AN EVALUATION OF THE SUITABILITY OF DECOMPOSED GRANITE AS FOUNDATION BACKFILL FOR GRAVITY SEAWALLS IN HONG KONG

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PREFACE

In keeping with our policy of releasing information of general technical interest, we make available some of our internal reports in a series of publications termed the GEO Report series. The reports in this series, of which this is one, are selected from a wide range of reports produced by the staff of the Office and our consultants.

Copies of GEO Reports have previously been made available free of charge in limited numbers. The demand for the reports in this series has increased greatly, necessitating new arrangements for supply. In future a charge will be made to cover the cost of printing.

The Geotechnical Engineering Office also publishes guidance documents and presents the results of research work of general interest in GEO Publications. These publications and the GEO Reports are disseminated through the Government's Information Services Department. Information on how to purchase them is given on the last page of this report.

A. W. Malone
Principal Government Geotechnical Engineer
April 1995

FOREWORD

This report was initially produced as a paper for the working group preparing the General Specification for Civil Engineering Works - Marine Works. The paper was produced by Mr E.B. Choot under the direct supervision of the then CGE/Island, Mr G. E. Powell. Some technical review was provided by Mr R. A. Forth, SGE/Island.

The paper is of general interest and particularly relevant now that the revised General Specification has been issued. For this reason the paper has been upgraded to a GEO report to allow wider circulation.

(G. E. Powell)
Chief Geotechnical Engineer/Design

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1. INTRODUCTION

At the request of the Working Party on the revision of the Unified General Specifications for Marine Works, an evaluation was conducted to determine if decomposed granite can be used to replace marine sand as the foundation backfill for gravity seawalls in Hong Kong.

Marine sand has traditionally and successfully been used as the backfill material for seawall trenches. The types of marine sand used are generally those which are unsuitable for structural purposes and are allowed to have at source fines contents of between 5% to as high as 40%, depending on the method of placement. Throughout the years however, the source of suitable marine sand for seawall foundation backfill has slowly been depleted, resulting in the need in some cases for contractors to use relatively more expensive crushed rocks to backfill seawall trenches. The use of readily and cheaply available decomposed granite will result in significant cost savings for gravity seawalls in Hong Kong.

The evaluation presently carried out consists of a review of the available literature on the properties and behaviour of decomposed granite marine fill, and the analysis of seawall stability during various stages of construction, with due consideration to the probable pore pressures developed in the foundation backfill. Conclusions are drawn and recommendations made as appropriate.

2. TYPICAL SEAWALL SECTIONS AND CONSTRUCTION SCHEDULE

As a start, typical seawall sections and construction schedules were obtained from the Port Works Division. Examples of typical seawall and breakwater sections are presented in Figures 1 and 2, and their dredged levels and thicknesses of foundation backfill are summarized in Table 1. It is of interest to note as exemplified by the as-built section for Western Reclamation, that in most cases, due to the construction procedure, substantially more sand is placed in the trench than required by the design profile, resulting in additional factor of safety for as-built seawalls.

The typical seawall sections have been idealized for stability analyses. The idealized sections are shown in Figure 3. There are respectively 10 metres, 15 metres and 20 metres of foundation backfill material in the trench for the three idealized seawall sections.

According to information obtained from the Port Works Division, seawall trenches are normally backfilled immediately following the excavation of the trench. The placing of pell mell rubble, levelling stones, and seawall blocks normally takes 6 months to complete, and contractors are allowed to schedule this activity anytime within a two-year usual contract period. Following the placement of seawall blocks, the contractor would normally place reclamation fill to about 10 metres behind the wall immediately. This is especially important during the rainy season to prevent the seawall blocks from being displaced by typhoon. The rest of the reclamation fill will be placed anytime after that, depending on the availability of fill and reclamation schedule. The typical sequence of seawall construction is illustrated in the form of a bar chart in Figure 4.

3. LITERATURE REVIEW

A review of available literature in Hong Kong revealed that there were two previous studies carried out on the properties of decomposed granite marine fill.

The first was conducted in connection with the construction of the Plover Cove reservoir in the early 1960's. Due to limited prior experience with decomposed granite marine fill, an extensive investigation was conducted to establish the suitability of using decomposed granite marine fill to form the impermeable core for the dam. Despite its higher permeability, decomposed granite was chosen over decomposed volcanic rocks due to its higher strength and reasonably rapid pore pressure dissipation characteristics. Besides extensive laboratory and field testing, a well instrumented test mound was also constructed of the materials intended to be used for the core of the dam. Various types of monitoring instrument were also installed during the actual construction of the reservoir. The investigation was conducted on decomposed granite with fines contents ranging from 25 to 50%, and the results of investigation are available in references such as Lamb (1962), Ford & Elliot (1965), Holt (1967) and Guildford & Chan (1969).

The second study was conducted by Y. C. Lo for his Master's Thesis at the Hong Kong University in connection with a breakwater at Cheung Chau which was in part constructed on trench backfilled with decomposed granite from Sau Mau Ping. The results are available in Lo (1980). Samples of the in situ as placed decomposed granite backfill were obtained and a series of laboratory testing were conducted to establish its properties.

A similar literature search was carried out for the properties of in situ as placed marine sand but unfortunately, none could be found. Presumably, the properties of marine sand, which usually are required by specification to contain 20% fines after placement, has not been a problem in Hong Kong and therefore has not been studied in any detail.

For the purpose of this study, decomposed granite is defined to encompass Grade IV, V and VI decomposed rock in accordance to the classification in the Geotechnical Manual for Slopes (GCO, 1979). It is however unlikely that Grade VI decomposed granite, i.e. residual soil, could fulfill the purpose as foundation backfill for seawalls due to its poor drainage characteristics and the usual inclusion of significant amount of deleterious matters.

4. PROPERTIES OF DECOMPOSED GRANITE MARINE FILL

In Figure 5, the permeabilities of decomposed granite marine fill quoted from various sources are summarized. Several points are note worthy :

(a) Available laboratory test results indicate that the permeability of decomposed granite marine fill is low to very low (10^{-5} to 10^{-9} m/sec) in accordance to the range of values presented by Terzaghi & Peck (1967).

(b) Tests conducted by Lo (1980) indicate that the permeability of decomposed granite marine fill does not vary with fines content. This is different from what can be observed from the upper limit range of permeability from Holt (1967) which indicate that the permeability of decomposed granite does decrease significantly with increasing fines content. The latter is probably more reasonable given that the results in Lo (1980) were only based on a few consolidation tests.

(c) At fines content of greater than 20%, the permeability values from Lo (1980) appear to correspond with values obtained by mixing coarse silt with coarse grained materials, as quoted by DM-7 (NAVFAC, 1971). This generally agrees with the classification of decomposed granite by particle size distribution.

(d) The limited field permeability results indicate that field permeability of the in-placed decomposed granite marine fill should exceed that obtained in the laboratory by as much as one order of magnitude. This is probably a result of field segregation and preferential horizontal drainage.

(e) While there is a lack of information on the properties of marine sand fill, it is expected that the permeability of marine sand could be substantially higher than that of the decomposed granite marine fill. A quick calculation using the popular empirical equation for sand, $K = 100D_{10}^2$, indicates that the permeability of marine sand should be at least two orders of magnitude higher than that of the decomposed granite at comparable fines content. This is probably attributable to the higher in placed void ratio and more angular particle shapes of marine sand fill.

Available values of coefficients of consolidation (C_V) for decomposed granite marine fill are summarized in Figure 6 and the following can be noted :

(a) Laboratory C_V values of decomposed granite slurry are much higher than those from field samples of decomposed granite marine fill at a given fines content and are probably unrepresentative.

(b) Lo (1980) again indicates no significant change in C_V values with fines content, while the results from Plover Cove indicate significant reduction of C_V with fines content.

(c) The only available field C_V data indicates that field C_V is about 3 times that of the laboratory C_V at the same fines content. It was also reported by Lamb (1962) that the field permeability of sandy decomposed granite (around 25% fines) could not be measured, implying a rather high field C_V value for that material.

Available information indicates that the void ratios of in-situ decomposed granite marine fill ranges from 0.5 to 0.8. Its compression Index (C_c) is around 0.10, and its effective friction angle ranges from 30 to 43 degrees.

It should be noted herein that while all the data had been plotted against fines content, fines content is actually not the only governing parameter affecting the characteristics and suitability of a fill material. There are also other equally important parameters such as the actual gradation, void ratio, plasticity and particle shape. Nonetheless, the data had been so plotted to form a convenient basis for discussion. Further study is required to assess the relative importance of different governing parameters, and the resulting effect on the conclusion of this study.

5. SENSITIVITY ANALYSES

5.1 Important Geotechnical Considerations

In replacing marine sand with decomposed granite as the backfill material for seawall trenches, several issues of geotechnical significance has to be considered.

First of all, because of the low permeability of the decomposed granite marine fill, it is important to determine if any residual construction pore pressure would be left entrapped beneath the seawall. Incomplete dissipation of the residual excess pore pressure will lower the factor of safety by lowering the effective stress, and hence the available resistance against failure.

Secondly, there may be a reduction in factor of safety due to the comparatively lower strength of decomposed granite marine fill. This is not seen to be a significant factor as available literature suggests that decomposed granite's effective angle of friction is in excess of what is normally assumed in seawall stability analyses. However, because of the expected low permeability of decomposed granite marine fill, it is equally important to consider the case where the reclamation fill loading is applied relatively quickly resulting in failure in an undrained mode with a lowered factor of safety due to shear induced pore pressures.

In addition, even with a reasonable long term factor of safety, the seawall should not fail during construction. It is also necessary to make sure that post constructional settlement is kept within a reasonable limit.

5.2 Residual Construction Pore Pressures

In Figure 7, the maximum expected residual pore pressures expressed as percentages of vertical stress, are plotted versus time after construction for various assumed thicknesses of decomposed granite foundation backfill and for various values of coefficients of consolidation.

The pore pressure dissipation curves in Figure 7 were solely the result of theoretical derivation where the residual pore pressures had been calculated assuming double drainage and based on one dimensional theory of consolidation. The assumption of double drainage is unconservative but generally correct as seawalls are normally dredged and founded on permeable stratum containing less than 30% of fines materials. In recent years however there is an increasing tendency to found seawall on stiff alluvium of low permeability. This unconservative assumption of double drainage however, is far outweighed by the conservative use of laboratory coefficient of consolidation in the calculations. It should further be noted that in order to be conservative, only the maximum residual pore pressures are plotted. Average residual pore pressure within the foundation backfill should be somewhat lower than those values indicated on the plots.

5.3 Seawall Stability Analyses

Figure 8 shows typical results obtained from stability analysis of a seawall with 15 m of foundation backfill. Factors of safety were obtained by using the non-circular stability analysis developed by Morgenstern & Price (1965) available in the GENESYS Computer Programme.

Two details of the typical stability analysis are noteworthy. First of all, the critical failure surface does not pass through the marine deposits. This is understood to be due to the normal practice of adjusting the width of the base of seawall trench so that the critical failure surface does in fact pass through the seawall, rather than through the marine deposits. It will be assumed herein that this will still continue to be the normal practice, and subsequent analyses will only concentrate on potential failure surfaces through the seawall itself. Secondly, the critical failure surface is observed to pass through the pell mell rubble rather than through the foundation backfill. This is significant because it demonstrates that a certain amount of pore pressure can be tolerated within the foundation backfill without materially lowering the overall factor of safety of the seawall.

By trial and error, it was found out that for this particular section of seawall, with 15 m of foundation backfill, a 41% excess pore pressure can be tolerated within the foundation backfill. With that excess pore pressure the factor of safety through the foundation backfill becomes equal to that through the pell mell rubble.

Similar analyses were conducted on the idealized seawall sections with 10 m and 20 m of foundation backfill and the respective allowable excess pore pressures are 73% and 26% as indicated in Figures 9 and 10. On the basis of the above analysis the correlation between allowable pore pressures versus thickness of foundation backfill can be obtained and are summarized in Figure 11.

In re-examining the typical construction schedule bar chart in Figure 4, it can be seen that seawall construction, from dredging to the placement of seawall blocks, would normally require at least 8 months in total to complete. During the construction period, a fair amount of construction excess pore pressure would have dissipated. For simplicity, it will be assumed that seawall loading is applied instantaneously and that there is a six-month pore water pressure dissipation period during construction to get an estimate of the end-of-construction residual pore pressures. This is regarded as a reasonable assumption given that major proportion of seawall loading resulting from sandfilling and the placement of pell mell rubble would have been applied during the initial period of construction as can be seen from the bar chart in Figure 4.

Assuming instantaneous loading, and a six month excess pore water dissipation period, Figure 11 and Figure 7 can then be combined to show a summary plot in Figure 12 of the minimum waiting time required after the end-of-construction of seawall before the placement of reclamation fill is allowed, versus the thickness of foundation backfill for various coefficients of consolidations. The results in Figure 12 can be utilized in the following manner:

(a) Given a known thickness of foundation backfill and a coefficient of consolidation of the backfill materials, restrictions can be placed on the amount of waiting period require before reclamation fill can be placed behind the seawall, or alternatively,

(b) Given a known thickness of foundation backfill and reclamation schedule, restriction can be placed on the minimum required coefficient of consolidation of the backfill material.

5.4 Stability during Construction

The foregoing deals with the stability of seawall after construction due to loading from reclamation fill. It is conceivable that due to the entrapment of pore pressure, a seawall may actually fail during construction.

Figure 13 shows the result of stability analysis of a completed seawall prior to the placement of any reclamation fill behind the wall. A reasonable amount of entrapped pore pressure, corresponding to a coefficient of consolidation of 50 m^2/yr, instantaneous construction and a six month pore water pressure dissipation period, had been assumed in the analysis. The minimum factor of safety obtained is 2.9 which is substantially higher than that of the after construction case.

An additional stability analysis was conducted assuming the immediate placement of 10 metre of reclamation fill behind the seawall. The resultant factor of safety has been reduced to 1.85, which is still within acceptable limit and higher than the 1.4 factor of safety obtained in the previous section due to reclamation fill loading. It can therefore be concluded that stability during construction should not be a main design concern.

5.5 Drained Versus Undrained Shear

The methods of soil mechanics always assume that the soil behaves in a fully drained, or fully undrained manner. Unfortunately, neither of those assumptions is valid for the decomposed granite marine fill, whose behaviour is dependent on the rate of loading.

Assuming conservatively that the loading due to the placement of reclamation fill happens instantaneously, whereby the shearing can be expected to occur in an undrained manner; and an undrained strength ratio of 0.25, it can be seen in Figure 14 that the calculated undrained factors of safety of the seawall would vary between 1.05 to 1.20. As the factor of safety is still above unity, the seawall is considered stable even under the assumption of the most adverse loading conditions. This analysis assumes that the required waiting period determined by Figure 12 had been allowed before the instantaneous application of loading due to the placement of reclamation fill. It should be noted the undrained factors of safety obtained were very conservative in that it has been assumed that no additional excess pore water pressure dissipation occurred during the placement of reclamation fill.

5.6 Residual Settlements

The residual post construction settlements were estimated to be 2 cm, 15 cm, and 30 cm based on a compression index of 0.10 and void ratios of 0.8 and the end of construction residual pore pressures for seawall sections with 10 m, 15 m and 20 m foundation backfill thicknesses respectively. These residual settlements are considered acceptable.

6. CONCLUSIONS

Based on the review, considerations, and analyses in the foregoing sections, the following can be concluded:

(a) Decomposed granite may be considered as alternative to marine sand as the foundation backfill material for gravity seawalls in Hong Kong.

(b) In view of the comparatively low permeability of decomposed granite marine fill, and depending on a number of other factors such as foundation backfill thickness and construction schedule, a certain amount of construction pore pressure can be expected to be entrapped within the foundation backfill of the seawall and it is important to take into considerations the entrapped pore pressure in assessing the seawall stability.

(c) Figure 12 presents a rational and convenient chart with which limits can be placed on either the coefficient of consolidation of the foundation backfill material, or the required time before placement of reclamation fill is allowed behind the seawall in consideration of the possible entrapment of pore pressures within the foundation backfill of the seawall.

(d) It can be seen from Figure 6 that the coefficient of consolidation for decomposed granite marine fill with 25% fines is at least 40 m^2/year. With that coefficient of consolidation, and judging from the chart in Figure 12, one can safely assumed that the entrapment of pore pressure should not adversely affect the stability of seawalls if the thickness of decomposed granite foundation backfill beneath the seawall is less than about 15 m. Construction schedule limitation will have to be imposed if a greater thickness of foundation backfill, or decomposed granite with a higher percentage of fines is to be used.

(e) Despite the use of fines contents for correlation, it should be noted that fines content is not the absolute indicator of the suitability of decomposed granite as the foundation backfill for seawalls. There are other important parameters such as the void ratio, plasticity which should rightly be considered as well. The study of the comparative importance of various governing parameters however is beyond the scope of this brief review and therefore it is important that the result of this review be applied with reasonable amount of caution and judgement.

(f) The foregoing analyses and conclusions were based solely on data available from literature review. It would be extremely useful to carry out some field trials to validate that the assumptions and results are reasonable.

7. RECOMMENDATIONS

It is recommended herein to the Working Party that:

(a) Allowance should be made in the general specification for the use of decomposed granite as the backfill material for seawall foundation. As a start, and subject to revision based on experience, the following specification adopted from MTRC is recommended:

> "Crushed decomposed granite for underwater foundation shall be well-graded with a uniformity coefficient exceeding 5 and a plasticity index not greater than 6. All materials shall pass through a B.S. 75 mm sieve with not more than 25% material passing a 63 μm sieve".

(b) It should be emphasized in the companion explanatory document to the revised general specification that the decomposed granite as specified is only suitable for use in seawall sections with less than 15 m thick foundation backfill, and where seawall construction schedule for any typical section is approximately the same or slower than those shown in the bar chart in Figure 4. For cases where the above assumptions are not valid, restrictions will have to be imposed. The results of the evaluation presented in this report should be referred to for those cases.

(c) Whenever practicable, field trials should be conducted to improve upon the current understanding of the behaviour of decomposed granite as the foundation backfill for seawalls. This may lead to a relaxation of the limitations imposed and encourages a more widespread economic incorporation of decomposed granite in seawall sections.

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LIST OF TABLES

Table 1 - Summary of Typical Seawall and Breakwater Sections

Location	Type	Dredger Depth (mCD)	Thickness of Foundation Backfill (m)
Stonecutter	Seawall	-18	7
Western	Seawall	-27	10
Chaiwan	Seawall	-28	13
Chaiwan	Breakwater	-32	20
Stonecutter	Breakwater	-18	9

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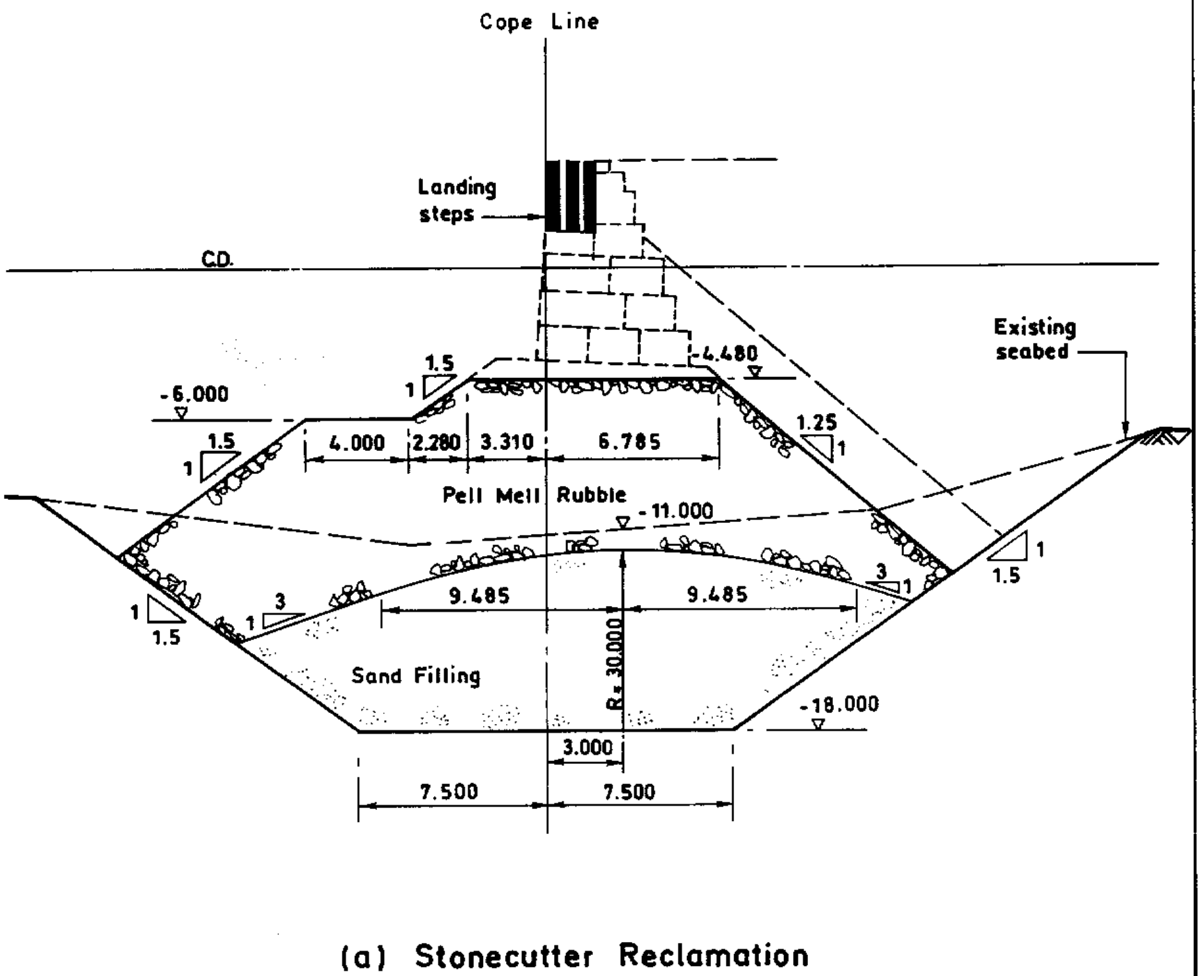
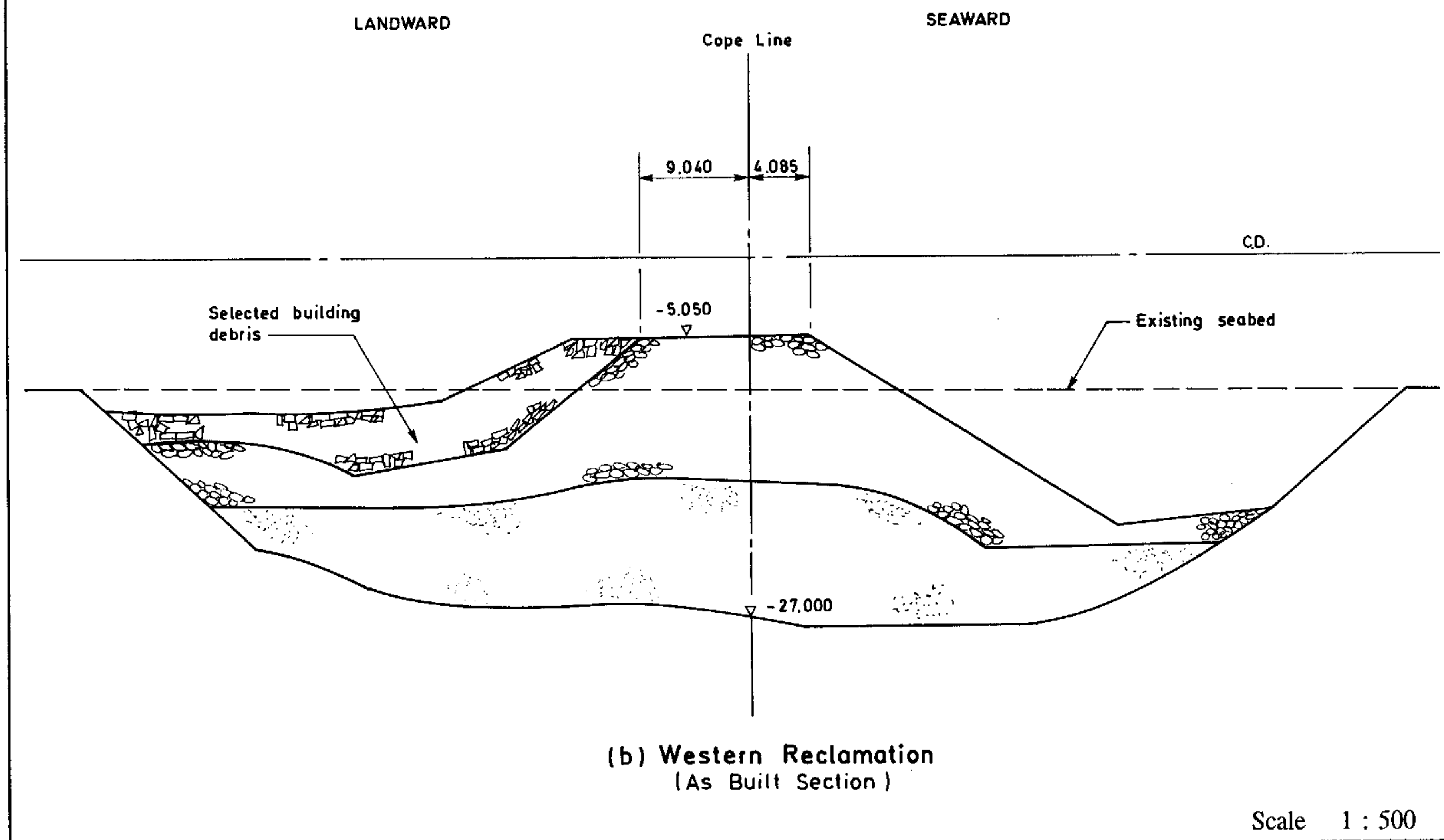


Scale 1 : 300

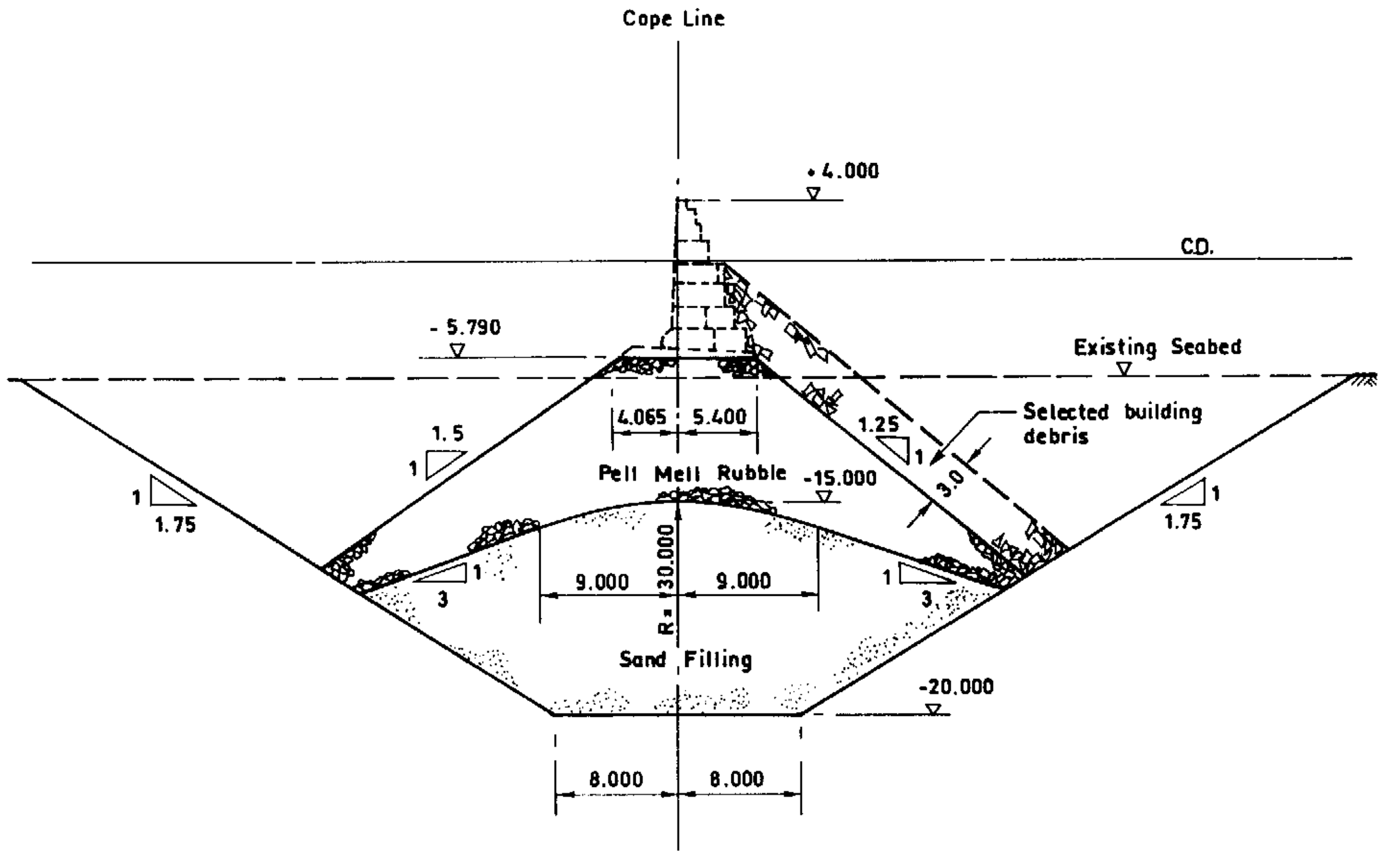
Note : All dimensions are in metres

Figure 1 - Typical Seawall Sections (Sheet 1 of 3)



Note : All dimensions are in metres

Figure 1 - Typical Seawall Sections (Sheet 2 of 3)

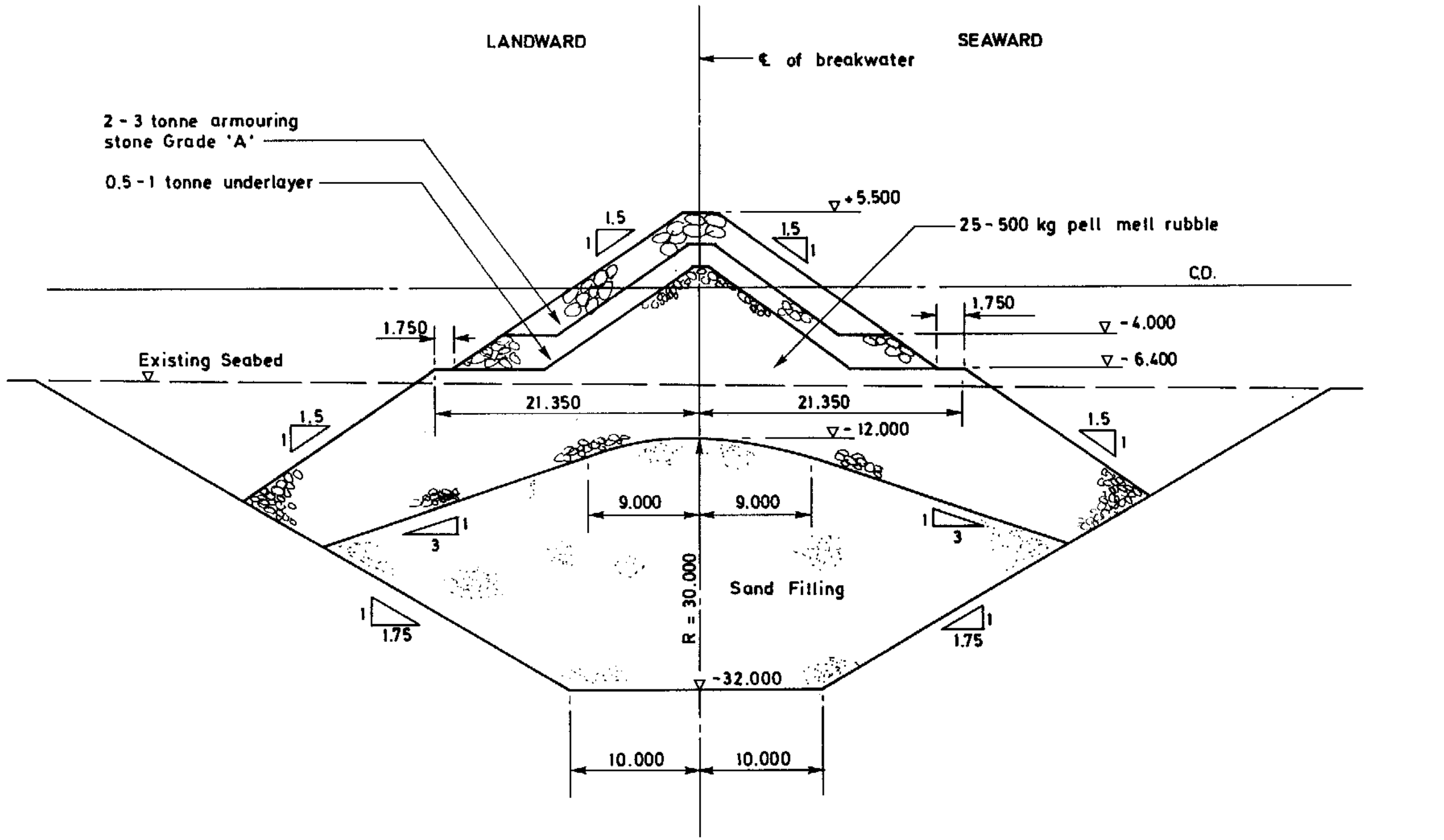


(c) Chaiwan Reclamation

Scale 1 : 500

Note : All dimensions are in metres

Figure 1 - Typical Seawall Sections (Sheet 3 of 3)

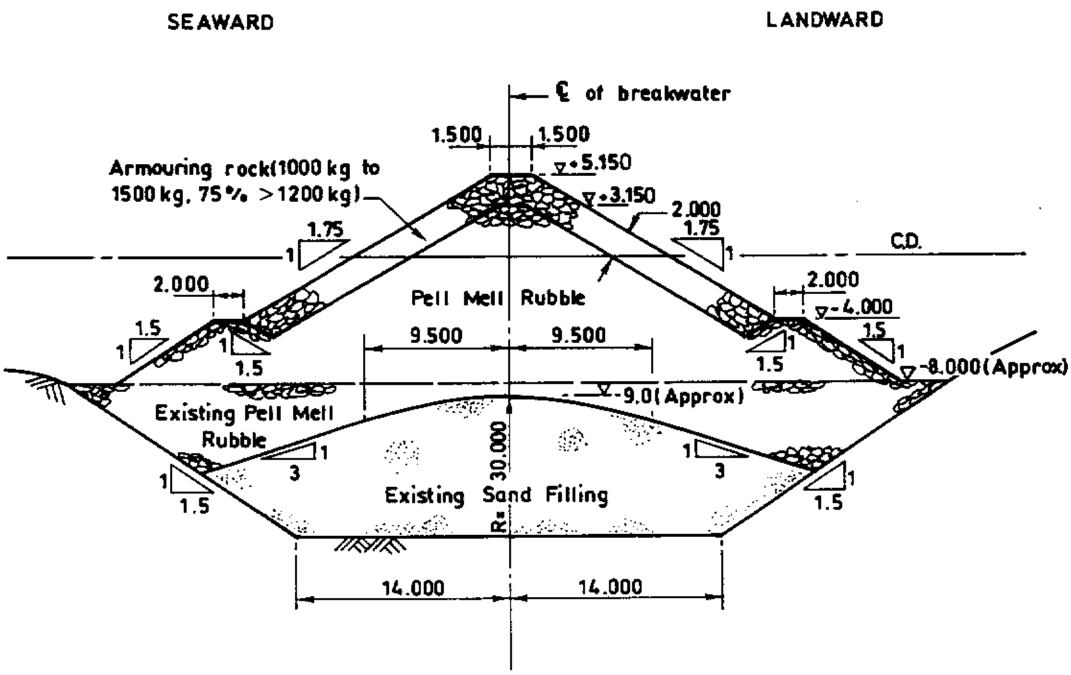


(a) Chaiwan

Scale 1 : 500

Note : All dimensions are in metres

Figure 2 - Typical Breakwater Sections (Sheet 1 of 2)



(b) Stonecutter

Scale 1 : 500

Note : All dimensions are in metres

Figure 2 - Typical Breakwater Sections (Sheet 2 of 2)

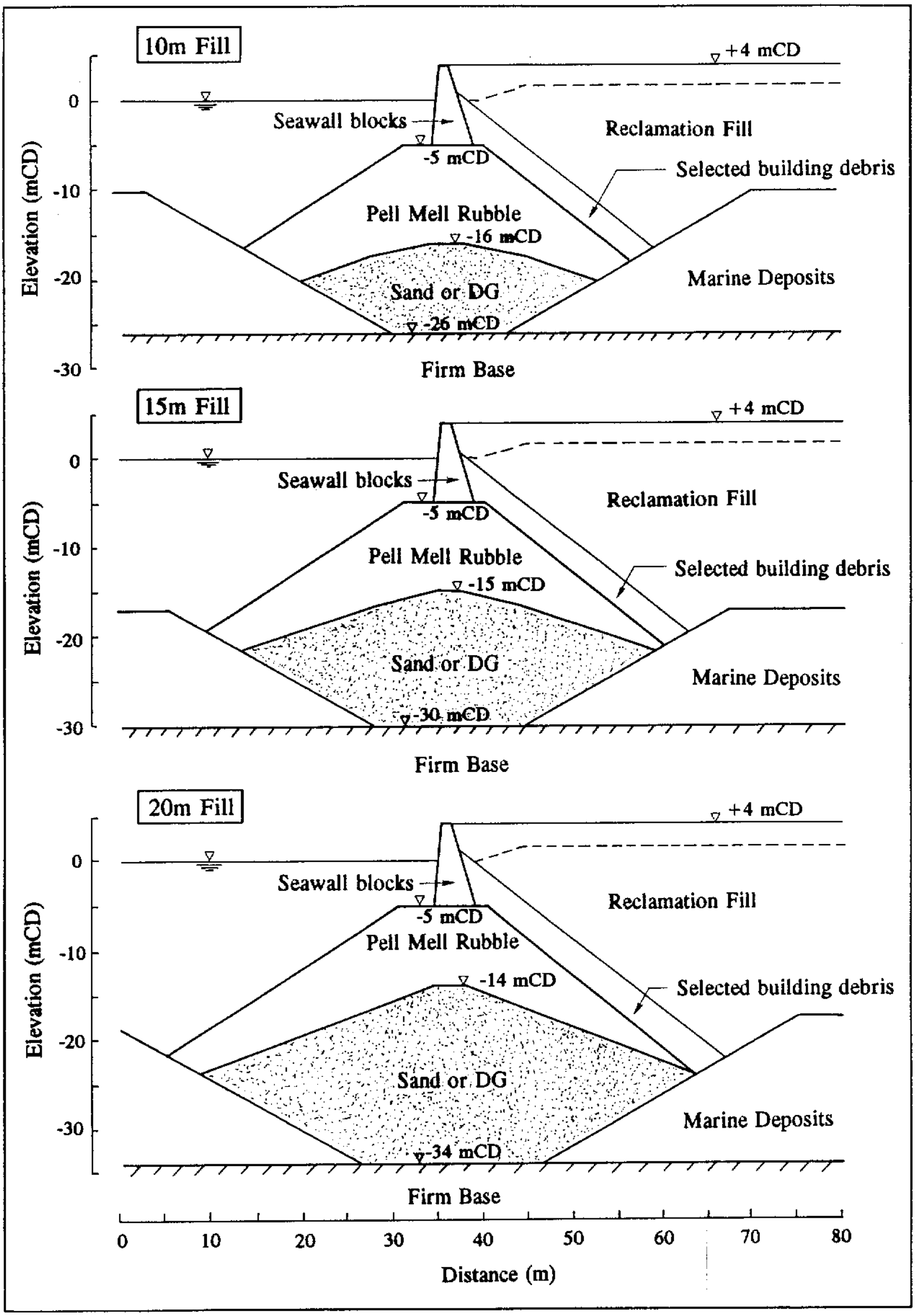


Figure 3 - Idealized Seawall Sections for Stability Analyses

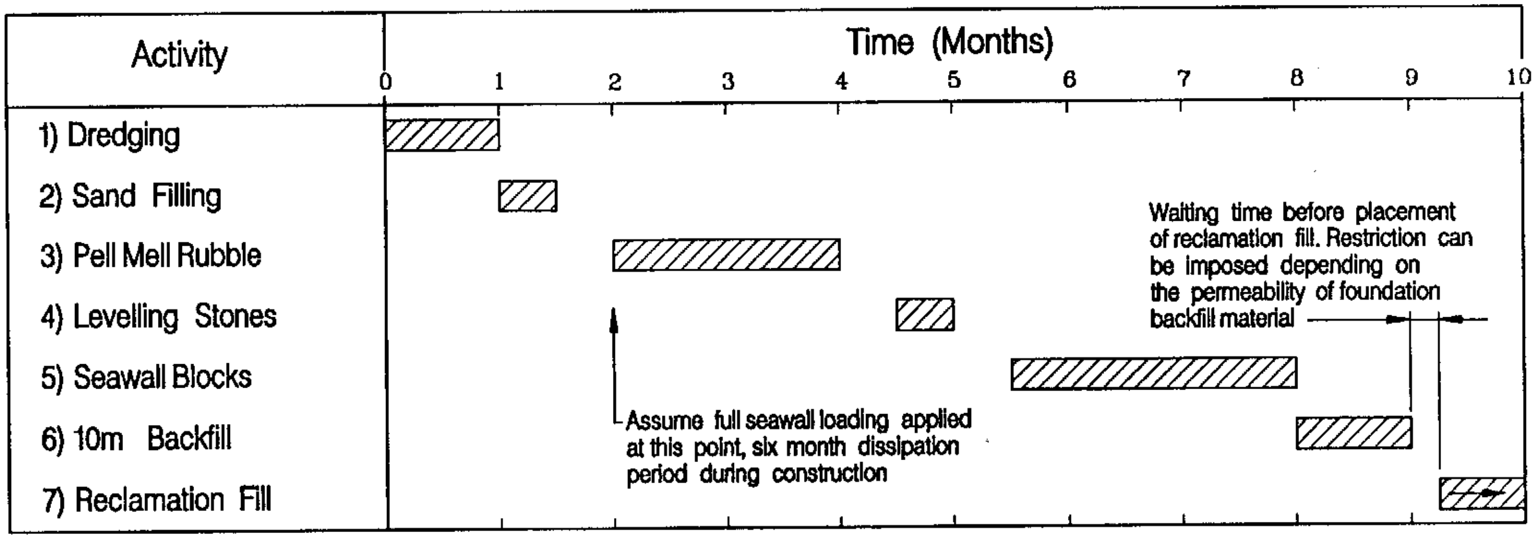
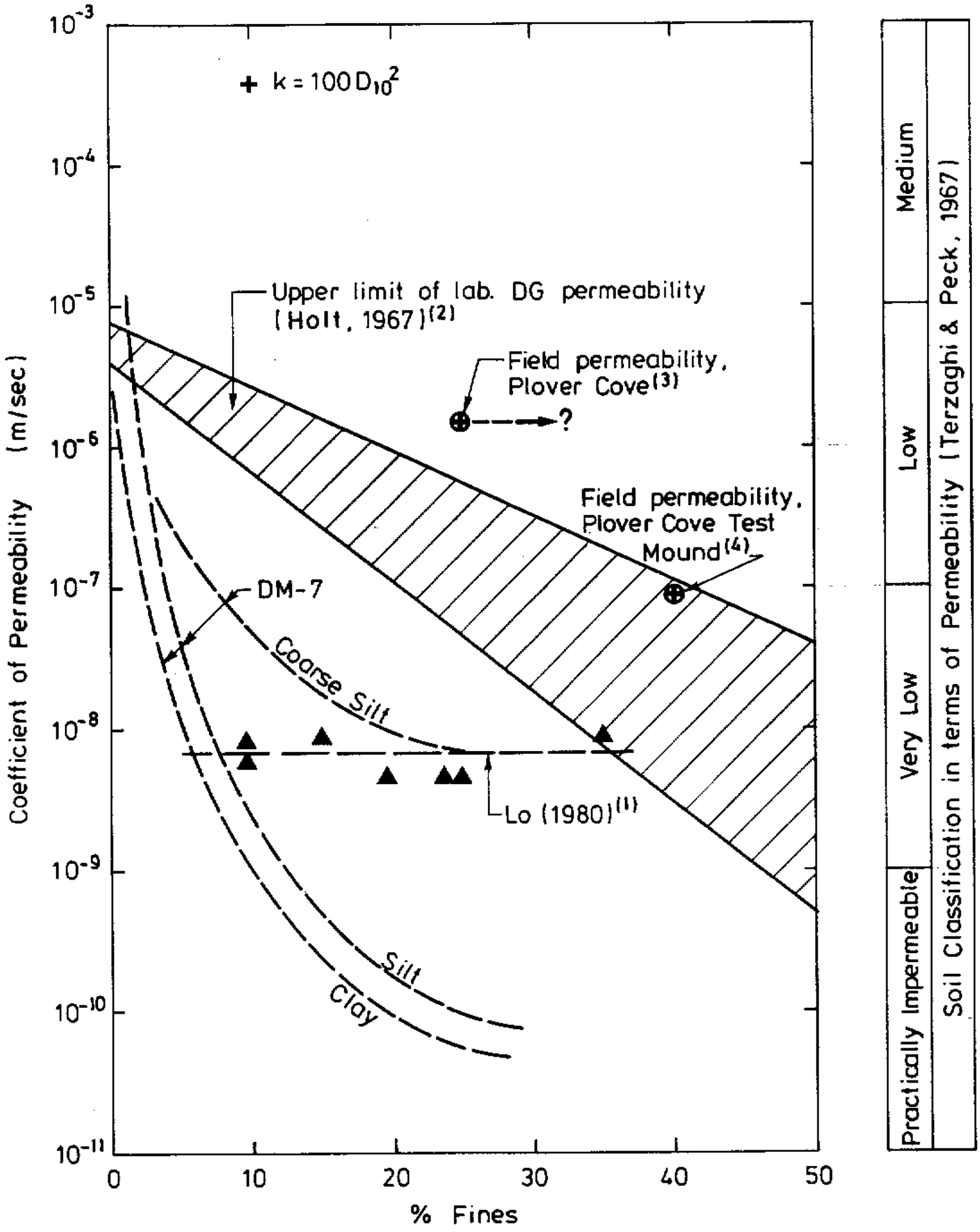
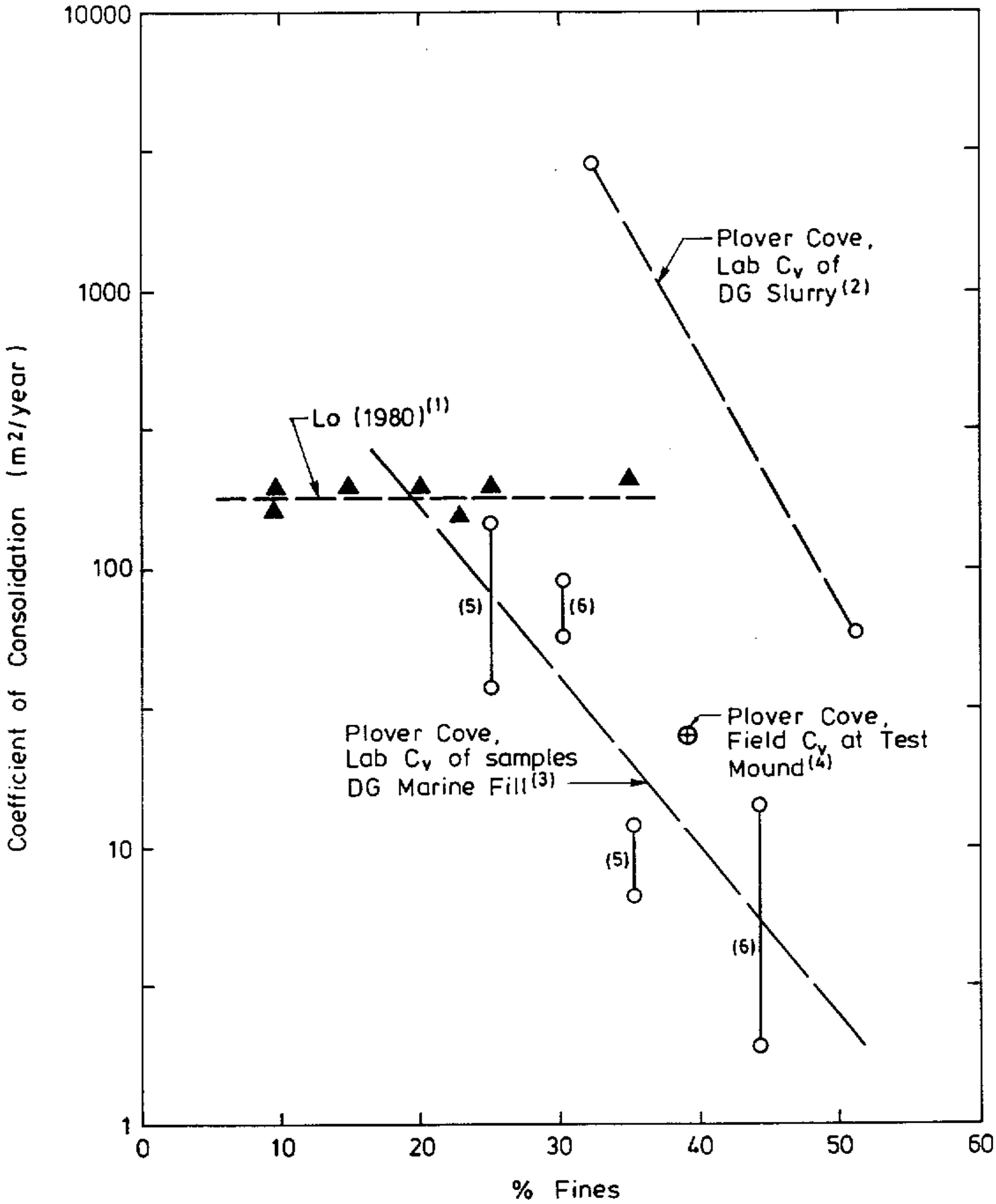


Figure 4 - Bar Chart of Typical Sequence of Seawall Construction



Notes :
(1) Average values for lab. permeability, 100kPa < $\overline{\sigma_v}$ < 500kPa.
(2) 0.55 < e < 0.75.
(3) Data from Holt (1967) plotted at 25% Fines.
(4) Data from Guildford & Chan (1969).

Figure 5 - Permeability of Decomposed Granite Marine Fill



Notes : (1) Average values for 100kPa < $\overline{\sigma}_v$ < 500kPa.
(2)
(3) Data from Guildford & Chan (1969).
(4)
(5) Samples from Test Mound.
(6) Samples from Completed Embankment.

Figure 6 - Coefficient of Consolidation of Decomposed Granite Marine Fill

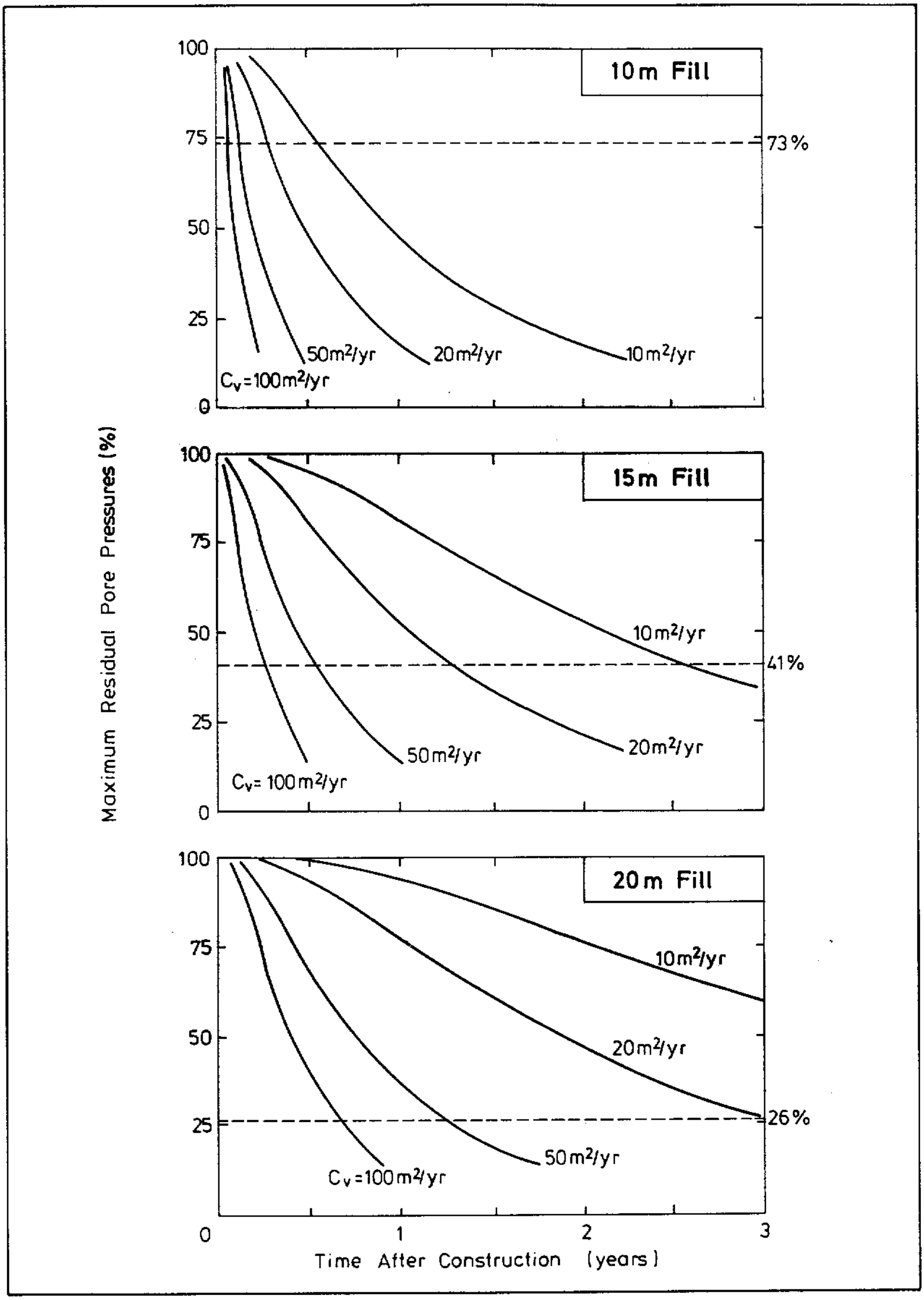


Figure 7 - Estimated Maximum Residual Pore Pressure for Different Foundation Backfill Thicknesses

Materials	c' (kPa)	ϕ' (deg)	γ (kN/m^3)
1) Seawall Blocks	0	45	24
2) Pell Mell Rubble	0	45	20
3) Reclamation Fill	0	30	19
4) Building Debris	0	35	18
5) Sand or DG	0	30	19

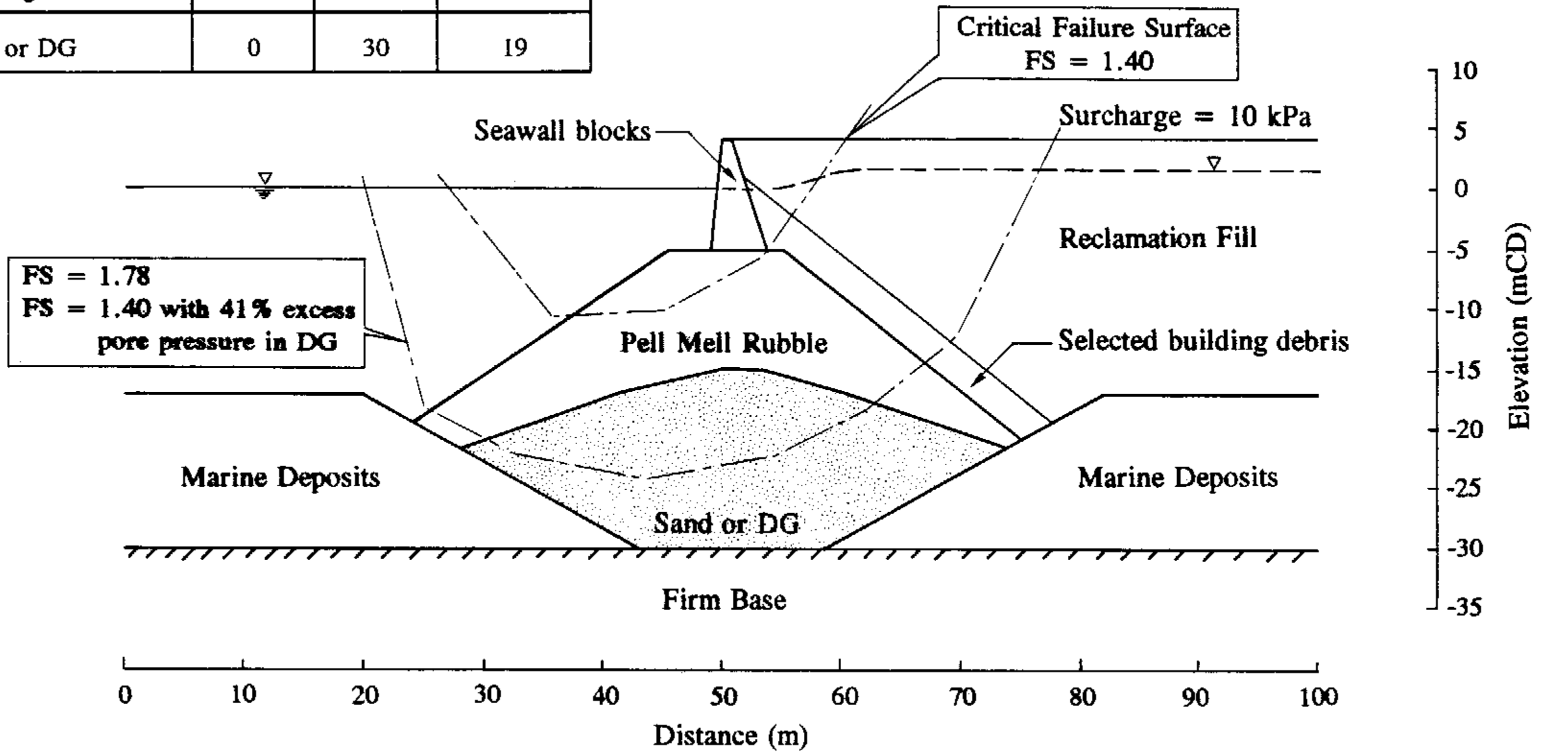


Figure 8 - Stability Analyses of Seawall with 15 m Foundation Backfill

Materials	c' (kPa)	ϕ' (deg)	γ (kN/m³)
1) Seawall Blocks	0	45	24
2) Pell Mell Rubble	0	45	20
3) Reclamation Fill	0	30	19
4) Building Debris	0	35	18
5) Sand or DG	0	30	19

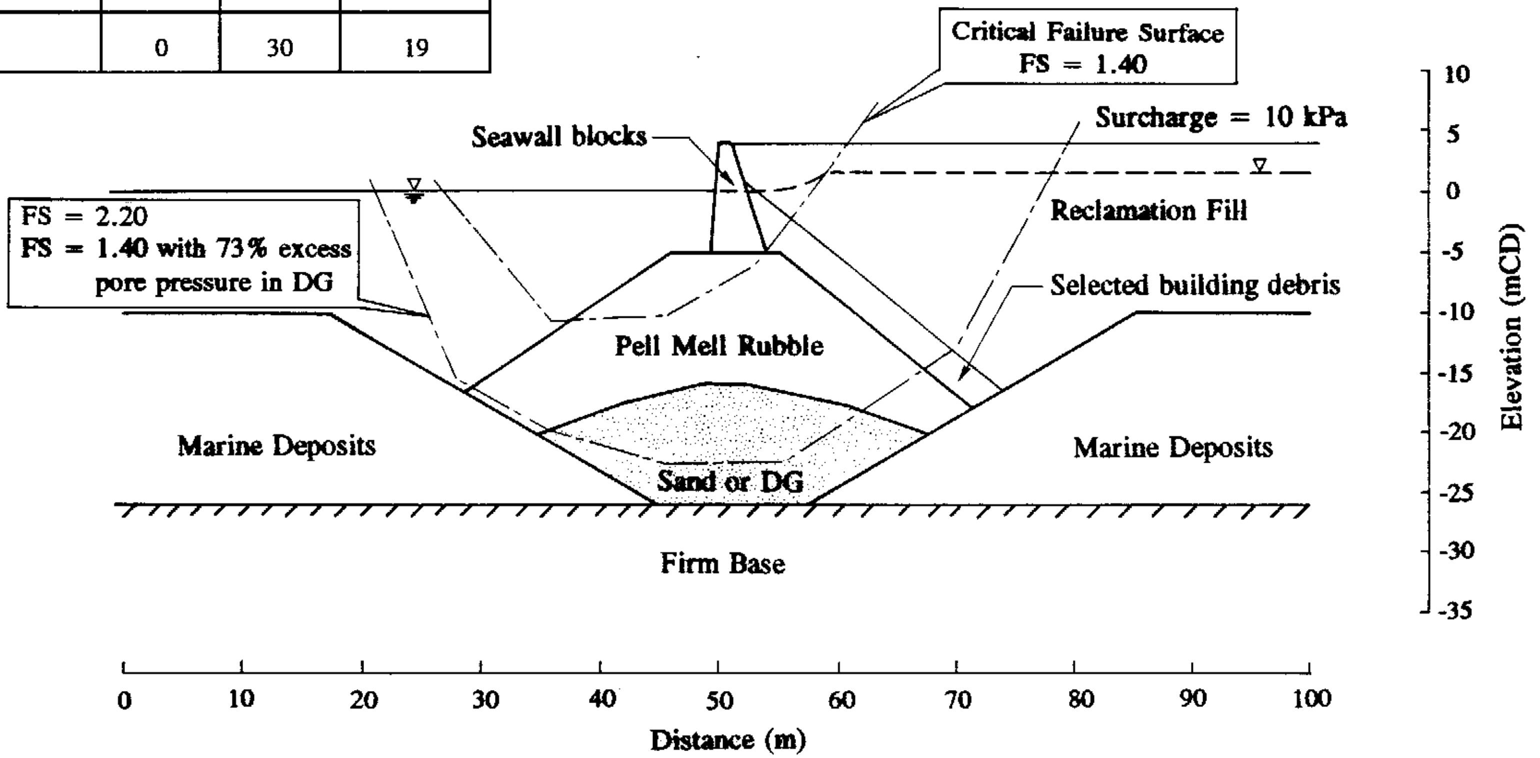


Figure 9 - Stability Analyses of Seawall with 10 m Foundation Backfill

Materials	c' (kPa)	ϕ' (deg)	γ (kN/m^3)
1) Seawall Blocks	0	45	24
2) Pell Mell Rubble	0	45	20
3) Reclamation Fill	0	30	19
4) Building Debris	0	35	18
5) Sand or DG	0	30	19

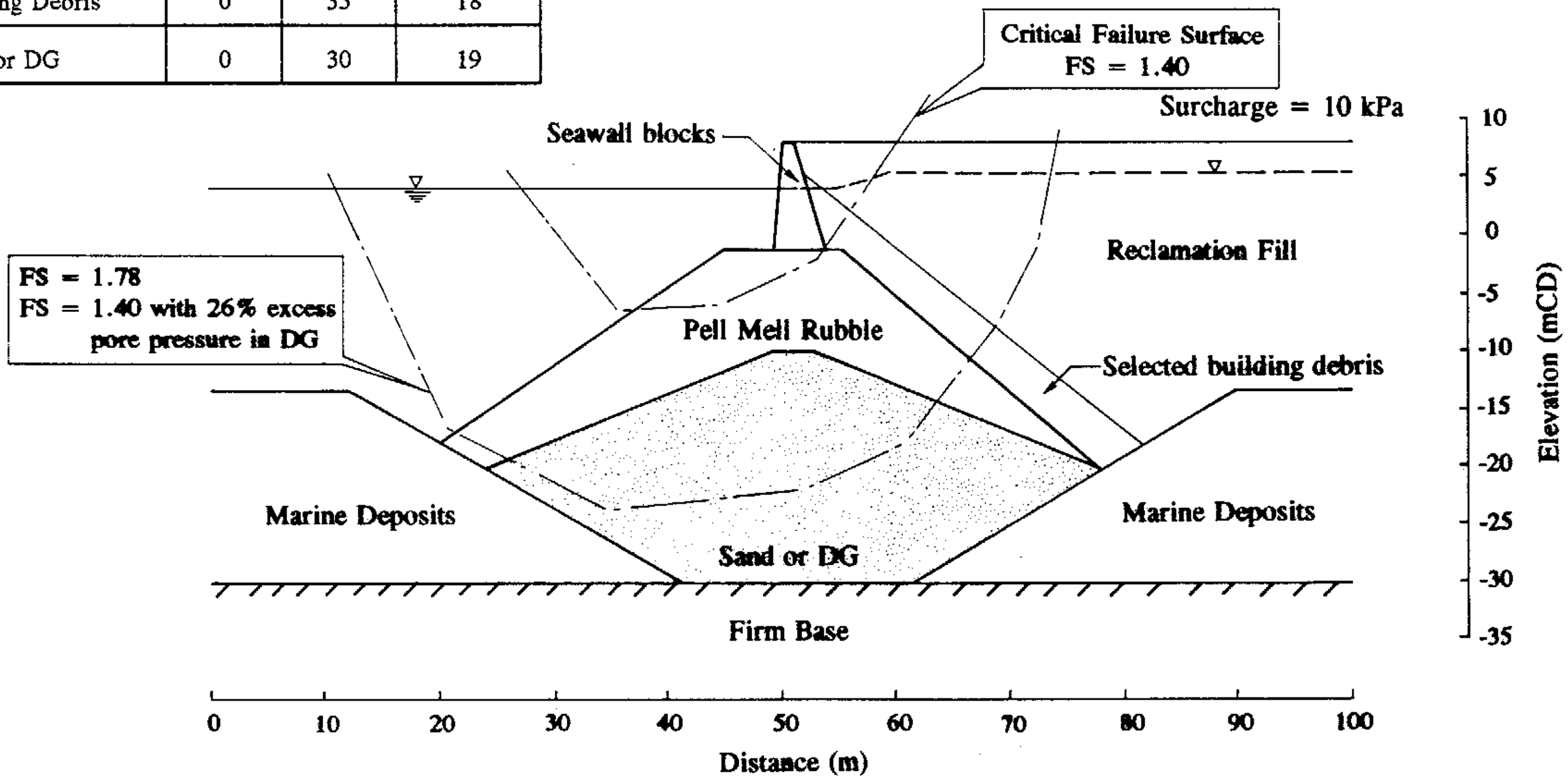


Figure 10 - Stability Analyses of Seawall with 20 m Foundation Backfill

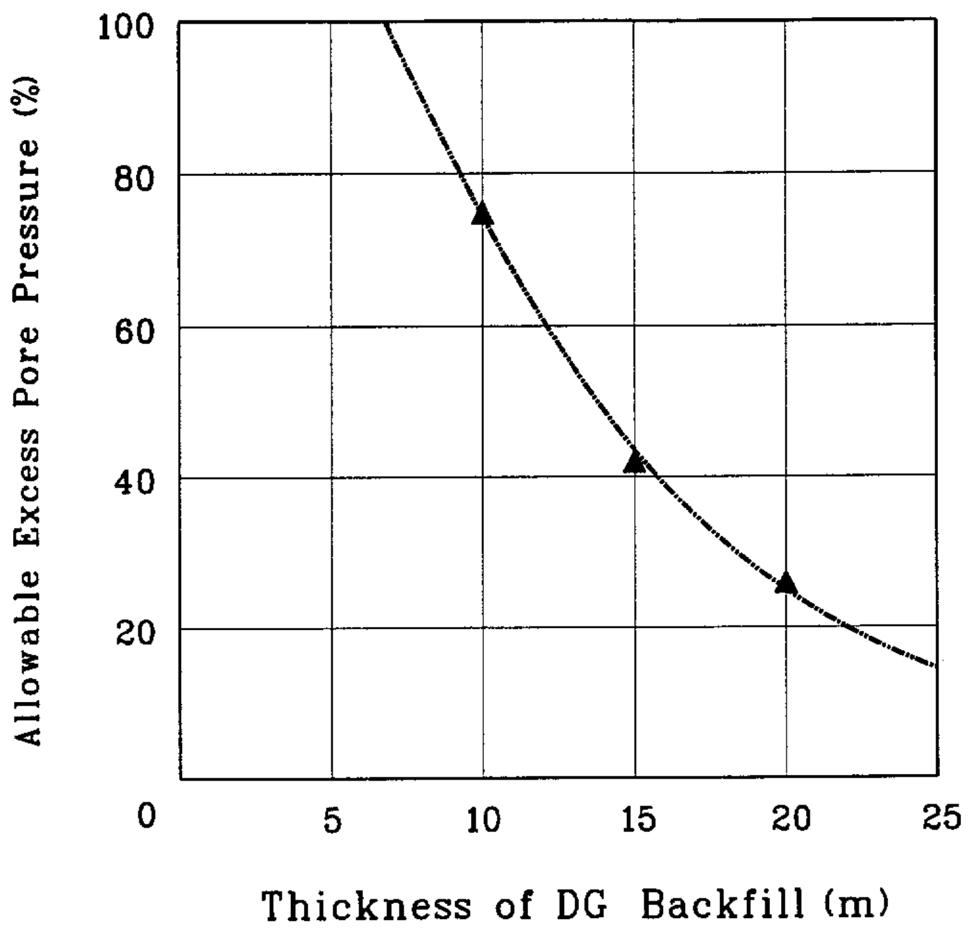


Figure 11 - Allowable Excess Pore Pressure for Different Thicknesses of DG Foundation Backfill

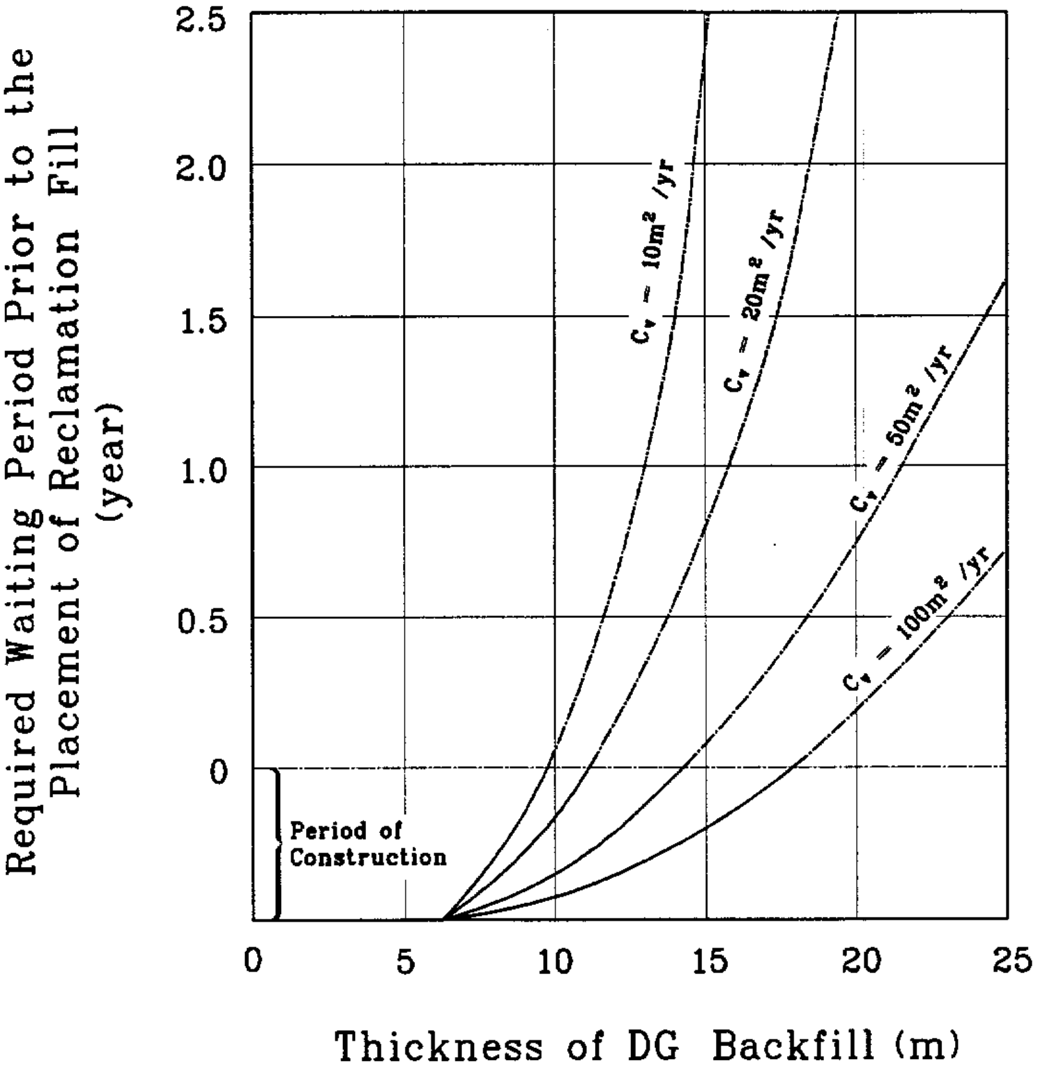


Figure 12 - Required Waiting Period Prior to the Placement of Reclamation for Different Thicknesses of DG Foundation Backfill

Materials	c' (kPa)	ϕ' (deg)	γ (kN/m^3)
1) Seawall Blocks	0	45	24
2) Pell Mell Rubble	0	45	20
3) Reclamation Fill	0	30	19
4) Building Debris	0	35	18
5) Sand or DG	0	30	19

Stage	Excess Pore Pressure (%)	Factor of Safety
a) End of Construction of Seawall	45	0.9
b) Placement of 10 m Reclamation Fill	45	1.65

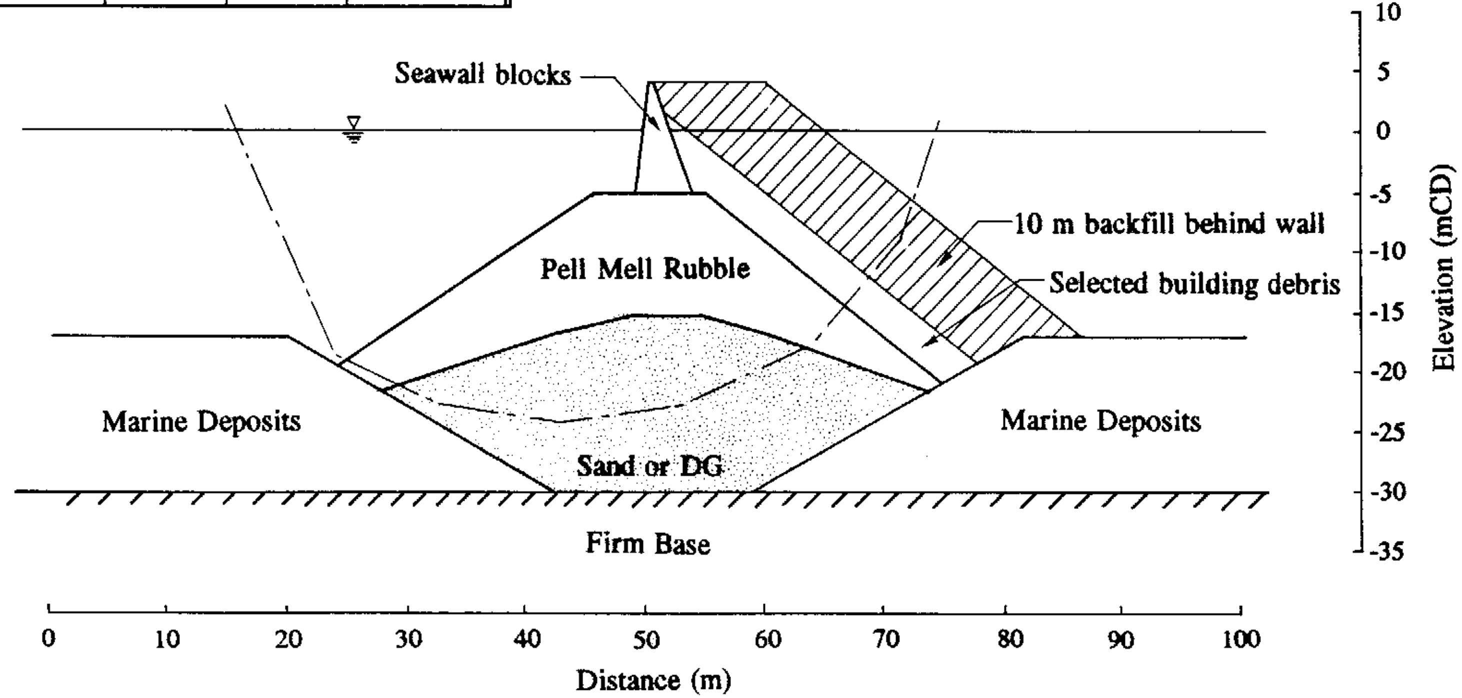


Figure 13 - Stability during Construction

Materials	c' (kPa)	ϕ' (deg)	γ (kN/m^3)
1) Seawall Blocks	0	45	24
2) Pell Mell Rubble	0	45	20
3) Reclamation Fill	0	30	19
4) Building Debris	0	35	18

Thickness of DG Fill (m)	Excess Pore Pressure (%)	Assumed Undrained Strength (kPa)	Factor of Safety
10	73	15	1.20
15	41	35	1.12
20	26	45	1.05

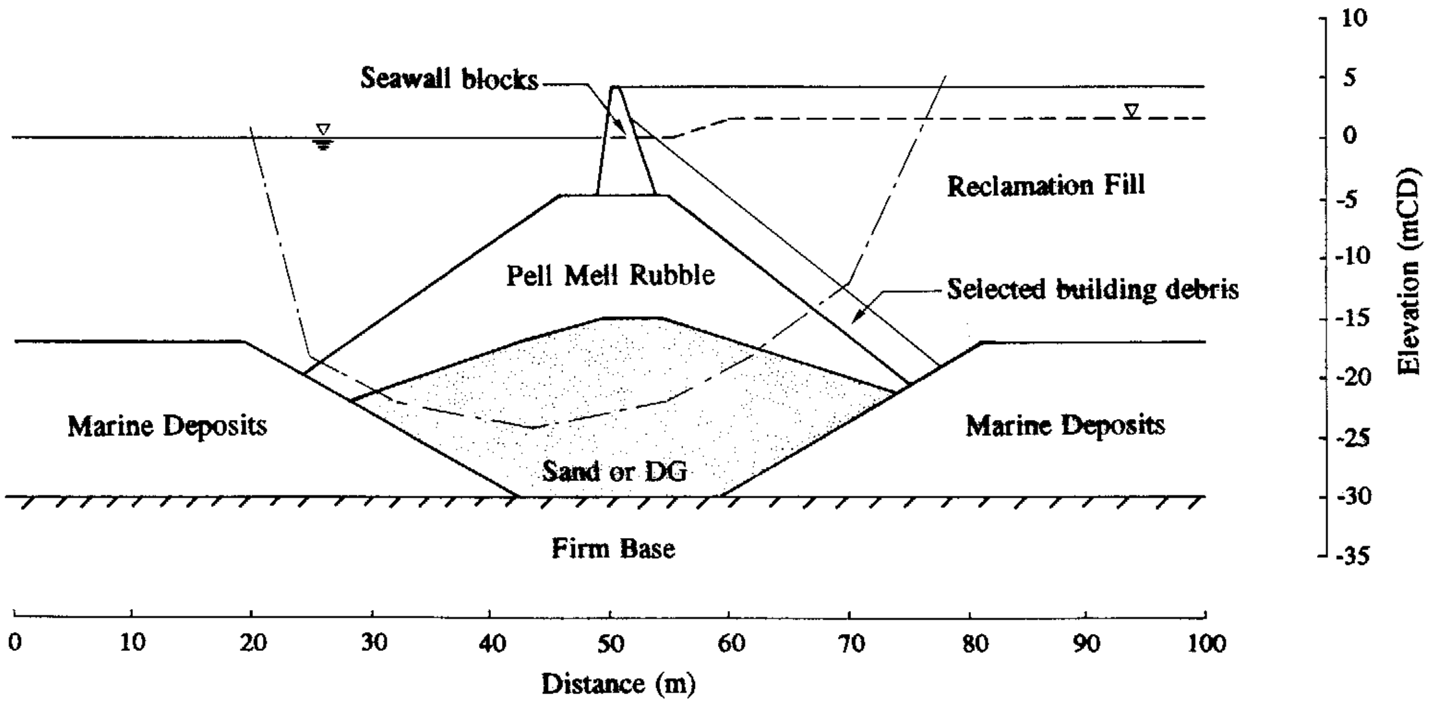


Figure 14 - Undrained Factors of Safety for Seawall