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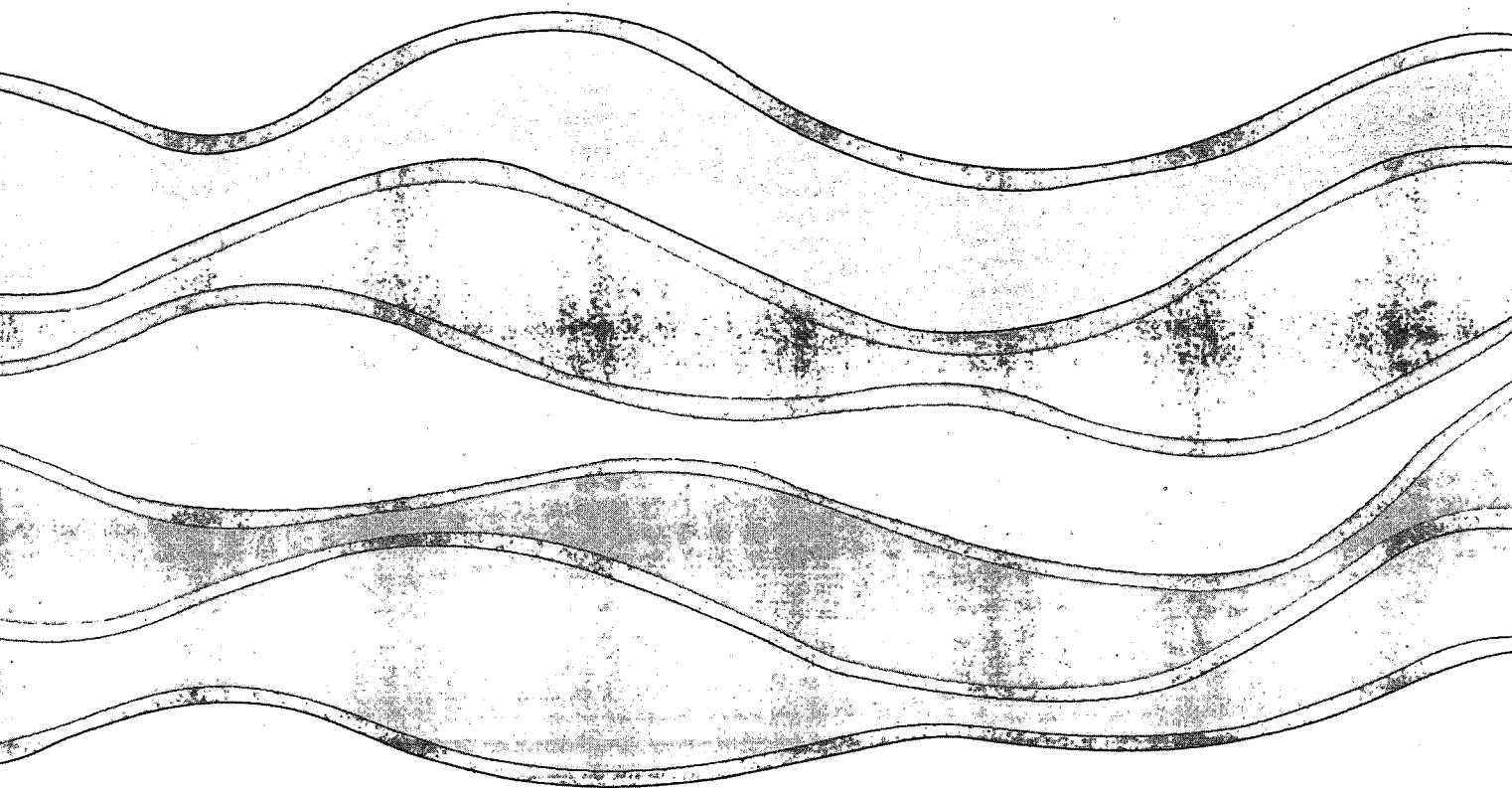
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DESIGN CONSIDERATIONS FOR
SUBAQUEOUS CAPPING IN
HAMILTON HARBOUR

DISTRIBUTION OF SAND ON HARBOUR
BOTTOM DURING CAP PLACEMENT

J.E. Graham and A.J. Zeman

NWRI Contribution No. 92-52

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**DESIGN CONSIDERATIONS FOR SUBAQUEOUS
CAPPING IN HAMILTON HARBOUR**

**DISTRIBUTION OF SAND ON HARBOUR
BOTTOM DURING CAP PLACEMENT**

J.E. Graham and A.J. Zeman

Lakes Research Branch
National Water Research Institute
Burlington, Ontario L7R 4A6

NWRI Contribution No. 92-52

MANAGEMENT PERSPECTIVE

The technique of subaqueous capping requires precise placement of a cap of clean isolating material in order to contain the contaminated sediments properly. The report examines several aspects of the placement methods for the sand cap. These include the cap radius, the maximum slug layer thickness, the horizontal displacement of sand due to depth-averaged currents, the number of layers needed for the required cap thickness and the distribution thickness of a slug layer on the harbour bottom for specific water depths and grain sizes. The results presented in the report will be verified, by core sampling and visual inspection, during a monitoring program which will play an important role in the pilot-scale demonstration project.

SOMMAIRE À L'INTENTION DE LA DIRECTION

La technique de l'enfouissement sous l'eau exige la mise en place précise d'un matériau isolant non contaminé afin de bien contenir les sédiments contaminés. Le rapport examine plusieurs aspects des méthodes de mise en place du sable comme matériau de recouvrement. Il s'agit du rayon de recouvrement, de l'épaisseur maximale de la couche de recouvrement, du mouvement horizontal du sable en raison des courants moyens calculés en fonction de la profondeur, du nombre de couches nécessaires pour obtenir l'épaisseur de recouvrement et l'épaisseur de la répartition d'une couche de recouvrement sur le fond du port pour des profondeurs d'eau et des granulométries données. Les résultats présentés dans le rapport seront vérifiés, par un échantillonnage de carottes et une inspection visuelle, dans le cadre d'un programme de surveillance qui jouera un rôle important au niveau du projet de démonstration à l'échelle pilote.

ABSTRACT

The calculations contained in this report are all based on the assumption that the slug is a spherical ball when dropped into the water and that the slug has no initial momentum.

The final radius of the slug, the maximum slug layer thickness and the horizontal displacement of sand due to depth-averaged currents are evaluated using the approaches adopted by Krishnappan (1975). The initial slug sizes considered range from 0.001 m^3 to 1.0 m^3 , the grain sizes range from 0.044 mm (very fine sand) to 0.7 mm (coarse sand), and the distances to the bottom range from 1 m to 20 m. The maximum slug layer thickness is primarily a function of the vertical distance to the bottom, volume of the slug material, and the grain size of the slug components. The number of layers needed for the desired cap thickness were also calculated.

Results of the present report can be used for initial recommendations regarding the optimum placement technique. The slug should have a small volume and be dropped from the upper half of the water column in order to reduce the amount of disturbance and resuspension of fine-grained bottom sediments.

RÉSUMÉ

Les calculs présentés dans le présent rapport reposent tous sur l'hypothèse selon laquelle le matériau de recouvrement devient une balle sphérique lorsqu'il est relâché dans l'eau et qu'il n'a aucune impulsion initiale.

Le rayon final du bouchon, l'épaisseur maximale de la couche de recouvrement (bouchon) et le mouvement horizontal du sable en raison des courants moyens calculés en fonction de la profondeur sont évalués au moyen d'approches adoptées par Krishnappan (1975). Les volumes des dimensions de bouchon étudiées varient entre 0,001 m³ et 1,0 m³, la dimension des grains, entre 0,044 mm (sable très fin) et 0,7 mm (sable grossier), et la distance au fond, entre 1 m et 20 m. L'épaisseur maximale de la couche de recouvrement est surtout de la hauteur au fond, du volume du matériau, et de la taille des grains des composantes du bouchon. Le nombre de couches requis pour obtenir l'épaisseur de la couche de recouvrement souhaitée a également été calculé.

Les résultats du présent rapport peuvent être utilisés pour la formulation des premières recommandations relatives à la technique de mise en place optimale. Le bouchon devrait avoir un faible volume et être relâché au niveau de la moitié supérieure de la colonne d'eau afin de réduire les perturbations et la remise en suspension des sédiments de fond de faible granulométrie.

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Radius of Slug vs. Distance to Bottom

- 1a Grain Size: 0.044 mm, 0.001 m³ to 1.0 m³
- 1b Grain Size: 0.18 mm, 0.001 m³ to 1.0 m³
- 1c Grain Size: 0.25 mm, 0.001 m³ to 1.0 m³
- 1d Grain Size: 0.70 mm, 0.001 m³ to 1.0 m³
- 1e Multiple Grain Sizes, 0.001 m³ to 1.0 m³

Max. Cap Thickness vs. Distance to Bottom

- 2a Grain Size: 0.044 mm, 0.001 m³ to 1.0 m³
- 2b Grain Size: 0.18 mm, 0.001 m³ to 1.0 m³
- 2c Grain Size: 0.25 mm, 0.001 m³ to 1.0 m³
- 2d Grain Size: 0.70 mm, 0.001 m³ to 1.0 m³
- 2e Multiple Grain Sizes, 0.001 m³ to 1.0 m³
- 3a Layer Thickness with a Current of 0.01 m/s
 Slug Size: 0.001 m³, Distance to Bottom: 5 m
- 3b Layer Thickness with a Current of 0.0025 m/s
 Slug Size: 0.001 m³, Distance to Bottom: 10 m
- 3c Layer Thickness with a Current of 0.001 m/s
 Slug Size: 0.001 m³, Distance to Bottom: 15 m
- 3d Layer Thickness with a Current of 0.025 m/s
 Slug Size: 0.01 m³, Distance to Bottom: 5 m

- 3e Layer Thickness with a Current of 0.01 m/s
Slug Size: 0.01 m³, Distance to Bottom: 10 m
- 3f Layer Thickness with a Current of 0.005 m/s
Slug Size: 0.01 m³, Distance to Bottom: 15 m
- 3g Layer Thickness with a Current of 0.1 m/s
Slug Size: 0.1 m³, Distance to Bottom: 5 m
- 3h Layer Thickness with a Current of 0.025 m/s
Slug Size: 0.1 m³, Distance to Bottom: 10 m
- 3i Layer Thickness with a Current of 0.01 m/s
Slug Size: 0.1 m³, Distance to Bottom: 15 m

Number of Layers vs. Slug Size

- 4a Layer Thickness: 5cm, Distance to Bottom: 5 m
2 m Spacing Between Slug Centres
- 4b Layer Thickness: 5cm, Distance to Bottom: 5 m
3 m Spacing Between Slug Centres
- 4c Layer Thickness: 5cm, Distance to Bottom: 10 m
3 m Spacing Between Slug Centres
- 4d Layer Thickness: 5cm, Distance to Bottom: 10 m
4 m Spacing Between Slug Centres
- 4e Layer Thickness: 5cm, Distance to Bottom: 15 m
4 m Spacing Between Slug Centres
- 4f Layer Thickness: 5cm, Distance to Bottom: 15 m
5 m Spacing Between Slug Centres

1.0 INTRODUCTION

The pilot-size capping project under preparation in Hamilton Harbour requires that a layer of sand be spread over the bottom of the harbour. As part of the project preparation, it is useful to analyze the effectiveness of different sand placement techniques using the radius of a slug and the maximum thickness of one slug layer when dropped from different water depths and for different grain sizes. Another objective is to ascertain the location and the distribution thickness of the slug layer on the harbour bottom in the presence of depth-averaged currents in the water column.

Once the individual slug thickness and area are estimated, the number of layers needed to achieve a design cap thickness of approximately 50 cm is determined using the procedure described in section 2.4.

These results are valid only under the conditions that the initial slugs are spherical and that there is no initial momentum of the slugs when they are dropped into the water.

2.0 THEORY

2.1 Radius of Slug

The slug radius is a linear function that depends on the distance to the bottom. With the assumption that the original slug is spherical, the initial radius is calculated. The final radius can be described by the expression

$$R_f = R_0 + \alpha z \quad (1)$$

where R_0 is the original slug radius, z is the distance the slug has travelled through the water column and α is an experimentally determined dimensionless constant (Krishnappan 1975).

2.2 Maximum Slug Layer Thickness

The maximum slug layer thickness, h_{max} , is computed using the approach adopted by Krishnappan (1975). The thickness is a function that ultimately depends on the volume of the slug, grain size and the distance to the bottom. The standard deviation of the distribution of solid particles in the slug, σ , must be calculated first in order to determine h_{max} . A distance of two standard deviations was used to approximate the radius (instead of eight as selected by Krishnappan since smaller slugs sizes and shorter vertical distances will be used in the pilot project). This approximation will give an accuracy of 99% for moderate distances of 5 to 20 m to the bottom. Hence the standard deviation is given by the formula

$$\sigma = \frac{R_f}{2} \quad (2)$$

where R_f is the radius of the slug as it reaches the bottom. The value for σ can then be substituted into the equation for the maximum slug layer thickness (Krishnappan 1975)

$$h_{MAX} = \frac{V_s}{2\pi(1-n)\sigma^2} \quad (3)$$

where V_s is the volume of the original slug and n is the porosity. The assumed value of n is 46%, which is the typical value for a loose uniform fine sand (Kézdi 1974). The value of h_{max} is used in the subsequent section for the cap distribution thickness.

2.3

Horizontal Displacement of the Slug Due to Currents

Given that the original slug is spherical, the sand particles settle at the bottom and the distribution of the height of the mound formed can be described by a Gaussian curve using the formula

$$h = h_{MAX} \exp\left[-\frac{(r-Ut)^2}{2\sigma^2}\right] \quad (4)$$

where r is the radial co-ordinate, U is the ambient current of the receiving water and t is the total duration of the travel of the slug.

2.4

Number of Slug Layers

Once the individual slug thickness is obtained, the number of slugs needed to provide the required cap thickness can be determined. Firstly, the bottom volume of one slug is calculated and the spacing between slug centres is chosen, depending on the amount of overlap desired. A value for the spacing close to the radius of the slug will provide the desired overlap. The average thickness of one layer is then calculated, for a square containing nine overlapping slugs, by dividing the volume of capping material by the area of the harbour bottom covered. Finally, the number of slugs needed to build up the cap layer can be determined by dividing the desired cap thickness by the average slug layer thickness.

3.0

RESULTS

3.1

Radius of Slug

The radius of the slug, as it travels down through the water column, increases linearly. The slug radius, for a distance to the bottom of 1 m, ranges from

approximately 0.25 to 0.75 m. This range applies to all grain sizes and all slug sizes. As the slug descends, the slug of the smaller grain size tends to disperse more than that of the larger grain size (Figs. 1a - 1e). This can be attributed to the fact that the smaller grains have less inertia and therefore have a higher rate of movement outwards. The slug radius was calculated for volumes of 0.001 m³ to 1.0 m³ and for distances to the bottom of 1 m to 20 m.

3.2 Slug Layer Thickness

The maximum cap thickness decreases exponentially with depth and is only slightly dependent on the grain size (Figs. 2a to 2e). For small distances to the bottom, the cap thickness is not accurate because the radius divided by two is not a valid assumption for short depths and small radii. However, it is unlikely that small distances to the bottom will be used in the pilot project. For this reason, the values corresponding to the distances less than five metres are not shown in Figs. 2a to 2e. Finally, the cap thickness decreases as the distance to the bottom increases since the same volume of sand is distributed over a larger area of the harbour bottom.

3.3 Horizontal Displacement of the Slug Due to Currents

When a current occurs in the water column, the slug is swept away horizontally from the drop site. The distance the slug travels depends on the grain size, duration of travel and current velocity. The slugs with the larger grain sizes have more inertia and therefore are displaced less than the slugs with the smaller grain sizes (Figs. 3a to 3i). The slugs composed of larger grains will have a shorter duration time which will limit their horizontal movement. The ambient current will also affect the horizontal displacement depending on the strength of the current. Since the slugs should be deposited on the harbour bottom with the accuracy of one

metre or less (emperical value used by the US Corps of Engineers, M. Palermo, private communication), only those graphs which had horizontal distances from the drop site less than one metre were included in this report. Depths of 5 and 10 m and 15 m, slug sizes of 0.001 m^3 , 0.01 m^3 and 0.1 m^3 and currents of velocities ranging from 0.001 m/s to 0.1 m/s were used in Figs. 3a to 3i.

3.4 Number of Slug Layers

The number of layers needed to achieve a desired cap thickness depends primarily on the slug size, the distance to the bottom and the spacing between slug centres. In comparing Figs. 4b to 4c and 4d to 4e, the graphs with the same spacing between centres but with different distances to the bottom, it can be seen that the two curves are nearly identical. The reason for this is that the same volume of capping material occupies the same area of the harbour bottom in both cases. The only difference between the two is that there will be a difference in the overall unevenness in the design cap layer. When comparing the graphs with the same distance to the bottom and the same slug sizes but with different spacing between slug centres, it will take more layers to produce the same cap thickness for the greater spacing between slug centres, since a greater area of the harbour bottom is covered by the same volume of capping material.

4.0 CONCLUSIONS

Using both the previous report (Zeman and Graham, 1991) and this report, preliminary recommendations can be made regarding the optimum placement technique and sand sizes.

1. Low impact velocities are ideal since these will cause only slight disturbance and resuspension of the fine-sized bottom sediments. To achieve low impact velocities, small slug sizes (0.001 m^3 to 0.1 m^3) consisting of fine-sized material (0.044 to 0.18 mm) should be used.
2. The amount of penetration into the bottom sediments ranges from 2 to 50 mm for slugs of fine-sized material with low impact velocities.
3. Slugs composed of fine-sized material will be swept further away from the drop site when there is an ambient current present.
4. The number of slugs needed to produce the required cap thickness will be greater than that of the larger slugs.
5. Long term stability of the cap, using site-specific wave and current data, has to be considered in the design and this consideration is beyond the scope of this report.
6. It is desireable to provide an effective barrier to the movement of contaminants by using fine sediment with relatively high absorptive capacity.
7. The optimum solution may be to use a two layer cap with the lower layer of finer sediment and a "sealant" and the upper layer of coarser sediment (0.5 mm mean size) as an armour.

ACKNOWLEDGMENTS

This work is sponsored by the Great Lakes Cleanup Fund of Environment Canada.

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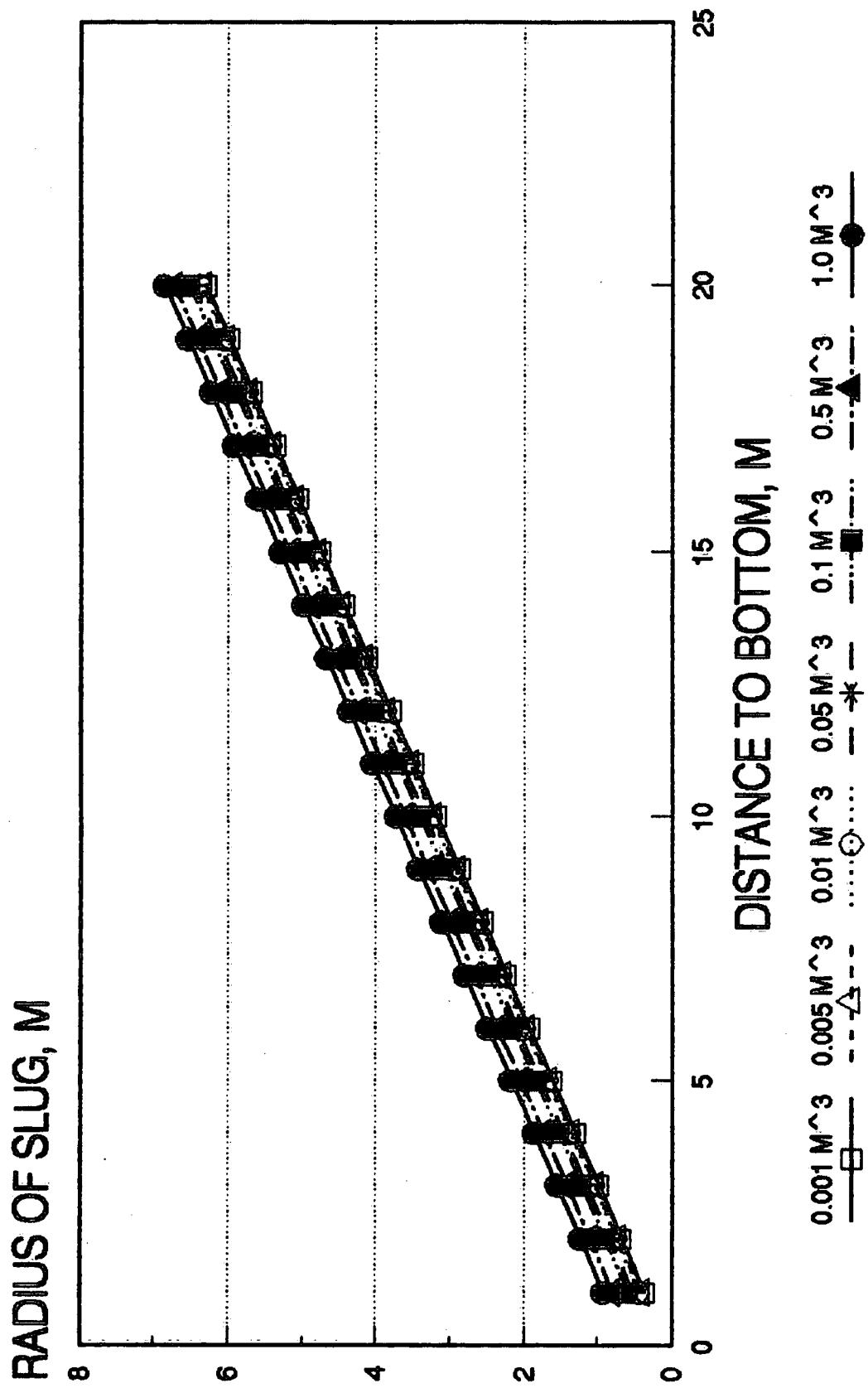
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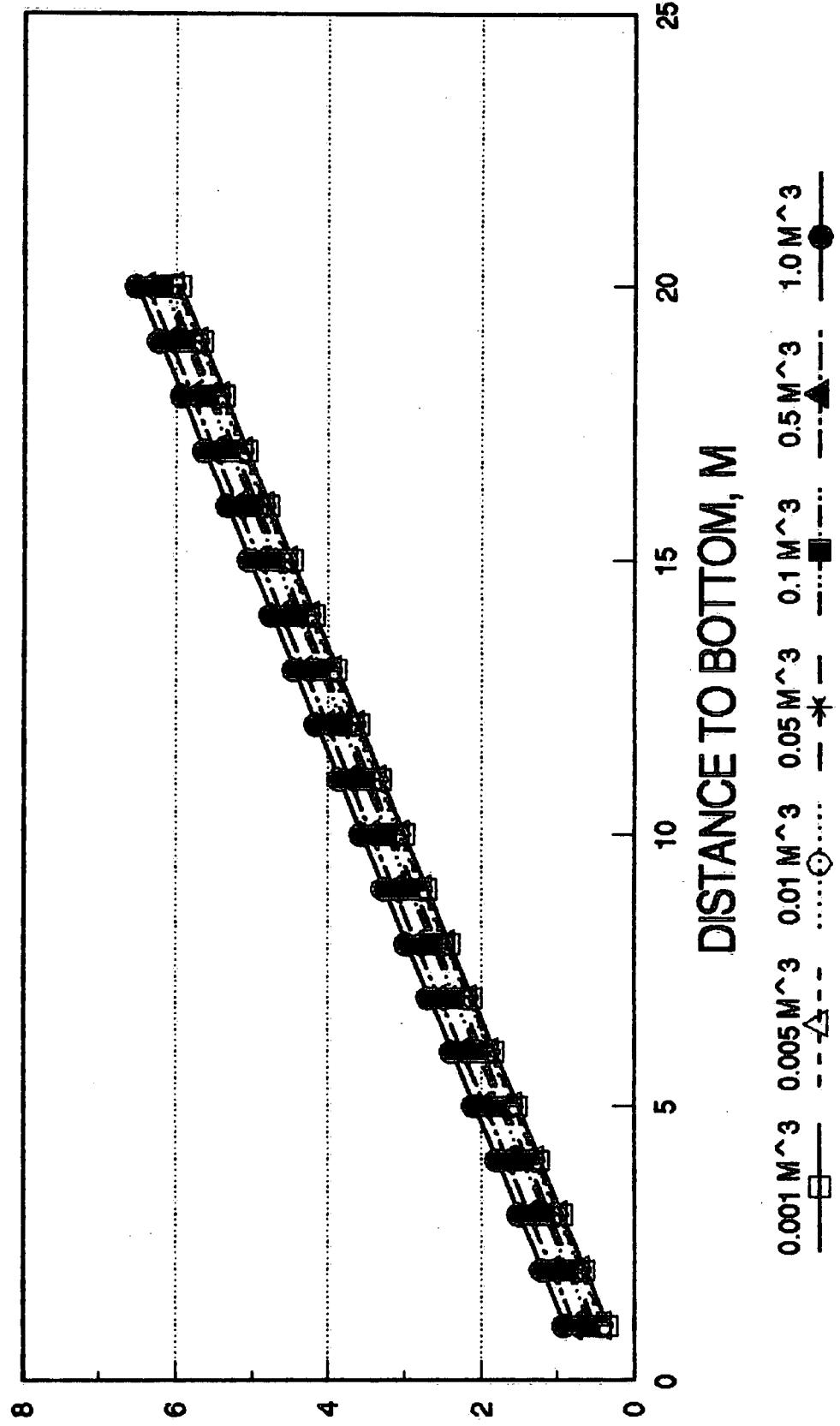
RADIUS OF SLUG VS. DISTANCE TO BOTTOM

GRAIN SIZE: 0.044 MM



RADIUS OF SLUG VS. DISTANCE TO BOTTOM
GRAIN SIZE: 0.18 MM

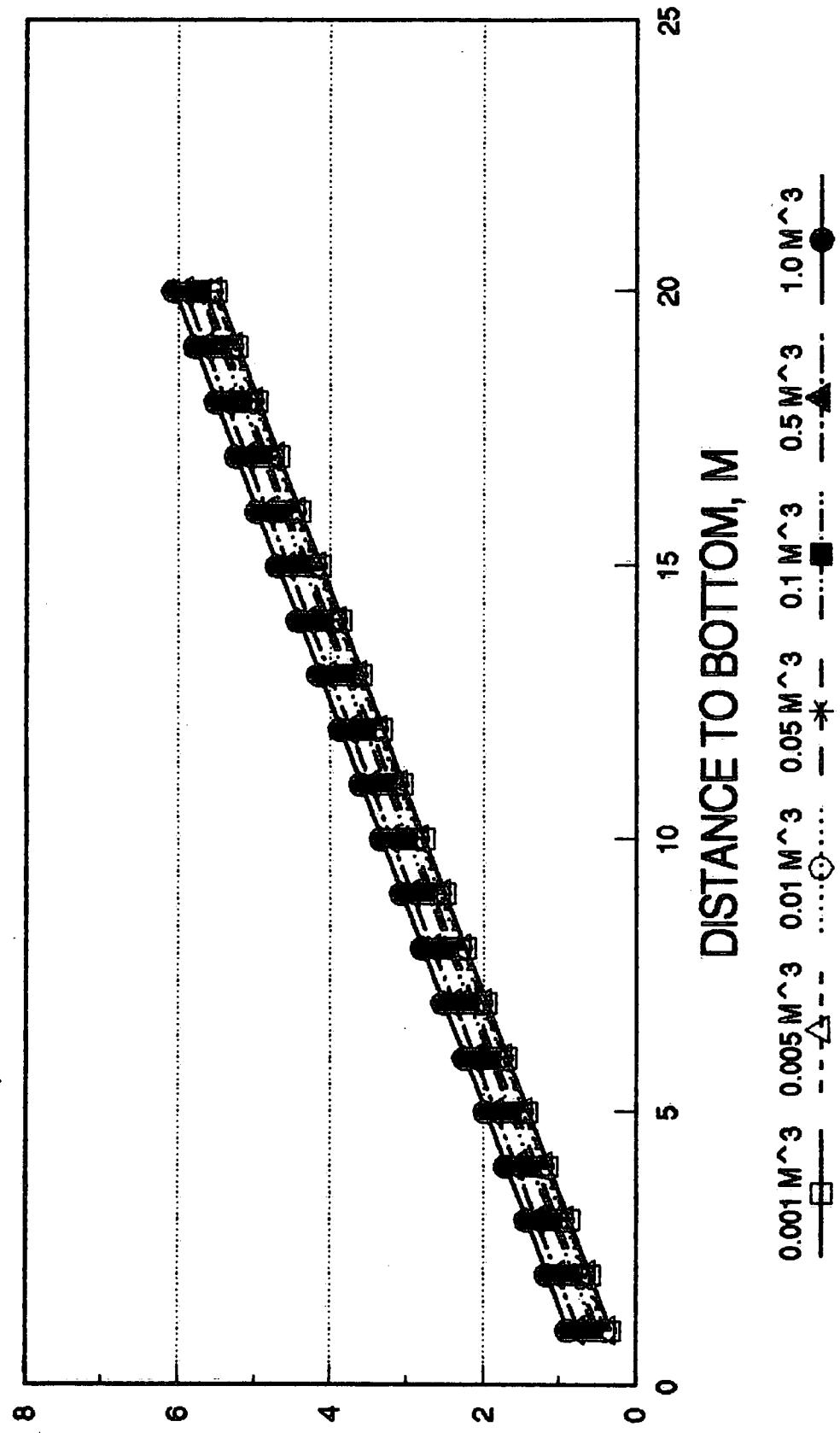
RADIUS OF SLUG, M



RADIUS OF SLUG VS. DISTANCE TO BOTTOM

GRAIN SIZE: 0.25 MM

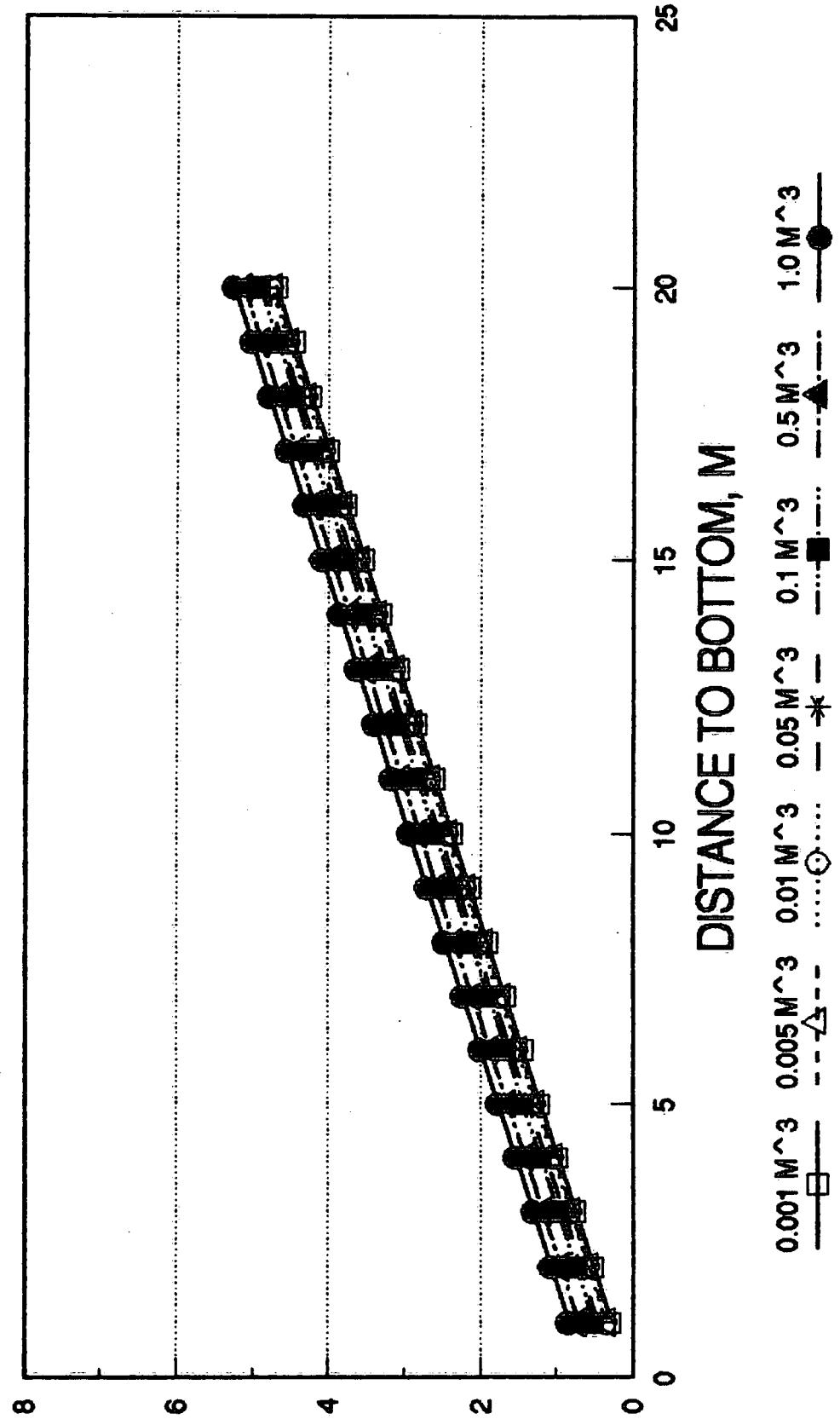
RADIUS OF SLUG, M



RADIUS OF SLUG VS. DISTANCE TO BOTTOM

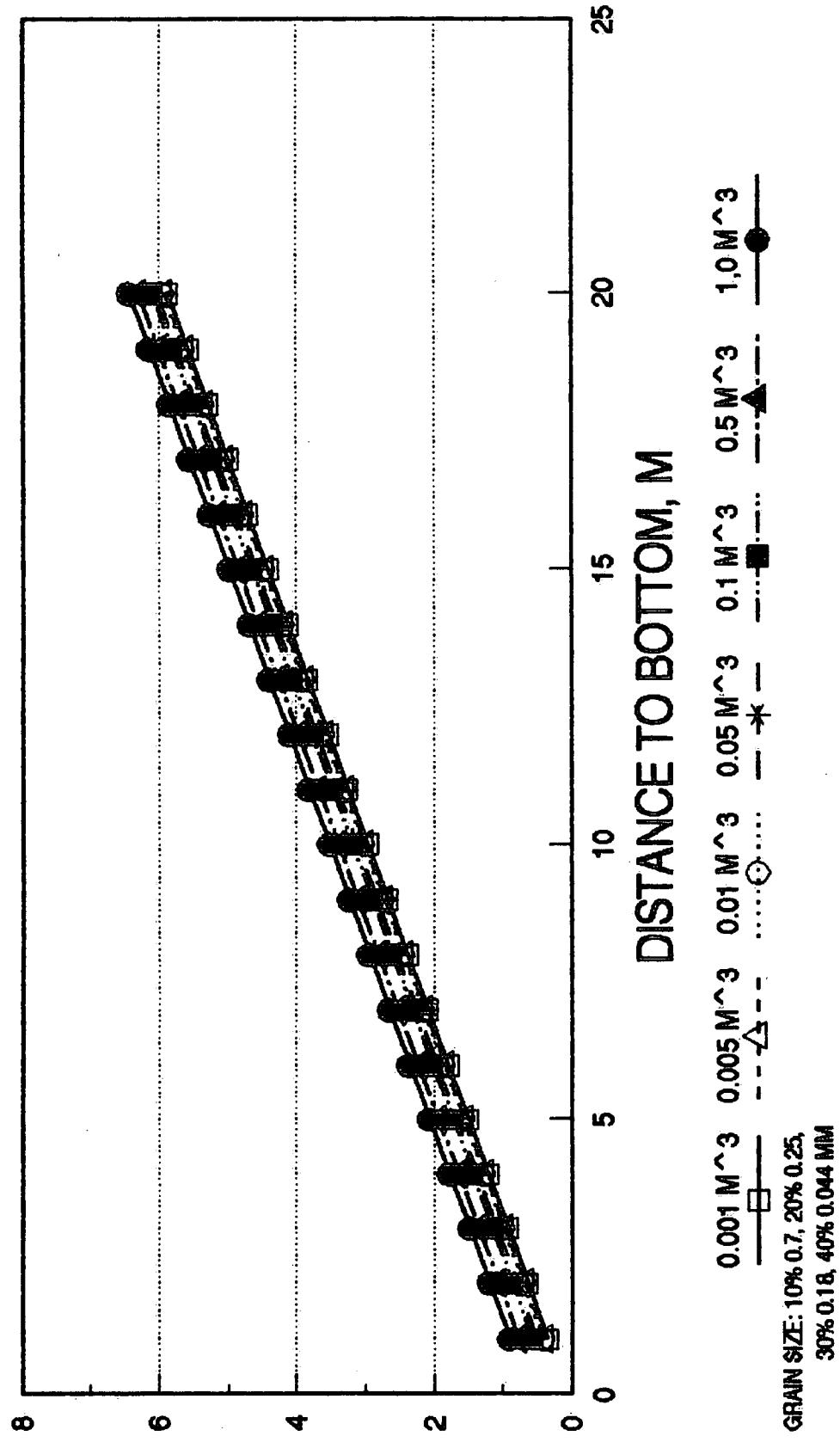
GRAIN SIZE: 0.70 MM

RADIUS OF SLUG, M



RADIUS OF SLUG VS. DISTANCE TO BOTTOM MULTIPLE GRAIN SIZES

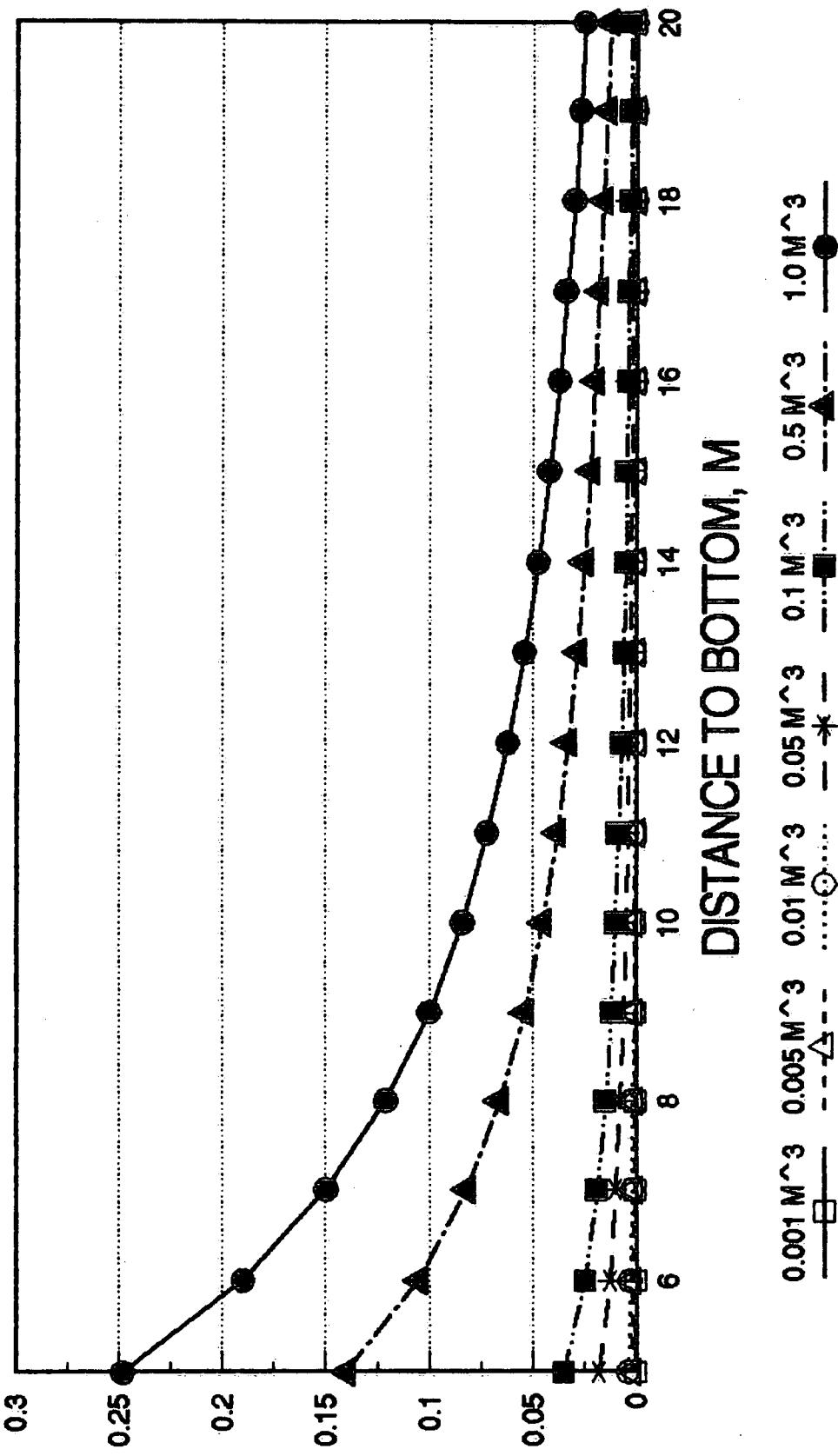
RADIUS OF SLUG, M



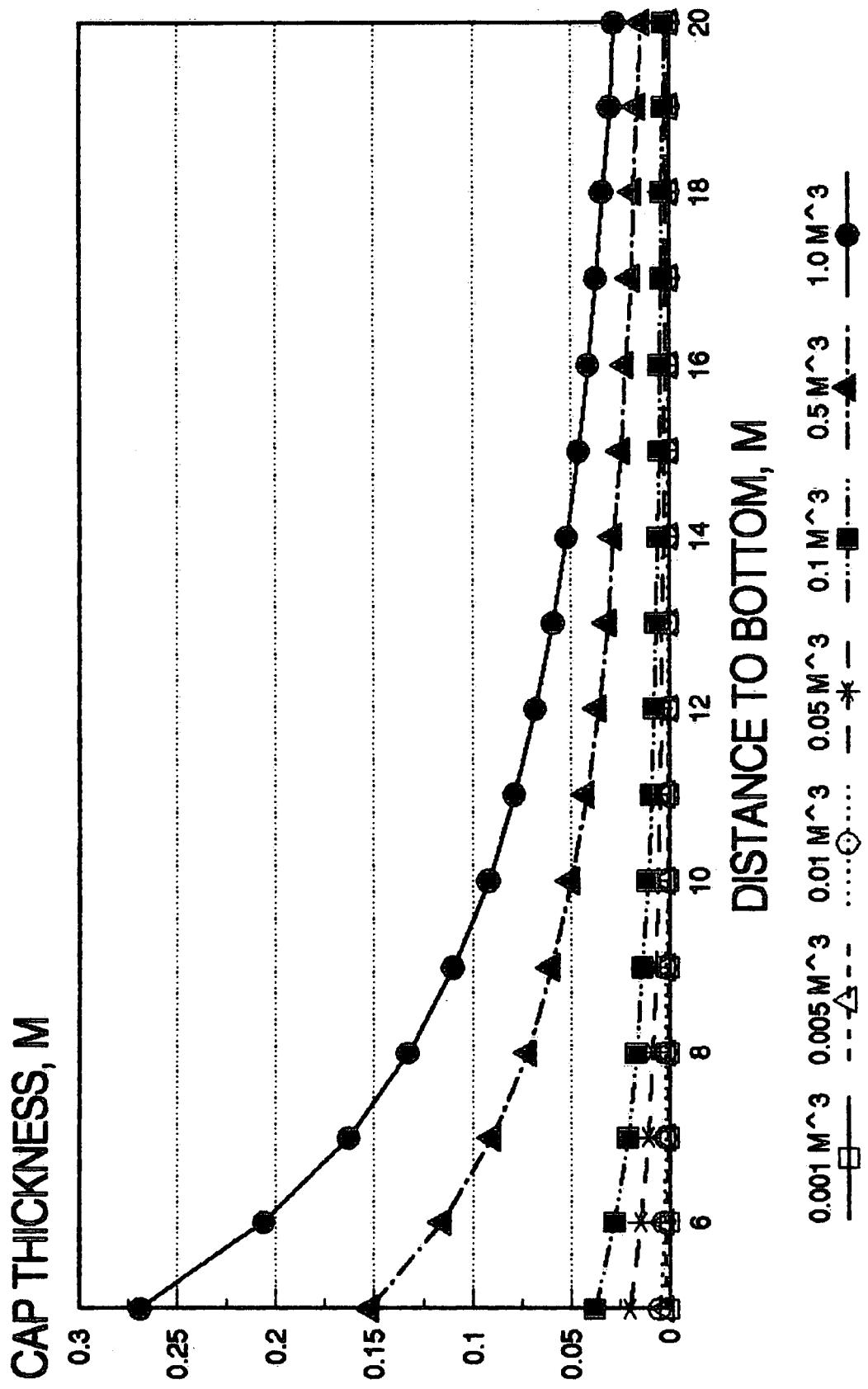
MAX CAP THICKNESS VS. DISTANCE TO BOTTOM

GRAIN SIZE: 0.044 MM

CAP THICKNESS, M



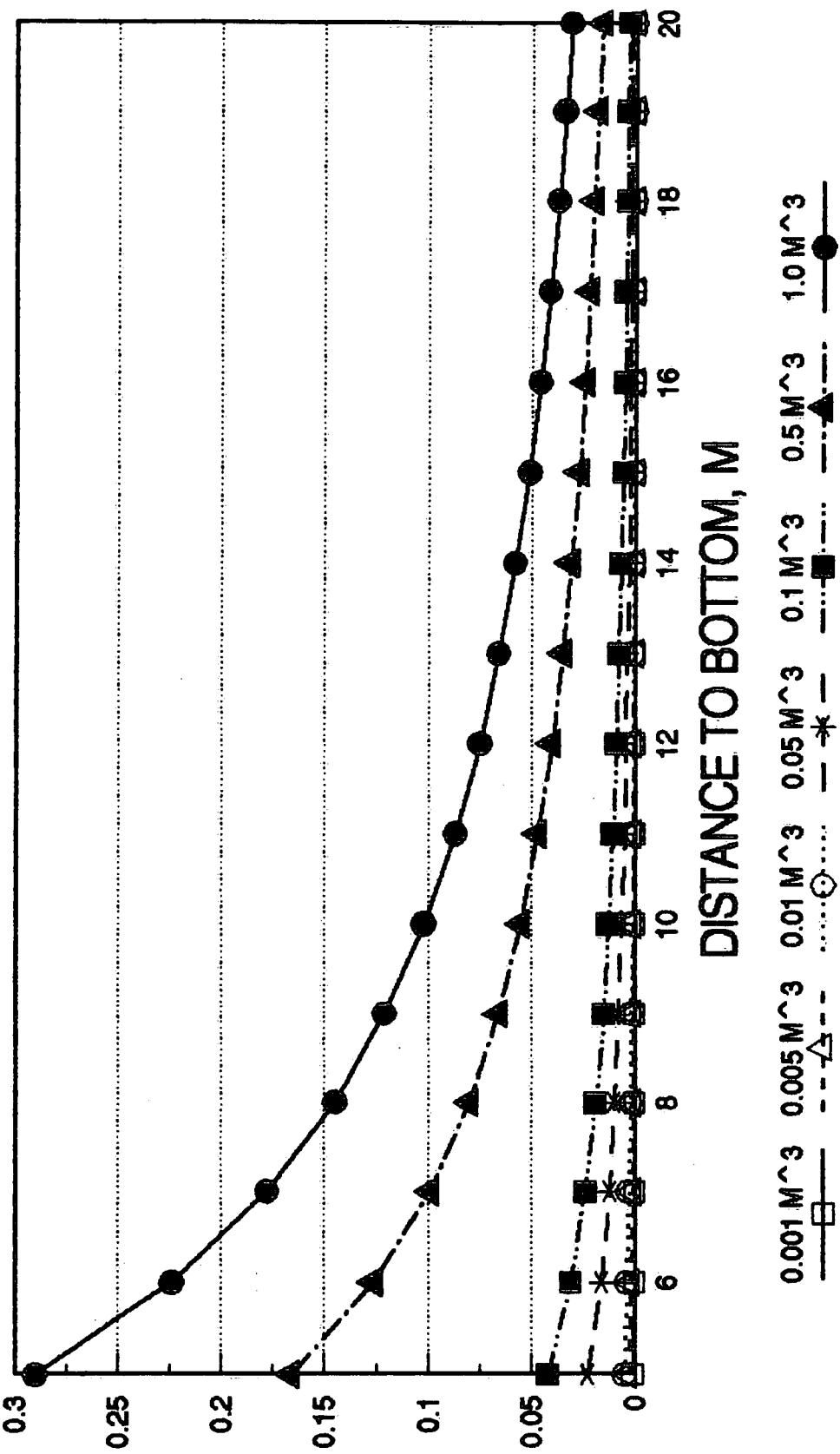
MAX. CAP THICKNESS VS. DISTANCE TO BOTTOM
GRAIN SIZE: 0.18 MM



MAX. CAP THICKNESS VS. DISTANCE TO BOTTOM

GRAIN SIZE: 0.25 MM

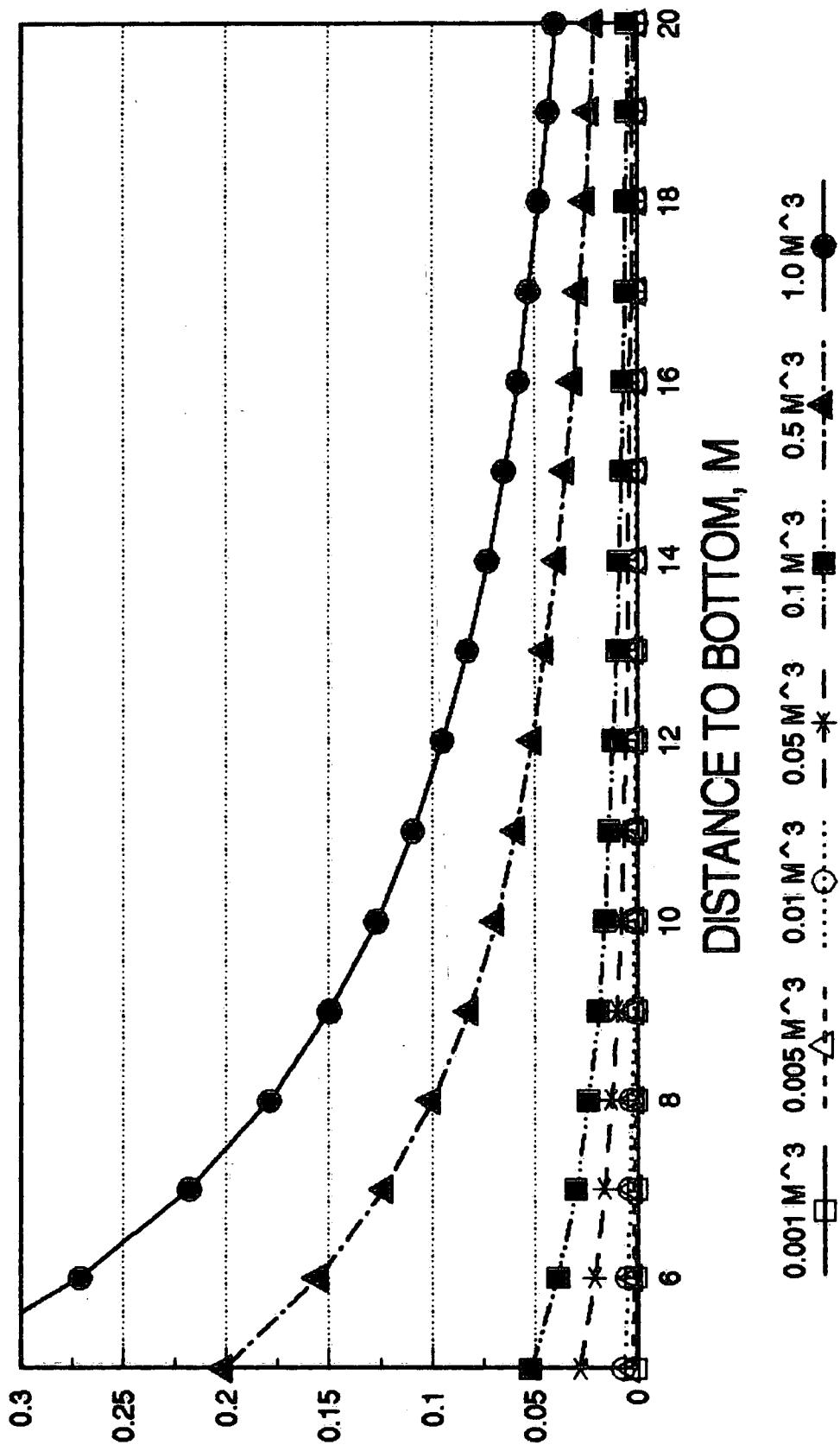
CAP THICKNESS, M



MAX CAP THICKNESS VS. DISTANCE TO BOTTOM

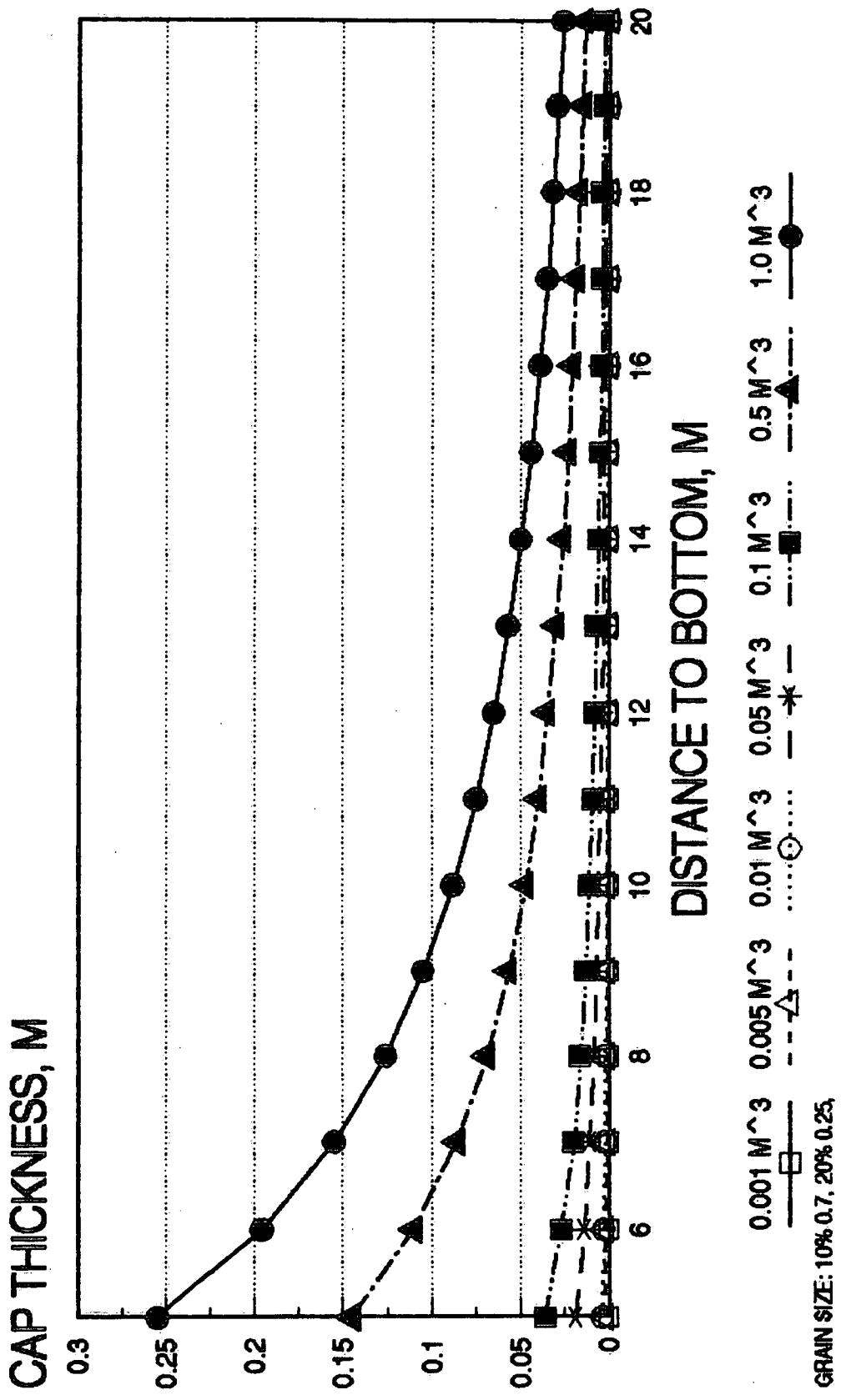
GRAIN SIZE: 0.7 MM

CAP THICKNESS, M



MAX. CAP THICKNESS VS. DISTANCE TO BOTTOM

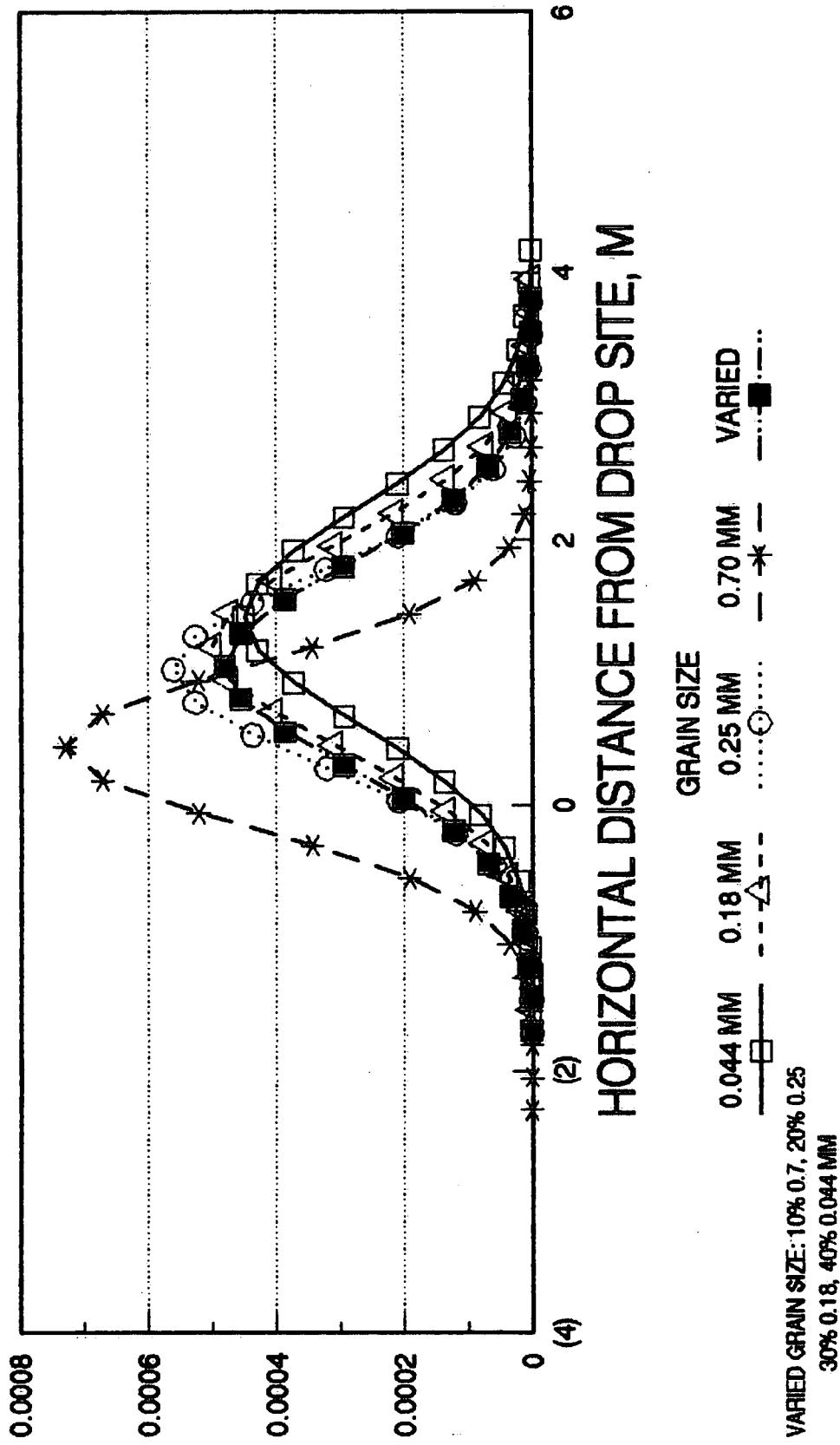
MULTIPLE GRAIN SIZES



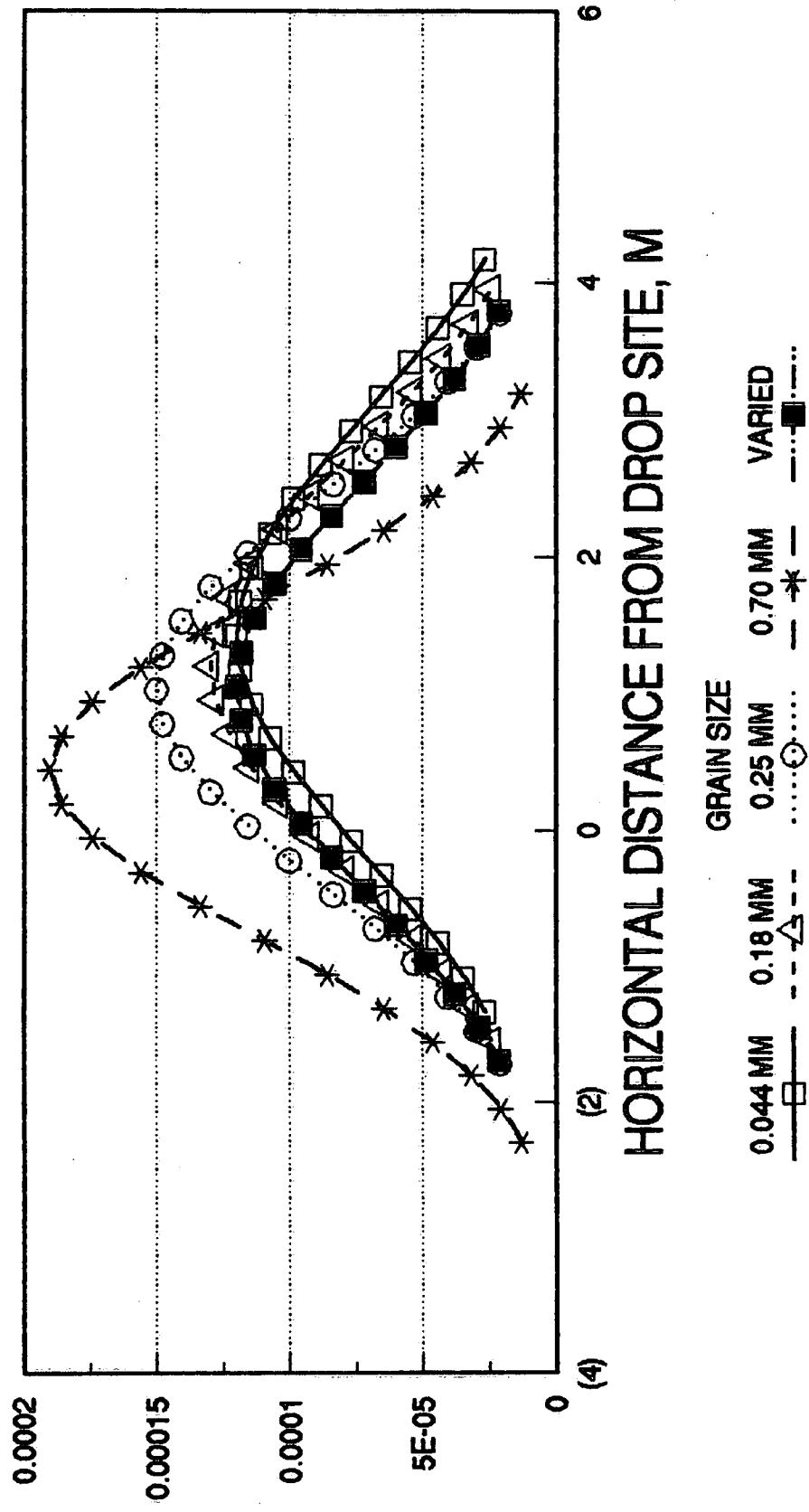
LAYER THICKNESS WITH A CURRENT OF 0.01 M/S

SLUG SIZE: 0.001 M^3 , DISTANCE TO BOTTOM: 5 M

LAYER THICKNESS, M



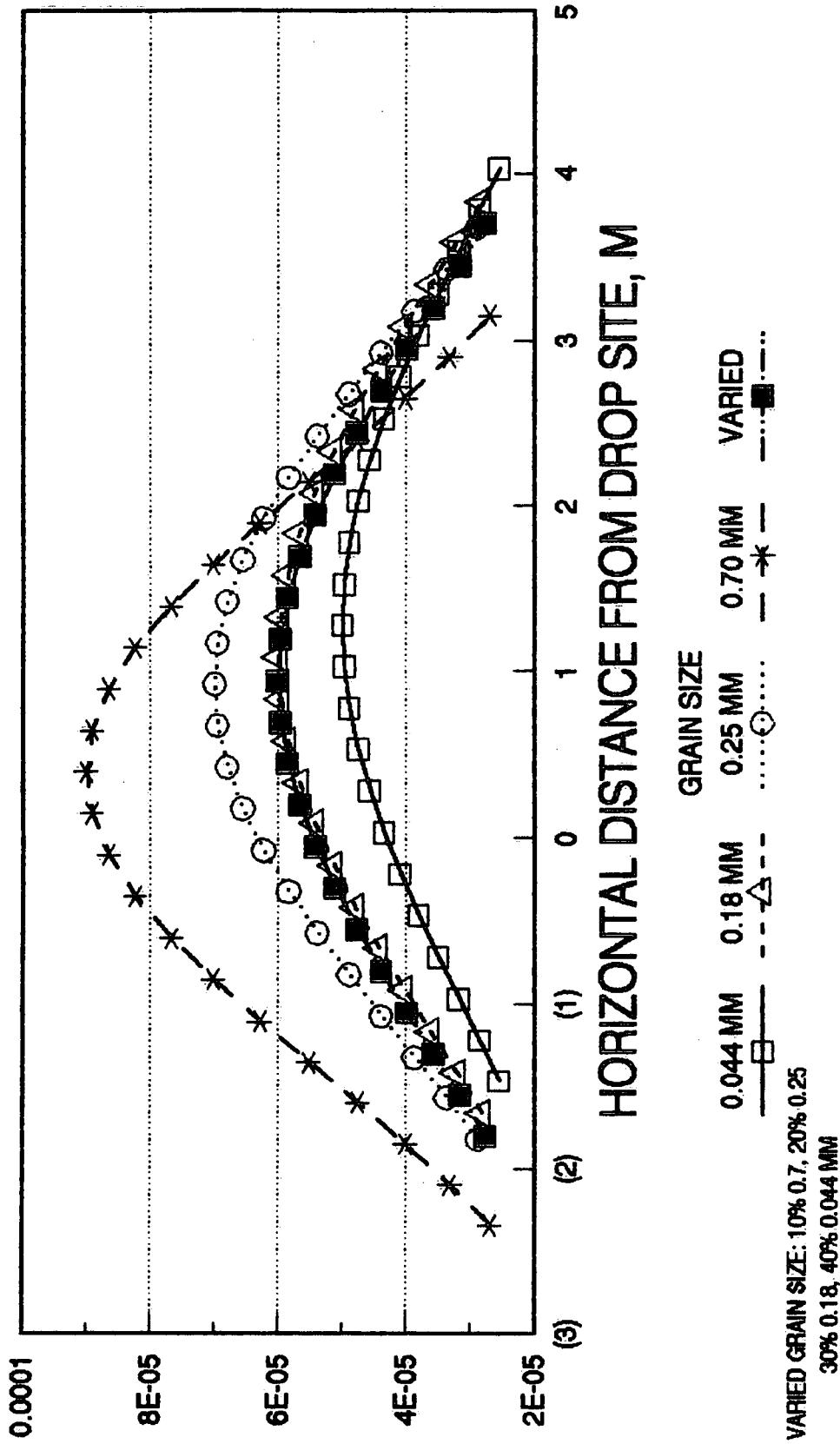
LAYER THICKNESS WITH A CURRENT OF 0.0025 M/S
SLUG SIZE: 0.001 M³, DISTANCE TO BOTTOM: 10 M



LAYER THICKNESS WITH A CURRENT OF 0.001 M/S

SLUG SIZE: 0.001 M^3 , DISTANCE TO BOTTOM: 15 M

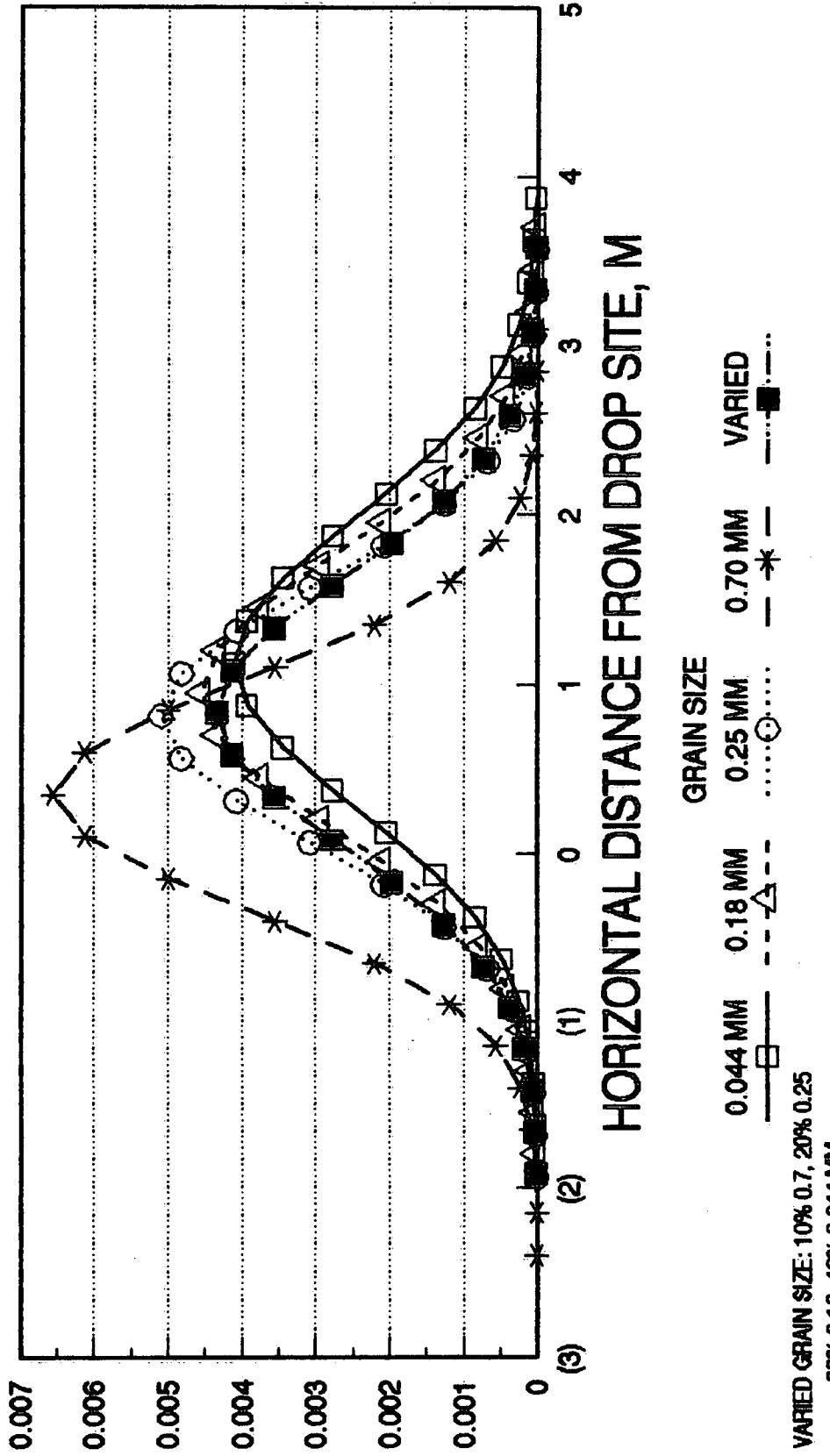
LAYER THICKNESS, M



LAYER THICKNESS WITH A CURRENT OF 0.025 M/S

SLUG SIZE: 0.01 M³, DISTANCE TO BOTTOM: 5 M

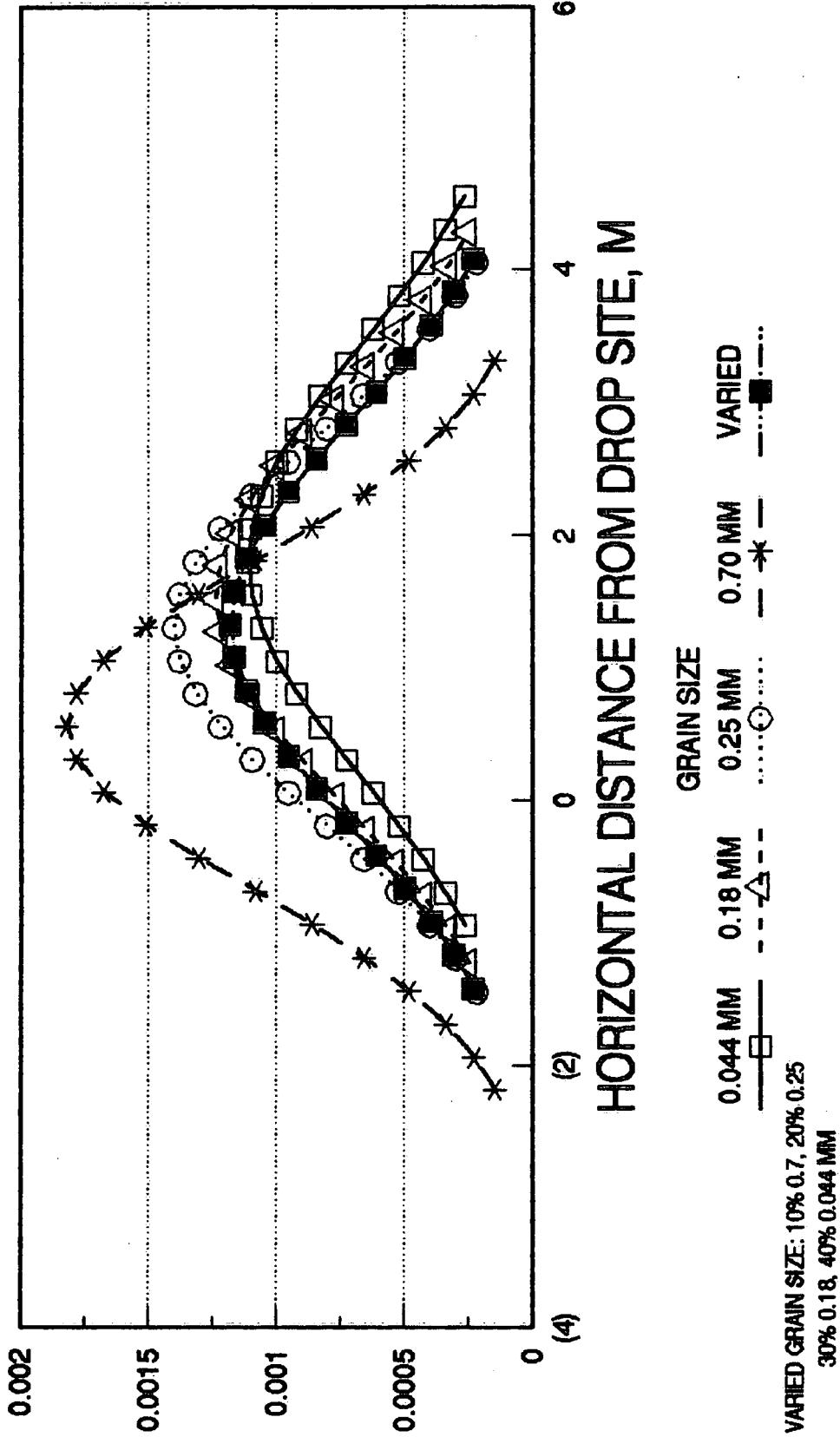
LAYER THICKNESS, M



LAYER THICKNESS WITH A CURRENT OF 0.01 M/S

SLUG SIZE: 0.01 M \wedge 3, DISTANCE TO BOTTOM: 10 M

LAYER THICKNESS, M

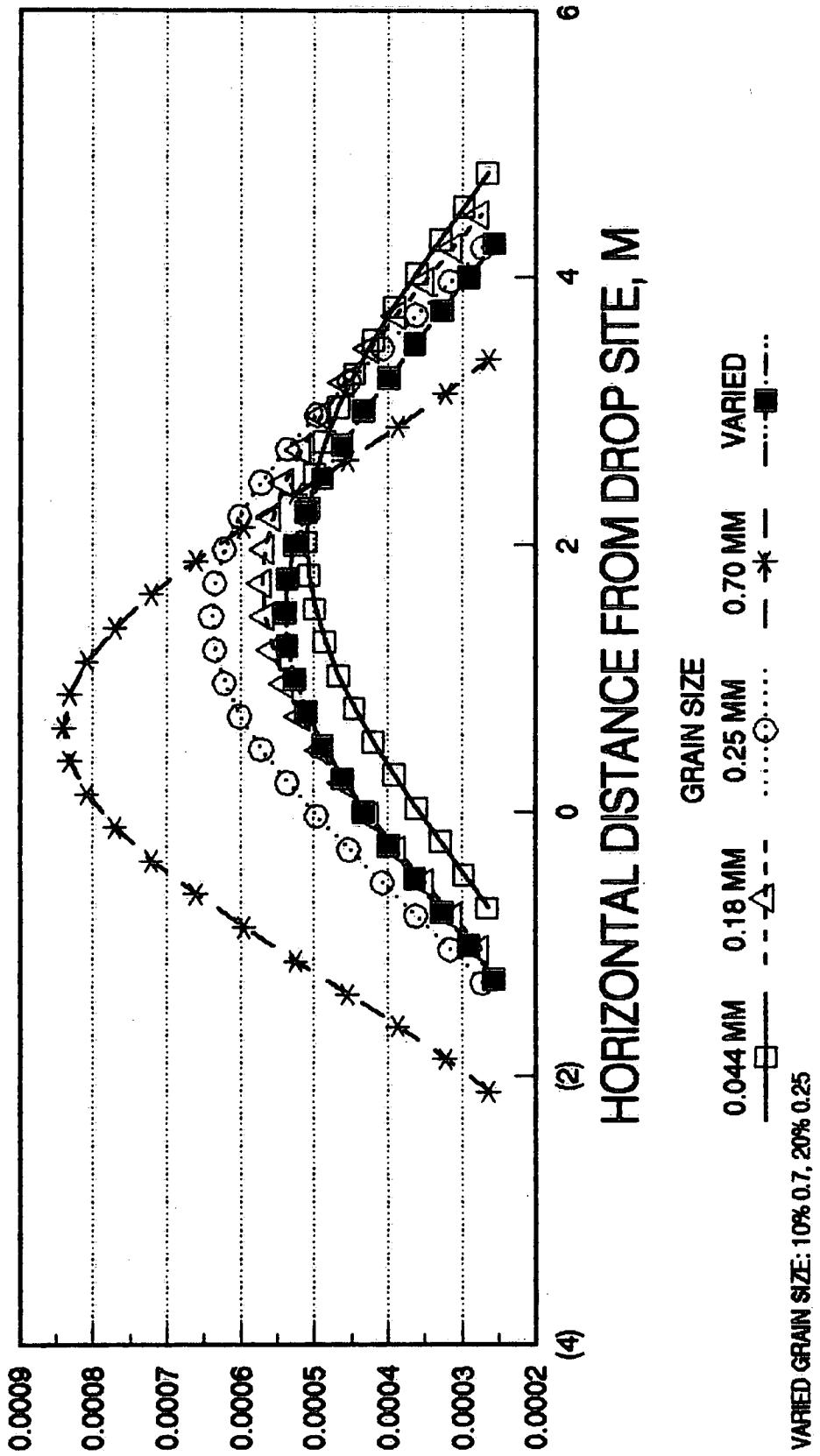


VARIED GRAIN SIZE: 10% 0.7, 20% 0.25
30% 0.18, 40% 0.044 MM

LAYER THICKNESS WITH A CURRENT OF 0.005 M/S

SLUG SIZE: 0.01 M \wedge 3, DISTANCE TO BOTTOM: 15 M

LAYER THICKNESS, M



LAYER THICKNESS WITH A CURRENT OF 0.1 M/S

SLUG SIZE: 0.1 M³, DISTANCE TO BOTTOM: 5 M

LAYER THICKNESS, M

0.06

0.05
0.04
0.03
0.02
0.01
0

(2)
(4)

6

HORIZONTAL DISTANCE FROM DROP SITE, M

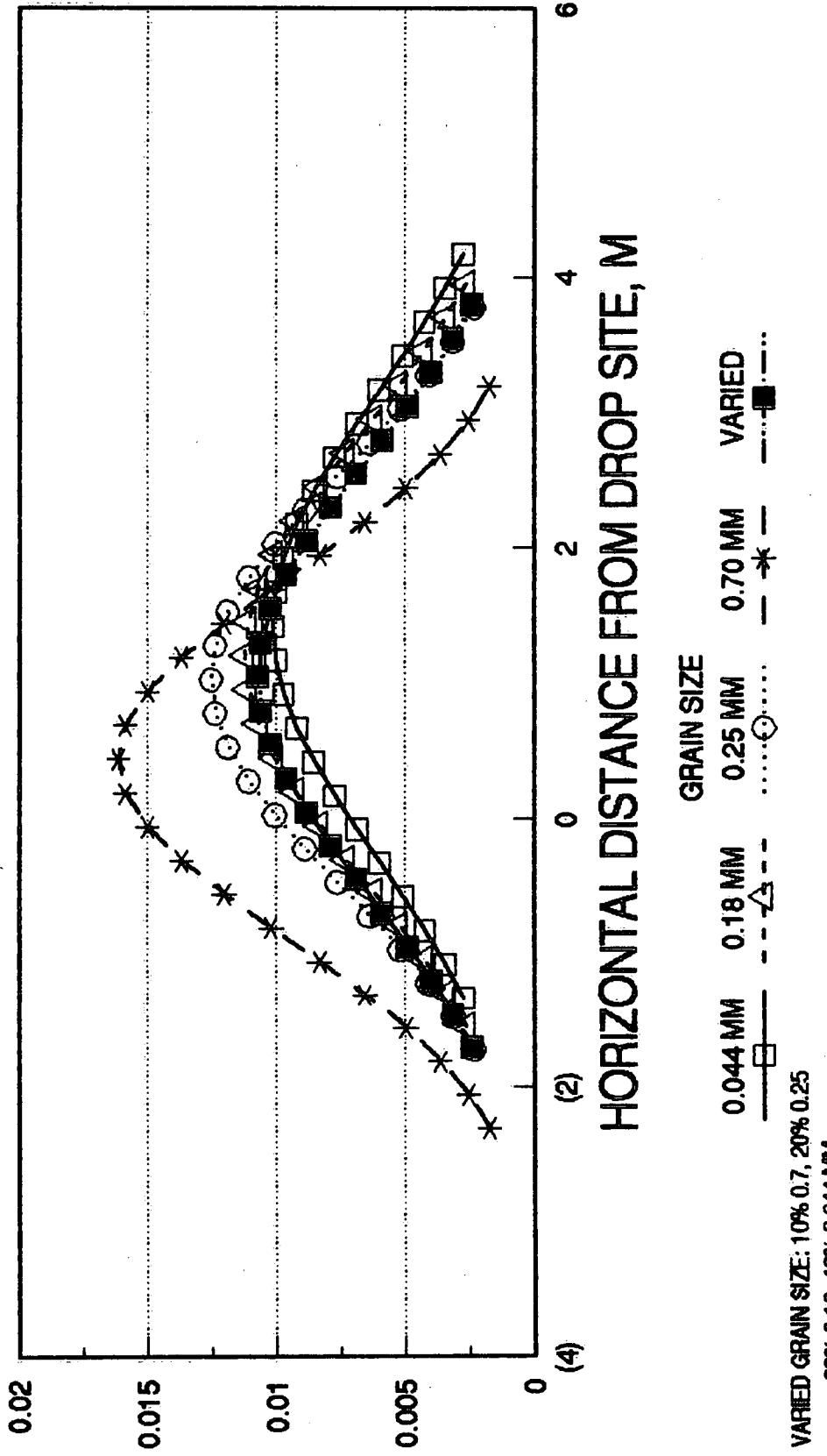
GRAIN SIZE
0.044 MM —□— 0.18 MM - -△-- 0.25 MM○..... 0.70 MM - *- VARIED ■ - - -

VARIED GRAIN SIZE: 10% 0.7, 20% 0.25
30% 0.18, 40% 0.044 MM

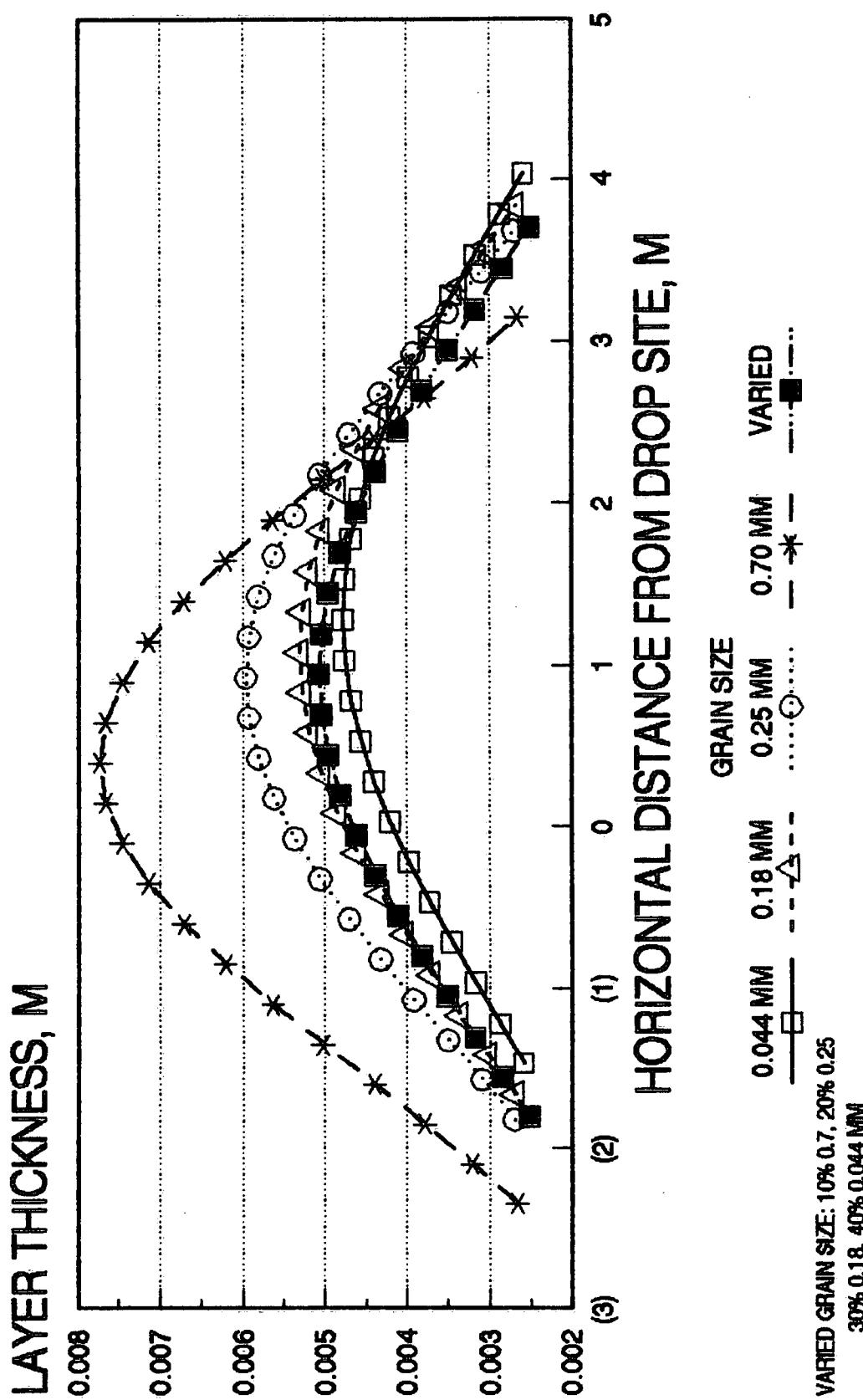
LAYER THICKNESS WITH A CURRENT OF 0.025 M/S

SLUG SIZE: 0.1 M^3 , DISTANCE TO BOTTOM: 10 M

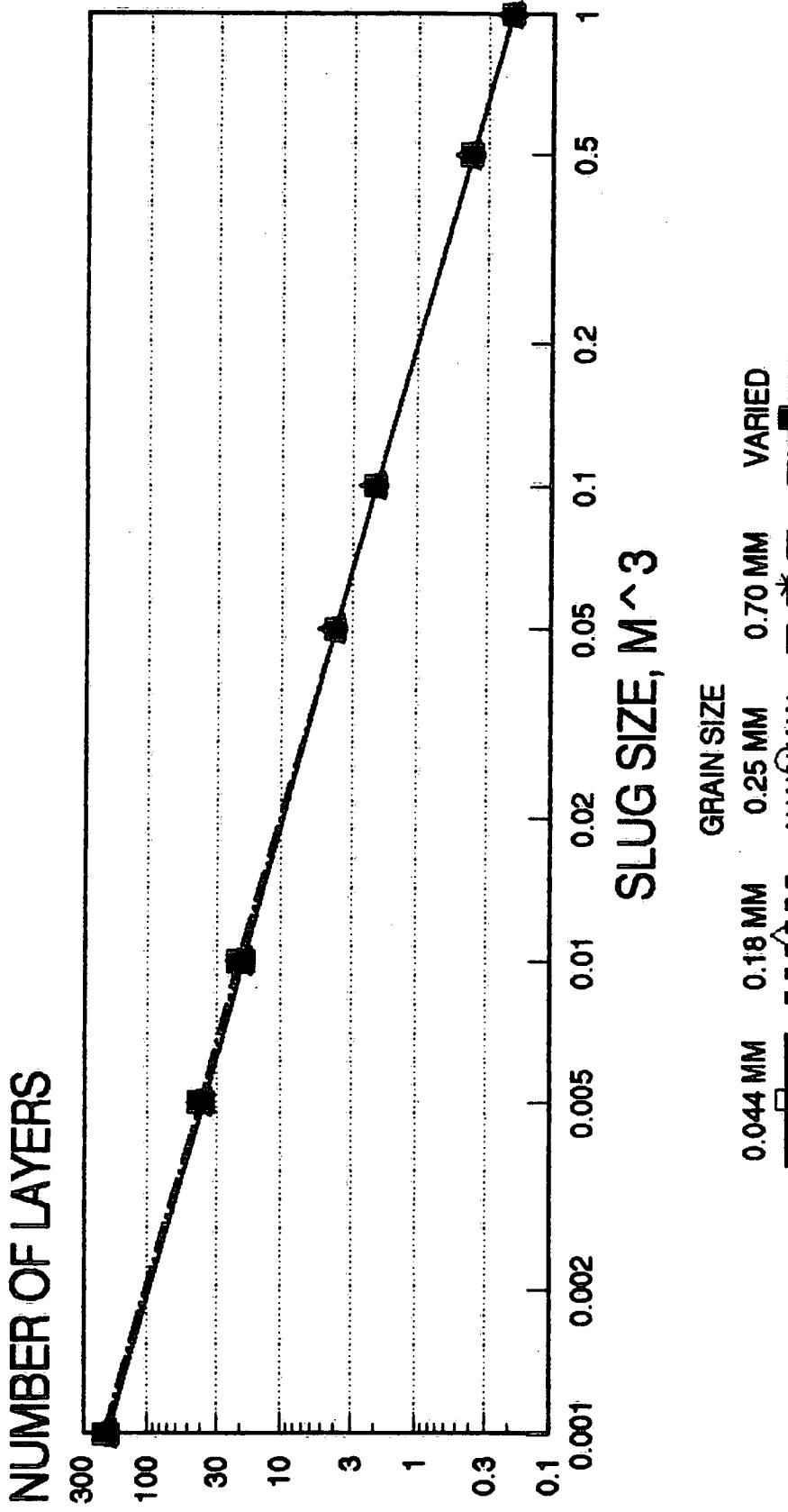
LAYER THICKNESS, M



LAYER THICKNESS WITH A CURRENT OF 0.01 M/S
SLUG SIZE: 0.1 M³, DISTANCE TO BOTTOM: 15 M

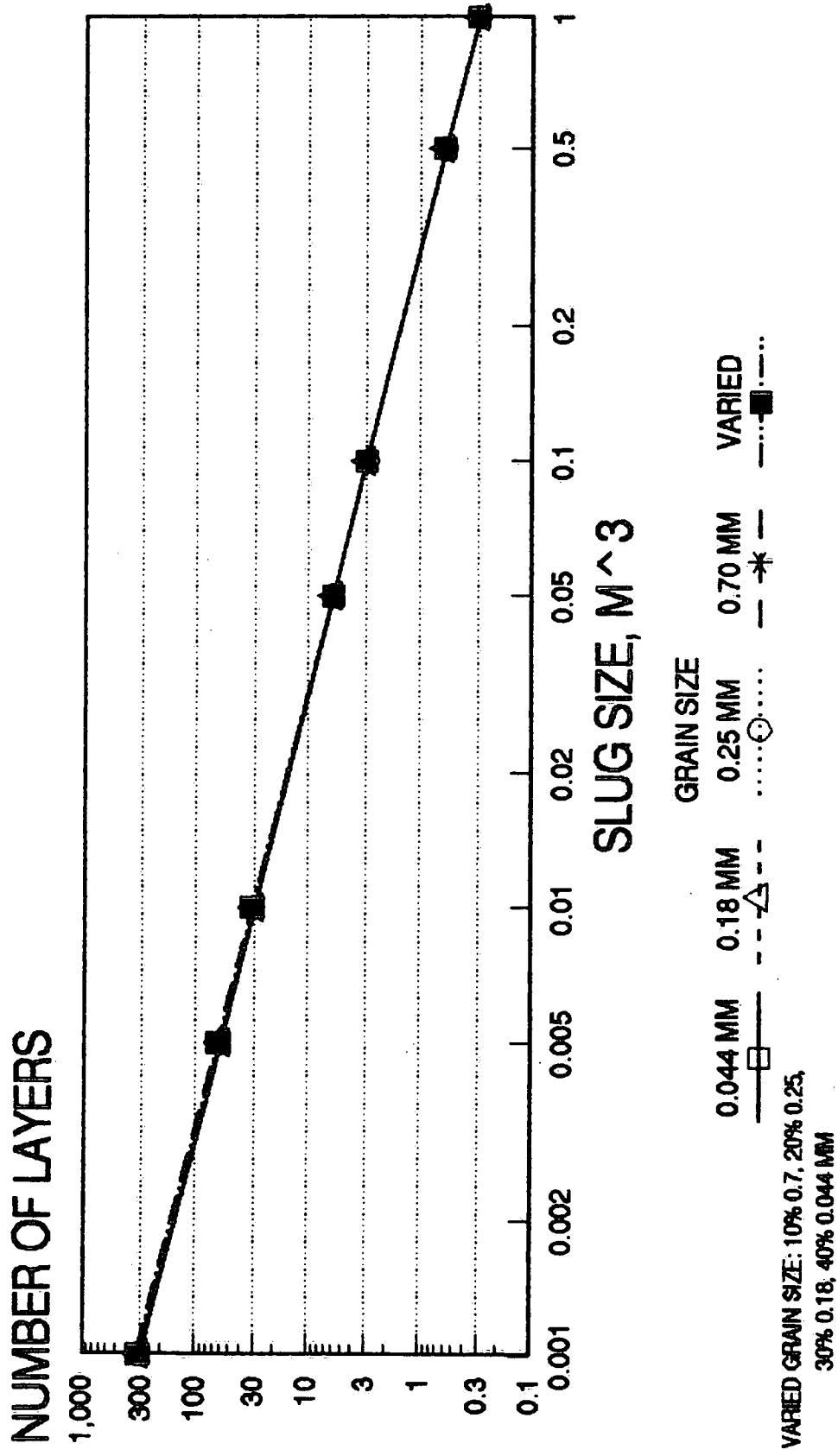


NUMBER OF LAYERS VS. SLUG SIZE
CAP THICKNESS: 5 CM, DISTANCE TO BOTTOM: 5 M
2 M SPACING BETWEEN SLUG CENTRES



VARED GRAIN SIZE: 10% 0.7, 20% 0.25,
 30% 0.18, 40% 0.044 MM

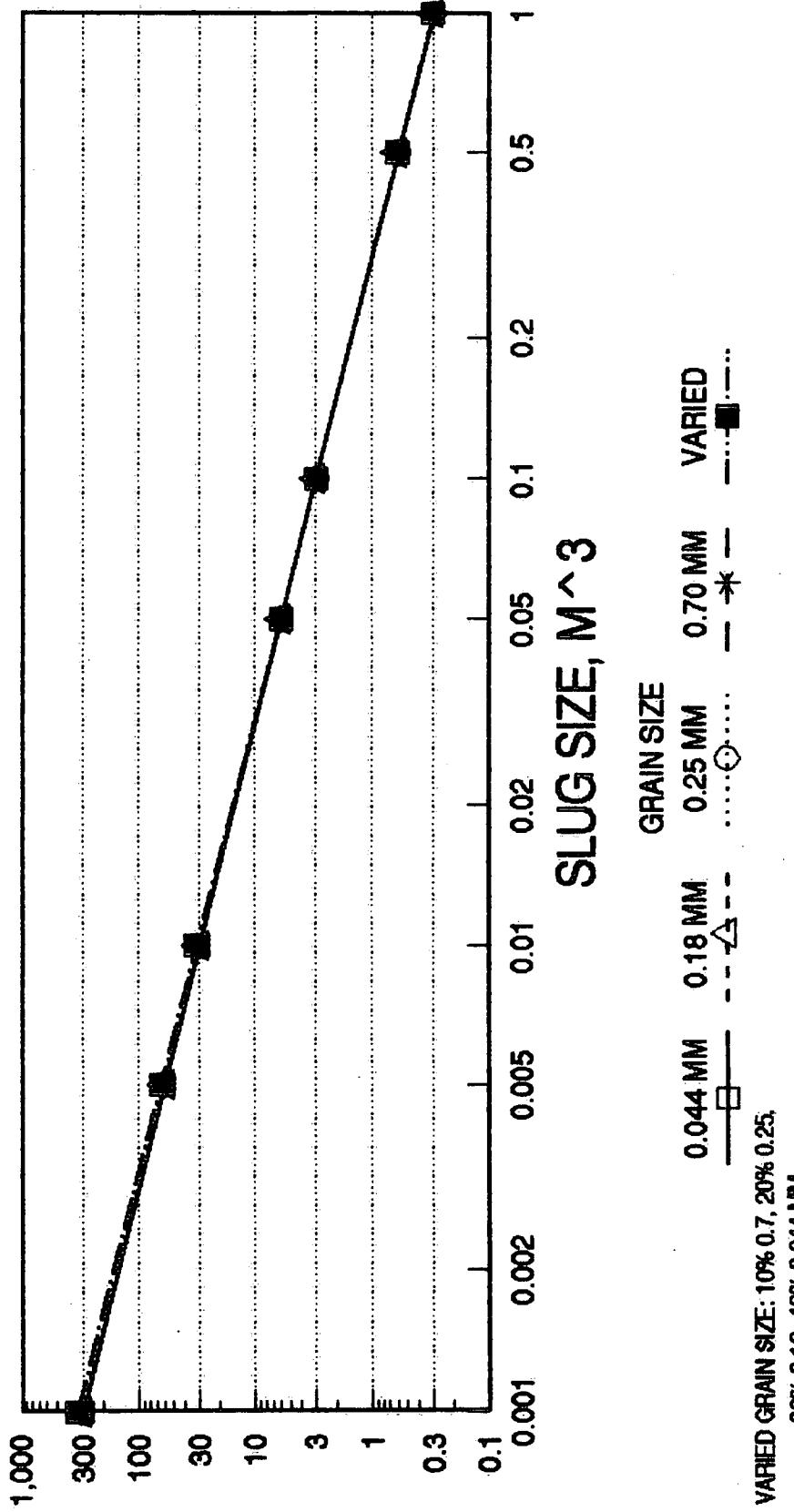
NUMBER OF LAYERS VS. SLUG SIZE
CAP THICKNESS: 5 CM, DISTANCE TO BOTTOM: 5 M
3 M SPACING BETWEEN SLUG CENTRES



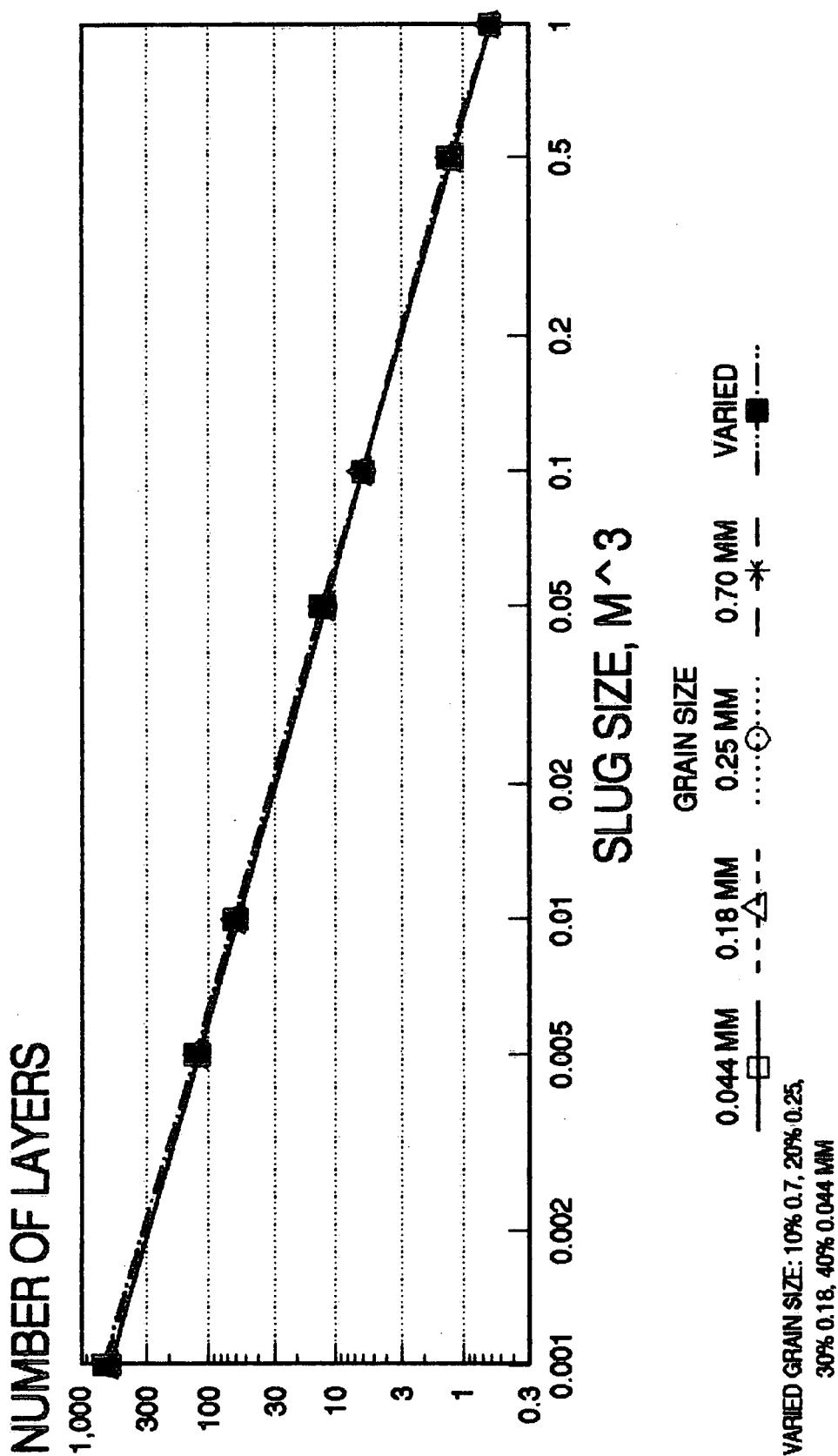
NUMBER OF LAYERS VS. SLUG SIZE

CAP THICKNESS: 5 CM, DISTANCE TO BOTTOM: 10 M
3 M SPACING BETWEEN SLUG CENTRES

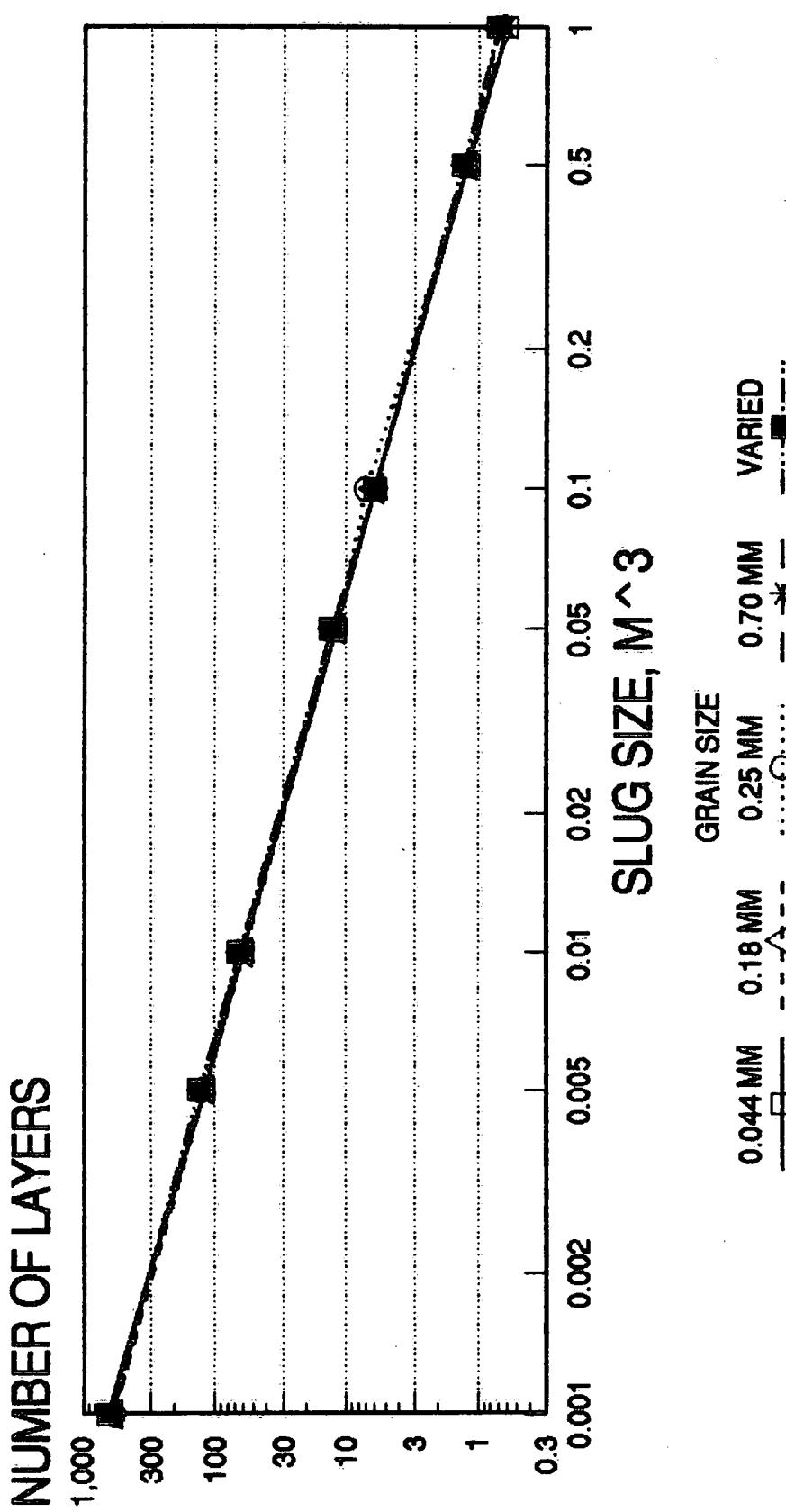
NUMBER OF LAYERS



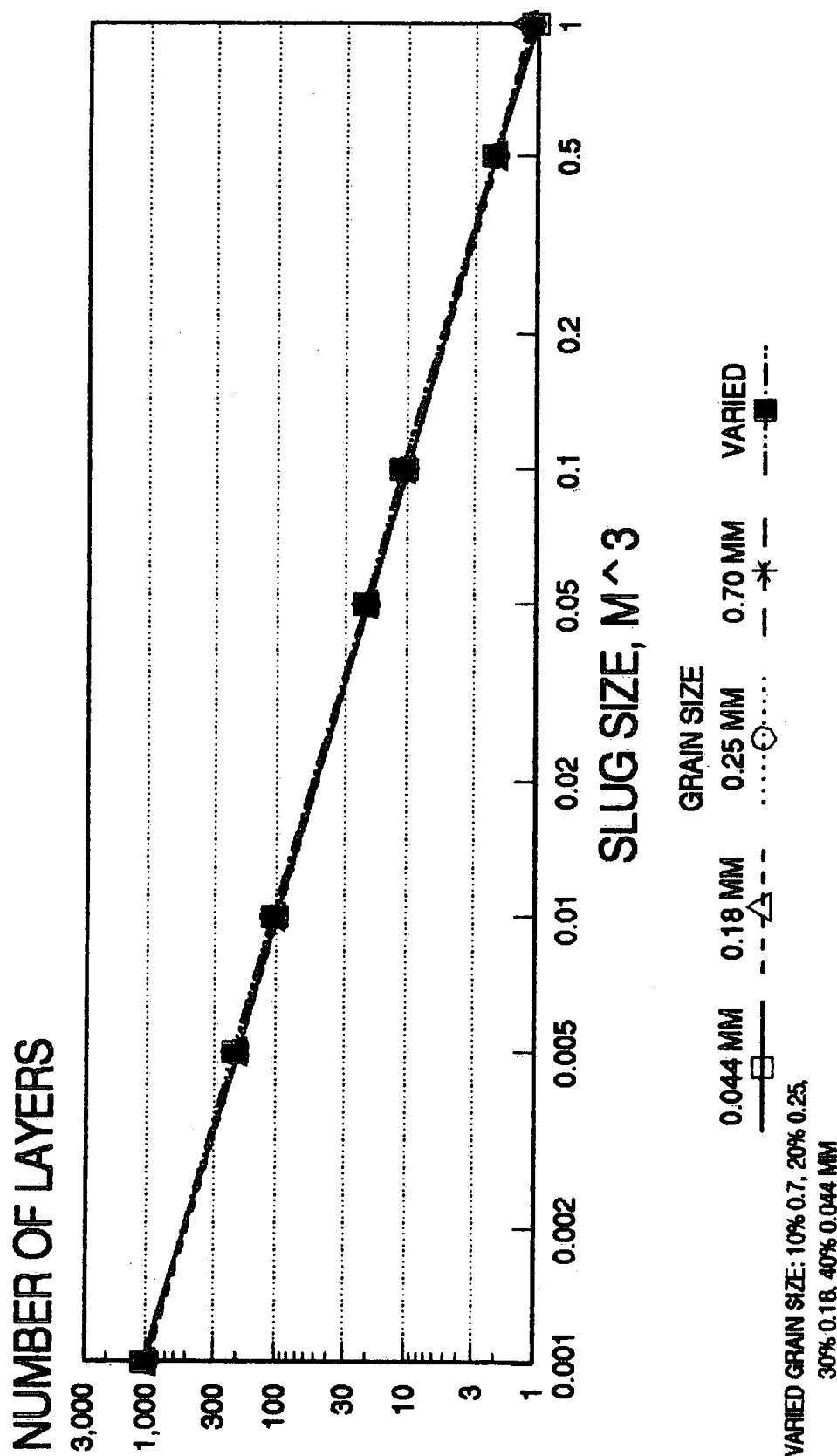
NUMBER OF LAYERS VS. SLUG SIZE
CAP THICKNESS: 5 CM, DISTANCE TO BOTTOM: 10 M
4 M SPACING BETWEEN SLUG CENTRES



NUMBER OF LAYERS VS. SLUG SIZE
CAP THICKNESS: 5 CM, DISTANCE TO BOTTOM: 15 M
4 M SPACING BETWEEN SLUG CENTRES



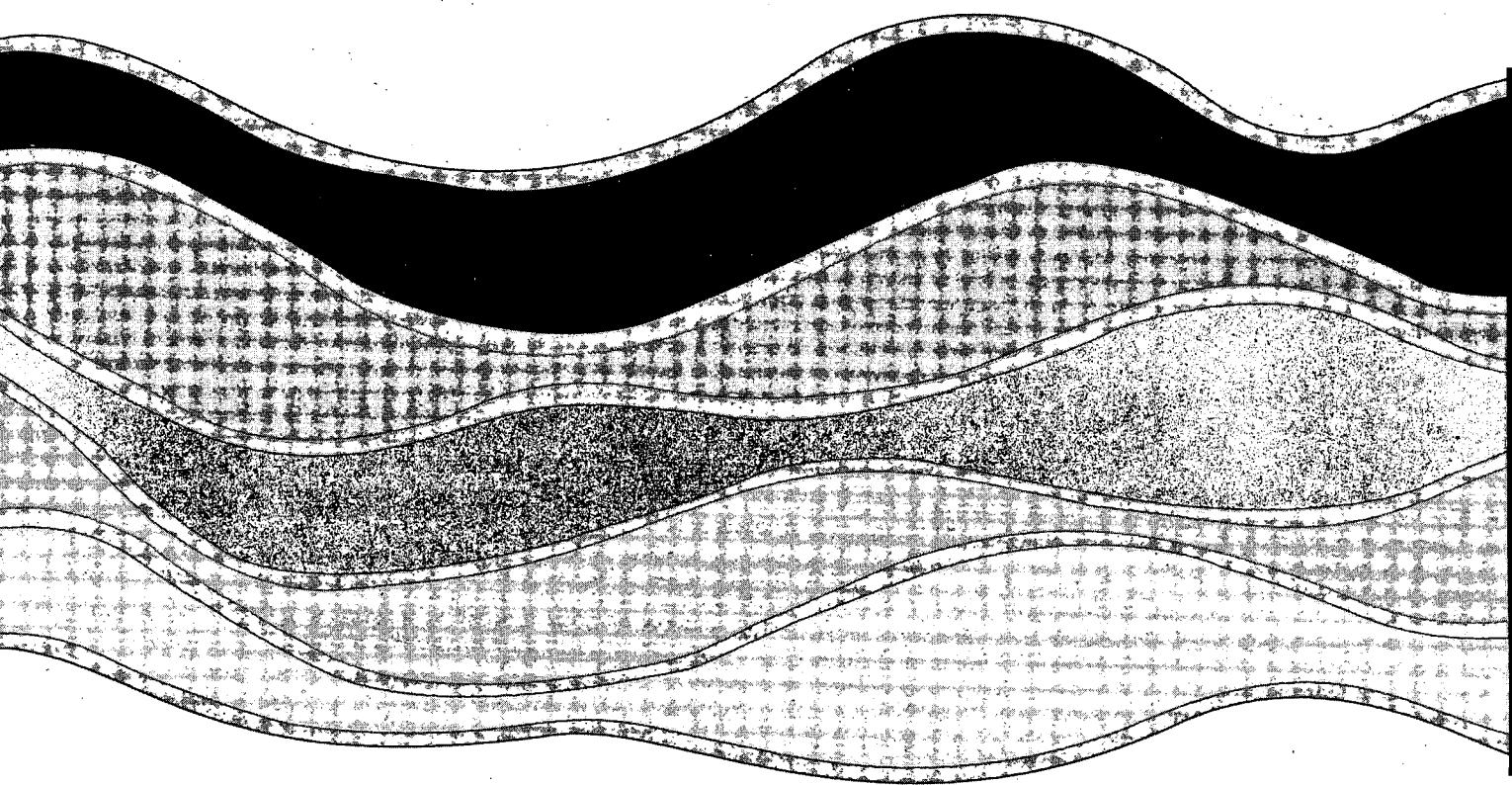
NUMBER OF LAYERS VS. SLUG SIZE
CAP THICKNESS: 5 CM, DISTANCE TO BOTTOM: 15 M
5 M SPACING BETWEEN SLUG CENTRES



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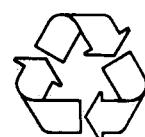


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