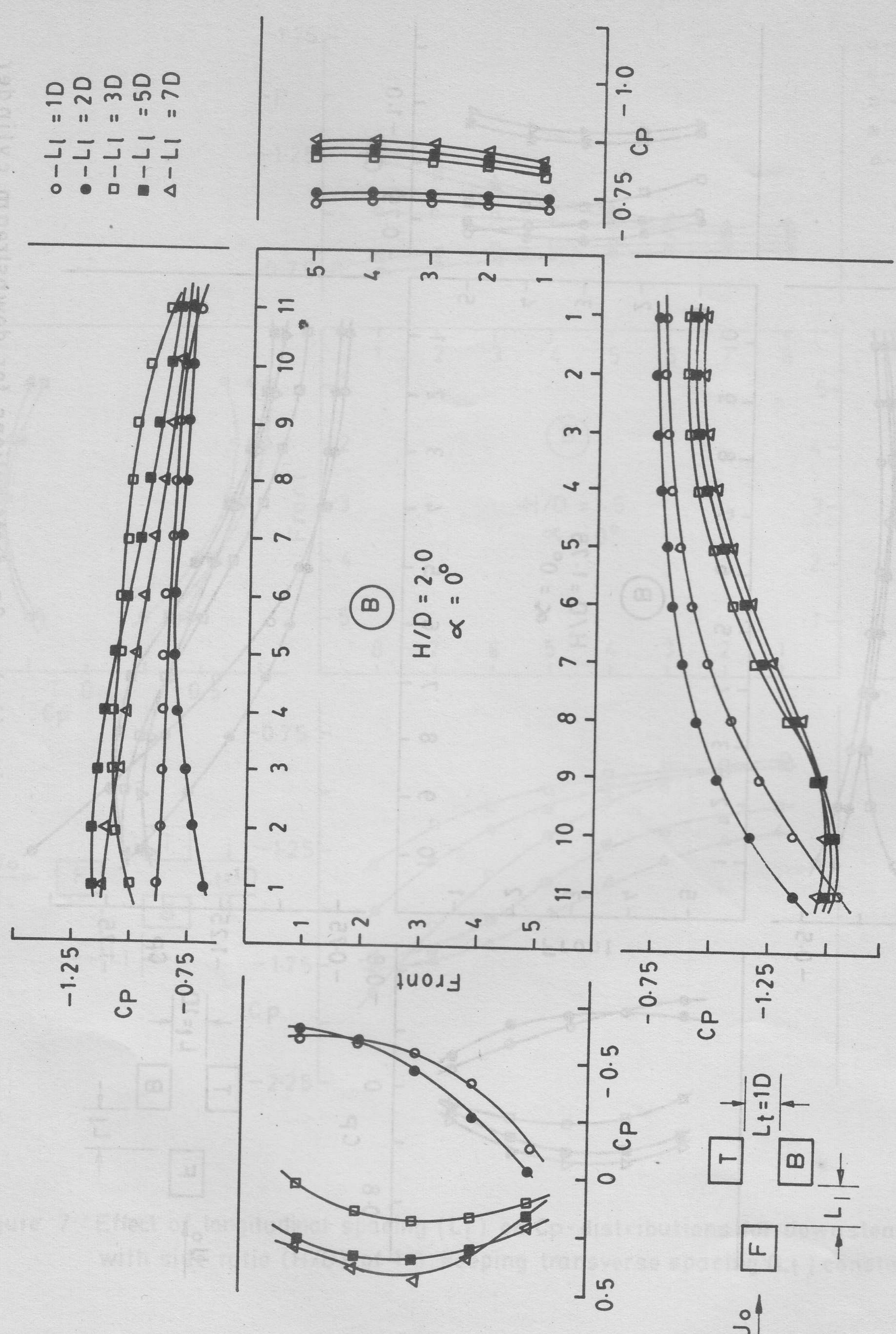

Figure 9 Effect of longitudinal spacing (L_l) on C_P - distribution for downstream cylinder with side ratio (H/D) of 2·0, keeping transverse spacing (L_t) constant at 1D

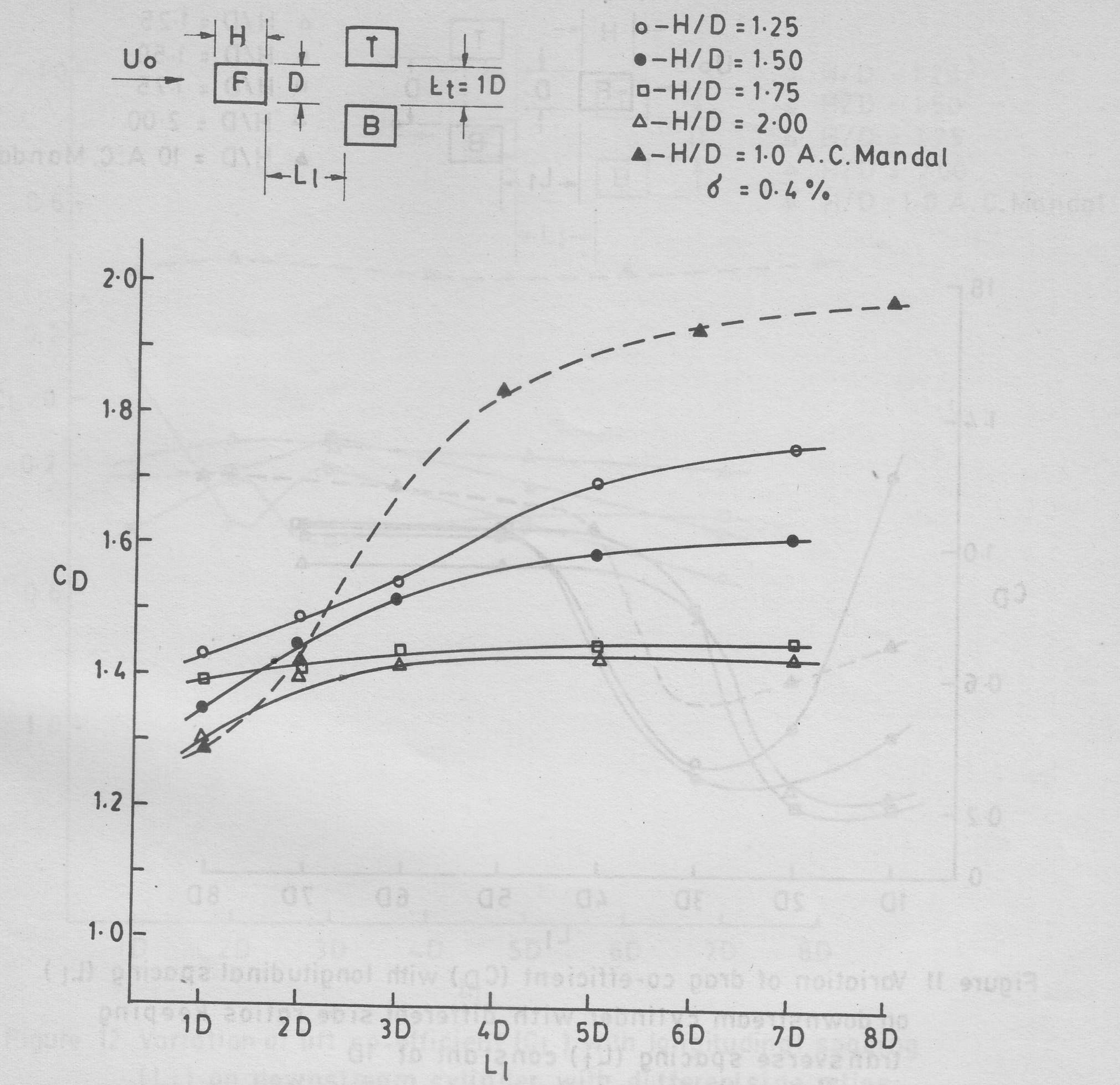

Figure 10 Variation of drag coefficient (C_D) with longitudinal spacing (L_l) on upstream cylinder for different side ratios (H/D) at constant transverse spacing (L_t) of 1D

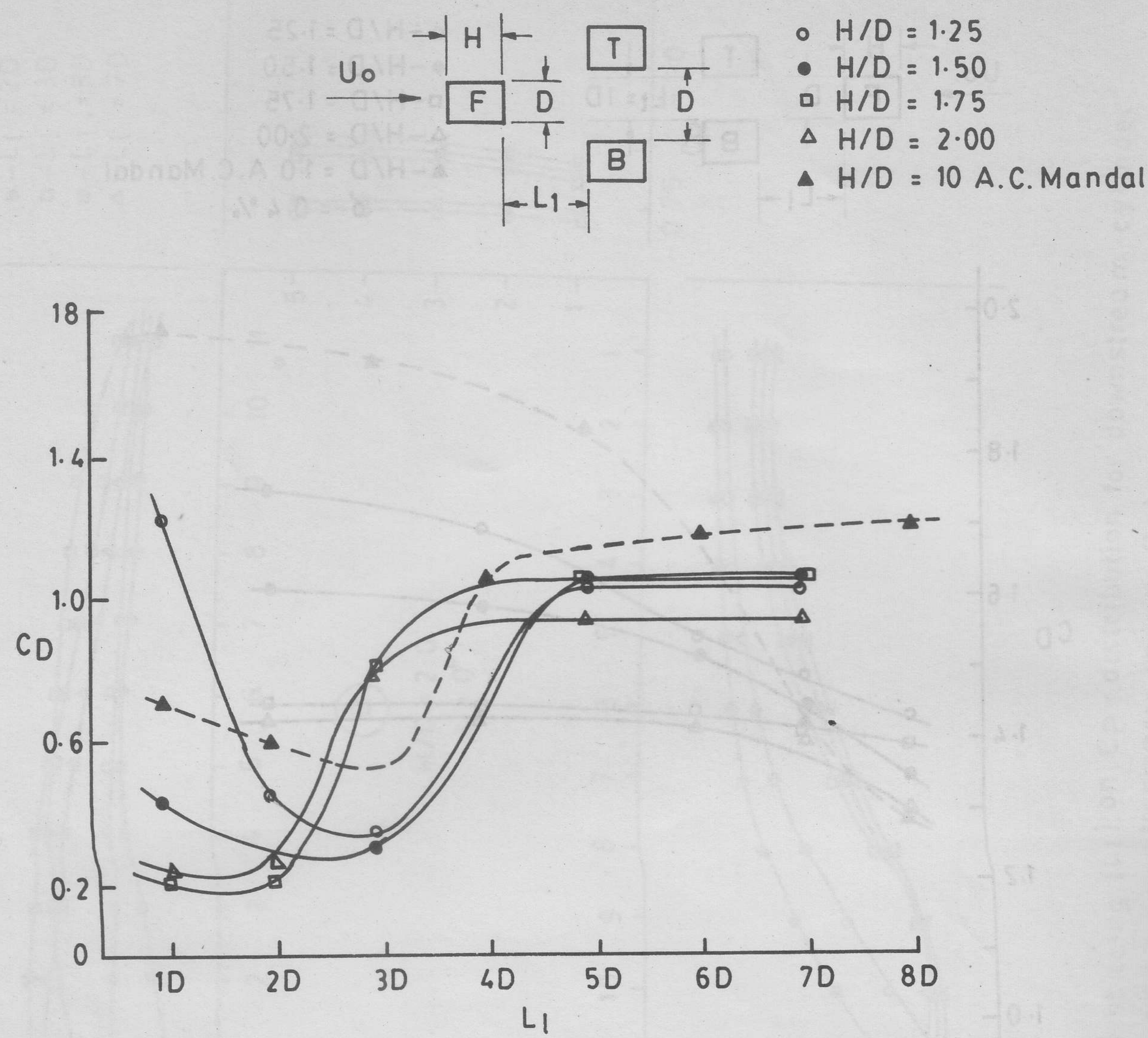

Figure 11 Variation of drag co-efficient (C_D) with longitudinal spacing (L_l) on downstream cylinder with different side ratios keeping transverse spacing (L_t) constant at 1D

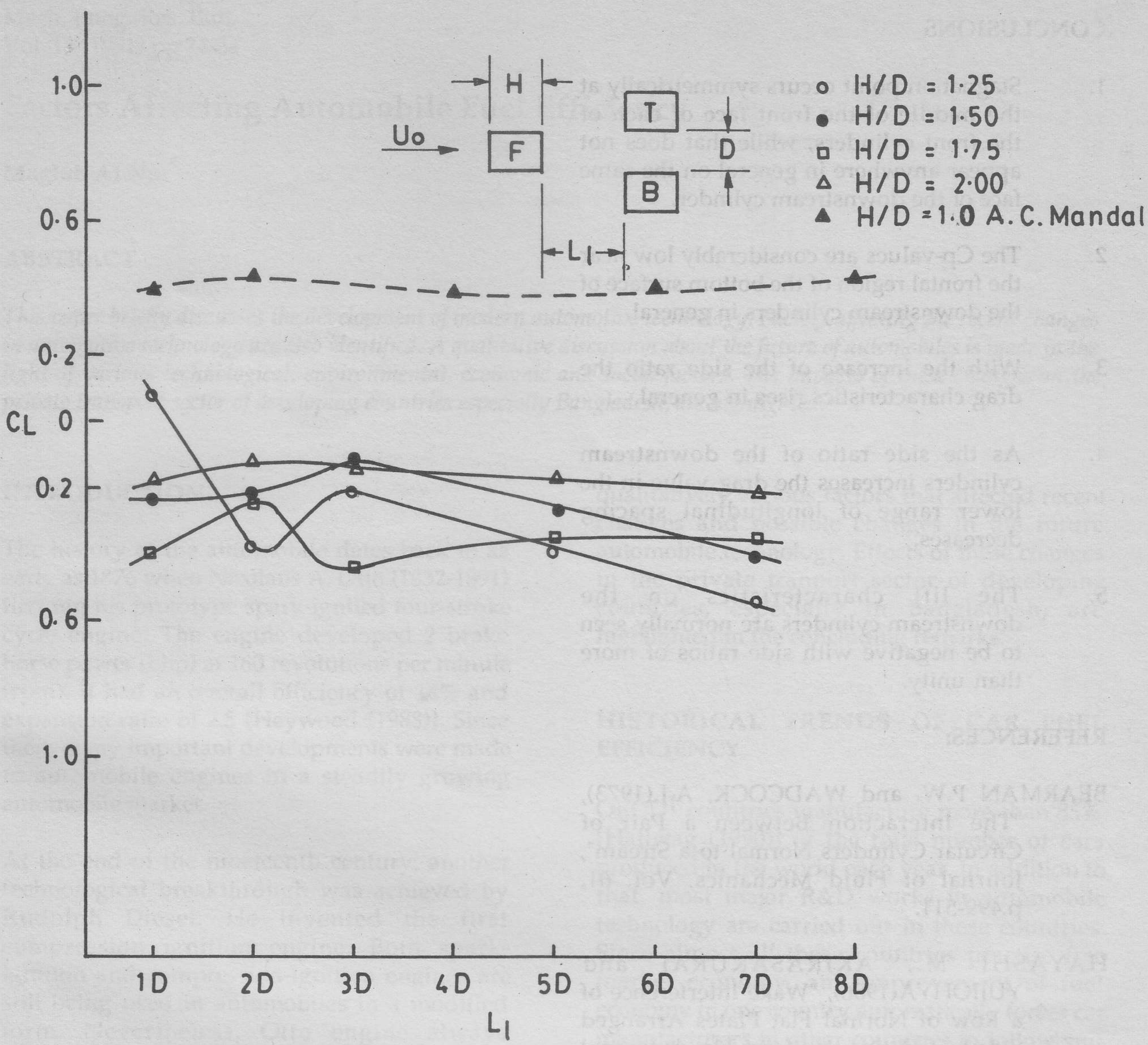

Figure 12 Variation of lift co-efficient (C_L) with longitudinal spacing (L_l) on downstream cylinder with differentside ratios keeping transverse spacing (L_t) constant at 1D

CONCLUSIONS

1. Stagnation point occurs symmetrically at the middle of the front face of each of the front cylinders, while that does not appear anywhere in general on the same face of the downstream cylinder.

2. The Cp-values are considerably low near the frontal region of the bottom surface of the downstream cylinders in general.

3. With the increase of the side ratio the drag characteristics rises in general.

4. As the side ratio of the downstream cylinders increases the drag value in the lower range of longitudinal spacing decreases.

5. The lift characteristics on the downstream cylinders are normally seen to be negative with side ratios of more than unity.

REFERENCES:

BEARMAN P.W. and WADCOCK, A.J.(1973), "The Interaction Between a Pair of Circular Cylinders Normal to a Stream", Journal of Fluid Mechanics, Vol. 61, p.499-511.

HAYASHI M., AKIRASAKURAI and YUJIOHYA(1986), "Wake Interference of a Row of Normal Flat Plates Arranged Side by Side in a Uniform Flow", Journal of Fluid Mechanics, Vol. 164, p.1-25.

ISLAM, A.M. TITO and MANDAL, A.C.(1990), "Flow Characteristics on a Rectangular Cylinder with Variable Angle of Attack and Side Dimension", Mechanical Engineering Research Bulletin, Vol. 13.

MANDAL, A.C. and ISLAM, O.(1980), " A Study of Wind effect on a Group of Square Cylinders with Variable Longitudinal Spacing", Mechanical Engineering Research Bulletin, Vol. 3.