FLOW RESISTANCE DUE TO FLOATING PARTIAL ICE COVERS

by

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ABSTRACT

This paper presents the results of a laboratory flume study aimed at estimating the flow resistance under a floating partial ice cover (simulated). These findings are compared to the summarized results from an earlier study which estimated the flow resistance under a fixed, partial ice cover (simulated). Both floating and fixed partial cover conditions were studied by varying: 1) percentage cover (0-100%), 2) depth of flow (127-254 mm) and 3) average velocity (0.40-1.20 m/s).

The results from these studies indicated that the maximum resistance occurred between 35-45 percent cover for floating partial covers and 45-55 percent cover for fixed partial covers. The maximum resistance ratio Nc/No (composite resistance coefficient over the resistance coefficient for open channel conditions) was found to be 1.55 for floating partial covcers and 1.56 for fixed partial covers. This would mean that Nc composite Manning coefficient) was 0.031 and 0.036 for floating and fixed partial covers respectively. This information should be of interest to river managers and engineers since the design information on this topic is very limited.

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1. INTRODUCTION

In northern climates, such as that in Canada, the formation of ice covers on rivers and streams is a regular winter phenomenon. Partial ice cove, a transition condition between open and covered channel conditions, is one of the different forms of ice cover possible. Information concerning flow resistance under partial ice cover is required for effective control and management at rivers during winter; also, for design purposes. Currently such information is scarce in literature.

In 1982 a study was implemented at the University of New Brunswick which examined flow resistance for various degrees of a fixed partial cover; a detailed report of this study was published as a Master of Science Thesis in 1982 titled "Resistance to flow in partially-covered channels" (Tang, 1982). One of the recommendations made at the end of that study was that the experiments be extended to floating partial cover conditions. This study implemented that recommendation.

1.1 Objectives of Study

The principal purpose of this study was to determine the resistance effects of a floating-partial cover for:

a) Different degrees of partial cover,
b) For a specified degree of partial cover, investigate the effects of variation of depth,
c) For specified degree of partial cover and depth of flow, investigate the effects of variation of velocity.

These resistance effects were to be compared to those for flows in open channels and flows under a fixed partial cover, for similar conditions.

1.2 Scope of Study

In this laboratory investigation experiments were conducted in a 12 m long, 0.305 m wide rectangular flume with various degrees of simulated ice-cover. The study was limited to five degrees of cover, with three flow depths and generally two to four velocities for each depth. The openings in the covers were of fixed shape and arranged in a symmetrical pattern, while the size of the openings were varied to achieve the required percentage of cover.

In this study the same flume and sets of cover were used as in the previous study in order to obtain an optimum comparison.

The analysis of the resistance phenomena was primarily based on the Manning's equation. The resistance characteristics of the top cover were calculated using the conventional approach of analyzing the composite resistance of a covered channel. Briefly, this procedure consists of partitioning the channel into two zones, contiguous at the plane of maximum velocity, and analyzing them as two separate channels.

1.3 Limitations

The experiments cannot be strictly considered a model study simulating flow resistance of partial ice covers in natural streams; the pattern of ice-cover openings in nature are never as regular as the ones in the laboratory. However, this study should help provide a better understanding of the flow resistance phenomena, and provide valuable design information for river engineers, particularly, the maximum resistance characteristics while the stream regime is changing from the open to ice-covered condition.

2. EXPERIMENTAL APPROACH

In this section the equipment and procedures used in the experiments are outlined. All the experiments were conducted in the Hydraulic Laboratory of the University of New Brunswick.

2.1 Experimental set-up and equipment

The experiments were conducted in a 12 m long rectangular flume with a channel width of 0.305 m. The slope of the flume was controlled with two sets of hydraulic cylinders which were operated from a master control console. The slope of the energy line for the flow was calculated with the use of two 76.2 mm diameter stilling wells. A 1.52 m high head tank was used to provide as constant a head as possible for the flume channel. A baffle system was installed to reduce the turbulence generated in the head tank; this system worked well.

A sheet of expanded metal with an average height of 10 mm, was placed on the flume bed to increase the bed resistance in relation to the plexiglass side walls. This was done to justify the assumption of two dimensional flow. At the end of the flume a vertical tailgate, manually controlled with the use of a hydraulic cylinder, was used to eliminate draw down. A KENT velocity probe coupled to a NIXON model 402 digital output indicator, was used to measure local velocities. A MARSH McBIRNEY model 201 M electromagnetic velocity meter was used, in a fixed location, to monitor the constancy of the flow.

2.2 Channel Cover System

Four different sets of covers were built from 9.5 mm thick plywood and 50 mm thick styrofoam. The dimensions and arrangement of the openings in the covers are shown in Fig. 7. In order to obtain the desired degree of submergence, i.e. simulating the density of ice, bags filled with gravel were placed, evenly spaced, on top of the covers.

2.3 Program of Investigations

Five different cover conditions were studied: 0, 25, 50, 75 and 100% cover. For each of these cover conditions three flow depths, 127 mm, 191 mm and 254 mm, were studied; for each flow depth two to four average velocities, ranging from 0.44 m/s to 1.05 m/s, were examined.

2.4 Experimental Procedure

The first step in any experimental run was to install a set of covers, if needed, and start the flow of water. Next the cover would be weighted using plastic bags filled with gravel to simulate a 63.5 mm thick ice cover. Then the slope of the flume bed would be set at the slope of the experiment that was to be compared with the previous study. Subsequently, the depth of flow was adjusted to give the required depth, and the cover was made parallel to the bed of the flume, using the tailgate.

Next the velocity profile was measured approximately half-way down the flume and at the centerline of the channel. The velocity profile consisted of a series of 20 average local velocity measurements. After the velocity measurements were completed, the readings of the stilling wells were taken along with the temperature of the water for defining the hydraulic gradient.

All the needed data was then keyed into and processed by an IBM PC using a LOTUS 1-2-3 software package.

3. ANALYTICAL APPROACH

This chapter describes the approach adopted for the analysis of the resistance phenomena for open, and covered (partial or complete) channels.

3.1 Analysis of Channel Resistance

The Manning's equation was used as a basis of the analysis. The Manning's equation is:

$$n = 1/V \, R^{2/3} \, S^{1/2}$$

where V = the average cross-sectional velocity (m/s),
S = the slope of the energy line,
R = the hydraulic radius = A/P (m),
A = cross-sectional area perpendicular to the flow(m^2),
P = shear perimeter of the channel (m),
n = resistance coefficient.

The average velocity was found by intergrating the velocity profile and then dividing by the cross- sectional area. The slope of the energy line was assumed to be parallel to the piezometric gradient obtained with the use of the stilling wells.

In the analysis of all the experiments, the hydraulic radius was taken to be the depth of flow. This assumes that the flow is two dimensional, i.e. a wide rectangular channel. This assumption can be justified by the large difference in roughness of the bed as compared to the flume side walls (expanded metal and plexiglass respectively).

3.2 Analysis of Composite Channels

The following approach was used to find the Manning's resistance coefficient"n" for the cover zone in the experiments where a cover was used. The depth of flow is divided into two zones, a top and a bottom zone, that are separated by a plane parallel to the bed and passing through the point of maximum velocity. These zones could then be treated as separate channels because the shear stress along the separation plane was assumed to be zero. The Manning's equation could now be applied to these two channels using their individual depths and average velocities to find their resistance coefficients.

In the analysis of the top channel, for calculating the hydraulic radius the shear perimeter was taken as the width of the top channel, even though the cover, in some cases, was not continuous. It was believed that the entire width of the channel would contribute to the shear and not just the solid part of the cover; this assumption was made because of the eddies generated at the openings in the cover (the form drag would equal or exceed the friction drag). Such an assumption simplified the analysis substantially and yielded reasonable results.

The following subscripts have been used in the analysis:

0 - refers to the open channel conditions,
1 - refers to the bed or bottom zone in composite channel conditions,
2 - refers to the top or cover zone in composite channel conditions,
c - refers to the combined effects of the top and bottom zones in composite channel conditions.

The analysis, as explained so far, allows the calculation of N1 (bed zone resistance) and N2 (cover zone resistance). However Nc, the composite resistance coefficient of the composite channel is of more interest in practical river operations. Nc can be computed using the following methods:

a) the arithmetic average method

$$Nc = (N1 + N2)/2$$

b) Larsen's method (in Ashton, G.D., 1986, pp 312)

$$\frac{1}{Nc} = \frac{(1/N2)\, Y2^{5/3} + (1/N1)\, Y1^{5/3}}{(1/2)^{2/3}\, Yc^{5/3}} \qquad y = \text{flow depth}$$

c) Sabaneev's method (in Ashton, G.D., 1986, pp 313)

$$\frac{Nc}{N1} = \left[\frac{1 + (N2/N1)^{3/2}}{2}\right]^{2/3}$$

The differences in Nc obtained by using the three methods were insignificant; therefore, only the results using method (a) are shown.

4. PRESENTATION AND DISCUSSION OF RESULTS

In this section the effects of floating covers on flow resistance will be presented and compared with the results obtained for fixed covers.

4.1 Open Channel Resistance Characteristics

The average resistance coefficient for open channel conditions was found to be 0.021. In field conditions it is often assumed that the resistance coefficient of the bed zone for covered conditions is the same as the resistance coefficient for open channel conditions. The results obtained from these experiments showed this assumption was not valid.

4.2 Comparison of Bed Zone Resistance for Open and Covered Conditions.

The variation of bed zone resistance coefficients for open channel conditions compared to covered conditions (N1/No) is presented in Fig 2. The maximum value of N1/No occurred in the 35 to 45% cover range, where the (N1/N0) ratio attains the peak value of 1.75. There is an increase in the ratio of N1/N0 when the average velocity increases, which holds true for all flow depths. Good consistency of data was indicated by the shapes of the curves, which were basically the same for all flow depths.

When comparing the results obtained for fixed covers (see Fig 3) to those for floating covers, a difference in the basic shapes of the curves was noted.

From the results of both studies it is clear that the assumption of constancy of the bed zone resistance coefficient is invalid.

4.3 Variation of Cover Zone Resistance

The variation of cover zone resistance coefficient (N2/N0) for the floating cover condition is presented in Fig 4, where it can be seen that the maximum variation occurs between 35 and 45% cover. A peak value of N2/No = 1.50 is observed in this range and this peak value is roughly the same for all flow depths. Again the trend of increasing resistance with increasing velocity is apparent.

When comparing the results of the two studies (for fixed cover results see Fig 5) it appears that the peak values of N2/N0 are roughly the same for the lower velocities. However, the ratio of N2/No appears to be larger for fixed cover conditions for higher velocities. This may be explained as follows; the floating cover has the ability to adjust to changes in pressure by moving up or down. These changes in pressure, generated by eddies at the openings, will increase with increasing velocities. Therefore, the difference between resistance due to the floating and fixed covers will be larger for higher velocities.

Another difference between the results from the two studies is the shift of the peak resistance values to a lower percentage cover for floating cover conditions.

4.4 Variation of Composite Resistance

The composite resistance coefficients were calculated using three different methods, arithmetic average, Larsen's method and Sabaneev's method. As discussed earlier, only the results of the arithmetic average method were plotted because all three methods gave nearly identical results (See Fig 6 for results). Again, the maximum resistance coefficient values were found in the 35 to 45 % cover range, where a peak value of 1.55 for the ratio Nc/No was observed.

A comparison of the Nc/No ratios between the two studies is not needed since Nc = (N1 + N1)/2 and the comparisons for the N1/No and N2/No ratios have already been made. The difference between floating and fixed covers is best seen in the N2/No plots; therefore all the conclusions will be drawn from there.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results obtained from these studies it has been found that:

1. For floating covers, the peak resistance values occurred between 35 and 45 percent cover.

   In this range, a maximum value of 1.55 was obtained for the ratio of Nc/No. This would mean that Nc = 0.031 for the experimental bed condition.

2. For fixed covers, the peak resistance values occurred between 45 and 55 percent cover.

   A maximum value of 1.56 was obtained in this range for the ratio of Nc/No. This would mean that Nc = 0.036 for the experimental bed condition.

3. Flow resistance is roughly the same for floating and fixed partial covers at low valocities. For higher velocities floating covers indicated less flow resistance than fixed covers.

4. Percentage cover had a larger effect on flow resistance than the experimental range of variations in depth or velocity.

5. Flow resistance increased with increasing velocity.

6. The common assumption of constancy of bed zone resistance is not valid.

The following recommendation has emerged from this study and is suggested as a basis for further investigation. The edges of the cover openings in the direction of flow should be angled to simulate a natural ice cover more realistically. (This has already been considered and a "follow-up" study will likely be conducted in the summer of 1987.)

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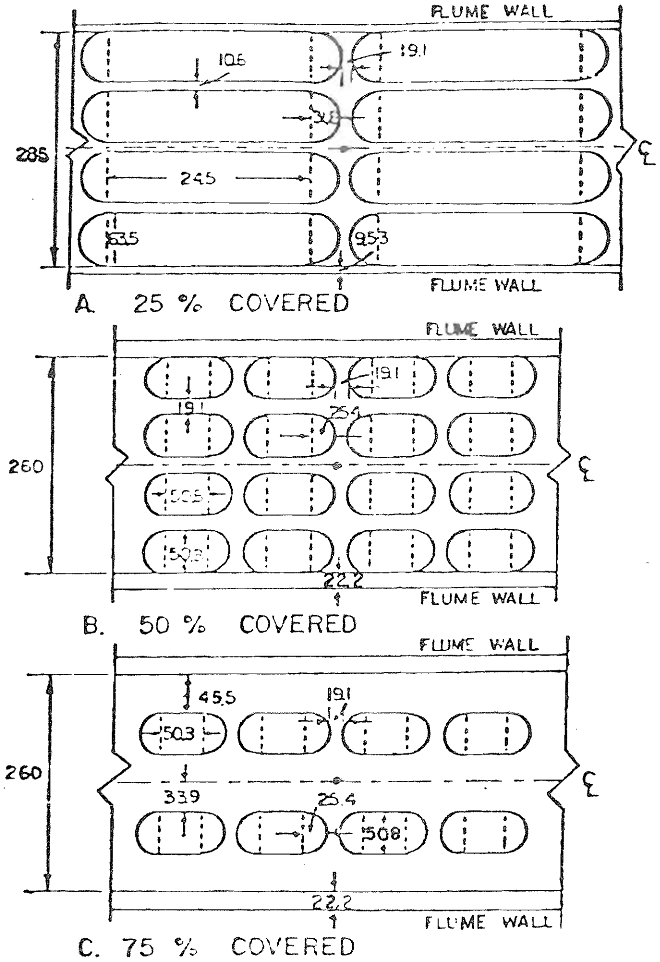
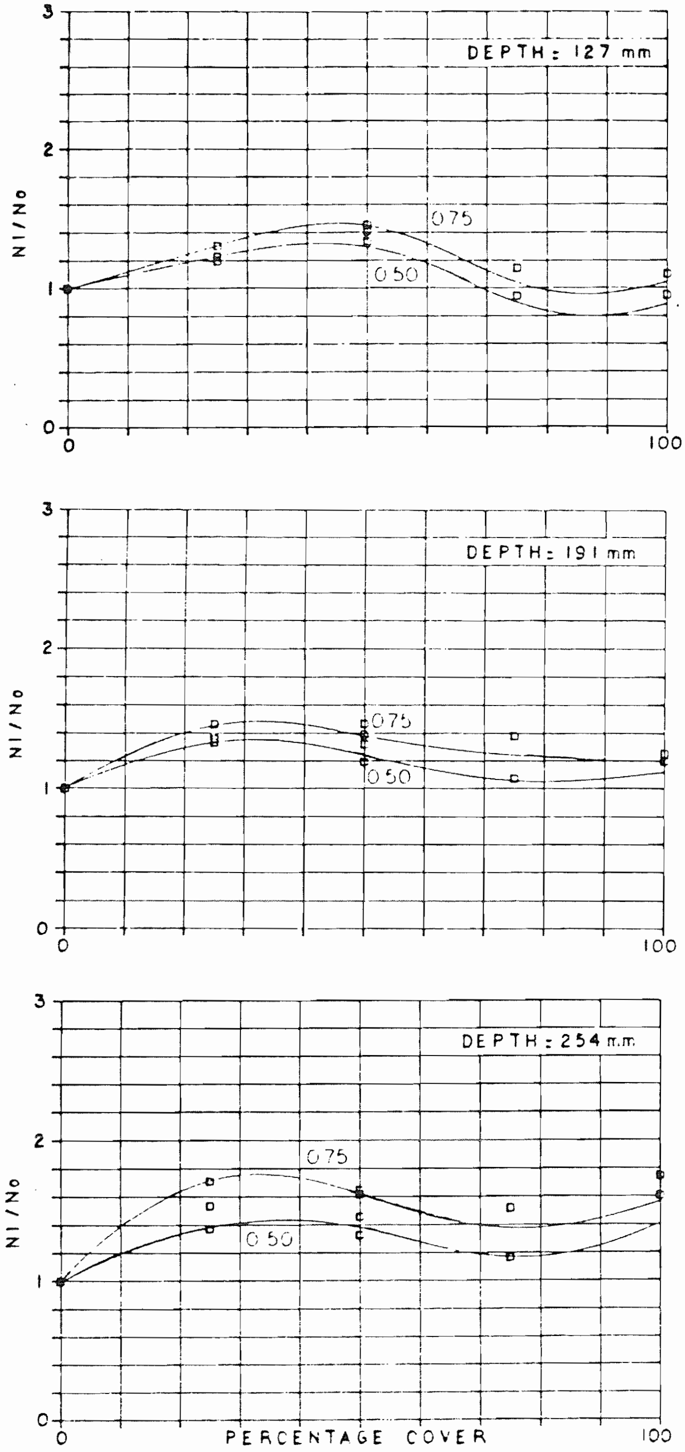


Notes: 1. All dimensions in mm.

2 Ends of all openings semi-circular.

● Typical positions for velocity probe

FIG. 1 PLAN VIEW OF TOP COVER— ARRANGEMENT OF OPENINGS



Note: The numbers on the curves refer to velocities in m/s

FIG. 2 VARIATION OF BED RESISTANCE COEEFICIENTS N1/No (FLOATING COND.)

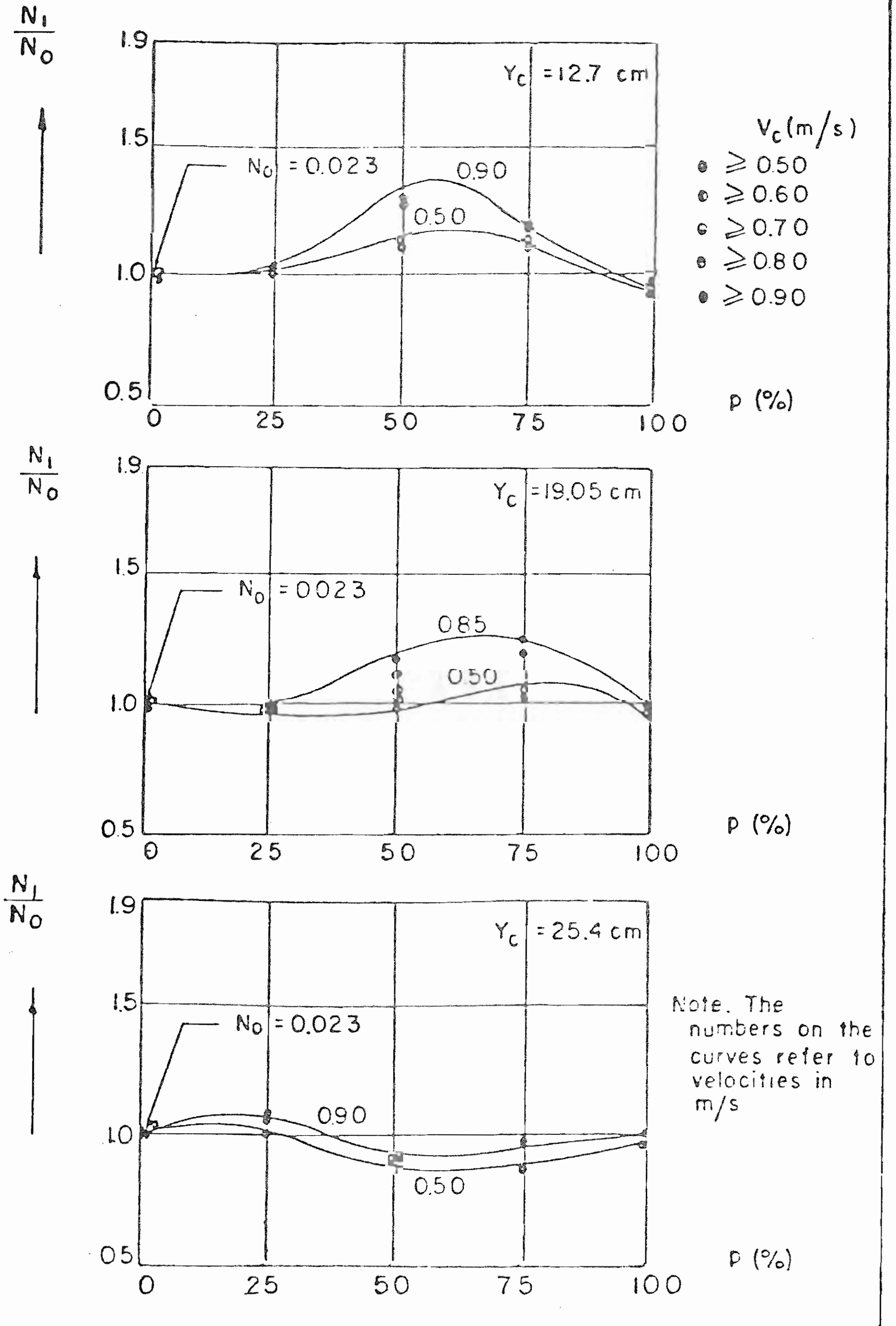
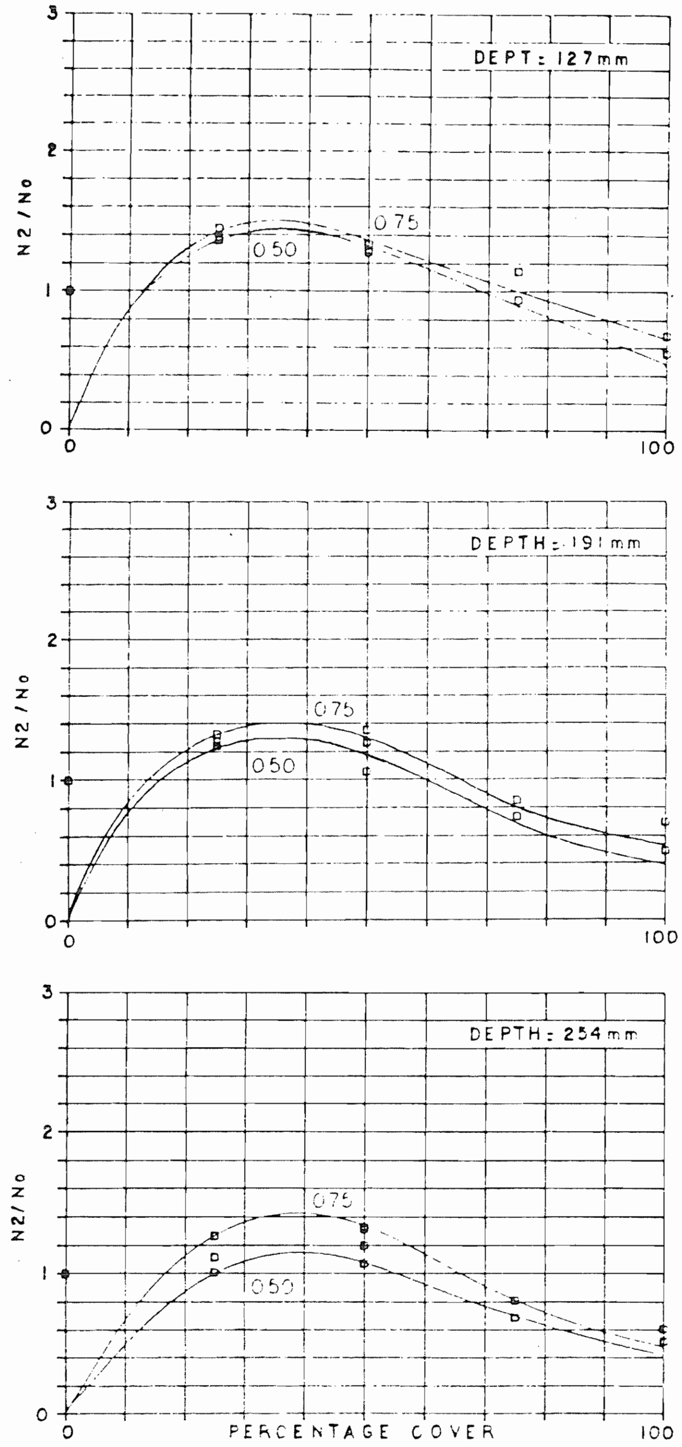
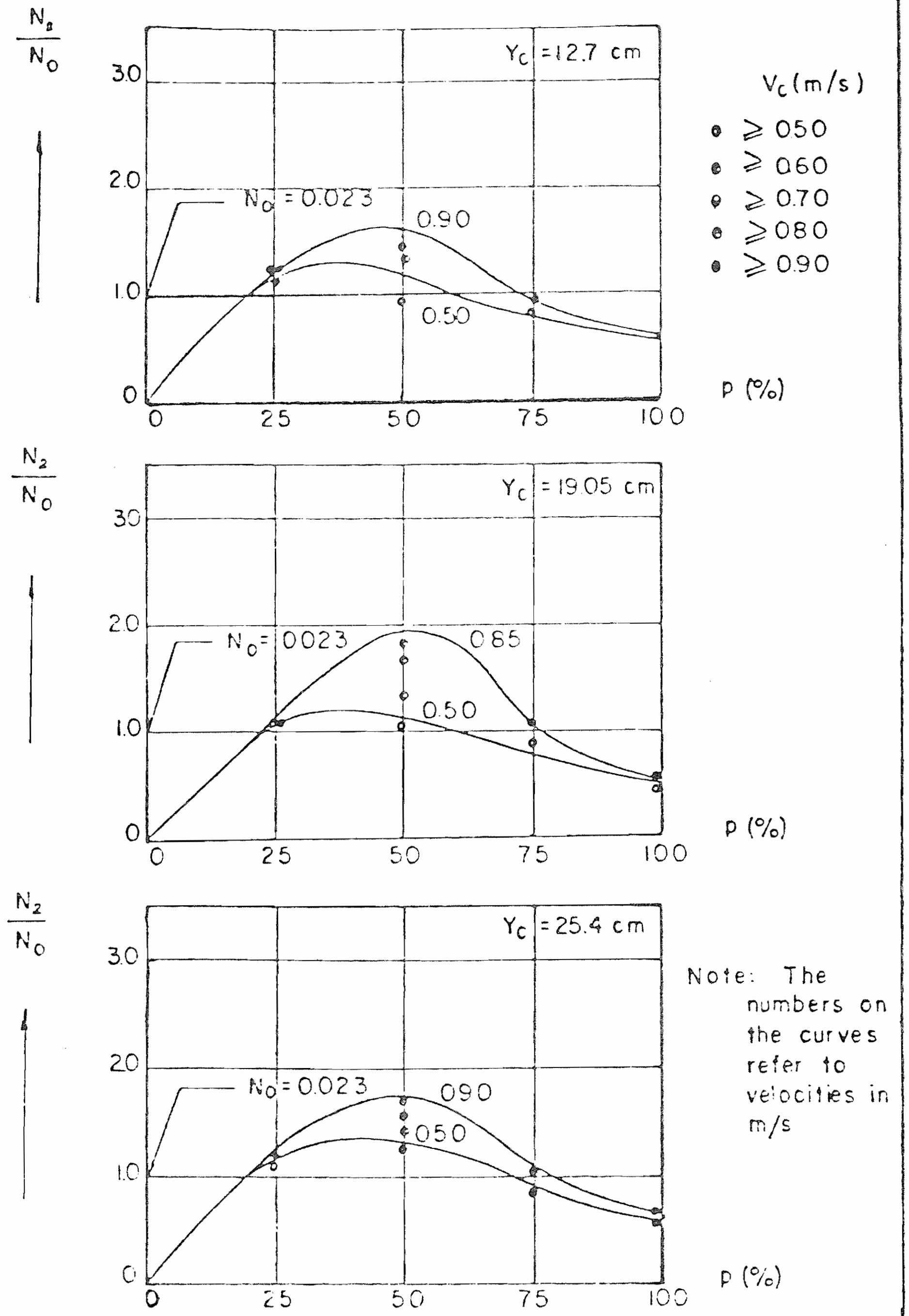


FIG. 3 VARIATION OF BED RESISTANCE COEFFICIENTS N_1/N_0 (FIXED COND.)



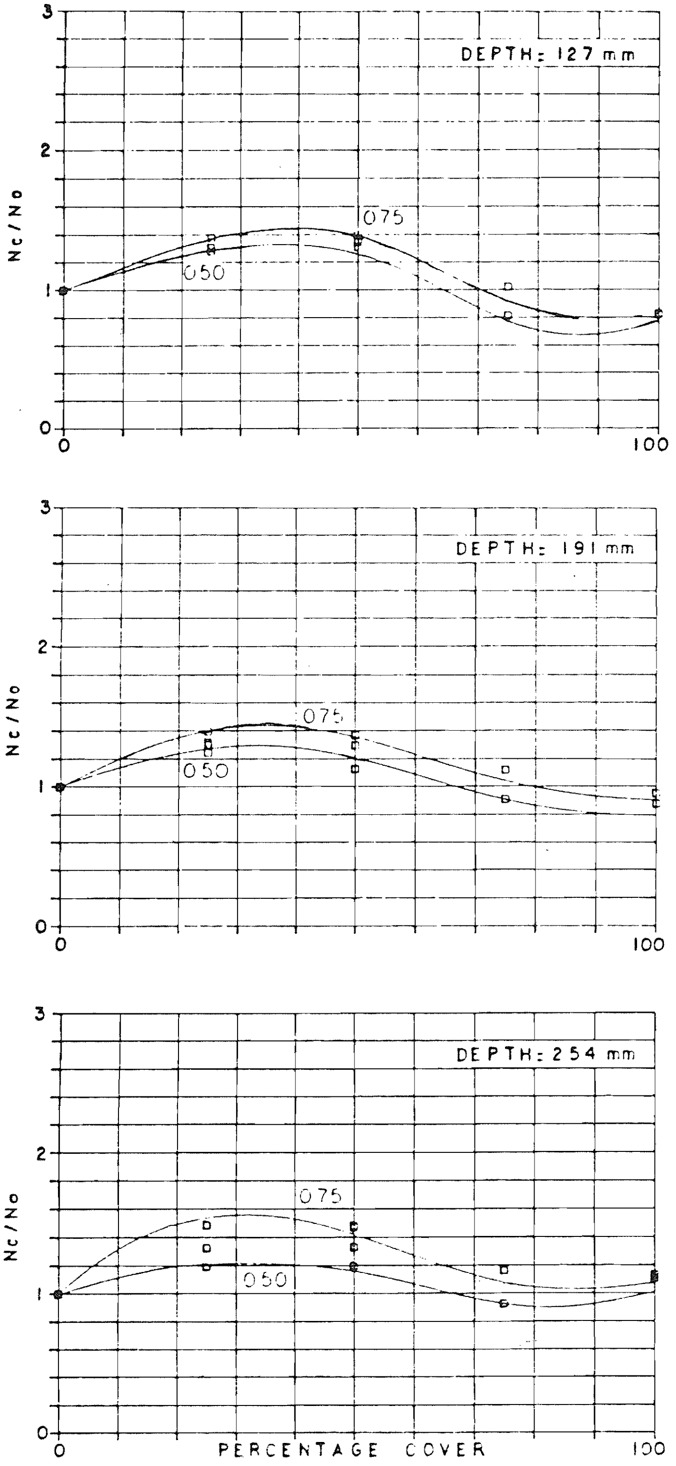
Note: The numbers on the curves refer to velocities in m/s

FIG. 4 VARIATION OF COVER RESISTANCE COEFFICIENTS N2/No (FLOATING COND.)



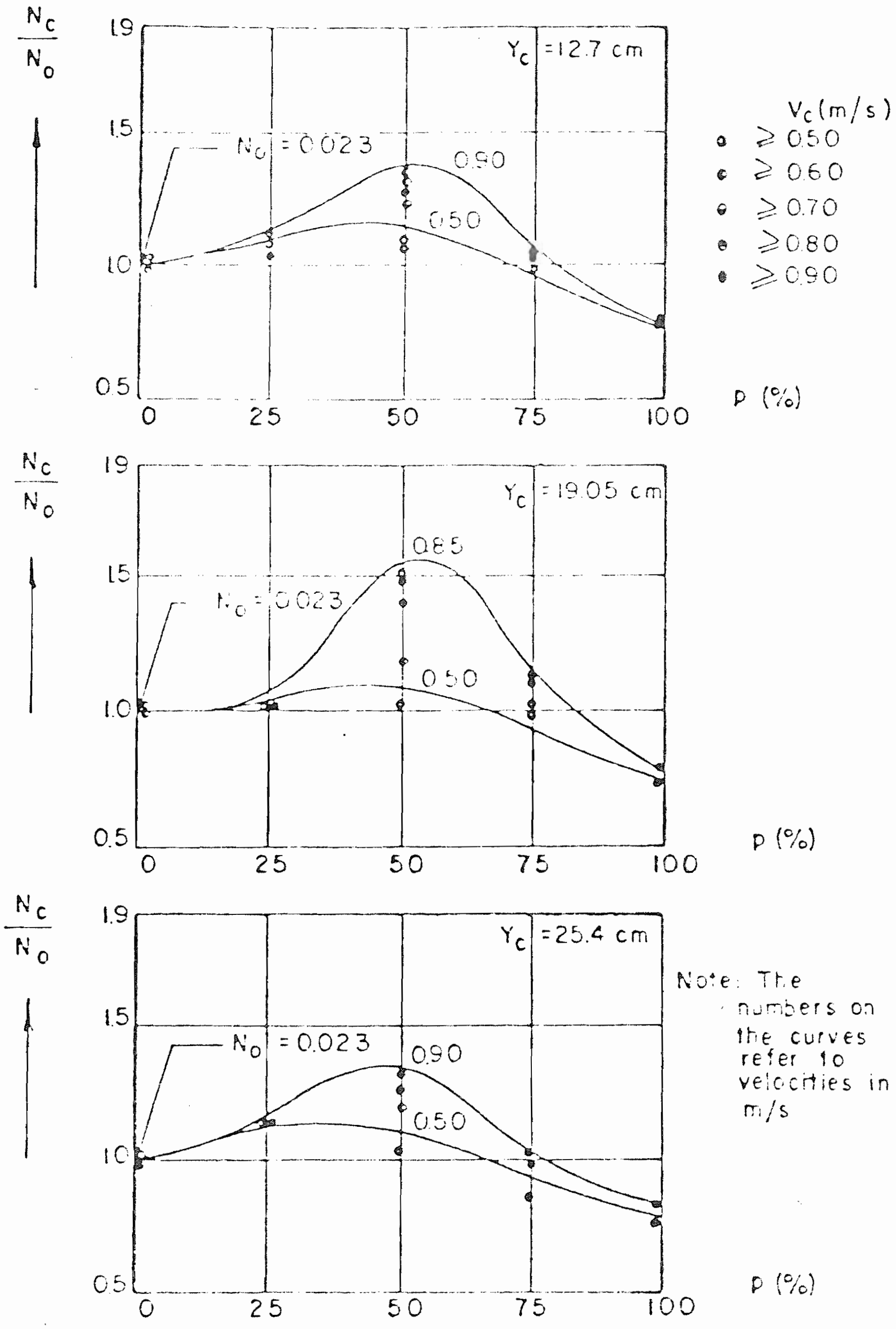
Note: The numbers on the curves refer to velocities in m/s

FIG. 5 VARIATION OF COVER RESISTANCE COEFFICIENTS N_2/N_0 (FIXED COND.)



Note: The numbers on the curves refer to velocities in m/s

FIG. 6 VARIATION OF COMPOSITE RESISTANCE COEFFICIENTS Nc/No (FLOATING COND.)



Note: The numbers on the curves refer to velocities in m/s

FIG. 7 VARIATION OF COMPOSITE RESISTANCE COEFFICIENTS Nc/No (FIXED COND.)