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Environmental Demands and their Effects on Design

Exigences de l'environnement et conséquences sur le projet

Umweltanforderungen und ihre Auswirkung auf den Entwurf

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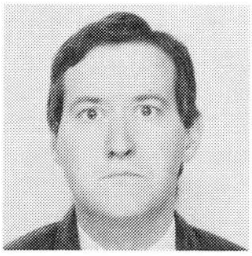

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SUMMARY

The paper describes how careful engineering in the Great Belt Link project has reconciled environmental criteria for the earthworks with purely constructional demands. The dredging materials have been re-used in ramps, causeways, and dikes, instead of being dumped, even if they were classified in-situ as unsuitable for construction purposes. The unsuitable materials have been converted to acceptable fill by grain sorting, the production of suitable fill from the unsuitable materials being explained in detail. Finally, the type of earth structures built and the special quality control are described.

Exigences de l'environnement et conséquences sur le projet

Résumé

Une étude d'ingénierie soignée pour la liaison du Great Belt a permis de réconcilier des critères de l'environnement pour les travaux de terrassement avec des exigences purement constructives. Les matériaux dragués ont été réutilisés pour des remblais de routes et de digues au lieu d'être jetés à la mer, même si ils étaient inutilisables pour la construction. Les matériaux non appropriés ont été améliorés par filtrage et séparation des agrégats. La méthode utilisée est expliquée dans le détail. Les types de structures en terre construites et les différents contrôles de qualité sont décrits.

Umweltanforderungen und ihre Auswirkung auf den Entwurf

Zusammenfassung

Der Artikel beschreibt, wie sorgfältig Ingenieurarbeit beim Grossen Belt Projekt die Umweltkriterien für die Erdarbeiten mit den Anforderungen seitens der Bauausführung in Einklang brachte. Das ausgebaggerte Material wurde bei Rampen, Dämmmen und Deichen wiederverwendet, anstatt es zu deponieren, und zwar sogar dann, wenn es als für konstruktive Zwecke unbrauchbar eingestuft wurde. Wie im Detail erklärt, wurden die unbrauchbaren Materialien durch Kornfraktionierung in brauchbares Auffüllmaterial umgewandelt. Schliesslich werden die Arten der Erdbauwerke und die spezielle Qualitätskontrolle beschrieben.

1. INTRODUCTION

This paper presents some of the effects of environmental demands on the design and construction of the Great Belt Link in Denmark. The sensitive environment of the Baltic has dictated that the water exchange through the Great Belt to the Baltic shall remain unchanged in spite of the constrictions imposed by the causeways and bridge piers of the link. This is achieved by increasing the constricted flow cross section of the link by dredging.

Since the 17 km link for part of the length consists of causeways and earth ramps (up to 25 m high) it was obvious that the dredged materials should be reused in the earth works, thus achieving a perfect soil balance completely as when building railroads where soil dug out in the hills is used as fill in the embankment. Thus the environmental demands become completely reconciled with the constructional demands. Some local environmental effects were of course foreseen due to the dredging but they were completely immaterial compared with the greater issue of maintaining the environment of the Baltic.

Because of the above considerations the earthworks and causeways were put out for tender under the constraint that they should be built of the dredged materials. The causeways and ramps midway at the link (Sprogoe) are shown in Fig. 1.

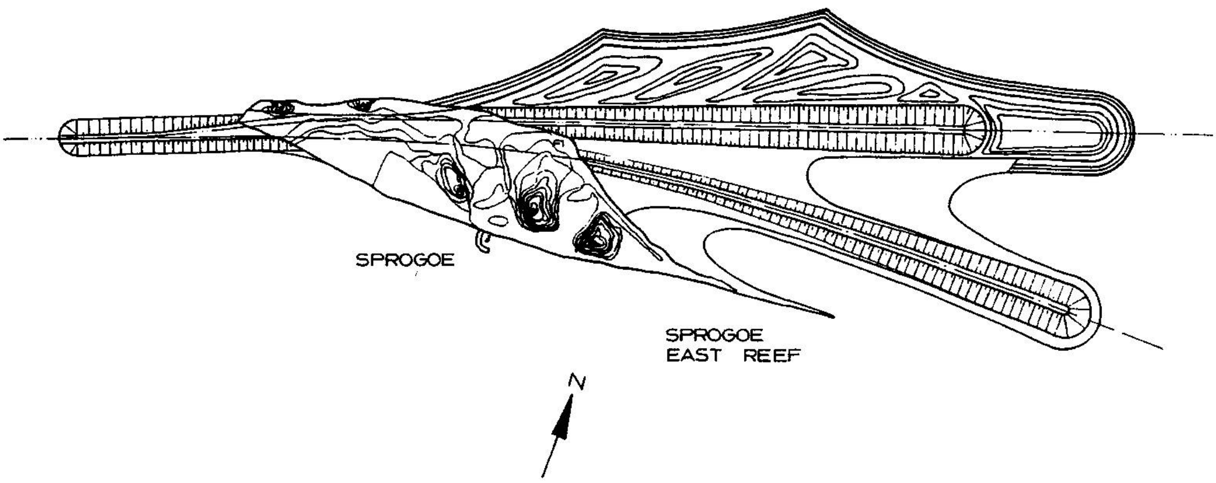

Fig. 1 Final earthworks in the middle part of the Great Belt Link (Sprogoe).

The materials to be dredged are for the smaller part late and post glacial materials and for the greater part hard glacial materials (moraine till) with typical in-situ shear strength between 100 kN/m2 and 400 kN/m2. Due to the large content of hard clay it turned out that the tenderers did not believe that the work could be made by reusing the dredged materials. As one Contractor put it during a pretender meeting "Do you really yourself believe that 25 m high ramps can be built in the Danish winter with dredged moraine clay"? Well, the Great Belt Link Company and the authors believed it and this paper describes how the work was successfully executed completely as intended.

Part of the soils to dredge were excellent fill materials and were of course directly used in the filling of the causeways and the ramps. These soils was dredged by the hopper suction dredger and directly pumped into the ramps and dikes of the islands in the middle of the Great Belt (Sprogoe).

Another part of the soils to dredge were soft organic materials which could not be used for construction. On the other hand if they were dumped in the sea they might have enhanced the lack of oxygen in the lower strata of the Great Belt. Therefore these soils were deposited in sedimentation basins placed within the confines of the island Sprogoe, Fig. 2. Besides being storage basins

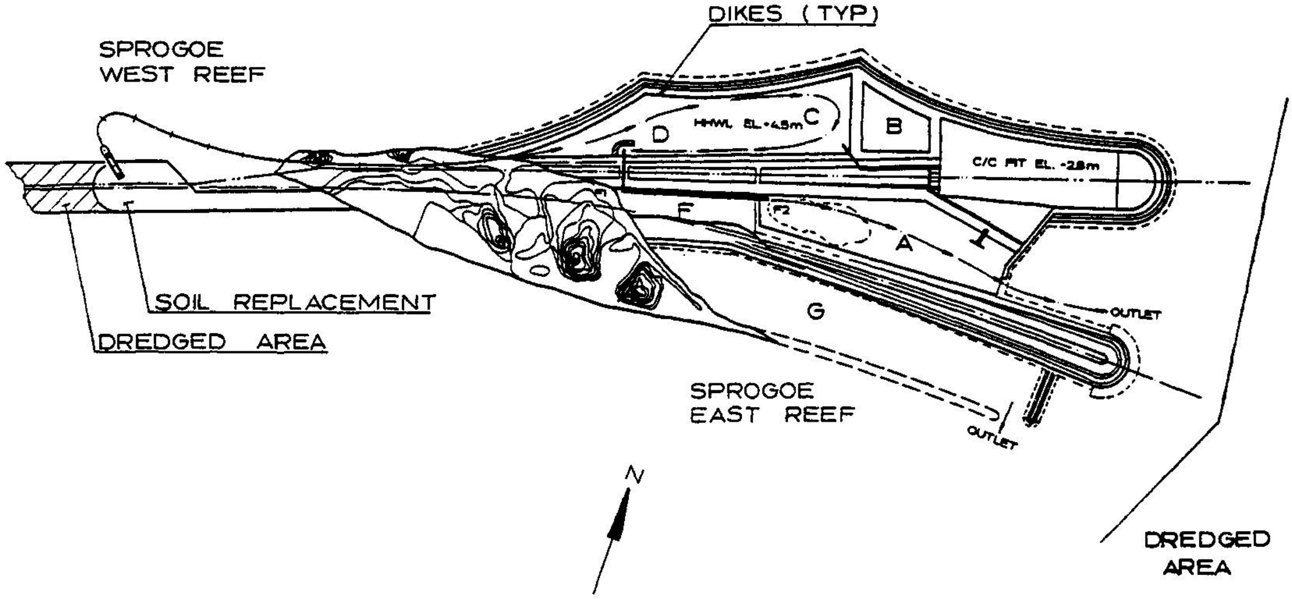

Fig. 2 Sedimentation basins at Sprogoe.

the completed basins, when filled with materials and regulated to final shape, would serve as barriers against water intrusion into the tunnel ramps. The soft organic materials were dredged by means of cutter suction dredger and the materials were pumped in slurry to the basins. Even though the materials had some cohesion they were broken down in the flow through the pipeline into clay balls, gytje balls, stones, gravel, sand, silt and clay. At the outlet the broken down materials were separated such that the coarser fraction was deposited close to the pipe outlet, whereas the finer particles were carried away with the flow and deposited in the center of the basins. The coarser fractions were in fact excellent material and were used to increase the height of the dikes around the sedimentation basins and for filling in the dike structures. In fact the sorting mechanism was so effective that in certain areas the material became coarse sand and gravel which was used as frost upheaval ballast for the expressway.

The greater part of the fill materials were used in the high ramps. The dredge materials available for this fill were sand and moraine clay. These materials were dredged with cutter suction dredger and pumped in slurry into the ramps and the areas to be reclaimed. In the flow through the pipeline the materials were broken down in clay balls, stones, gravel, sand, silt and clay. By regulating the retention times in the reclamation and ramp basins the fill could be produced exactly to specifications. The spill water with dredgeate was let out into a secondary sedimentation basin (G or A in Fig. 2) for final clearing of spill water before being let out into the Great Belt.

The produced material was called engineered fill and was used for the construction of the 25 m high ramps In fact the materials were directly jetted in up to elevations above +20 m.

2. PREVIOUS WORK

A large number of projects have been executed in the past where clayey or silty materials have been dredged and used for fill in structures. Examples are the Logan Airport in Boston, Roberts Bank Offshore Island, Johansen and Birkland (1980) or Halmstad in Sweden in 1978, Hartlen and Ingers (1987). The reclamation of the Roberts Bank Offshore Island expansion in Vancouver, BC, Canada, was made with cutter suction dredger pumping in-situ silt into the main reclamation at the outlet. The dredgeate was either let directly to sea or carried to deeper areas by a pipeline. The similar work made in Halmstad, Sweden, was a forerunner of the reclamation of Sprogoe dredging moraine clay by cutter suction dredger and jetting it into a reclaimed area.

The novel feature of the present project is that the material is directly used in the well defined structures such as 25 m high ramps with steep slopes (1:2) and in water retaining dikes and not just in reclamations of diked areas.

3. THE FIRST STEPS

3.1 Introduction

The first steps for reusing the materials were made due to the demand for storage volume in the sedimentation basins midway on Sprogoe Island . Since the perimeter was already built the only possibility was to increase the height of the dikes around the basins. The operation was not without risk because the water level in the basins had to be raised to El. +4.5 m at the same time as the adjacent cut and cover tunnel was built in a dry pit at El. -28 m.

3.2 The Material

The suitable material which were used are presented in Table 1. It demonstrates the separation of the materials, originally being gytje and clay, into an artificial sand material, the Engineered Fill.

The large contents of silt and clay in the samples presented in Fig. 1 are deceptive, because the clay and the silt and even the gytje occur in clumps in the otherwise quite coarse material. These clumps are quite hard and behave as stones in a mix and consequently the material behaves as sand. It is seen that the material is very heterogeneous.

Sample No.	d50 mm	d60/d10	0.074 mm	16 mm	32 mm	Organic content
In-situ	0.01	70	92%	100%	100%	5.0%
In-situ	0.10	18	35%	100%	100%	3.0%
1	0.50	60	18%	97%	100%	4.6%
2	0.5	8.75	10%	95%	98%	3.0%
3	0.35	3.5	5%	100%	100%	3.5%
4	0.22	3.75	8%	98%	100%	2.8%
5	0.17	3.0	11%	100%	100%	3.0%
6	0.35	2.7	3%	95%	98%	2.7%
7	0.15		17%	100%	100%	2.5%
8	0.42	3.33	3%	99%	100%	3.0%
9	0.15		15%	99%	100%	3.6%
Mean	0.31	>9.4	10%	98%	100%	

Table 1 Soil samples taken from the Sprogoe West Reef and from the coarse part of materials jetted into basin D (1-9).

3.3 Construction of the Dikes, Principles

The construction of the dikes was made by excavating the materials in the basins, transporting them out, and placing them with dumpers. Bulldozers were used for final shaping. In certain areas the dikes were built directly on deposited unconsolidated sludge which was displaced currently by the overburden.

The dikes built in these rather miscellaneous materials were supposed to sustain a water level of 3 m. The inhomogenity was too large to introduce rigorous quality control by inspection. Instead the dikes were built as prescribed but with a certain tilt of the downstream slope. A tilt of 1:2 was chosen because in case of heavy load the first area to slide was the foot of the slope. This sliding was therefore the indicator of the weak spots. When the sliding started there was a safety of 1.8 against complete dam break. Hence during the rising of the water levels and the depositing of the materials the downstream slope was monitored and every time a slide at the foot of the dike was observed a doubling of the dike width was made in the particular areas. This was far more economical and easier in execution than introducing all kinds of geotechnical tests. All compaction was made by the work traffic of the construction vehicles. By this a SP value of 92% was reached.

It turned out that only three times it was necessary to repair the dikes and that these repairs were only a matter of a few hours.

4. TEST WITH PRODUCING OF ENGINEERED FILL FOR RAMPS

4.1 General

The fine results with dikes built by Engineered Fill led of course to the consideration that the method could be used for the ramp construction of the 25 m high ramps. In order to test whether it was possible a number of field tests were made with dredged moraine clay or with a dredged mix of sand and moraine clay. The ratio between sand and moraine clay was highly varying. The basic problem was that the content of silt and clay in the moraine clay is between 50% and 60% and has to be washed out and reduced to below 15% in order to be sufficiently draining for stability and work purposes.

4.2 Execution of Tests

The tests were simply executed by pumping the materials into a corner of an already completed reclamation. Initially the elevation of the outlet was low, approx. 2 m above the ambient water level. Part of the deposited fill was satisfactory i.e. rapidly draining material, but in a corner a dead area with very fine and swampy material was formed. There could be two reasons for that - first that the dredged material was very clayey, or second, there was too small momentum in the flow in the reclamation basin. It turned out that the latter reason was the reason. Elevating the outflow to El. +4.0 m creating a steep incline for the flowing water raised the sediment carrying capacity of the run-off such that the fines effectively were washed out and a good stable material was deposited.

The steep incline was the key to control the wash out of the fines because when th flow became supercritical (wavy surface) then the transport capacity for the suspended sediment was very high. Therefore if the clay and silt fraction in a dredged material is high then the run-off incline shall be steep.

The strong moraine till dredged resulted in a rather high percentage of stones, gravel, and clay balls which settled in the immediate vicinity of the outfall of the pipeline and quickly created heaps in front of the pipeline. Some of the clay balls were transported further downstream in the reclamation basin and created local heaps which could trap some clay and silt in dead zones. In order to release these silt and clay pockets the deposited material was regularly plowed with bulldozers. However, especially for the engineered fill it turned out that this plowing operation should be kept at a minimum, because the load of the bulldozer tracks tend to smash and remould the clayballs after repeated crossings, hereby creating a more silty - and thereby less draining material. In the end a suitable compromise with respect to plowing was reached.

The heaps of clay balls creating in front of the outlet had to be removed. Using bulldozers the clay balls were kneaded and the material dozed aside became muddy with a behaviour like fresh concrete with high water content. Settling and draining of the rehandled material took rather long time when placed with an almost horizontal surface but it was possible to heap up the material and thereby improve the draining conditions. Alternatively a backhoe was used to remove the clay balls. Hereby a heaping up of the material was easily achieved. When the heaped material was drained it formed an excellent material especially when there was sufficient sand materials to fill the voids between the clay balls.

When pumping operations stopped excavation in the run off area could easily be performed and the settled material was used to create bunds to guide and concentrate the run off to avoid settlement of fines. The settled material was very densely compacted by the strong vertical downwards seepage through the fill. Here again the advantage of jetting in the fill on a steep incline showed up, because the incline produced large hydraulic gradients for this seepage.

The seepage could of course disturb the stability of the bund by creating quicksand at the downstream slope and thereby generate slides. This was solved by building the ramps in terraces with bunds of 4-6 m height and then use the quicksand formation of the foot of the bunds at the terraces as indicators for dam break as described in section 3.3.

From time to time some quicksand and well formations were formed and the water started to run. However, here the gravel content of the fill of 3-5% helped in sealing up the small gorges made by the wells thus making them stable.

By such operations of pumping and excavation it was possible to construct the Eastern Ramp almost completely by means of hydraulic filling up to level +20 m without any damaging slip failure of the outer slopes.

When the hydraulic filling was completed compaction tests were made which proved that very high density was achieved and that there was no need for further compaction for fulfillment of the requirements. It appeared that even deposits of coarse silt (80-85% passing the 0.078 mm sieve) were compacted to more than 100% Standard Proctor by means of the accretion in streaming water. The deposits could without further compaction function as substructure for the motorway and railway of the Great Belt Link.

As can be understood there was no on-line testing of the material and its compaction because the execution method itself did the work. This kept the work simple which was essential when the filling in rate was 1600 m3/h (cutter suction dredger, Leonardo da Vinci). Only the compaction in the upper 2 m layer was documented.

5. CLASSIFICATION OF FILL, QUALITY CONTROL

5.1 Classification of Soil

Reverting to Table 1 the materials deposited in the basins could be classified as sand, but with a relatively large content of clay and silt. A large part of the clay and silt, however, were trapped in the clay balls which have maintained their original shear strength of 100-400 kN/m3. For some part of the soft deposits even gytje balls had survived the transport. A more realistic classification of the material was therefore to take the clay and gyttje balls out (as stones) and then put the rest of the material through a sieve analysis. The problem was of course then to define when the balls of clay, gytje and silt should be classified as stones and when they should be classified as loose material.

The problem was solved by executing the sieve analysis in the following way:

1. The material was disintegrated with finger rubbing. Finger forces were used to crush the different clumps, but no more. If the clumps (>16 mm) did not disintegrate they were classified as stones and taken out of the sample together with the stones. These clumps were then referred to as clay balls. No mechanical milling or grinding of any of the clay/ silt/gytje clumps took place.

2. The material <16 mm was dried at 60 degrees C.

3. The above material was sieved (without washing) and the grain size distribution was determined.

5.2 Compaction

Standard Proctor tests of the above material proved to be meaningless, because of the large inhomogenities in the material. Therefore the final documentation of compaction was based on:

1. Water content
2. Dry weight of material (of samples spanning the clay balls).

The water content was kept below 14% and the dry weight of the material should be either above 18 kN/m3 or 19 kN/m3 depending on the compaction specification.

The problem was to measure the dry weight. Taking up a volume and drying it was easy enough, but the volume had to be large (400x400x400 mm3). The in-situ volume determination would on the other hand have been very inaccurate. The method was therefore not considered viable. Therefore the only method left was the isotope method (Troxler). This method, however, had to be modified because the instrument was close to being too small for the inhomogenities in the material.

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REFERENCES

HARTLEN J. and C. INGERS, Use of Dredged Clay for Land Reclamation. Proceedings Baltic Conference on Design, Construction and Maintenance of Harbour Structures. Norrkoeping, Sweden, Sept. 24-25, 1987.

JOHANSEN, C. and O. BIRKELAND, Expansion Plans for the Roberts Bank Offshore Island Port Facilities, World Dredging Conference, 1980.