PORT AND OCEAN ENGINEERING UNDER ARCTIC CONDITIONS
TECHNICAL UNIVERSITY OF NORWAY

DREDGING SYSTEMS

AND

THE BASIC DREDGE LAWS

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Each Dredge Law provides you with a fundamental and convenient relationship between two or more of the factors which affect dredge production. By the judicious application of these laws, you will be able to understand the complex dredging cycle and to make the changes in design or operating procedure to maximize the output of a given dredge.

It is appropriate that the first dredge law deals with the economic purpose of a dredge, the production (i.e. excavation and transport) of solids. This law is obvious and generally accepted. (Sketch No. 1)

I. PRODUCTION VARIES AS FLOW X AVERAGE % SOLIDS.

II. AVE. % SOLIDS = PEAK % SOLIDS X DREDGE EFFICIENCY.

The peak % solids is the maximum % solids the suction line can carry at any moment, and is limited by the cavitation point of the dredge pump. The dredge efficiency is the average % solids divided by the peak % solids, but since this is an abstract, mathematical expression, it can be simply explained as the actual production of the dredge compared with the production which would be realized if the maximum instantaneous rate were achieved continuously. (Sketch No. 2)

III. PEAK % SOLIDS VARIES AS V_s; TYPE OF SOLIDS: $\frac{1}{d_s}$

It is apparent that low velocities will not carry high % solids since low velocities have low turbulence and would "drop out" or fail to transport the materials. It should be emphasized that the velocity which determines the dredge production is the suction line velocity, not the discharge line velocity.

The type of solids also affects the % solids transported at a given velocity. If the particle size is relatively large and dense, a greater turbulence is required to keep it in suspension. Empirical data is generally required here, although theoretical equations have been developed for homogeneous materials.

The most frequently overlooked factor affecting % solids is the diameter of the suction pipe. A brief analysis of any pipe line friction equation will disclose that at a given velocity, the friction (and therefore turbulence) decreases as the diameter increases. This decreased turbulence allows the transport of less material; therefore, to transport the same % as a smaller line, the velocity in a large line must be increased to obtain the same turbulence. The relationship is a function of the square root of the diameter. (Sketch No. 3)

IV. MAXIMUM (SHORT-LINE) PRODUCTION VARIES AS AREA OF SUCTION PIPE.

A dredge pump is a device that evacuates its casing; it cannot reach down the suction pipe to pick up the slurry. The only force available to push the slurry to a dredge pump mounted at water level is the barometric pressure. The design of the "Barometric Pump" is perhaps the most critical aspect of the dredge, for as all dredge men know, if the dredge pump is run faster than the suction line can deliver slurry, cavitation results.

An analysis of the basic hydraulic equation $h = V^2 \div 2g$ discloses that h varies as V^2 and V varies as the square root of h. Since the only h available to force slurry through the suction pipe is the barometric head (constant at sea level), the maximum velocity is a constant. It follows then that since Flow = Vel. (a constant) x Area, that Flow and Production vary as A_s. (Sketches No. 4A & B)

V. OPTIMUM V_s VARIES AS DIGGING DEPTH

By an analysis of the suction line losses, h_v; h_e; h_f; h_{sg} it can be demonstrated that since the sum total of these must equal barometric head, regardless of digging depth, that it is necessary to trade off velocity head for specific gravity head as digging depth increases. A reduction in velocity head reduces velocity and requires a reduction in pump speed; therefore, GPM and pump speed must diminish to an optimum value as digging depth increases. (Sketch No. 5)

VI. DISCHARGE LINE LENGTH VARIES AS PUMP HP.

An analysis of the HP equation shows that since GPM is a constant at a given digging depth; and since pump efficiency is a constant at a given GPM; that HP varies as head which, in turn, varies as discharge line length; therefore, HP determines not maximum output but rather how far it can be pumped. If it is desired to pump further, a booster most be added or the % solids reduced. (Sketch No. 6)

VII. PRODUCTION IS LIMITED BY:

(1) SUCTION CONDITIONS (BAROMETRIC HEAD)

(2) PUMP HP AVAILABLE (DISCHARGE HEAD REQUIREMENT)

(3) VELOCITY (CONVEYING CAPACITY)

The seventh law is a general statement of the first six laws. A typical production chart is attached which shows the effect of the limitations imposed by suction conditions (horizontal lines), the pump HP (sloping lines) and the velocity carrying capacity (curved asymtotic line). (Sketch No. 7A)

Now, I hope it is obvious to you after your exposure to the Dredge Laws, that there are ways to eliminate the restrictions on production as manifest in these production charts. First, let's look at the effect of increasing the suction size (SK. #7B). You will see the short line production increases in proportion to the area of the suction line (Dredge Law #4) but now the HP is not available to pump it as far.

Next, let's use a 20" discharge line rather than a 24". The maximum production is still the same, but since h_f varies as $d_d^{\ 4.85}$ (Hazen & Williams formula) it can not be pumped as far. (SK. #7C).

Suppose we add a booster pump (SK. #7D). The maximum production remains the same (D.L. #4), but the pumping distance is essentially doubled since the HP is doubled (D.L. #6) (SK. #7D).

Now, consider the addition of a pump on the ladder to attack the suction limitation. Note that not only is the 10' DD output increased, but the depth at 50' is more than doubled. If you need to dig to 100', the output would be quadrupled giving the output of an additional three dredges at 5% of the investment, and without the other three operating crews. Booster pumps can be added also, if needed. (SK. #7E)

ABBREVIATIONS:

	=	Varies as
V_s	=	Velocity in suction pipe
d_s	=	Diameter of suction pipe
A_s	=	Area of suction pipe
h_v	=	Velocity head
h_E	=	Entrance loss
h_f	=	Friction loss
h_{sg}	=	Head requirement for specific gravity over 1.0
H	=	Total dynamic head
D.D.	=	Digging Depth
S.G. or sg	=	Specific Gravity

I PRODUCTION VARIES AS FLOW X AVE % SOLIDS

PRODUCTION IN THE ENGLISH SYSTEM IS NORMALLY IN UNITS OF YDS^3/HR & FLOW IN G.P.M., WHILE % SOLIDS IS IN-SITU VOLUME INCLUDING VOIDS, NOT TRUE VOLUME. THE LAW IS TRUE REGARDLESS OF THE UNITS USED ALTHOUGH CONSTANTS MUST BE CHANGED WHERE UNITS ARE CHANGED. THE TRUE EQUATION IN ENGLISH UNITS IS

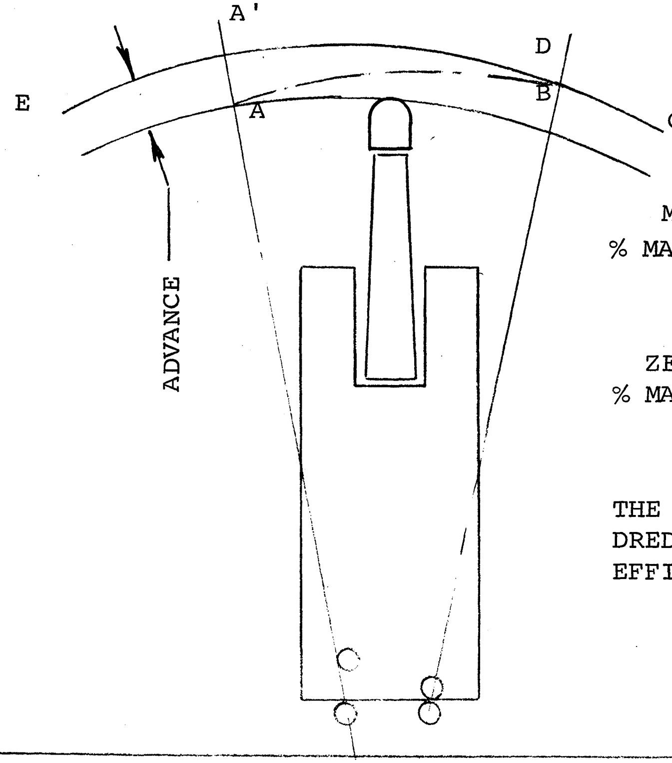
$$YDS^3/HR = GPM \text{ X AVE \% SOLIDS X } .297$$

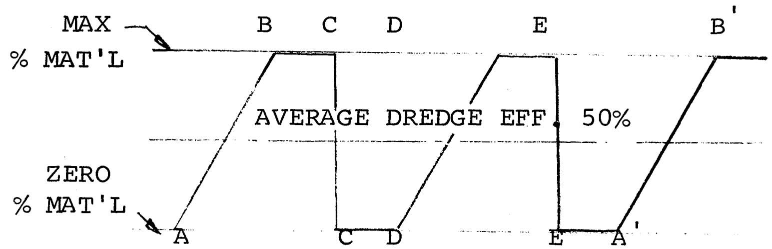
WHERE

$$.297 = \frac{60 \text{ MIN./HR.}}{7.48 \text{ GAL}/FT^3 \text{ X } 27 \text{ } FT^3/YD^3}$$

SK. #2

II AVE % SOLIDS = PEAK % SOLIDS X DREDGE EFF.





THE "WALKING" (ADVANCING OPERATION) OF A DREDGE IS A MAJOR FACTOR AFFECTING DREDGE EFFICIENCY.

SK. #3

III PEAK % SOLIDS VARIES AS (1) V_s; (2) TYPE OF SOLIDS; (3) $\frac{1}{\sqrt{ds}}$

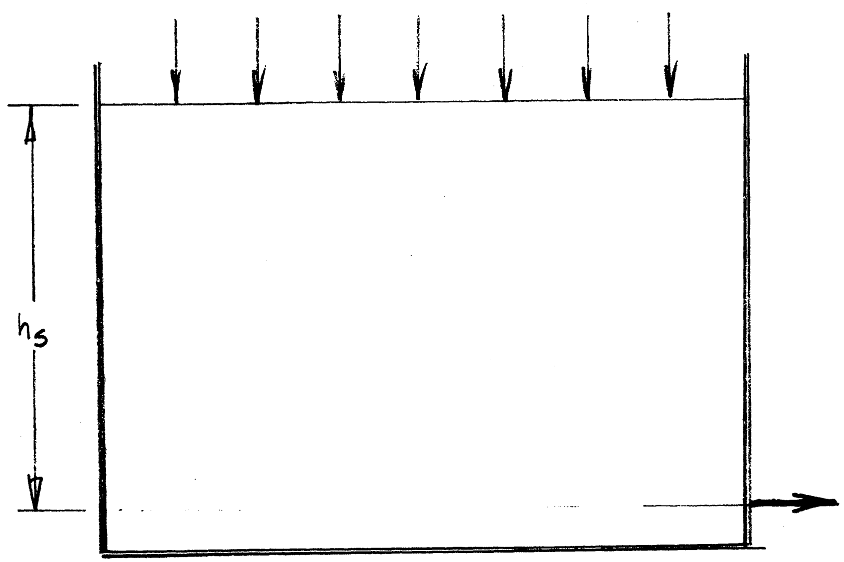
TURBULENCE IN THE CARRYING MEDIUM IS REQUIRED TO KEEP SOLIDS SUSPENDED.

(1) THE GREATER THE VELOCITY, THE GREATER THE TURBULENCE.

(2) THE DENSER AND LARGER (UP TO A POINT) THE SOLIDS, THE GREATER THE TURBULENCE REQUIRED TO SUSPEND AND TRANSPORT THE SOLIDS.

(3) THE LARGER THE PIPE, THE LOWER THE TURBULENCE AT A GIVEN VELOCITY.

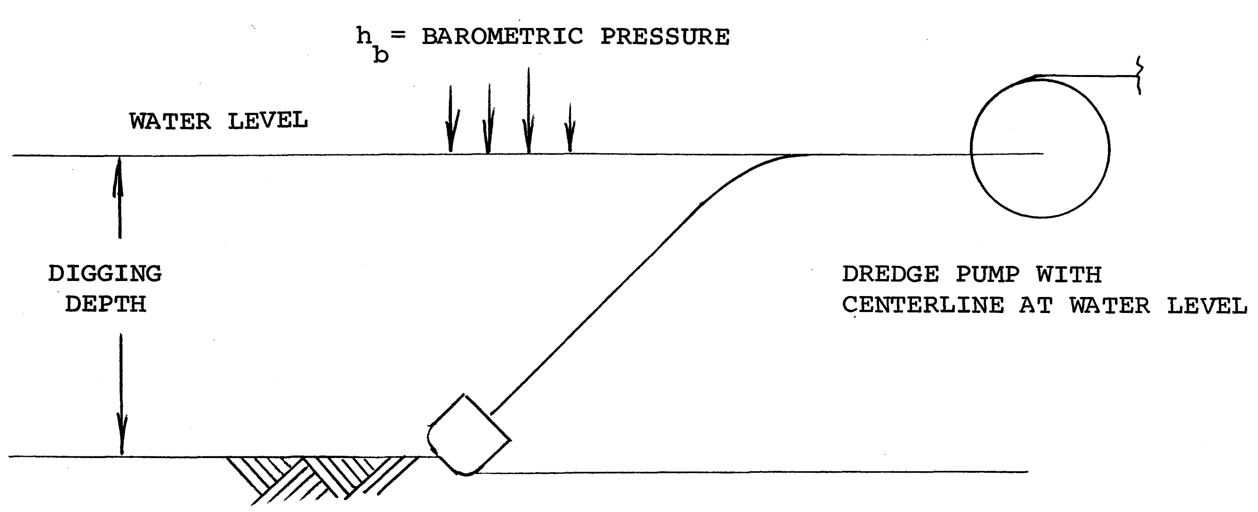
SK 4A



$h_s = \frac{V^2}{2g}$		EQUATION EXPRESSING BASIC HEAD-VELOCITY RELATIONSHIP.
h_s	V^2	CONSTANTS ELIMINATED; RELATIONSHIP UN-ALTERED.
V	$\overline{h_s}$	TRANSPOSITION OF TERMS ONLY, AND ASSUMING DISCHARGE AGAINST BAROMETRIC PRESSURE.
V	$\overline{h_s + h_b}$	ASSUMING DISCHARGE AGAINST ABSOLUTE ZERO.
V	$\overline{h_b}$	ASSUMING DISCHARGE AGAINST ABSOLUTE ZERO AND h_s ELIMINATED

SK. #4B

IV MAX. OR SHORT LINE PRODUCTION ∼ A_s



SINCE h IS BAROMETRIC PRESSURE AND A CONSTANT, MAX. V IS CONSTANT

SINCE FLOW = V x A, THEN FLOW ∼ A

SINCE PRODUCTION VARIES AS FLOW (DREDGE LAW I), IT ALSO VARIES AS A

SK. #5

V OPTIMUM V_s DIGGING DEPTH

LOSS FACTOR	WATER AT 16 FT/SEC	SLURRY 30' D.D. 1.5 S.G.	SLURRY 50' D.D. 1.36 S.G.
$h_v = \frac{V^2}{2g} \times S.G.$	4	6	5
$h_E = K \frac{2}{2g} \times S.G.$*	2	6	5
$h_F = K \frac{V^2}{2g} \times S.G.$**	1	3	2
$h_{SG} = D.D. \ (S.G._{slurry} - S.G._{water})$	$\underline{0}$	$\underline{15}$	$\underline{18}$
	7'	30'	30'

BY REFERRING TO DREDGE LAW #1,

PRODUCTION ~ FLOW X AVE % SOLIDS,

IT BECOMES OBVIOUS THAT AT 50' DIGGING DEPTH BOTH FLOW & % SOLIDS HAVE DECREASED; THEREFORE, AS D.D. INCREASES, PRODUCTION DECREASES IN AN EXPONENTIAL MANNER.

* K FOR THESE CALCULATIONS IS ASSUMED TO BE .5 WHEN PUMPING WATER; 1.0 WHEN PUMPING SLURRY.

** IN ORDER TO AVOID THE USE OF DECIMALS, THESE FRICTION FIGURES ARE QUITE ROUGH.

SK. #6

$$HP = \frac{GPM \times 8.34 \times S.G. \times H}{33000 \times EFF}$$

BY ELIMINATING ALL CONSTANTS AND IGNORING THE RELATIVELY SMALL SUCTION LINE LOSSES, WE GET

$HP \sim H \sim$ LINE LENGTH.

GPM SHOULD BE CONSTANT FOR ANY GIVEN DIGGING DEPTH.

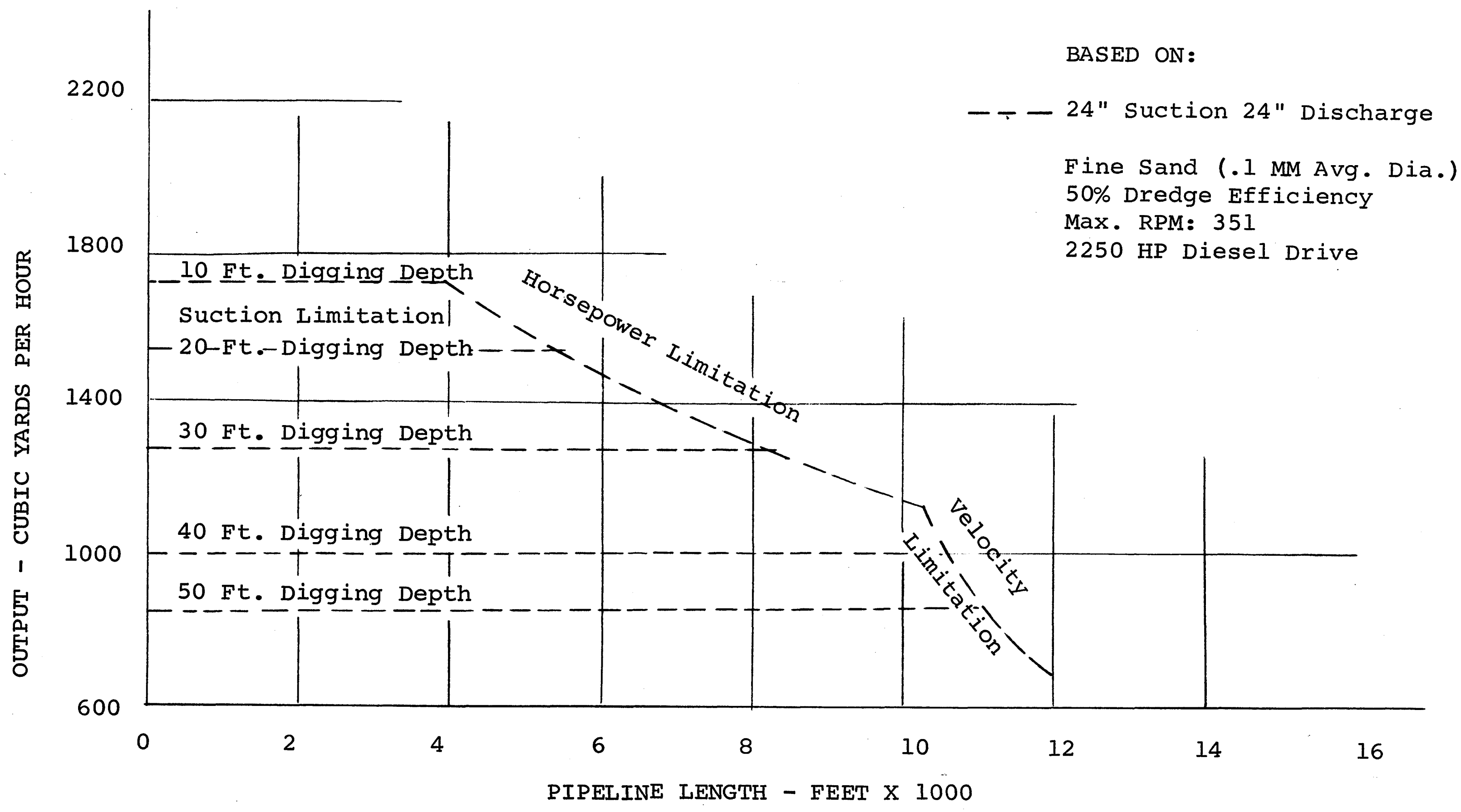
AVERAGE S.G. IS A FUNCTION OF VELOCITY, AND, THEREFORE CONSTANT.

EFF IS CONSTANT AT CONSTANT GPM.

SK. #7A

VII. PRODUCTION IS LIMITED BY:
1. Suction Conditions
2. Pump H.P. Available.
3. Suction Velocity

CALCULATED OUTPUT CURVES

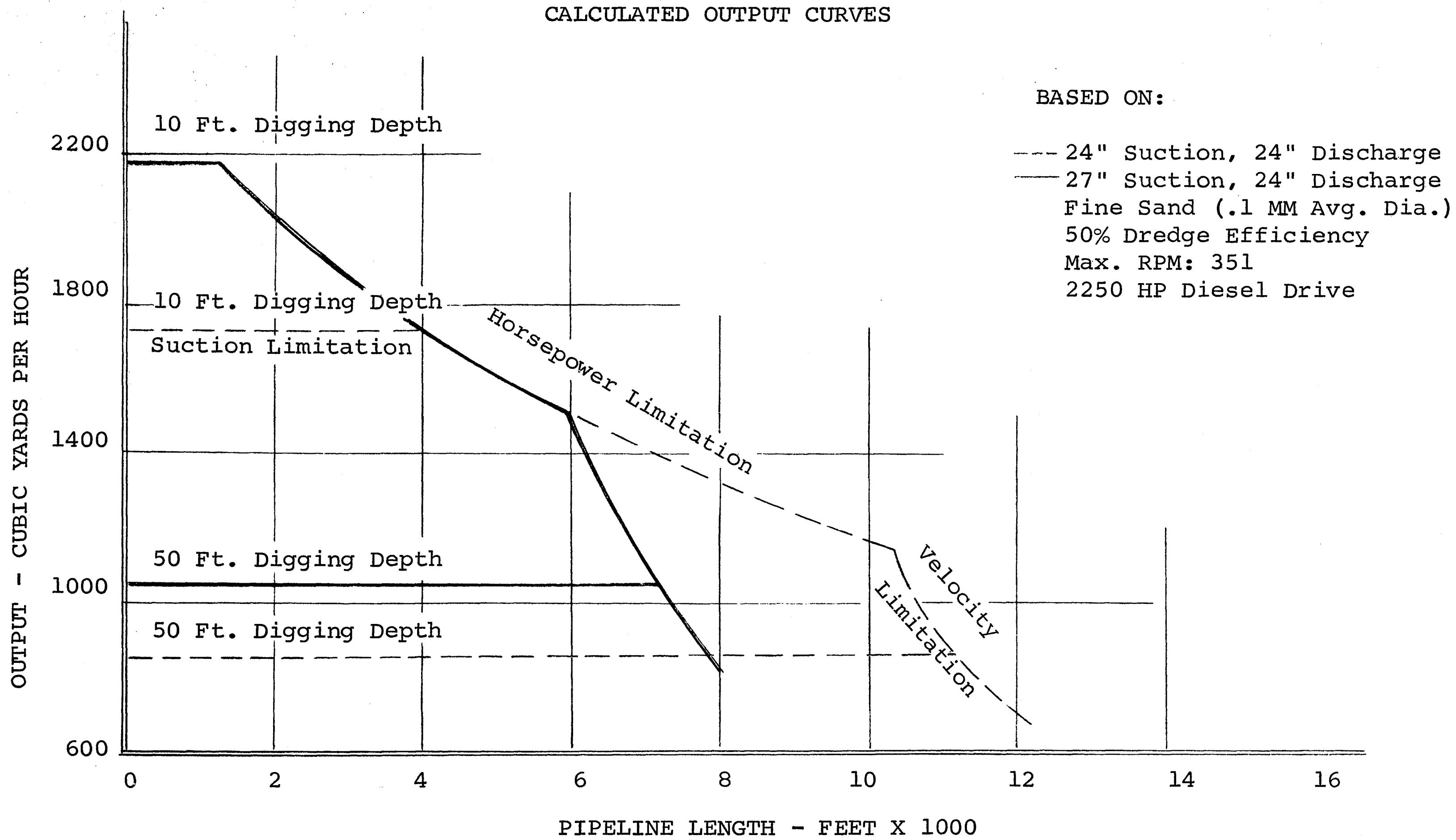


SK. #7B

VII PRODUCTION IS LIMITED BY:

(1) Suction Conditions
(2) Pump HP Available
(3) Suction Velocity

CALCULATED OUTPUT CURVES



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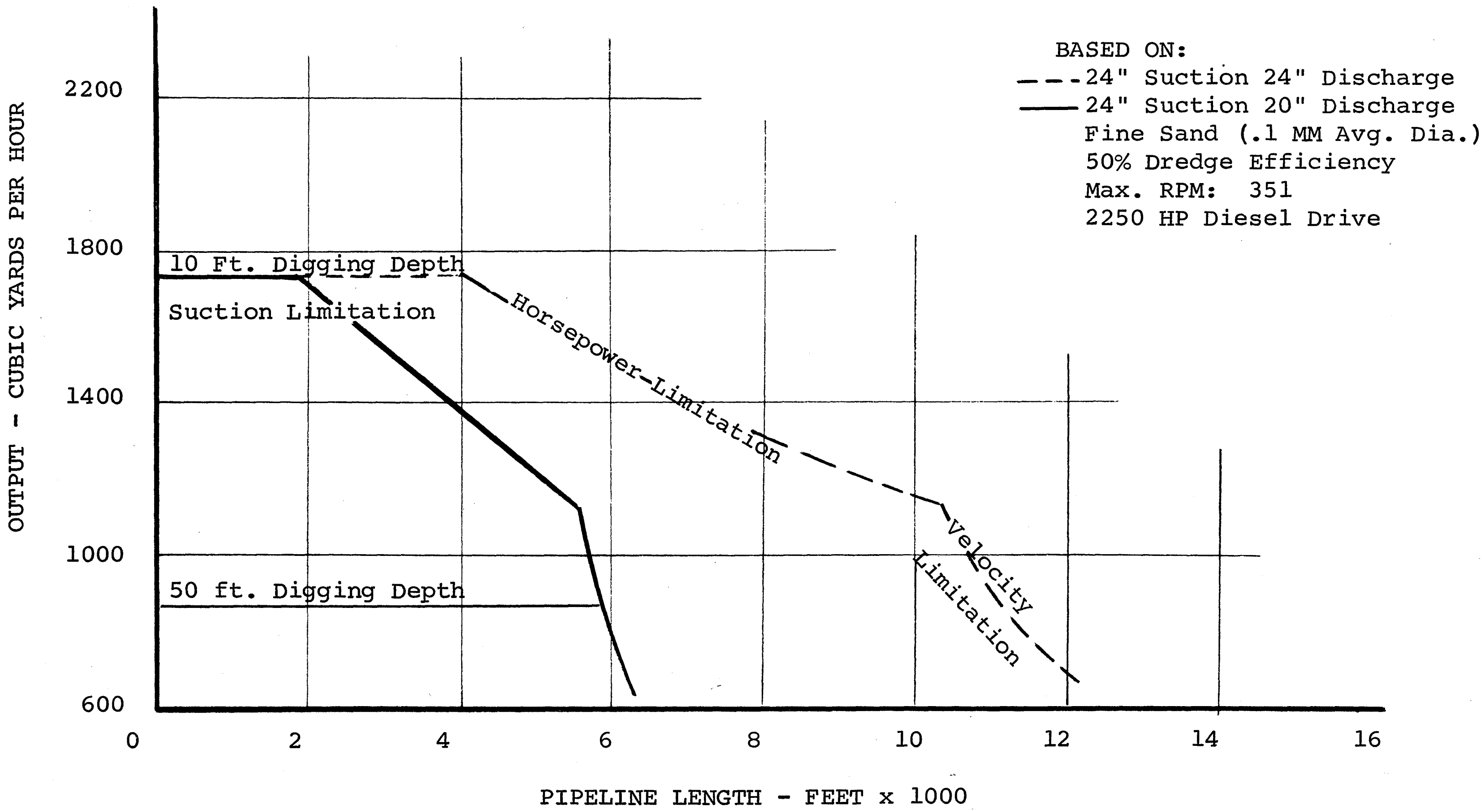
CALCULATED OUTPUT CURVES



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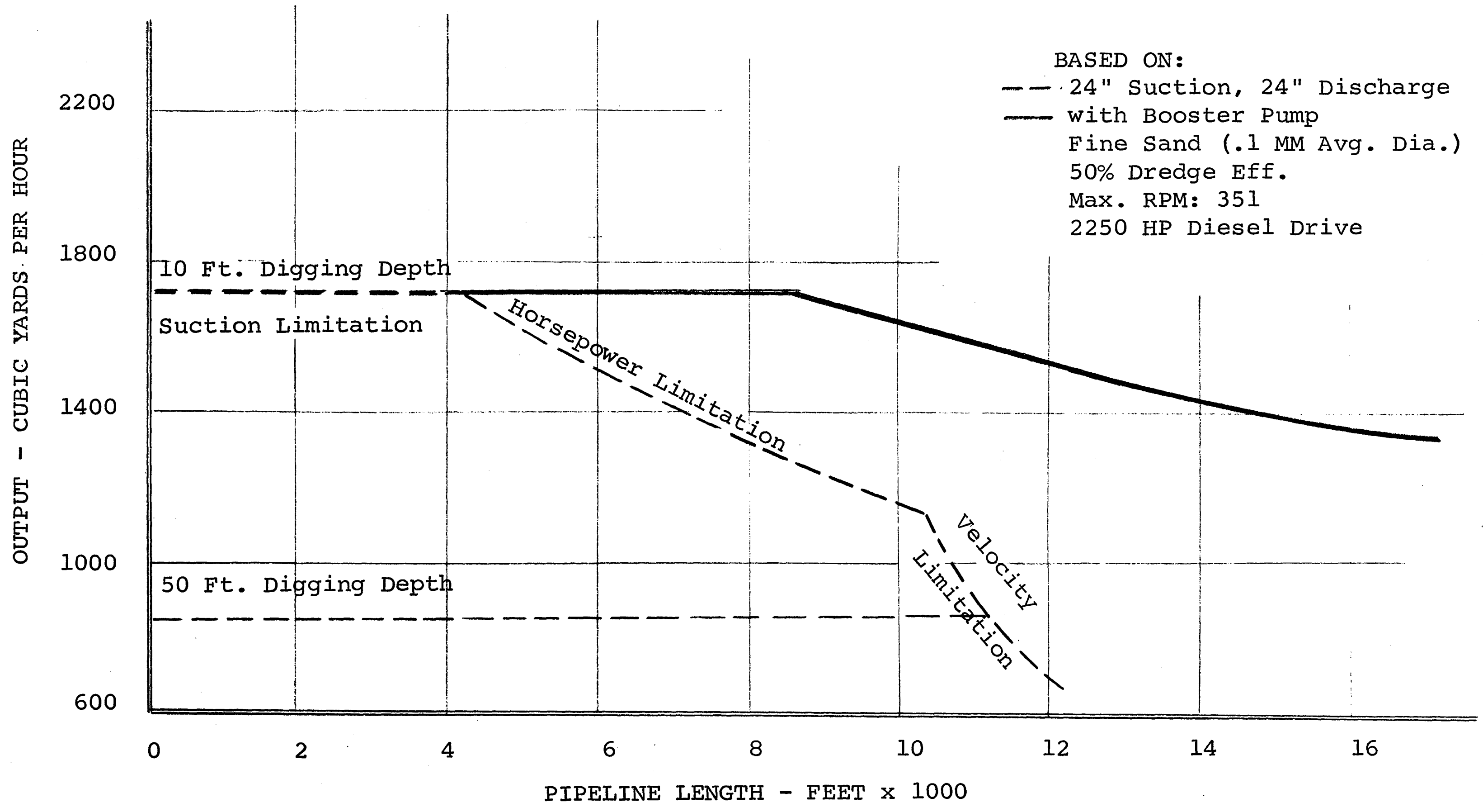
CALCULATED OUTPUT CURVES



SK #7D

VII PRODUCTION IS LIMITED BY:

(1) Suction Conditions
(2) Pump HP Available
(3) Suction Velocity

CALCULATED OUTPUT CURVES