DELFT NETHERLANDS

INTERNATIONAL COURSES IN

HYDRAULIC AND SANITARY ENGINEERING

J. STUIP

REVETMENTS 2

PROVISIONAL EDITION '80

SYLLABUS REVETMENTS 2

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TYPES OF REVETMENTS / EXECUTION METHO[D]

LOOSE BALLAST

FIXED BALLAST

COHESIVE TYPES

1. GENERAL INTRODUCTION INTO REVETMENTS

WHEN AND WHERE TO USE :

WHEN

- WHEN NON ACCEPTABLE SCOUR(EROSION) IS EXPECTED OF NON OR N- ENOUGH COHESIVE BOTTOM MATERIALS SUCH AS SAND OR SILTY SAND. SCOUR BY WAVES AND CURRENTS.
- SCOUR :PERMANTLY OR IN THE CONSTRUCTION STAGE OF THE WORKS.

WHEN NOT

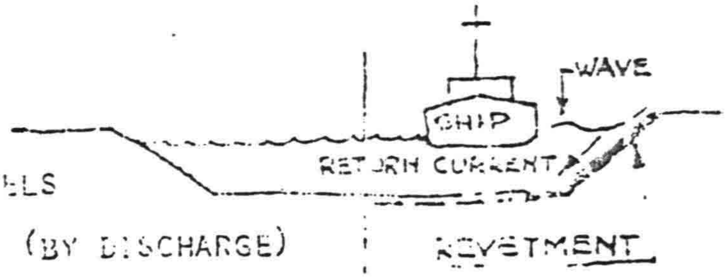
- SCOUR OF SHORT DURATION
- PERIODS OF SCOUR FOLLOWED BY PERIODS OF SANDING UP.
- COHESIVE MATERIAL SUCH AS CLAY OR ROCK IS UNDERLYING THE SAND AT A SHORT DISTANCE.
- EQUILIBRIUM SITUATION OF A SCOUR HOLE AT A FOR THE CONSTRUCTION NON DANGEROUS DEPTH.
- RESERVE IN THE CONSTRUCTION STABILITY. CHEAPER THAN PROTECTIVE MEASURES.
- THE ERODED MATERIAL IS REPLACED BY SAND, SUCH A BEACH SUPPLETIONS.

WHERE TO APPLY REVETMENTS

A PERMANENT APPLICATION

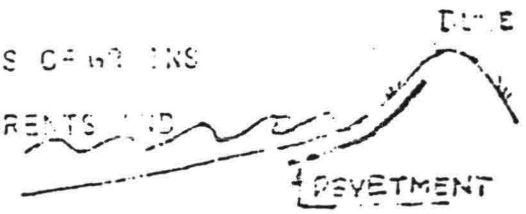
. RIVERS AND SHIPPING CHANNELS

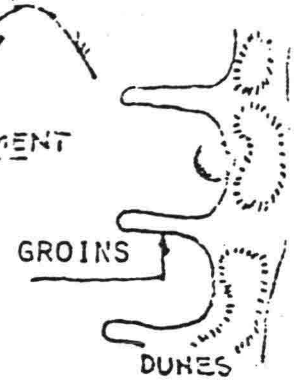
TYPE OF ATTACK ;CURRENTS (BY DISCHARGE) AND CURRENTS AND WAVES INDUCED BY SHIPS.



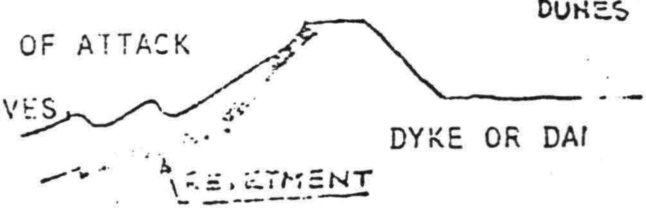
. PROTECTION OF COASTS, BASIS OF GROINS

TYPE OF ATTACK (TIDAL) CURRENTS AND WINDWAVES.



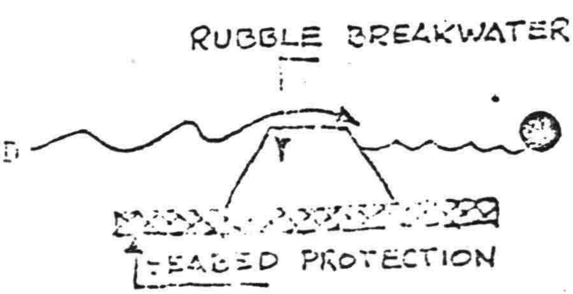


. PROTECTION OF DIKES AND DAMS ;AT THE COAST OR IN ESTUARIES, TYPE OF ATTACK (TIDAL) CURRENTS AND WINDWAVES.



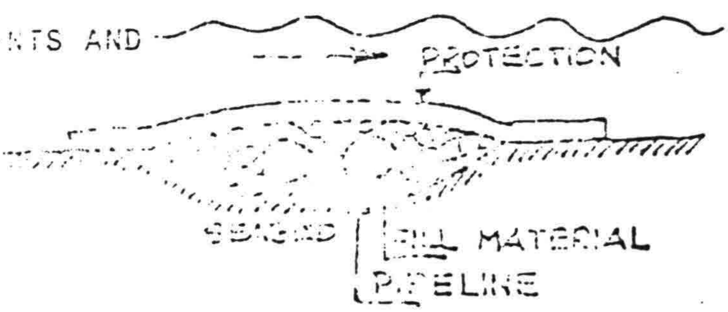
. BREAKWATERS AND HARBOUR DAMS.

TYPE OF ATTACK TIDE CURRENTS AND WINDWAVES



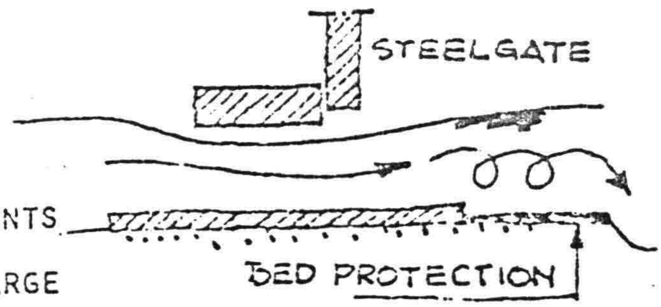
PROTECTION OF MARINE PIPELINES

TYPE OF ATTACK TIDE CURRENTS AND WINDWAVES

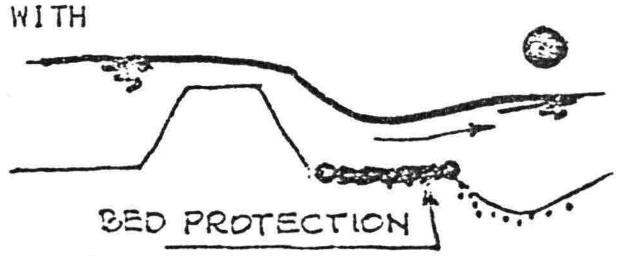


④

. DOWN STREAM OF DISCHARGE SLUICES OR NAVIGATION LOCK TYPE OF ATTACK (TIDAL) CURRENTS WITH HIGH TURBULENCE AND LARGE ENERGY LOSSES.

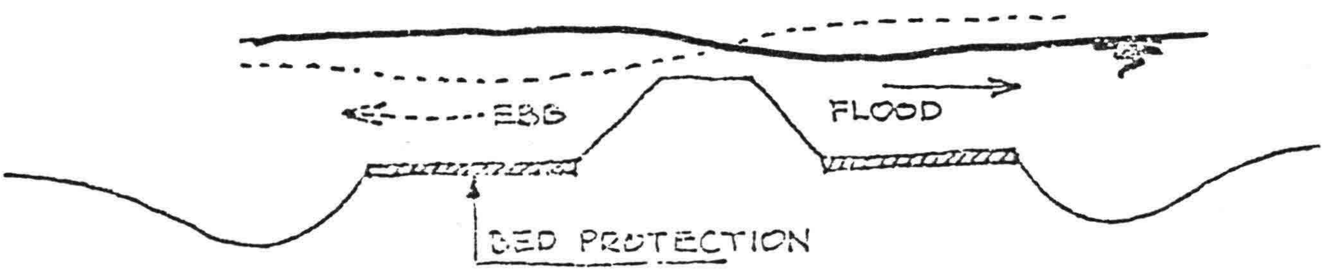


. DOWN STREAMS OF (RIVER) DAMS, WITH AN OVERFLOW.
TYPE OF ATTACK CURRENTS.



B. <u>TEMPORARY APPLICATIONS</u>

. DURING THE CONSTRUCTION STAGE OF AN ESTUARY CLOSING OR A DIKE BREACH CLOSING
TYPE OF ATTACK TIDAL CURRENTS WITH HIGH TURBULENCE AND LARGE ENERGY LOSSES



THE APPLICATIONS ARE <u>ALSO</u> DIVIDED INTO:

- APPLICATIONS NECESSARY BECAUSE OF THE INFLUENCE OF THE CONSTRUCTION ON THE HYDRAULIC CONDITIONS. THERE IS A STRONG RELATION BETWEEN THE GEOMETRY OF THE CONSTRUCTION AND THE SEABED AREA TO BE PROTECTED. (DISCHARGE SLUICES, ESTUARY CLOSINGS).

- APPLICATIONS NECESSARY BECAUSE MORPHOLOGICAL CHANGES OF THE SEABED NEAR THE CONSTRUCTION, NOT OR NOT ENTIRELY CAUSED BY THE CONSTRUCTION ITSELF (MEANDERING OF RIVERS, SHIFTING OF TIDAL GULLIES, BEACH PROTECTION).

SOMETIMES IT IS POSSIBLE TO INFLUENCE THE COHESIVE OR THE CONTACT PRESSURE OF THE ORIGINAL BED MATERIAL IN SUCH A WAY THAT FURTHER PROTECTION IS NOT NECESSARY. (COHESION INFLUENCED BY CHEMICALS, CONTACT PRESSURE INFLUENCED BY PUMPING). THESE METHODS ARE RARELY APPLIED.

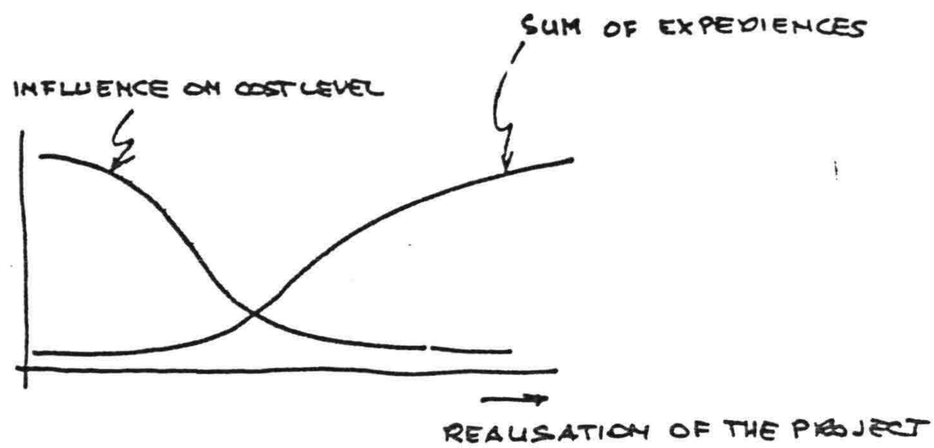
TYPE OF REVETMENTS

THE CLASSIFICATION OF REVETMENTS CAN BE DONE IN MANY WAYS. HERE THE PERMEABILITY AND FLEXIBILITY ARE USED.

FLEXIBILITY \ PERMEABILITY		HIGH → LOW
HIGH	LOOSE MATERIAL	FILTER CONSTRUCTIONS
	"CAGED"	GABIONS
	MATTRESSES — LOOSE BALLAST	WILLOW MATT. MATT. + POLYPROP. CLOTH IN SITU MATT.
	MATTRESSES — FIXED BALLAST	POLYPROP. + CONCRETE BLOCKS POLYPROP + GRAVEL
	COHESIVE MATERIALS	POLYPROP + STONE ASPHALT SAND ASPHALT FIX STONE CLAY
LOW	MONOLITHIC CONS.	GROUTED RUBBLE ASPHALT CONCRETE CONCRETE

DESIGN PHILOSOPHY

IT IS ESSENTIAL THAT IN - COMPARING TO THE EXECUTION STAGE OF THE PROJECT THE LESS SPECTACULAR DESIGN STAGE MUCH EFFORT SHOULD BE PUT INTO THE PROJECT. THIS BECAUSE OF THE FACT THAT IN THIS STAGE THE INFLUENCE ON THE LEVEL OF THE TOTAL COST IS THE LARGEST

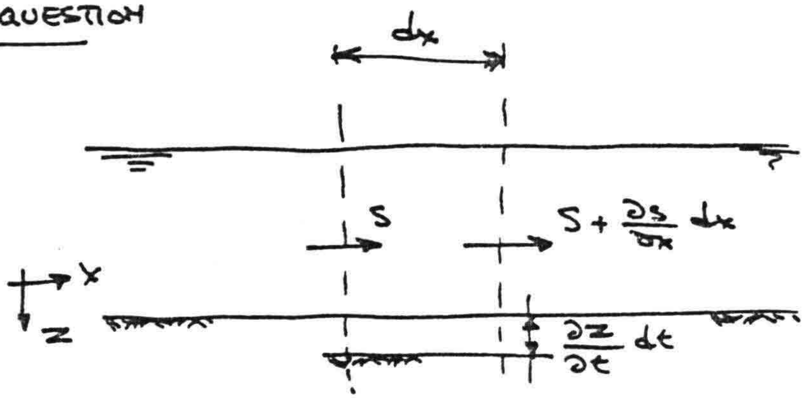


THE REALISATION PROCES CAN BE DIVIDED INTO THE FOLLOWING STAGES:

I. PROBLEM FORMULATION
II. SEARCH FOR IDEAS
III. BASIC SHAPE DEVELOPMENT
IV. DIMENSIONING FINAL FORM
V. CONSTRUCTION, CONTROL
VI. ~~OPERATION~~ USE, CONTROL, MAINTENANCE

IN THE FIRST STAGES THE MAIN QUESTIONS ARE THE WHAT? - QUESTIONS, THAT CAN BE ANSWERED BY MEANS OF A THOROUGH ANALYSIS OF THE PROBLEM.
AFTER THAT THE HOW? - QUESTIONS WILL BE TREATED, AND ALTERNATIVE SOLUTIONS ARE GENERATED. AFTER JUDGING AND CHOOSING THE FINAL DESIGN AND CONSTRUCTION METHODS ARE ELABORATED.

AN EXAMPLE IN THE FIELD OF REVETMENT (EVENTUALLY!):
WHAT? QUESTION



$$\frac{\partial z}{\partial t} = \frac{\partial S}{\partial x}$$

S = TRANSPORT OF BED MATERIAL

IN GENERAL : $\frac{\partial S}{\partial x} dx + \frac{\partial z}{\partial t} dt = 0.$

1. IF: $\frac{\partial S}{\partial x} = 0$ THAN: $\frac{\partial z}{\partial t} = 0$: NO PROBLEM

2. IF: $\int_0^X \frac{\partial S}{\partial x} dx \neq 0$ THAN: $\int_0^T \frac{\partial z}{\partial t} dt \neq 0$: EROSION OR SEDIMENTATION ; IF $\int_0^X \frac{\partial S}{\partial x} dx$ IS SMALL THAN PROBABLY NO PROBLEM IF T = LARGE, BUT A PROBLEM IF T = SMALL

3. IF $\int_0^X \frac{\partial S}{\partial x} dx \neq$ SMALL THAN $\int_0^T \frac{\partial z}{\partial t} dt \neq$ SMALL AND

MEASUREMENTS SHOULD BE TAKEN TO PREVENT UNACCEPTABLE SCOURING OR SEDIMENTATION.

IN THE CASE OF SCOURING THREE MAIN/PRINCIPLE SOLUTIONS ARE AVAILABLE:

1. DECREASING THE "ATTACK" (WATER MOVEMENT), LOAD
2. INCREASING THE "STRENGTH" (REVETMENT)
3. SUPPLETION (OR DREGING): "MAINTENANCE", "REPAIRING" $\int \frac{\partial s}{\partial x} dx + \frac{\partial z}{\partial t} dt + \underline{\underline{\Delta H}} = 0$

ΔH = PERIODICAL MAINTENANCE

IN THE STAGE "SEARCH FOR IDEAS" THESE SOLUTIONS ARE ELABORATED AND THE "HOW-ANSWERS" SHOULD BE GIVEN IN THE FOLLOWING STAGES.

TO ANALYSE AND TO CHARACTERISE THE ALTERNATIVE CONSTRUCTIONS THE LIMIT STATE MAY BE USEFULL.
THE LIMIT STATE DESCRIBES THE BEHAVIOUR OF THE CONSTRUCTION UNDER LOADING CONDITIONS THAT IS JUST ACCEPTABLE

- Ultimate limit state
  - (ultimate load carrying capacity
  - (loss of equilibrium
- fatigue limit state
  - (cumulated effects of loads
  - (desintegration of constr. mat.
- progressive collapse limit state
  - (overloading single elements introduces total collapse

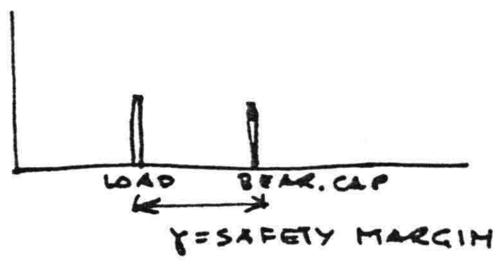
etc.

SAFETY FACTOR/ PROBABILITY OF FAILURE

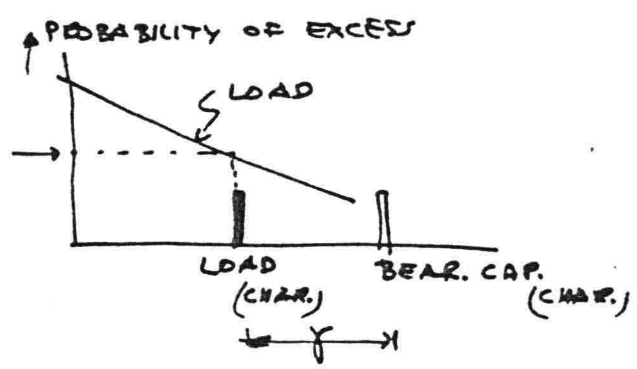
THE BEARING CAPACITY SHOULD BE HIGHER THAN THE "DESIGN LOAD". THE MARGIN BETWEEN "THE" LOAD AND "THE" BEARING CAPACITY IS THE SAFETY MARGIN.

ACCORDING TO THE STOCHASTIC CHARACTER OF THE BEARING CAPACITY AND THE LOAD THERE IS NO "THE" B.C. AND "THE" LOAD. BOTH CAN BE CHARACTERISED BY PROBABILITY FUNCTIONS OR CHARACTERISTIC VALUES OF THESE FUNCTIONS.

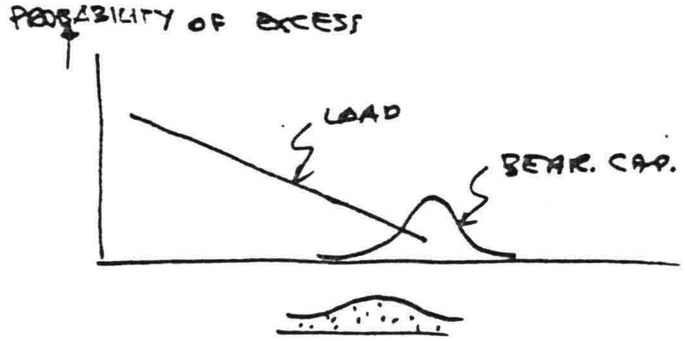
DETERMINISTIC :



QUASI PROBABILISTIC:



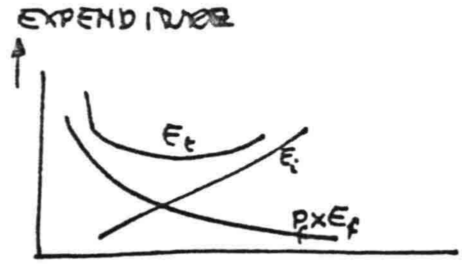
SEMI - PROBABILISTIC



PROBABILITY OF FAILURE

$$\int Pr(Load) * Pr.(B.C.)\, d(L,B)$$

ECONOMIC OPTIMALISATION



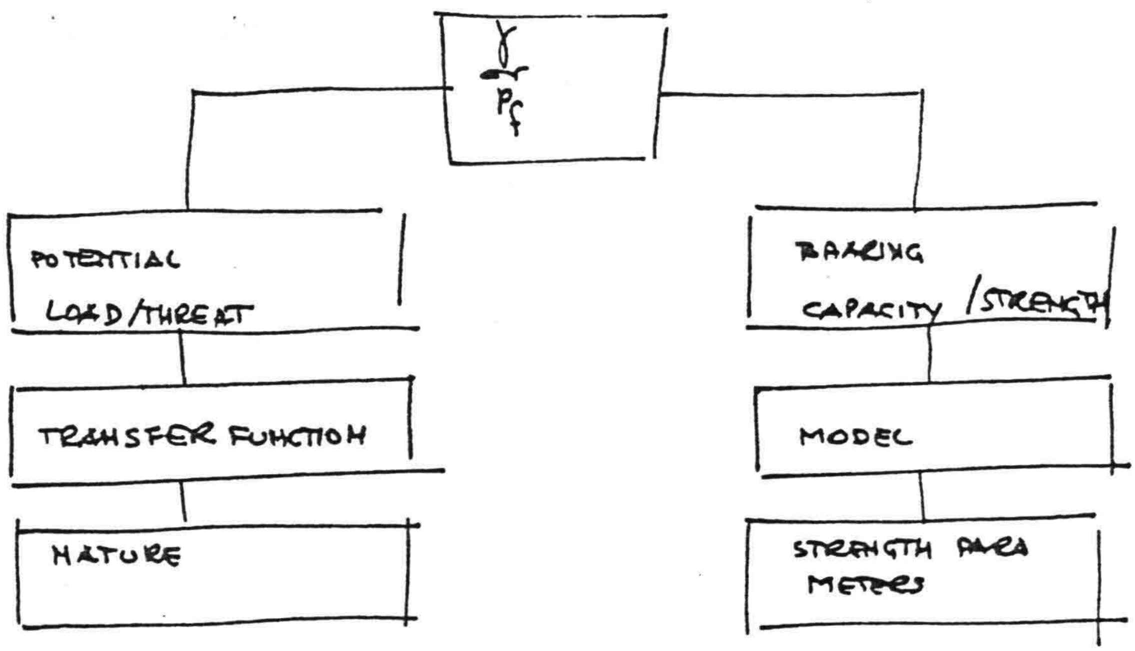
$E_t = E_i + p_f E_f$

E_i = initial expenditure

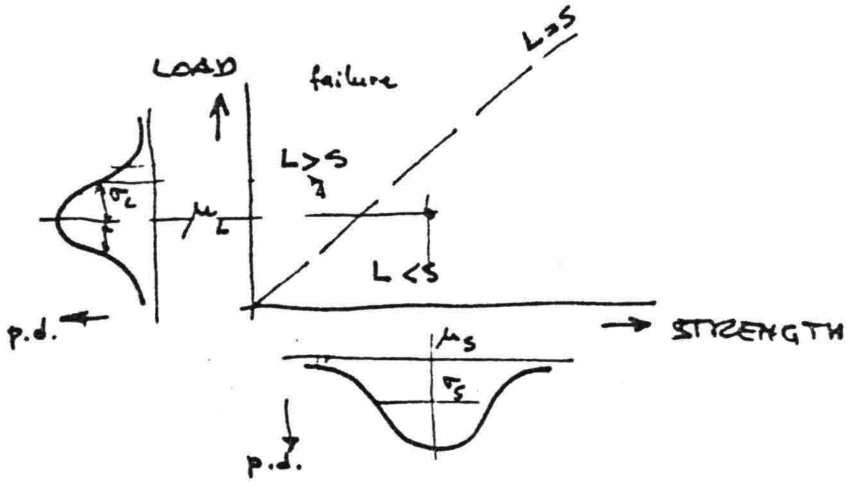
E_f = (pot.) future costs

p_f = probability of failure

IN GENERAL THE LIMIT STATE CAN BE VISUALIZED BY THE FOLLOWING GRAPH:



THE PROBABILITY OF FAILURE IS NOT ONLY AFFECTED BY THE MEAN OF LOAD AND STRENGTH BUT ALSO BY THE STANDARD DEVIATION. SO THE RELIABILITY OF THE CONSTRUCTION CAN BE INFLUENCED BY THE VARIATION IN STRENGTH OF AND/OR LOAD ON THE CONSTRUCTION. A STRUCTURE WITH A CONSTANT QUALITY OF BUILDING MATERIAL OR ELEMENTS IS MORE RELIABLE. THE FOLLOWING EXAMPLE MAY ILLUSTRATE THIS:



$P_{failure}$ = all possible combinations of L>S

$$P_{failure} = \iint P(\text{strength}) * P(\text{load}) * d_s\, d_L$$

DEFINING THE RELIABILITY FUNCTION:

$$Z = \text{STRENGTH} - \text{LOAD}$$

IF THE PROBABILITY DENSITY FUNCTIONS ARE NORMAL:

$$\mu(z) = \mu_S - \mu_L$$
$$\sigma(z) = \sqrt{\sigma_S^2 + \sigma_L^2}$$

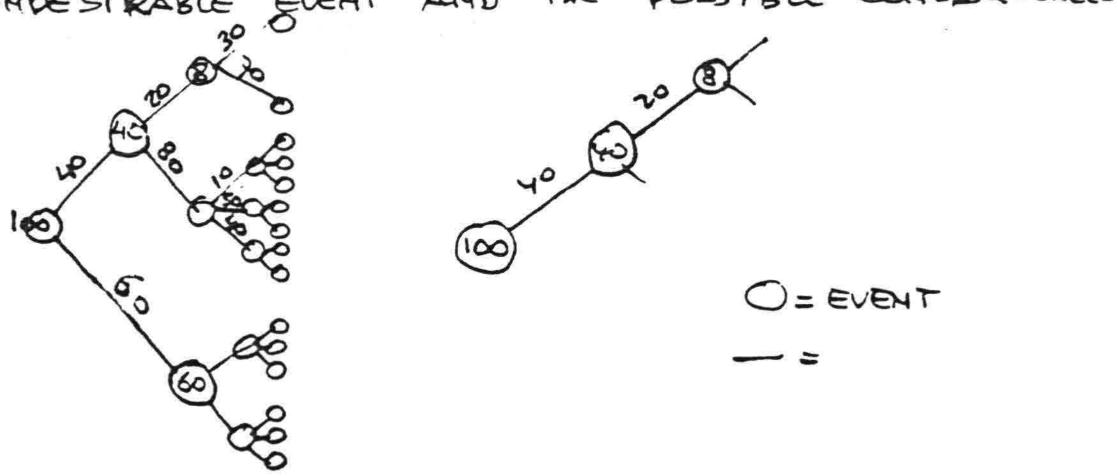
TO BECOME FULLY ACQUINTED WITH THE BEHAVIOUR OF THE CONSTRUCTION AND ITS COMPONENTS A THOROUGH ANALYSIS OF THE FAILURE - MECHANISME AND THE PROBABILTY OF THE FAILURE HAVE TO BE CARRIED OUT.

THIS ANALYSIS - RISK ANALYSIS - CAN BE DONE WITH THE TECHNIQUES OF THE FAULTTREE AND EVENTREE

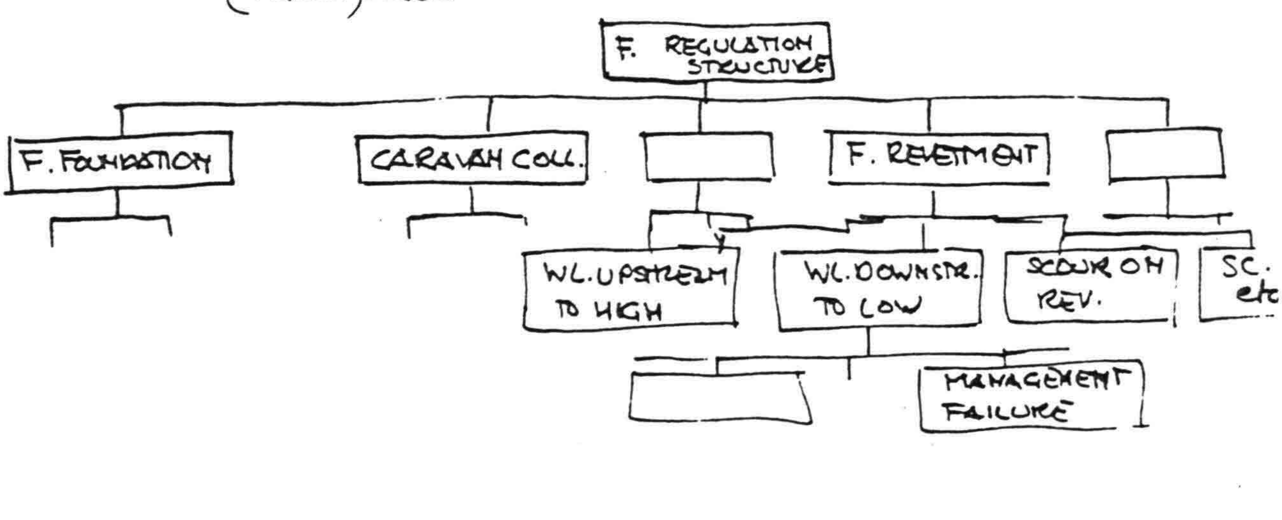
IN THIS ANALYSIS ONE IS FORCED TO DEFINE WHAT IS A FAILURE, WHAT IS THE PROBABILITY OF THE FAILURE, AND WHAT IS THE CONTRIBUTION OF THE FAILURE IN THE PROBABILITY OF FAILURE OF THE COMPLETE CONSTRUCTION.

THE FAULTTREE IS A SCHEMATIC PRESENTATION OF ALL UNDESIRABLE EVENTS THAT MAY LEAD TO A FAILURE OF THE CONSRUCTION

THE EVENTTREE GIVES A SCHEMATIC PRESENTATION OF ONE UNDESIRABLE EVENT AND THE POSSIBLE CONSEQUENCES

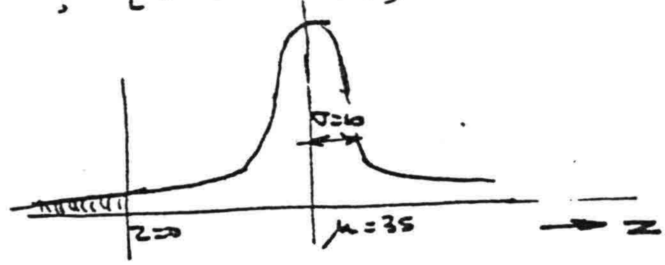


(FAULT)TREE



CASE 1. IF $\mu_S = 135$, $\mu_L = 100$ → $\mu(z) =$ 135 - 100 = 35

$\sigma_S = 6$, $\sigma_L = 8$ → $\sigma(z) = \sqrt{6^2 + 8^2} = 10$

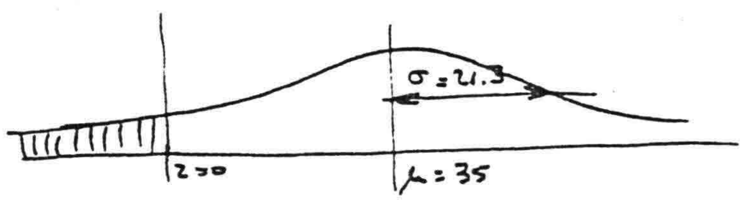


z=0 or 3,5 σ ($\mu - 3{,}5\sigma = 0$)

$P_{failure}$ FOR 3,5 σ = $2{,}5 * 10^{-4}$ (TABLE)

CASE 2. IF $\mu_S = 135$, $\mu_L = 100$ → $\mu(z) = 135 - 100 = 35$

$\sigma_S = 6$, $\sigma_L = 20.5$ → $\sigma(z) = \sqrt{6^2 + 20.5^2} = 21.3$



z=0 FOR 1,64 σ

$P_{failure}$ FOR 1,64σ = $5 * 10^{-2}$ (TABLE)

CONCLUSION:

CASE 1 a) SAFETY FACTOR $\frac{\mu_S}{\mu_L} = \frac{135}{100} = 1{,}35$

b) SAFETY FACTOR $\frac{\mu_S - 1{,}64\sigma_S}{\mu_L + 1{,}64\sigma_L} = 1.11$

c) $P_{failure}$ $= 2{,}5 * 10^{-4}$

CASE 2 a) SAFETY FACTOR $\frac{\mu_S}{\mu_L} = \frac{135}{100} = 1.35$

b) SAFETY FACTOR $\frac{\mu_S - 1.64\sigma_S}{\mu_L + 1.64\sigma_L} = 0.94$

c) $P_{failure}$ $= 5 * 10^{-2}$

LARGE PARTICLES AND HIGH VELOCITIES : PRESSURE FORCES

SMALL PARTICLES AND LOW VELOCITIES : VISCOUS FORCES

∴ PHENOMENON CHARACTERIZED BY REYNOLDS NUMBER:

$$Re = \frac{VD}{\nu}$$

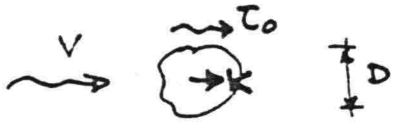
$$\text{OR} \quad Re_* = \frac{V_* D}{\nu}$$

V_* = SHEARSTRESS VELOCITY $= \sqrt{\frac{\tau}{\rho}}$

ν = KIN. VISCOSITY $= 1 * 10^{-6}\ m^2 s^{-1}$ at $20°C$

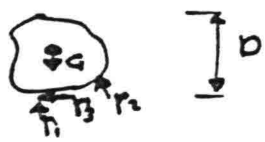
D = DIAMETER PARTICLE

FORCE ACTING ON THE PARTICLE: <u>LOAD</u>:



$$K = \text{factor}.\tau.D^2 = \alpha_1.\tau_0.D^2 \qquad (\alpha_1 = \alpha_1(Re))$$

"RESISTANCE, <u>STRENGTH</u>" OF THE PARTICLE :



$$\Sigma r = R = \text{factor}.G = \alpha_2 (\rho_s - \rho_w) D^3 \qquad (\alpha_2 = \alpha_2(\text{geometry}))$$

ρ_s = specific gravity of particle
ρ_w = specific gravity of water

<u>NO MOTION</u> : $\alpha_1 \tau_0 D^2 \leq \alpha_2 (\rho_s - \rho_w) g D^3$

$$: \quad \frac{\tau_0}{g(\rho_s - \rho_w) D} \leq \frac{\alpha_2}{\alpha_1} \leq \Psi(Re)$$

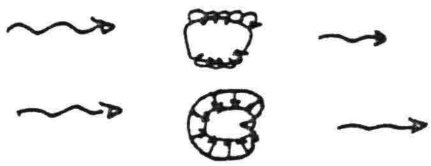
THEORETICAL CONSIDERATIONS
LOAD AND RESISTANCE

- IN THE LECTURES SEDIMENT TRANSPORTATION (BREUSERS) A DETAILED DESCRIPTION OF THE INITIATION OF PARTICAL MOTION DUE TO WATERMOTION IS GIVEN; ALSO IN REVETMENTS 1 BASIC ASSUMPTIONS ARE GIVEN (CHAPTER 2)

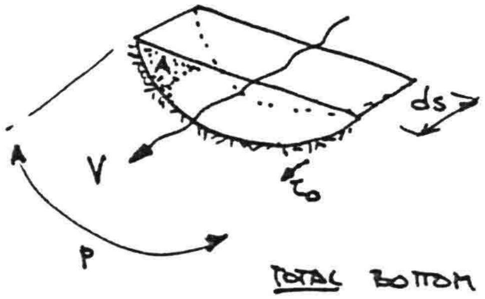
- A SHORT REVIEW :

FORCES ACTING ON THE PARTICLE:

- VISCOUS FORCES
- PRESSURE HEAD



THESE FORCES ARE RELATED TO THE BOTTOM SHEARSTRESS : τ_0

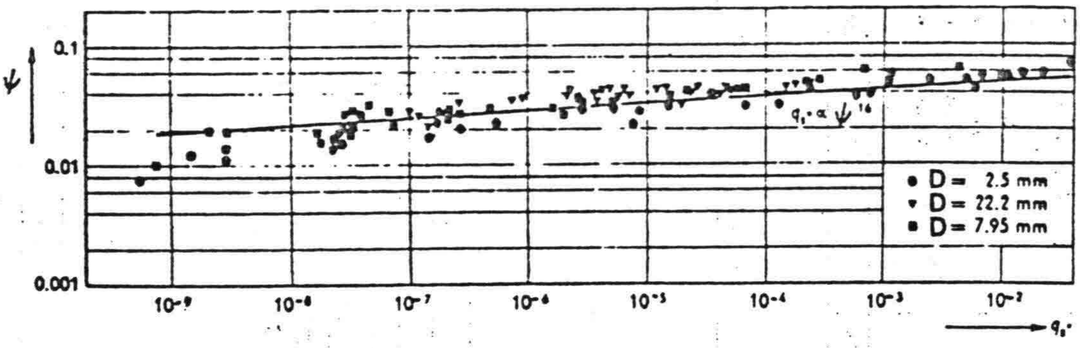


TOTAL BOTTOM SHEARSTRESS = $\tau_0 \cdot p \cdot ds$
TOTAL FORCE DUE TO GRAVITY = $\rho g A . ds . I$

WITH : $R = \frac{A}{P}$ $\longrightarrow$ $\tau_0 = \rho g R I$

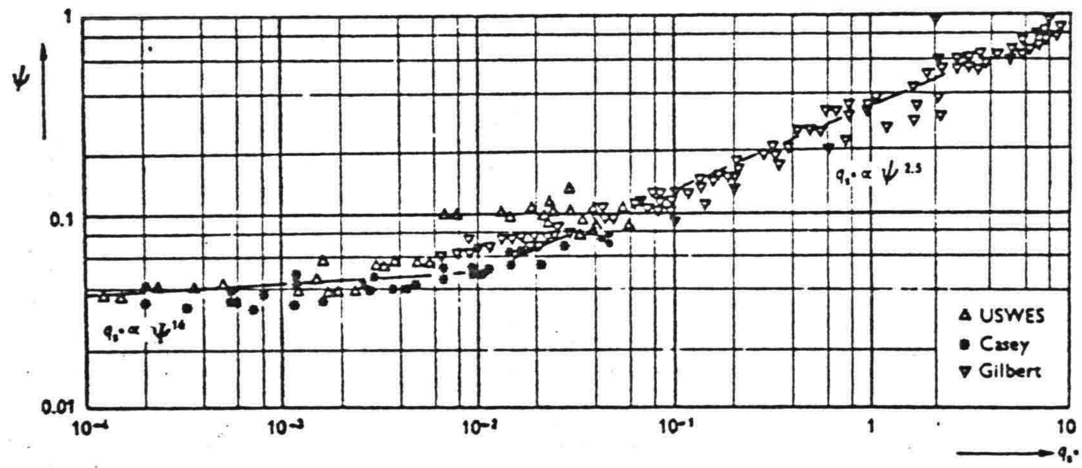
OR WITH CHEZY $\bar{V} = C\sqrt{RI}$ $\rightarrow$ $RI = \frac{\bar{V}^2}{C^2}$

$$\tau_0 = \rho g \frac{\bar{V}^2}{C^2}$$



Variation of bed load transport at low shear values.

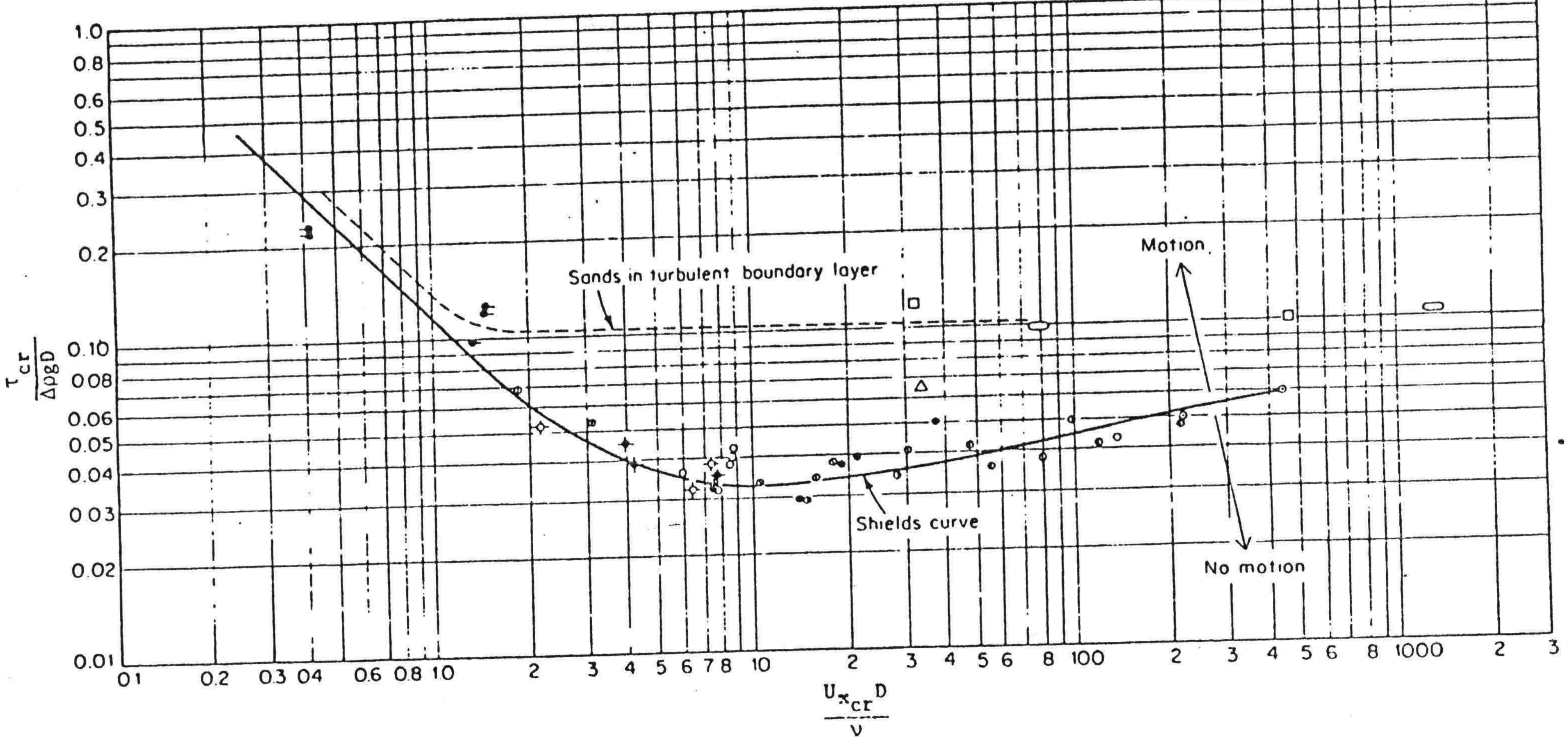
Débit de charriage à tension de frottement faible.



Variation of bed load transport at high shear values.

Débit de charriage à tension de frottement élevée.

(PAINTAL)



Fully developed turbulent velocity profile

Sym	Description	γ_s, g/cm³
○	Amber (Shields)	1.06
●	Lignite (Shields)	1.27
◐	Granite (Shields)	2.7
◐	Barite (Shields)	4.25
◐	Sand (Casey)	2.65
✧	Sand (Kramer)	2.65
✦	Sand (U.S.W.E.S.)	2.65
◐	Sand (Gilbert)	2.65

Turbulent boundary layer

•–	Sand (Vanoni)	2.65
–•	Glass beads (Vanoni)	2.49
□	Sand (White)	2.61
⬭	Sand in air (White)	2.10
△	Steel shot (White)	7.9

Shields' diagram; dimensionless critical shear stress vs. shear Reynolds number. [*After* VANONI (*1964*).]

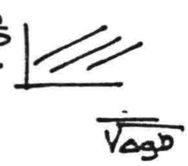
THESE MODEL INVESTIGATIONS GIVE THE "COMBINED" RESULT OF LOAD AND STRENGTH OF THE PROTECTION CONSTRUCTION.

IT SHOULD BE TAKEN INTO ACCOUNT THAT IN MANY CASES THE INVESTIGATION OF THE STRENGTH OF THE CONSTRUCTION IS CARRIED OUT BY VARYING THE LOAD (SHEAR STRESS) AND NOT THE STRENGTH.

THE MODEL INVESTIGATIONS USUALLY ARE PRESENTED AS A FUNCTION OF:

$$\frac{\bar{V}}{\sqrt{\Delta g D}}$$

SEE FIG.



THIS BECAUSE OF:

$$\psi = \frac{\tau}{(\rho_s - \rho_w) g D}$$

$$\tau = \rho_w g \frac{\bar{V}^2}{C^2}$$

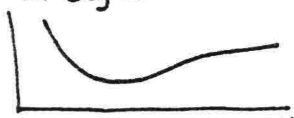
$$\psi = \frac{\rho_w g \bar{V}^2}{(\rho_s - \rho_w) g D C^2}$$

$$\frac{\bar{V}}{\sqrt{\Delta g D}} = \sqrt{\frac{\psi}{g}} \cdot C = \text{factor}$$

this "factor" is a function of Re, geometry etc and determined by experiments

$\Psi(Re) = \underline{\text{SHIELDS PARAMETER}} = \dfrac{\tau}{\Delta \rho g D}$ $\left(\Delta = \dfrac{\rho_s - \rho_w}{\rho_w} \right)$

EXPERIMENTS : SEE FIG. $\Psi = \dfrac{\tau}{\Delta \rho g D}$



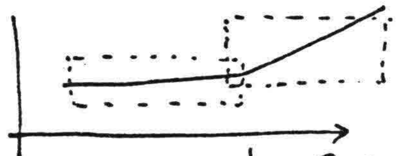
$\rightarrow Re_* = \dfrac{V_* D}{\nu}$

ORIGINALLY SHIELDS FOR <u>SEDIMENT TRANSPORT</u>

APPLICATION FOR <u>REVETMENTS</u> : <u>"NO" MOTION AT ALL</u>

EXPERIMENTS FOR LOW SHEAR STRESS : <u>PAINTAL</u>

EXPERIMENTS: SEE FIG. $\Psi = \dfrac{V_*^2}{\Delta g D}$



$\rightarrow \phi = q_s / (\Delta g D^3)^{1/2}$

q_s = sediment transport

FOR PARTICLE STABILITY ON <u>SLOPES</u>: SEE ALSO BREUSERS

BECAUSE OF ASSUMPTIONS AS UNIFORM FLOW, FULLY DEVELOPPED MIXING / BOUNDARY LAYER ETC. THE RESULTS OF SHIELDS AND PAINTAL DO NOT HOLD IN CASE OF SCOUR PROTECTION NEAR HYDRAULIC STRUCTURES.

IN SOME CASES THE τ_0 OR $\bar{V}$ ARE MULTIPLIED BY A FACTOR >1 TO TAKE INTO ACCOUNT THE INFLUENCE OF TURBULENCE ETC. (SEE ALSO BREUSERS)

IN MANY CASES SPECIFIC MODEL INVESTIGATIONS ARE NECESSARY TO DIMENSION THE SIZE OF THE ARMOR STONES OF THE BOTTOM PROTECTION, SILLS, WEIRS, ETC.

FILTER RULES

DETAILED INFORMATION FOR "LOAD INDEPENDENT" FILTER RULES SEE REVETMENT 1, CHAPTER 3.4.

SHORT REVIEW : REQUIREMENTS :

1. SANDTIGHTNESS
2. PERMEABILITY
3. STABLE SKELETON (INTERN STABLE)

TO FULFIL THE REQUIREMENTS THE CRITERIA :

- RELATIVE CRITERIA : $\frac{D_{\alpha f}}{D_{\beta b}}$ < Constant (see REV. 1, 3.4)

- ABSOLUTE CRITERIA : $\frac{D_{\alpha f}}{D_{\beta b}} < D_{\gamma f}$ or $D_{\delta b}$

- UNIFORMITY CRITERIA : $U = \frac{D_\alpha}{D_\beta}$ < constant or  see later

A RECENT STUDY GIVES FOR THE ABSOLUTE CRITERIA:

$$^{10}\log\left[\frac{D_{10f}}{D_{10b}} - 2\right] < \frac{1.9}{^{10}\log\left[D_{10b} - 0.001 \times 10^{-3}\right]}$$

(Kawakami, 1961)

UNIFORMITY CRITERIA

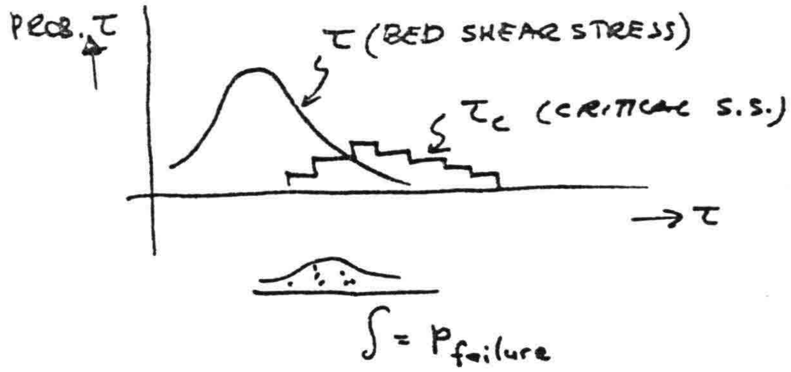
1. $U = \frac{D_{60}}{D_{10}}$

NO MIGRATION	:	$u < 10$
POSSIBLE MIGRATION*	:	$10 < u < 20$.
MIGRATION	:	$u > 20$

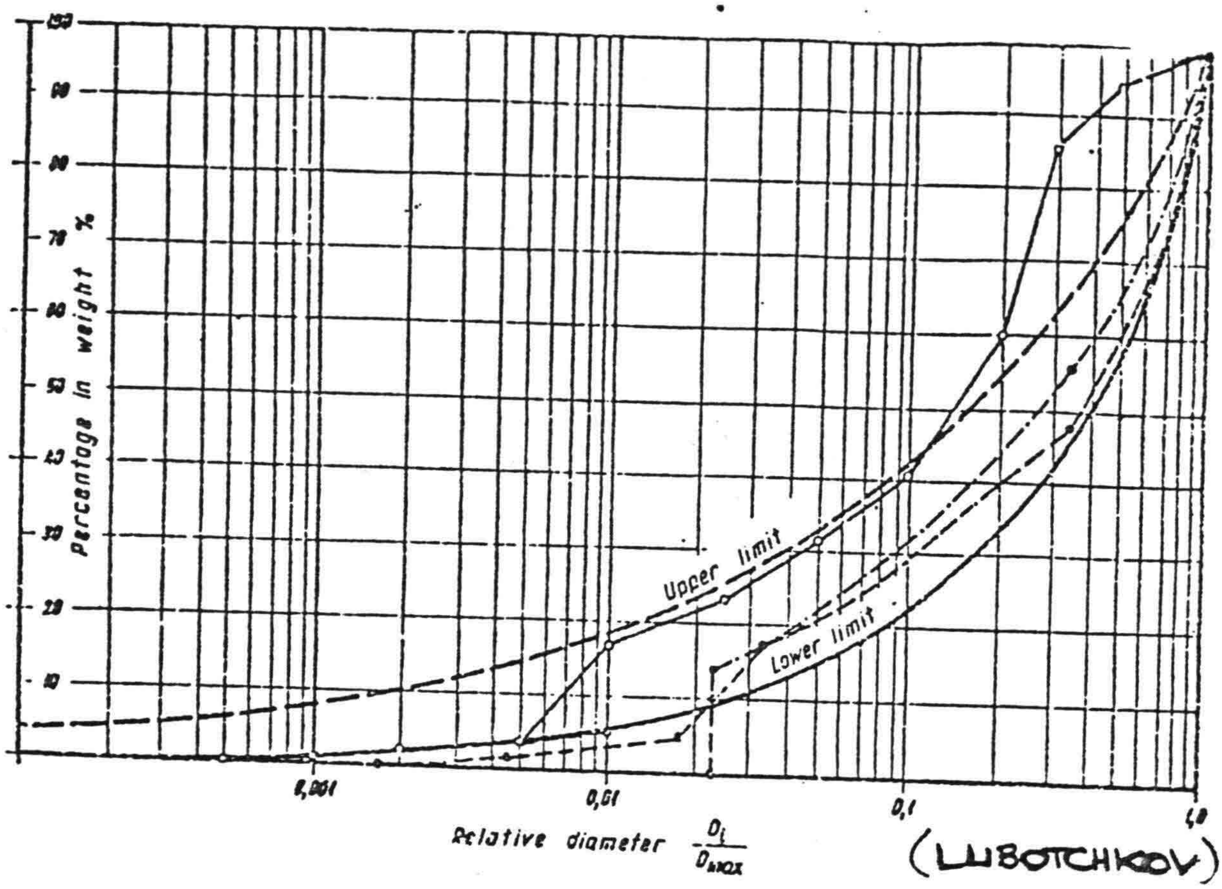
---

* DEPENDING HYDR. CONDITIONS = LOAD

ATTEMPTS HAVE BEEN MADE TO SEPARATE THE INSTANTANEOUS LOAD (BED SHEAR STRESS), [illegible] THE BEARING CAPACITY OF THE BEDMATERIAL (CRITICAL SHEAR STRESS) (GRASS 1970)

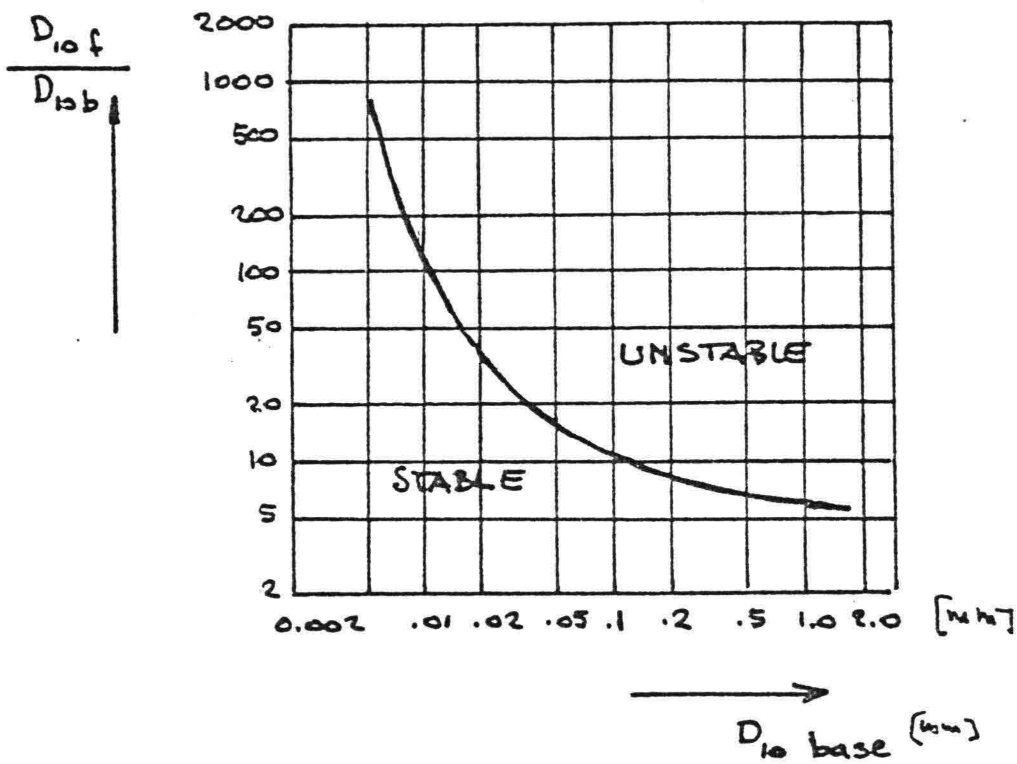


UPTILL NOW THERE ARE NO PRACTICAL RESULTS AVAILABLE

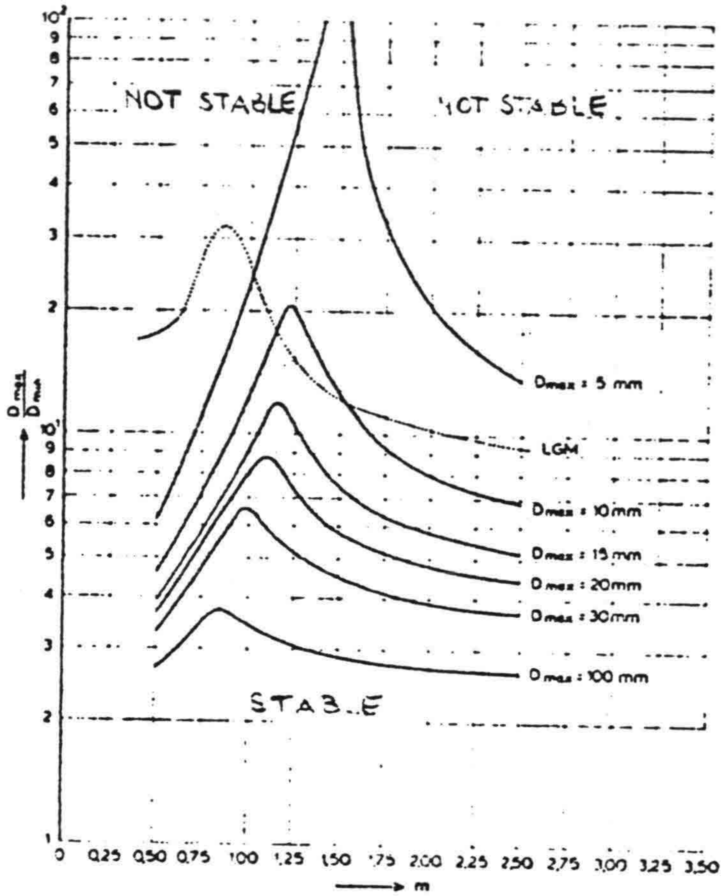


Percentage in weight %
Upper limit
Lower limit
0,001
0,01
0,1
1,0
Relative diameter $\frac{D_i}{D_{max}}$

(LUBOTCHKOV)

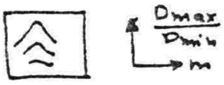


(KAWAKAMI, 1961)



$$D_x = \frac{x}{100} + \frac{1-x}{100}\left(\frac{D_{min}}{D_{max}}\right)^{Y_m}$$

2. ACC. RECENT CALCULATIONS:

SEE FIG.. 

GRAINSIZE DISTRIBUTION WRITTEN AS:

$$D_x = \left\{ \frac{x}{100} + \frac{1-x}{100} \left(\frac{D_{min}}{D_{max}} \right)^{1/m} \right\}^m * D_{max}$$

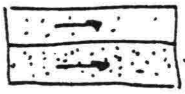
3. Lutbotchkov = LIMITS FOR GRAINSIZE DISTRIBUTION

THE ABOVE MENTIONED RULES GIVE DESIGN CRITERIA FOR FILTERS INDEPENDENT OF THE HYDRAULIC CONDITIONS = LOAD CONDITIONS

DESIGNING LARGE HYDRAULIC STRUCTURES IN THE NETHERLANDS SUCH AS HOOK OF HOLLAND HARBOUR MOLES, STORM SURGE BARRIER IN THE EASTERN SCHELDT THE "IGNORANCE" OF FILTER BEHAVIOUR WAS INACCEPTABLE. THEREFORE RESEARCH WAS CARRIED OUT AS WELL AS FOR THE LOAD CONDITIONS AS FOR THE STRENGTH OF THE FILTER CONSTRUCTION. RESULTS OF EXPERIMENTS OF THE LATER FOLLOWS BELOW:

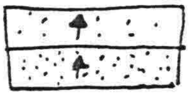
DEFINITIONS / FLOW CONDITIONS :

1)

f
b


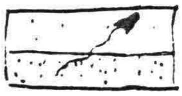
I_f FLOW PARALLEL TO INTERFACE

$I_b = I_f$ (CYCLIC $I_b \neq I_f$)

f
b


$I_f < I_b$ FLOW PERPENDICULAR TO INTERFACE

I_b

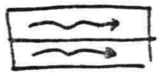
f
b


COMBINATION

} • STATIC
• CYCLIC
• BOTH

PHYSICAL PHENOMENON :

1. f b



MORE OR LESS A "TUBE-FLOW"

" $V = C\sqrt{RI}$ "

OR $I :: V^2$ OR V_*^2

FIG

GIVES THE RELATION:

$$I_{cr} = \left\{ \frac{13}{n^{2.85} D_f^{1.33}} + \frac{n^{1.65}\sqrt{D_f}}{330\ D_b^{2.3}} \right\} V_{*cr}^2$$

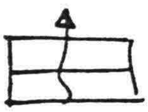
I_{cr} = CRITICAL GRADIENT PARALLEL TO INTERFACE

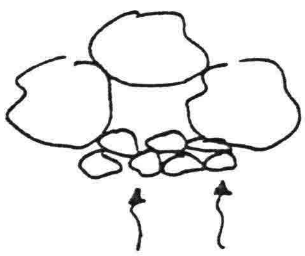
D_f = D_{50} filter , D_b = D_{50} base

n = porosity filter

V_{*cr} = SHIELDS crit. V_* base

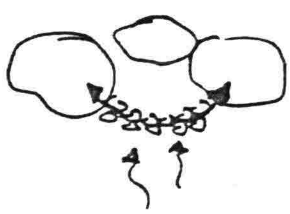
2. f b





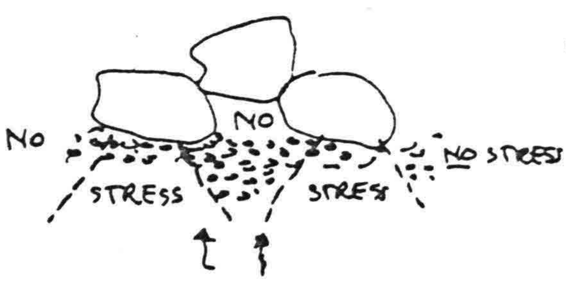
PENETRATION BASE → FILTER IMPOSSIBLE

$$\frac{n_f D_{20f}}{D_{50b}} \leq 1$$



ARCHING, BRIDGING

$$1 < \frac{n_f D_{20f}}{D_{50b}} < 6$$



LOCAL FLUIDISATION

$$\frac{n_f D_{20f}}{D_{50b}} \geq 6$$

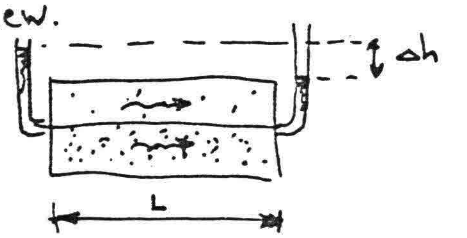
2) THE CRITERION FOR INACCEPTABLE BEHAVIOUR OF THE FILTER CONSTRUCTION (LIMIT STATE) DEPENDS ON THE EFFECT OF THIS BEHAVIOUR ON THE TOTAL CONSTRUCTION.

FOR INSTANCE: 1) FILTER CONSTRUCTION IN A REVETMENT: THE LOSS OF STABILITY OF SOME GRAINS OR EVEN STONES CAUSES NOT A COMPLETE FAILURE OF THE FILTER, "SOME" SETTLEMENT IS ACCEPTABLE

2) FILTER CONSTRUCTION AS AN ELEMENT OF THE FOUNDATION OF THE STORM SURGE BARRIER: SETTLEMENT DUE TO (LOCAL) INSTABILITY IS "NOT" ACCEPTED.

IN THE RESULTS MENTIONED BELOW THE I_{cr} IS THE PARAMETER FOR JUST ACCEPTABLE BEHAVIOUR OF THE FILTER.

I_{cr} = critical gradient in the medium or interface under review.

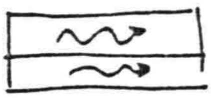


$I = \frac{\Delta h}{L}$

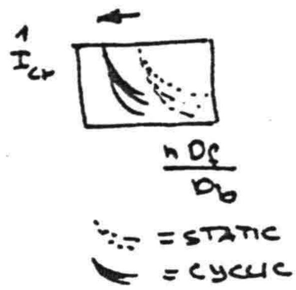
I_{cr} IS DEFINED AS THAT GRADIENT FOR WHICH INITIATION OF PARTICALS IN THE MEDIUM UNDER REVIEW OCCURS. THIS IS RATHER SUBJECTIVE, SEE ALSO THE SHIELDS CRITERIA FOR INITIATION OF MOTION.

IN GENERAL: $I_{cr} = f\left(D_b, \frac{D_f}{D_b}, n_f\right)$

n = porosity

4.  CYCLIC 

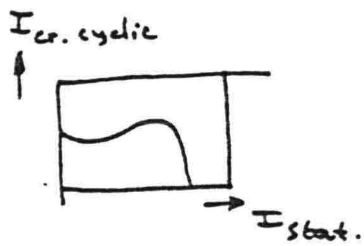
- HYDRAULIC COMPACTION OCCURS, $I_{cr.cycl}$ BECOMES EQUAL $I_{cr\ stat.}$
- SECUNDAIR VERT. GRADIENTS ARE GENERATED

5.  CYCLIC 

$I_{cr \cdot cycl.} < I_{cr\ stat.}$

6.  CYCLIC ?

7.  CYCLIC + STATIC AFTER COMPACTION PROBABLE MORE OR LESS THE SAME AS 4.

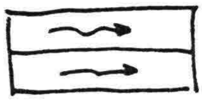
8.  CYCLIC + STATIC 

$I_{cr.\ cycl} = 0$ IF $I_{STAT} = I_{cr.\ STAT.}$

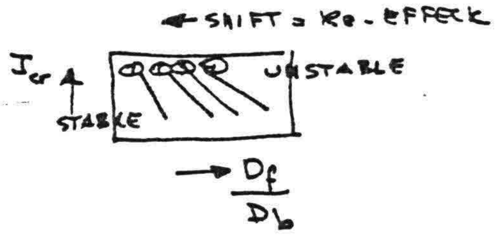
9.  CYCLIC + STATIC ?

<u>RESULTS</u> OF EXPERIMENTS (EXECUTED IN THE FACILITIES IN THE FIGURE BELOW, DELFT HYDRAULIC LABORATORY)

1.

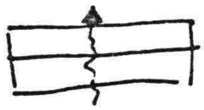


<u>STATIC</u>

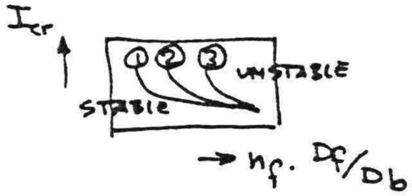


THE RESULTS ARE APPLICABLE FOR
① GRAVEL – QUARRY STONE
② COARSE SAND – SPLIT
③ FINE SAND – SPLIT
④ FINE SAND – GRAVEL

2.



<u>STATIC</u>

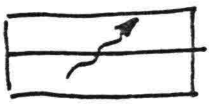


THE RESULTS ARE FROM EXPERIMENTS WITH SAND 1. D_{50} = 150 μm

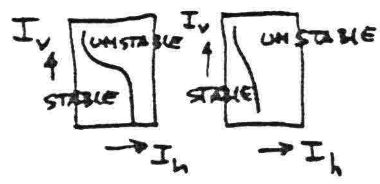
2. D_{50} = 220 μm

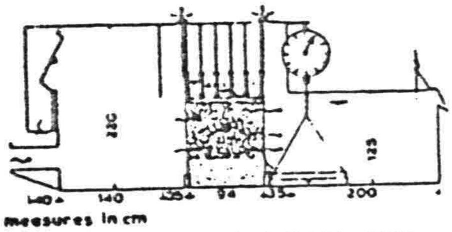
3. D_{50} = 460 μm

3.

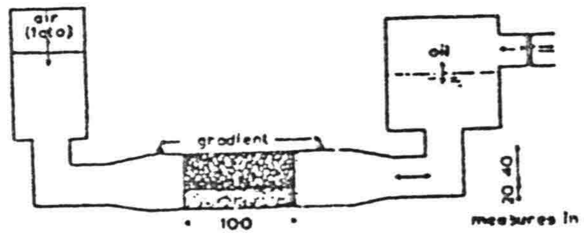


<u>STATIC</u>

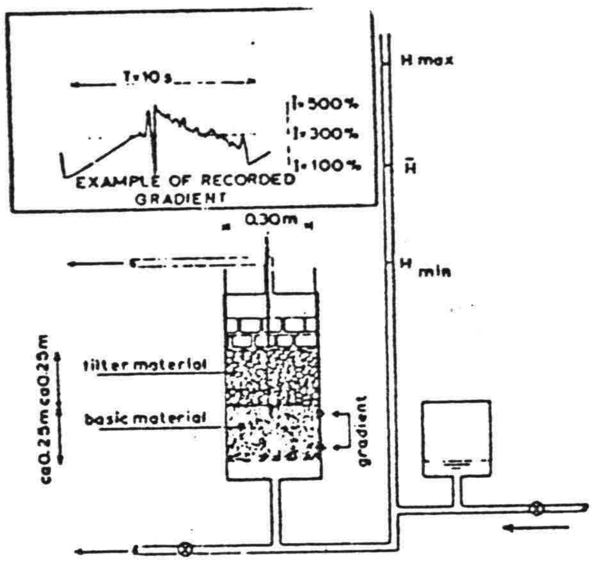




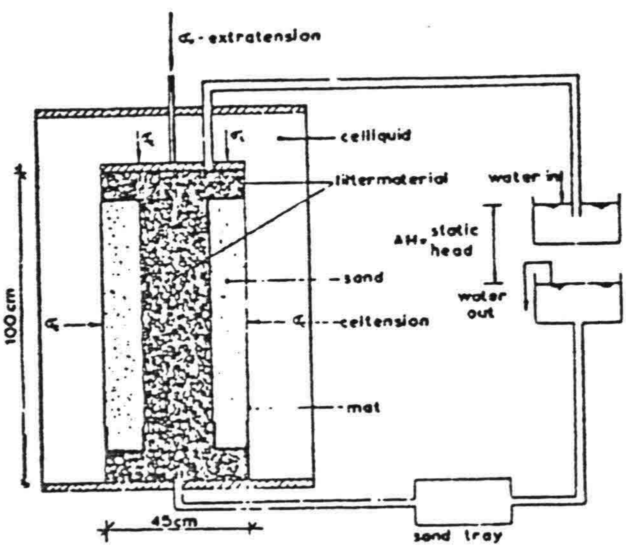
STATIC FLOW PARALLEL AND
PERPENDICULAR TO INTERFACE



CYCLIC FLOW PARALLEL TO INTERFACE



STATIC AND CYCLIC FLOW PERPENDICULAR
TO INTERFACE

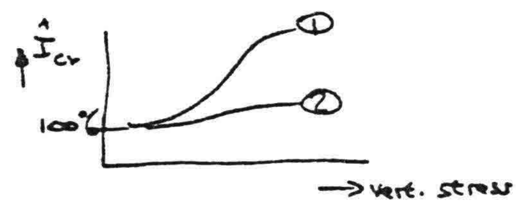


CYCLIC FLOW PERPENDICULAR TO INTERFACE
STATIC FLOW PARALLEL TO INTERFACE

Test facilities.

- EFFECT OF VERTICAL STRESS (DUE TO DEAD WEIGHT OF OR LOADING ON THE STRUCTURE ABOVE THE FILTERCONSTRUCTION) ON $\hat{I}_{cr}$ (cyclic) :

SEE FIG.



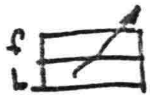
FILTER ① : IS A FILTER WITH ARCHING PHENOMENA

$$- \frac{n D_{10f}}{D_{50b}} = 4.4$$

FILTER ② : IS A FILTER WITH LOCAL FLUIDISATION

$$- \frac{n D_{10f}}{D_{50b}} = 13$$

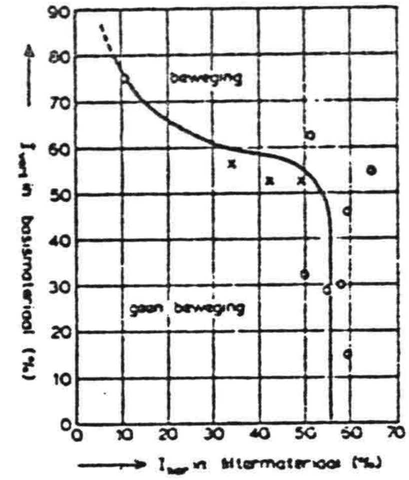
3.



STATIC

x serie A I_{hor} gekozen, I_{vert} kritiek gezocht

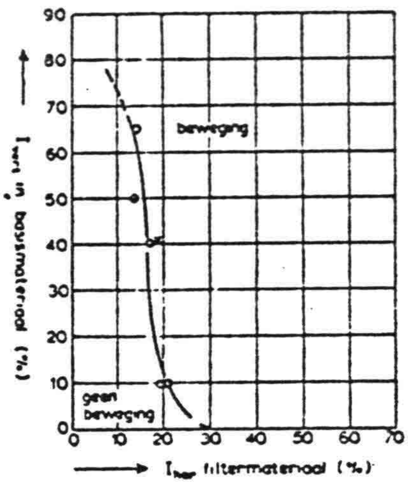
o serie B I_{vert} gekozen, I_{hor} kritiek gezocht



D_{50b} = 150 µm

D_{50f} = 3,8 mm , p = 8

"GRADED"

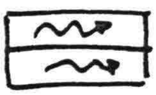


D_{50b} = 150 µm

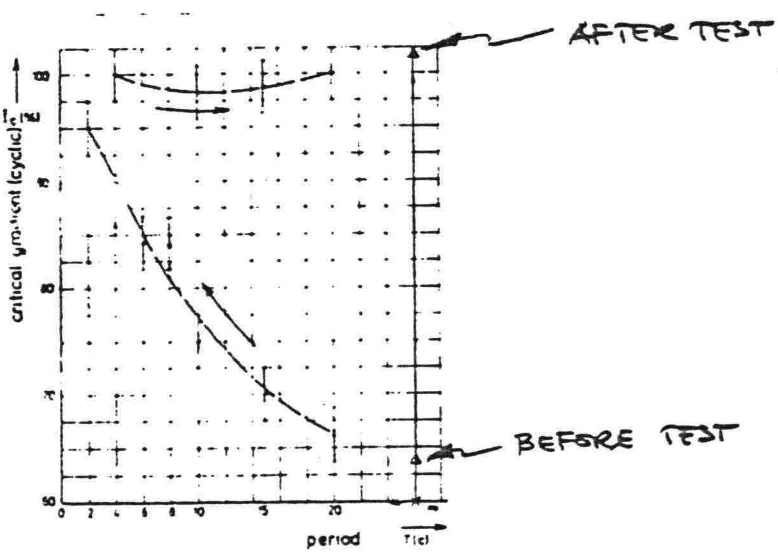
D_{50f} = 4,5 mm , p = 25

"UNIFORM"

4.



CYCLIC

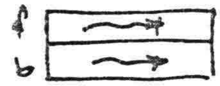


D_{50b} = 150 µm

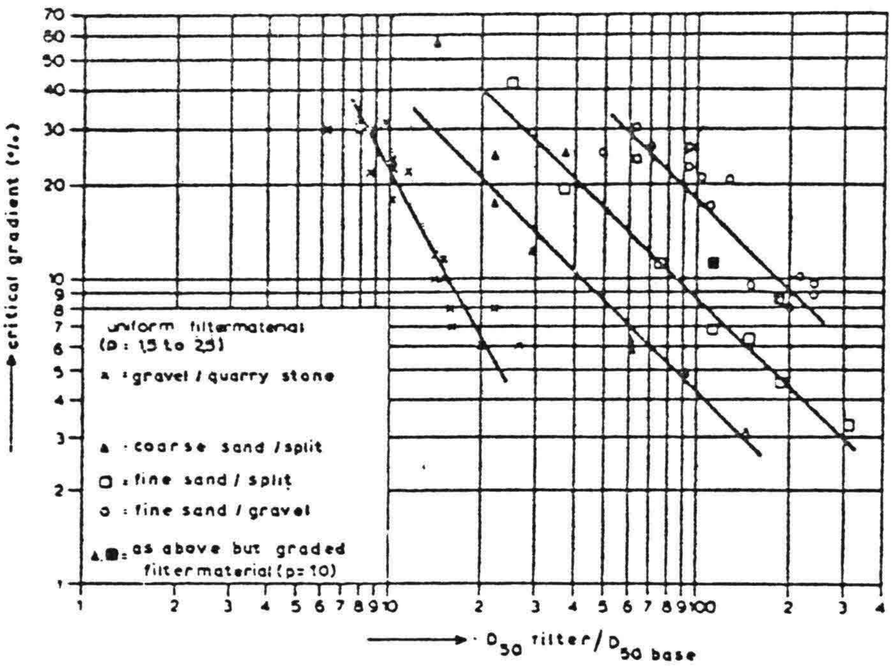
D_{50f} = 3.8 µm

$\frac{D_{90f}}{D_{10f}}$ = 8

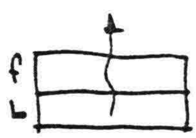
1



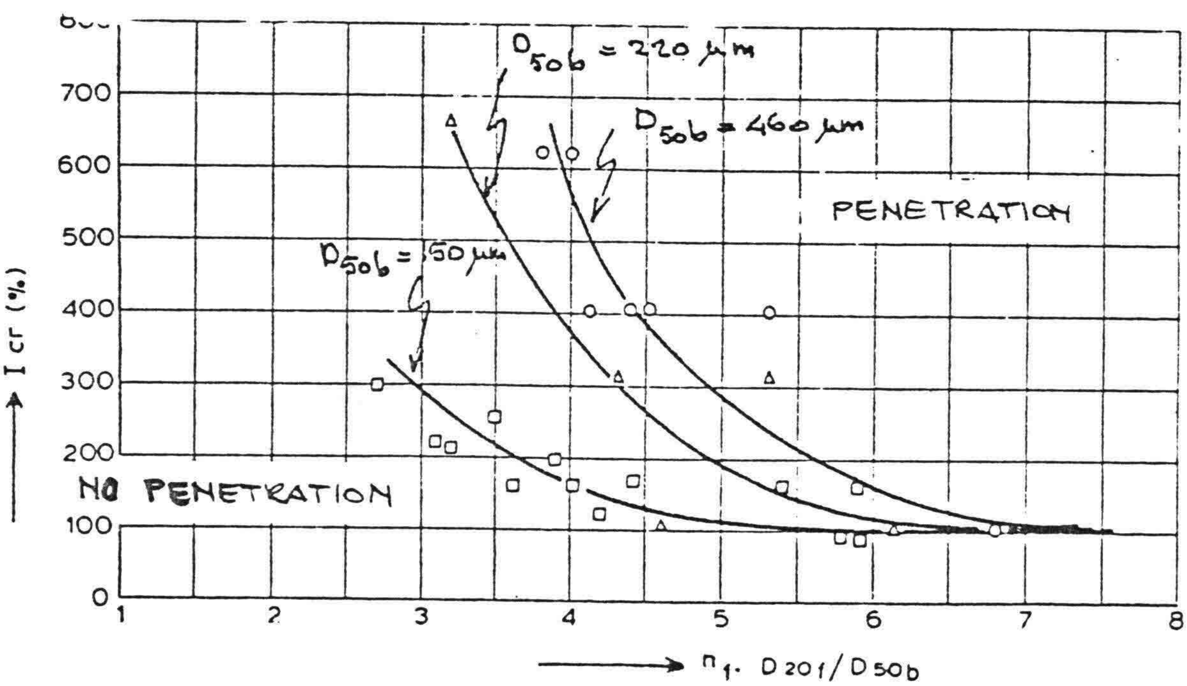
STATIC

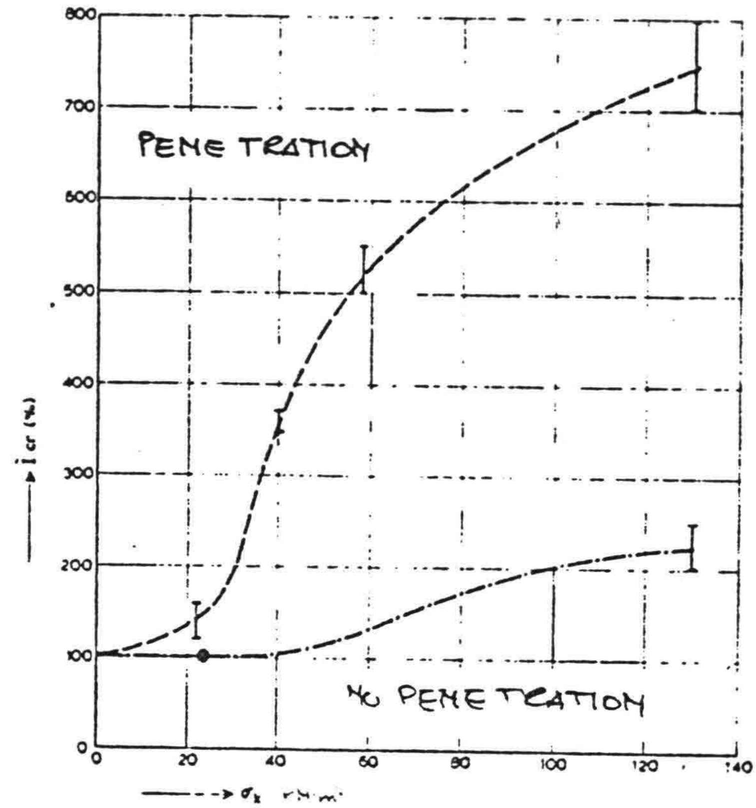


2.



STATIC





basis
$D_{50_b} = 150\ \mu m$

filter A 1,4 - 8,1 mm
$D_{50f} = 3,4$ mm
$D_{20f} = 2,0$ mm
$n_f = 33\ \%$

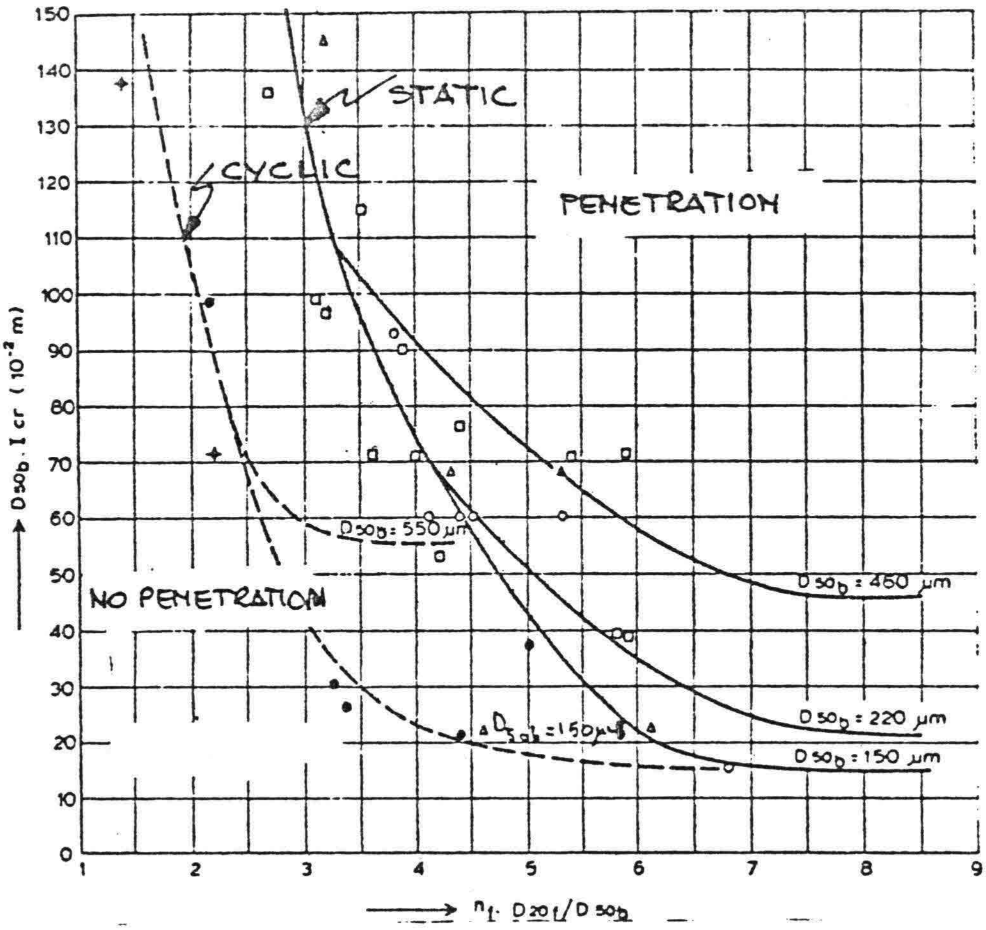
$\frac{n_f D_{20f}}{D_{50_b}} = 4,4$

filter B 5 - 10 mm
$D_{50f} = 7,0$ mm
$D_{20f} = 5,5$ mm
$n_f = 35\ \%$

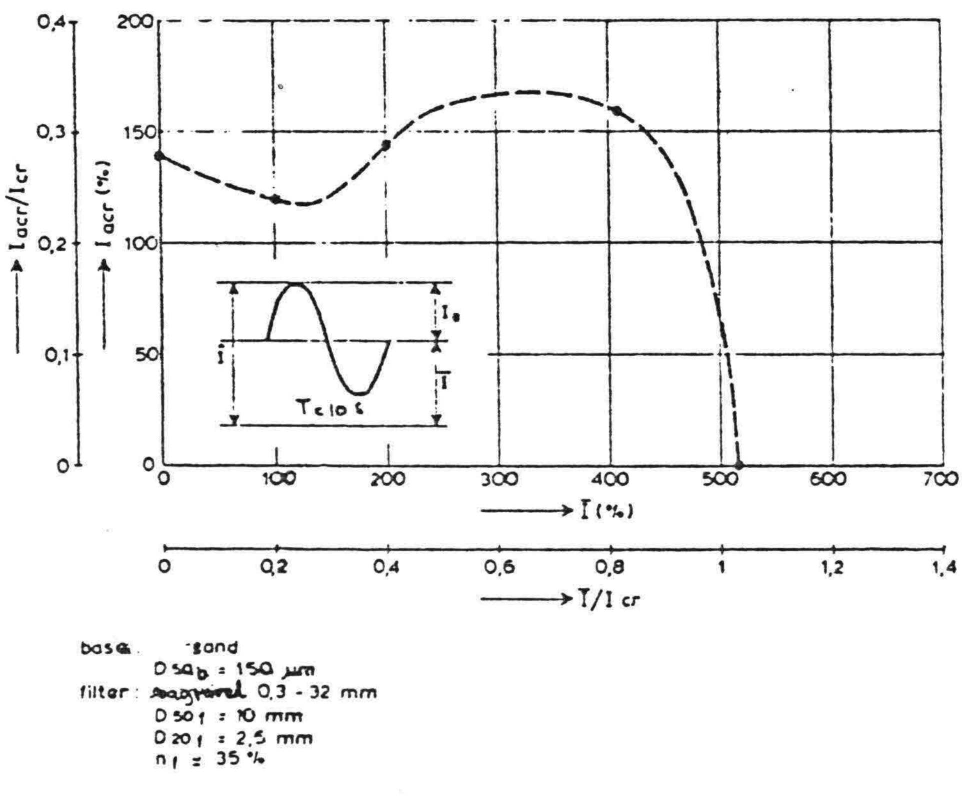
$\frac{n_f D_{20f}}{D_{50_b}} = 13$

EFFECT OF GRAIN PRESSURE ON $\hat{I}_{cr}$

CYCLIC



CYCLIC + STATIC



base: sand
D_{50b} = 150 μm
filter: ~~sea gravel~~ 0,3 - 32 mm
D_{50f} = 10 mm
D_{20f} = 2,5 mm
n_f = 35 %

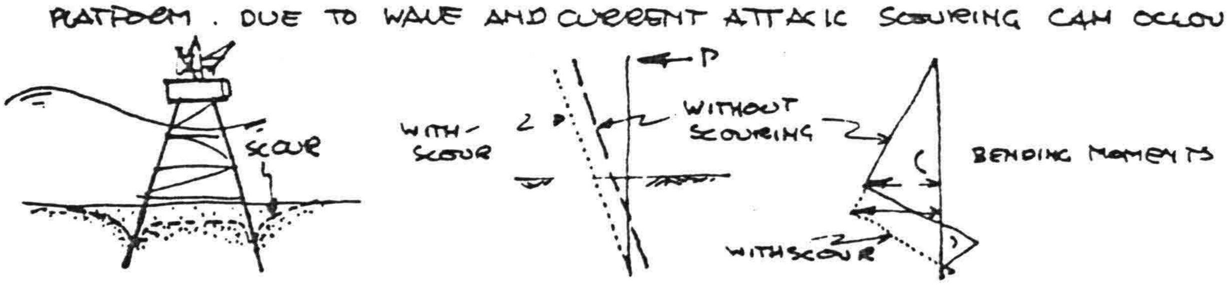
THE INSTABILITY OF THE SUBSOIL OF THE APRON CAUSES DESINTEGRATION OF THE APRON AND AFTER THAT A SCOURHOLE AT THAT PLACE WILL DEVELOP AND CAUSES IN ITS TURN A THREAT FOR THE SILL AND ITS FOUNDATION.

IT IS ALSO POSSIBLE THAT THE SCOUR HOLE IS SO DEEP AND OR THE SLOPE SO STEEP THAT LIQUIFACTION OF THE UNDERNEATH THE APRON (AND/OR RIVER BANK) OCCURS AND CAUSES A FAILURE OF THE SILL IN A VERY SHORT TIME

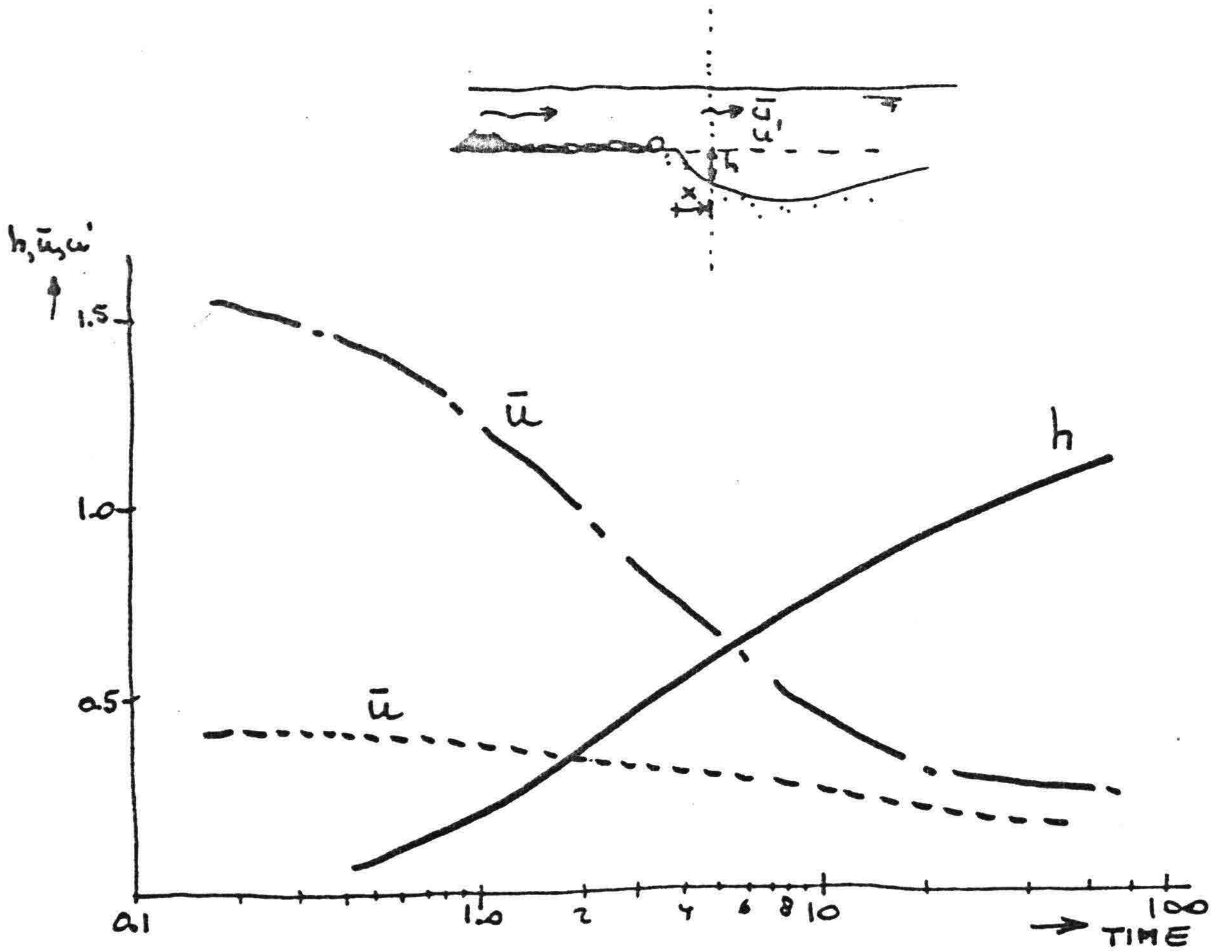
<u>CONCLUSION</u>: IN DIMENSIONING THE REVETMENT IN TERMS OF SAFETY MARGIN OR PROBABILITY OF FAILURE IT IS NECESSARY TO STUDY THE BEHAVIOUR OF THE TOTAL CONSTRUCTION OF WHICH THE REVETMENT IS AN ELEMENT.

- IN TERMS OF THE LOAD AND STRENGTH THE DEPTH OF THE SCOUR HOLE = LOAD (POTENTIAL THREAT) AND THE THE LENGTH (AND WIDTH) OF THE REVETMENT = STRENGTH PARAMETER

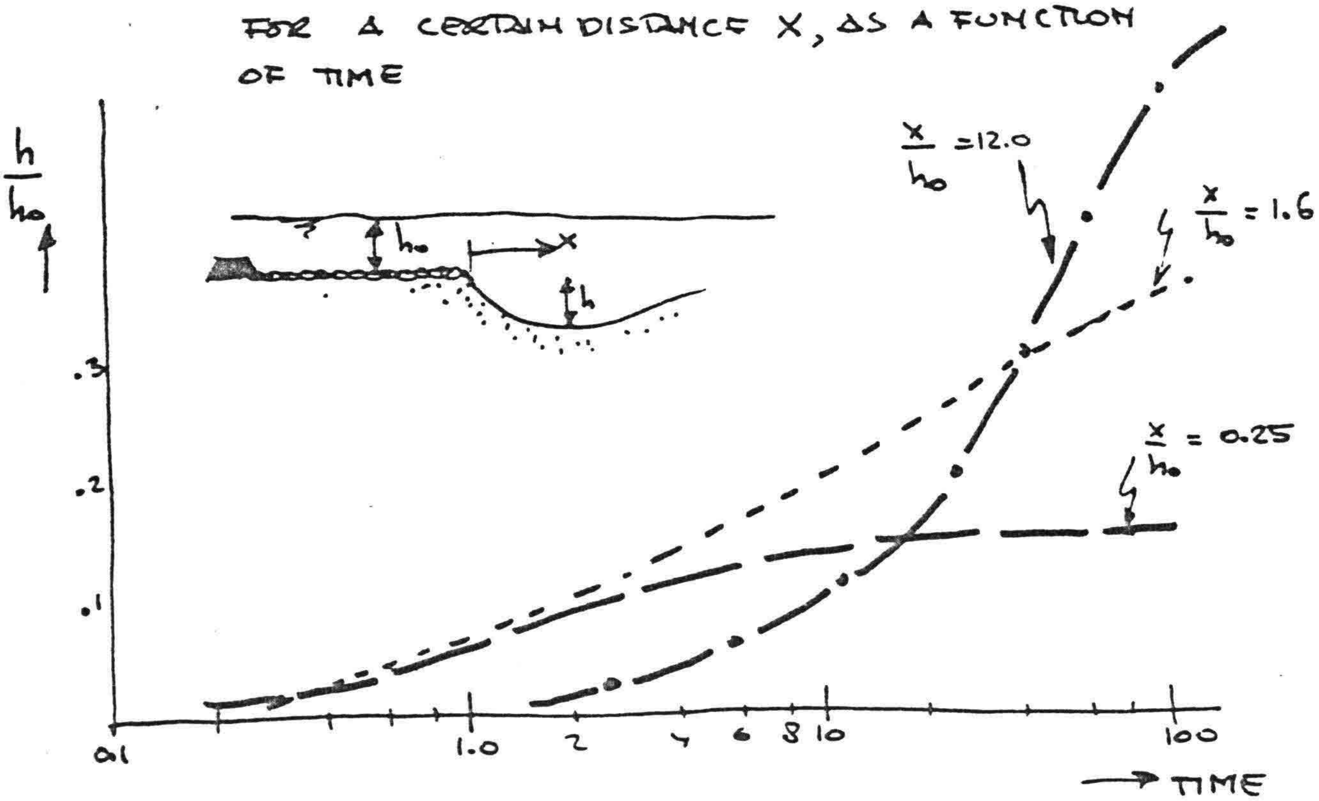
<u>ANOTHER EXAMPLE</u> IS THE REVETMENT AROUND THE LEGS OF A OFFSHORE PLATFORM. DUE TO WAVE AND CURRENT ATTACK SCOURING CAN OCCOUR



TO PREVENT THE COLLAPSE (OR UNACCEPTABLE BEHAVIOUR) OF THE TOTAL CONSTRUCTION A REVETMENT COULD BE NECESSARY, OR WHEN SCOURING IS TAKEN INTO ACCOUNT STRONGER LEGS OR FEETS OF THE PLATFORM.
A THOROUGH ANALYSIS OF THE WHOLE STRUCTURE GIVES THE CONTRIBUTION OF THE FAILURE OF THE REVETMENT TO THE PROBABILITY OF FAILURE OF THE TOTAL PLATFORM. THERE ARE OTHER CONTRIBUTIONS TO THIS PROB. OF FAILURE SUCH AS FIRE, SHIP COLLISION ETC.



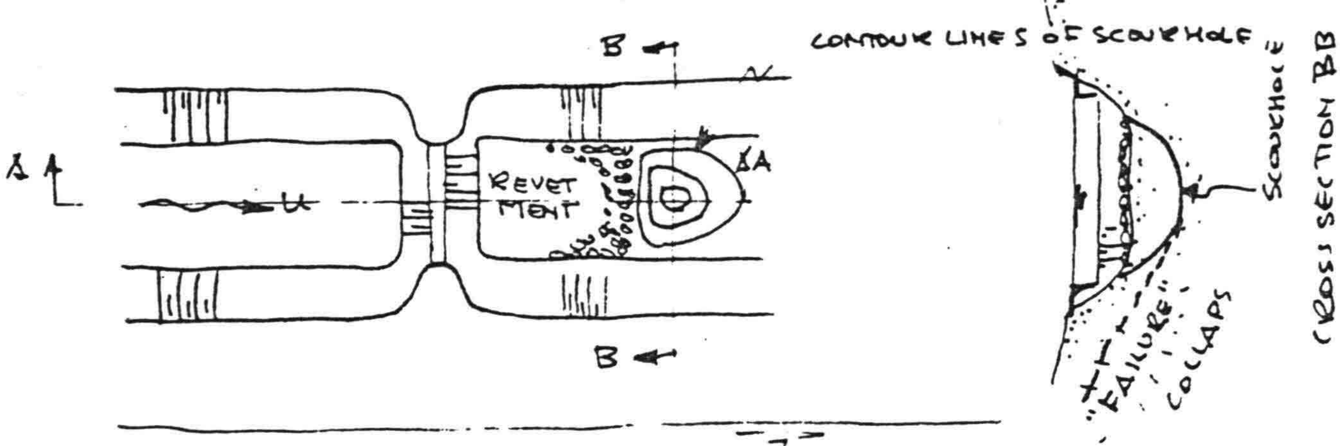
SCOURING DEPTH, VELOCITY AND TURBULENCE FOR A CERTAIN DISTANCE X, AS A FUNCTION OF TIME

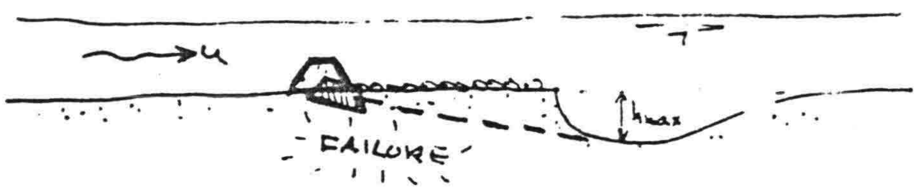


LOCAL SCOURING DEPTH AS A FUNCTION OF TIME ($\curvearrowright x/h_0$)

DIMENSIONS IN HORIZONTAL DIRECTION

EXAMPLE
POTENTIAL THREAT FOR PROTECTED CONSTRUCTION





CROSS SECTION AA

DUE TO THE CONTRACTION OF THE SILL AND DOWNSTREAM A RETARDATION OF THE CURRENT THE SAND TRANSPORT CAPACITY INCREASES

THE REVETMENT (APRON IN THIS CASE) HAS SUCH AN EXTENT THAT THE DEPTH OF THE SCHOURHOLE (AND THE SLOPE JUST DOWNSTREAM OF THE APRON IS NOT A POTENTIAL) THREAT FOR THE SUBSOIL UNDERNEATH THE APRON. (SEE ALSO FAULT TREE APRON)

THIS HOLDS FOR THE DIRECTION PARALLEL AND PERPENDICULAR TO THE CURRENT. ALSO THE RIVERBANK CAN COLLAPSE DUE TO THE SCOURHOLE! (THREE DIMENSIONS (OR FOUR, INCLUDING TIME)

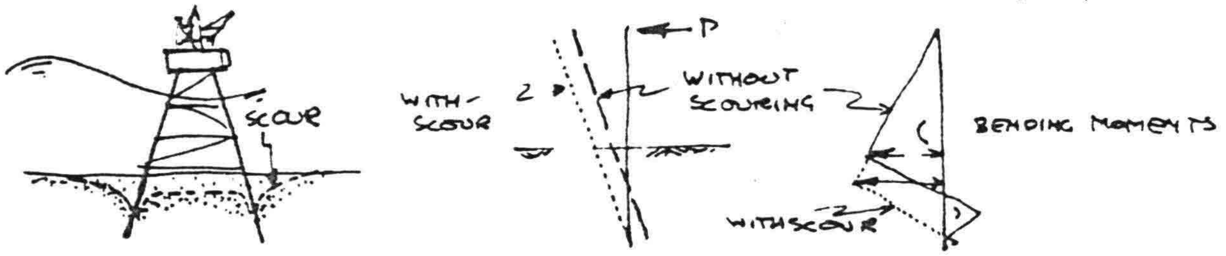
THE INSTABILITY OF THE SUBSOIL OF THE APRON CAUSES DESINTEGRATION OF THE APRON AND AFTER THAT A SCOURHOLE AT THAT PLACE WILL DEVELOP AND CAUSES IN ITS TURN A THREAT FOR THE SILL AND ITS FOUNDATION.

IT IS ALSO POSSIBLE THAT THE SCOUR HOLE IS SO DEEP AND OR THE SLOPE SO STEEP THAT LIQUIFACTION OF THE UNDERNEATH THE APRON (AND/OR RIVER BANK) OCCURS AND CAUSES A FAILURE OF THE SILL IN A VERY SHORT TIME

<u>CONCLUSION</u>: IN DIMENSIONING THE REVETMENT IN TERMS OF SAFETY MARGIN OR PROBABILITY OF FAILURE IT IS NECESSARY TO STUDY THE BEHAVIOUR OF THE TOTAL CONSTRUCTION OF WHICH THE REVETMENT IS AN ELEMENT.

- IN TERMS OF THE LOAD AND STRENTH THE DEPTH OF THE SCOUR HOLE = LOAD (POTENTIAL THREAT) AND THE THE LENGTH (AND WIDTH) OF THE REVETMENT = STRENGTH PARAMETER

<u>ANOTHER EXAMPLE</u> IS THE REVETMENT AROUND THE LEGS OF A OFFSHORE PLATFORM. DUE TO WAVE AND CURRENT ATTACK SCOURING CAN OCCOUR

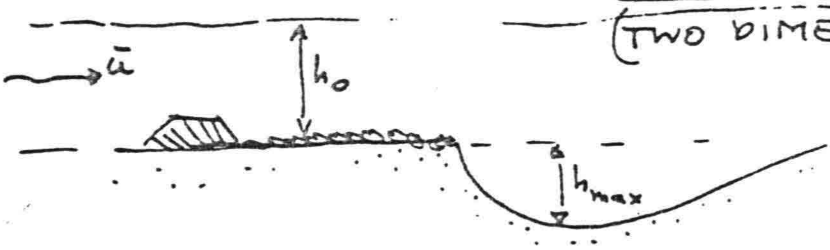


TO PREVENT THE COLLAPSE (OR UNACCEPTABLE BEHAVIOUR) OF THE TOTAL CONSTRUCTION A REVETMENT COULD BE NECESSARY, OR WHEN SCOURING IS TAKEN INTO ACCOUNT STRONGER LEGS OR FEETS OF THE PLATFORM.

A THOROUGH ANALYSIS OF THE WHOLE STRUCTURE GIVES THE CONTRIBUTION OF THE FAILURE OF THE REVETMENT TO THE PROBABILITY OF FAILURE OF THE TOTAL PLATFORM. THERE ARE OTHER CONTRIBUTIONS TO THIS PROB. OF FAILURE SUCH AS FIRE, SHIP COLLISION ETC.

RESULT OF SYSTEMATICAL SCOURING MODEL TESTS

(TWO DIMENSIONAL CONDITIONS)



$$\frac{h_{max}(t)}{h_0} = \left(\frac{t}{t_1}\right)^{0.38}$$

$$t_1 = \frac{K \cdot \Delta^{1.7} \cdot h_0^2}{(\alpha \bar{u} - u_{cr})^{4.3}}$$

$K = 250$

OR BETTER: $K = 330 \left(\frac{h_{max}}{h_0}\right)^{2.53}$

$$\Delta = \frac{\rho_s - \rho_w}{\rho_w}$$

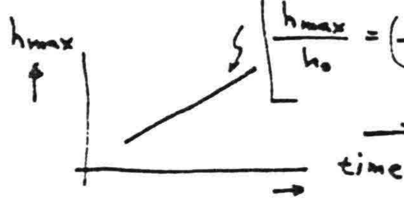
α = DIMENSIONLESS COEFFICIENT, DEPENDING ON GEOMETRY PARAMETERS (SEE FIG )

u_{cr} = CRITICAL VELOCITY FOR INITIATION OF MOTION (SHIELDS, PARTIAL)

α TO BE DETERMINED WITH MODEL TESTS.
FOR SIMILARITY OF α FOR MODEL AND PROTOTYPE THE EXPERIMENTS SHOULD FULFIL THE SCALE LAWS:

$$n_t = n_\Delta^{1.7} \cdot n_h^2 \cdot n_u^{-4.3}$$

SO:
MODEL TESTS RESULTS IN:

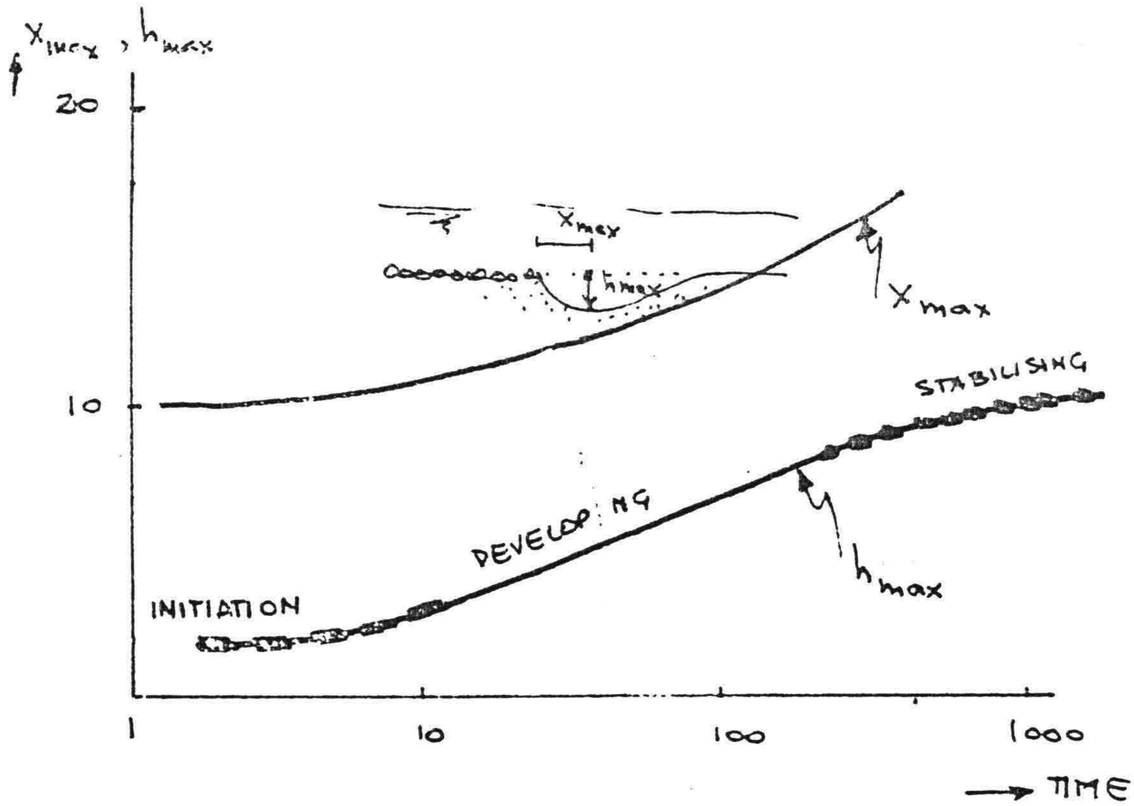


$\left[\frac{h_{max}}{h_0} = \left(\frac{t}{t_1}\right)^{0.38}\right]_{MODEL}$ → GIVES α

THE GRAPH IS THE SAME FOR PROTOTYPE, BUT h_0 AND t_1 DIFFER FROM MODEL.

FROM MODEL RESULTS $\alpha\bar{u}$ = KNOWN.
FROM PROTOTYPE : h_0, Δ, u_{cr} = KNOWN } → t_1

SO THE RELATION FOR PROTOTYPE IS KNOWN



THREE STAGES IN THE SCOURING PROCES:

1. INITIATION OF PARTICALS AND SMALL SCOURING HOLE ("IN STATU NASCENDI")
2. DEVELOPING OF THE SCOURE HOLE; THE SHAPE IS MORE OR LESS THE FINAL SHAPE, NOT THE "FINAL" DIMENSIONS
3. STABILISING STAGE; THE SHAPE AND DIMENSIONS REMAINS ALMOST CONSTANT DUE TO EROSION AND SEDIMENTATION AGAIN.

FOR DEVELOPING STAGE:

THE BEHAVIOUR OF THE DEEPEST POINT OF A SCOURHOLE:

$$h_x(t) = A(x)\, h_0 \ln \frac{t}{t_0(x)}$$

or:

$$t = t_0(x)\, e^{\frac{h_x(t)}{h_0 A(x)}}$$

EXPERIMENTS: → $t_0(x)$ AND $A(x)$

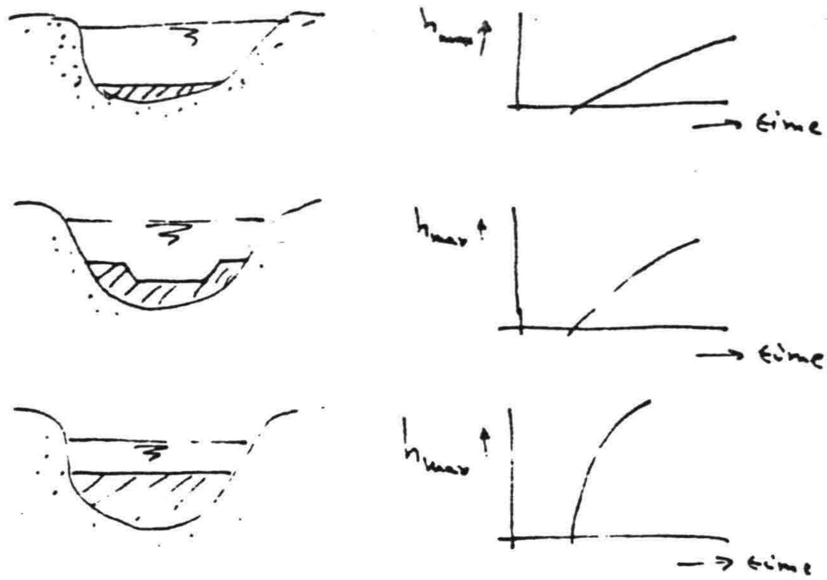
MODEL TESTS FOR DIFFERENT EXECUTION STAGES

PROCEDURE, EXAMPLE EXECUTION OF A SILL

STAGE 1

STAGE 2

STAGE 3



DURATION OF RESP. STAGE 1,2,3 IS t_1, t_2, t_3.

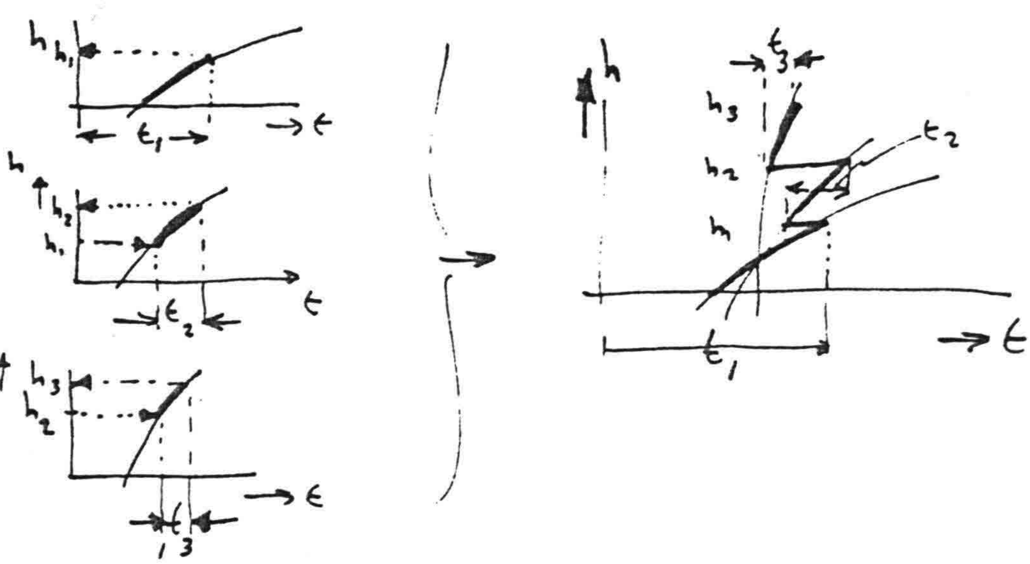
WE MAY USE THE SUPERPOSITION PRINCIPLE; THE SHAPE OF THE SCOURING HOLE ~~PREV. STAGE~~ AFTER COMPLETION OF EXECUTION STAGE 1 IS THE STARTINGSITUATION OF THE NEXT EXECUTION STAGE, BUT NOT IN THE TEST FACILITY ITSELF BY IN EVALUATING THE RESULTS

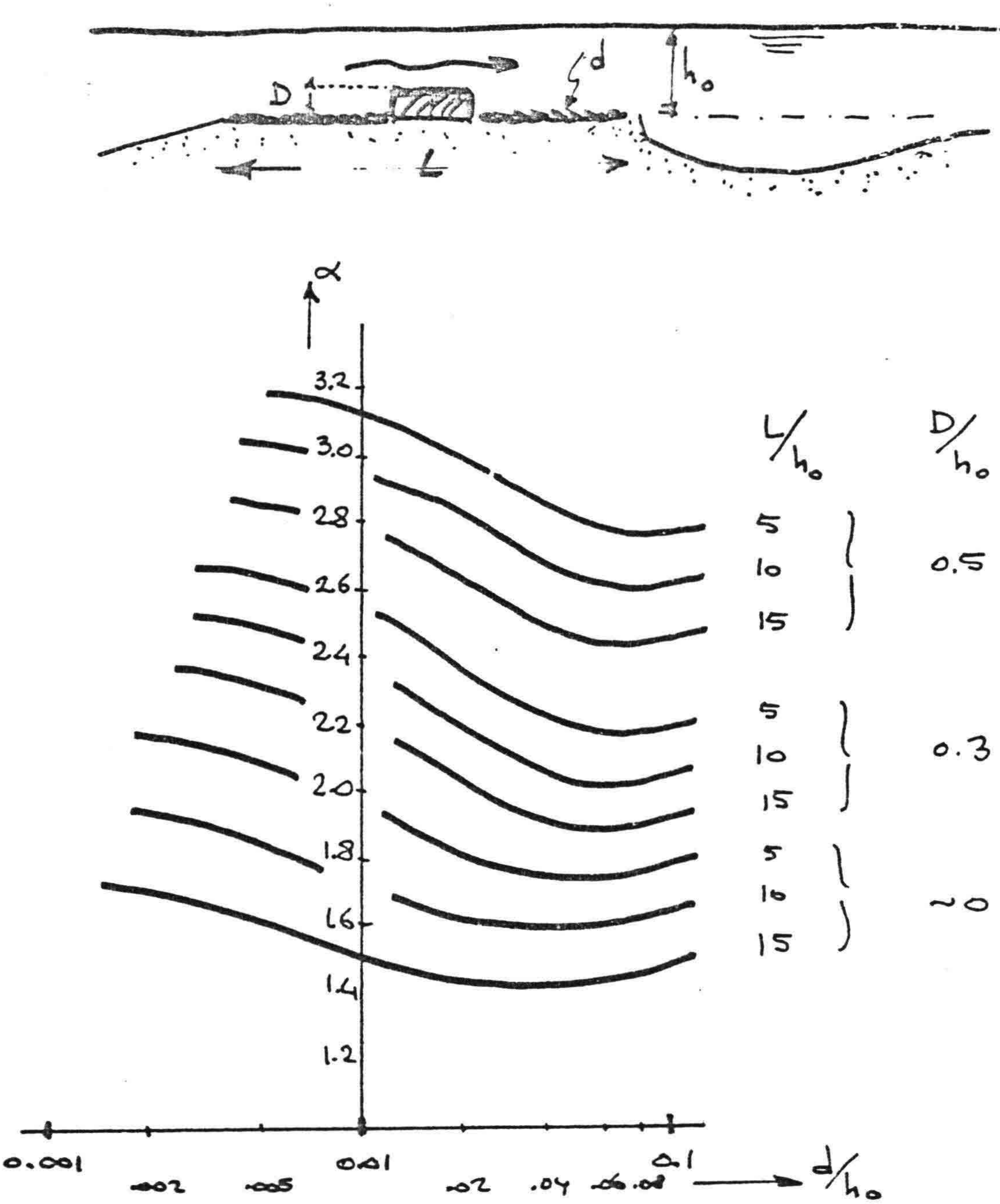
SO:

STAGE ①

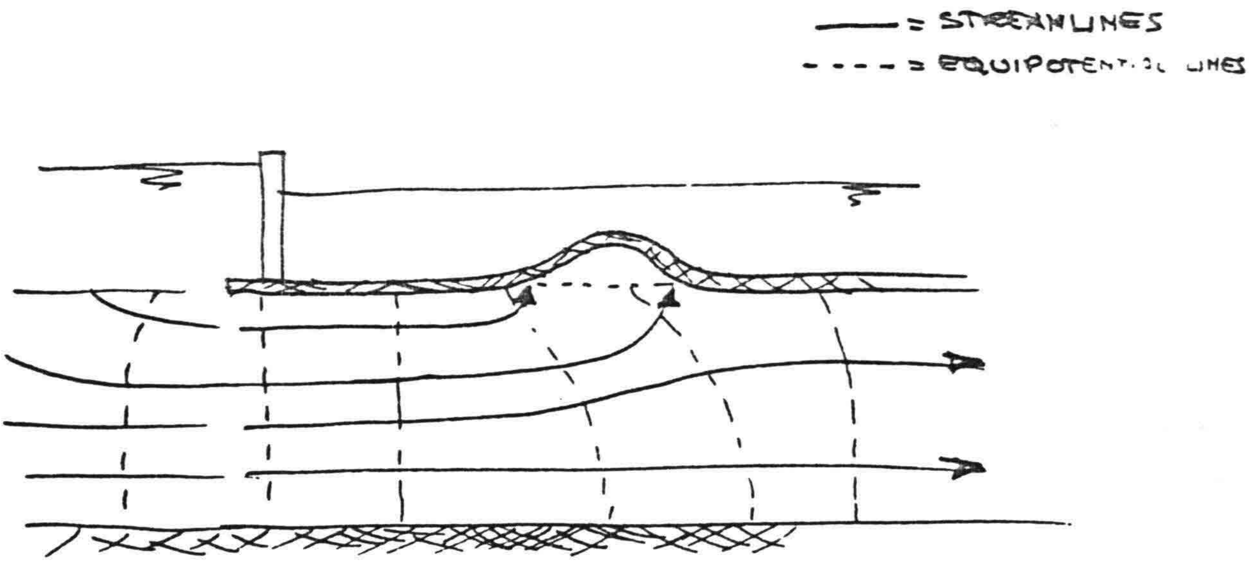
STAGE ②

STAGE ③





VALUES OF α FOR VARIOUS GEOMETRY PARAMETERS (ONLY INDICATION)



'= UPLIFTING THE GROUNDWATER DISCHARGE INTO BUBBLE

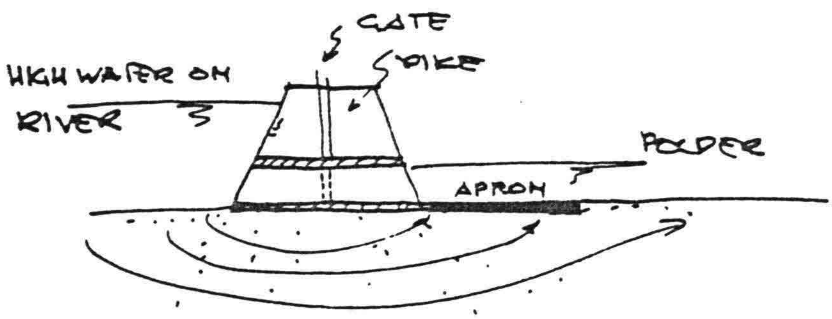
DISCHARGE THROUGH FLOW TUBE: $q = k \cdot i$

FROM FLOW NET (AND KNOWN k) THE DISCHARGE CAN BE CALCULATED.

– DEPENDING ON 1) THE DURATION OF THE UPLIFT PRESSURE,
2) STRENGTH AND STIFFNESS OF CONSTRUCTION.
3) PERMEABILITY OF THE SUBSOIL

THIS IS AN ACCEPTABLE SITUATION (LIMIT STATE) OR NOT

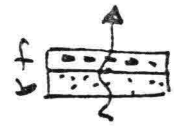
THESE SITUATIONS OCCURS IN CASES AS:



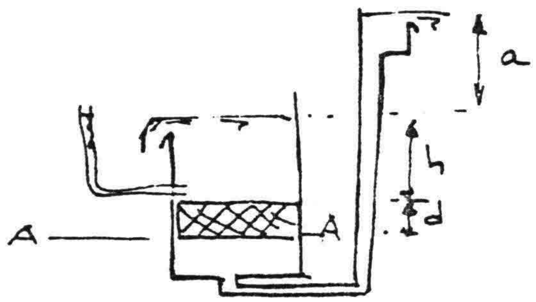
VERTICAL DIMENSIONS

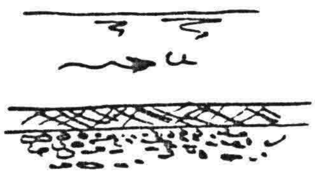
- PERMEABLE CONSTRUCTIONS : FILTERS

SEE "FILTER RULES"



- IMPERMEABLE CONSTRUCTIONS (CELLAR FLOOR / FLUIDISATION)





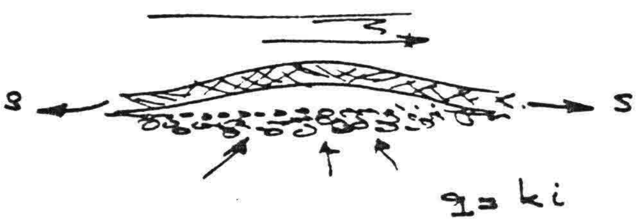
REST:

EQUILIBRIUM AT INTERFACE AA:

$$\rho_s g d + \rho_w g h = \rho_w g (a + h + d)$$

$$d = \frac{\rho_s - \rho_w}{\rho_w} a = \Delta a$$

BUBBLES: $d < \Delta a$ (UPLIFT FORCES)

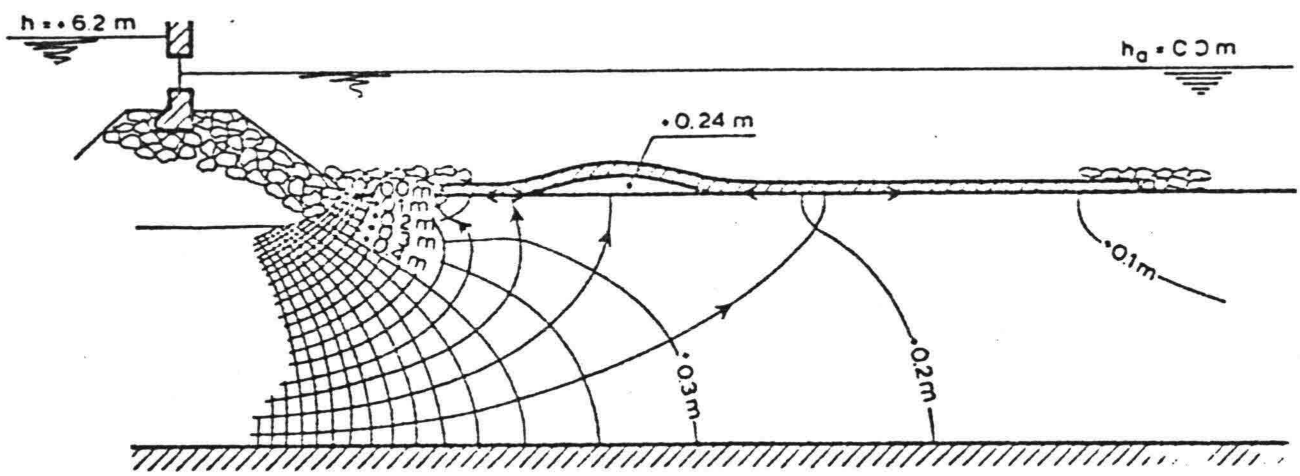


$q = ki$

S = tension in revetment due to deformation

S = VERY SMALL BECAUSE OF THE RELATIVELY LOW VELOCITY OF DEFORMATION.

IF S = 0 THAN : REST-SITUATION AND WATERPRESSURE BELOW CONSTRUCTION = W.P. ABOVE CONSTRUCTION + de

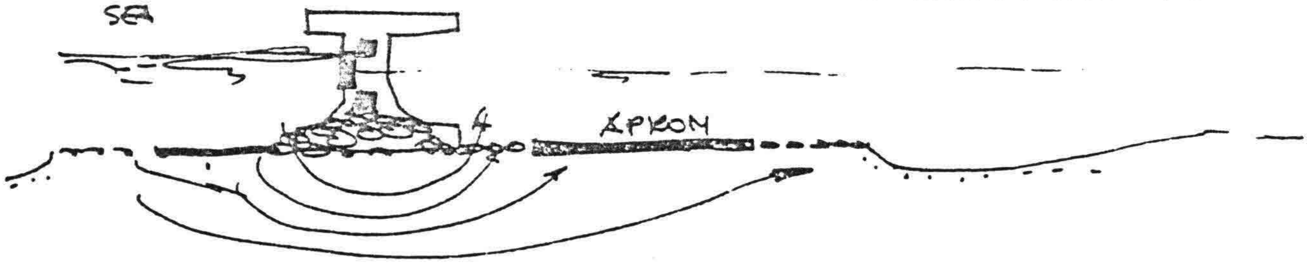


BUBBLE UNDERAPRON

FOR THE OPTIMUM DESIGN OF THE APRONS OF THE STORM SURGE BARRIER VARIOUS LAYOUTS AND DESIGNS HAVE BEEN STUDIED. THE RATE OF PERMEABILITY AND THE LAYOUT (HORIZONTAL DIMENSIONS) HIGHLY AFFECTS THE UPLIFT PRESSURE AND SO CONSEQUENTLY THE VERTICAL DIMENSIONS AND THE TOTAL COSTS.

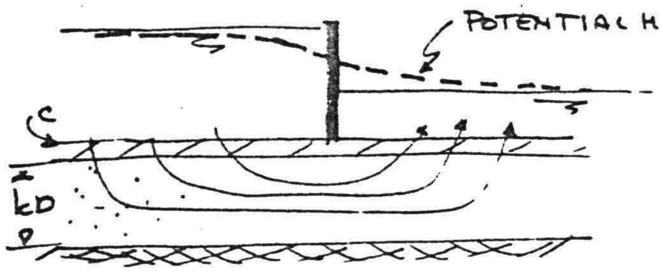
THE ALTERNATIVE LAYOUTS AND THE RESULTING UPLIFT PRESSURE ARE GIVEN IN THE FOLLOWING DIAGRAMS. (CLOSED BARRIER)

STORM SURGE BARRIER



MATHEMATICAL MODELS FOR HYDRAULIC LOAD ARE:

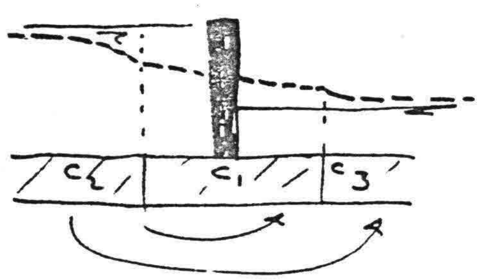
CASE 1. MOST SIMPLIFIED. (SEE ALSO HYDROLOGY, GROUNDWATERFLOW)



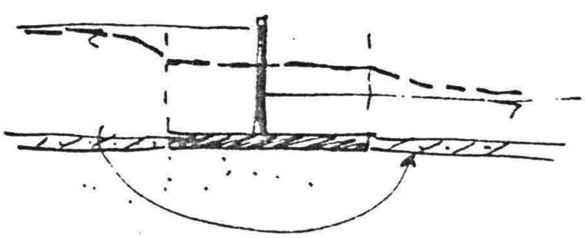
$z = z_0 e^{-x/\lambda}$

$\lambda = \sqrt{kD.c}$

CASE 2.

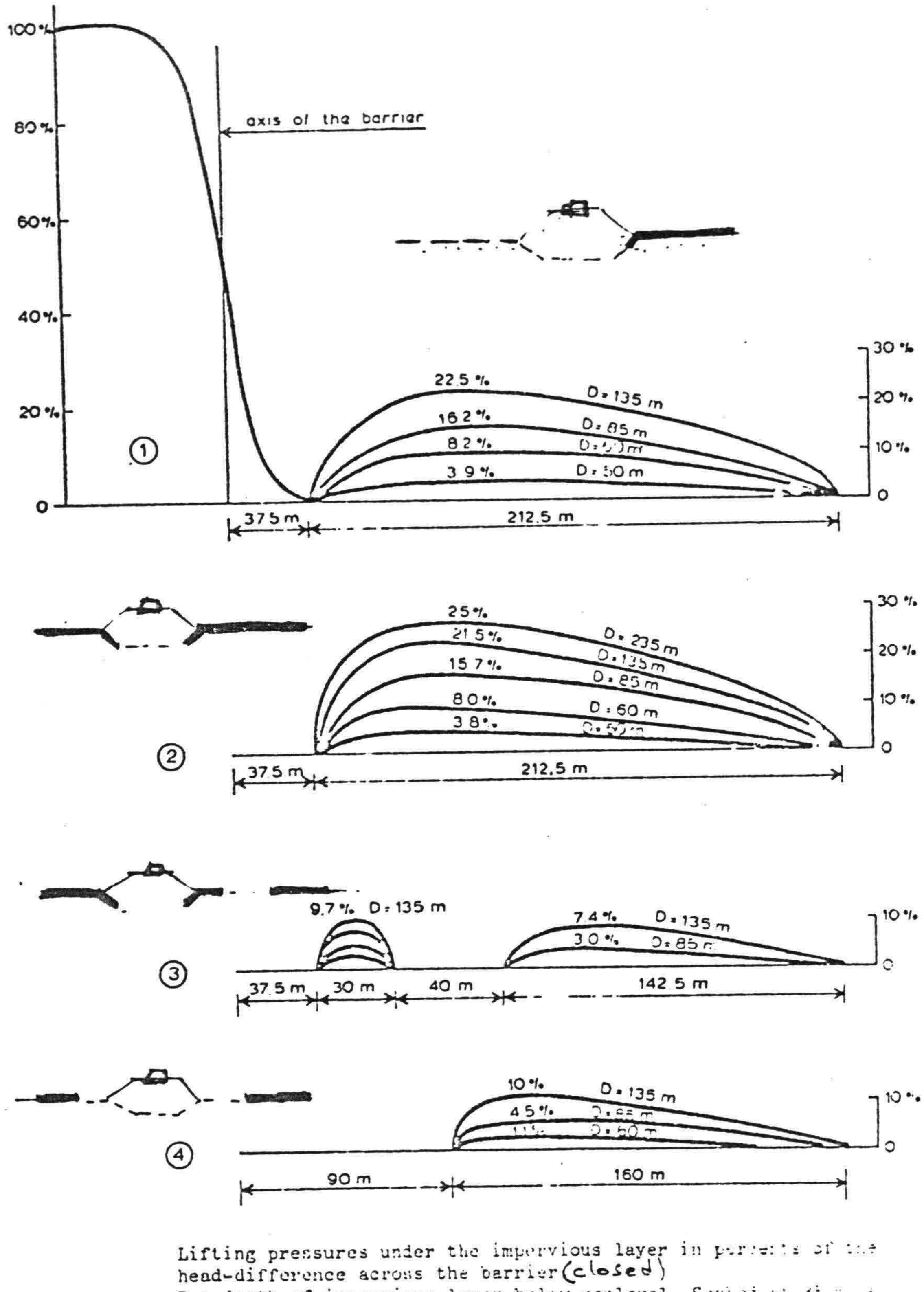


CASE 3.

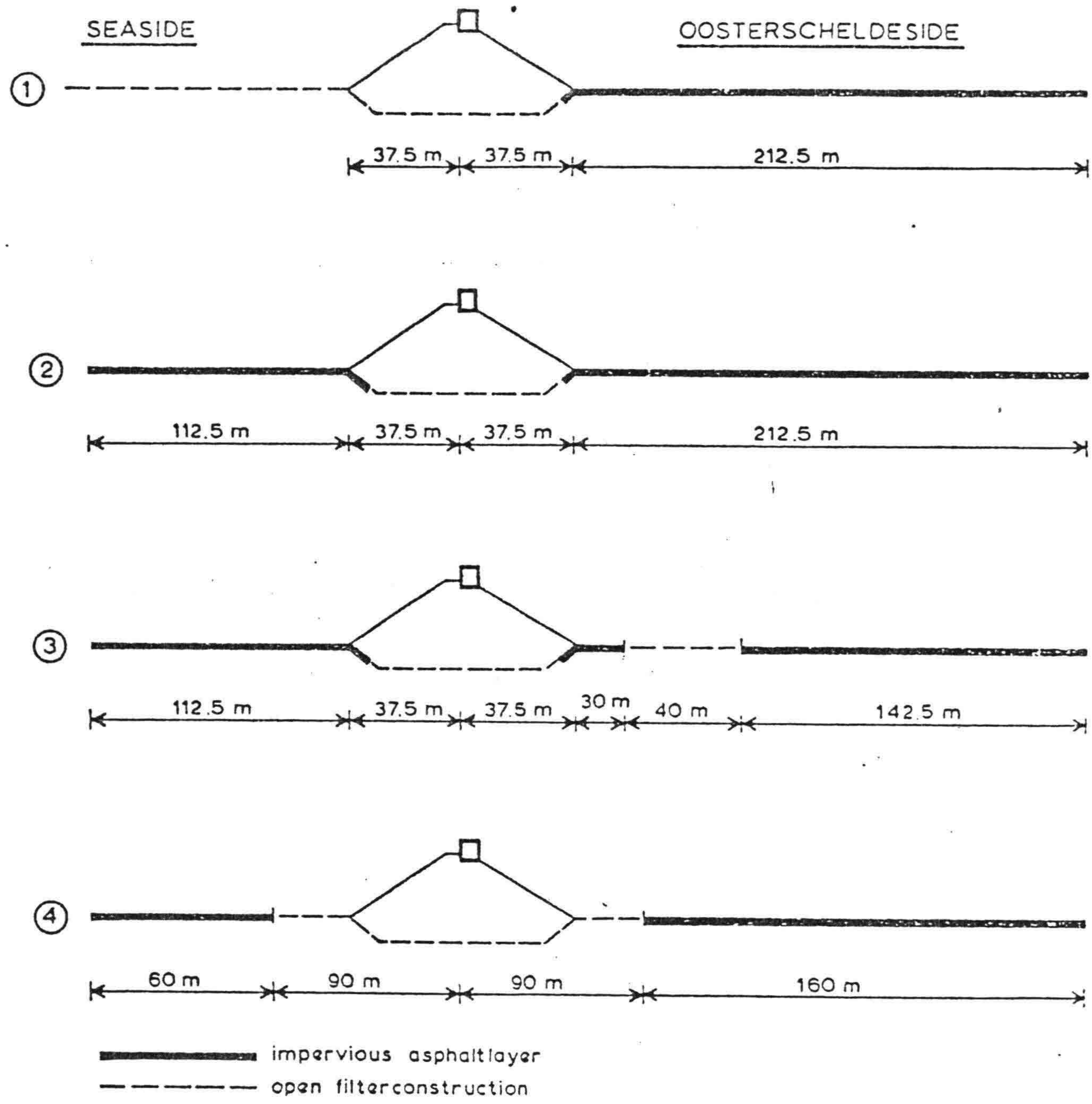


ETC. → COMPLEX SITUATIONS: - ELECTRICAL ANALOGUE

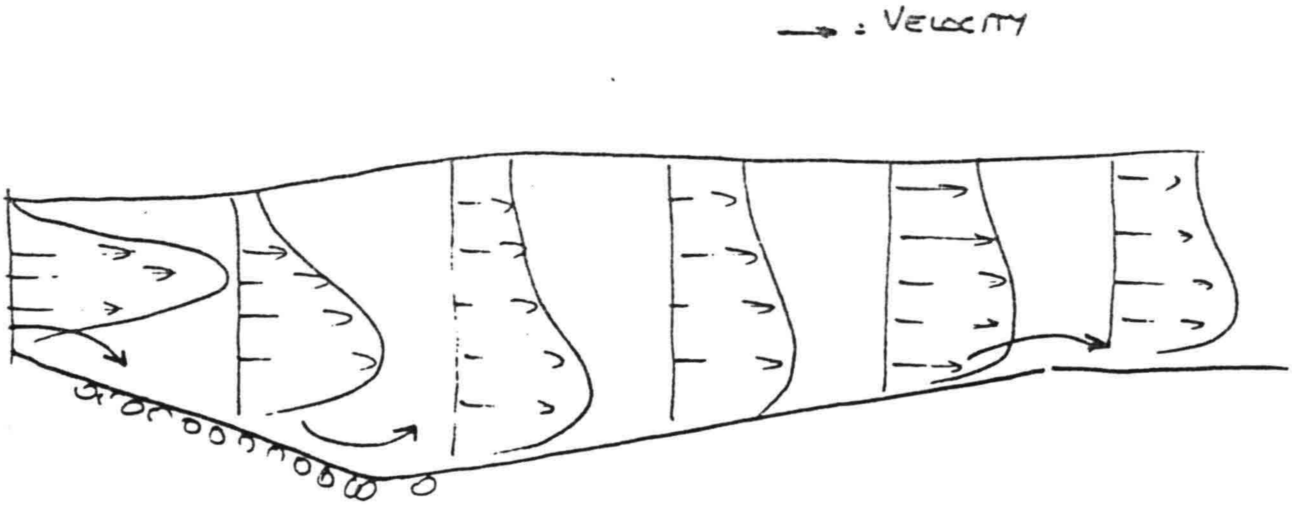
- NUMERICAL SOLUTIONS

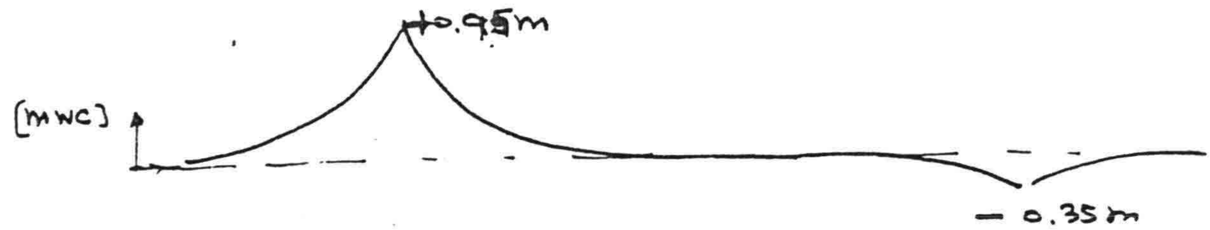


Lifting pressures under the impervious layer in [illegible] of the head-difference across the barrier (closed)
D = depth of impervious layer below sealevel. [illegible] sealevel.

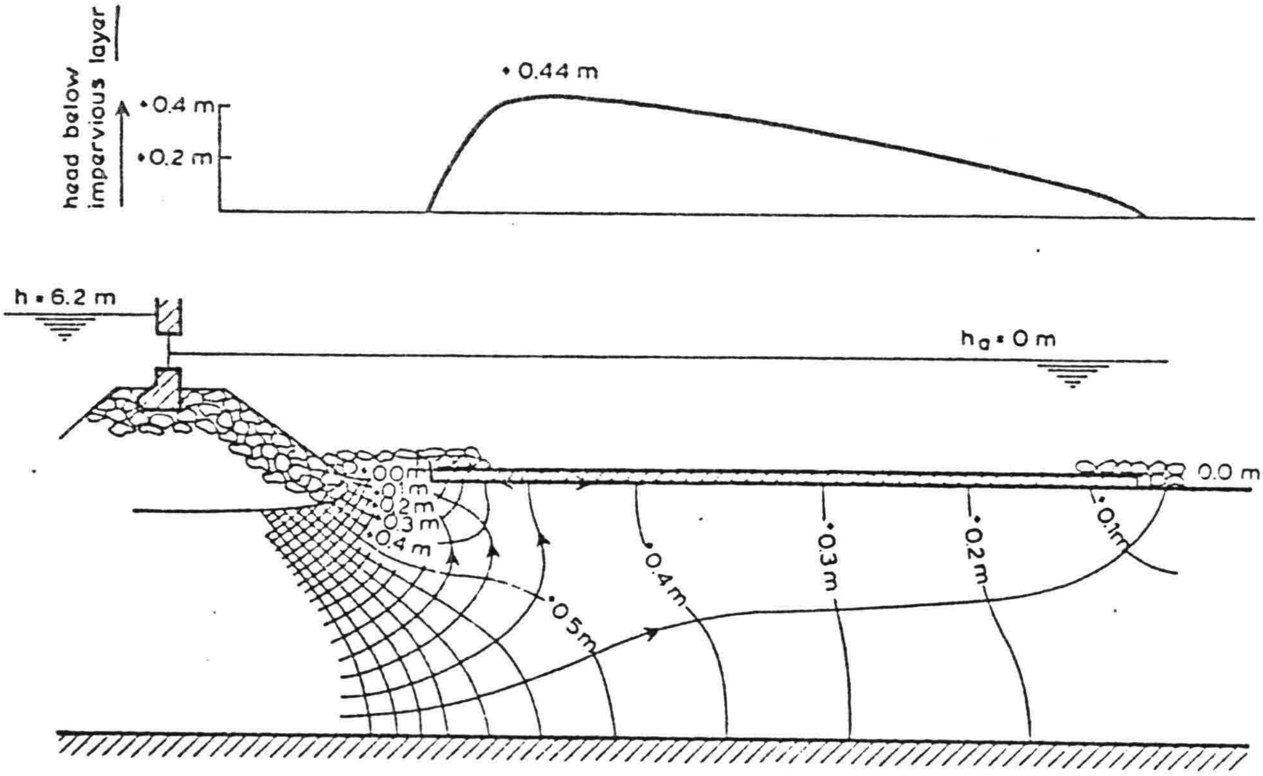


ALTERNATIVES FOR APRON GEOMETRY



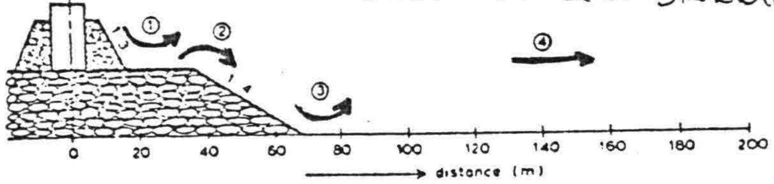


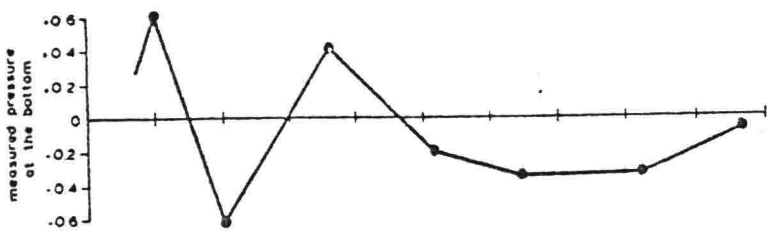
DEVIATION FROM HYDROSTATIC PRESSURE AT THE BED



Pattern of flow-lines and equi-head-lines.

FAILING GATE : THERE IS A POSSIBILITY THAT ONE OR MORE GATES OF THE BARRIER ARE FAILING. THIS CASE CAUSES RATHER SEVERE HYDRAULIC CONDITIONS FOR THE APRON, DIFFERENT FROM THE CASE "CLOSED BARRIER"





Pressure-head pattern, measured in a flume.

ZONE 1: HIGH PRESSURES CAUSED BY ↺ STREAMLINES
2: LOW PRESSURES CAUSED BY ↷ STREAMLINES
3: HIGH " " " ↺ "
4: HYDROSTATIC PRESSURES → "

§ STRUCTURAL ASPECTS _

DESIGN, EXECUTION OF REVETMENTS IN TIDAL ESTUARIES

IN GENERAL:

ELEMENTS THAT ARE DETERMINING FOR THE EXECUTION METHOD AND CONSEQUENTLY FOR THE DESIGN OF REVETMENTS IN A LARGE EXTENT ARE:

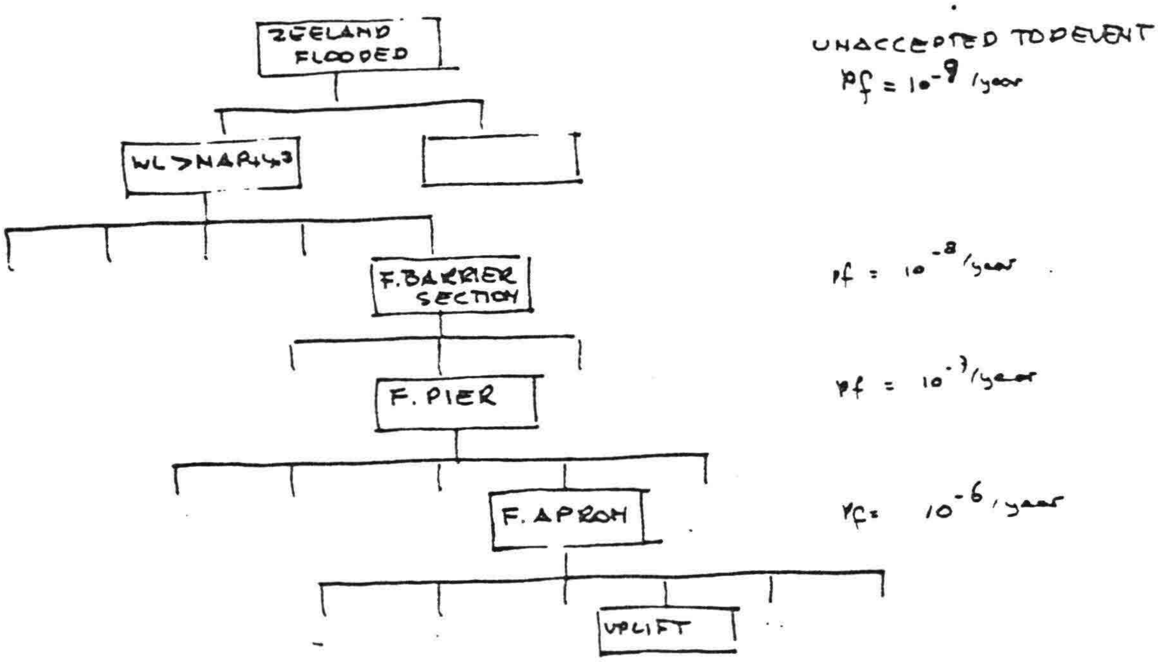
- EXECUTION TIME

AVAILABILITY OF:
- MANPOWER
- SKILLED LABOUR
- MENTALITY OF LABOUR
- MENTALITY OF SOCIETY (LAWS, CODES, REGULATIONS, CUSTOMS, POLICY IN EMPLOYMENT OF INLAND MATERIALS AND LABOUR, ETC.)
- MATERIALS AND EQUIPEMENT
- METHOD OF FINANCE (YEAR BUDGET, PROJECT BUDGET, EXPORT OF FOREIGN CURRENCY, ETC)
- AUXILIARITIES:
  - LAND-, WATER-, AIR-, AND RAILWAYS
  - COMMUNICATION
  - MAINTENANCE FACILITIES
  - RESEARCH FACILITIES
  - (WORKING) HARBOURS
  - HYDROMETEO SERVICE
  - ETC

LOCAL (FUTURE) CONDITIONS
- HYDRAULIC
- GEOTECHNICAL
- METEOROLOGICAL
- SHIPPING, RECREATION
- LANDSCAPE, ENVIRONMENT
- ETC.

POSSIBLE FAILURE MECHANISMES OF THE APRON OF THE STORM SURGE BARRIER IN THE OOSTERSCHELDE · LIMIT STATES

- UPLIFT OF IMPERMEABLE ASPHALT LAYER DUE TO STATIC HEAD
- UPLIFT DUE TO WAVE (CYCLIC) ACTION
- OVERTURNING OVERLAPPING OF ASPHALT SHEETS BY CURRENT, NORMAL SITUATION
- OVERTURNING OF SHEET. AROUND PLACES WITH A LACK OF ASPHALT SHEETS
- OVERTURNING OF EDGE OF SHEET AFTER LOSS OF COVER STONE
- FATIGUE OF ASPHALT
- LOSS OF SANDTIGHTNESS / DESINTEGRATION OF ASPHALT OR UNDERLAYING LAYERS
- LOSS OF ASPHALT DUE TO COLD FLOWING OF ASPHALT



FAULTTREE S.S.B. OOSTERSCHELDE (INDICATIVE)

FOR "SMALL" REVE[illegible] (NO BREAKWATERS ETC) THE GRADIENT IN THE UPPERLAYER AND OVER THE INTERFACE WILL BE RATHER SMALL AND OF SHORT DURATION. DUE TO VARYING WATERLEVELS (TIDES) AND WAVE ACTION THIS BEACH TYPE REVETMENTS WILL DEFORM. THE PROFILE, - IF DESIGNED IN THE RIGHT WAY - WILL TEND TO AN "EQUILIBRIUM PROFILE"

DESIGNING SUCH A GRAVEL BEACH THE TWO MAIN QUESTIONS ARE: 1) OPTIMUM THICKNESS OF LAYER AND 2) OPTIMUM SLOPE

TO GENTLE — OPTIMUM, MINIMUM EROSION AND ACCRETION — TO STEEP

DHL* STUDIED THE PHENOMENA, CHARGED BY RWS AND PUBLISHED THE RESULTS IN LAB. PUBL. AND ALSO IN THE PROC. OF COASTAL ENG. CONGR. 1978, pg 939 etc: "EQUILIBRIUM PROFILES OF COARSE MATERIAL UNDER WAVE ATTACK", v. Hijum. THE SHAPE OF THE EQUILIBRIUM PROFILE IS DETERMINED BY:

1. THE EXTERNAL PARAMETERS (H_o, L_o, T, h, k, $tg\alpha$, D)
2. THE INTERNAL PARAMETERS (GEOMETRY OF PROFILE)

---

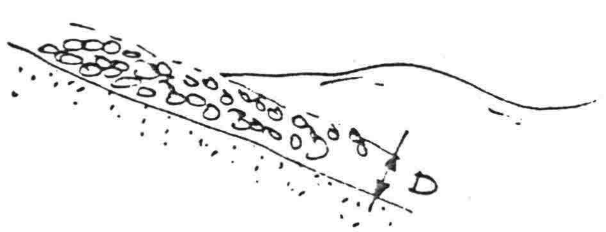
* DHL = Delft Hydraulics Laboratory

WHEN THE BED OR BANK IS ATTACKED BY CURRENT AND WAVES SCOURING CAN OCCUR. AS ALLREADY HAS BEEN SHOWN THREE POSSIBILITIES ARE AVAILABLE TO WITHSTAND THIS THREAT:

1. DIMINISH THE LOAD (I.C. TO LEAD THE HIGH-CURRENT AWAY FROM BED, BANK ETC BY GEOMETRICAL MEASUREMENTS, GROYNES, JETTIES ETC.)
2. ENLARGE THE STRENGTH (I.C. "GLUE" THE SEABOTTOM, LARGER INDIVIDUAL BOTTOM PARTICES, LOWERING WATERPRESSURE (SUNCTION)).
3. MAINTENANCE (I.C. SUPPLETION)

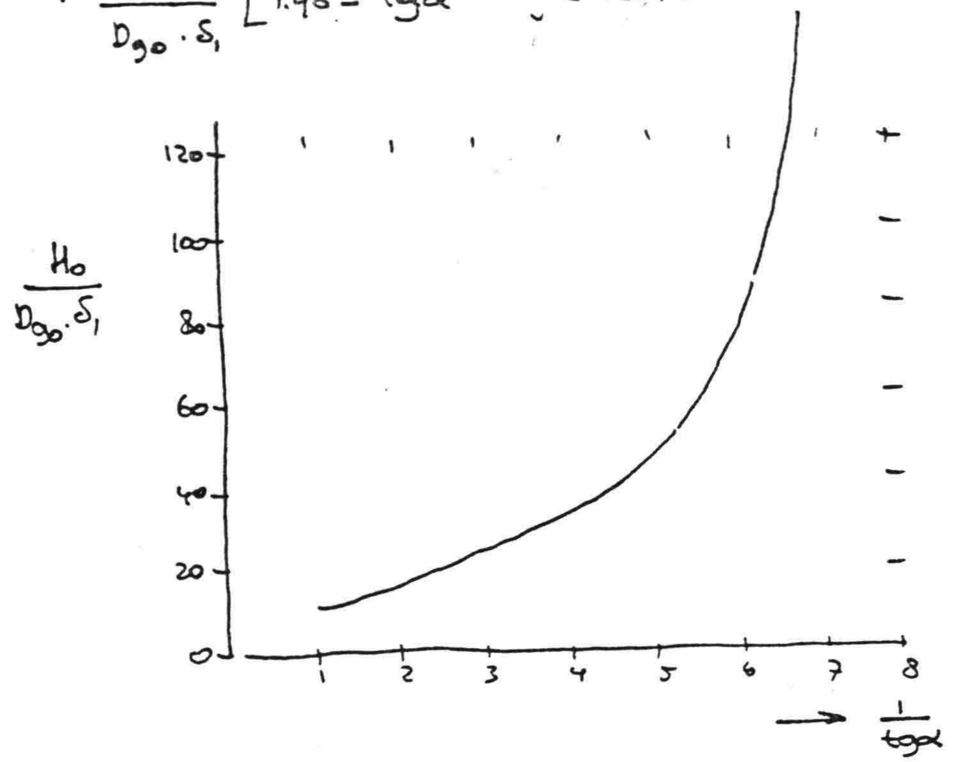
IN THIS CHAPTER ONLY THE 2nd SOLUTION WILL BE TREATED.

(1.) WHEN THE ATTACK BY CURRENT AND WAVES IS A LITTLE LARGER THAN THE "STRENGTH" OF THE ORIGINAL BOTTOM PARTICLES A LITTLE LARGER GRAINS CAN BE APPLIED. THIS SOLUTION GIVES A BEACHTYPE "REVETMENT".



ONE OF THE RESULTS IS THAT THE OPTIMUM <u>INITIAL SLOPE</u> CAN BE DETERMINED (WITHIN THE LIMITATIONS MENTIONED IN THE TEST REPORT)

$$: \frac{H_0}{D_{90} \cdot \delta_1} \left[1.98 - \tan\alpha\right]^{-1/37} = 12.48$$

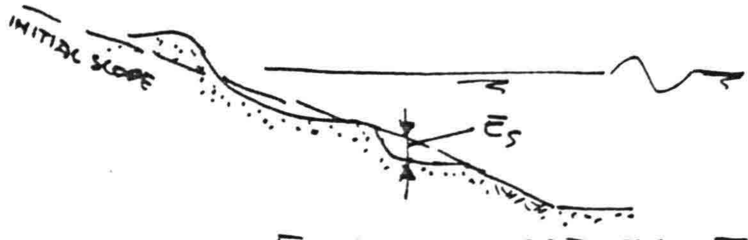


WHERE: H_0 = "DESIGN" WAVE HEIGHT (E.G. $H_{SIGNIFICANT} = H_{13\%}$)

D_{90} = 90% DIAMETER

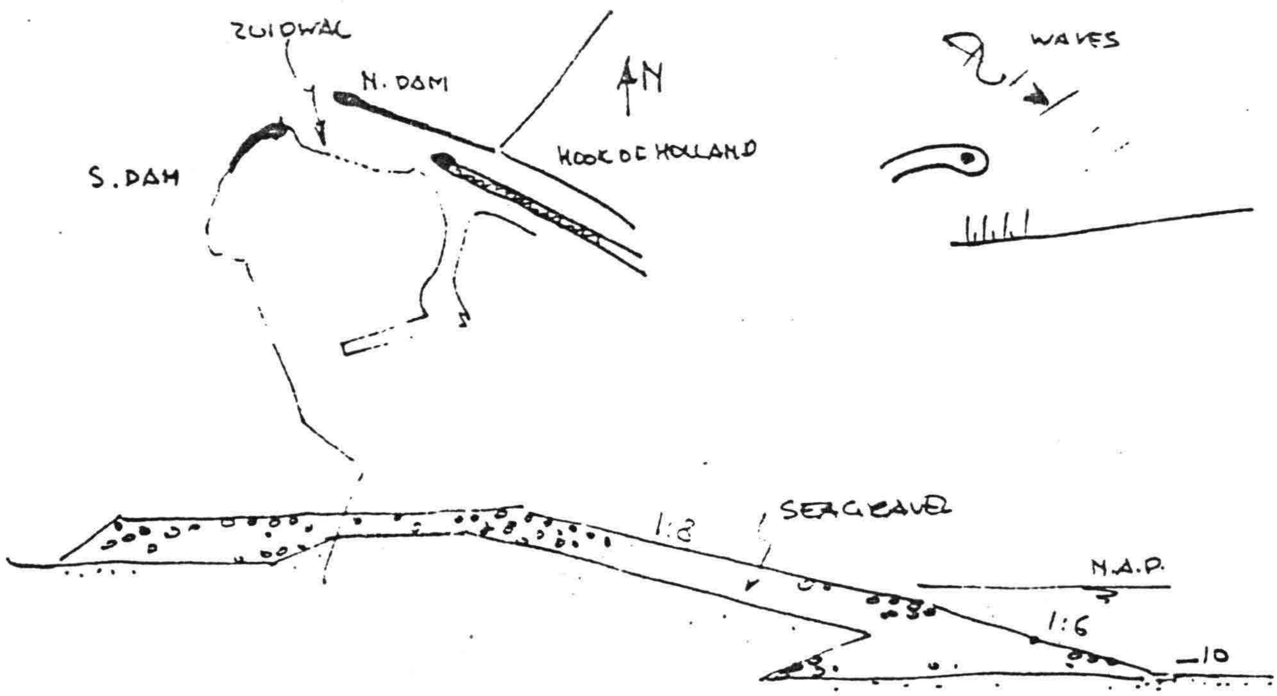
$\delta_1 = \sqrt{\frac{D_{90}}{D(\delta_1)}}$ $D(\delta_1) = 6 \times 10^{-3}$ (m) ; IF $D_{90} \geq 6 \times 10^{-3}$ THAN $\delta_1 = 1$

THE <u>THICKNESS OF LAYER</u> OF GRAVEL SHOULD BE SO THAT FREE PROFILE DEVELOPING CAN OCCUR. THE EROSION DEPTH MAY GIVE AN INDICATION WHAT THE THICKNESS SHOULD BE



WITH THE TEST RESULTS E_s CAN BE DETERMINED.
IT IS RECOMMENDED TO DIMENSION THE WHOLE GRAVEL LAYER WITH THIS THICKNESS AND APPLY A SAFETY MARGIN DUE TO VARYING WATERLEVELS (TIDES) AND LIMITATIONS OF TEST RESULTS

EXAMPLE: ZUIDWAL HOOK OF HOLLAND



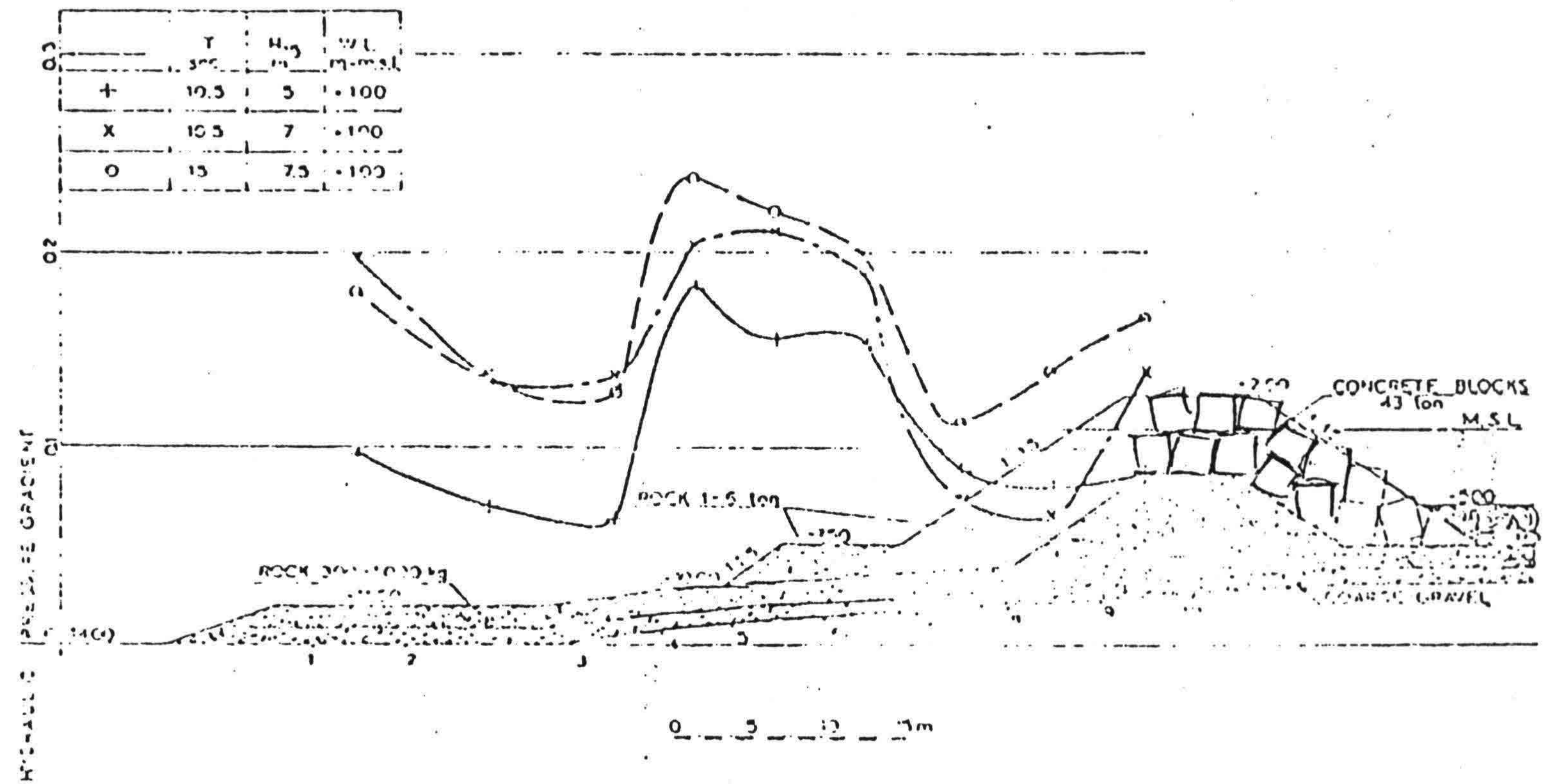
REQUIREMENTS TO THE "ZUIDWAL":

- LOW WAVE REFLECTION COEFFICIENT
- FLEXIBLE IN PLANNING
- SMALL CONSTRUCTION AREA (OTHERWISE SAND BEACH WAS POSS.)

$H_0 \sim 5$ (m) $D_{90} \sim 20 \times 10^{-3}$ (m) $\rightarrow$ $tg\alpha \sim 1:7$

THE EXPERIENCE AFTER CONSTRUCTION OF A "PILOT BEACH" WAS THAT DUE TO THE LONGSHORE CURRENT CAUSED BY THE WAVES THE PROFILE WAS ERODED MORE THAN COULD BE EXPECTED FROM THE MENTIONED TEST RESULTS (ONLY FOR PERPENDICULAR INCOMING WAVES).

ONE OF THE POSSIBLE SOLUTIONS WAS GRAVEL WITH LARGER DIMENSIONS, OR REDUCING THE LONGSHORE CURRENT BY GROINS (OPEN)



Hydraulic pressure gradients as observed in a model study of the Europoort breakwater

(2) WHEN THE ATTACK BECOMES ... GREATER THE PARTICLE SIZE SHOULD BE LARGER AND IT BECOMES A FILTER CONSTRUCTION

IT IS ALSO POSSIBLE TO CAGE THE GRAINS IN OR IRON CAGES (→ GABIONS) OR WILLOW CAGES (BUZZONI), OR FABRIC "CAGES" (GRAVEL SAUSAGE). (SEE FILM "GABBIONI MACCAFERRI")

EXAMPLE FILTER CONSTRUCTION AS REVETMENT IN FRONT OF THE BREAKWATER OF HOOK OF HOLLAND.

AS MENTIONED BEFORE THIS FILTERCONSTRUCTION WAS DESIGNED WITH THE RESULTS OF MODEL TESTS, WHERE THE GRADIENTS IN THE FILTER ARE THE LOAD ON THE CONSTRUCTION

"LOAD TESTS"

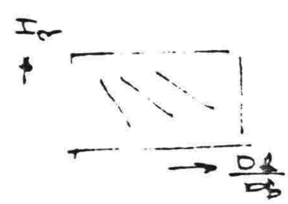
SEE FIG. NEXT PAGE

THE GRADIENTS ARE GENERATED BY WAVES. IN THE FIGURE THE 15% VALUES THAT WHERE MEASURED ARE GIVEN.

GRADIENTS OF 20 TO 30 % OCCUR

"STRENGTH TESTS"

SEE FIG.



(pg. 32)

THE RATIO $\frac{D_f}{D_b} \sim 10$. VARYING THIS FACTOR INTRODUCES A VARIATION IN PERMEABILITY AND CONSEQUENTLY A VARIATION IN GRADIENTS!

3. WHEN NON-COHAESIVE FILTERS ("GRAINS") CAN NOT BE USED DUE TO SILTY SUBSOIL, DEEP WATER, HIGH VELOCITIES DURING EXECUTION ETC. MATTRESSES ARE USED

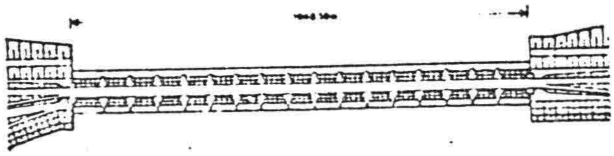
THESE MATTRESSES FULFIL THE FUNCTION OF FILTER: THE SPACE/ PORES BETWEEN THE FILTER ELEMENT(S) ARE SO SMALL THAT NO PARTICLES FROM THE SUBSOIL (BASE) CAN ESCAPE. (THE THICKNESS OF THE FILTER LAYER AND THE GRAINSIZE AFFECTS THE PERMEABILITY, SO THAT ALSO THE GRADIENT-PATTERN IN THE FILTER IS INFLUENCED).

THERE ARE MANY, MANY TYPES OF MATTRESSES (IN FACT IT IS A KIND OF A "GABION", CAGE FOR LOOSE MATERIAL) ALL TYPES HAVE IN COMMON:

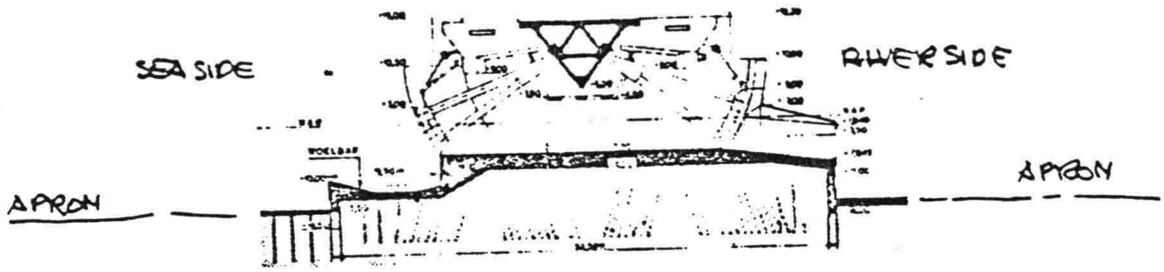
MAIN FUNCTION = PREVENTION OF ESCAPING PARTICLES FROM BASE

DEPENDING ON EXECUTION METHODS, AVAILABILITY OF (LOCAL) MATERIAL, EQUIPEMENT, SKILLED LABOUR ETC, ETC. ELEMENTS ARE ADDED TO THE MAIN FILTER ELEMENT:

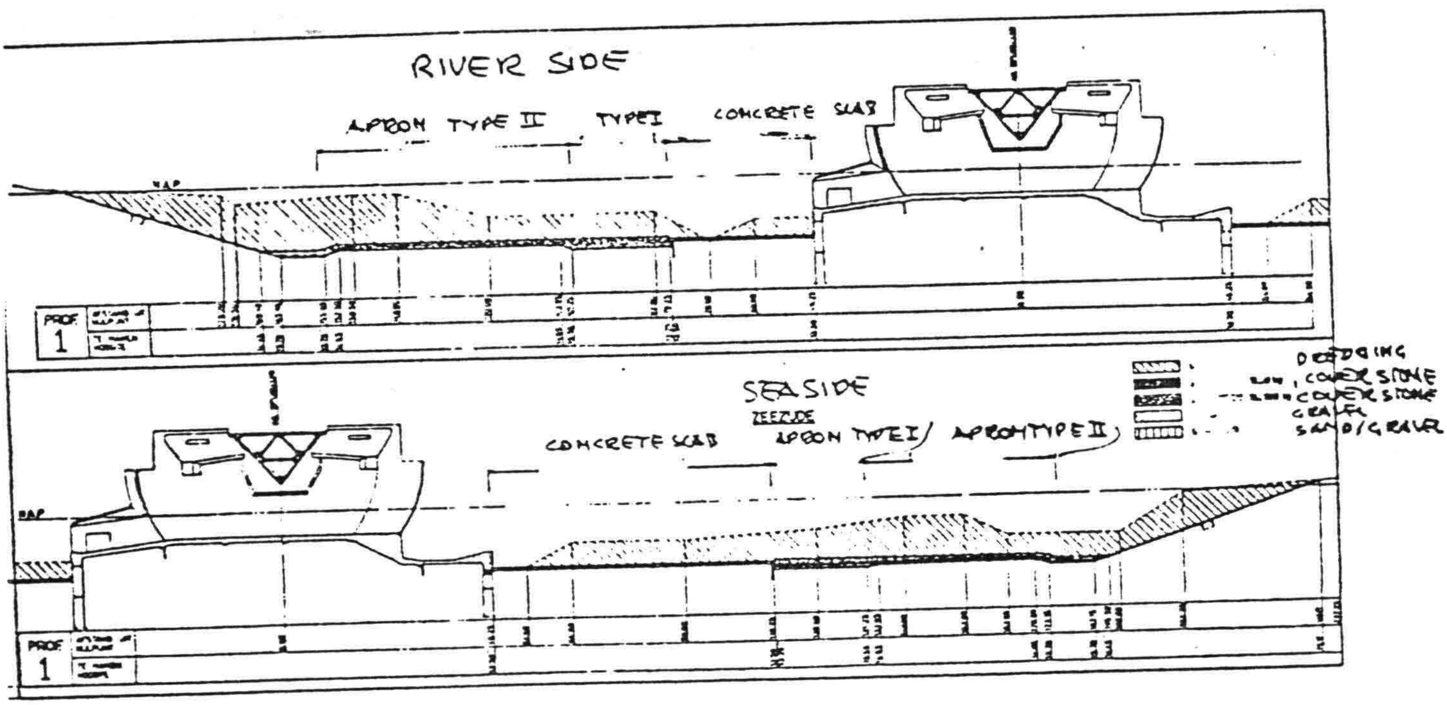
- FOR BOUYANCY : USUALLY FASCINE ROLLES, BRUSHWOOD ETC.
- FOR TRANSPORT (FORCES): ROPES, POLES, STEEL CABLES ETC.
- FOR BALLASTING : COVER STONES, "LOCKED" GRAVEL (SAUSAGES)



PLAN VIEW



HARINGVLIET SLUICES
CROSS SECTION



CROSS SECTION

REVETMENTS/APRONS

EXAMPLE

FILTERCONSTRUCTION IN THE APRON BEHIND HARINGVLIET SLUICES

THESE FILTERS WERE DESIGNED WITH THE WELL KNOW FILTERRULES, AS MENTIONED IN REV. 1

(I) SEASIDE TYPE, EXECUTION UNDERWATER

(II) HARINGVLIET SIDE TYPE, EXECUTION IN CONSTRUCTION PIT

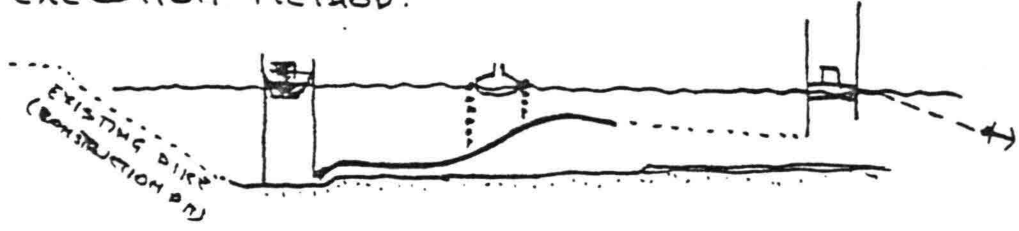
BOUNDARY CONDITIONS. 1, STABLE TOP LAYER (AGAINST WAVE AND CURRENT ATTACK)
2, STABLE SKELETON } FILTER
3, NO PENETRATION OF BASEMATERIAL

(I) TOP LAYER:

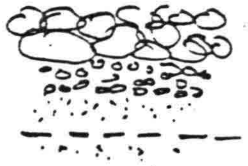
COVER STONE 300-1000 kgf, DETERMINED BY MODEL EXPERIMENTS.

1.2(m) 300-1000 kg, ϕ · 80 cm(~)
0.5m 10-40 kg, ϕ: 20cm (~)
0.35 30-80 mm
0.20 3-8 mm fabric
0.15 2-4 mm
SUBSOIL 0.1-0.2 mm

EXECUTION METHOD:



(II)



0.8, 10-300 kg ϕ: 40cm(~)
0.35, ϕ 30-80 mm
0.20 ϕ 3-8 mm - fabric
0.15 ϕ 2-4 mm
SUBSOIL 0.1-0.2 mm

EXECUTION METHOD: WITH TRUCKS AND CRANES

SLIDES:

THE SLIDES ARE ILLUSTRATIONS FOR THE "PILOSOPHY" THAT DEPENDING ON THE ABOVE MENTIONED ASPECTS OF AVAILABILITY OF EXECUTION TIME, SKILLED LABOUR ETC ETC AND THE LOCAL HYDRAULIC, GEOTECHNICAL- ETC. ETC. CONDITIONS

. . A CERTAIN TYPE OF REVETMENT IS THE MOST SUITABLE.

- CAISSON CLOSURE
- KORNWERDERZAND WILLOW MATTRES IN EX. } BED PROTECTION NECESSARY
- SANDBAG CLOSURE
- HARINGVLIET, APRON

WILLOW MATTRESS, STRUCTURE
WILLOW MATTRESS, BEGIN SINKING PROC. } MANY PEOPLE (IN SHORT TIME PERIOD) INVOLVED
WILLOW MATTRESS LAST SINKING STAGE

3x "MODERN" VERSION OF WILLOW MATTRESS } POLY PROB I.S.O. BRUSHWOOD FILTERCONSTR. (IND. TRIAL PRODUCTION)

2x BANK REV. ALSO MATTRES + POLYPR.

2x STONE DUMPING VESSEL } FEW PEOPLE ON (CONSTR.) SITE

BROUWERSHAVENSE GAT DAM

GABION

FILTER UNDERNEATH } "CAGED" PARTICLES/STONES

ASPHALT + DUMP. STONE / GABIONS

ASPHALT CONCRETE, EXEC. WITH SPECIAL EQUIP., NO FORELAND → NO. Heymans

2x SAND BAGS ARE ALSO "GABIONS", "CAGED MATERIAL

5x BLOCK MATTRESS } INDUSTRIAL PRODUCTION IN FACTORY AND ON SITE

CARDIUM - SPECIAL EQUIP. FOR COMPLEX SUBMARINE ACTIVITIES, FILTERC.

2x JAN HEYMANS,

6x LIMIT STATES

ONLY A FEW EXAMPLES OF A LIMIT STATE

1.

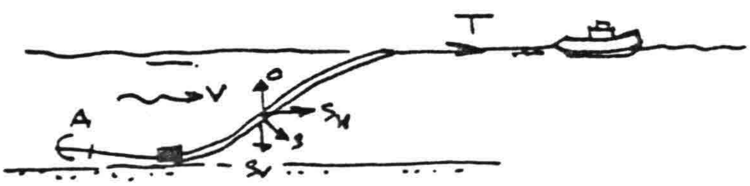
W=fN

THE MATTRES SHOULD NOT SLIDE ALONG THE SLOPE,
ONE OF THE QUESTIONS IS : WHAT IS THE FRICTION ANGLE?
THIS DEPENDS HIGLY ON: 1 QUALITY OF THE SUBSOIL
AND 2 TYPE OF MATTRES

	WILLOW MATTRES	MATT. WITH POLYPROPYLEEN UNDERNEATH
ON SAND	0.9	0.8
ON SILT	0.05	0.15

ESPECIALLY IN THE INITIAL FASE (JUST AFTER THE SINKING OPERATION) THE SITUATION IS MOST DANGEROUS DUE TO THE "SUDDEN" LOADING OF THE SUBSOIL.
(SEE ALSO REVETMENT 1, CHAPTER 3.3.)

2. DURING SINKING OPERATIONS:



A= ANCHORING FORCE
S= VELOCITY PRESSURE
T= PULLING FORCE (REAR BARGE)
O= UPLIFT FORCE (BOUANCY)

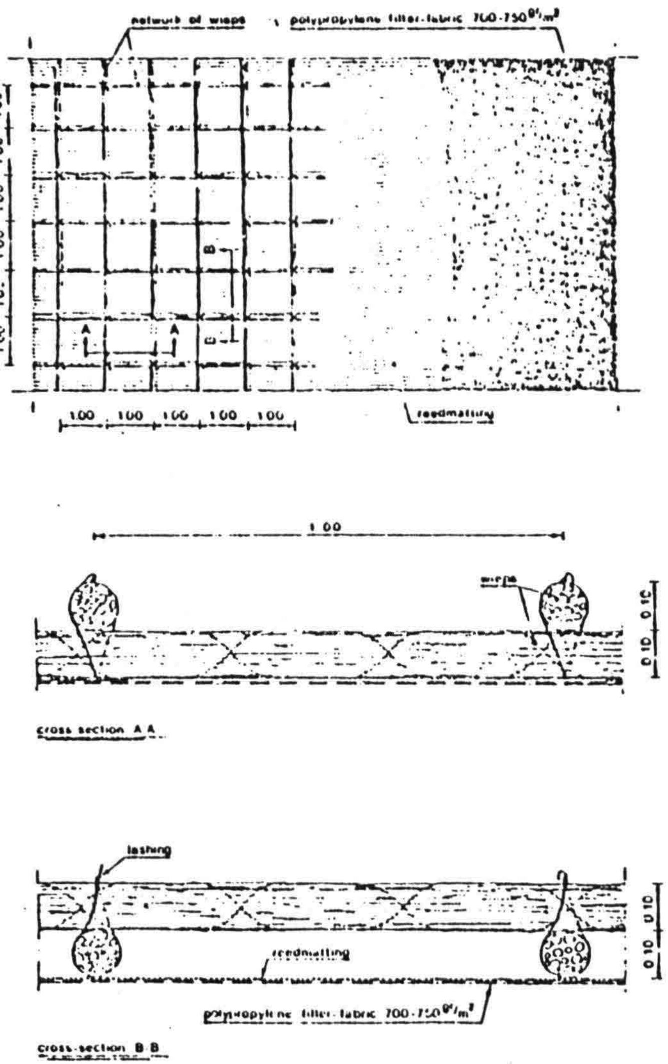
SEE NEXT GRAPH

- FOR "CAGING" COVER STONES : WATTLE WORKS
- FOR PREVENTION OF DAMAGE (DUE TO DUMPING STONES): BRUSHWOOD; (ADOBE) STRIPS ETC.
- FOR STRENGTH DURING SINKING OPERATION: STEEL CABLES, STRONG FABRIC ETC.
- FOR PREVENTION OF OVERTURNING EDGES: EXTRA BALLAST, OVERLAPS ETC.

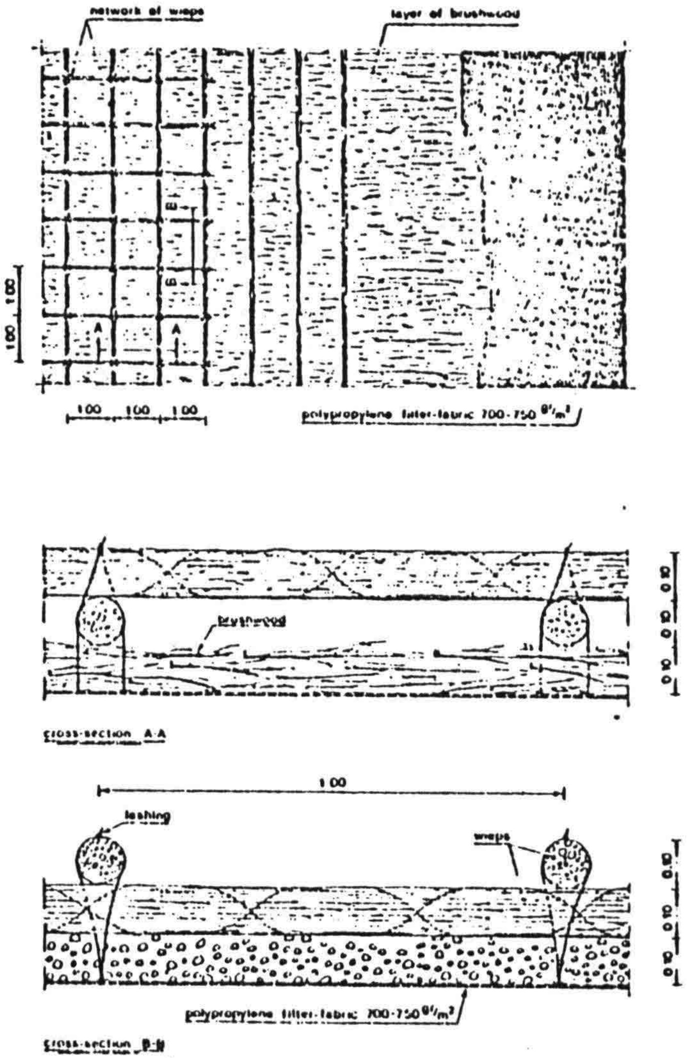
IN MANY TYPES THE FILTER GRAINS ARE NOT EVEN THERE AND THE CAGE IT SELF HAS TO FULFIL THE MAIN FUNCTION OF FILTERING. IN OTHER CASES THIS FUNCTION IS FULFILED BY REED, LEAFS OF PALMTREES ETC.

AS MENTIONED BEFORE, DESIGNING A CONSTRUCTION AND EXECUTION METHOD A THOROUGH ANALYSIS SHOULD BE CARRIED OUT, PREFERABLE WITH THE FAULTTREE AND EVENTTREE ANALYSIS, ALL POSSIBLE LIMIT STATES SHOULD BE STUDIED AS WELL FOR THE CONSTRUCTION AS FOR THE EXECUTION AS FOR THE AUXILIARITY EQUIPEMENT

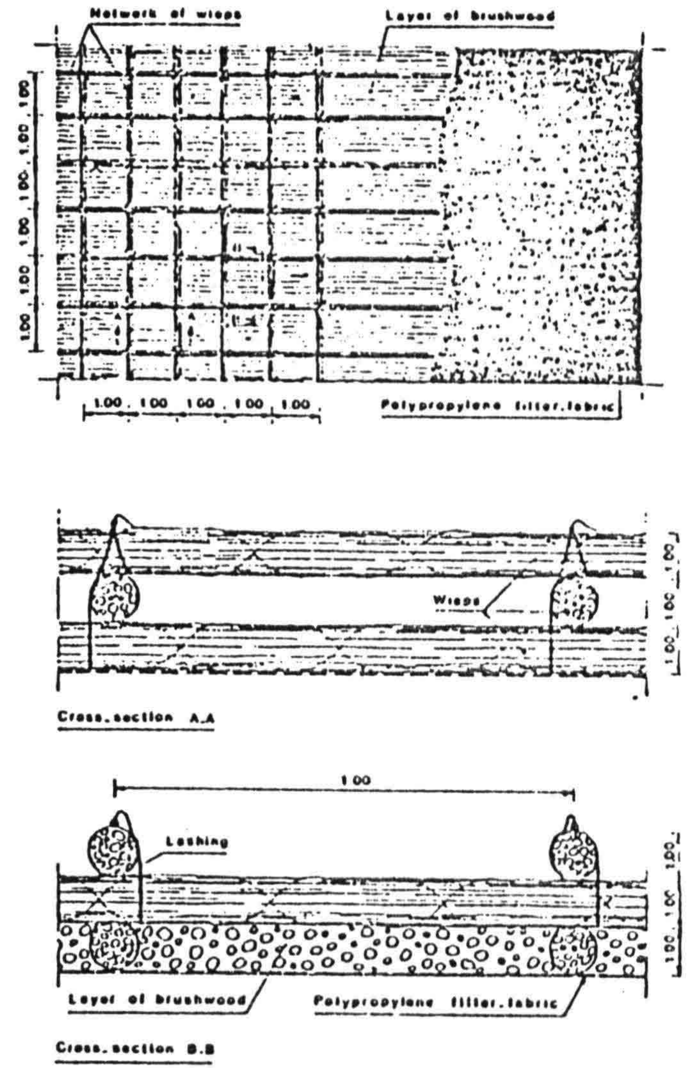
IN MANY CASES, ESPECIALLY WITH NEW TECHNIQUES, SIMULATION PROGRAMMES SHOULD BE CARRIED OUT FYSICALLY AND/OR MATHEMATICALLY MODELS.



MATTRESS OF POLYPROPYLENE FILTER FABRIC, REEDMATTING AND WIEPS

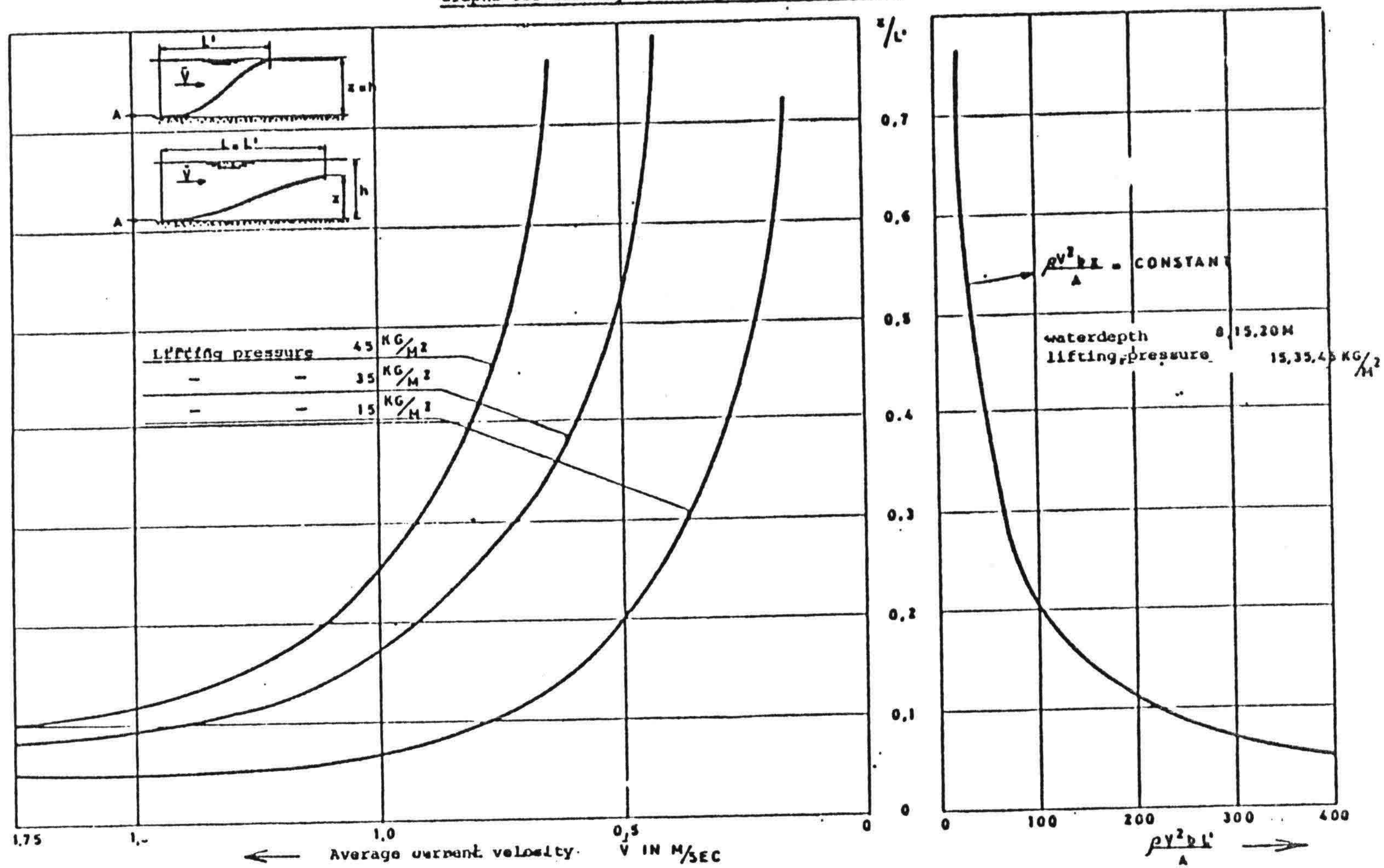


MATTRESS OF POLYPROPYLENE FILTER FABRIC BRUSHWOOD AND WIEPS



MATTRESS OF POLYPROPYLENE FILTER FABRIC WITH ONE LAYER OF BRUSHWOOD AND WIEPS

Graphs for sinking without pulling rear barge.



V – Average current velosity m/sec

z – Distance between the rear of the mattress and the bottom in m.

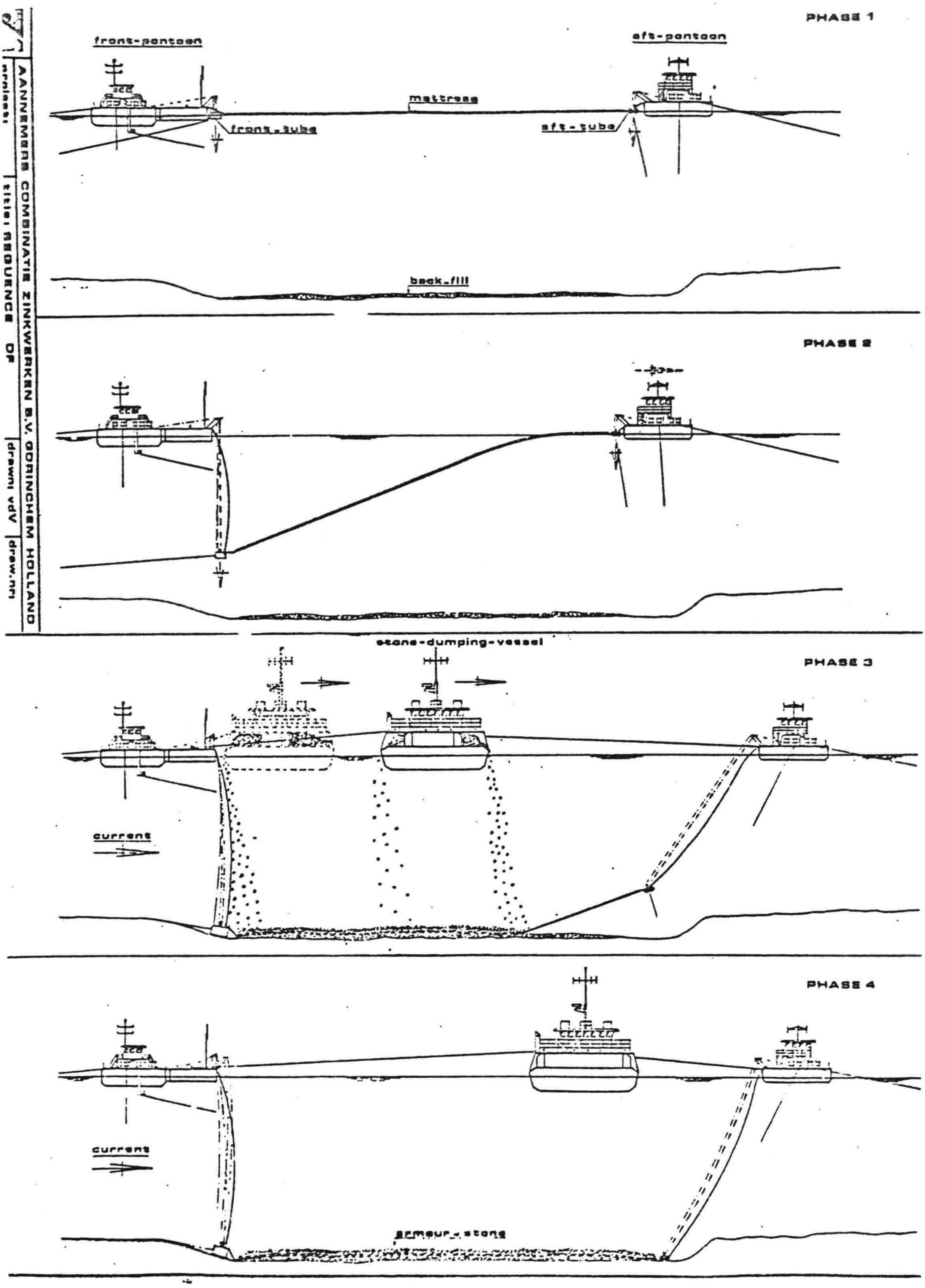
h – Waterdepth m

ρ – density of the water (= 1000 kg/m³)

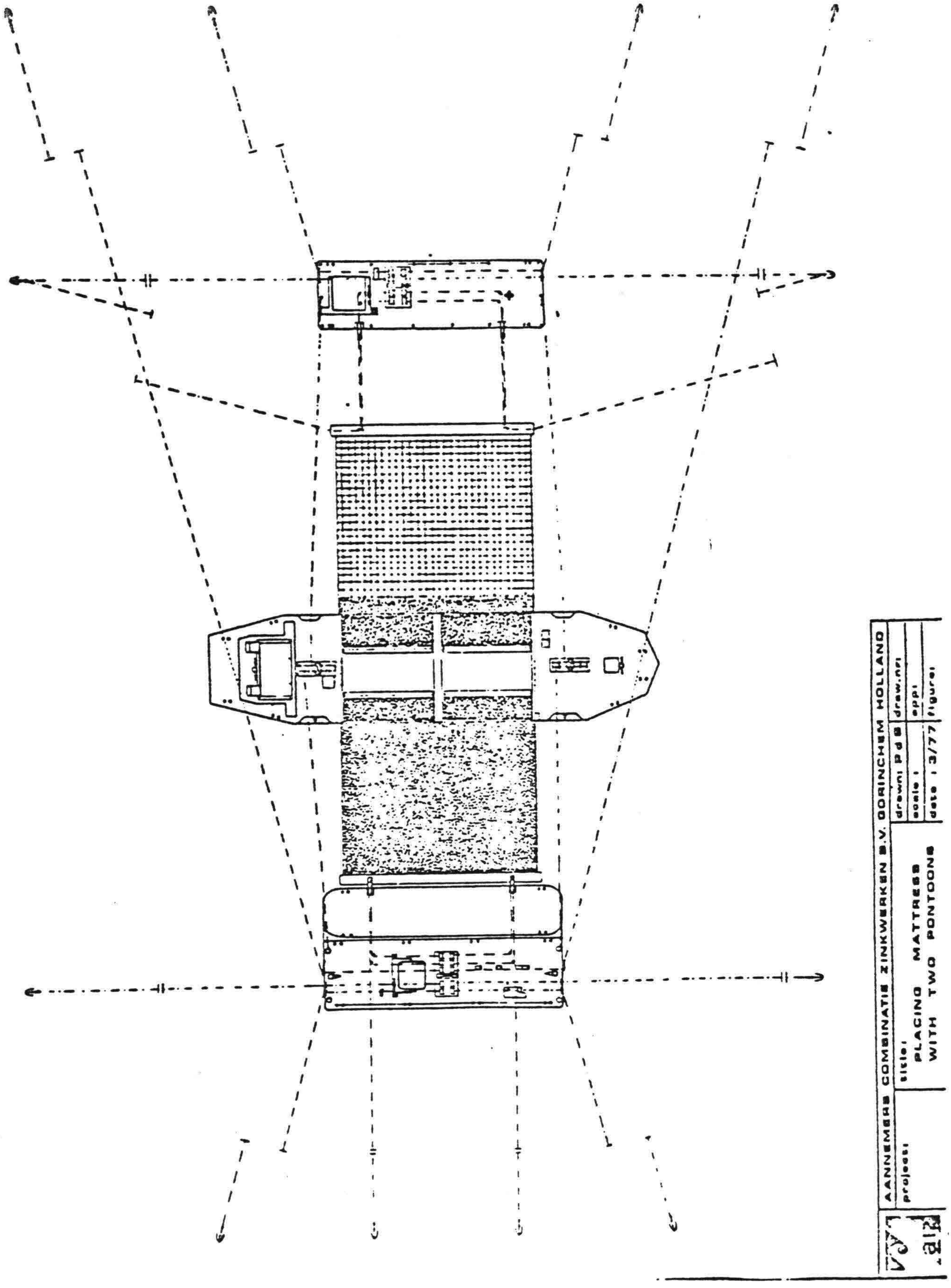
b – width of the mattress m

L' – horizontal projection of the underwater lenght of the mattress

A – anchor force kg

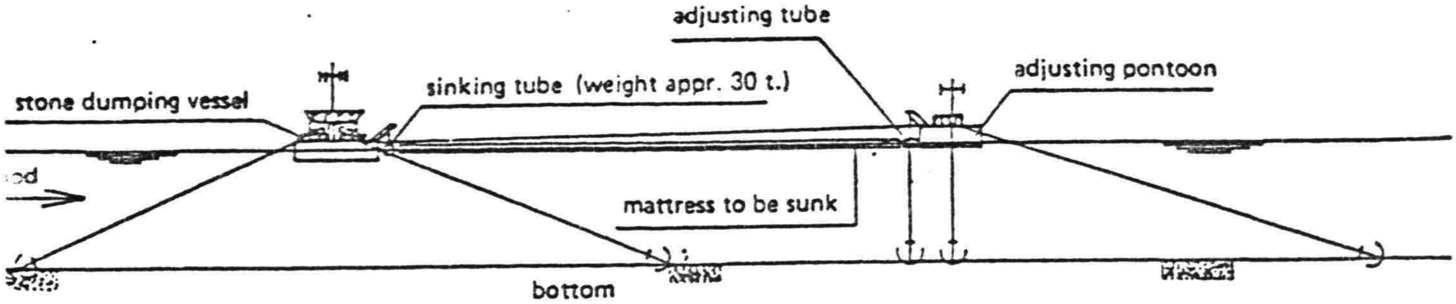


SYSTEM WITH FRONT AND REAR BARGE AND STONE DUMPER

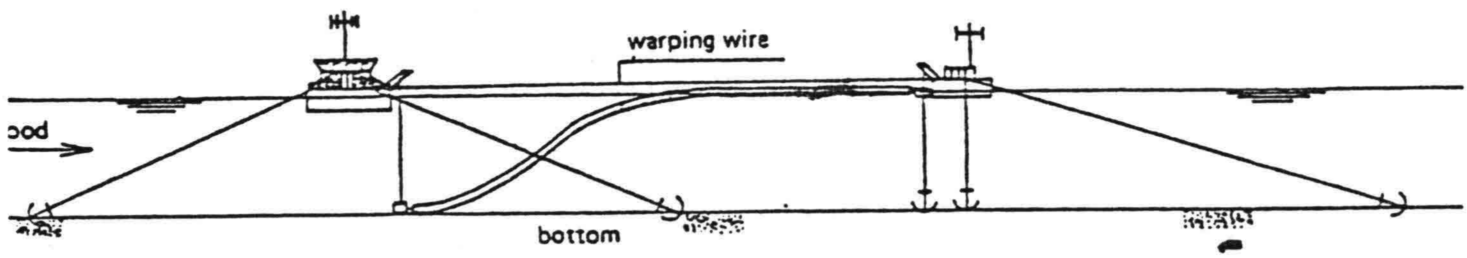


SYSTEM FRONT- AND REAR BARGE + STONE DUMPER

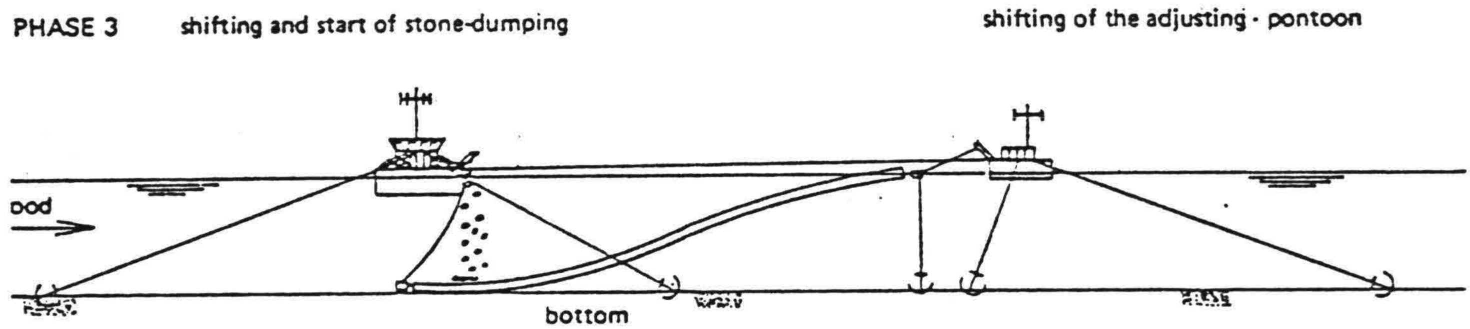
PHASE 1 equipment in position to start sinking



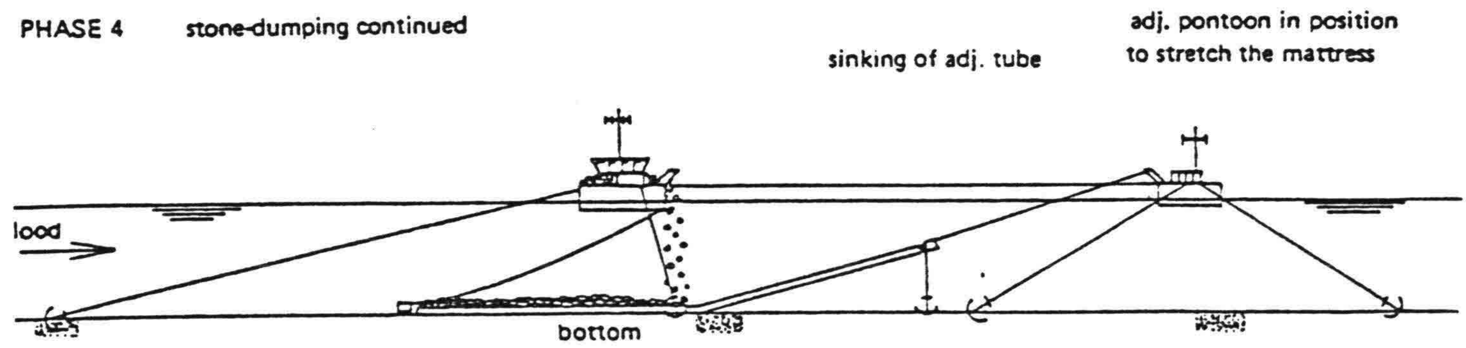
PHASE 2 sinking of the sinking-tube



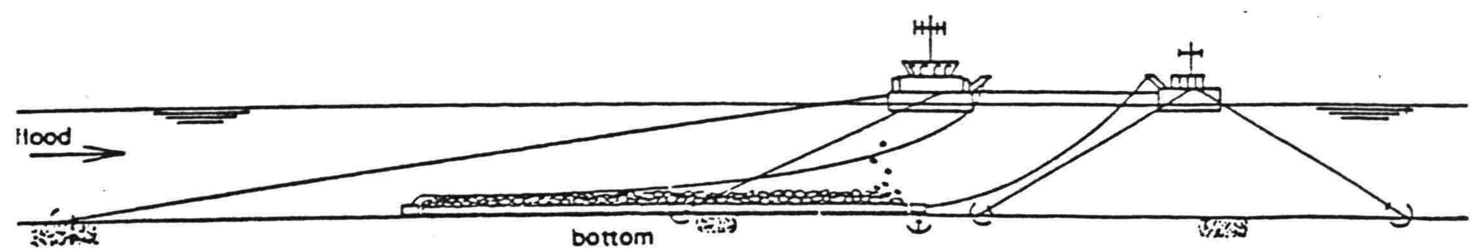
PHASE 3 shifting and start of stone-dumping



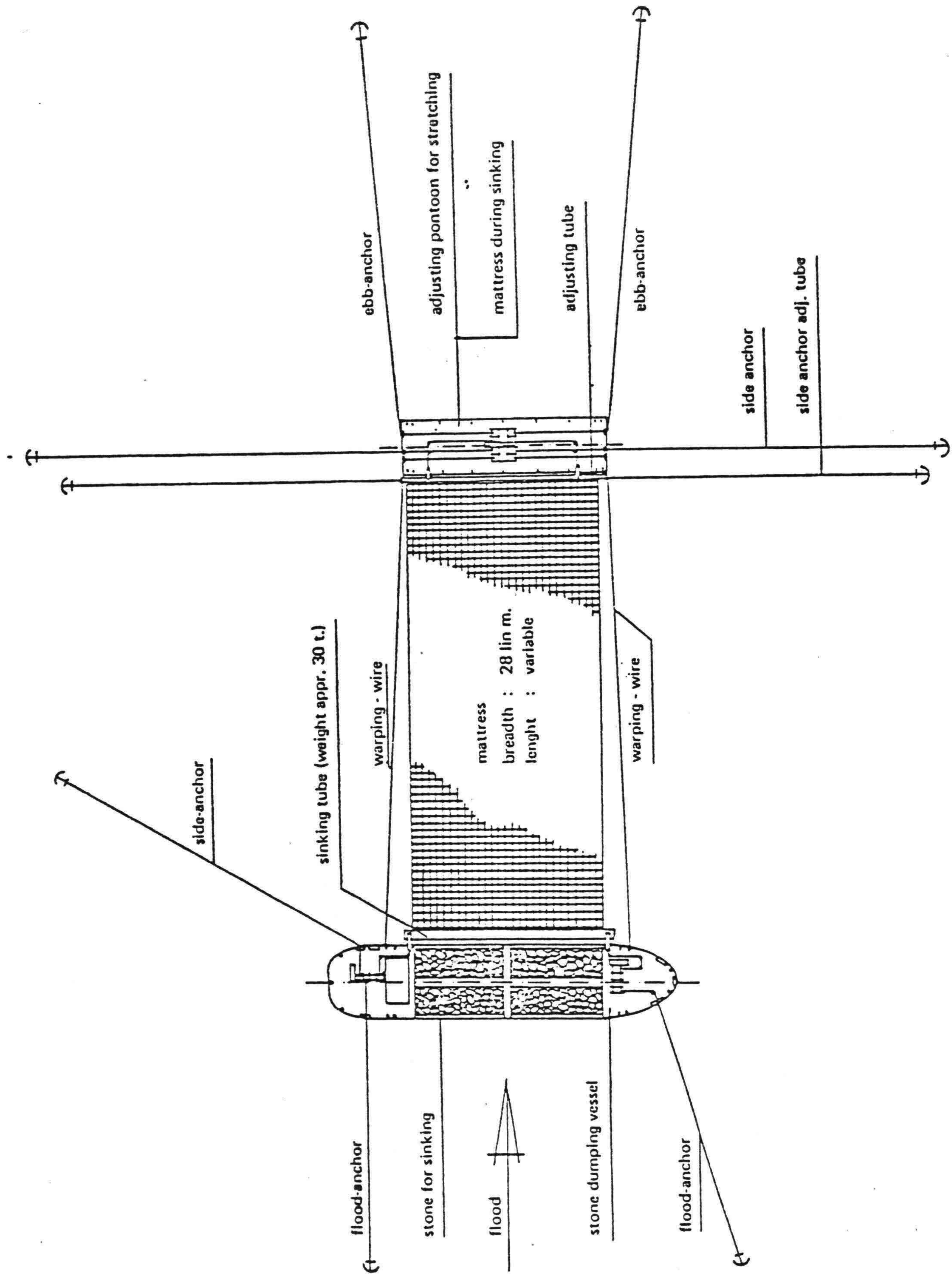
PHASE 4 stone-dumping continued



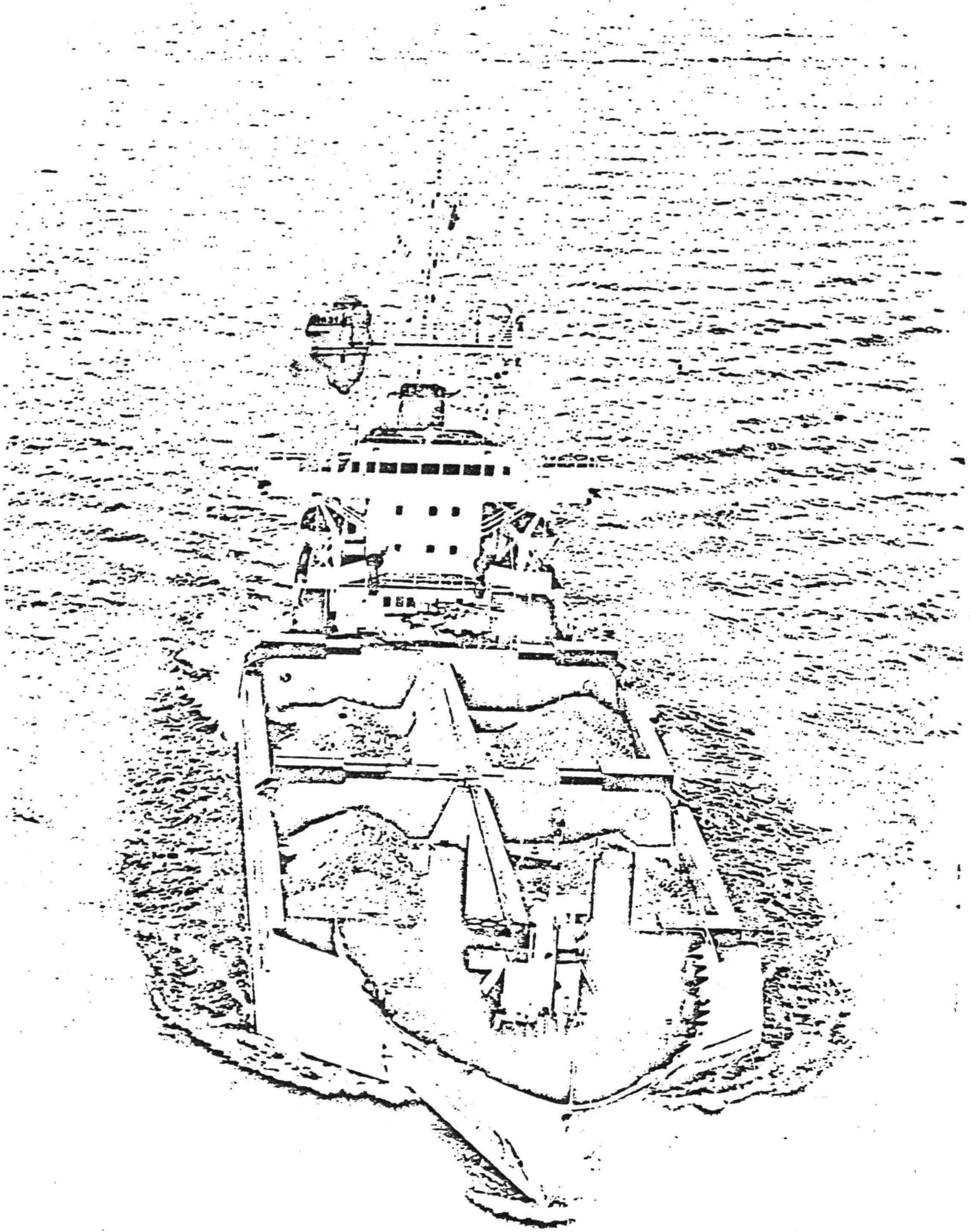
PHASE 5 sinking of mattress completed

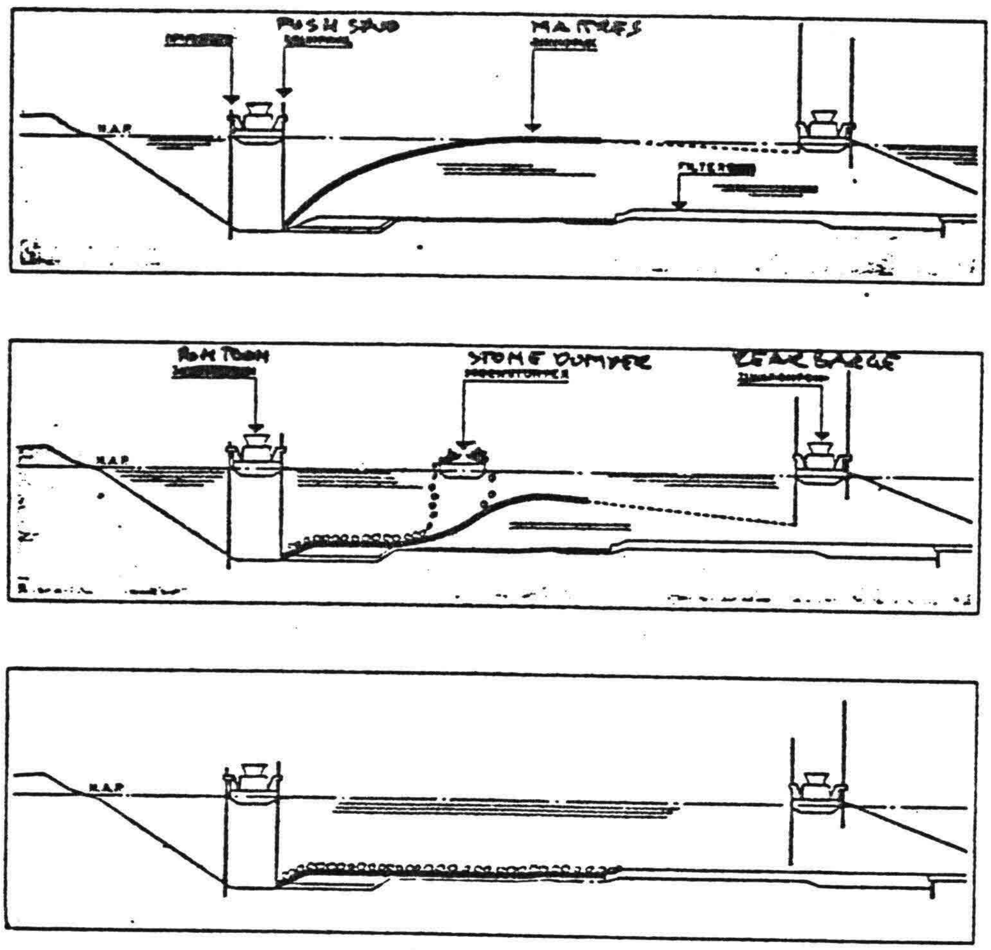


SYSTEM STONE DUMPER = FRONT BARGE



SYSTEM STONE DUMPER = FRONT BARGE
(2 VESSELS)

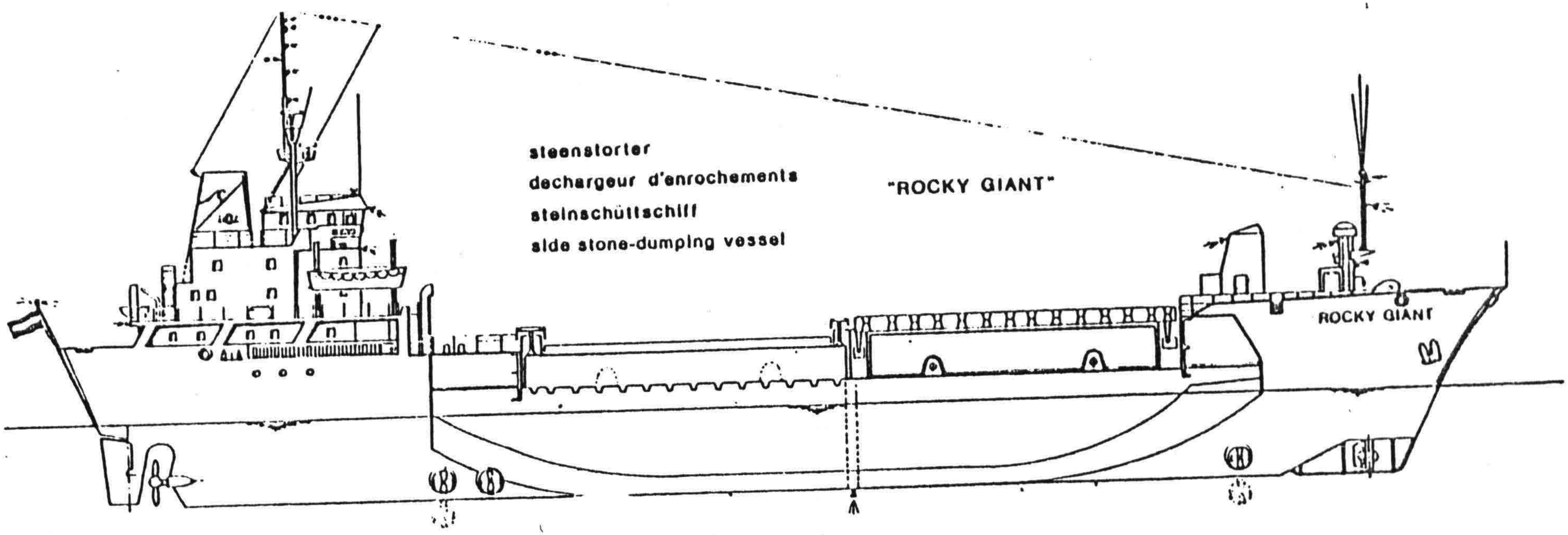


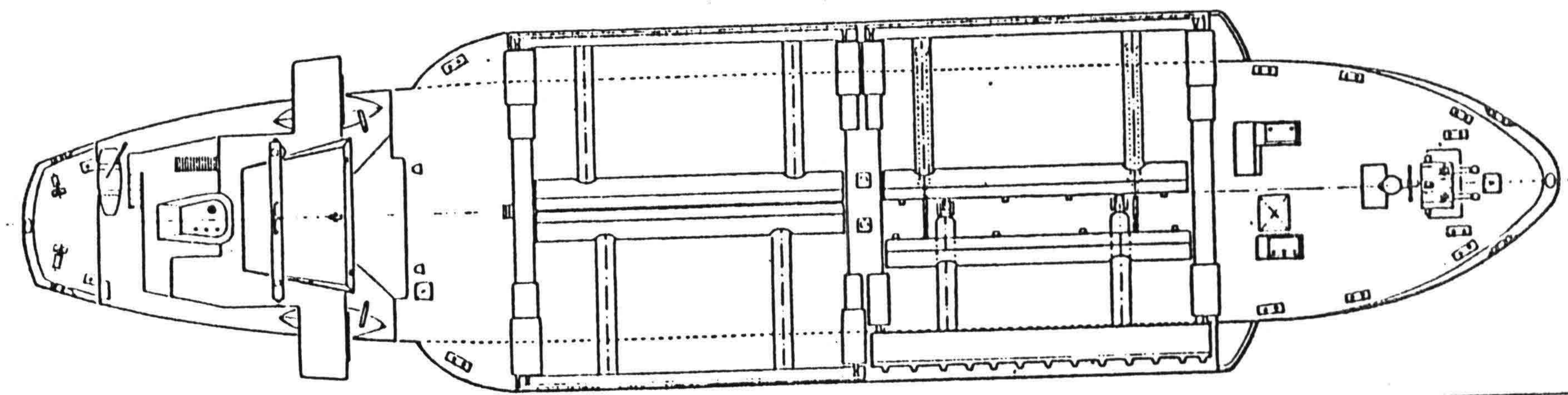


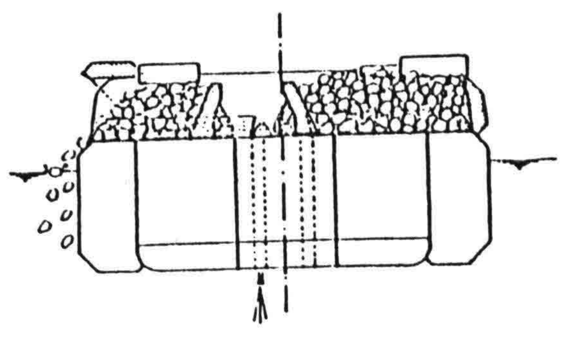
SYSTEM WHEN - THERE IS A LACK OF WORKING SPACE
- HIGH ACCURACY IS REQUIRED.

steenstorter
dechargeur d'enrochements
steinschüttschiff
side stone-dumping vessel

"ROCKY GIANT"



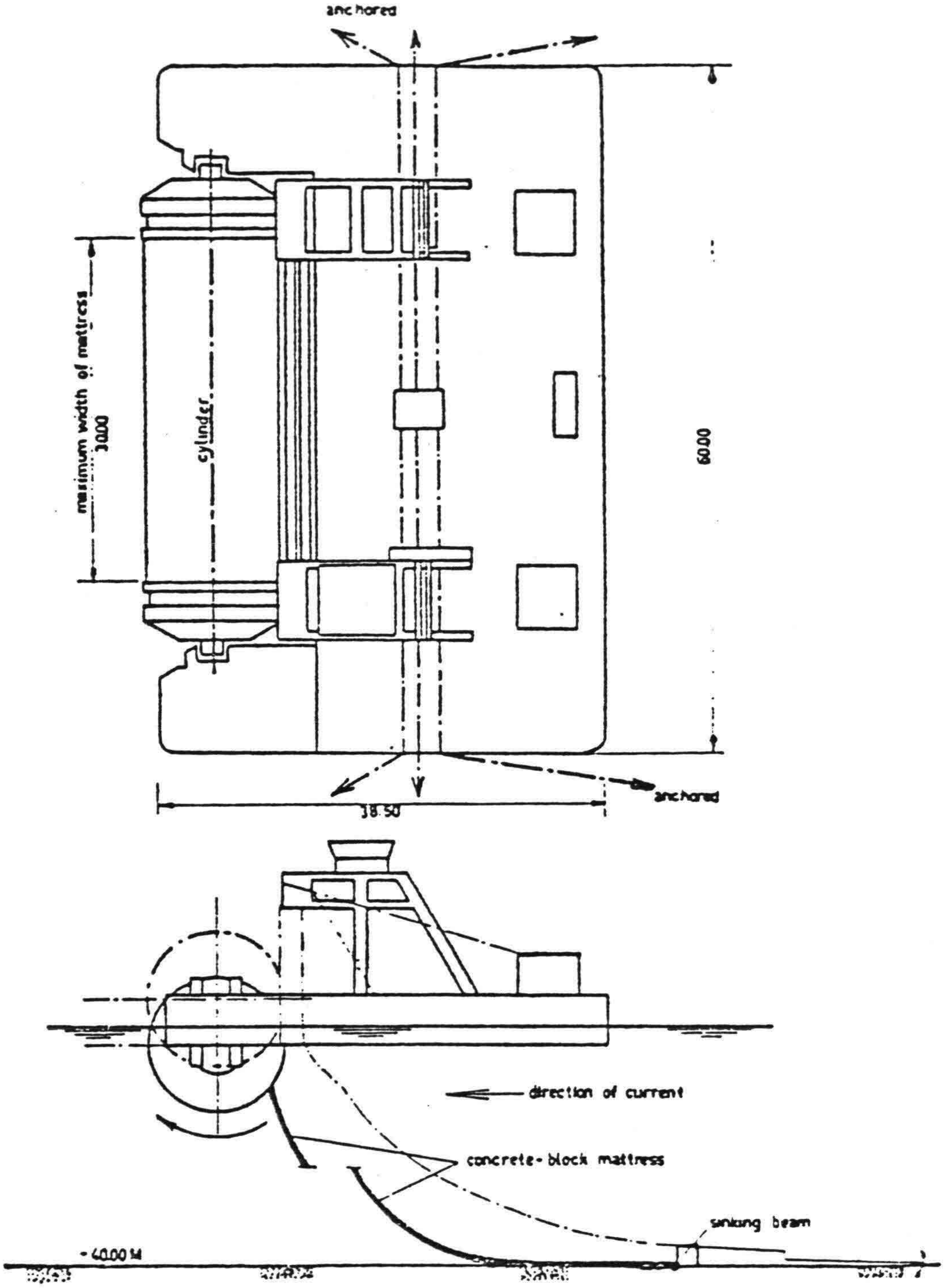




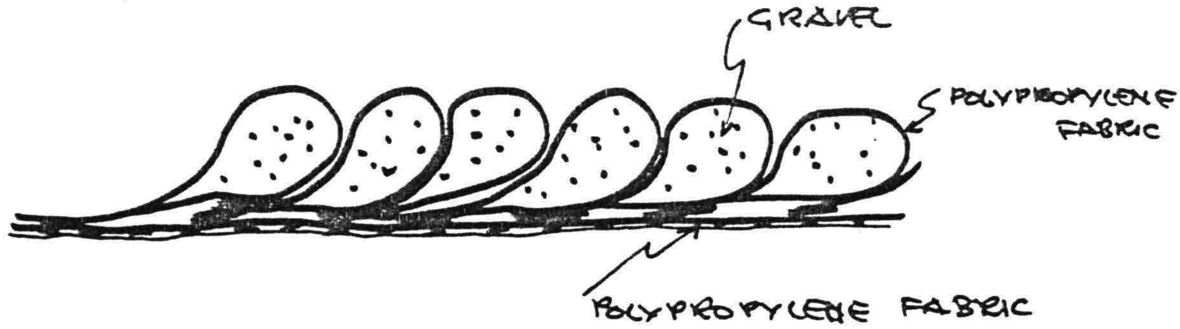
afmetingen	lengte o.a.	breedte o.a.	holte	diepgang geladen	tonnage	vermogen p.k.	voort-stuwing	dynamic positioning system pk.
dimensions	longueur h.t.	largeur h.t.	creux	tirant d'eau en charge	tonnage	puissance c.v.	propulsion	d.p.s. c.v.
abmessungen	länge g.l.	total breite	tiefe	tiefgang des geladenen schiffes	ladefähig-keit	leistung p.s.	propulsion	d.p.s. p.s.
dimensions	length o.a	beam	depth mld.	load draught	carrying capacity	power h.p.	propulsion	d.p.s. h.p.
	91.35 m	21.00 m	6.90 m	5.31 m	2500 t	2000	fixed propellor	4x050+ 1x2000

FOR SITUATIONS WERE THE LOCAL HYDRAULIC CONDITIONS ARE SEVERE, LESS TIME IS AVAILABLE, LARGE QUANTITIES OF BED PROTECTION ARE REQUIRED THE EXECUTION METHOD WILL BE A HIGHLY MECHANIZED ONE.
AN EXAMPLE OF SUCH A METHOD IS THE BLOCKMATTRESS, AS USED FOR THE OOSTERSCHELDE BARRIER. THIS BLOCK MATTRESS HAS CONCRETE BLOCKS MANUFACTURED AND FIXED ON A POLYPROPYLENE SHEET WHICH IS THE FILTERCONSTRUCTION. THE MATTRESS IS MANUFACTURED IN A FACTORY ON SHORE UNDER CONTROLLED CONDITIONS (HUMIDITY, TEMPERATURE ETC) AND PLACED ON THE SEA BED IN A SINGLE OPERATION, BEING UNROLLED FROM A LARGE DRUM CONNECTED TO A PONTOON. 3,5 MILLION m^2 HAVE BEEN LAID NOW IN THE OOSTERSCHELDE (SEE ALSO REVETMENTS 1)

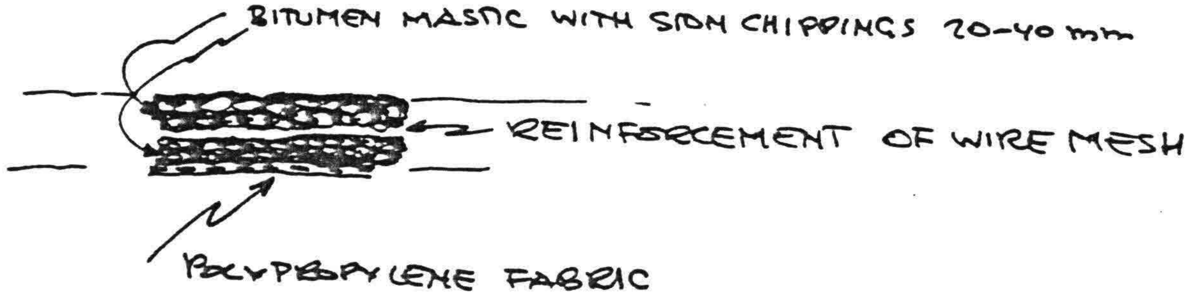
(4) THE ABOVE MENTIONED REVETMENTS WERE OF THE (CAGED) FILTER TYPE AND BALLAST TYPE (LOOSE OR FIXED BALLAST). A THIRD TYPE IS THE "GLUED TYPE". THE INDIVIDUAL GRAINS ARE GLUED TOGETHER WITH BITUMEN PRODUCTS. THERE ARE TWO MAIN GROUPS: PERMEABLE AND IMPERMEABLE CONSTRUCTIONS.
THE PERMEABLE CONSTRUCTIONS HAS A FILTER FUNCTION. IF THE PORES BETWEEN THE GLUED INDIVIDUAL GRAINS ARE TO LARGE A FILTER FABRIC CAN BE APPLIED, WHERE THE GLUED GRAINS GET A BALLASTING FUNCTION, BUT THE PERMEABILITY SHOULD NOT BE SMALLER IN THIS CASE. AN EXAMPLE OF THIS TYPE IS THE STONE ASPHALT MATTRESS



anchored
maximum width of mattress
30.00
cylinder
60.00
38.50
anchored
direction of current
concrete-block mattress
sinking beam
-40.00 M



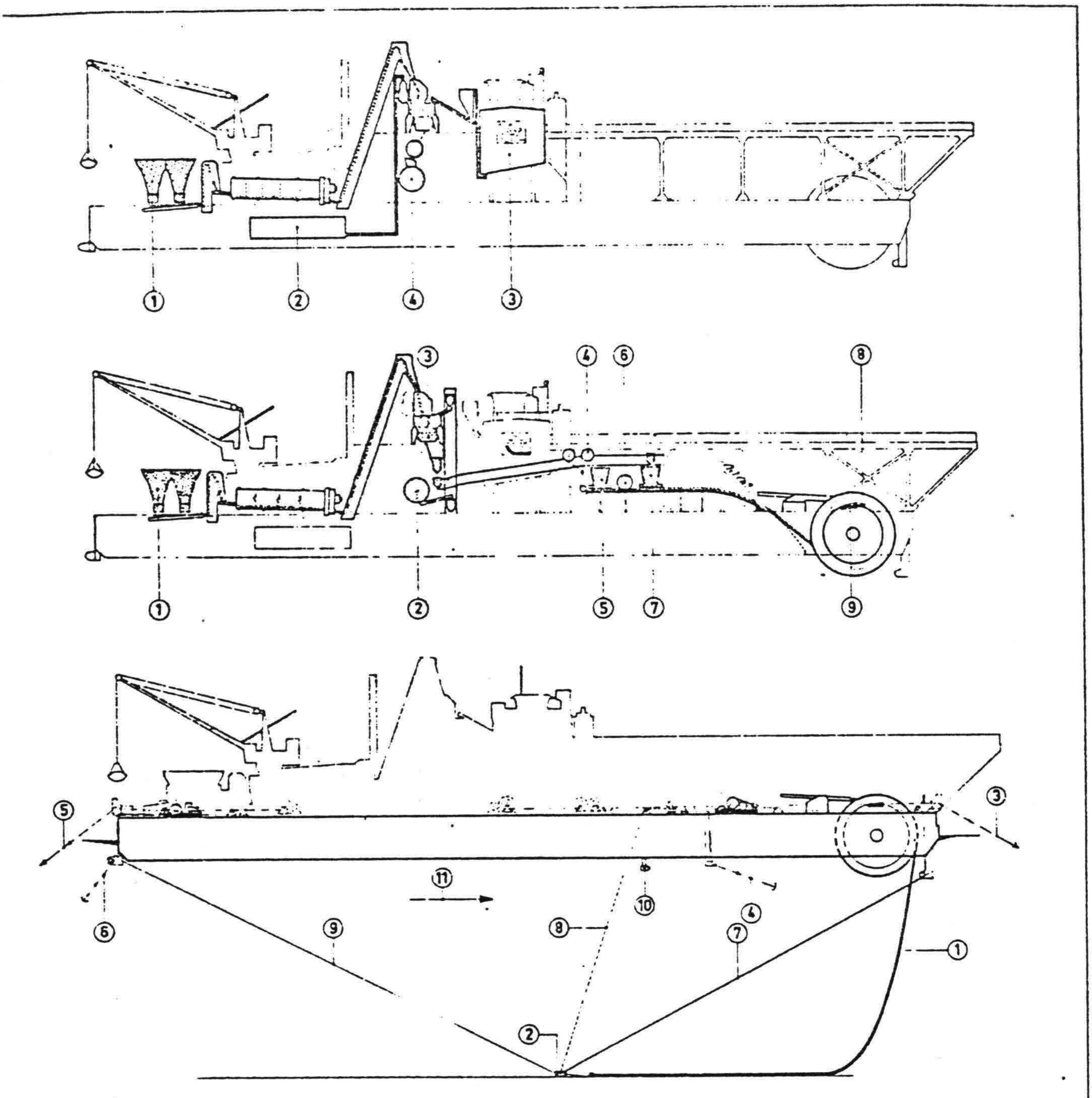
MATTRESS OF POLYPROPYLENE FABRIC
WITH FIXED BALLAST OF "GRAVEL SAUSAGES"



STONE ASPHALT MATTRESS

IN CASES WERE DURING EXECUTION STAGES SOME DAMAGE CAN BE ACCEPTED, OR WHEN THE ATTACK BY WAVES AND CURRENTS IS JUST A LITTLE BIT MORE THAN THE "STRENGTH" OF THE SAND SAND-ASPHALT CAN BE USED.
THE PERMEABILITY OF A SAND-ASPHALT LAYER IS ALMOST THE SAME AS THAT FOR SAND ONLY, BUT THE GEOTECHNICAL STABILITY BECOMES LARGER.
IN CASES WERE THE ATTACK BECOMES LARGER, LARGER GRAINS SHOULD BE APPLIED AND THEN THE SO CALLED FIXTONE IS FORMED. THIS MATERIAL IS ALSO OPEN.

IF A <u>IM</u>PERMEABLE CONSTRUCTION IS DESIRED MORE BITUMEN IS APPLIED IN THE MIXTURE, IN COMBINATION WITH OTHER AGGREGATES AND FILLERS.
AS ALREADY MENTIONED THESE TYPE OF STRUCTURES SHOULD HAVE ("DEAD") WEIGHT ENOUGH TO RESIST (STATIC) PRESSURES.
THE LIMIT STATE FOR DYNAMIC PRESSURES AND QUASI-STATIC PRESSURES SHOULD BE STUDIED THOROUGHLY IN ORDER TO DETERMINE THE REQUIRED PHYSICAL PROPERTIES AND GEOMETRY OF THE MIXTURE.
THERE EXISTS MANY TYPES OF THESE KIND OF REVETMENTS AND EXECUTION METHODS DUE TO VARIOUS FACTORS AS AVAILABILITY OF EXECUTION TIME, MATERIALS, ETC AND LOCAL HYDRAULIC AND GEOTECHNICAL CONDITIONS (SEE REVETMENTS 1)
THE ASPHALT-SHIP THE "JAN HEYMANS" IS AN EQUIPEMENT THAT IS DEVELOPPED TO MANUFACTURE AND SINKING, LAYING ETC ASPHALT MASTIC, FIXTONE MATTRESSES



rom top to bottom: the production of asphalt mastic, the ıanufacture of fixtone mattress and laying a fixtone mattress

1 Sand
2 Bitumen
3 Filler
4 Asphalt mastic

1 Crushed stone
2 Asphalt mastic
3 Fixtone
4 Filtercloth
5 1st layer of fixtone
6 Wire-mesh reinforcement
7 2nd layer of fixtone
8 Edge ballast
9 Tail beam

1 Fixtone mattress
2 Anchor beam
3 Bow cable
4 Forward side-cables
5 Stern cable
6 Rear side-cables
7 Anchor-beam lifting cables
8 Anchor-beam guide cables
9 Anchor-beam rear cables
0 Echo-sounder
1 Sailing direction during operation

bitumarin

Company for the development and application of bitumen to hydraulic engineering Bitumarin b.v.

8 De Virieusingel - Zaltbommel - The Netherlands
p.o. box 42
telephone 04180-31 51
cables: Bitumarin Zaltbommel telex: 50025

GROYNES

STRUCTURAL ASPECTS

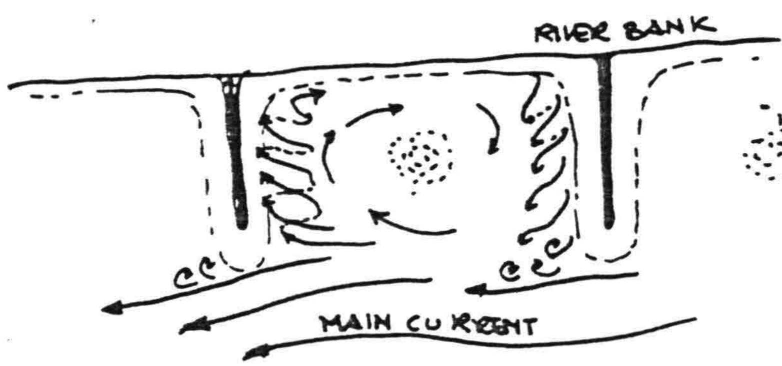
IN THE LECTURES OF SEDIMENT TRANSPORT THE FUNCTION OF GROINS ARE DISCUSSED.
IN THIS NOTE THE STRUCTURAL ASPECTS ARE DEALT WITH AND NOT THE IMPACT OF THE STRUCTURE ON THE RIVER REGIME, BEDFORMATION ETC.

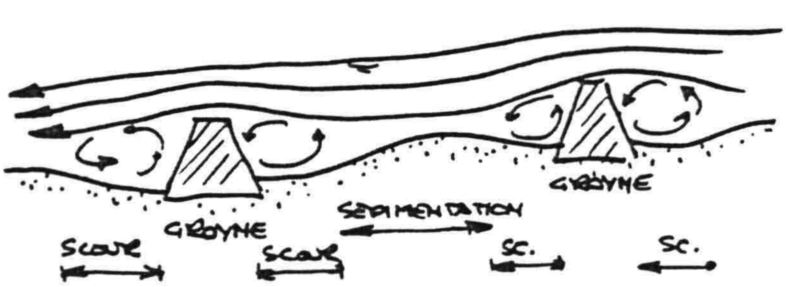
VARIOUS TYPES OF GROINS CAN BE DISTINGUISHED.
THERE ARE MANY METHODS TO GROUP THE DIFFERENT TYPES, FOR INSTANCE A CRITERION THAT IS RELATED TO THE WORKING PRINCIPLE (LAYOUT, OF THE GROIN SYSTEM, GEOMETRICAL ASPECTS) OR A CRITERION THAT IS RELATED TO STRUCTURAL FEATURES

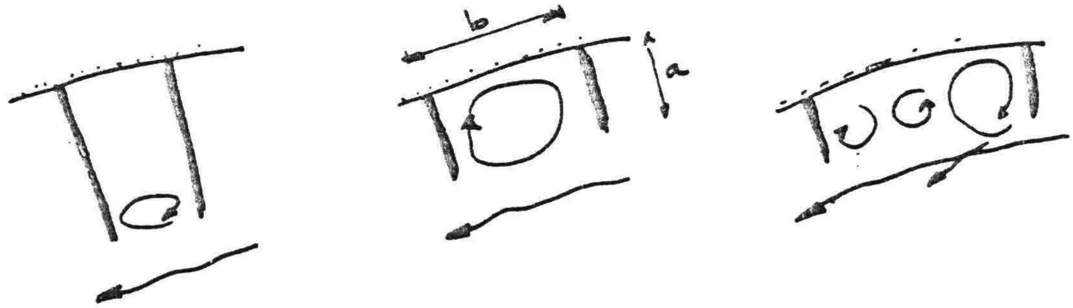
→ A FEW REMARKS ON THE WORKING PRINCIPLE:

AIM:
- DIVERT CURRENT FROM RIVER BANK
- KEEP SEDIMENT BETWEEN GROYNES
- DEEPING OF MAIN RIVERBED

} → IMPACTS THE GROYNE SYSTEM



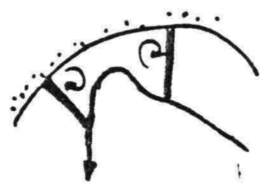




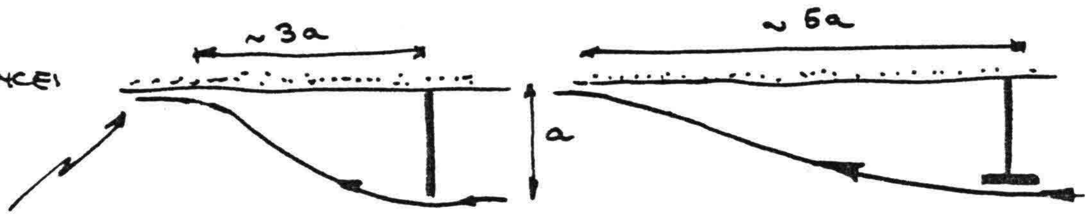
b ≈ 2a

NOT GOOD	GOOD	NOT GOOD
(TO EXPENSIVE, NARROWING MAINCURRENT)	DEVELOPMENT OF ELLIPTICAL EDDY	

BE CAREFULL IN RIVERBENDS:



EXPERIENCE:

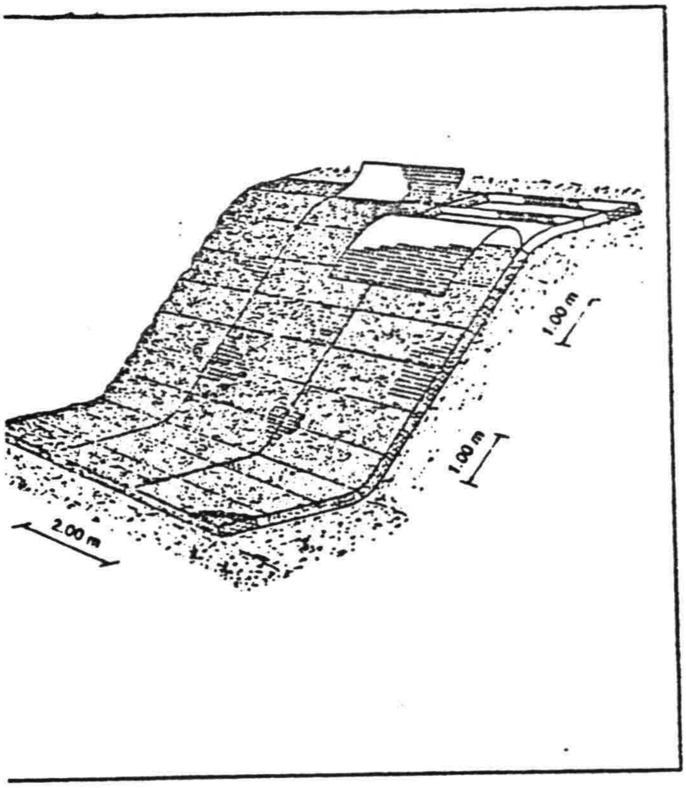


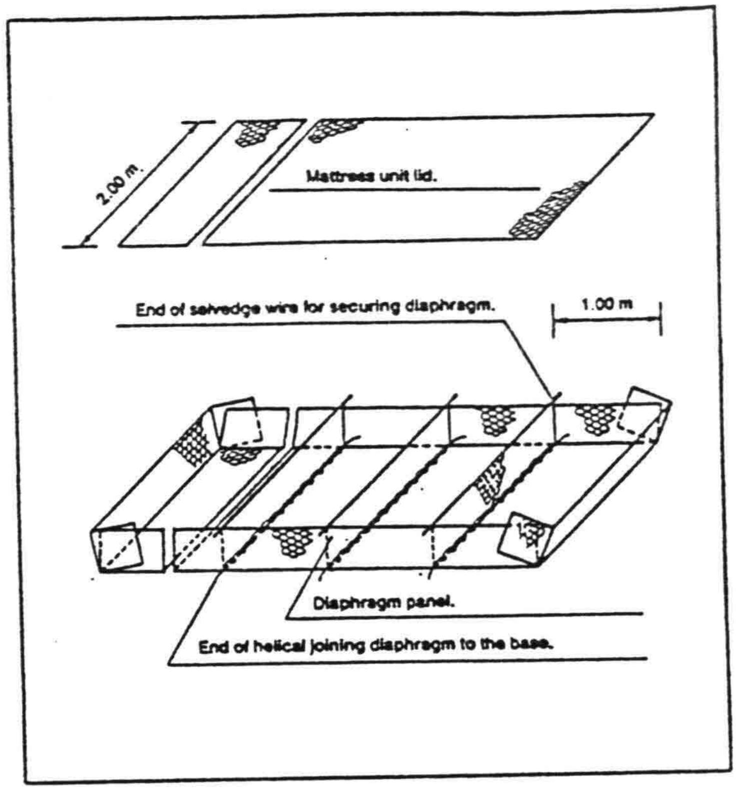
"STAGNATION POINT"

HAMMER END

DUE TO THE VARIOUS LOCAL CONDITIONS, AVALLABILITY OF MATERIAL, ETC, THE EXECUTION METHODS AND CONSEQUENTLY THE DESIGN OF THE GROYNE ARE NUMEROUS, BUT SPECIFIC FOR A SPECIAL SITUATION.

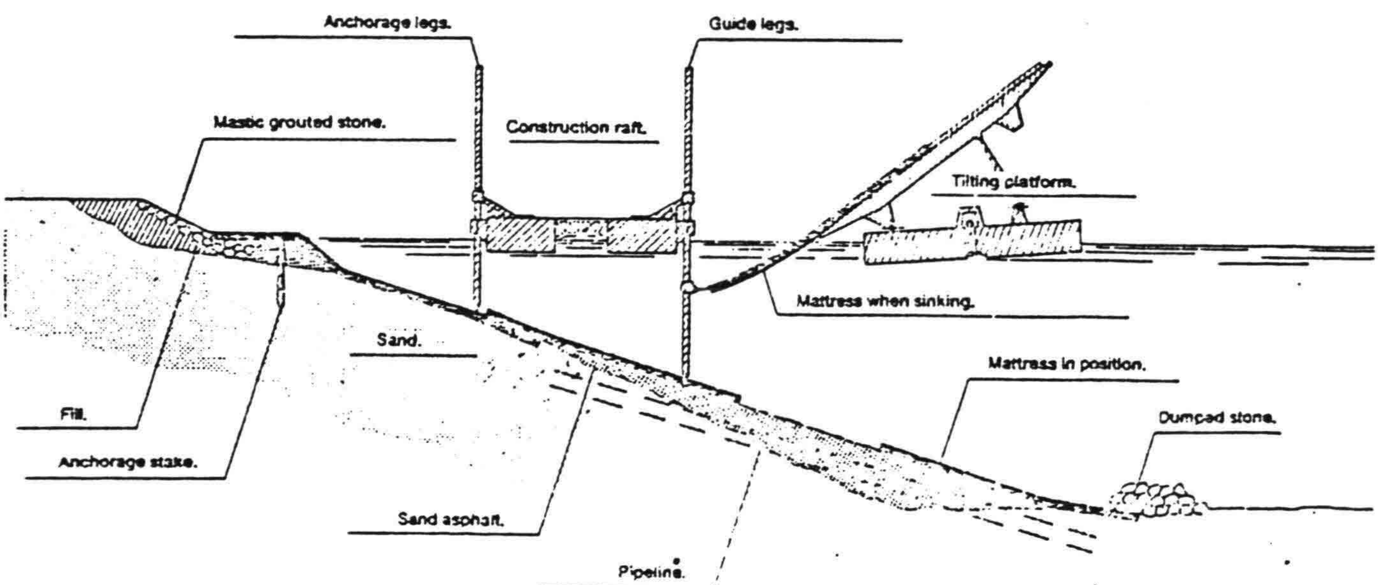
IN THE UPPER COURSE OF THE RIVER THE SIZE OF THE SEDIMENT IS LARGE IN COMPARISON WITH THE SEDIMENT NEAR THE COAST. IT IS OBVIOUS THAT IN THE UPPERCOURSE OF THE RIVER FOR THE BUILDING MATERIAL BOULDERS ETC. IS MORE APPLICABLE (ALSO IN "HARMONY" OF THE LOCAL ATTACK, SOMEWHAT LESS STRENGTH) AND IN ESTUARY REGIONS "STRENGTHENED" SAND.





- GABION TYPE MATTRESS ("RHENO MATTRESS)

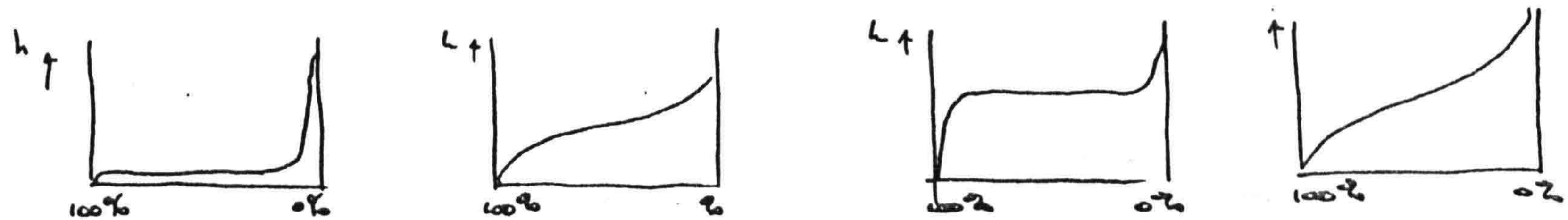
CAN BE "COATED" WITH ASPHALT TO MAKE THE MATTRESS IMPERMEABLE AND/OR FOR PREVENTION AGAINST AGGRESSIVE FLUIDS



MATTRESS "LAUNCHING" FROM A SPUD PONTOON

	breakwaters groynes seawalls	coastal dams causeways	dikes	bed protection	bank protection	high dams deep reservoirs	waterproofing	pipeline protection
1 stone-asphalt	• massive armour of heavy or light stone asphalt • grouting with light stone-asphalt	• sill protection of sluicing gap (light stone asphalt) • revetment under and above water (light stone-asphalt).	• permeable or massive revetment above and under water (light stone-asphalt).	• only required under extreme conditions e.g. on sloping beds and strongly attacked aprons (massive or permeable light stone-asphalt).	• permeable revetment of light stone-asphalt. • massive revetment of light stone-asphalt where great strength is required.	• impervious revetment and crest protection of submersible dams (light stone-asphalt). • impervious core in zig-zag pattern (light stone-asphalt).	• under extreme conditions only.	
2 in-situ mastic asphalt	• toe protection against scour • grouting of light stone revetments e.g. of groynes	• bed protection in and beyond sluicing gaps • grouting of stone sills and revetments • toe protection of revetments.	• grouting of stone revetments above and under water • toe protection.	• the ideal material for protecting unstable soils, applicable at any water depth.	• grouting of stone and gravel revetments above and under water. • toe protection.	• horizontal and sloping seals.	• anchor-proof bottoms of inland waterways. • reservoir bottoms. • buried membranes (down to pure blown bitumen). • sealing operations under difficult conditions.	• burying and scour protection of small pipelines and cables. • grouting of stone protection.
3 asphaltic grouting	• massive grouting of heavy stones with light stone-asphalt or of lighter stones with mastic asphalt to form massive impervious armour • pattern grouting with light stone asphalt or lighter grouting asphalt to form permeable armour.	• massive or pattern grouting of stone sills and revetments.	• massive or pattern grouting of stone revetments above and under water.	• massive or pattern grouting of stone layers to form very strong protection.	• massive or pattern grouting of stone under and above water to form impermeable or permeable revetments. • grouting of coarse gravel on banks with very light mastic, also possible under water on gravel > 5 cm.			• massive or pattern grouting of stone protection
4 sand-asphalt	• massive core. • sand core or fill retaining dikes (cavaliers). • water-pressure reducing mass under impervious revetments	• sill construction of sluicing gap • blocking of sluicing gap. • retaining dikes of sand core. • filter layer under permeable revetments • waterpressure reducing mass under impervious revetments.		• permeable bed protection but only suitable between well protected borders.	• dry paved filter layer under permeable revetments • permeable revetment of restricted strength			• burying and ballasting in one operation.
5 sro-sand	• can be used to replace hot sand-asphalt which, however, should be preferred in open water because of its greater strength.			• not fully equal replacement of sand-asphalt.	• the ideal filterlayer under permeable revetments for construction under water. • permeable and flexible bank protection with restricted strength, in any case below the reach of wave action.			• burying and ballasting in one operation.
6 asphalt concrete		• revetment above HW level.			• revetment above HW level • waterproof lining revetment.	• impervious surface lining. • impervious core.	• waterproof and strong revetment of waterways. • surface lining of reservoirs and irrigation systems.	
7 prefab mattresses	• toe protection with articulated mastic mattresses			• articulated mastic mattresses where in-situ method not feasible, e.g. around legs of offshore platform or in shallow water.	• reinforced mattresses of permeable or impermeable material (massive or articulated) • massive or articulated mastic mattresses for toe protection.	• reinforced mastic slabs for making horizontal or sloping seals.	• prefab slabs of blown bitumen or mastic for buried membranes and surface lining, if necessary reinforced against uneven settlements. • heavy mastic mattresses for underwater lining of waterways	• heavy type articulated mastic mattresses for ballasting and protection against scour.

APPLICATIONS OF BITUMEN PRODUCTS IN HYDRAULIC STRUCTURES (INDICATIVE, NOT ABSOLUTE)

	UPPER COURSE	MIDDLE COURSE	LOWER COURSE	ESTUARY
1. DIRECTION OF FLOW				
2. VARIATION IN Q(t)				
3. RELATION Q,h				
4. DURATION CURVES				
5. WAVES	HYDRAULIC JUMPS FLOODS	FLOODS, SHIP WAVES, TRANSLATION WAVES	WIND WAVES, SHIP WAVES TIDES, TRANSLATION WAVES	SHIP WAVES, TIDES, WIND WAVES, SWELL, FLOODS (FROM THE SEA, HIGH TIDES)
6. SEDIMENT SIZE	$D(x) = D_0 e^{-\alpha x}$	($\alpha_{Rhine} \sim 0.36$;	$\alpha_{mississippi} \approx 0.09$)	x = distance
7. RIVER BANK, SLOPE				

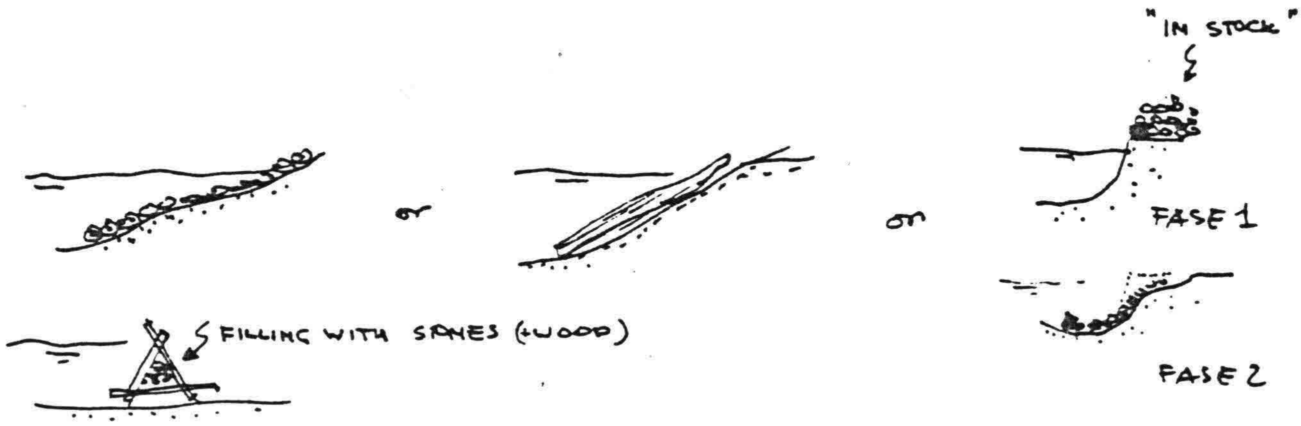
1. UPPER COURSE: (STONE AND WOOD AVAILABLE, DRY SEASONS)
GABIONS, " SACRED COWS, CRIBS, PILE GROYNES

2. MIDDLE COURSE: (SAND, GRAVEL, (BRUSH)WOOD AVAILABLE, NO PRONOUNCED DRY SEASONS)

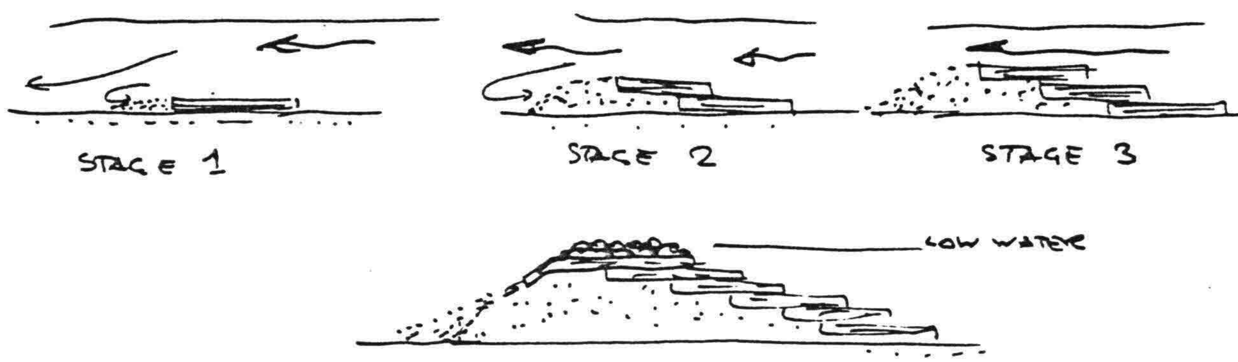
3. LOWER RHINE: SAND, BRUSHWOOD AVAILABLE, SLACK WATER

4. ESTUARY : SAND AVAILABLE, WAVE AND CURRENT ATTACK SEVERE, SO COVER STONE, "GLUEING" (EG. FIXTONE) NECESSARY

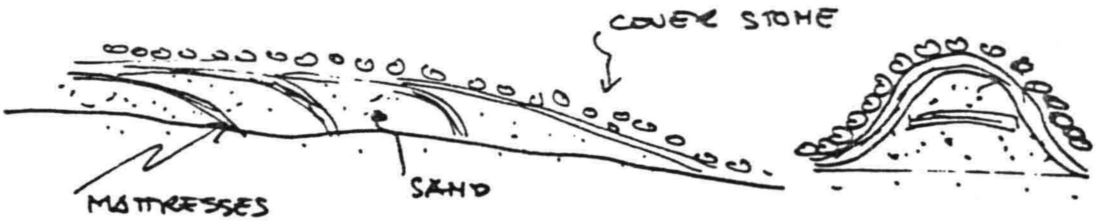
ad 1.



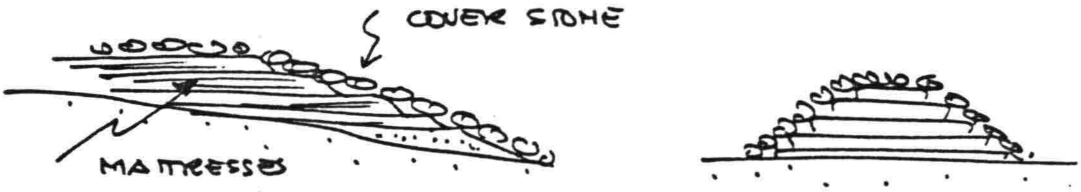
ad 2



ad 3



ad 4



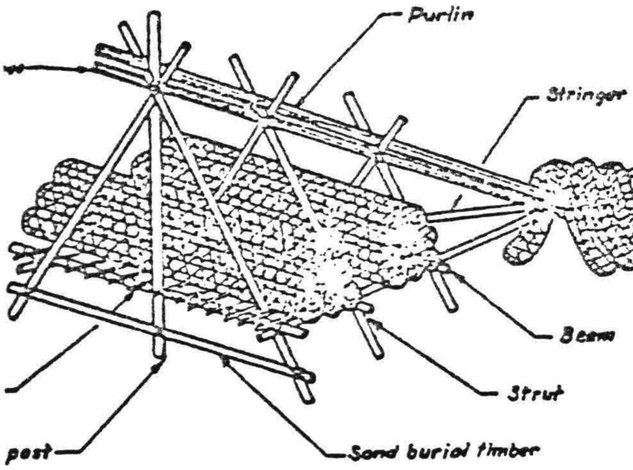


FIG. 26 SACRED COW

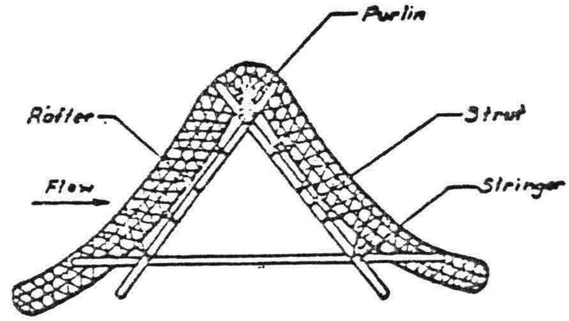


FIG. 28 STABLED COW

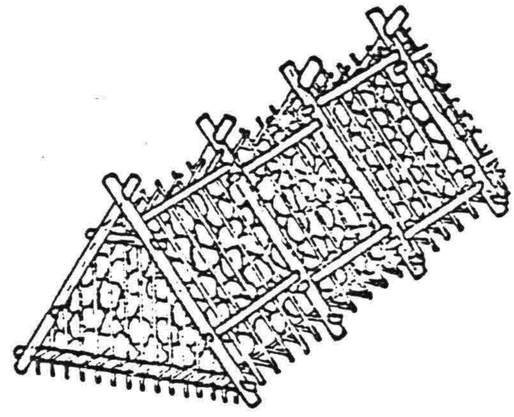


FIG. 30 TRIANGULAR PRISM CRIB

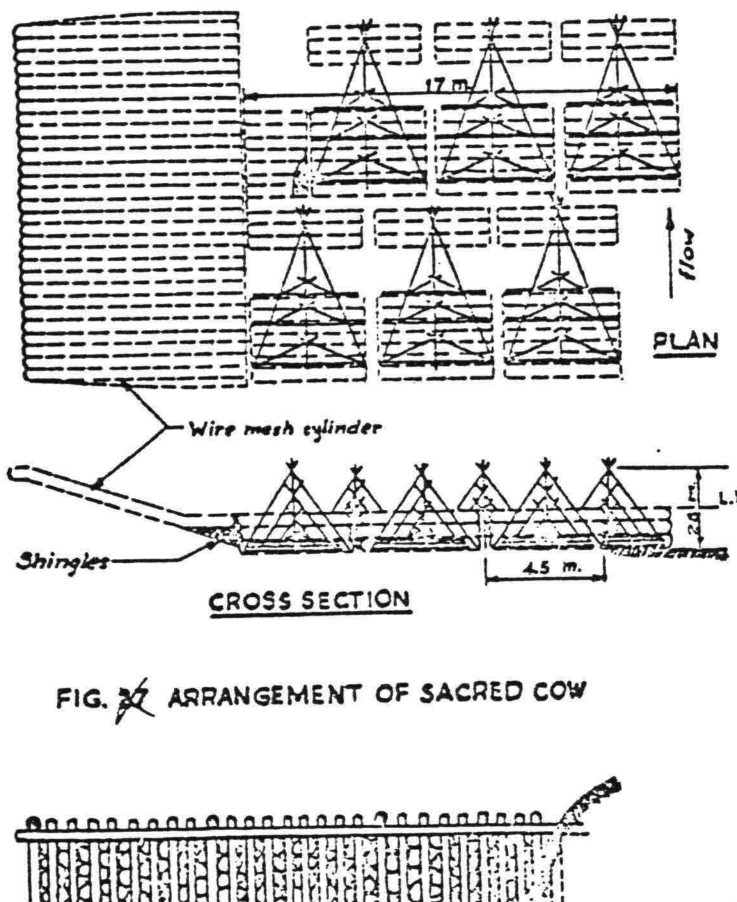


FIG. 27 ARRANGEMENT OF SACRED COW

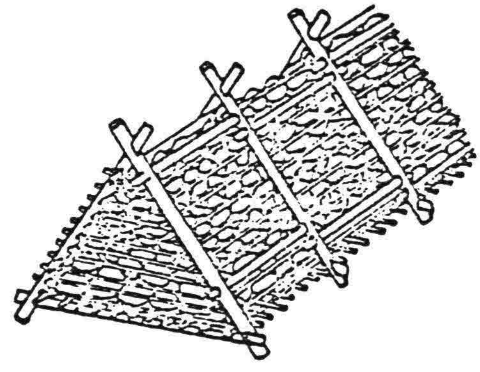


FIG. 31 TRIANGULAR PRISM CRIB

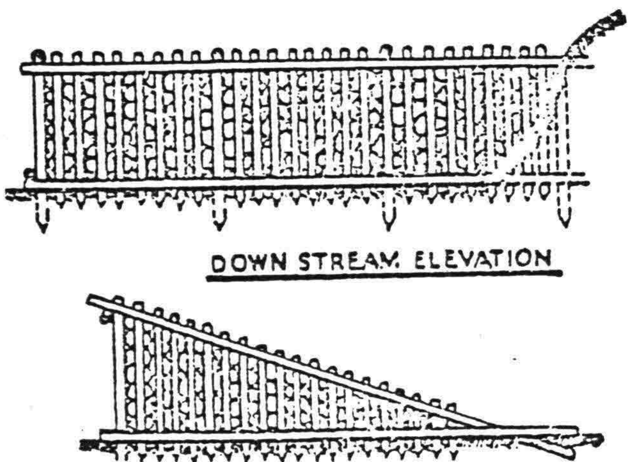


FIG. 29 WEDGE SHAPED CRIB

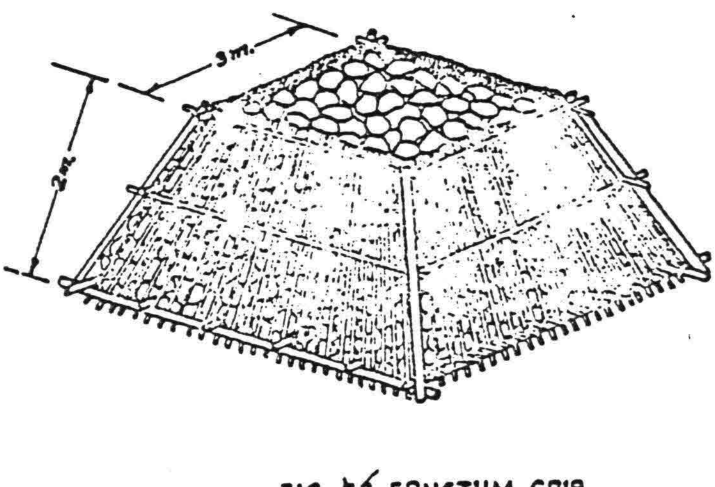
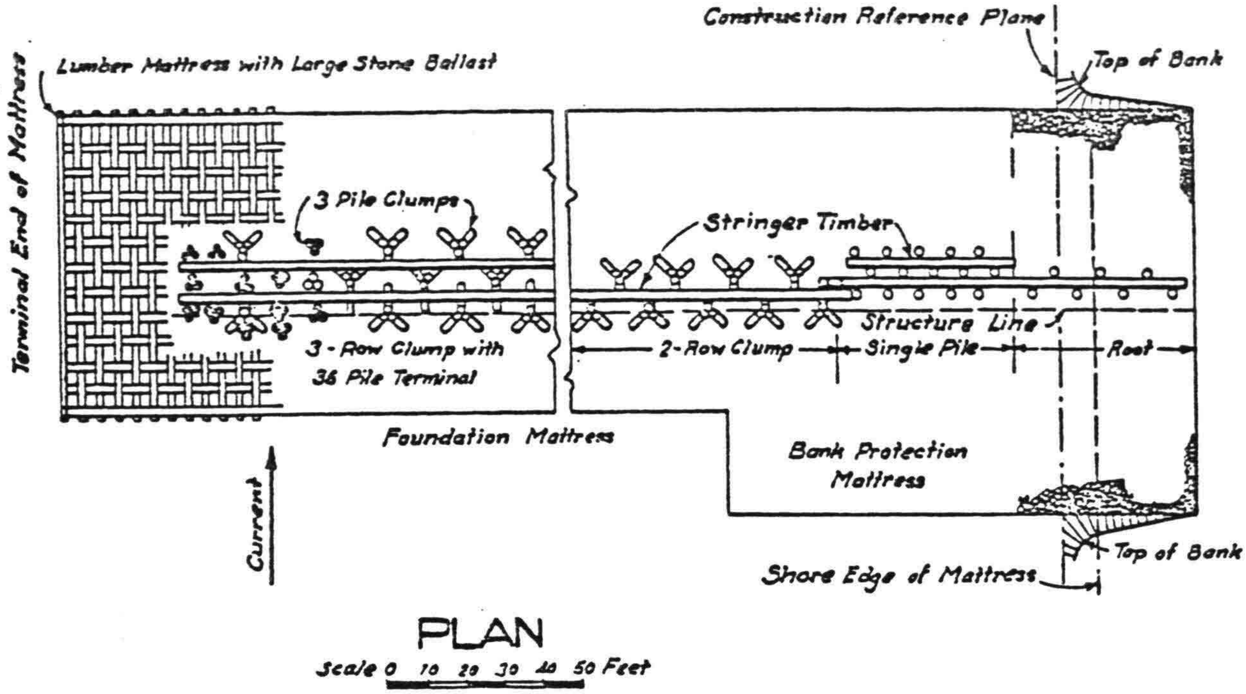
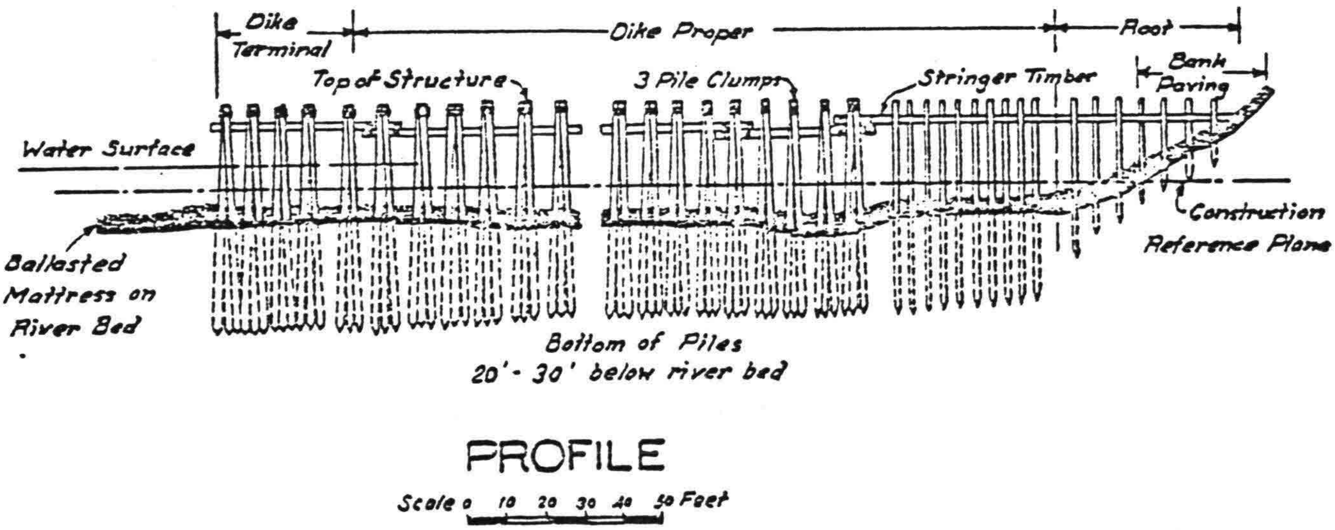
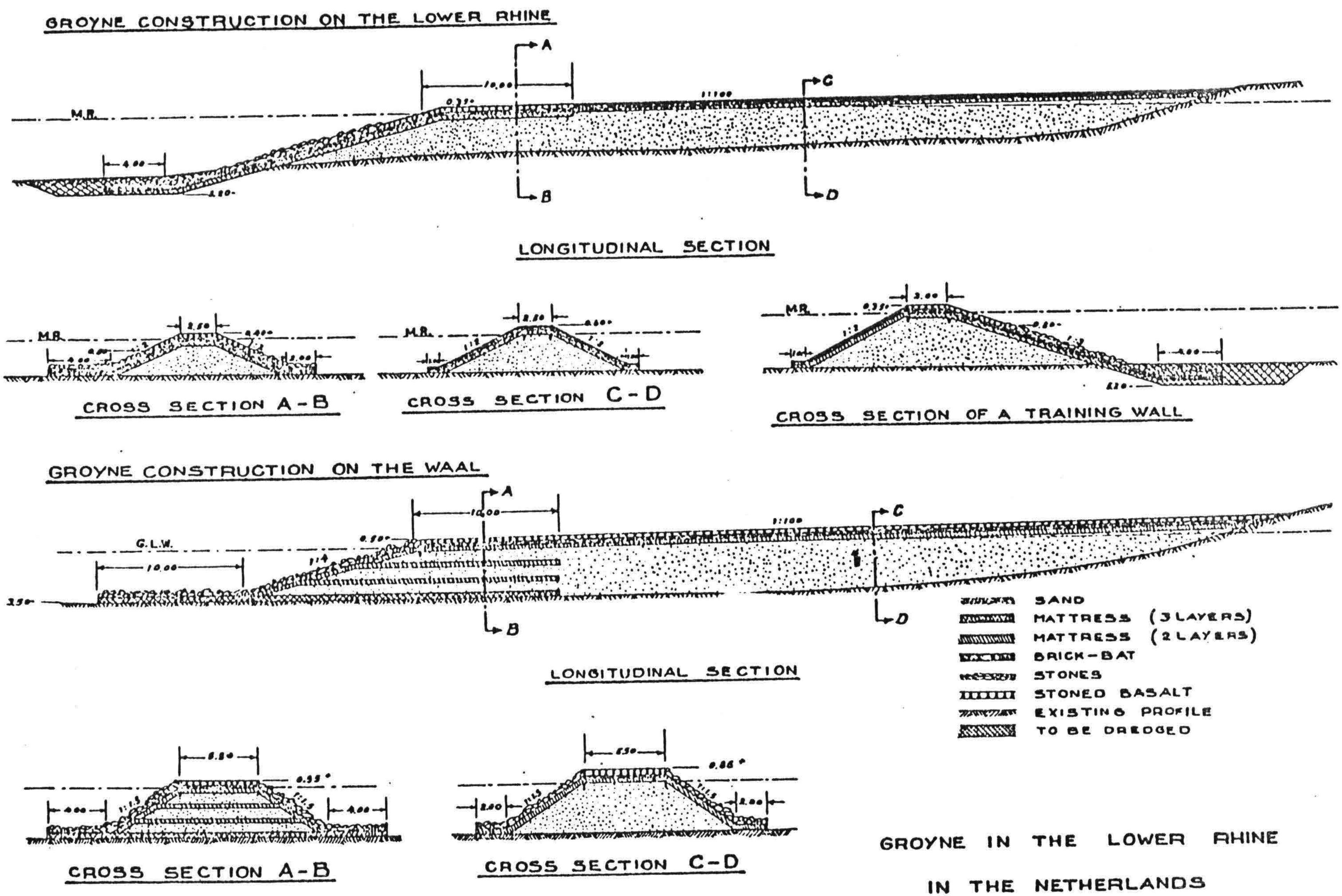


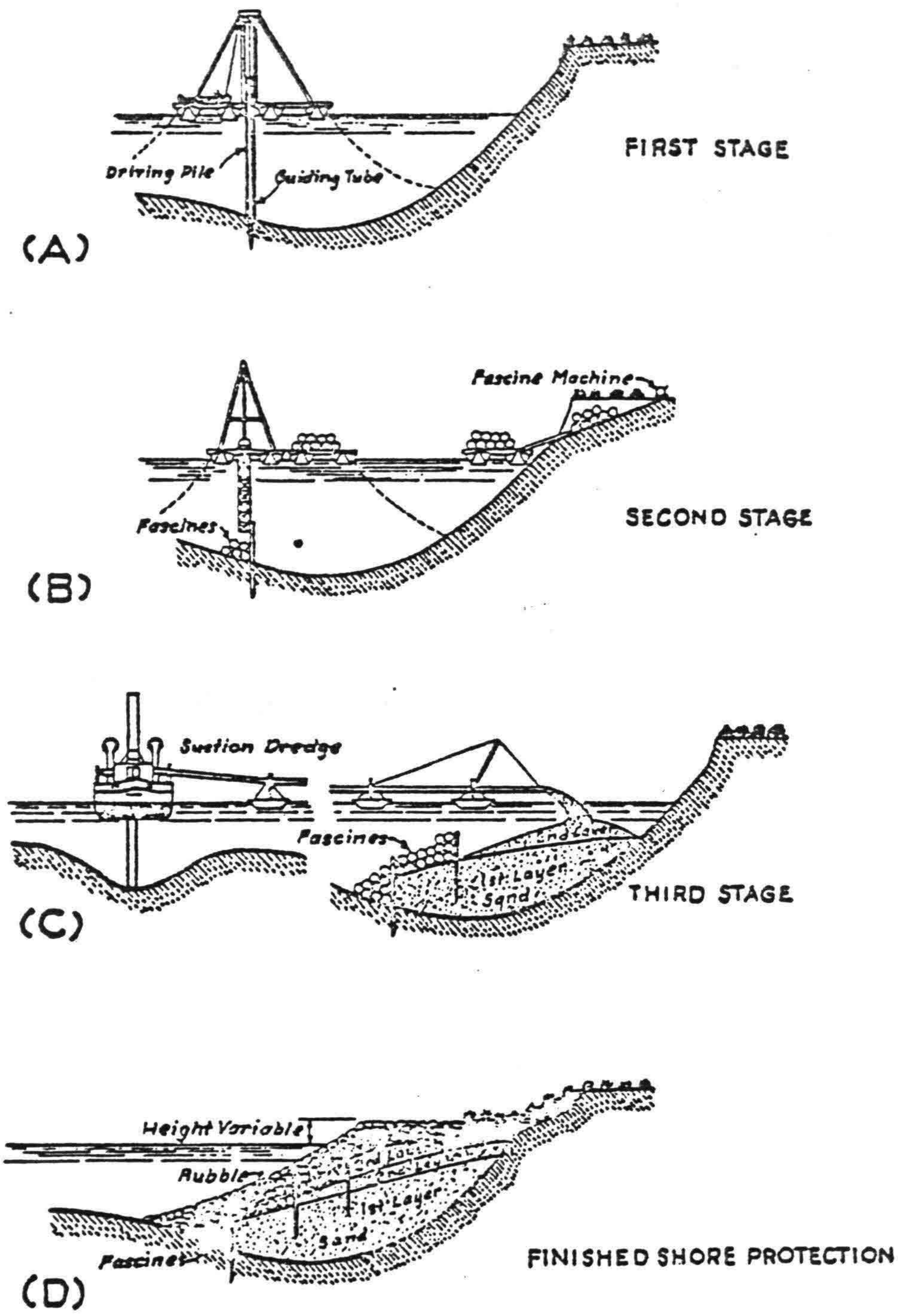
FIG. 32 FRUSTUM CRIB





PILE CLUMP GROYNE


GROYNE CONSTRUCTION ON THE LOWER RHINE
M.R.
10.00
1:100
A
B
C
D
LONGITUDINAL SECTION
CROSS SECTION A-B
CROSS SECTION C-D
M.R.
CROSS SECTION OF A TRAINING WALL
GROYNE CONSTRUCTION ON THE WAAL
G.L.W.
10.00
1:100
1:4
LONGITUDINAL SECTION
SAND
MATTRESS (3 LAYERS)
MATTRESS (2 LAYERS)
BRICK-BAT
STONES
STONED BASALT
EXISTING PROFILE
TO BE DREDGED
CROSS SECTION A-B
CROSS SECTION C-D
GROYNE IN THE LOWER RHINE
IN THE NETHERLANDS



CONSTRUCTION OF SHORE PROTECTION ON THE RIVER PO