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Planning and Design of Trans-Tokyo Bay Highway
Projet de l'autoroute sur la Baie de Tokyo
Projektierung und Entwurf der Autobahn über die Bucht von Tokio

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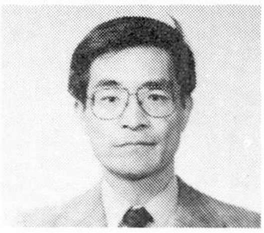

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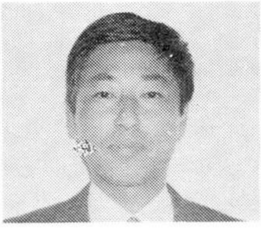

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SUMMARY

As the first phase of an ambitious plan to directly cross the Tokyo Bay over a 15km distance, the Trans-Tokyo Bay Highway Project was approved by the Government to proceed with participation of the private sector. The project scope is far beyond that of conventional ones, and the structures will be constructed in the Bay of an area 20kmx50km where surface traffic is busy, fisheries are active, and the likelihood of large-scale earthquakes is high. Therefore, impacts on the Bay environment by the construction activities were carefully studied to select optimum design and construction method whereby the environment would be best protected.

Projet de l'autoroute sur la Baie de Tokyo

Résumé

La première phase d'un projet ambitieux destiné à traverser directement la Baie de Tokyo sur une distance de 15 km a été approuvée par le gouvernement. Il prévoit la participation du secteur privé. Ce projet va bien au-delà des projets conventionnels et les constructions projetées concernent une surface de 20km x 50km avec un traffic de surface conséquent, des pêcheries actives et une probabilité élevée de tremblements de terre. C'est pourquoi l'influence des activités de construction sur l'environnement de la Baie a été étudiée avec soin afin de choisir les projets et les méthodes de construction protégeant au mieux l'environnement.

Projektierung und Entwurf der Autobahn über die Bucht von Tokio

Zusammenfassung

Als erste Phase eines ehrgeizigen Planes, die Tokioter Bucht über eine Entfernung von 15 Kilometern direkt zu überqueren, wurde durch die Regierung gebilligt, das Trans-Tokio-Bay-Highway-Projekt unter Beteiligung der Privatwirtschaft fortzusetzen. Der Projektumfang sprengt herkömmliche Massstäbe, und die Bauwerke werden in der Bucht in keinem 20 x 50 Kilometer grossen Gebiet mit regem Schiffsverkehr, Fischerei und hoher Seismizität errichtet. Deswegen wurden Einflüsse durch Bautätigkeit auf die Oekologie der Buchtsorgfältig studiert, um die am besten verträglichen Entwürfe und Bauverfahren auszuwählen.

1. INTRODUCTION(see Photo 1)

The Trans-Tokyo Bay Highway(hereinafter referred to as the TTBH) will cross the bay at its mid-section. Linking the cities of Kawasaki and Kisarazu by tunnels, a bridge and man-made islands, it will be a 15.1km route for the exclusive use of road traffic, and will be linked to the Tokyo Bay Coastal Highway, the Metropolitan Central Connecting High way, and the Tokyo Outer Loop Highway to form part of the Tokyo Metropolitan Highway Net-work. The construction of the TTBH began after completion of an environmental impact study carried out by the Japan Highway Public Corporation(hereinafter referred to as the JHPC), and the execution of work is mainly supervised by the Trans-Tokyo Bay Highway Corporation(hereinafter referred to as the TTB), a private enterprise company funded by t he JHPC, relevant local governments and private companies.

The paper presents:

①General outline of the project
②Environmental impact assessment in the official project approval procedure
③Follow-up environmental surveys during construction
④Environmental protective measures based on the assessment

2. GENERAL OUTLINE OF THE PROJECT

2.1 Description of the region(see Photo 1)

Metropolitan Tokyo, Kanagawa Pref. and Chiba Pref. with population of 25 million and area of 10,000 km^2, all front on Tokyo Bay, are situated in the central region of Japan. The western part of the bay has long been an important meeting place of transportation routes and a large market of goods and materials, and now a thriving focus of politics, trade and industry. Tokyo in particular is a center of all aspects of national life such as politics, economics, and culture, and is now playing an important international role.

2.2 Project objectives and the TTBH functions(see Photo 1)

The population distribution and the road traffic situation in the South Kanto region show a unipolar concentration on the center of Tokyo. This is a primary factor in the land and housing problems, typified by cramped housing, high living cost and traffic congestion, and the lack of safety in the case of large-scale disasters occuring in highly and dense-ly built-up areas.

To find the answers to each of the problems, the Natioal Land Agency compiled in January 1983 a Basic Plan for the Restructuring of the Metropolis for the first half of the 21st century, aimed at "correcting the unipolar structure; restraining the growth of business and administrative functions in th^ metropolitan center; promoting independent city zones in the metropolitan suburbs; and, by a new mutually relational association between the zone and the central metropolitan area, restructing the association between them."

The realization of the plan requires preparation of high quality transportation network between those core cities and establishment of highway linking the metropolitan center with the Boso Peninsula. The TTBH will play an important role in the network as part of National Route 409, with the object of forming part of a greater metropolitan area high-way network with the subseqently listed functions, reorganizing various functions of the metropolitan area, and raising level of industrial activity.

① To contribute to the well-ballanced development in the metropolitan area
② To improve efficiency of the industrial activities
③ To form a southern bypass for the Tokyo Metropolitan vicinity

2.3 Benefits of the project(see Table 1 & 2)

The TTBH is expected to produce a drop in the traffic figures of 20,000～30,000 vehicles a day on the roads between Tokyo and Chiba-Ichihara, thus relieving the future traffic congestion. Furthermore, the TTBH is expected to shorten the travel distance and time bet ween Kawasaki-Yokohama-Tokyo(on the Bay west side) and Kisarazu(on the east). And it is also estimated that the TTBH will bring an annual increse of ¥5 trillion in production in the entire South Kanto Region in the early 21st century, and an increse in local tax revenue of ¥200 billion per year in the same region.

2.4 General outline of the project(see Photo 2)

Scope of the project is summarized as below;

a)Name of road & route:Trans-Tokyo Bay Highway; National Highway No.409
b)Work Area & Length:Ukishima, Kawasaki, Kanagawa~Nakashima, Kisarazu, Chiba; 15.1km
c)Road standard:Type 1/Class 2, Design speed 80km/h, Design loads TL20ton and TT43ton
d)Carriageway:Dual 2-lane(Triple 2-lane in final form)
e)Traffic Forecast:64,000 veh/day(33,000 veh/day in the 1st year)
f)Work Schedule: 10 years (see Photo 8)
g)Project Cost:¥1,150 billion

2.4.1 Basic structure and construction method(see Photo 2)

The plan calls for tunnels running 9km from the Kawasaki coast where surface traffic is heavy; a bridge for 4.5km from the Kisarazu coast where the water is shallow and surface traffic is light; Kisarazu Manmade Island connecting tunnel and bridge; Kawasaki Manmade Island, midway along the tunnel section; and Ukishima Access, to functionally connect the tunnel to the land on the Kawasaki side.

①Ukishima Access(see Photo 3)
Ukishima Access consists of an tunnel access shaft and an underwater manplaced embankment extending from seashore to the bay bottom. The embankment provides stability for tunnel boring and cover for buoyancy protection. Soft soils underlying the fill is stabilized so as to maintain face stability and to prevent subsidence of soils beneath the tunnel. Steel trestles are placed to protect and enclose the tunnel path. In-between the trestles embankment fill is placed to form a mound. Side protection core and armor rock as well as crest protection concrete blocks are also placed. The ventilation shaft, also serving as tunnel access shaft is constructed by the caisson method, after stabilization of underlying soils and driving of foundation piles.

②Kawasaki Man-made Island(see Photo 4)
Selected location of the Kawasaki Manmade Island is 5km offshore of the Kawasaki Harbour, where water is 28m deep and soils under the seabed are very soft for a depth of more than 30m. Therefore, the soils are stabilized by sand compaction method, followed by a steel trestle installation which works as a retaining wall, a mole structure and a working plat form. "Island" fill is then placed within the structure. To form a cylindrical retaining structure, a diaphragm wall is excavated within the island fill to a depth of 135m. Then a reinforced concrete permanent wall will be constructed using a "top-down" construction procedure, followed by the placing of a bottom slab. The island serves as a tunnel access shaft as well as a ventilation shaft.

③Kisarazu Island(see Photo 5)
As the soft soil layer at the selected location for the Kisarazu island is relatively thin, the soils is dredged and replaced with selected sand and gravel. The island is subsequently reclaimed starting from the tunnel access and slope portion and proceeding to the eastward flat portion. Ventilation shaft will be structured by floating braced steel shell caisson method to be towed in position.

④Shield Tunnel(see Photo 6)
To insure stabe and watertight tunnel face under high water pressure in very soft soils, slurry shield tunneling method is selected as the optimum method. Total of eight shields start their advance, two from the Ukishima Access, four from the Kawasaki Island and two from the Kisarazu Island to meet under the bay at points midway between the shafts at the same time. The method is preferd because of advantages that it will not influence busy surface traffic in the bay even under construction, and that an additional tunnel can be constructed easily due to its phased constructability.

⑤Bridge(see Photo 7)
The bridge substructure is constructed by two different construction procedures according to the structural design and water depth. In the deepest area, open caissons with braced steel shells fabricated on land is floated in position and set down by crane barge. In the shallowest area where the water is 6m deep, cluster piles are driven with pile driver set on temporary trestle, and where the water is deep enough, cluster piles are driven from barges. For the superstructure, smaller factory-fabricated blocks are assembled to larger blocks on land, then transported to position and erected collectively using giant crane barge. In the shallow water area, fabricated girders are continuously erected backward from offing to land with stiffleg derrick traveler.

3. ENVIRONMENTAL IMPACT ASSESSMENT

3.1 Environmental impact assessment at the time of project authorization

The JHPC has undertaken the assessment according to the procedure shown in Table 3, in which the 1984 Cabinet decision on "Main Items to be Enforced Regarding Environmental Impact Assessments" was firstly applied. The assessment results showed the effects that the project would have during construction and after completion, would be limited to a narrow area around the highway, and that these effects would be extremely small. All formalities started on June 16, 1986 and were completed on July 10, 1987.

3.2 Establishing environmental factors for assessments

Considering the project scope and the characteristics of the surrounding area, environmental factors for assessment were established, as shown in Table 4.

3.3 Public inspection

Public inspection was carried out for 30 days after public announcement of July 27,'86 at Kanagawa side and July 20, '86 at Chiba side, followed by three explanatory meetings at both sides to recognize public opinion. The number of written opinions submitted by residents on the environmentalimpact assessment results numbered 1,770 in Kanagawa Pref. and 157 in Chiba Pref., for a total of 1,927. Table 5 shows the opinions by category of environmental factors.

4. FOLLOW-UP SURVEYS DURING CONSTRUCTION WORK(see Fig.1)

Follow-up surveys during construction work are now being carried out by the JHPC and the TTB with the cooperation of relevant local authorities, in order to swiftly recognize the effects that the project will have on the environment, and to prevent environmental deterioration through reflecting such recognition in the execution of works. With regards to the selection of items for surveys, decisions as to the methods and frequency of surveys, and the assessment of results will be put forward by the "Trans-Tokyo Bay Highway Environ mental Advisary Committee" composed of men of learning and experience. Items to be covered in follow-up surveys, the survey methods and their frequeucy are shown in Table 6.

5. ENVIRONMENTAL PROTECTIVE MEASURES

5.1 Environmental protective measures during construction

In order to restrict the effects of construction work on the environment to a minimum, the following measures will be adopted:

A) Reclamation with pit sand follows mole construction, in order to reduce the effects that turbidity would have on the waters of the bay.
B) Pollution control curtains will be set up during dredging activities, in order to prevent the diffusion of turbidity.
C) In sand fill work of replacement method, sand bins and tremie pipes will be used in order to prevent the spreading of particles that could worsen turbidity.
D) In order to reduce the effects of noise and vibration, work will be done in such that machinery will not be in operation simultaneously with and in close proximity to other machinery.
E) During pile driving for the bridge piers, noise reduction devices, such as noiseproof covers, will be used if necessary to reduce the impact of noise in the coastal area.
F) Pollution control curtains will be used at sites where dredged mud is treated in order to prevent the spreading of particles that might worsen turbidity.

5.2 Environmental protective measures in service of highway

In order to reduce its effects on seawater quality, waste water from highway facilities will be discharged after treated at a waste water treatment plant to bring it to levels at or better effluent quality standards.

6. AFTERWORD

The TTBH received national government authorization in July '87, after many ups and downs over a period of 20 years from the surveys were first begun. With authorization granted, under a new type of organization taking advantage of its private enterprise structure, the TTB takes charge of construction and management of the project such as securing of low-cost funds for financing the project, drawing up detailed designs, or carrying out the construction work, after conducting whatever surveys and tests would be necesary. The JHPC undertakes deliberations on the various necessary procedures and coordinate project activities with regards to, for instance, site acquisition and compensation to local fisheries.

With all procedures regarding environmental impact assessment completed and negotiations with the local fisheries on compensation concluded on Dec. 22. 1988, the groundbreaking ceremony was held on May 27, 1989. By Oct. 1990, 22% of the project had been completed on the contract volume basis, with work steadily progressing on the construction of Ukishima Access, Kawasaki Man-made Island, Kisarazu Man-made Island and Bridge, for all of which experimental construction works and foundation improvement works have been successfully concluded.

The 1984 Cabinet decision reflects a widely accepted recognition that no large-scale project like the TTBH, which could have influence on wide area, could proceed without public consensus even if the project has higher B/C ratio and if it is socially important. In addition, maintaining once reached consensus through good public relation is essential to carry out the project smoothly and successfully.

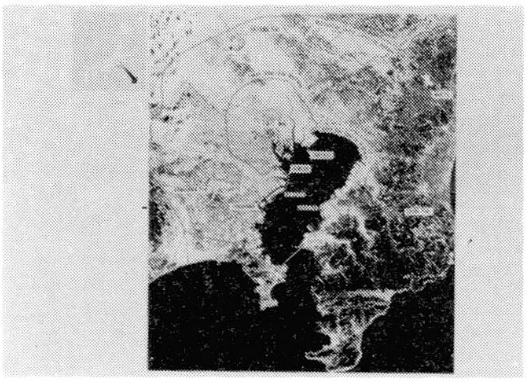

Photo 1-1 Metropolitan highway network

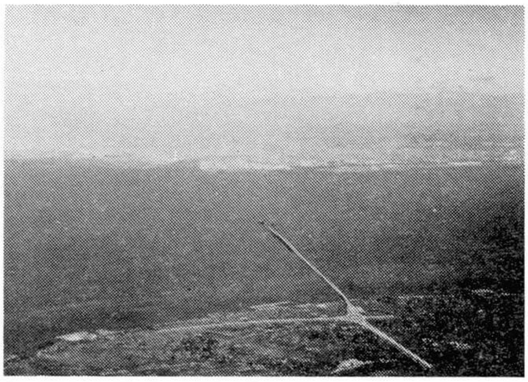

Photo 1-2 Highway bird's-eye view

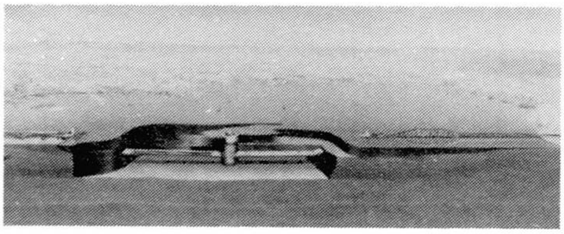

Photo 2-1 Highway conceptual plan

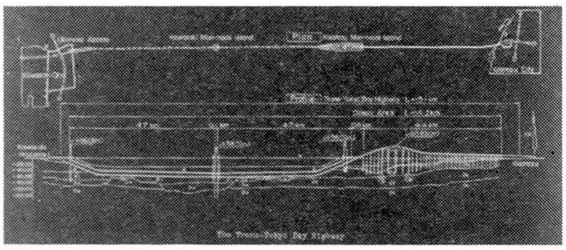

Photo 2-2 Highway plan and profile

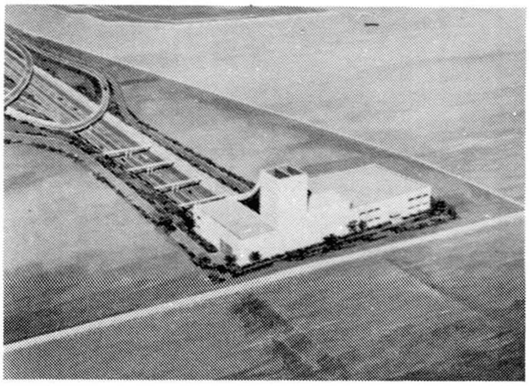

Photo 3 Ukishima access conceptual plan

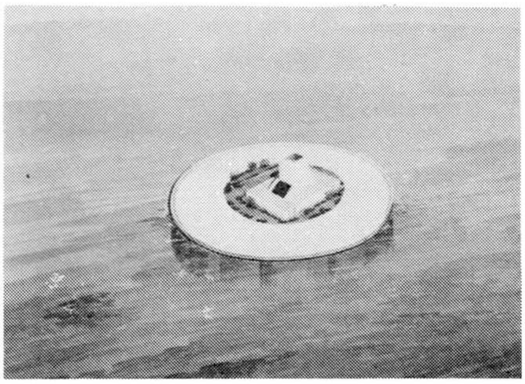

Photo 4 Kawasaki man-made island conceptual plan

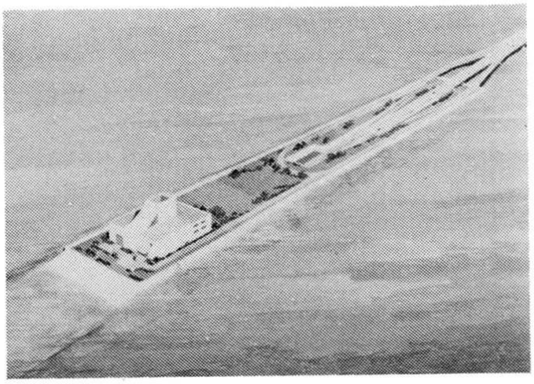

Photo 5 Kisarazu man-made island conceptual plan

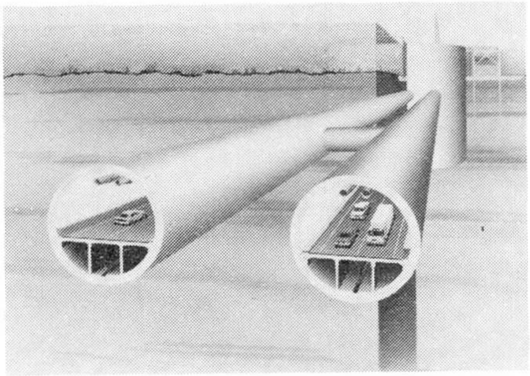

Photo 6 Tunnel conceptual plan

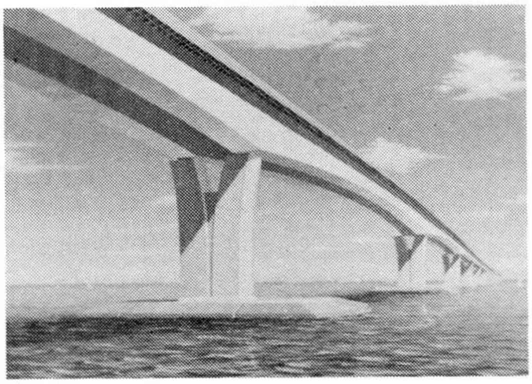

Photo 7 Bridge conceptual plan

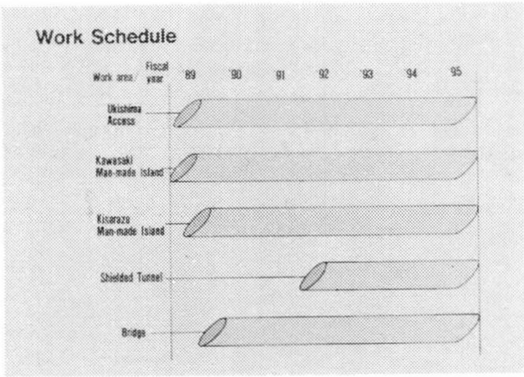

Photo 8 Construction schedule

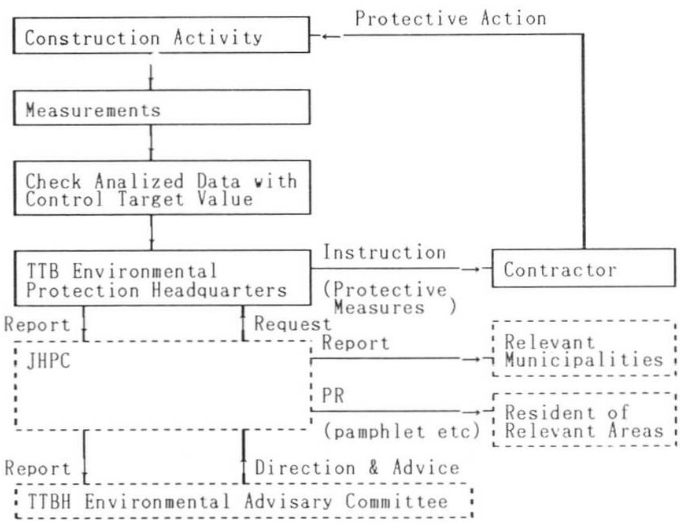

Fig.1 Environmental surveillance and protection procedure during construction

Journey Details			Kawasaki Kisarazu	Yokohama Kisarazu	Tokyo Kisarazu	Route
Travelling Distance	Existing Roads		Approx.110km	Approx.120km	Approx. 90km	
	TTBH Route		Approx. 30km	Approx. 40km	Approx. 45km	
Travelling Time	Existing Roads		166 min.	197 min.	145 min.	Yokohama · Haneda route Metropolitan Expressway National Highway No.16
	Future Option	Not Via TTBH	118 min.	135 min.	106 min.	Tokyo Bay Coastal Highway East Kanto Kisarazu route
		Via TTBH	46 min.	50 min.	53 min.	Tokyo Bay Coastal Highway TTBH

Table 1 Travel times and distances from Kawasaki · Yokohama · Tokyo to Kisarazu

Effects / Instances	Reduction in Total Travelling Distances	Reduction in Total Travelling Times	Direct Benefits
Without Induced Changes in Traffic	Approx. 700,000 veh./day	Approx. 60,000 veh.hrs/day	Approx. ¥200 mill./day
With Induced Change in Traffic	Approx.3,100,000 veh./day	Approx. 160,000 veh.hrs/day	Approx. ¥680 mill./day

Table 2 Direct effects to be introduced by the TTBH

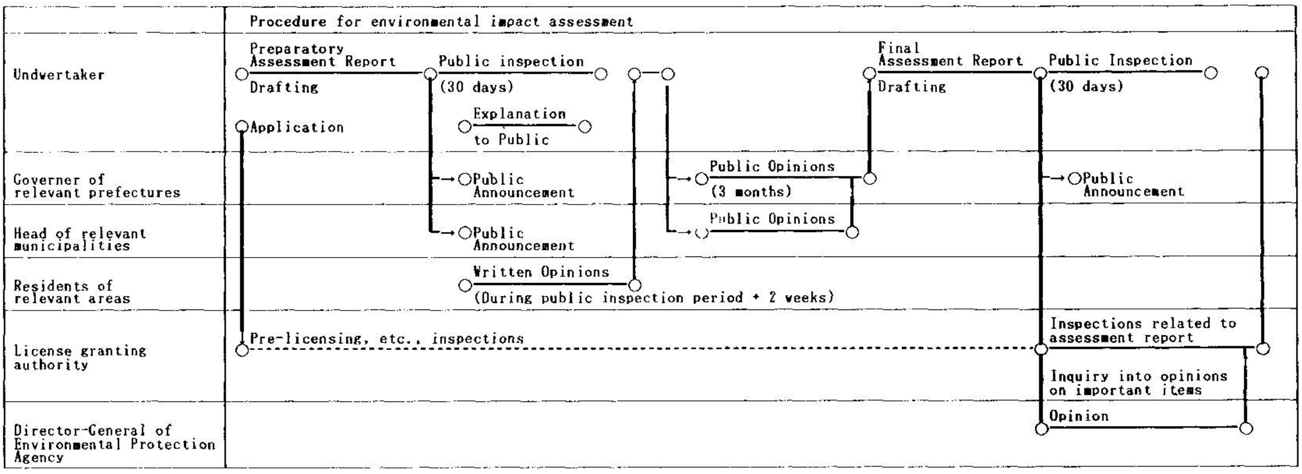

Table 3 Environmental impact assessment implementation guideline by Cabinet decision

Project Stage	Environmental Indicator / Environmental Impact Factor			Atmospheric Pollution: NO_2	Atmospheric Pollution: CO	Water Contamination: COD	Water Contamination: SS	Noise	Vibration	Geography Geology	Flora and Fauna: Terrestrial Fauna	Flora and Fauna: Terrestrial Flora	Flora and Fauna: Marine Organism	Landscape
After Completion	Installations	Marine Section	Man-made Islands			○				○			○	○
			Tunnels											◎
			Bridge			○				○			○	○
		Land Section	Highway Structure								○	○		
	In Use	Vehicular Traffic		○	○	○		○	○		○	○	○	
During Construction	Construction	Marine Section	Man-made Islands	○			○						○	
			Tunnels											
			Bridge	○			○	○	○				○	
		Land Section	Highway Structure	○				○	○		○	○		

Note: ◎ indicates ventilation shafts.

Table 4 Emvironmental impact factors and emvironmental indicators

Survey Items	Frequency of Survey
Air Quality *SO_2, NO_2, Wind Direction & Velocity	* Quarterly(4 seasons) before construction begins. * Quarterly during construction(in each season when construction is in full progress); continuous measurements over a week in every case
Noise & Vibration *Noise Level, Vibration Level	* Once before construction begins. * Quarterly during construction(when construction is in full progress)
Water Quality *Turbidity *SS, VSS, DO *pH, COD, n-hexane Extract, Chlorophyll α *T-N, I-N, T-P, PO_4-P *Mercury, Cadmium, Cyanogen, Hexavalent, Arsenic, Lead, Organoposphorus, Chrome, PCB	* Weekly before construction begins. Daily during construction * Weekly * Monthly * Quarterly(4 seasons) before construction Monthly during construction * Quarterly before costruction During construction, once on each man-made island when dredging is in full progress
Sea Currents *Tidal & Constant Currents	* Twice a year(summer and winter) in every other year
Bottom Sediment *Particulate Composition, Water Content, Sulfides, Specific Gravity, IL, COD, Sediment Volume, ORP	* Twice a year(summer and winter)
Terrestrial Flora *Flora	* Twice a year(summer and winter) * Once every three years for plant community distribution
Terrestrial Fauna *Birds *Mammals, Amphibians, Reptiles, Insects	* 6 times a year(4 seasons, and twice during migratory periods) * Quarterly(4 seasons)
Marine Organisms *Zooplankton, Phytoplankton, Benthos, Fishes & Molluscs, Banzu Mudflats Biota	* Quarterly(4 seasons)
Topography & Geology *Topography of Banzu Mudflats *Topography around Bridge Piers	* Yearly * Yearly, after erection of bridge piers begins.

Table 5 Follow-up environmental survey -items and frequency-

Area	Kawasaki	Kisarazu
General		
Project Scope	8	39
Project Benefit	2,806	24
Existing Environment		
Atmospheric Pollution	14	-
Water Contamination	5	9
Noise	1	-
Terrestrial Flora & Fauna	-	12
Marine Organisms	3	7
Selected Environmental Indicator	34	12
Prediction		
General	4	-
In Use		
Basic Conditions for Prediction	23	1
Atmospheric Pollution	37	19
Water Contamination	4	14
Noise	-	5
Vibration	-	1
Topography & Geology	-	9
Terrestrial Flora & Fauna	-	2
Marine Organisms	-	3
During Construction		
Water Contamination	5	12
Noise	-	1
Marine Organisms	2	1
Assessment		
Aimed Environments	-	12
In Use		
Atmospheric Pollution	585	22
Water Contamination	4	5
Noise	-	5
Terrestrial Flora & Fauna	-	3
Marine Organisms	9	6
Landscape	-	1
During Construction		
Noise	-	1
Marine Organisms	-	6
Protective Measures		
In Use	5	121
Follow-up Survey	-	1
Others	6,252	261

Table 6 Opinion count on environmental impact assessment

Aesthetic Design on the Seto Ohashi Bridge
Projet esthétique des ponts de Seto Ohashi
Aesthetisches Projekt der Seto-Ohashi-Brücken

Takeaki IIJIMA
Counsellor
Honshu-Shikoku Bridge Auth.
Tokyo, Japan

Takeaki IIJIMA, born in 1938, received his civil engineering degree at Waseda Univ., Tokyo, Japan. He was engaged in the construction of the Seto Ohashi Bridge, and is now responsible for the design of Akashi Straits Bridge.

Hiro-o JIN
Chief, Planning and Dev.
Honshu-Shikoku Bridge Auth.
Tokyo, Japan

Hiro-o JIN, born in 1942, received his civil engineering degree at Kyushu Univ., Fukuoka, Japan. He was engaged in the design and construction of the Seto Ohashi Bridge.

SUMMARY

The Seto Ohashi Bridge is a group of long-span bridges linking Honshu to Shikoku, it has been constructed in the Seto Inland Sea National Park and completed in April, 1988. This paper reports the countermeasures to preserve natural scenery in the National Park and the basic concept of the aesthetic design of the Seto Ohashi Bridge. At present, approximately 70 thousand people a day in automobiles and trains pass through the Bridge, and it has become an increasingly attracting area for sightseeing in Japan because of its structural beauty harmonizing with natural scenery.

Projet esthétique des ponts de Seto Ohashi

Résumé

Les ponts de Seto Ohashi forment un groupe de ponts à grande portée reliant les îles de Honshu et de Shikoku. Ils se trouvent dans le Parc national de la Mer intérieure de Seto et ont été terminés en avril 1988. L'article présente les mesures prises pour préserver le paysage naturel du parc national et présente le concept fondamental de ce projet esthétique. Actuellement près de 70'000 personnes utilisent quotidiennement cette liaison en voiture et en train. Cet ensemble est devenu une zone attractive pour le tourisme, grâce à la beauté des structures, en harmonie avec le paysage naturel.

Aesthetisches Projekt der Seto-Ohashi-Brücken

Zusammenfassung

Der Seto-Ohashi-Brückenzug ist eine Gruppe weitgespannter Brücken, die Honshu und Shikoku verbinden. Er wurde im Seto-Inland-See-Nationalpark gebaut und im April 1988 fertiggestellt. Dieser Artikel berichtet über die Massnahmen, um das natürliche Landschaftsbild im Nationalpark zu erhalten, und über das Grundkonzept des ästhetischen Entwurfs der Seto-Ohashi-Brücken. Augenblicklich benutzen ungefähr 70'000 Personen in Autos und Zügen täglich die Brücken, und sie sind zu einem attraktiven Ausflugsziel in Japan geworden, weil ihre bauliche Schönheit mit der natürlichen Szenerie harmoniert.

1. PREFACE

The Seto Inland Sea is known as a region that has the most representative natural scenery in japan. It was first designated as a national park concurrently with Daisetuzan and Aso,etc.,in 1934 and its natural scenery has been protected ever since.
Also, while the Seto Inland Sea has aesthetic archipelago scenery,it has been inhabited by people since ancient times. Fishing and marine transportation have long been prosperous industries.
One of the special features of Honshu-Shikoku Bridge projects,i.e. the Kobe-Naruto Route, Kojima-Skaide Route and Onomichi-Imabari Route,pass through the Seto Inland Sea National Park.
The Kojima-Sakaide route has been completed in 1988,the Kobe-Naruto and Onomichi-Imabari route are under construction by the Honshu-Shikoku Bridge Authority. The portion of the straits of the Kojima-Sakaide route has been popularily named the Seto-Ohashi Bridge after its completion,and it consists of six long-span bridges,viaducts and tunnels,etc.for a highway with four lanes and a railway with four tracks. The long-span bridges comprise three suspension bridges with a center span length of approximately 1000 m, two cable-stayed bridges with a center span length of 420m each and one truss bridge.
The Seto Ohashi Bridge was approved as a route to be completed earlier by the Third Nationwide Comprehensive Development Program of April 1977 ,it was subject to the condition that the environmental impact assesment be made without delay. In response to the condition,the Authority made the environmental impact assesment,which included procedures of opening explanation meeting for residents around the route for the first time in japan.
This paper reports the basic concept of aethetic design of the Seto Ohashi Bridge concerning protection of natural scenery and harmony aethetic aspects of the structures with beautiful scenery.

2. BRIDGES AND NATIONAL PARK

The Seto Inland Sea National Park encompasses a wide area,stretching over 10 prefectures of Chugoku and Shikoku and surrounded by four straits,i.e.Kitan and Naruto in the east and Hoyo and Kanmon in the west.

Fig.1 Location of the three routes

The most eminent feature of the Honshu-Shikoku Bridge Project among public works is that all three routes pass through this national park region.
The Natural Parks Act was promulgated in 1957 for the purpose of preserving natural scenery in the natural parks, which were under jurisdiction of the Environmental Agency since the establishment of the Agency in 1977.
When someone needs to construct a structure such as building within natural park special region,he is subject to the permission of the Directer General of the Environmental Agency under item 3 of Article 17 of the Natural Park Act. However,since Honshu-Shikoku Bridge Authority is regarded as a national administrative organization,the project was subject to consultation with the Directer General of the Environmental Agency under item 1 of Article 40 of the Act,and did not have to obtain the permission of the Directer General of the Environmental Agency.
According to the Natural Parks Act,the Environmental Agency shall respect the opinions of the Committee on Preservation of Natural Environmental,which is established in the Environmental Agency under Article 13 of the Natural Environmental Preservation Act in exercising its right of jurisdiction. The opinions of the Committee was substantially made through the "Subcommittee on Examination of Problem on Honshu-Shikoku Bridges"which was established as a division of the Committee.
Members of the Subcommittee at the time of consultation concerning the Seto Ohashi Bridge consisted of experienced scientist and professinals, ranging from lawyers,authority of science of fishery,and journalist to designer,etc. The Subcommittee met four times on the construction of the Seto Ohashi Bridge,and summary of the conclusion of which was that it was inevitable to proceed the project with the condition that through measures be taken to preserve the natural environment.

3. PRESERVATION OF NATURAL SCENERY

Mt.Washu area,where the Seto Ohashi Bridge route pass through in Honshu side ,is famous for sightseeing spot at which people can commmand the beautiful scenery of archipelargo and is designated as a Type 1 of National Park Special Region where is most valuable to preserve natural scenery.
In the construction plan of the Authority, the open cut method of construction was initially planned in the Mt.Washu area.
However, the opinion of the Environmental Agency was that the plan should be reconsidered to minimize the alteration of the topography of Mt.Washu area as technically possible as the Authority could.
In response to this opinion , the Authority had begun to reconsider the initial construction plan of open cut method in Mt.Washu area.
From the viewpoint of preservation of natural beauty of Mt.Washu area,a tunnel definitely excels as the method of construction. However,as the tunnel is adjacent to the Shimotui-Seto Bridge,which is a suspension bridge with a double-deck structure,the section of the tunnel had to be as same as of the suspension bridge. Consequently,the tunnel would become an unprecedented large section tunnel if it was to be a single section including a four lane highway and a four-track railway line. If it was to be separated into four tunnel sections,it would be tunnels that are considerably close to each other in the upper and lower direction and in the horizontal direction,making it extremely diffucult to construct.
As it was also judged that the overburden was thin and geology was of weathered granite with extensive cracking ,which posed extreme tecnically diffic-

ulties,the open cut method of construction was planned initially.
However the Authority had begun the technical examination of the tunneling method to minimize the alteration of topography due to the opinion of the Environmental Agency.
The technical examination was undertaken by the committee composed of experienced scientist and professionals of the Japan Society of Civil Engineers, etc. The examinations and evaluations were repeated based on the knowledge of tunnel engineering and underground stress analysis with computer,which has remarkably progressed in recent years. As a result of these examinations ,it had been clear that the tunneling was technically feasible through N.A.-T.M. method and new in-situ surveying technologies. Also,a double section tunnel plan had been selected finally. This finally determined that the highway and railway pass through Mt.Washu by tunnel,suiting the intention of the Environmental Agency for preservation of the scenery.(Refer to Fig.2)

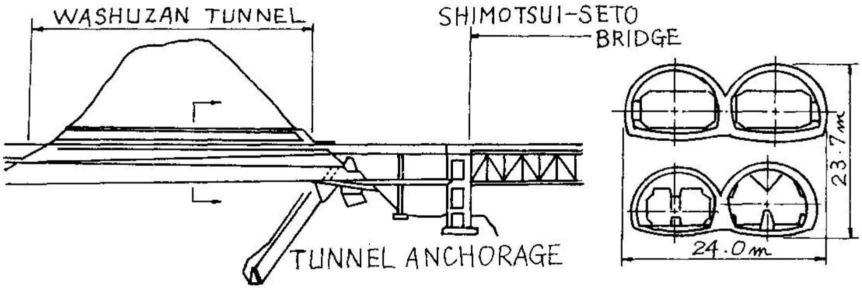

Fig.2 Side view and cross section of Washuzan Tunnel

4. SCENERY OF BRIDGES

To examine the aethetic aspects of a continuous group of large bridges that span the straits on the delicate and graceful archipelargo scenery of Shimotui and Bisan-Seto,the first problem would be to determine where the vista points should be located.
For the examination of the aethetic aspects of the group of the long-span bridges,main vista points were selected,i.e.two points on the Honshu side and two points on Shikoku side for the people who come to view the scenery of the National Park.
On the Honshu side a noted Mt.Washu vista point in this region and Ojigadake ,to make a vista point of distant view a slightly away therefrom, were selected. On the Shikoku side,Shotsujisan,located on the opposite shore of Washuzan,and Goshikidai,which is slightly away therefrom, were selected. Also, as a representative vista point from the islands in the neighborhood,Honjima was selected and Marugame-Shimotui ferry boat route was selected as a vista point from aboard a ship. The examination was conducted using color photo montages from these vista points to determine whether the structure type and color of each bridge are in harmony with the scenery of the National Park.

4.1 Bridge Type

Although it is difficult to imagine having a structure type other than a suspension bridge for the bridges that span Shimotsui-Seto straits and Bisan-Seto straits,Hitsuishjima Bridge and Iwakurojima Bridge located in the middle of these two suspension bridges make an important point from the viewpoint of scenery of a group of long-span bridges of the whole route;the selection of bridge type presented important problem.

Considering the conceivable center span of about 400 m of the two bridges due to the topography and the geology,types of the bridges to be examined were narrowed to suspension,truss,arch and cable-stayed bridges.
First,the suspension bridge plan was judged unfavorable as it was disadvantageous economically and given the immense complexity of forming a miniature version of Shimotsui-Seto Bridge and Bisan-Seto Bridge also from the viewpoint of the scenery. The arch bridge plan was eliminated from among the candidates due to the topography and geology and because the arch rib forms a reverse symmetry with cables of the suspension bridges.
On the other hand,the cable-stayed bridge plan was considered a good plan from the viewpoint of scenery as the tower and straight line cables accentuate the whole route as well as maintain continuity of the horizontal line. However,the construction of large-scale cable-stayed bridge such as this was unprecedented in the world technically, and many problems were pointed out in terms of structure and design. In the case of the truss bridge plan,there are many experiences of making the bridge a cantilever-truss type and less problems technically,and the chord members opening up and down accentuate the center of the whole route also from the viewpoint of scenery giving the feeling of profound and solemn beauty.(Refer to Fig.3)

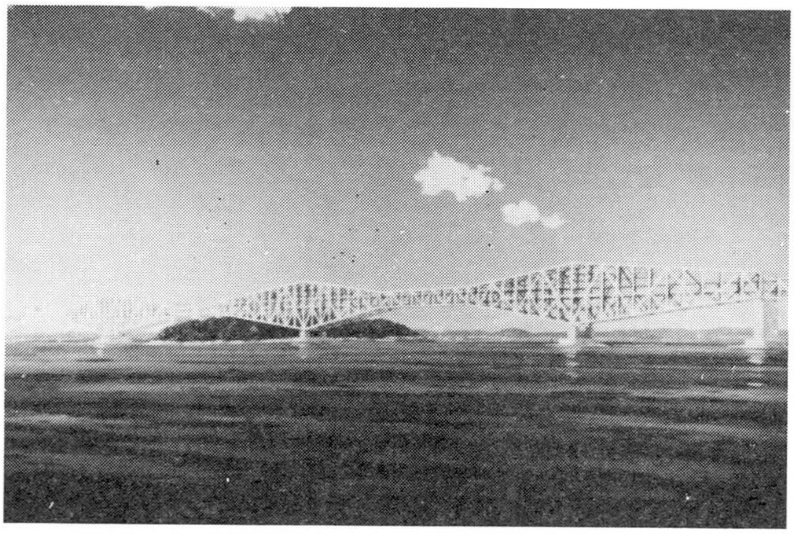

Fig.3 Proposal of cantilevered truss bridge

Through these examinations,the cantilevered truss bridge with a bilateral symmetry was submittred as a first plan for Hitsuishijima and Iwakurojima Bridges. However,the Environmental Agency imposed the condition "to make the bridges cable-stayed bridge unless it is impossible technically" based on the opinions of the Subcommittee to the plan of the Authority. In response to this condition,the Authority,in an effort to further enhance the accuracy of the technical results of the cable-stayed bridge accumulated thus far,continued to examine the issue with committees organized in J.S.C.E.,etc.
As a result of this examination,the Authority had obtained the prospect of conquering technical problems by adopting a Hi.-Am. socket that is high in fatigue strength for the cables in which fatigue became a problem due to the train load,and by providing a buffer system for corner bending of cables to protect the cables from bending fatigue,the cable-stayed bridge plan was adopted and the plan was realized.

4.2 Configuration of Tower

Towers of the suspesion bridge and the cable-stayed bridge can be positioned as a symbol of each bridge as they can be viewed easily from many vista points regardless of distance. For this reason,the configuration of the tower was examined in the various plans not only from the viewpoint of functions but also from that of scenery.
There are many types of towercolumns,such as straight,inclined,and bent towers,and further from the configuration of loop material there are truss type and rigid-frame type,which have good features from the viewpoints of structure and scenery. Also there are triangular,convex,and crossforms in the sectional configuration of the towers which have both advantages and disadvanttages from the viewpoints of scenery and structure. By combining these configurations of tower columns,loop materials and sections and taking into consideration the position of each bridge from the viewpoints of scenery,economy and workability, the basic configuration was determined.

4.2.1 Shimotsui-Seto Bridge

By taking the vista point at Mt.Washu where more than one million tourists visit a year,the tower becomes the most prominant structure,which is positioned as a gateway on the Honshu side to the Seto Ohasi Bridge. For the aethetic design,a questionnaire survey was conducted on the evaluation items from the viewpoint of scenery by preparing sketches of twenty different types of towers. As a result of the questionaire,the rigid-frame type tower,unlike the one that could not been seen in the case of Innoshima and Ohnaruto Bridges,became influential,and as there was not too much difference in the economical comparison with the truss-type tower,the vertical tower with rigid frame type was adopted. As the tower is shorter by about 50m conpared with the tower of Minami and Kita Bisan-seto Bridges,the characteristics are that it is more streamlined as it has no diagonal members as compared with the truss-type tower.(Refer to Fig.4)

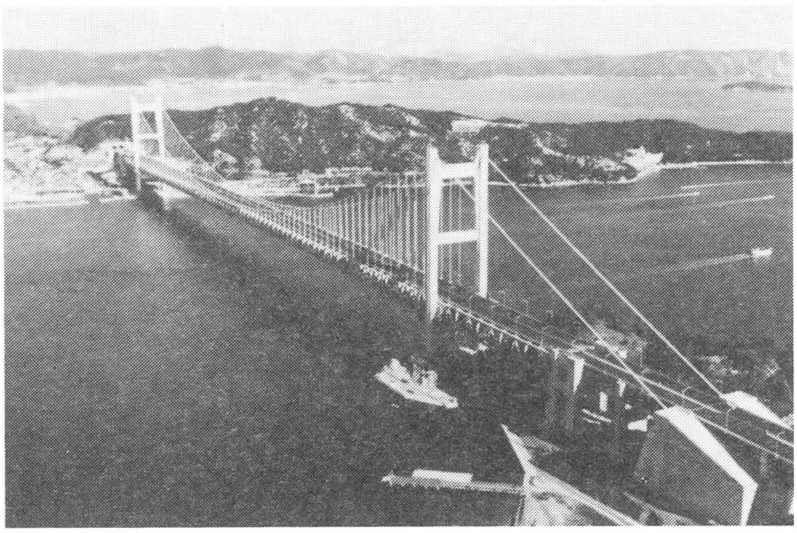

Fig.4 Shimotui-Seto Bridge

4.2.2. Minami and Kita Bisan-seto Bridges

A duplex suspension bridge that has a common anchorage is located in the wide sea area of Bisan-Seto,and tourists can not view the suspension bridges closely as in the case of Washuzam. Therefore,the evaluation of tower configuration was made from both distant and intermediate views. The selection of the basic configuration was made by preparing sketches of 32 plans that combined the types of the towers and various types of loop materials and by evaluating from the viewpoints of scenery and economy,thus selecting the inclined tower with diagonal chord. The horizontal chord and the diagonal chord of the tower were determined to be finer than the tower column to prevent them from appearing too labyrinthine.(Refer to Fig.5)
It was also taken into considerations in the design that the configuration of the top of the tower,the angles of diagonal members of the truss and the ratio between height and width of the space above the roadway surface were unified.

4.2.3 Hitsuishijima Bridge and Iwakurojima Bridge

Compared with the suspension bridges at the end of this route,as these two bridges was close to the islands and there were bus stops provided on the upper road surface between the bridges,scenery closer to the island itself and from the highway was seriously considered in the aethetic design of the tower. Consequently, the basic form prepared based on the various Japanese motives such as a shrine or temple,the roof of a traditional farmhouse,etc., near this route were applied to the towers of these cable-stayed bridges. To provide a visual imression of continuity,the basic form was employed to the piers of the viaducts which is adjacent to the cable-stayed bridges.
The group of bridge piers and towers harmonize with each other and create a sense of rhythm in the visual flow of the entire bridges.(Refer to Fig.6)

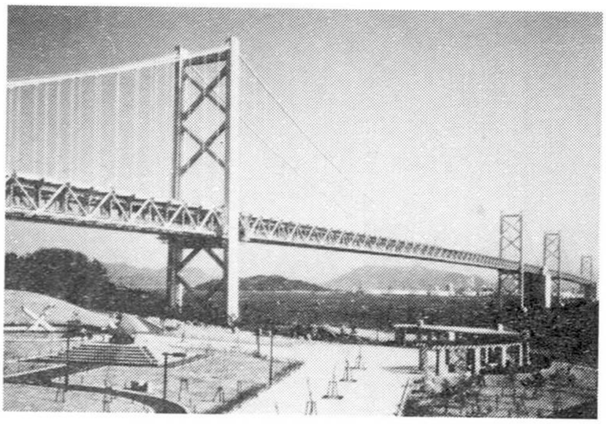

Fig.5 Minami and Kita Bisan-Seto Bridge

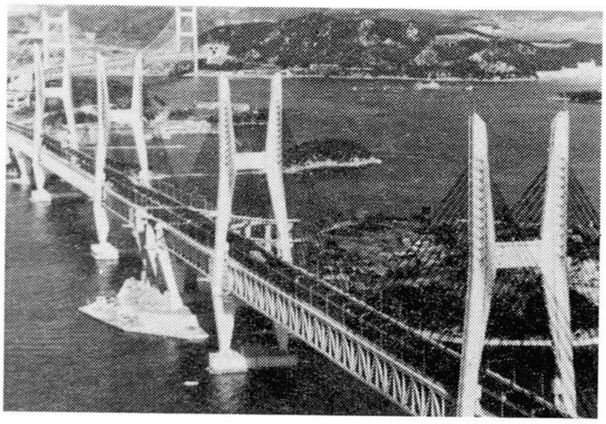

Fig.6 Two cable-stayed bridges

4.3 Texture of Anchorage

Flat surface of the wall of anchorage for suspension bridge awes everyone around it because of its enormous size. To soften this, it was proposed to provide a texture on the wall of the anchorage.

On the other hand it was also pointed out that the flat surface of the wall of the anchorage may become a cause of radar interference for ships navigating nearby. The Authrity has carried out investigations for countermeasures against radar false images through a committee which is consisted of experienced scientist,professionals and maritime interests. And it was determined that by making the surface of the wall of the anchorage a slope at a angle of more than 5° for the purpose of diverting main direction of radar waves, the radar fales image could be prevented. The texture of this slope was consequently determined to be incorporated in the design from the viewpoint of the scenery. The shadow of the multi-stage slope changes depending on the position of the sun,which both accentuate the wall and softe softens the enormity of the anchorages.(Refer to Fig.7)

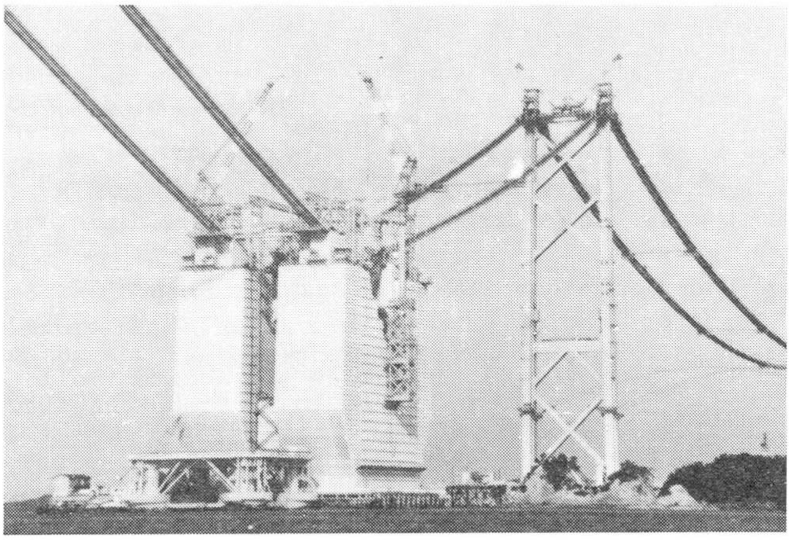

Fig.7 Texture of anchorage

5.POSTSCRIPT

Construction project and protection of nature are primarily contradictory. The construction of the Seto Ohashi Bridge might have been detrimental to the national park,which makes the natural scenery of archipelargo as its keynote,and so it was requested that every effort be made to pursue a new scenic beauty that harmonizes with the natural scenery. We tacled this difficult task with all our energy. As a result,the Seto Ohashi Bridge has been evaluated as a new spot for sightseeing as well as a fast and safe traffic route which carry approximately 70 thousands people a day.

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Effect on Tidal Current of Constructing the Akashi Kaikyo Bridge

Influence de la construction du Pont Akashi Kaikyo sur le courant de marée

Einfluss des Baus der Akashi-Kaikyo-Brücke auf die Gezeitenströmung

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SUMMARY

The world' s longest suspension bridge, the Akashi Kaikyo Bridge, is now under construction. This paper reports on mathematical analysis and hydraulic model experiments conducted to estimate the effect on tidal flow in the surrounding sea of the reclaimed land for anchorages on each side of the Akashi Straits, and of the piers for the main towers in the middle of the Straits.

Influence de la construction du Pont Akashi Kaikyo sur le courant de marée

Résumé

Le pont suspendu le plus long du monde est actuellement en construction au Japon. Ce rapport présente l'analyse mathématique et les expériences de modèle hydraulique conduites pour estimer l'effet sur le courant de marée dans l'environnement marin modifié par la récupération de terrains sur la mer pour les butées et les pylônes du pont dans le détroit.

Einfluss des Baus der Akashi-Kaikyo-Brücke auf die Gezeitenströmung

Zusammenfassung

Die längste Hängebrücke der Welt, die Akashi-Kaikyo-Brücke, wird augenblicklich in Japan gebaut. Dieser Bericht präsentiert die mathematische Analyse und die ausgeführten hydraulischen Modellversuche, um die Wirkung auf die Gezeitenströmung in der Meeresumgebung abzuschätzen, die durch die Landgewinnung für die Ankerköpfe und die Brückenpfeiler in der Meerenge verändert wurde.

1. Outline

The Akashi Kaikyo Bridge, constructed on the Kobe- Naruto Route of the Honshu - Shikoku Bridges, is a 3- span, 2- hinged stiffening truss suspension bridge with a total length of 3,910m, and a center span of 1,990m. Construction work at the site was begun in May 1988, and is currently progressing on the substructures and on the fabrication of the main towers.

The Akashi Straits -- which this bridge spans -- links Osaka Bay with Harima Nada (the eastern section of the Inland Sea). The Straits are only 4km wide at the narrowest point, and are as deep as 110m in some parts. The tidal current at the Straits is well known as one of the fastest in Japan, reaching a maximum velocity of around 4m/sec. The sea in this area is heavily used. A width of 1,500m in the center of the Straits is designated as an international navigation channel, used by approximately 1,400 ships a day. Marine industries such as fishing and seaweed cultivation are also very active.

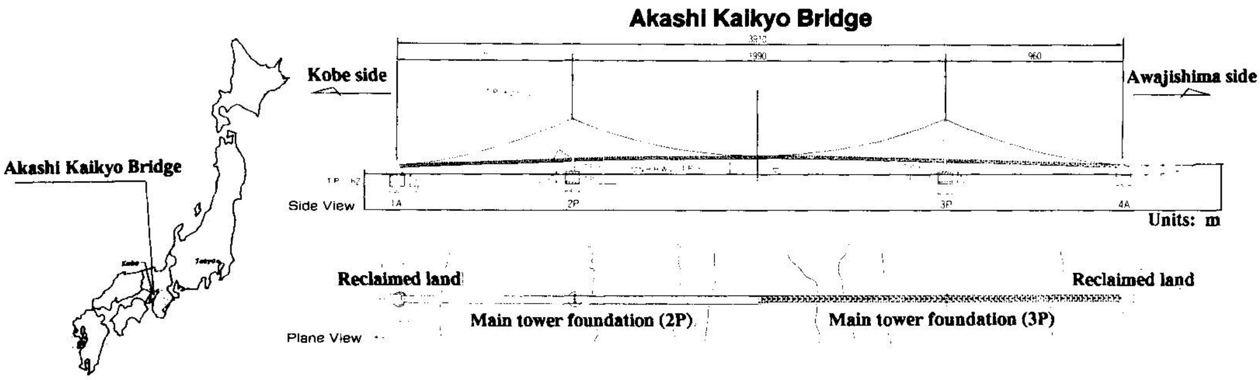

Figure 1 The Akashi Kaikyo Bridge

Figure 1 is a general view of the Akashi Kaikyo Bridge. This figure shows the relative positions and sizes of the two main piers for the towers in the middle of the Straits, and of the reclaimed land for the anchorages on each side (Approximately 6.2ha for anchorage 1A, 2.5ha for 4A).

The Honshu - Shikoku Bridge Authority carried out environmental impact assessments before construction of the bridge was started. The estimation of the effect on tidal current reported here was part of those assessments, and was conducted using two methods, mathematical analysis using a supercomputer, and hydraulic model experiments.

2. Investigation by mathematical analysis

2.1 Basic equations and mathematical analysis methods

Two mathematical models were used for the mathematical analysis. One was a wide area model (Osaka Bay model), and the other was a straits model (Akashi Straits model). These models were used for two- layer tidal current simulation to investigate the effect of the Akashi Kaikyo Bridge on tidal current. The two- layer model was considered to be most appropriate for mathematically estimating the tidal current conditions affected by the complex sea bed and shoreline shapes around the Akashi Straits because it can take vertical flow into consideration.

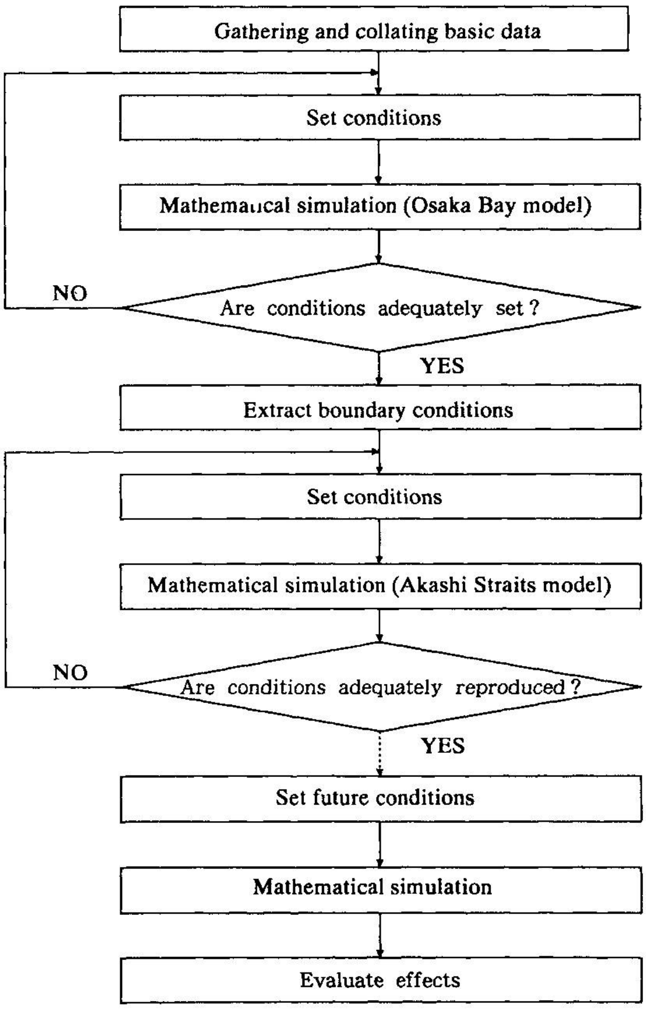

Figure 2 Procedure for predicting changes in tidal current

The procedure for the analysis is shown in Figure 2.

The mathematical models were based on the Navier- Stokes equation of motion and equation of continuity for incompressible fluids as shown in equations (1) to (4). Vertical movement was approximated using hydrostatic pressure, and the velocity of the vertical flow was obtained from the equation of continuity. The mean depth was used for the depth of each element.

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}-fv=\frac{1}{\rho_o}\frac{\partial p}{\partial x}+\nu_H\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+\nu_V\frac{\partial^2 u}{\partial z^2} \quad (1)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+u\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}-fu=\frac{1}{\rho_o}\frac{\partial p}{\partial y}+\nu_H\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+\nu_V\frac{\partial^2 v}{\partial z^2} \quad (2)$$

$$-g=-\frac{1}{\rho_o}\frac{\partial p}{\partial z} \quad (3)$$

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad (4)$$

Where:

- x, y, z : coordinates with vertical axis upwards (cm)
- t : time (sec)
- u, v, w : flow velocity in x, y, z directions (cm/sec)
- p : pressure (g/cm/sec2)
- ρ_o : standard sea water density (g/cm3)
- g : gravitational constant (cm/sec2)
- f : Coriolis constant (sec- 1)
- ν_H : horizontal eddy viscosity coefficient (cm2/sec)
- ν_V : vertical eddy viscosity coefficient (cm2/sec)

In the mathematical analysis, these basic equations were used for two layers, and non- stationary analysis was performed using the finite differential method to obtain the flow velocity and water levels.

2.2 Calculation zone

The flow conditions (changes in velocity of tidal current and water level over time) were first obtained for the Osaka Bay model, using 1km square elements covering an area 78km from east to west, and 67km from north to south as shown in Figure 3. The results obtained were then used for calculations in the Akashi Straits model, with 250m square elements covering an area 30km from east to west, and 21km from north to south to clarify the detailed characteristics of tidal current in the area around the Akashi Straits. The range of the Akashi Straits model was decided by trial and error.

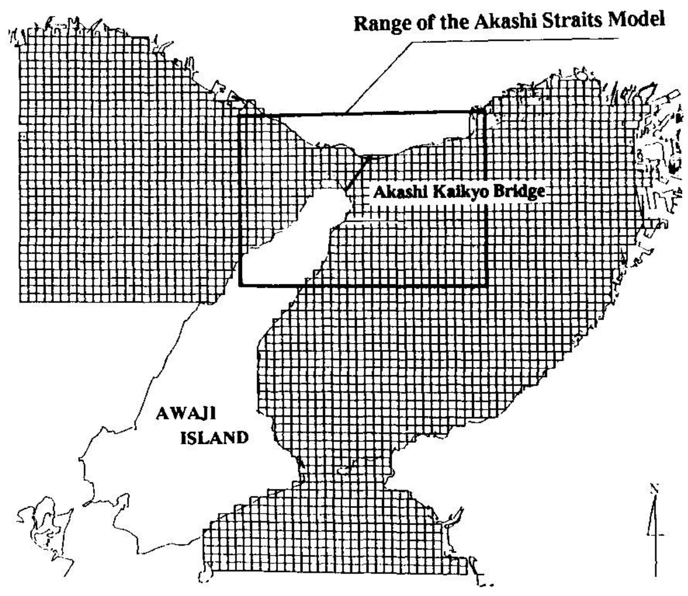

Figure 3 Mesh diagram for the Osaka Bay Model

2.3 Boundary conditions

The tides investigated were the annual mean tide and the annual mean highest tide.

The tide level oscillations to the open boundaries were applied as the boundary conditions for the Osaka Bay model. The tide level of the mean tide is considered to be the M2 partial tide, and the tide level of the mean highest tide is considered to be both the M_2 partial tide and S_2 partial tide. These tide level oscillations are given by equation (5). Measured data was used for the amplitude and delay angle, and the period was taken to be 12 hours.

$$\zeta = a\cos\left(\frac{2\pi}{T}t - \frac{\pi}{180}k\right) \quad (5)$$

Where:

- ζ : tide level (cm)
- a : amplitude of partial tide (cm)
- k : delay angle of partial tide (degrees)
- t : time (sec)
- T : period of tide level oscillation (sec)

The boundary conditions for the Akashi Straits model were given by the flow velocity oscillations and tide level oscillations obtained from the mathematical analysis using the Osaka Bay model. These figures were obtained from harmonic analysis of the results from the Osaka Bay model over one cycle, and utilized in the calculations for the Akashi Straits model using equation (6). Linear interpolation was used spatially.

$$v = a_0 + a_1\cos\left(\frac{2\pi}{T}t - \frac{\pi}{180}k_1\right) + a_2\cos\left(\frac{2\pi}{T}t - \frac{\pi}{180}k_2\right) \quad (6)$$

Where:

- v : flow velocity (cm/sec)
- a_0 : flow velocity with residual tide flow (cm/sec)
- a_1 : flow velocity for half day cycle (cm/sec)
- k_1 : delay angle for half day cycle (degrees)
- a_2 : flow velocity for quarter day cycle (cm/sec)
- k_2 : delay angle for quarter day cycle (degrees)
- t : time (sec)
- T : period of flow velocity oscillations (sec)

Trials were conducted to decide whether to apply flow velocity oscillations or tide level oscillations to the open boundaries of the Akashi Straits model. The best representation of the flow characteristics of the Akashi Straits was obtained when flow velocity oscillations were applied to the eastern and southern boundaries and tide level oscillations were applied to the western boundary.

Calculations also took into consideration real data for outflows from the main rivers inside the zone, adjusted to the size of the model. The coefficients used in the calculations were determined by trial and error.

2.4 Accuracy

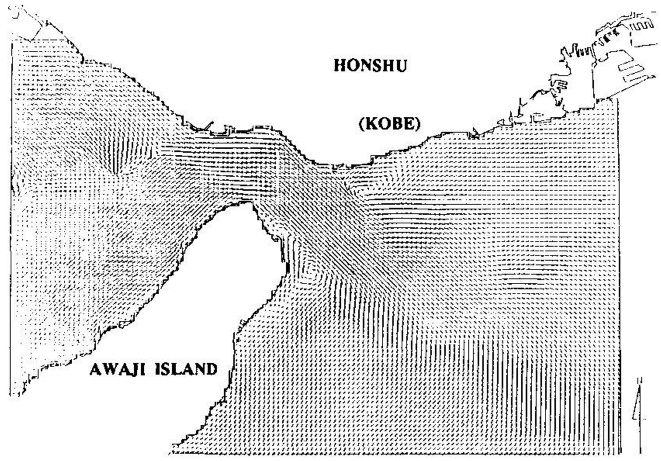

Figure 4
Flow conditions estimated using the Akashi Straits model (mean highest tide, eastern flow at maximum, upper layer)

One example of flow conditions around the Akashi Straits estimated using the Akashi Straits model is shown in Figure 4. The accuracy of this model in estimating the actual tidal current was considered in terms of flow patterns, flow levels (amplitude, delay angle), and tidal flow ellipse, comparing the calculated figures with real measurements. The model was found to be satisfactorily accurate.

2.5 The effect of the Akashi Kaikyo Bridge on tidal current in the Akashi Straits

The effect of the reclaimed land for anchorages and foundation for main towers of the Akashi Kaikyo Bridge on tidal current was analyzed using the Akashi Straits model. In this analysis, the proposed land shapes were represented as follows.

(1) The reclaimed land was handled as an equivalent land element.

(2) Section reduction was considered for the main piers. In other words, the transit section area in the continuous equation was reduced by the equivalent amount.

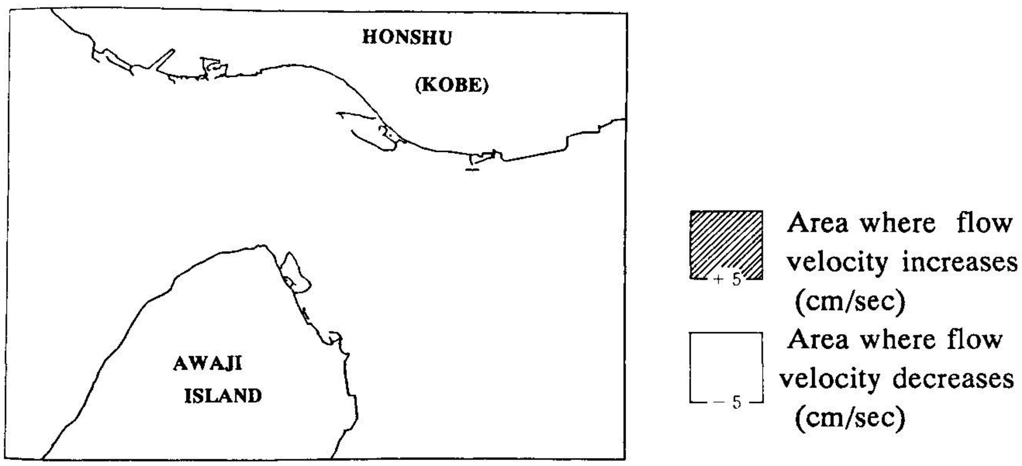

Figure 5 Flow velocity difference contours
(mean highest tide, west flow at maximum, upper layer)

One example of the flow velocity difference contours (future flow velocity minus present flow velocity) obtained by these methods is shown in Figure 5. As shown by the contours in Figure 5, the flow velocity becomes slower next to the reclaimed land of the Akashi Kaikyo Bridge, but this effect is relatively small. It can be considered that the effect of the bridge is small.

3. Investigation by hydraulic model experiments

3.1 Experimental zone

Mathematical analysis using the Akashi Straits model accurately estimated current flow conditions around the Akashi Straits, and it is considered to be a powerful means of prediction. However, it cannot provide a good estimation of phenomena smaller than the size of the mesh. Because the effects of the foundation of main towers are considered as section reduction, local effects close to the foundations are not obtained.

Flow structure and boundary conditions in hydraulic model experiments are often substantially different from true conditions, but the results still contain a lot of important information.

To examine the correlation with the mathematical analysis, two different hydraulic model experiments were conducted based on Froude's law. A wide area model experiment was conducted to examine the overall flow conditions, covering an area of sea around the Akashi Straits approximately 16km from east to west and 14km from north to south. The model was built with a horizontal scale of 1/1000 and a vertical scale of 1/500. A narrow area model experiment was also conducted with a scale of 1/100 in a flat vessel of 5m width to help understand the local flow conditions close to the main towers.

3.2 Results

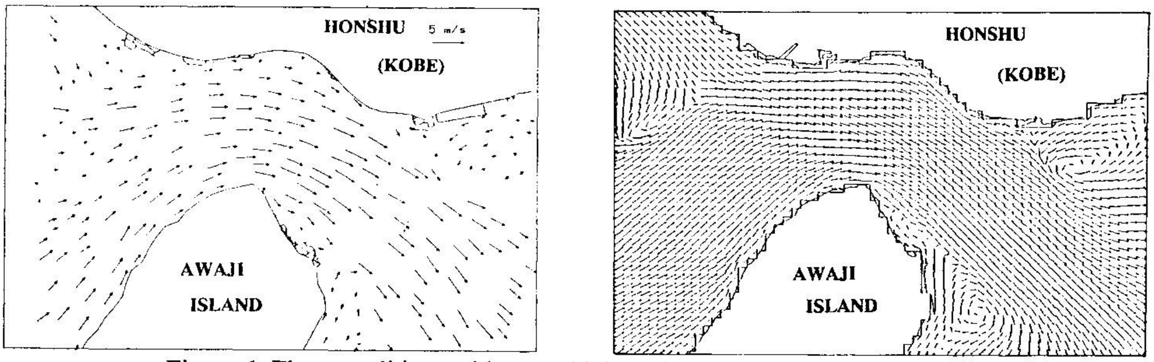

Figure 6 Flow conditions with mean highest tide, east flow at a maximum
(Left: Model experiment, Right: Mathematical analysis)

Figure 6 shows one example comparing the results of the wide area model experiment with the results of the mathematical analysis.

Examining flow direction, flow velocity, eddy areas, current rips, etc., it can be seen that there is a relatively good correlation between the two sets of results for flow characteristics.

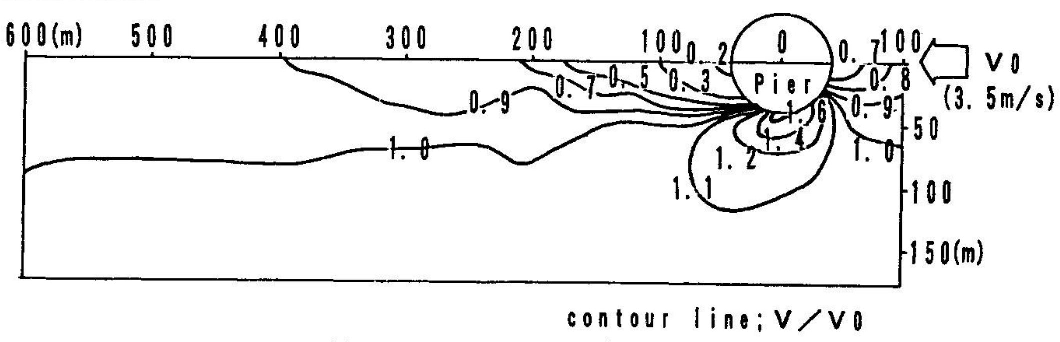

Figure 7 Flow around a circular pier

Figure 7 shows the mean surface flow velocity around a main pier as obtained from the narrow area model experiment. It can be seen that large changes in flow velocity are limited to a relatively small area around the pier.

Conclusion

Before constructing the Akashi Kaikyo Bridge, the Akashi Kaikyo Bridge Authority has conducted mathematical analysis and model experiments to investigate its effect on the tidal flow in the sea around the bridge. The investigations show that the effects will be relatively small, and restricted to the areas close to the actual structures.

Society now places a great importance on environmental impact assessments for large construction projects. Large construction projects have a variety of effects on the marine environment, and this is an important subject, but methods of prediction and evaluation have not been adequately established for many of the parameters involved. It is hoped that a great deal more progress will come from further study.

Environmental Impact of the Disposal of Channel Tunnel Spoil
Environnement et dépôt des matériaux d'excavation du tunnel sous la Manche
Umwelteinfluss der Abraumdeponien des Aermelkanaltunnels

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SUMMARY
After an extensive study of potential disposal sites for over 7 million m^3 of rock, disposal in lagoons behind a new sea wall was chosen for UK spoil and pumping it as a slurry behind a dam in a dry valley for the French. The paper describes the reasons for these choices and some of the studies carried out to assess the impact of spoil disposal upon the environment. Such studies are essential for projects of any magnitude in an increasingly environmentally conscious world.

Environnement et dépôt des matériaux d'excavation du tunnel sous la Manche

Résumé
Une étude détaillée des sites potentiels pour le dépôt de plus sept millions m3 de roches a été entreprise. Une solution de dépôts dans des lagunes derrière une nouvelle digue a été choisie du côté anglais alors qu'une solution de pompage derrière un barrage à l'intérieur des terres a été retenue du côté français. L'article décrit les raisons de ces choix et quelques études réalisés pour évaluer l'influence des dépôts de matériaux d'excavation sur l'environnement. De telles études sont essentielles pour des projets majeurs dans un monde devenant de plus en plus respectueux de l'environnement.

Umwelteinfluss der Abraumdeponien des Aermelkanaltunnels

Zusammenfassung
Nach einer extensiven Studie der möglichen Lageanordnungen von über 7 Millionen Kubikmeter Fels wurde im Vereinigten Königreich eine Anordnung in Lagunen hinter einem neuen Seedeich gewählt, während es in Frankreich als Schlämme hinter einen Damm in eine trockene Schlucht gepumpt wurde. Der Artikel beschreibt die Gründe für diese Entscheidungen und einige Studien über den Einfluss der Abraumlagerung auf die Umwelt. Derartige Studien sind in einer zunehmend umweltbewussten Welt sehr wichtig für Projekte jeder Grösse.

1. INTRODUCTION

The Channel Tunnel rail link runs between the Cheriton and Sangatte terminals on the UK and French sides respectively (see Figure 1). The construction of the two 8.4m outside diameter running tunnels and the 5.4m outside diameter central service tunnel requires the removal of over 7 million m^3 of insitu Cretaceous Lower Chalk of Chalk Marl. The Marl is mainly calcite but in places contains up to 40% clay. The total quantity of spoil to be disposed of is greater as excavation fractures the rock, producing bulking. Depending on the method of disposal and subsequent treatment, $1m^3$ of insitu rock can be represented by $1.3m^3$ to $1.7m^3$ of spoil.

Before and during the passage of the Channel Tunnel Act through the UK Parliament many options were examined for spoil disposal, including filling of redundant chalk and gravel pits and reclamation for port development. All the advantages and disadvantages were examined including transport mode and distance, disruption, noise and pollution as well as the financial implications. On the UK side it was finally agreed that most of the spoil should be transported by conveyor and disposed of behind a new sea wall in front of existing sea defences at the toe of Shakespeare Cliff. The area reclaimed would be used as the working site and subsequently as a recreation/conservation area, with a small area allotted for the tunnel cooling plant. The remainder of the spoil was to be taken through the completed service tunnel as fill for the Terminal site.

On the French side, the decision was taken not to use the spoil in any way but to pump it as a slurry behind a new dam at Fond Pignon. The French disposal volume was therefore proportionally greater than the UK because of different method of disposal.

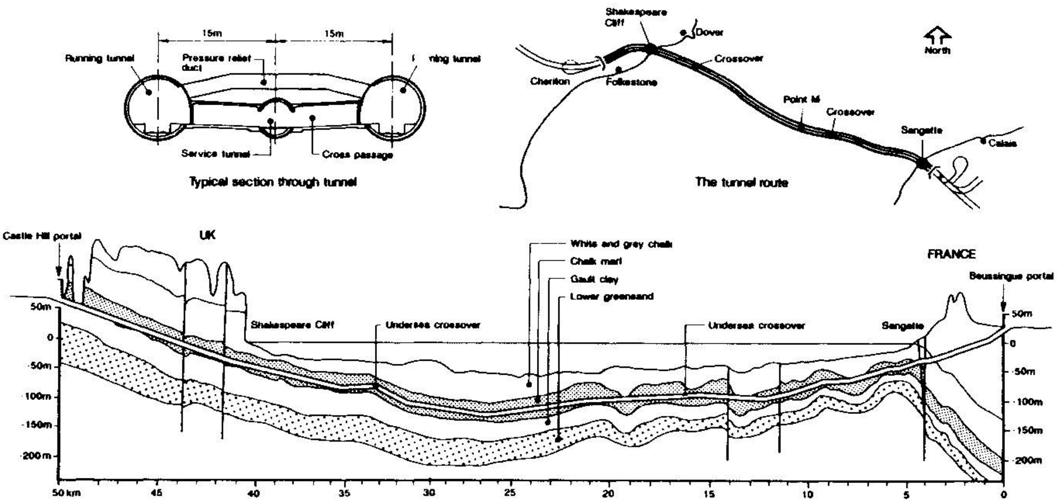

Fig 1 Plan, geological cross-section and section through the tunnels

2. SELECTION OF THE DISPOSAL SITES

In 1986 the British and French Governments awarded the Channel Fixed Link concession to the Channel Tunnel Group France Manche. After the award the Group separated into Eurotunnel (ET), who are now the Concessionaires, and an association of contractors, Transmanch Link (TML), who are entirely responsible for constructing and commissioning the Channel Tunnel Project, including driving the tunnels.

Tunnelling required the removal of over 7 million m^3 of insitu rock, some 4.6 million m^3 coming from the UK side. ET's UK Submission Scheme proposed that most of the UK spoil would be used to create a working platform at Shakespeare Cliff, with some spoil going to raise levels of the Cheriton Terminal site leaving the site for the remainder of the spoil to be decided.

Alternative sites for the remaining spoil were examined by the Surplus Spoil Working Party (SSWP), set up under the Chairmanship of Kent County and included representative from local District Councils, British Rail, and nature conservancy authorities. In all the SSWP examined 70 potential spoil sites against general criteria eg. spoil acceptance rates and environmental impact as well as technical aspects including modes of transport.

The majority of the sites were disused mineral excavations in Kent, within 2 km of a railway line. Piped transfer of the slurrified spoil was considered and rejected on geographical and environmental grounds (on the French side this proved to be the most appropriate method). Road transport was not considered as KCC wished to restrict heavy construction traffic even to deal with the inevitable peaks in spoil production. The local environment was examined in some detail, as were specific spoil disposal activities that could impinge on the above, eg. the generation of a fine slurry and dust, noise etc.

The SSWP finally shortlisted three sites to be investigated further, Lappel Bank (a mudflat in the River Medway), St James Lane (a narrow disused chalk pit) and a dry chalk valley at West Hougham, which lies in an Area of Outstanding Natural Beauty (AONB). After this intensive study the Government decided that, on balance, an extension to the construction platform at Shakespeare Cliff was preferable to any of the above.

The platform at Shakespeare Cliff is the working site from which six tunnels were driven, three towards France and three back inland towards the Cheriton Terminal. The inland drives were 8.1 km long and the marine drives were programmed to be 22 km long, meeting the French marine tunnels on the French side of the Channel mid point. All the marine tunnel spoil was to be deposited at Shakespeare Cliff together with the service tunnel spoil from the land drive. Once the land service tunnel was completed it would then be filled out with a 9km conveyor to take the 1 million m^3 of land drive spoil to Cheriton.

Filling, in addition to that available from the tunnels, was required at Cheriton and various sources were examined including spoil from the Kent coal field. However, it was decided that, mainly on environmental grounds regarding the transport of filling materials, it would be preferable to use dredged sand from the Goodwin Sands. Because of the success of this operation, which involved the dredging and depositing in a near-shore by barge which then, pumped to a head of 60 m over a distance of in excess of 7 km and its beneficial effect on the construction programme for the terminal, it was decided to obtain all the 2.75 million m^3 from this source. This of course left a problem of what to do with the surplus tunnel arisings. Again numerous schemes were studied, including the dumping/disposal outside UK territorial waters. However, a parallel study of the cooling capacity requirements for the Tunnels had shown that cooling was required about 1 month and not as originally envisaged, 1 year, after completion. While the cooling buildings might have been sited in the centre of the Shakespeare platform, this was not acceptable to the planners and it was agreed, after much debate and a full environmental assessment, to site the buildings near the access adits at the east end of the site. Thus, an additional spoil lagoon (number 5) was required at Shakespeare Cliff and the spoil destined for Cheriton was used to fill it.

3. SPOIL PROPERTIES AND DISPOSAL

The tunnels are driven through Cretaceous Lower Chalk or Chalk Marl, consisting of mainly calcite but, lower down, up to 40% clay. Typically a sample might contain 10% quartz, 60% calcite and 30% smectite. As such it is a good tunnelling medium in that it is both competent and relatively easy to excavate. Indeed, tunnels by Col. Beaumont over 100 years ago and a trial tunnel in the early 1970's showed this to be the case. It was always envisaged that the UK tunnels would go more than halfway across the Channel and thus, for the Shakespeare platform, the approved volume of UK rock to be excavated allowed the tunnels to go 2 km further ie through 3.42 million m^3 of rock to point M, up to a maximum of 3.76 million m^3.

It was originally envisaged that spoil would be produced at a peak average rate of about 14,000 tonnes/day for a 24 hour 7 day a week operation. This was equivalent to an individual tunnel advance rate of about 200 m/week. In reality the running tunnels have been achieving about 320 m/week and peaking at 380 m/week. This is considerably more than the planned rate and it is fortuitous that the Shakespeare Cliff site was chosen as transport elsewhere would have been difficult for this production rate.

Tunnelling from the full faced boring machines produces spoil ranging in size from 75 mm downwards, with the majority being in the 35-55 mm range. It was known that handling the spoil, would lead to its degradation and the marine spoil would have a chloride content of 6000 mg/l (brackish) to 20,000 mg/l (saline).

In both the French and UK tunnels spoil is transported from the tunnel face in trains and tipped into receiving bunkers at pit bottom. At Shakespeare Cliff the bunkers feed a conveyor bringing spoil to the surface where an overland conveyor transports it to a radial spreader for distibution. All conveying equipment is designed with a capacity of 2400 tonnes/hour ie. twice the hourly average production rate. The radial spreader has, however been little used, with most of the spoil being transported from the end of the tunnel conveyor by lorry, each lorry placing up to 55 m^3/hour. It was also planned that only the top 4 m of spoil would be compacted in 1 m layers, but greater depths have been compacted both to reduce the overall volume and improve the ground conditions.

Trials in the UK examined the Chalk's "bulking factor" ie. its increase in volume after excavation and transport. Initially the results both at Barrington Quarry near Cambridge and within the works as they proceeded, indicated that with some compaction, bulking factors of between 1.2 and 1.25 could be achieved, but the overall factor has proved to be is nearer 1.37 ie. as originally envisaged.

On the French side spoil is transported by train to the main access shaft behind the shoreline at Sangatte. Here, water is added and it is pumped some 700 m behind a earthfill dam situated in a small dry chalk valley called Fond Pignon. The spoil contains some 50% of saline water when deposited and 20% after consolidation. The estimated final bulking factor of 1.67 has again proved to be low and, because of this and additional spoil quantities, the dam has had to be raised twice rather than the once planned.

4. DISPOSAL SITE DESIGN AND ENVIRONMENTAL IMPACT STUDIES

4.1 Shakespeare Cliff Platform

The 1986 Channel Tunnel Act allowed the construction of the working platform and lagoons at Shakespeare Cliff but limited construction to the seabed fronting 100 year old rail sea defences where the cliffs behind had 'greened'. On either side wave action and erosion ensured the cliffs were 'white' and this balance was not to be changed.

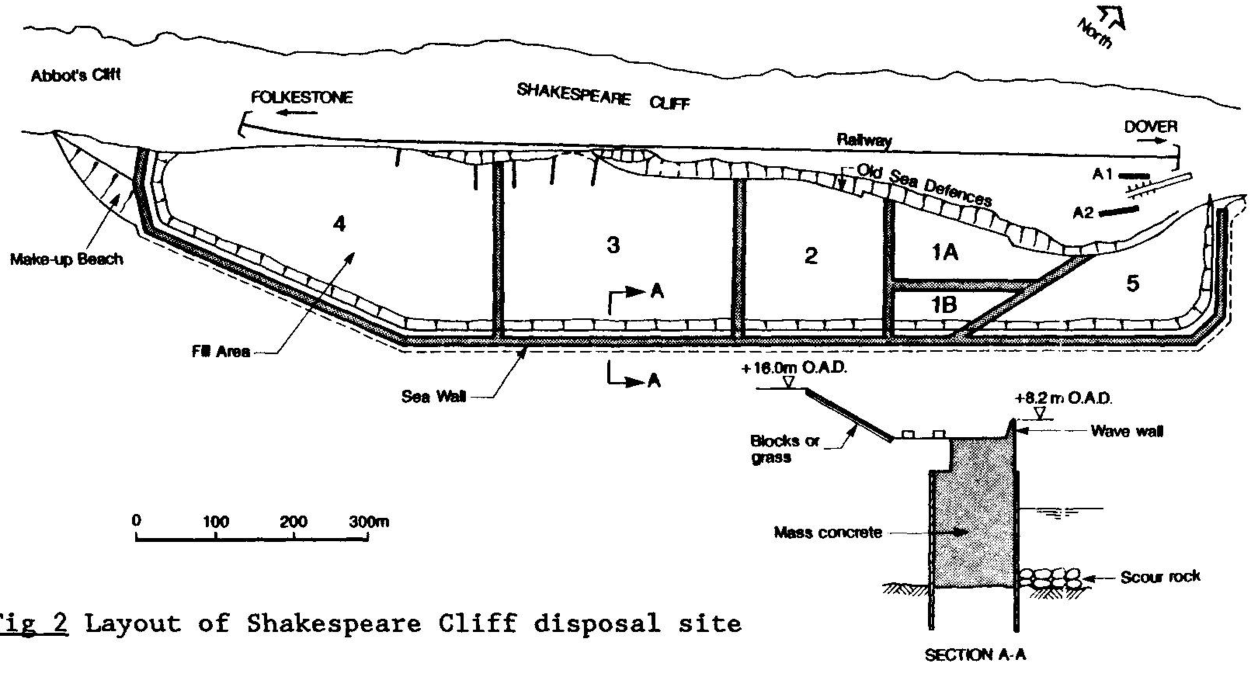

Fig 2 Layout of Shakespeare Cliff disposal site

For tunnelling to begin there had to be a disposal area and because of delays in obtaining final planning approval, TML built temporary lagoons within the agreed main lagoon area. As most tunnel construction activity was to take place at Shakespeare, it was also essential to reclaim it rapidly to provide working space.

A seawall of piled cells filled with mass concrete to 7 m Above Ordnance Datum (AOD) going from cliff to cliff (see Figure 2), which has taken over 3 years to construct, protects the spoil. On top of the mass concrete is a 1.2m wave wall along the front edge and behind at a 13.5 m wide zone of wave energy absorbing structures running up to a level of 8.5 m AOD, with grassed blockwork or 'reinforced' grass extending to the profiled platform which has an average level of 16 m AOD. A blanket of 4t scour rock protects the toe of the seawall.

Spoil could not be placed in the open sea and tunnelling could not wait for the completion of the 1.8km seawall. Thus, a series of crosswalls had to be built from the shore to the new seawall as it progressed, ensuring spoil was only placed in closed lagoons. In total there are five lagoons with the temporary lagoons forming part of lagoon 1 (see Figure 2). The capacity of lagoons 1 to 5 are 510,000m^3, 811,000m^3, 1,387,000m^3, 1,606,000m^3 and 712,000m^3 respectively, giving a total of 5,026,000m^3 covering a seabed area of 393,000m^2. Boreholes, together with seismic and bathymetric surveys were carried out as part of the design, together with piling trials. Noise levels were also measured on top of the cliffs and in the adjacent village of Aycliffe for the various types of piling hammer used.

Lagoon water is expelled, as filling proceeded, or with ingress from groundwater, or rainfall or due to wave overtopping. It was essential therefore to ensure that the dispelled water was clean and the first crosswall was essentially a long settling tank into which flocculating agents could be added, if necessary. However, the temporary piled lagoon walls filled with gravel proved so successful in filtering water, that all the subsequent crosswalls were gravel filled and were used as access roads. The final lagoon has a filtration cell and, as with all the lagoons, the discharge water has been cleaner than that in the surrounding sea.

Throughout construction silt concentrations have been monitored both in the lagoons and the sea using optical pHOX meters, which measure turbidity in mg/l formazin equivalents. Lagoon water levels were also measured. For example the lagoon 4 water level was raised by about 0.6 m in May 1990 and while the turbidity of the lagoon water was higher than in April, it was lower in the sea. Figure 3 shows lagoon turbidities higher than the sea (but discharged water was not) but the lagoon results were affected by algal blooms.

Suspended solid concentrations were also measured at 3 depths in the coastal zone at two stations at either end of the platform and there were sediment sampling stations in deep water off Folkestone and Dover. The purpose of these was to establish the ambient levels of suspended sediment concentrations in the coastal waters and to identify the dependence of natural concentrations on variation of tide and waves. The six inshore pHOX meters recorded continuously and pumped samples were also taken to assist in calibration. Nunny type NBT82 samplers monitored concentrations at the deep water stations, which also included recording Aanderaa current meters. The samples showed that while calcite predominated, the make-up of the suspended solids was different from the spoil, containing more quartz, kaolinite and illite.

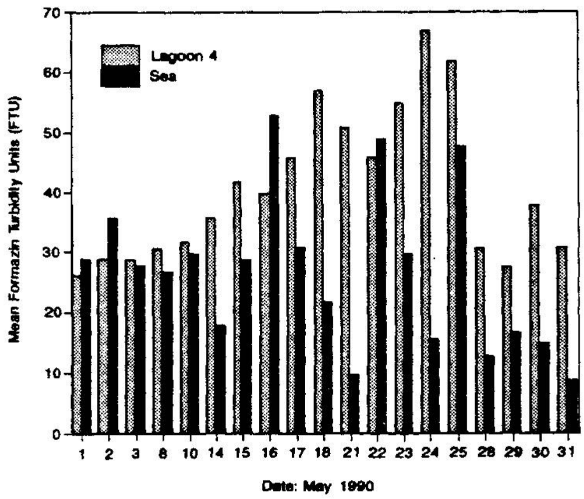

Fig 3 Turbidity, Lagoon 4

While wind derived storm conditions were used initially to establish the seawall design conditions, a wave rider buoy was installed for a period of two years during construction and its results were also used to assess variations in suspended loads. Sediment concentrations were shown to be dependent on tidal level and while correlation was achieved, the spread of concentrations within wave energy and persistence classes remained wide. Typically standard deviations reached 75% of the mean for wave heights of <1.5 m improving to 50% or less for higher waves. Concentrations normally were between 50 and 100 mg/l, peaking at about at about 600 mg/l and 400 mg/l in the coastal zone and offshore respectively.

The Channel Tunnel Act contained provision for the protection of Dover Harbour, which lies just over 2 km to the east of the platform. It was therefore decided to examine the movement of spoil in the event of a catastrophic failure of the seawall. There is a net transport of water eastwards up the Channel into the North Sea and the mathematical model studies showed that while spoil would pass Dover Harbour, little would enter to cause siltation. Also, the environmental impact of such a failure would be relatively small as there would be a rapid dilution and spreading of the spoil.

The existing intertidal and sublittoral flora and fauna, which are relatively limited due to the exposure and type of seabed, have been the subject of long term monitoring and skilled eye surveys. Some 97 intertidal species of seaweed were recorded at Shakespeare in 1989 compared with 94 in 1988 and the benthic faunal survey showed a general reduction in diversity for the same period. The conclusion reached was that the changes seen were as expected in areas such as this where the seabed is highly variable and no effects from the platform construction could be observed.

Cliff stability has also been studied and, as Table 1 shows cliff erosion rates behind the existing platform are surprisingly very similar to those exposed to the sea, the mean rate being 0.1 m/year. Erosion does however lead to spectacular failures of these 100m high cliffs and a failure to the west of the site on 26 January 1988 moved same 6000 m^3 of rock, which was pushed out into the sea in the form of a semi-circular dam. A nearby failure in 1912 moved same 50,000m^3 of rock and the largest failure has been estimated at about 200,000m^3. Clearly, such failures inject considerable quantities of chalk into the coastal zone as is evidenced by the boulder strewn foreshore.

Table 1 Summary of cliff top recession rates

Location	Cliff length m	Sea defence	retreat m/yr	Range of slopes
West end of Abbot's Cliff Tunnel	100	Seawall	0.40	1 in 1.1 to 1 in 0.7
Abbot's Cliff to 1912 rock fall	525	Shingle Beach	0.13	1 in 1.1 to 1 in 0.7
1912 rockfall to west end of sea walls	550	Bare chalk platform	0.08	1 in 1.1 to 1 in 0.5
Sea walls to Abbot's Cliff Tunnel	225	Seawall	0.10	1 in 1.2 to 1 in 0.9
Abbot's Cliff Tunnel to Akers Steps	1250	Railway platform and Seawall	0.12	1 in 1.1 to 1 in 0.7
East of Akers Steps	1000	Shingle Beach	0.06	1 in 0.7 to 1 in 0.4

The monitoring of plant and animal life has not been limited to the sea but has included studies of the unique chalk cliffs and downs. Seeds of over 35 plant species have been collected by Wye College for reseeding the new platform, most of which will be kept as a nature reserve on completion of construction. Seeding trials for the platform and the upper slope protection are proceeding.

Studies of the wave conditions and beach gravel movements have shown that the net littoral drift is from west to east up the Channel. While the potential for movement is large the actual quantities moved in the littoral zone are small due to the limited supply of gravel. The net accretion updrift of Dover Harbour is some 3,000 m^3 annually and the construction of the Shakespeare platform in up to 6 m of water (below low water) would disrupt this drift. Studies indicate that it would take over 100 years before littoral drift was re-established.

To assist littoral material to by-pass the platform a beach and groyne are to be built at its west end with its extent limited because of the unique geological exposures which might be covered by a more extended beach. The beach level variation in up to 30 beach sections have been monitored since the start of the project but recently have been concentrated on Dover West Beach (downdrift of the platform). While significant changes have been seen, these are thought to be due to seasonal changes, cliff falls (which act as substantial groynes) and significant events such as the 16 October 1987 storm, rather than to the presence of the platform. Provision has been made in the Channel Tunnel Act for ET to repair 100 m of beach adjacent to Dover Harbour's Admiralty pier, should erosion be seen during the 120 year lifetime of the project.

4.2 Fond Pignon Dam

The approach of the French Planning Authorities is different from those in the UK and the choice of a land fill site negated the need for the extensive marine environmental studies seen on the UK side. However, many studies, an local fauna and flora and groundwater were undertaken.

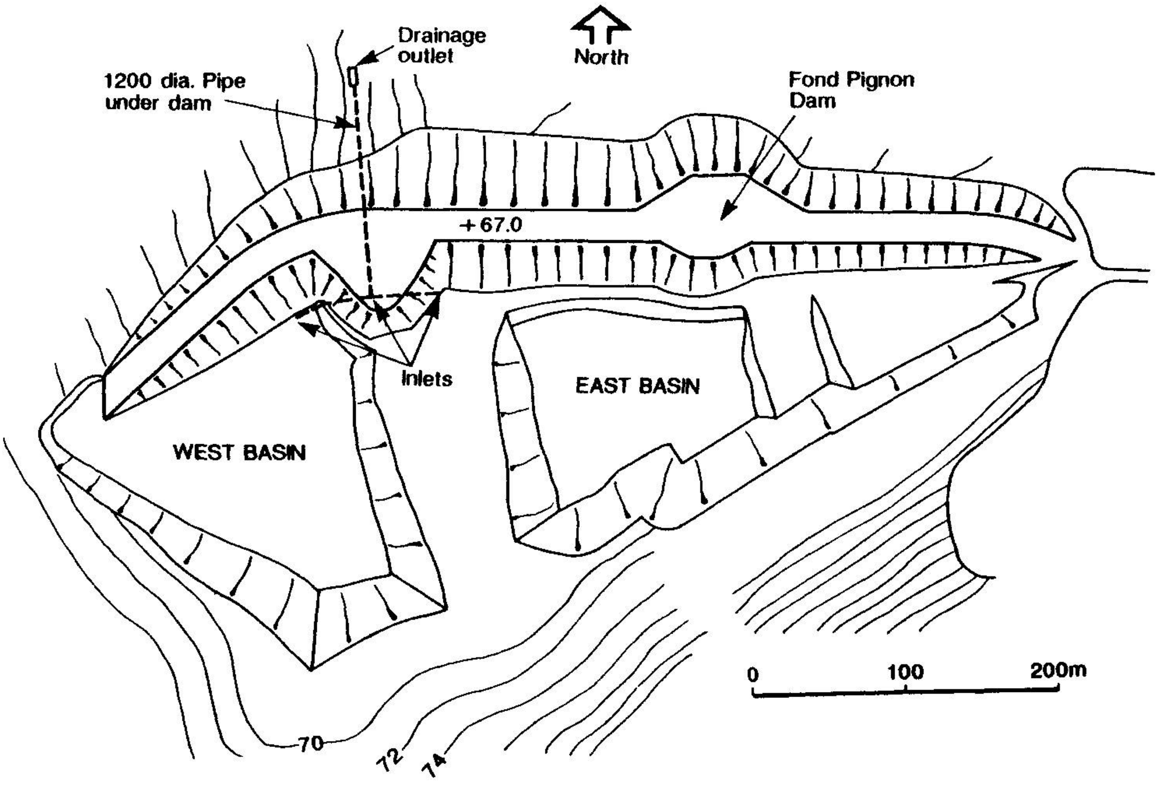

Fig 4 Fond Pignon disposal site

One reasons why TML at Sangatte opted to pump the chalk spoil in a slurry was the nature of tunnelled rock. As Figure 1 shows, part of their tunnelling was in White Chalk and there are a number of major faults (reaching the seabed) through which the tunnels must pass. Also, in general their depth of weathering was greater. Thus, the generally wetter spoil is taken by train to the very large access shaft behind the cliffs at Sangatte and then crushed and turned into a slurry before being pumped to the Fond Pignon site, which lies in a small dry chalk valley, 700 m from the shaft. Originally it was intended that the dry spoil from the drives on the landward side of the access shaft would be sent to the terminal but, for reasons of economy and programming, all spoil went to Fond Pignon.

The planned volumes of insitu spoil excavated on the French side was 2.82 million m^3 and, with a bulking factor of 1.67 the Fond Pignon dam was designed to retain 4.71 million m^3. The reservoir was designed to retain materials with a water content of between 40% and 60% and allow the exuded water from the chalk slurry to be discharged and reused.

The retention reservoir is divided into two areas by a bund roughly perpendicular to the earthfill dam (see Figure 5) which covers two old underground blockhouses. The intention was to construct the dam in two phases, the first about 19m high to provide initial storage of up to 1.4 million m^3 and then to monitor behaviour of the spoil and obtain a bulking factor. The second phase would raise the dam a further 9 m to 11 m, depending on circumstances. It has however been necessary to raise the dam further still because of the better than programmed French tunnelling rates and a higher bulking factor. The dam design was subject to the approval by Comité Technique Permanent des Barrages (Permanent Technical Committee for Dams). However, as it is not a large dam, it was not covered by Decree No 68450 of 16 May 1968 regarding monitoring and warning of downstream populations (there are none in any case) or the statutory order of 11 September 1970 regarding the flood wave.

The comprehensive programme of geotechnical investigations carried out to ensure the project was technically feasible included 15 water testing wells. Pumping spoil required a water content of about 50% when deposited and 20% after consolidation. Seepage studies show that salt concentrations in adjacent ground, greater than 10% of the original concentrations, only inside a 1200 m wide belt between the dam and the sea. This area is well away from any water catchment and should have no effect on potable water quality. Two wells sunk downstream allow groundwater levels and quality to be monitored.

On completion the area will be landscaped and replanted by species similar to that of the surrounding countryside. Replanting trials are underway at present.

5. CONCLUSION

The paper describes some, but not all, of the studies that have been carried out both in terms of the design and to examine the environmental impact of the schemes for spoil disposal. For the Shakespeare Cliff platform alone there have been over 40 studies and many more studies have been carried out on the terminal areas, including archaeological digs.

It might be thought that too much effort has been put into the environmental studies but, while they have been considerable, their costs are normally small compared with the size of the project.

The Channel Tunnel studies have led to a limiting of any potential environmental impact the project might have. They have also advanced knowledge and understanding of the environment and, importantly, re-assured all statutory authorities and the general public that the early assumptions regarding the impact of the works were indeed correct.

During the course of the work every effort was made to obtain the agreement and co-operation of not only the authorities but the general public as well as. ET have held regular "Environmental Forums" at which the progress of the work and the various studies are described and discussed and copies of reports are sent to the relevant interested parties. The general public's interest in the project is high and catered for at ET's Exhibition Centre, which has received about 350,000 paying visitors annually since it opened in September 1988.

Interaction between the Salhus Floating Bridge and the Environment

Interaction entre le pont flottant de Salhus et l'environnement

Wechelwirkungen zwischen der Salhus-Schwimmbrücke und der Umwelt

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SUMMARY

A 1200 m long floating bridge is planned to be built across the Salhus fjord located close to Bergen, Norway. The bridge is shaped as a continuous arch, penetrating approximately 3 - 4 m below the sea surface. The local fish farming industry fears that the presence of the bridge will form a deeper and more brackish water layer which might be harmful to their industry. This conflict has delayed for years the decision to build the actual floating bridge. The paper explains some of the measures that have been taken in order to resolve the conflict.

Interaction entre le pont flottant de Salhus et l'environnement

Résumé

Un pont flottant de 1200 m est prévu sur le fjord de Salhus, près de Bergen, Norvège. Le pont en arc est continu et pénètre d'environ 3 - 4 m sous le niveau de la mer. L'industrie locale de la pêche craint que la présence du pont ne crée une couche d'eau saumâtre en profondeur, laquelle pourrait avoir des conséquences néfastes sur leur industrie. Ce conflit a repoussé pendant des années la décision de construction du pont flottant. L'article explique les mesures prises afin de résoudre ce conflit.

Wechselwirkungen zwischen der Salhus-Schwimmbrücke und der Umwelt

Zusammenfassung

Der Bau einer 1200 Meter langen Schwimmbrücke über den Salhus-Fjord nahe Bergen, Norwegen, ist geplant. Die Brücke ist als kontinuierlicher Bogen geformt, der ungefähr 3-4 Meter in das Meer eintaucht. Die lokale Fischfarmindustrie fürchtet, dass die Anwesenheit der Brücke eine tiefere und mehr brackwasserhaltige Schicht bilden wird, die schädlich für ihre Industrie sein könnte. Dieser Konflikt hat den Baubeschluss um Jahre verzögert. Der Artikel erläutert einige der Massnahmen, die unternommen wurden, um den Konflikt zu lösen.

1. INTRODUCTION

The planning of the Salhus floating bridge has continued for more than 20 years. One of the reasons for its delay is not the lack of technology for constructing such a bridge, similar bridges are built elsewhere. The main reason turns out to be a long lasting conflict with other interests in the area, basically the local fish farming industry. They fear that the presence of the floating bridge will influence on the brackish water conditions in the fjord in such a way that they will suffer from severe economic losses. Accumulated over a time period of 25 years, losses have been estimated by governmental authorities to be of order 100 - 500 mill NOK. These figures are so large that they approach the cost of the bridge itself. This fact has motivated the Road Authorities to apply more advanced hydrodynamic models to investigate the expected impacts on the brackish water masses from the bridge more carefully.

2. THE SALHUS FLOATING BRIDGE CASE

The Salhus floating bridge is planned to cross an approx. 1350 m wide fjord in the area north of Bergen (see map on Fig. 2.1). On the Bergen side, ship traffic will be allowed to pass through an entrance which is approx. 170 m wide. On the northern side, the bulk of the ship traffic will be allowed to pass through an entrance named Hagelsundet, which is approx. 200 m wide.

The fjord area inside the floating bridge is of order 150 km^2. A number of rivers enters the area, causing a brackish layer to be formed inside the Salhus site. The western coast of Norway is exposed to westerly winds, which cause the precipitation in the area to be severe. During the spring season, the melting of the snow in the mountains gives rise to a brackish water formation within the whole area under consideration. A similar situation occurs in the autumn, before the precipitation enters as snow in the winter time.

Within the same area, a large number of fish farming industry plants have been established during the last 10 - 15 years. Of these, approximately 15 plants are based on the selling of market-sized salmon. These are growing in floating and transparent cages exposed to the brackish water masses. However, the salmon is sensitive to the presence of the brackish layer when trapped in the cages. Today, losses are sometimes experienced in the cages due to natural changes in the brackish water conditions. The fish farming industry is therefore concerned about possible "trapping" of the brackish waters inside the floating bridge in such a way that a deeper and an even more brackish layer is formed. They fear that their losses will then increase considerably.

The governmental authorities have asked for a quantification of the possible additional losses due to the presence of the floating bridge. A relatively simple hydrodynamic model was built in order to predict the changes in the brackish water depth and salinity due to the presence of the bridge. Results from the calculations were resented by Gjerp et. al. (1986). The model predicted average changes in the salinity and the depth of the brackish layer inside, given an average wind velocity, average fresh water inflow and bridge geometry.

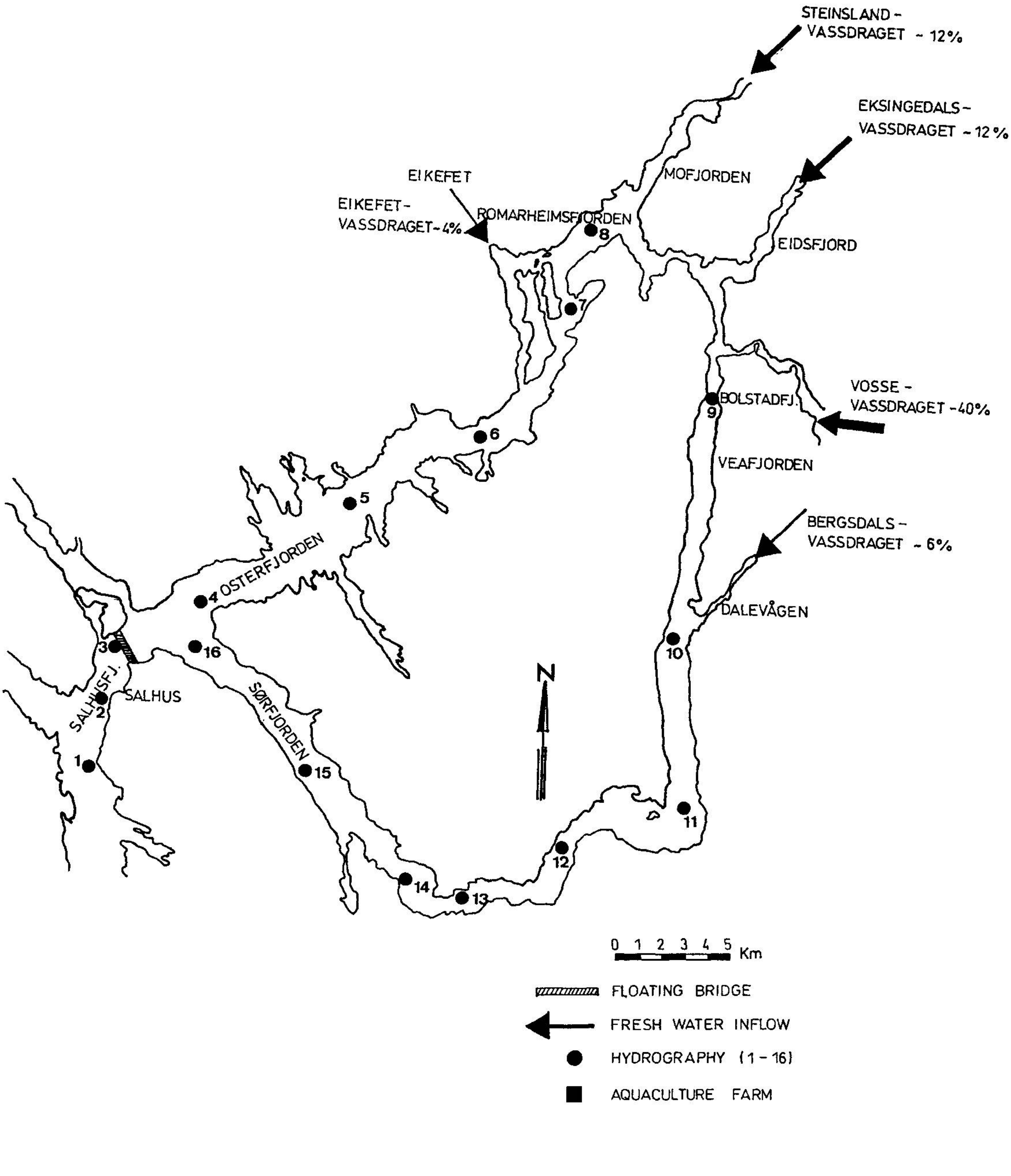


Fig. 2.1. Map of the fjord areas inside the bridge location. Main sources of the fresh water inflow are shown. Locations of the hydrographic stations, numbered 1 - 16, are shown (circles). The locations of the 5 fish farming sites are shown (squares). The city of Bergen is located close to the down left corner of the figure.

This model does not take into account the geographic variation of the brackish water conditions within the area under consideration. Nor does the model include a description of the time and geographic variation in the wind conditions and the fresh water inflow. The model assumes "stationary" conditions. The residence time of the water masses inside may run up to 14 days, which makes the assumptions in the model not realistic. The results from applying the model described by Gjerp et. al. (1986) can therefore be characterized as a first approximation to the description of the brackish water changes inside the floating bridge.

In 1988 the governmental bodies finally agreed to build a floating bridge across the Salhus fjord, on the following terms:

* Alternative solutions for the lay-out of the floating bridge which would allow the brackish water to pass through should be considered.

* A monitoring programme should be conducted to determine the impacts from the floating bridge.

In addition, the Road Authorities decided to apply a more advanced hydrodynamic model to improve on the description of the brackish water changes. The motivation for this was to be able to improve on the calculation of losses imposed on the fish farming industry by the bridge.

The bridge is at present sceduled to be installed on site at the turn of the year 1993/94.

3. THE MONITORING PROGRAMME

The monitoring programme includes hydrographic measurements of the brackish water masses, a number of surveys for observing possible biological changes in the area, and fish physiological laboratory investigations in order to determine the response of salmon to brackish water stresses. The duration of the programme is expected to last for 3 years before and 3 years after the installation of the bridge.

The hydrographic measurements are partly carried out on 5 different fish farming plants in the area, including daily measurements of temperaure and salinity down to 10 m depth. These measurements reveal the time variations of the brackisk water on actual fish farm locations. In addition, hydrographic surveys are carried out every fortnight in the area. These cruises reveal the geographic variations of the brackish water conditions. The locations for the 5 fish farming industry plants as well as the stations for the hydrographic surveys (numbered 1 - 16) are shown in Fig. 2.1.

Fig. 3.1 shows one example of brackish water changes recorded during the measurement program. The figure shows the salt water changes at the location Trengereid during February, 1990. Note the rapid thange in salinity conditions at February 7 and February 21-24. Such changes are expected to be harmful to the fish farming industry. However, no losses were experienced during these two cases.

Fig. 3.2 shows the results from the survey carried out at April 9, 1990. This figure illustrates the geographic variations in the salinity conditions which are sometimes experienced in the area. Salinity are shown for increasing station numbers from left to right. Note the rapid change in the salinity in the Vaksdal area (see the map in Fig. 2.1).

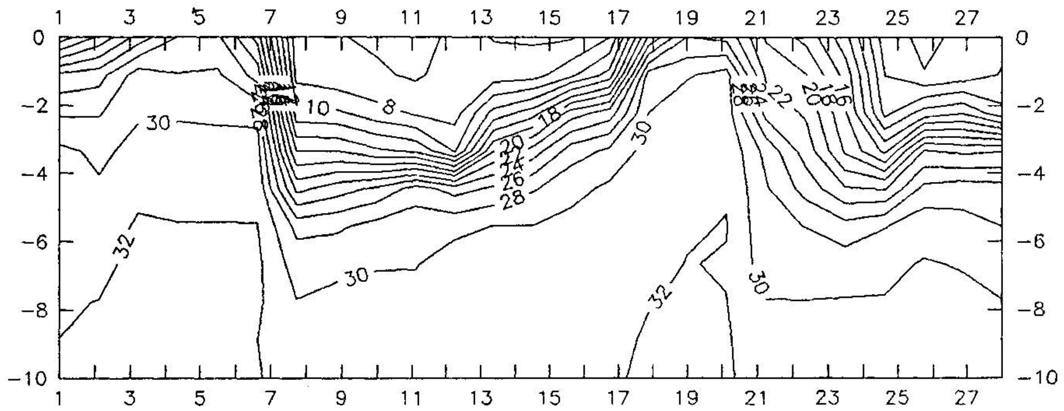


Fig. 3.1. Plots of the salinity (^{o}/oo) measured at Trengereid in February 1990. Horizontal axis: Date. Vertical axis: Depth in m.

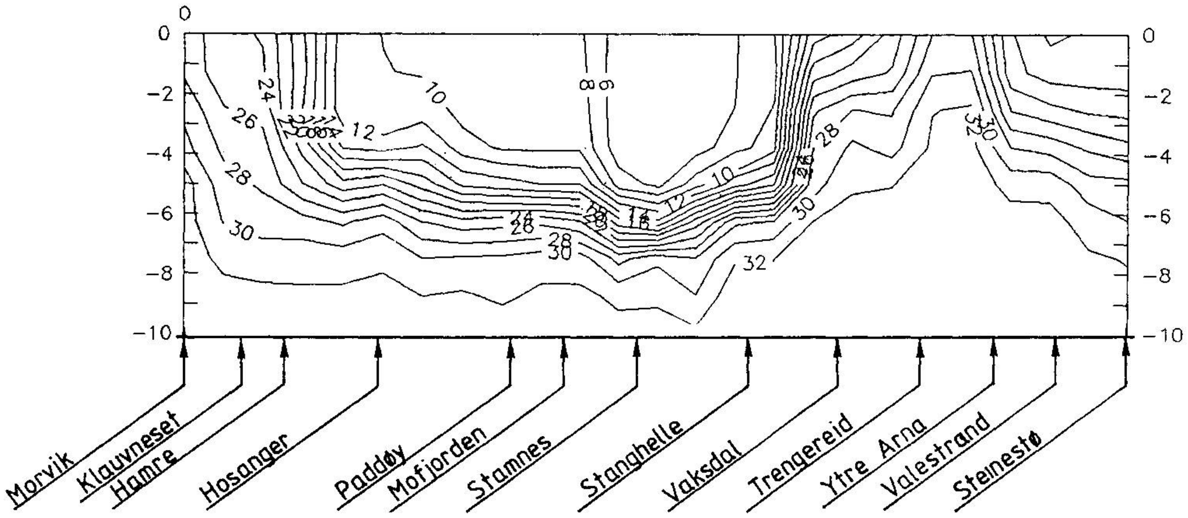


Fig. 3.2. Plots of the salinity (^{o}/oo) measured at April 9, 1990. Horizontal axis: Location of measuring site, se map in Fig. 2.1. Numbers are running 1 - 16 from left to right. Vertical axis: Depth in m.

Due to the large time- and geographic variations of the hydrographic conditions in the area, it will be difficult to separate the natural variations of the brackish water conditions from the imposed variations caused by the floating bridge. To do this, the model "MIKE-12" was applied, as explained in the next chapter.

4. THE DHI HYDRODYNAMIC MODEL "MIKE-12"

Bjerknes has pointed out (Bjerknes, 1985) that actual values of salinity within the brackish layer may not be the crucial parameter for the fish stresses rather than rapid time changes in the brackish water conditions. Such changes cannot be described by

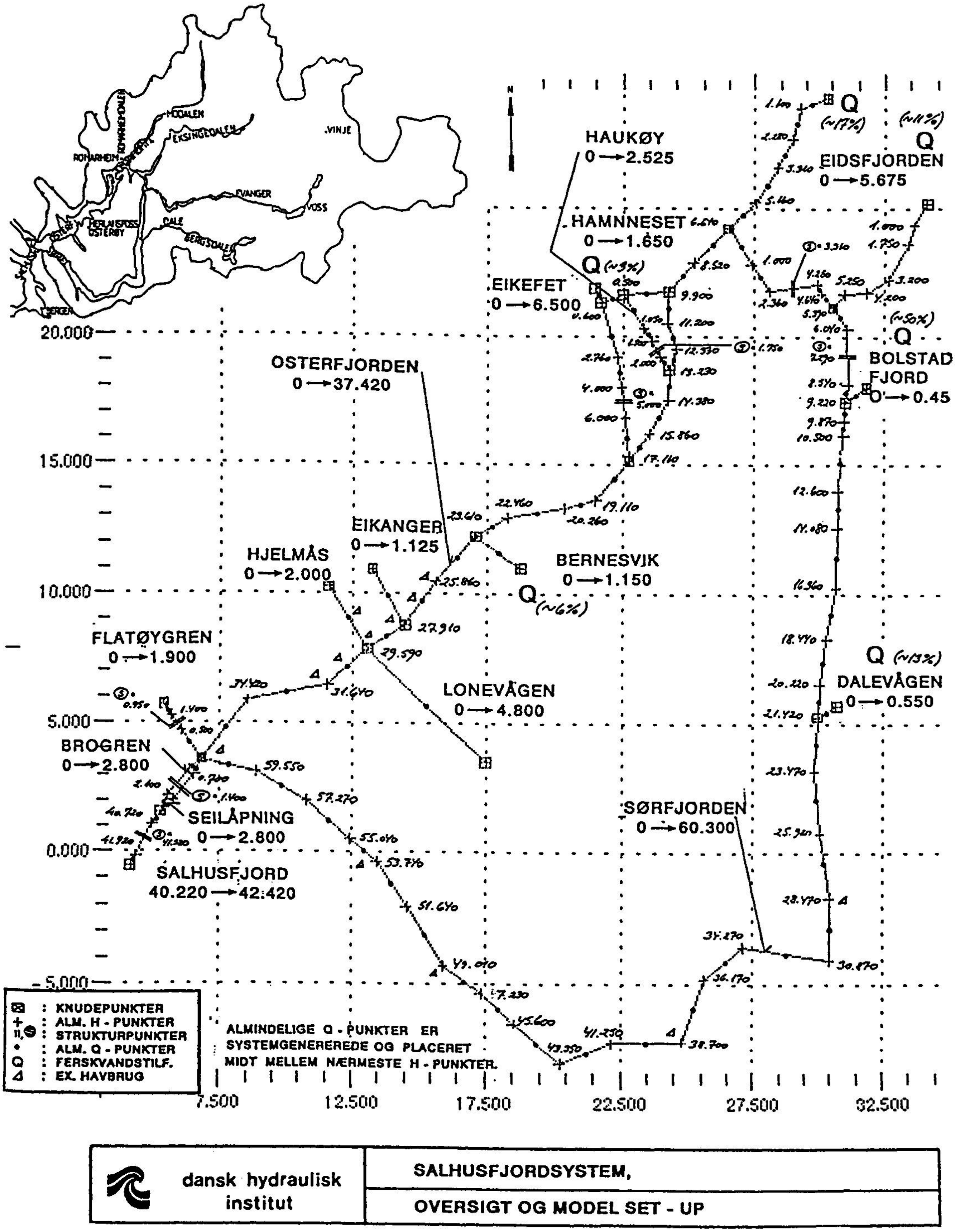


Fig. 4.1. Structural lay-out of the DHI hydrodynamic model "MIKE-12". Open boundaries are located at Salhusfjord (point no. 42.420) and at Flatøygren (point no. 1.900). Locations for fresh water inflow are denoted Q (6 locations). Location of the floating bridge is close to "SEILÅPNING".

means of a "stationary" type brackish layer model. The DHI model "MIKE-12" has the ability to describe such time changes as well as geographic variations in the brackish layer. This model was therefore chosen for the the more advanced description of the brackish layer conditions.

The model is based on a two-layer description where the hydrodynamic equations are applied to each layer. Acceleration terms as well as diffusion terms and sink/source terms within each layer are included. The model resolves the brackish water properties in time and along the main fjord axis, as shown in Fig. 4.1. All physical properties are integrated laterally (normal to the main fjord axis) and within each of the two layers. Forcing factors are fresh water inflow (which enters the model area at 6 different locations), tides and wind. The tides are specified on the border, while the wind is specified at the surface. Both wind direction and strength are allowed to vary, both in time and space, within the model area.

The wind causes local pile-up of the brackish water masses due to surface stresses. At the same time, it generates mixing between the two layers and thus causes the salinity (or density) in the upper brackish layer to vary. Some initial mixing at the river entrances is included. The model also allows for internal hydraulic jumps and corresponding mixing at the location of the floating bridge and at narrow passages where the flow conditions become supercritical. Further details of the DHI hydrodynamic model "MIKE-12" is given in Møller et.al. (1989).

In order to account for the bridge effects, laboratory investigations were carried out with a floating bridge model installed in a water flume. The model bridge was exposed to a brackish water flow, running on top of a heavier water body below. Different geometries of the floating bridge were tested (surface roughness, width, depth and rounding of the corners) and the results parameterized for use in the mathematical model. Details are given in the reports from DHI (DHI 1989 and Møller et.al. 1989).

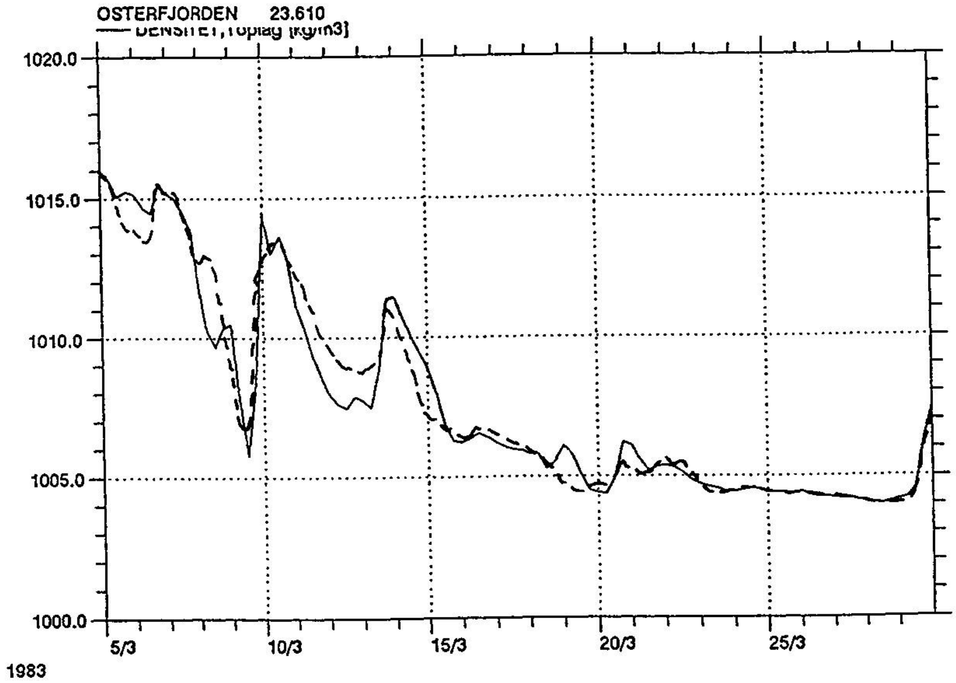
The effects imposed by the floating bridge were then determined by first computing the brackish layer behavior in the fjord system (given the actual time-varying wind conditions and the fresh water inflow as input) without the floating bridge present. Then the computations were repeated, but this time with the floating bridge present in the mathematical model. The difference in brackish layer depth and salinity (density) computed for the two runs represents the bridge effect.

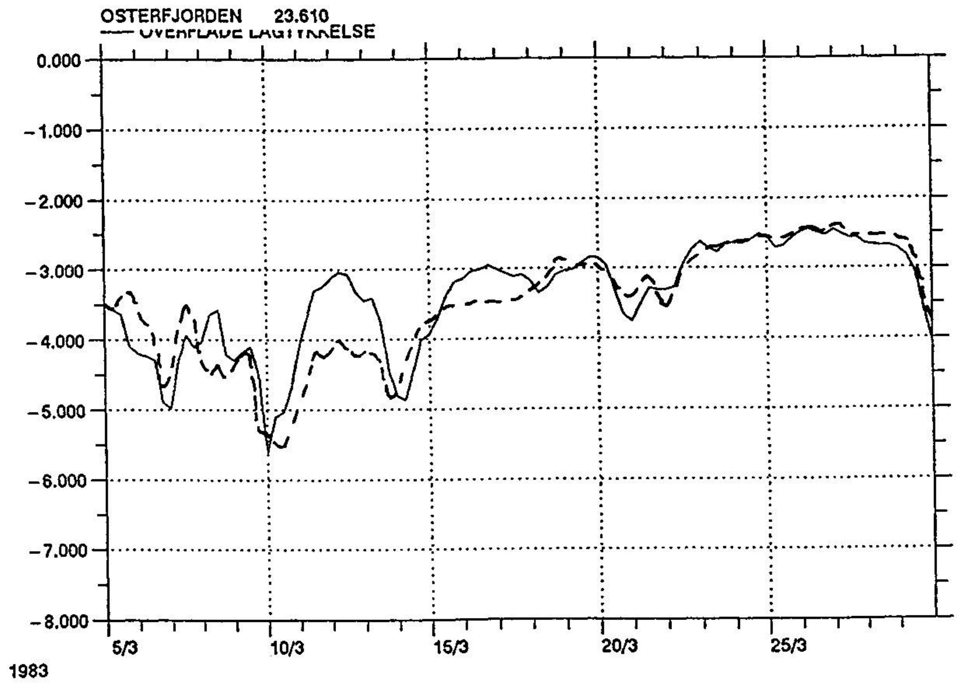
5. VALIDITATION OF THE MODEL

The hydrographic material collected provides an excellent basis for verification of the "MIKE-12" model. The model was verified to compare reasonably well with recordings of the hydrographic conditions during a time period in Aug/Sept. 1989. The comparison shows best agreement between the recorded and the simulated depth of the brackish layer. For the simulation of the salinity, the agreement is less satisfactory, although the trends are reproduced. The discrepancy is attributed to strong local variations in the wind fields which are not reproduced by the model. Further details are given in Rye (1990).

6. A CASE STUDY; MARCH 1983

During March 1983, losses were experienced on many fish farming locations within the Osterfjorden area. The cause of the losses has been attributed to a fresh water episode which started in the beginning of March 1983.





Figs. 6.1 and 6.2. Density (upper figure) and brackish layer thickness (lower figure) for the Osterfjorden location computed for March 1983. Full line: Without bridge present.
Broken line: Bridge included.

Fig. 6.1 shows the computed density in the brackish layer during the time period of March 5 - 30, 1983, for one location in Osterfjorden (Point No. 23.610). Fig. 6.2 shows the similar results for the brackish layer depth during the same time period. The full lines in Figs. 6.1 and 6.2 show the results from computations without the floating bridge present, while the broken line shows the results with the floating bridge included.

It turns out that in this particular case, the differences are small. The density reduction is almost not present, in fact, the density changes are both positive and negative. The increase in the brackish layer thickness is rather modest. In addition, there seems to be a bridge effect present which tends to decrease the oscillations induced by the wind.

The mathematical model has been applied to simulate other time periods as well. The general trend is that the bridge effect is largest when the fresh water inflow is large combined with the absence of the wind. In such a case, the increase in the brackish layer thickness may exceed 1 m in the areas closest to the bridge (Møller et.al. 1989). The amplitude of the changes decays somewhat with an increasing distance from the bridge. Such conditions occur frequently in the springtime when the snow melting in the mountains takes place.

7. SUMMARY

The revised computations as well as the monitoring programme have brought about a better understanding of the mechanisms involved when salmon is exposed to brackish water stresses. However, the governmental bodies have shown some reluctancy to include this new information into their loss estimates. This could be harmful for the aquaculture industry in particular, because some of the losses which are experienced in the past are probably not originating from brackish water stresses, but have other causes. This is at present not fully recognized by the fish farming industry. It is therefore a risk that the fish farming industry may experience additional losses because their true origin is not fully recognized.

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Construction in Arctic and Sub-Arctic Environments

Construction dans des environnements arctiques et subarctiques

Konstruktion in arktischer und subarktischer Umwelt

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SUMMARY

Marine construction in the Arctic and sub-Arctic must address the special problems raised by the unique physical and ecological environment. Of special concern are the perceived hazards of noise and construction activity on caribou, sea mammals, and nesting waterfowl. The impacts of near-shore and on-shore support for marine operations must be addressed, especially roads, gravel removal and embankments, ice jams, waste disposal, coastal erosion and air pollution. Dominating all is the potential for oil spills in wetlands and in the sea ice.

Construction dans des environnements arctiques et subarctiques

Résumé

Les constructions marines dans les régions arctiques et subarctiques doivent prendre en compte les problèmes spéciaux soulevés par cet environnement physique et écologique unique. Les problèmes particuliers concernent les dangers du bruit et des activités de construction sur la flore et la faune côtières. L'influence des installations proches de la côte et en mer doit être prise en compte, en particulier les routes, les gravières et les digues, les blocs de glace, les déchets, l'érosion côtière et la pollution de l'air. Le danger potentiel principal reste la pollution pétrolière dans les zones de marais et dans la glace.

Konstruktion in arktischer und subarktischer Umwelt

Zusammenfassung

Küstenbau in der Arktis und Subarktis muss die speziellen Probleme berücksichtigen, die sich durch die einzigartige klimatische und ökologische Umwelt ergeben, berücksichtigen. Von speziellem Belang sind die spürbaren Gefahren durch Geräusche und Bautätigkeit für Karibus, Meersäugetiere, und nistende Wasservögel. Zu beobachten sind die Auswirkungen von Infrastruktureinrichtungen für maritime Operationen in Küstennähe und an der Küste, insbesondere Strassen, Planierungen und Aufschüttungen, Eisstaus, Abfallbeseitigung, Küstenerosion und Luftverschmutzung. Besonders gravierend ist die Gefährdung durch auslaufendes Oel in Feuchtgebieten und im Meereis.

INTRODUCTION

Major marine activity in the Arctic and sub-Arctic regions has accelerated in recent years due to the discovery of large petroleum resources. This activity has included the construction of docks and causeways along the coasts, pipelines bringing water and oil to shore, artificial islands, shipping terminals, and offshore platforms.

The ambient environment in which these activities are being carried out is unique. It has often been characterized as fragile, although that word is mainly a representation of the slow progress of many natural processes as compared to those in warmer regions of the world.

Low temperatures, down to -50°C, persist for many months of the year. Long dark winters contrast with days of 24 hours of continuous sunlight during the summer. The air is calm during much of the year, punctuated by relatively violent local storms, the "polar lows." Haze and smoke hang low in the air during the winter.

The Arctic itself is dominated by the Polar Ice Cap 3 to 4 m. thick and 1500 km in diameter, slowly revolving counter clockwise. Along the coasts, annual ice forms, much of it anchored to the shore and thus designated as "fast ice." Between the polar ice cap and the fast ice lies the shear zone, a dynamic area of movement. When the annual ice is gone, the shear zone may be dominated with intermittent ice floes, driven through the sea by current and winds.

Glaciers reach down to the sea from the mountainous areas, along the coasts, terminating in ice shelves that spall off icebergs. In the true Arctic, these become captured by the ice sheet and circulate around the pole as "ice islands" for several years before breaking up.

The Arctic waters are typically cold, about -2°C, although in late summer, shallow coastal waters may warm up to + 8°C. Their oxygen rich waters are extremely productive biologically, with rapid plankton growth as the sunlight strikes open water. This in turn starts the spectacular migrant food chain of pelagic and anadromous fish, marine mammals, such as seals and whales, hordes of geese and ducks, and land predators, such as polar bears.

The mammal "Man" has inhabited the circumpolar regions for 12,000 to 15,000 years. The Inuit, apparently originating in northeastern Asia, spread their unique culture around the top of the world as the last ice age retreated. Their ability to survive has only been seriously challenged by the diseases brought by men from the south in the last century, and by the cultural changes imposed by Western Civilization in this century.

The Inuit peoples have become politically active in recent years, uniting across national borders, and making the world aware of their demands that their historical identity be preserved.

The Inuit are marine - oriented peoples, living by and on the sea. Their villages have survived through their unique capabilities and traditions. This culture spreads around the pole, across Arctic land claimed by 5 countries, yet through today's communications the Inuit are becoming aware of their common heritage and destiny.

The coasts themselves are maintained in relative stability by being permanently frozen. Permafrost often lies but a half meter or less beneath the surface. That surface is in turn protected by an insulating blanket of tundra, a collection of lichens, moss, ferns, and grasses.

The near-shore bottom of the seas is most often silt, loose on top, but often overconsolidated at a depth of a few meters. These bottom soils out to a depth of 50 m are continuously plowed by the keels of ice ridges.

The world has lately recognized the importance of these Arctic and sub-Arctic regions to the world's ecosystem, and governments have initiated regulatory and educational institutions to preserve it.

These Arctic regions also offer unique scientific opportunities to the world. Currently an international consortium of national scientific organizations is being formed, to join in cooperative and collective effort in carrying our investigations and improving our understanding of physical and biological processes in the northern polar regions.

Until the 20th century, the only intruders to this pristine environment were the explorers, the fur traders, the fishermen, and the whalers. Although their depradations were serious - measles, the near-extinction of the sea otter and the bowhead whale, the Arctic showed amazing recuperative ability.

Into this precarious, but quasi-stable environment, modern construction activity is being thrust, as a result of the insatiable demand of Western Civilization for minerals, principally oil, but also including gas, zinc, lead, tin and gold. The distinguishing element of these modern day invasions is their scale: they are characterized by large-scale activity on-shore, along-shore and off-shore. Their potential for major damage to the environment is thus multiplied by several degrees of magnitude over that of previous activities.

Concurrently, awareness of the global environment has become a politically important force in the Western World. Thus, we are currently faced with a conflict between the insatiable demand for resources and the highly vocal and articulate demands for preservation of this remote part of the globe in its original pristine state.

SPECIFIC PROBLEM AREAS

Freed from the hysteria which surrounds most large-scale proposed developments in the Arctic and sub-Arctic, specific concerns and problem areas emerge. Some are local, some global.

Ecology

Waterfowl, from terns to geese to ducks, nest by the millions on the Arctic coastal plains, feeding in the rich tundra and shallow water lakes.

Caribou are a herd animal, often grouping in bands of 1000 or more. They are migrant, sometime following fixed routes, other times driven by severe climates and predators to new areas.

Offshore, the seals are the dominate marine animal, food for polar bears and man. Whales of several species mate and rear their offspring in the Arctic. Walruses plow the mud bottom and sea otters search for clams on the seafloor of sub-Arctic areas.

The Arctic is famous for its huge stocks of fish. The Bering and the Barents Sea are the most protein-productive regions of the Northern Hemisphere.

Predators exist in a dynamic state of balance: Polar Bears, whose primary food is seals; wolves, who stalk the sick and crippled and aged caribou; foxes creeping towards the waterfowl.

Predators and hunted undergo cyclic patterns, slightly offset from each other. The result may be yearly populations that vary dramatically, sometimes by a factor of 10.

Environmentalists are properly concerned about any major disruption to this semi-balanced ecology, especially as there is still so little understood about the cyclic variations in populations. For example, even the killing of a relatively small member of female seals in a populous year has resulted in endangerment of the herd in a subsequent year of low reproduction.

The effect of an oil spill on these Arctic waters is certainly by far the most politically dramatic concern. The world-wide public views an oil spill as prima facie evidence of unbelievably disastrous environmental damage, despite considerable evidence to the contrary.

For example, the year following the large oil spill in Prince William Sound in Valdez, Alaska, was the most productive salmon fishing in history. It was exceeded only by the following year, 1990. It is probable that the most important effect of the oil spill as far as salmon were concerned was to reduce offshore catches due to the closing of the coastal waters for fear of contamination, allowing the fish to proceed to the estuaries and rivers. But even that does not explain the cyclic phenomena so characteristics of Arctic species.

Regardless of the factual and rational aspects, oil spills of any quantity are viewed by the public and the governments as totally unacceptable. As far as the engineering construction industry is concerned, they have the same status as loss of life: only zero is an acceptable amount.

Therefore, extreme care had to be taken with all construction activities to prevent any waste oil or oil drips from entering water. Oil on streams will flow to the sea. A small amount of oil on the sea will spread out in a sheen that is visible for many miles.

Of special concern are provisions for clean-up after an oil spill. These must be available for containment and clean-up under all circumstances: waves, broken sea ice, full ice cover.

Waves will disperse and break-up oil concentrations quite effectively. Conversely, they render booms and skimming devices ineffective.

Freed from all irrationalities, the most critical areas for oil spill are the marshes and low-lying tundra; the "wetlands." Here the natural degradation of oil as a result of sunlight and oxygen and bacteria takes much longer, and the effect on the animal and plant life is direct and persistent. It was the fishermens' quick response to the Valdez disaster that saved their rivers and streams, the salmons' breeding grounds. The fishermen fixed log and fabric booms across the rivers' mouths.

Grayling and salmon must find their breeding grounds in the gravelly stream beds. They can swim up streams that in places are only 50 mm deep, but they cannot cross a 50 mm high dam of gravel.

A simple solution for gravel reclamation in Arctic streams is to drag the bucket lengthwise, creating longitudinal furrows, instead of across the stream.

These anadromous fish, as they approach their breeding streams, swim close to the shore, in shallow water. Obviously causeways disrupt their passage. Openings in the causeways, bridged over, appear to be a logical answer, except that salmon are reluctant to swim under a shadow! Perhaps this is a genetically-transferred reaction to the shadow of the Alaskan brown bear which scoops out the fish with its giant claws.

More research on this phenomenon and means to overcome it is being carried out at present.

Although environmental groups have expressed concern over dredging and filling and the consequent plumes of silt-laden water, it must be recognized that Arctic rivers such as the Mackenzie, Yukon, Kuskokwim and their counterparts in Siberia, deliver enormous quantities of glacial silt and clays to the Arctic Ocean. Thus, the adverse effects of dredging, if any, will be limited to a small local region such as a harbor.

Noise has an adverse effect on many of the higher organisms, including man. It reportedly confuses whales, who communicate and navigate by sonics. It disturbs geese and ducks. Strangely, many animals become used to it: caribou no longer raise their heads as a helicopter buzzes overhead.

Adverse construction noise arises from a variety of operations.

Dredging creates water-borne low frequency noises as the rocks and gravel pass through the discharge line. Drilling similarly creates low frequency noises. These noises travel long distances through the water. The sounds are unfortunately in the range used for communication and navigation by the bowhead whale, a mammal believed extinct in the eastern Arctic and threatened in the Beaufort Sea.

Piledriving undoubtedly is as bad or worse, especially when driving the steel tubular piles typically employed in modern Arctic marine structures.

Waterborne noise can be attenuated and dissipated by air bubble curtains.

Another source of noise are power-driven boats and propellor-driven ships. Although the native population regularly use "skidoos" which create very loud air-borne noises, highly objectionable to man's ears, they claim that propellor noises, being in lower frequencies and waterborne, have greater adverse effect on fish and marine mammals. The natives claim, with some substantiation, that the whales are moving further offshore in their migration routes with each passing year, due to near-shore construction noise and activity.

Low flying aircraft can be very disturbing to nesting geese. Various operational restrictions have therefore been imposed by local authorities.

In an effort to prevent the adverse effects on the Bowhead Whale, which is designated as a threatened species, many construction and drilling operations are limited as to the times of year when they may be carried out. It is generally agreed by all that these noise-producing activities must be suspended as the semi-annual migrations pass.

Waste disposal in the Arctic is a difficult matter. The permanently frozen soils, permafrost, located only a half meter or so below the surface prevent dissipation and digestion in the soils. All surface effluents run off to the lakes, rivers and ocean. Only carefully planned and implemented chemical treatment, involving heat, chemicals, and bacteria, can convert the wastes of man, garbage and sewage, into environmentally acceptable effluents.

Similarly, solid waste is a much greater problem in the Arctic than in temperate climates. Low temperatures minimize corrosion and degradation. As a result, garbage becomes an attraction for Polar Bears, always a threat to a human community, since their natural food includes seals and man. Landfill disposal is impossible with permafrost. Even where unfrozen soil makes landfill feasible, the bears will dig it up, as demonstrated at Point Barrow. Today, some major oil centers in the Arctic are shipping their solid waste back to temperate climates on the return trips of the barges and ships that bring in their supplies.

COASTAL STABILTIY

As noted earlier, the coasts, largely dunes of sand and silts, are stabilized by being permanently frozen, insulated from summer warming by a thick coat of tundra. Any disturbance of this state of balance. which depends on only a few degrees of temperature disturbance, can lead to substantial slides and erosion.

Thermal disruption can arise from a variety of construction operations. Bulldozer tracks crush the tundra and expose the black earth beneath, which then absorbs the sun's radiation. A black pipeline laid on the soil can cause similar local thawing. Trenching and excavation of course disturb the thermal regime, which will be re-established with new boundaries. Removal of vegetation and clearing of snow will allow the soil to freeze more deeply, leading to formation of an ice dam during Spring run-off, with consequent local flooding.

A special problem along many of the Arctic shores is that they are comprised of frozen silt, with a high water content. Once thawed, they turn to muddy water, of little or no shear strength.

Water flowing over ice dams, or through culverts, will quickly thaw the soil. Drainage water from waste disposal can create a major gully.

Offshore much of the Arctic coastline are barrier islands: migratory sand bars, with the added factor of having a frozen core. These protect the shore from direct onslaught by waves and ice. In summer, sand thaws and erodes on the up-current end of the island, extending it on the downstream end. When construction and drilling operations stabilize these islands by building fixed structures, downstream erosion results just as in temperate climates. So far these effects have been accepted because they have not interferred with native offshore hunting and fishing to any degree.

Ice jams during Spring break-up can be caused by the contractor, as a result of constructing a winter road crossing of the river. They can also be caused by construction in the river such as trestles and bridges.

Embankments of gravel are an especial source of serious slumping. They may contain ice particles, which compact like rock in below-zero weather, yet on thawing create a high percentage of voids. A potential critical condition can arise when gravel, at -30°C is dumped into shallow water at -2°C, creating ice within its interstices. Later operations, such as drilling and production of hot oil, can lead to slumping.

Much has been written about the problems of construction roads in the Arctic: the need to insulate the road from the permafrost, and the need to provide proper drainage in order to prevent freeze-thaw phenomena. These problems are not peculiar to the coast, but dominate the construction planning in all Arctic operations.

Air quality requires special attention in Arctic operations. During low temperatures in the winter, particulate matter hangs in the heavy air, serving as nuclei to coalesce fog particles, which freeze. The result is an intensification of the naturally occurring Arctic haze and white-out, in which visibility is reduced to zero and all visual reference frames disappear.

While these atmospheric problems are widespread, they can be intensified in the vicinity of construction operations if care is not exercised to prevent or minimize discharge of diesel smoke and burning wood.

CURRENT TRENDS

Recent experience with oil and mineral related developments on the Arctic Ocean coasts of Alaska and Canada have shown that when early recognition has been given to potentially adverse impacts and appropriate measures have been taken, construction operations can be carried out within acceptable levels of temporary damage and indeed, in many cases, offsetting positive benefits can be achieved.

Lt. Gen. O. Hatch of the US Corps of Engineers, the organization in the United States charged as the lead agency to monitor and control environmental impacts, has stated that: "The emphasis is today shifting from mitigation of adverse impacts to integration of environmental objectives into the development process, a subtle, but all-important distinction."

The U.S. Arctic Research Commission has recommended research that will enable the development of the Arctic to be carried forward in an environmentally-safe manner. Among the specific research goals, given priority by the Commission, are "oil spill prevention technology, including clean-up of oil spills in broken ice," "waste disposal," "the improvement of technology for Arctic construction so as to reduce the high costs, while improving performance," and "the development of transportation systems for Arctic conditions."

Many papers have been presented at recent conferences dealing with the probable effects of global warming. Should this occur, Arctic coasts would see the earliest and greatest changes, with sea level rise, warmer air temperature, especially in winter, leading to thawing of near-surface permafrost, and probably more dynamic seas. These changes would pose major challenges and opportunities for marine construction in the Arctic.

CONCLUSION

The Arctic regions pose severe environmental constraints on construction activity. This paper has identified oil spills, gravel mining, causeways, noise, waste disposal, coastal erosion, and air pollution as the major sources of concern which are related to construction operations.

The Arctic and sub-Arctic are extremely important regions for biological productivity. Their ecology is in a delicate state of balance with the overall environment. Hence, disruptions by man's activities can have widespread disastrous results.

Although the Arctic is geographically remote from populous centers, it has attracted much attention politically. Not the least of the political forces to be concerned with are the native Inuits and their desires to continue their historical way of life even while benefitting from the positive elements of Western civilization.

This conflict can and has been successfully resolved in many large-scale construction operations. This paper suggest a few such solutions, but more are to be found in recent publications dealing with the Arctic.

When these concerns are neglected and ignored, the results, politically and economically, have often been severe or even catastrophic, damaging not only the Constructor's success and profitability, but also those of his Client.

Thus, the Arctic Constructor must address environmental mitigation with the same attention and intensity as he addresses the regions unique climatic, geotechnical, and ice phenomena. They are all integral problems inherent in the carrying out of construction operations in the Arctic.

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Vertical Mixing due to Ship Traffic and Consequences for the Baltic Sea
Brassages des eaux par les bateaux et conséquences pour la Baltique
Vertikale Verwirbelung durch Schiffsverkehr und deren Folgen für die Ostsee

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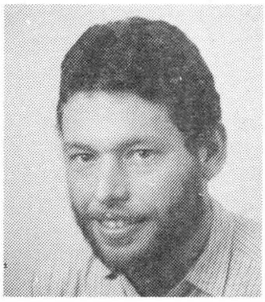
Odense, Denmark



Carsten Jürgensen, born in 1958, received his Ph. D. from the Technical Univ. of Denmark. The subject of his Ph. D. research was: entrainment introduced by piers, dams, and ships. Carsten Jürgensen is now responsible for the hydrographic monitoring carried out by the county of Funen, which includes monitoring in the Great Belt.

SUMMARY
The entrainment by ships is studied in laboratory experiments and verified in two full scale experiments. The results are applied to the Great Belt and the Baltic Sea. Simulations of the surface salinity in the Baltic Sea indicate, that the ship traffic in the Great Belt has a greater impact on the Baltic hydrography than the planned bridge over the Great Belt, without compensational dredging.

Brassages des eaux par les bateaux et conséquences pour la Baltique

Résumé
La propulsion des bateaux est étudiée en laboratoire et vérifiée par par deux essais en vraie grandeur. Les résultats sont appliqués au Great Belt et à la Mer Baltique. La simulation de la salinité en surface de la Mer Baltique indique que le traffic des bateaux dans le Great Belt a un effet plus grand sur l'hydrographie de la Baltique qu'un pont sur le Great Belt, réalisé sans aucun dragage de compensation.

Vertikale Verwirbelung durch Schiffsverkehr und deren Folgen für die Ostsee

Zusammenfassung
Die Wasserturbulenz infolge Schiffsverkehr wurde in Laborexperimenten studiert und durch zwei Grossversuche überprüft. Die Ergebnisse wurden auf den Grossen Belt und die Ostsee übertragen. Simulationen des Oberflächensalzgehaltes in der Ostsee zeigen, dass der Schiffsverkehr im Grossen Belt grösseren Einfluss auf die Hydrographie der Ostsee hat als die geplante Brücke über den Grossen Belt, und zwar ohne Ausgleichsbaggerung.

1. INTRODUCTION

At the 11th Conference of Baltic Oceanographers in Rostock 1978 the first questions about the possible hydrographical consequences of a fixed Belt link were raised. From that time on there has been increasing concern about how a traffic link might influence the sensitive two layer flow in the Great Belt and the natural balance of the complicated hydrography of the Baltic Sea. The present construction plans do in fact include a broad range of investigations designed to estimate the consequences of different structures. The basic philosophy in these plans is, that as long as the structure does not change the average hydraulic parameters in the Great Belt, the hydrography in the adjacent waters and especially in the central Baltic will remain unchanged. This is often called the "zero effect solution".

One factor, however, has not until now been a point of concern, namely the mixing effect of the ship traffic in the Belt, i.e. the ship induced mixing or entrainment of dense saline water from the lower layer into the less dense water in the upper layer. The driving force behind vertical mixing is the amount of turbulence close to the interface. It is obvious that the turbulence from the entire ship traffic is large, but the following key questions have to be answered before any statement can be made on the possible hydrographical consequences:

1) Is the level of ship turbulence significant compared with the background level of turbulence?

2) How is the turbulent energy input of a sailing vessel physically tied to the upward entrainment?

3) What consequence does the ship induced entrainment in the Great Belt have on the salinity in the Baltic Sea?

4) What are the environmental consequences of ship induced entrainment compared to the consequences of the fixed link?

The answers to these questions are of general interest as they also give some insight into the response of the Baltic Sea to man-made changes, especially in view of the actual discussion about the Great Belt bridge.

2. ENERGY ANALYSIS

The significance of the ship induced energy input can be illustrated by an order of magnitude calculation, where the ship induced energy is compared with the other dominant causes of mixing in the Great Belt area (20 km x 100 km):

1) Contribution S of total ship traffic
2) Contribution W of the wind
3) Contribution C of the current

1) Ship induced contribution S:

The average ship traffic in the Belt area is roughly estimated to be seven ships (three ferries and four cargo vessels), each powered on average by a 10.000 kW engine, resulting in a contribution from ships S of approx.

$S = 70$ MW

2) Wind contribution W:

The wind effect calculation is based on a surface friction factor $fs/2 = 0.0026$ and on an average windspeed of 7.5 m/s.

The effect W of the wind blowing over the Belt area is found to be:

$W = 100$ MW

3) Current contribution C:

The effect C of the average current is roughly calculated on the basis of an average head loss over the Great Belt of 0,20 m, and the corresponding discharge of approx. 75.000 m**3/s. For these numbers the current contribution C is:

$C = 150$ MW

The order of magnitude analysis can now be done by comparing the estimated energies:

$S/(W+C) = 1/4$

Based on yearly average data the estimated total ship traffic contributes 1/4 of the natural energy input to the Great Belt mixing. This ratio is expected to be higher in summer and lower in winter due to the seasonal changes of the wind and current intensities.

3. EXPERIMENTAL PROCEDURE

An entrainment process is traditionally described in terms of the involved energies (1). Entrainment in a subcritical, quasi-stationary two-layer flow is characterized by a constant ratio between the potential energy gained (lifting of dense, saline water) and of the turbulent energy produced in the flow (turbulence production). This ratio can be regarded as an efficiency ratio for entrainment. The present work deals with the entrainment in flows around propeller-powered ships. This flow is not subcritical and non-stationary and therefore not covered by the existing theory.

The production of turbulence is a key parameter. Laboratory measurements will of course always be influenced by scaling and model effect and will not reproduce the correct ratio between the three major sources of turbulence involved:

1) boundary layer turbulence
2) ship wake turbulence
3) propeller jet turbulence

Since it is physically impossible to achieve the "natural" ratio between these sources in the laboratory, entrainment experiments are carried out with different ship hulls at a variety of speed and draft conditions and for different propeller jets. This way the magnitude and the sensitivity of the entrainment function to different types of sources of turbulence is determined.

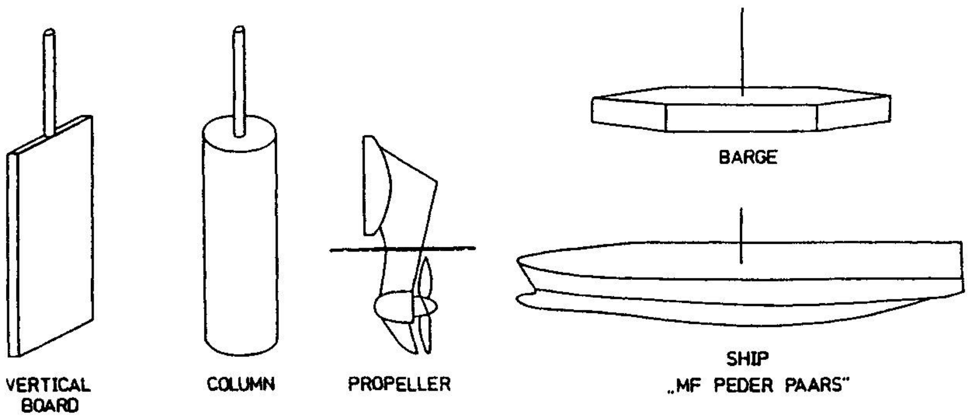


Fig. 1: Device used in entrainment experiments. The propeller is mounted on the different devices.

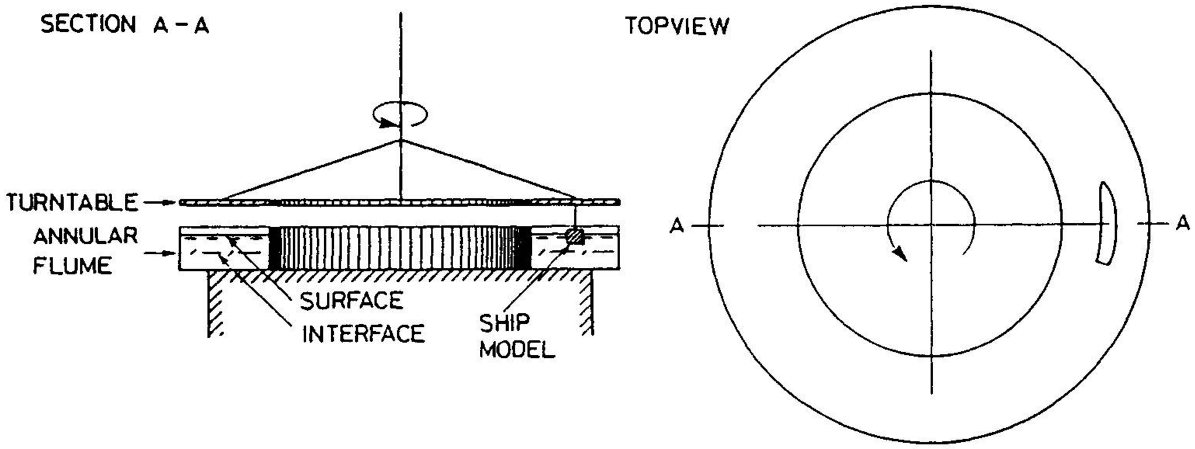


Fig. 2: Sketch of the experimental setup.

The experiments are conducted in an annular two layer flume, with an outer diameter of 1.00 m, two different widths of 0.2 m and 0.4 m, respectively and a total depth of approx 0.2 m. The stratification is achieved by salinity differences close to those found in the Great Belt. The devices are fixed to a turn-table and towed through the flume by the turn-table, see fig. 2.

The energy production is determined by:

$$PROD = (|Fdrag| + |Fprop|) * Vdrag$$

The gain of potential energy is found by measuring the density profiles at adequate time intervals.

4. RESULTS

The experimental measurements gave the following results:

1) A very clear relation between the relative draft D/Y and the entrainment efficiency POT/PROD was found, see fig. 3. The entrainment function is close to zero for very small D/Y-values (interface is far below the device) and close to zero for very large D/Y-values (the interface is much higher than the draft of the device). For intermediate D/Y-values there is an

efficiency maximum. The maximum efficiency is of the same order as the efficiency found in stationary, subcritical flows, which is 3-5%.

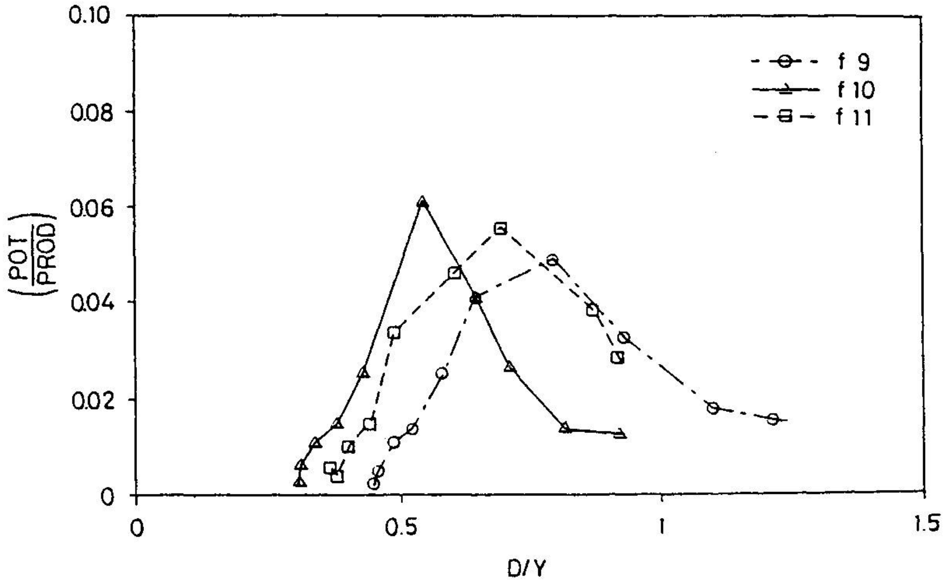


Fig. 3 Measured entrainment efficiency ratio in three experiments. The actual device is a barge without a propeller attached. Each experiment starts with high D/Y values. As the mixing takes place, the interface moves downward and the D/Y values become smaller.

2) The entrainment efficiency is not found to be sensitive to the densimetric Froude Number within the applied range, i.e. $20 < F^2 < 120$, F^2 nature = 100.

3) The entrainment does not depend on the shape of the density profile, i.e. whether it is a sharp pycnocline or not.

4) The shape of the different "ships" have only a minor influence on the entrainment. The advantage of testing a very broad range of ship hulls is now evident, since dramatic changes in the form of the hull only give minor changes in the entrainment function.

5) The entrainment efficiency of different propeller forces is found to be between 1% and 6%.

The magnitude and the variability of the propeller dominated entrainment efficiency is of the same order as the hull entrainment efficiency. This is a very important finding with regard to the entrainment associated with the local, non-stationary and supercritical flow of the propeller jet.

6) Full scale verification.

6.1) The laboratory results are compared with independent full scale measurements conducted in The Netherlands (2). The results are based on experiments with a motor vessel of 13.5m Lpp sailing in a stratified lock chamber of 350 m in length. The Dutch results are plotted along with the laboratory results in fig. 4.

6.2) A full scale experiment measuring the entrainment of ferries (3) has also been carried out in Nyborg Fjord, Denmark. Nyborg Fjord is approx. 5 km long, 0-3 km wide and 10-20 m deep. The ferries are 125 m long, 25 m wide and 6 m deep, and are powered by 10.000 kW engines. The result is shown in fig. 4.

Fig. 4 presents the main result of the experimental investigations. It shows the variation of the entrainment efficiency of a sailing vessel for different values of the parameter D/Y.

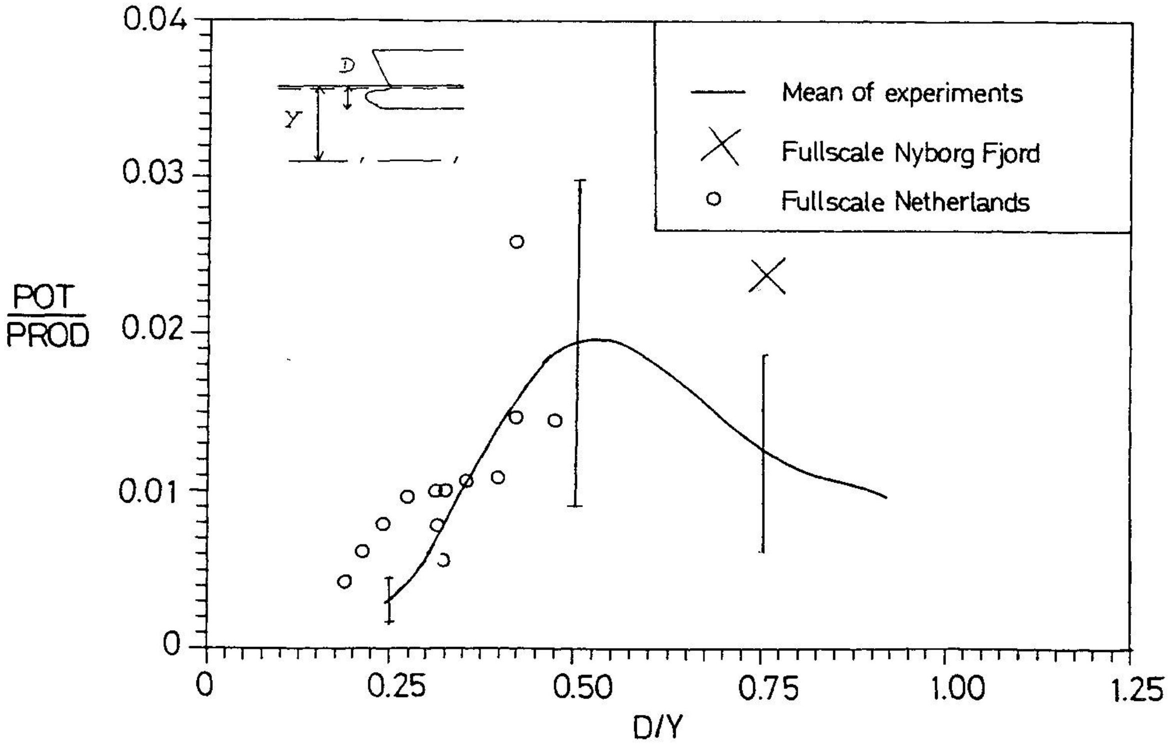


Fig. 4: Entrainment efficiency measurements POT/PROD as function of D/Y for a propeller-powered ship in force balance, i.e. $|Fprop| = |Fdrag|$. The line indicates the mean value and the error bars the standard deviation of the laboratory experiments. Results from full scale measurements are plotted for comparison.

5. APPLICATION TO A BALTIC SEA MODEL

The present findings are now applied to a simple, stationary box model of the Baltic Sea (2). The theory of a linear reservoir is used in order to create a dynamic model.

The two layer model is based on the linearized governing equations for the different regions of the Baltic Sea. This linearization requires that changes in the parameters are small. The model therefore works with relative parameters. The equations are solved with respect to the upward entrainment in the Great Belt.

Four normalized input time series are needed:

1) The freshwater runoff R into the Baltic Sea

2) The major salt water inflows Qe

3) The wind intensities W

4) The ship energy S

The model is solved for each year, and the solutions are convoluted in time in order to give a salinity time series for the upper Baltic which can be compared with measurements from the central Baltic and from the island of Christiansoe, north of Bornholm. Similar time series are found in all regions of the Baltic (2).

Fig. 5 shows the observed salinity time series and the computed salinites ind the upper Baltic. The line marked "OS" simulates a situation where shipping is not taken into account and where fresh water runoff and the major salt water inflows are the only parameters that have changed since 1900. The applied time constant is 10 years. The observations and the calculations are almost identical from 1900 until about 1945. This shows that the model works very well for this period and it suggests that there were no major changes in wind or ship induced mixing in that period. For the time after 1945 an increasing deviation between observations and calculations indicates that a model based on runoff and major salt water inflows alone, is not sufficient.

An important factor for mixing is the wind effect. Wind intensities based on "historical" observations had to be rejected, partly because they are visual judgements, and partly because they comprise observations from a large number of individual observers. Better data are computed on the basis of air pressure measurements. The monthly peak-to-peak values are used to compute a time series of the relative wind intensity. This "pseudo-geostrophical" wind indicates a constant or a slightly decreasing intensity. Taking all this into account the best estimate of the wind is obtained by assuming constant mean wind intensity since 1900.

The effect of the ship traffic is included in the line marked "1S", which means that the applied ship induced mixing corresponds to the ship-induced entrainment outlined above. The applied time series for the shipping intensities is based on the actual fuel consumption for the ferries at Nyborg-Korsoer and Halskov-Knudshoved from 1970 til 1988 and an extrapolation of these intensities for the period before 1970. The intensity of the total ship traffic was insignificant before aprox. 1945 and has increased almost linearly since. The mathematical model is applied with a convolution time constant of 10 years, which is a typical time scale for the upper Baltic. The model was not found to be very sensitive to the choice of the time scale. There is convincing agreement between the calculations and the observations. The typical increase of the salinity after 1960 is clearly shown in this case. Obviously an additional mixing mechanism like the one introduced by ships is neccessary to explain the increasing surface salinity in the Baltic Sea.

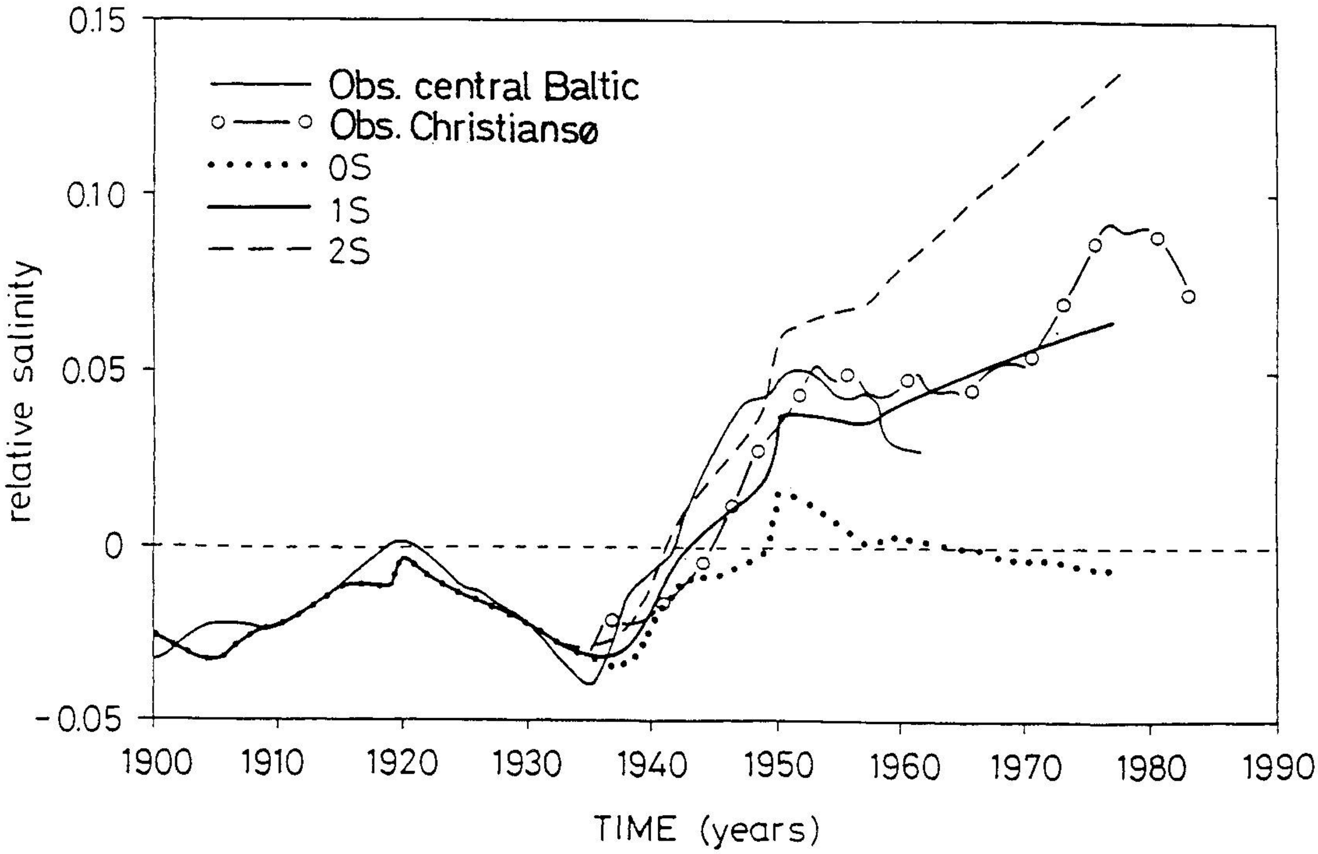


Fig. 5: Relative salinity time series in the upper Baltic:
Surface observations from the Baltic, 9 year sliding means.
Computations are made with a convolution time scale of 10 years:
Line "0S": No ship induced entrainment.
Line "1S": Including ship induced entrainment.
Line "2S": Including twice the calculated ship induced entrainment (sensitivity study).

The sensitivity of the results with respect to the importance of the effect of ships is shown with the line marked "2S". Here the shipping intensity is twice as high as estimated in the above energy analysis, based on the fuel consumption. The results indicate that the "central" estimate of the shipping intensities is in much better agreement with the salinity observations. It also shows that the Baltic is sinificantly sensitive to the mixing conditions in the Great Belt.

These simulations indicate, that the ship traffic in the Great Belt can be responsible for a salinity increase in the upper layer of the southern Baltic Sea of 0,6 ^{o}/oo (compared to an average of 7 ^{o}/oo) over the last 50 years. The current plans for the fixed link without compensational dredging will cause a maximum salinity decrease of 0,1 ^{o}/oo over the next 10 years. The compensation dredging, nowever, will reduce this effect.

After completion of the fixed link the ferry traffic across the Great Belt will stop and the total ship induced entrainment will be reduced by approx. one half. This reduction can cause a salinity decrease in the upper layers of the Baltic Sea of 0,2 to 0,4 ^{o}/oo during the next 10 years, as long as the general ship traffic through the Great Belt keeps constant. The secondary effect of the Great Belt bridge (reduced shipping intensity) has therefore greater impact on the Baltic Sea than the primary effect of the bridge (piers and dams).

The ship entrainment mechanism shows three interesting new points with respect to the "zero effect solution":

1) It gives an unique engineering opportunity to relate and compare the effect of compensation dredging and ship traffic.

2) It illustrates how much man already does interfere with the state of the Baltic Sea.

3) Despite the uncertanties it seems evident, that the secondary consequences of the fixed link have a greater impact on the Baltic Sea than the primary consequences.

This illustrates some of the problems connected to the principle of the "zero effect solution". It should be noted, however, that the impact of ship traffic is an anthropogenic effect and that any reduction of this interference with nature is desirable from an environmental point of view.

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Dredging and reclamation activities in Bahrain

Dragage et terrain récupéré sur la mer à Bahrain

Ausbaggerungen und Landgewinnungsaktivitäten in Bahrain

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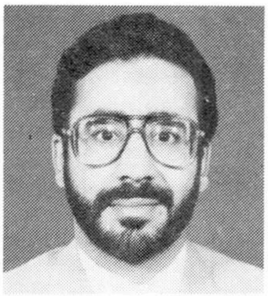

I. M. Madany was born in 1956, obtained his chemistry degree at Univ. of Texas, Austin, Tx, USA, and M. Sc and Ph.D. at UMIST, Manchester, England. He was involved in the field of pollution control, waste management, and public environmental awareness and he is associate professor at Arabian Gulf Univ.

SUMMARY

Over the last sixty years, considerable parts of the intertidal areas along the coasts of Bahrain have been either reclaimed or dredged. These operations, which were not preceded by effective planning and proper assessment led to drastic effects on the coastal marine ecosystem and environment, resulting in siltation, increased turbidity of the sea water and salinity of the island's ground waters. They have further degraded the biosystem, with many coral colonies, mangroves and sea grass beds destroyed. Furthermore, these have several social and economic impacts. Various dredging and reclamation activities and their environmental, social and economic impacts are reviewed.

Dragage et terrain récupéré sur la mer à Bahrain

Résumé

Au cours des 60 dernières années, d'importantes zones côtières ont été draguées ou récupérées sur la mer. Ces opérations, réalisées sans études approfondies, ont eu des effets catastrophiques sur l'écosystème et l'environnement marins côtiers. Ils ont causé un envasement et une augmentation de la turbidité de l'eau de mer et de la salinité de la nappe phréatique dans l'île. Le biosystème a subi une dégradation importante dans les palétuviers, les colonies de corail et les algues. En outre il y a eu des conséquences sociales et économiques négatives. Différentes activités de dragage et de récupération de terrains sont présentées avec leurs conséquences sur l'environnement, la société et l'économie.

Ausbaggerungen und Landgewinnungsaktivitäten in Bahrain

Zusammenfassung

Während der vergangenen 60 Jahre wurden beträchtliche Teile der Küstenzone Bahrains entweder aufgefüllt oder ausgebaggert. Diese Arbeiten, die nicht effektiv geplant und abgeklärt worden waren, führten zu drastischen Folgen für das maritime Oekosystem und die Umgebung. Sie verursachten Verschlammung, steigerten die Trübung des Seewassers und den Salzgehalt des Grundwassers der Insel. Sie haben das Biosystem weiter verschlechtert, Mangroven, Korallenkolonien und Seegras zerstört. Ausserdem hatten sie etliche soziale und wirtschaftliche Auswirkungen. Mehrere Ausbaggerungs- und Landgewinnungsaktivitäten und ihre Folgen auf Umwelt, Sozialgefüge und Wirtschaft werden dargestellt.

1. INTRTODUTION

The State of Bahrain is an archipelago composed of 33 islands located in the Arabian Gulf, with the Kingdom of Saudi Arabia to the West and Qatar to the East.

Bahrain island which measures 587 km² (86% of the total state land area), is the centre of most activities: it has the capital city (Manama), the primary port (Mina Salman), oil fields, and the oil refinery. Muharraq, the second largest island in the northeast, is connected to Manama by a causeway 2.4 km long, involving the area's first reclamation and dredging activities (1930). In addition, the international airport, iron pelletizing plant, and the drydock are located on this island. To the east of Bahrain is Sitra, the third largest island and also connected to the mainland by a causeway. Sitra, mainly an industrial centre has oil reservoires, a port for the export of oil, and an electricity-generating station and a desalination plant. Um-al-Nassan is another large island that is located in the northwest. It is now almost uninhabited but this is destined to change due to the Bahrain-Saudi Causeway. More detailed general information on the State of Bahrain is provided elsewhere (1).

The population of Bahrain, according to the 1981 census was 350798, and the estimated population in 1989 was 488545. The average annual growth during the period 1941-1981 is 7% which is considered very high compared to other countries, as shown in Table 1 (2).

Year	Population	Population density
Jan 1941	89970	
Mar 1950	109650	
May 1959	143135	
Feb 1965	182203	
Apr 1971	216078	326
Apr 1981	350798	517
1983*	390559	
1988*	473296	683
1989*	488545	705
* Estimated Values.		

Table 1. Population of Bahrain (1941 - 1989), and population density per Km²

The discovery of petroleum in 1932 marked a turning-point in the economy of the state, and attracted people from their traditional industries. Unfortunately, by 1981 oil production had fallen significantly. This situation forced the country to adopt a policy of economic diversification in order to increase and vary sources of income. The main emphasis was on industry, and later on commerce, fisheries, tourism, and agriculture. The need to industrialize urged the government to create industrial zones away from the centres of population, and this has created difficulties due to the limited area of Bahrain. The rapid development and the shortage of land became a problem. This problem was addressed by dredging and reclamation operations.

During the last 60 years, a number of sites along the coast of Barhain down to the coast of Sitra island have been either dredged or reclaimed. These activities increased significantly in the 1970s, serving both industrial and residential purposes, and lead to clear Changes in the area of Bahrain, as shown in Table 2.

Year	Area (km^2)
1975	661.87
1981	669.29
1983	684.98
1984	687.75
1985	690.86
1986	691.24
1987	692.39
1988	692.52
1989	693.15

Table 2. Changes in the area of Bahrain due to reclamation activities

In the early years of reclamation and dredging activities, only financial considerations were studied, and environmental and social factors were not taken into account. Thus, the areas reclaimed were selected randomly and based on convenience. Unfortunately, most of the reclamation activities have been carried out in the north-eastern and north-western coasts which are known to be the most productive from the fisheries point of view. This indicates the adverse effects of reclamation on one of the important economic sectors, namely fisheries. Moreover, some dredging activities have been carried out in areas where groundwater was low lying.

The main objective of this paper is to discuss briefly and highlight some of the effects of dredging and reclamation activities carried out in Bahrain, and introduce an integrated approach for the future planning of such acivities so that it takes into consideration social, economic and environmental aspects.

2. AREAS RECLAIMED

Reclamation of land by dredging marine sand from the sea is relatively inexpensive in Bahrain because the sea is very shallow for a considerable distance from the shoreline.

Approximately two meters of fill, readily available from dredging off-shore, is sufficient to raise the level above the high-water mark and permit development. Moreover, sea bed consists of hard sandy rocky bottom which facilitates development. The government in some reclaimed land follows a policy of renting the land to the industries for economic gain. The rent ranges from US $2.1 to 3.1 per m^2 or $1590.00 to 4750.00 per Year depending on the area and location of the site. By making a simple cost-benefit analysis, and looking at the jobs gained through industrial development, this operation seems very profitable. But this may not be the case if long term adverse environmental and social impacts are also investigated and compared. The following section presents a summary of the various sites that are reclaimed and the ultimate use of each site. Details of reclaimed areas and dredgers employed are reported elsewhere (3,4). Table 3 provides the sites reclaimed, while Figure 1 shows their locations.

2.1. North Sitra Industrial Area

This area was initially reclaimed in 1973 for the construction of Sitra power station and desalination plant. It was reclaimed by dredging in the immediate vicinity to form a deeper underwater intake channel. The reclamation was 180m wide by 300m long in an average water depth of 1m, and dredging was in a channel 40m wide and 5m long in an average predredging water depth of 3m. Other industries are located now in the area as presented in Table 3.

2.2. Mina Salman Port

The development of Mina Salman Port was possible through dredging associated with the deepening and re-alignment of the navigation channel

2.3. GIIC and ASRY Area

The total reclaimed area of Gulf Industries Investment company (GIIC) and Arab Ship Building and Repair Yard (ASRY) located southeast of Al-Hidd is approximately 2.5 km^2. The material required for reclamation was taken from an area south of the site, dredged to depths of 13.7m. The reclamation was accomplished by first forming retaining bunds with tipped landfill in order to enclose the area, then by hydraulic infilling with dredged material using caprock and limestone which are typical of the Bahrain coastal geology. Pipes were placed in the retaining bunds for the expulsion of water from the hydraulic filling which would carry with it certain amount of fine material including silt.

Area Reclaimed	Area (km^2)	Purpose of Recalmation
North Sitra	2.5	Industrial area (Power and desalination plant, sulfuric acid, aluminium extrusion and rolling mill, sand and gravel companies, sewage treatment, plastic and food factories), roads.
Mina Salman		Port, industrial area (paint factories, metal and plastic fabrication, soap and detergent plant).
Tubli bay	17	Sewage treatment, domestic waste pulverizing plant, housing, roads.
Manama south		Islamic center (0.3 km^2) and civic center (0.2 km^2).
Sanabis		Housing, government building, recreation (4.5 km^2).
GPIC	0.6	Methanol and ammonia plant, Jetty.
Budaiya	0.6	Housing, recreation.
Al-Dar Islands	0.033	Recreation.
Al-Muharraq	4	Airport, housing, recreation.
Arad and Al-Hidd	6	Industrial area (garages, fabrication), housing.
ASRY and GIIC	2.2	Ship repairing Yard, iron ore pelletizing plant, Workers housing, roads.
King Fahad Causeway	2.0	Roads.
Jaww	0.18	Police training centre.
Askar	0.0075	Avoid nuisance smell from the coast.

Table 3. Areas and purpose of reclamation in Bahrain

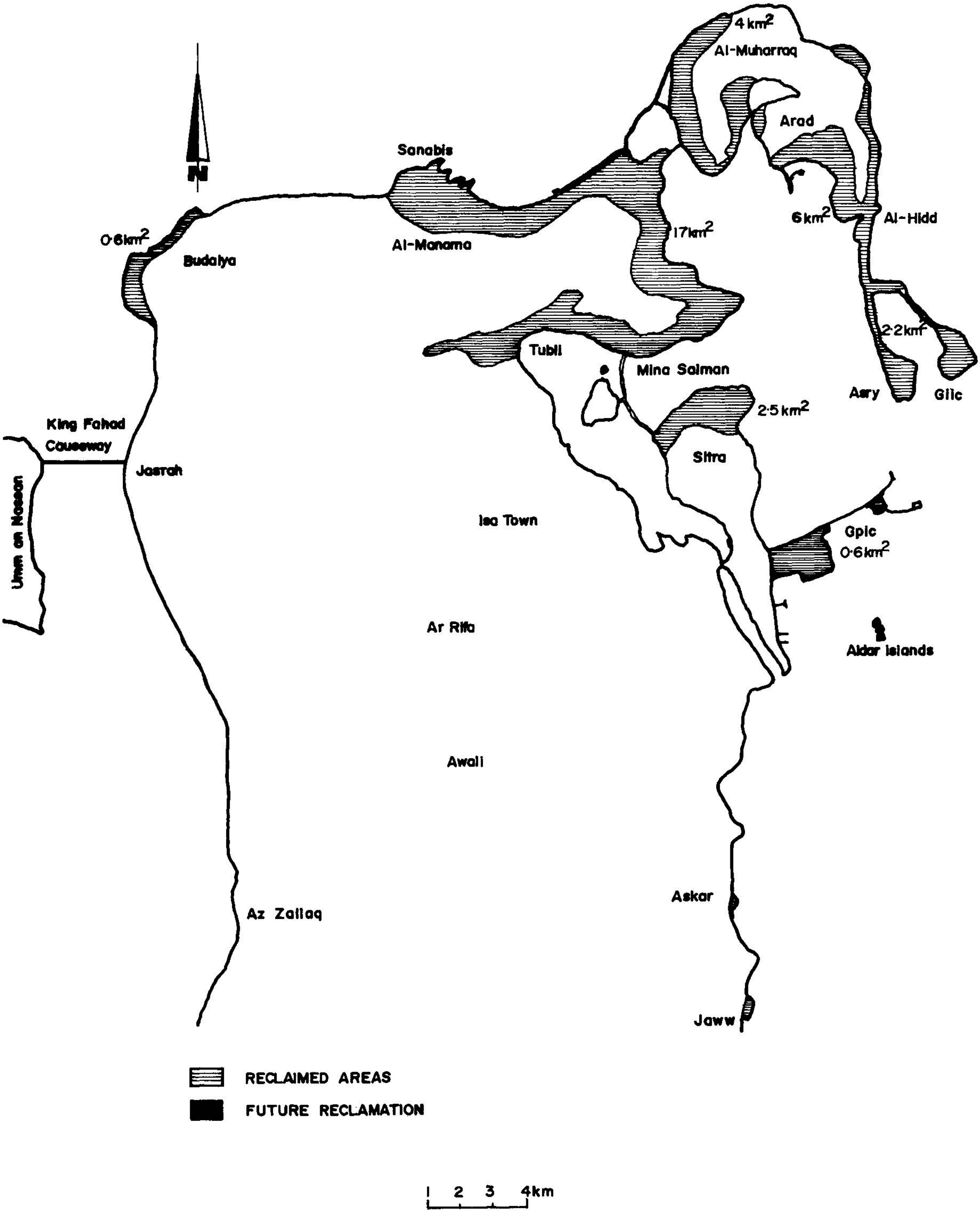

Fig. I. RECLAIMED AREAS IN BAHRAIN.

2.4. Gulf Petrochemical Industries Co. (GPIC)

The petrochemical site reclamation was approximately 0.6 km^2. Two channels were dredged, one was for cooling water, in this case the depth of the water was about 7m, and the length was about 3.5 km, and the other channel is an alternative to the existing fisherman's channel which, in some parts was filled with the reclamation material. Part of the dredged material was dumped into the sea making three artificial islands known as Al-Dar islands, with total area of approximately 0.033 km^2, as shown in Figure 1.

2.5. Bahrain - Saudi Arabia Causeway

The 25 km causeway represents a major engineering achievement in terms of cost, amount of materials involved and technology. The causeway comprises five bridges and seven embankments, 12 km in length. The bridges vary in length between 950 and 5150m, with solid embankments having been made between the spans in the shallower reaches of the Gulf.

A project of this size might have a profound effect on the environment and marine life. The shallow and almost landlocked Arabian Gulf is especially vulnerable (5).

2.6. Sanabis Area

The method of reclamation employed was by dredging and direct discharge to a bunded area which was constructed ahead of the reclamation. The operation resulted in an outslip to the sea estimated to be 250,000 m^3 of silt. This silt affected hadrah grounds (fish barrier traps) which means that the fishermen have lost their only source of income. In this case, the fishermen should be allotted alternate site and given adequate compensation. Moreover, there are several evidences showing the increase of salininty of groundwater in the area and rise in their level. This situation could destroy coastal vegetation, especially date palms, and this actually happened in Tubli reclamation work.

2.7. Budiya Coast

A study dealing with the outslips from dredging and reclamation activities at Budaiya area was carried out pre, during and post the operation (6). The results showed that dredging outslips were much less in quantity in comparison to those of the reclamation fill. The primary damage to fish is through silting of hadrah and mooring areas of fishing crafts. However, this project avoided some of the mistakes done in earlier projects. Moreover, the study proposes alternative methods of reclamation to be considered in future projects in order to reduce silt outslip such as the use of waterboxes.

These methods, however have other disadvantages of higher cost and concentration of silts in one area. In any case, it is not possible to carry out dredging and reclamation projects and avoid silt outslip totally.

2.8. Askar Coast

Askar reclamation was carried out for the purpose of avoiding the smell generated from dead algae and seagrass on the coast. Other coastal areas were developed in the north of the island mainly for recreational purpose.

2.9. Future Projects

A major reclamation project approved by the government which is under detailed study, is the new Muharraq-Manama Causeway. The length of the causeway will be approximately 2.5 km comprising one bridge and an average width of 30m. A total of 3-4 million m^3 of fill will be used (7). The project will serve the purpose of reducing the increasing traffic density on the exiting causeway. This reclamation also include constructing several small islands for recreational pruposes.

Several coastal areas are undergoing reclamation by the private sector using building rubbles and domestic waste, and desert fill as top soil. These reclamation activities are not properly managed and not well controlled. The coast of reclamation is approximately US $0.80 per ft^2, while the selling price ranges from US $8.00 to 8.50 per ft^2. Economically, this is a profitable operation, but might have significat impact on the marine environment.

In general, it can be concluded that recent governmental reclamation projects were studied more carefully than previous ones prior to execution, taking into consideration economic as well as social and environmental aspects reflected from the activity. Also, authorities have gained more experience in dealing with dredging and reclamation works. However, some reclamation are carried out randomly by the private sector without governmental control.

3. ENVIRONMENTAL, SOCIAL AND ECONOMIC IMPACTS

No doubt that dredging and reclamation have both negative and positive social, economic and environmental impacts. This study will consider negative as well as positive impacts but it will concentrate more on negative impacts because it was ignored in Bahrain and their effects are more profound.

To account for such impacts, these should be integrated in decision making at the early stages of planning and appraising of dredging and reclamation activities, and a continuous monitoring program should be introduced to account for any changes during and after completion of the project. Thus, follow up monitoring, which is seldom carried out, must be an essential part in impact assessment.

Although a number of methods could be used to assess these impacts, yet the most relevant mehtods are Environmental Impact Assessment (EIA), and Social Coast-Benefit Analysis (SCBA). The purpose of these methods is to determine, before implementation, the socio-economic and environmental impacts of a proposed action and to ensure that full considerations are given to all potential impacts of the action. The concensus of opinion among researchers show that the social, economic and environmental impacts of proposed actions can not be assessed comprehensively by the conventional planning procedures and techniques.

It is not very difficult to identify and describe qualitatively the possible social, economic and environmental impacts of dredging and reclamation activities, however, it is difficult to quantify most of these impacts, since many are indirect and have long term effects, and could be elaborated only in descriptive terms. In this section, a discussion of the environmental, social and economic impacts will be presented and the checklists approach is used to list potential impacts observed in Bahrain.

3.1. Environmental Impacts

The adverse impacts of uncontrolled and poorly managed dredging and reclamation activities on the marine habitats is well documented world wide. For example, in Singapore reclamation for housing and industry is one of the main coastal development acitvities, and is a major cause of the loss of Singapore's coastal vegetation. In the last 17 years, about 31 km^2 have been added to the land area of Singapore through reclamation. This increase was accompanied by a dramatic reduction in mangrove area from 12 percent of the total land area in 1922, to only three percent in 1987 (8). Dredging activities has also taken place along the west coast of Thailand and in the tin islands off the east coast of Sumatra, Indonesia. Reefs in the vicinity of the dredging activities were damaged due to smothering as well as by the increase in turbidity. Moreover, these operations have led to conflict with local fishermen by loss of fishing grounds (9,10). In Japan, after the 1960's, tremendous coastal areas were reclaimed for industrial purposes. These activities reached their peak in 1974 with 40.5 km^2 of the sea being reclaimed, and now registers between 10 and 15 km^2 per year. This caused the disappearance of shoaling and natural beaches and consequently resulted in loss of sites for bathing, fishing and gathering shellfish (11). Reclamation acitvities in the coastal areas of Jiddah in Saudi Arabia and Kuwait, also caused the loss of the ecosystem and death or migration of several coastal organisms (12,13).

Similarly, land reclamation and dredging in Bahrain have caused irreparable damage to the inshore bio-system, with many corals being killed (3). Some of the largest corals are over a hundred years old and will probably never manage to re-establish on silted sites.

The potential environmental impacts of coastal activities, such as dredging and land reclamation operations presently carried out in a concentrated area, seriously threatens the fishery of coastal and offshore waters, and could harm the productivity and quality of the marine ecosystem as a whole. The shallow nearshore areas that are presently destroyed by dredging and recalmation are the most diverse and productive ones in the sea; the sea-grass beds and the coral reefs. It is not only the limited areas actually dredged or reclaimed that are affected, but impacts are felt over much larger areas where siltation or changes in currents takes place. It seems likely that the death of extensive coral reef areas beyond the northern coast have been caused, at least partly, by increased turbidity of water due to dredging and recalmaiton far away from these reefs. The extensive beds of sea-grass along the coast have a central role as nurseries for shrimp and a number of fish species. Destruction of these sea-grass beds is bound to affect coastal fishery in affected areas.

The shallow sea bed around Bahrain consists mainly of sea-grass beds (by percentage cover, sea-grass beds represent the major soft and mobile habitat type within a 2-12 meter subtidal zone covering most of the east coast and some parts of the west coast), mixed rocks and sand bottoms. This is especially the case between Muharraq and Manama and around the coast of Sitra where extensive development activities have occurred (14).

Large areas of shallow sea bed have been directly affected by dredging and land reclamation operations, which are expected to continue.

In the coastal areas of Bahrain in particular, sea-grass have a sepcific role. They play host to the juvenile stages of commercially important penaeid shrimp and to several adult fish species such as Siganus spp. Moreover, they provide an important feeding ground for turtles and dugong (14). Mixed rock and sand bottoms provide an extremely wide variety of environments. They form habitats for a large number of organisms including shellfish such as crabs and a variety of fishes such as Moharras, Breams and Goatfish.

In additon to the above impacts, such activity has increased the salinity of groundwater, due to the mixing of sea water with groundwater in the dredged areas. This made groundwater unsuitable for domestic or agricultural uses. Reclamation activities in some of the coastal areas have disconnected naturally existing drainage channels causing the water table to rise. This caused flooding in the low lying areas leading to destruction of coastal vegetation.

The degree of environmental impacts of dredging and reclamation projects discussed above depend greatly on three major factors; (1) characteristics of the area dredged or reclaimed; (2) method of disposal employed and quality of fill material; and (3) type of dredger equipment used. Dredging and reclamation at biologically and commercially important areas will enhance the negative impacts caused by such activities. Choice of disposal method whether unconfined, partly-confined, or confined will determine the degree of destruction of the environment. Moreover, particle size and type of fill material can play a major role in this operation. Type of dredgers employed whether mechanically operating or hydraulically operating, will also decide the extent of the impacts (15).

The major adverse environmental effects of dredging and land reclamation activities carried out in Bahrain are summarized below:

1. Damage to the spawning grounds of the various marine species that lay their eggs on the bottom.
2. Damage to the sea-grass beds, mangroves and coral reefs.
3. Removal or alteration of the benthos that form the main source of food for many commercial fish species which will result in a reduction of fish catch.
4. Increased turbidity locally irritating or clogging fish gills, interfering with visual feeding and inhibiting photosynthesis.
5. Affect the genral current pattern, water movement and water quality in the area.
6. Increase in siltation due to the outslip of fine sediment, both at the cutter-head of the dredger and at the outfall end of the discharge pipe. Moreover, thick silt layers make problems for fishermen to get out to their fish traps, which cause them to lose their source of income.
7. The discharge of the fine material during dredging operations possibly resulting in the release of toxic compounds previously buried in the sediments.
8. Damage to barrier traps, long lines, pots and other types of nets.
9. Increase the salinity of groundwater.
10. Disconnection of the natural drainage of irrigation water causing damage to vegetation.

These points mentioned above could be used as a checklists in EIA processes employed to identify possible and likely impacts of dredging and reclamation acitivities, and then intergrate them into socio-economic analysis discussed in the following section.

3.2. Socio-Economic Impacts

The main benefit from dredging and land reclamation is to increase land available for housing, industrial, recreational and other purposes. This is gained at a very low monetary cost. The cost of dredging and reclamation is approximately US $0.80 per ft^2 the selling price now of reclamied land ranges from $8.00 to 8.50 per ft^2, which indicates large financial reward (4).

However, no doubt that dredging and reclamation in Bahrain have caused damage of the marine habitats, which has led to the reduction of fish and shrimp catch. Such reduction has been already noticed by local fishermen and many complaints have been sent to concerned governemtnal institutions for the adverse impacts of such operations. The annual statistics report of 1987 (16) shows that the landing of barrier traps, line and hooks have registered a decline of 29.2% and 34.0%, respectively in

1987 compared to 1986. The report also states that this decline in landing of barrier traps is due partially to the reclamation and excavation operations.

The implication of such reduction in fish and shrimp catch is the reduction in the net annual income of fishermen and increase in the number of citizens unemployed. Such a reduction could happen as a result of silting of hadrah and mooring areas of fishing crafts. The implication is made more clear by the fact that the greater part of Bahrain's catch is taken by the thousands of small inshore artisanal boats operating over the shallow reefs, sand flats and sea-grass beds which surround the islands of Bahrain. The landing of this artisanal sector in 1987 showed a decline of 6.5% in comparison to 1986 landing. The total revenue of this sector also showed a decline of 0.8% during the same period.

The government has to find alternative sites to the affected fishermen, or provide suitable compensation for the lost income. Although it is difficult to quantify this lost income at this stage of the research, yet we think the government departments concerned has to formulate appropriate plans to alleviate problems of fishermen. On the other-hand, it is important to mention that although reclamation has caused unemployment for a certain sector of people, it has simultaneously created employment and generated better and easier income for others. Thus, to take appropriate decisions regarding reclamation projects, jobs and income lost due to reclamation must be weighed against employment and income gained (4).

Nevertheless, the problem is not only that is related to income but also the fishing industry itself and an indigenous source of protein may decline. This has serious implications because of the role of the fishing industry in the Bahraini economy. It has been estimated that the industry provide employment for about 4.35 percent of the total working population or 10.5 percent of the indigenous Bahraini working population (4). Another implication of the decline in the fishing industry and reduction in fish catch, is the increase in imported fish in order to meet the rising demand for fish. Fish imports in 1983 made up to 39% of total fish consumption by weight, and it made up to 24.6% of total fish landing in 1987 (16). This has negative implications for the balance of payments of the state. In fact the available statistics does not only show that fish imports are rising, but also that Bahrain is a net looser in this respect. Table 4 shows fish imports and exports for the period 1979-1987. The table clearly indicates that Bahrain is importing more fish than exporting and that this gap is rising, ultimately leading to worse balance of payments.

Year	Imports		Exports		Net Balance	
	Q	V	Q	V	Q	V
1979	940.4	1.00	26.8	0.02	- 913.6	-0.98
1981	1786.3	1.60	232.5	0.13	-1553.8	-1.60
1983	3153.9	2.80	7.4	0.03	-3146.5	-2.77
1986	2931.6	2.30	365.7	0.40	-2565.9	-1.90
1987	3567.6	2.63	787.2	0.85	-2780.4	-1.78

* 1 Bahraini Dinar = US $2.64

Table 4. Fish imports and exports (Q) in metric tons, and their value (V) in Million Bahraini Dinars* for the period 1979-1987

Reclamation and dredging has seriously affected the groundwater resources of the island, these have blocked the natural agricultural drains leading to rising water-tables, intrusion of sea water and increasing salinity of agricultural soils and the ground water itself. In many areas groundwater is no longer suitable for domestic or agricultural use. This will not only affect the population and its distribution, but also the agricultural activities and its output. In fact it is common to observe an increasing number of dead palm-date trees along the coastline. The effect on agriculture will not only reduce the income of farmers but may also influence the agricultural activities, which will affect large sectors of the population. Additionally, this may lower and reduce indigenous food production leading to increased food imports with serious implications for the balance of payments and the national food security.

Another effect of reclamation and dredging is its impacts on the tourism industry. These activities affect the recreational beaches rendering them unfit for that purpose. At the state level tourism is becoming an important source of income and it is putting more efforts to enchance it. On the other-hand, reclamation in some areas has created attractive beaches for recreational purposes.

Although the selling price of reclaimed land is very high compared to the financial cost of dredging and reclamation, yet we beleive that not all economic, social and environmental costs have been taken into consideration. If account of these was made, the situation would have been much different, and probably less reclamation activities would have taken place. Figure (2) summarizes socio-economic effects of dredging and reclamation activities in Bahrain.

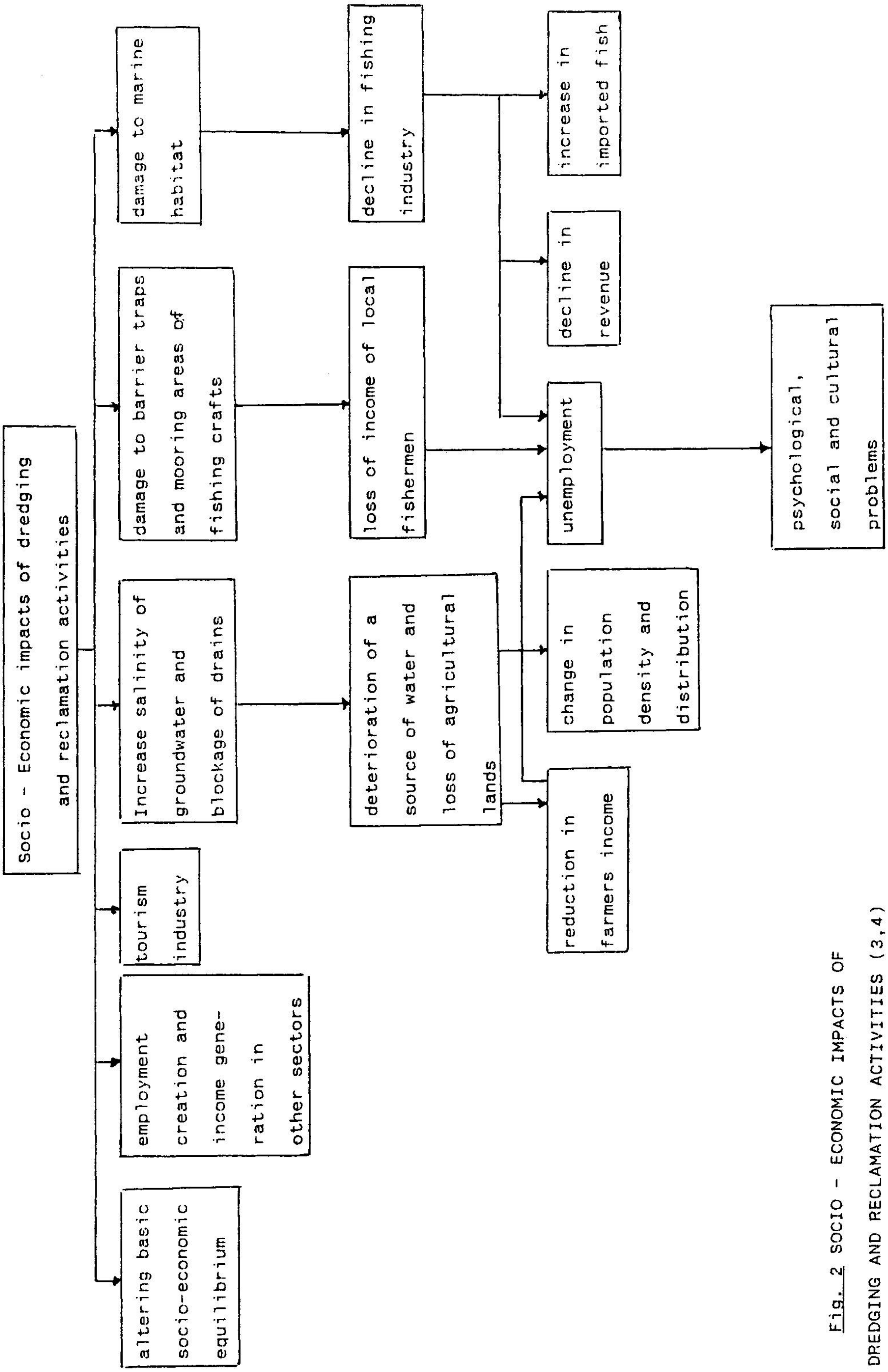

Fig. 2 SOCIO - ECONOMIC IMPACTS OF DREDGING AND RECLAMATION ACTIVITIES (3,4)

4. TOWARDS INTEGRATED ENVIRONMENTAL PLANNING

Our analysis has indicated that environmental impacts should be taken into consideration among other factors when assessing dredging and reclamation projects. To achieve such integration, it is important to integrate environmental impacts of the proposed activities at initial or conceptual stages of project planning. Figure (3) presents projects planning stages in an integrated model (4). The model is self-explanatory and it has been proposed here to facilitate integration of various aspects of the environment, ecological systems, resource management as well as negative and positive environmental impacts Also, it suggests the inclusion of public attitudes in the planning stages, since this is usually neglected.

However, there are problems and difficulties in quantification of certain type of environmental impacts and assigning monetary values to them. This indicates the difficulty in applying traditional cost-benefit analysis in the case of environmental impacts, and usefulness of other EIA techniques.

Once the project has passed the planning stages it will go for the implementation stage. This is followed by monitoring, auditing and evaluation. In doing so environmental impacts, and public opinion are taken into consideration at the initial stages of project planning and its duration. To achieve such an integration it is essential to formulate policies, legislations and create appropriate institutions.

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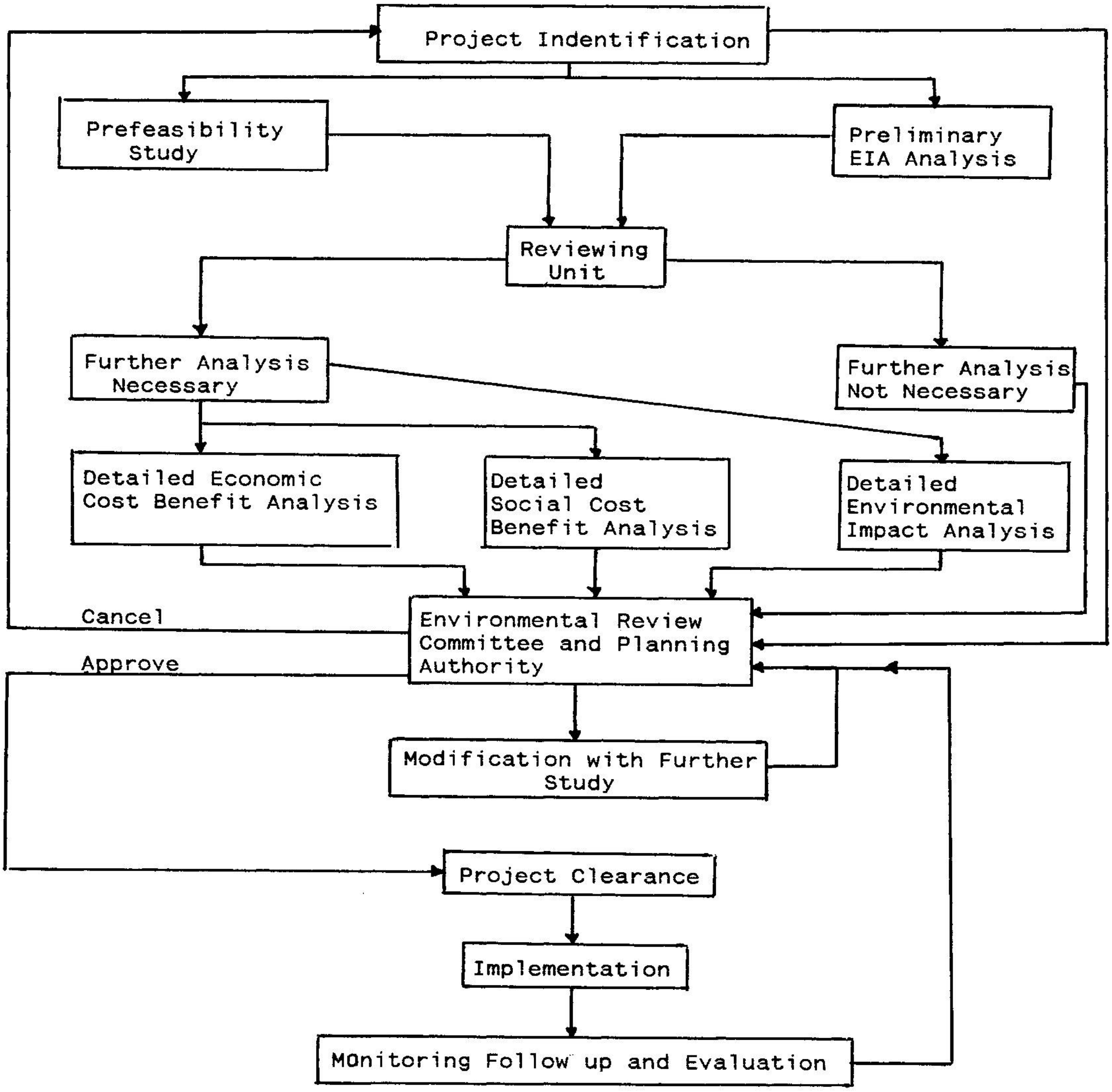

Fig. 3 Project planning stages (4)
(An intergrated model)

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