NAUTICAL DESIGN STUDIES
HAIFA PORT EXTENSIONS

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ABSTRACT

Detailed studies have been undertaken to assist in the design of major extensions to the port of Haifa. Both numerical and physical model studies were done to optimise the mooring conditions vis á vis the harbour approach and entrance layout. The adopted layout deviates from the normal straight approach to the harbour entrance. This layout, together with suitable aids to navigation, was found to be **nautically acceptable**, and generally better with regard to mooring conditions, on the basis of **extensive nautical design studies**.

INTRODUCTION

The **Port of Haifa** is situated at the southern end of Haifa Bay, which is about 12 km long by 6 km wide, with Mount Carmel at the south and Akko at its north end (see Figure 1). The original main breakwater with a length of 2,25 km was built in 1931. It was extended by 600 m during 1978/79 to protect the newly constructed container or eastern quay. At the same time, the harbour entrance area was dredged to a nominal depth of - 14 m LSD (Land Survey Datum). In recent years, the eastern quay has been extended by 300 m and a piled passenger jetty has just been completed at the western end of the harbour.

The Kishon harbour is situated east of the main port area close to Haifa's main industrial area. The harbour entrance is dredged to a depth of - 12 m LSD and it is protected by a 400 m long rubble mound breakwater. It is the home of the Israeli shipyard and repair industry.

As part of the **Master Plan** for the development of the Port of Haifa a 500 m main breakwater extension and several new container, general cargo and bulk quays are planned together with a new approach and entrance channel. Initial numerical wave agitation studies showed unacceptably high downtimes for the original layout, particularly for Quay no. 4 (re. Figure 2). Further studies were therefore undertaken to increase the operability of all the new

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berths to acceptable levels but, at the same time, to ensure good navigational conditions in the approach and entrance to the port.

These **studies** included :

- studies of the main breakwater layout giving the best protection against wave penetration
- a desk study of the nautical design of the entrance
- preliminary full-mission manoeuvring simulations
- a full simulation programme for the accepted layout.

The results of these studies are briefly described in the following sections.

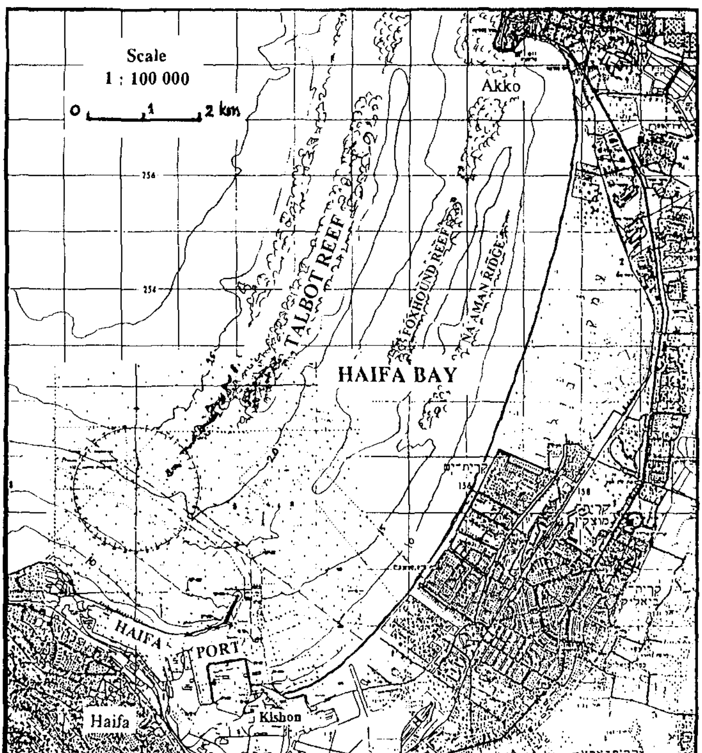

Fig. 1 Haifa Port in Haifa Bay

HAIFA PORT EXTENSION

The **Haifa Port Area Development Plan** was prepared by the Israeli Ports and Railways Authority (IPRA), with the assistance of Israeli and international experts in various fields. The primary goals of the development are to prepare Haifa Port to meet operational demands which require a high level of service efficiency. This is intended to be accomplished by staged development through the year 2020, as required by demand. The primary goals are as follows :

- furnish a high level of service which means an average waiting time for berths of not more than one hour per vessel
- develop the western part of the Haifa Port as a passenger port
- assure port accessibility by various transport modes (roads and railway)
- optimize integration of the port complex into the metropolitan area by coordinated development planning with surrounding systems
- develop the port hinterland for industrial, commercial and port services
- ensure environmental protection, quality of life and maximum safety.

The three primary components of the development plan are **breakwaters**, **layout** & designated usage of quays and port operational areas. The development of **Haifa East** will be implemented in the following phases (refer Figure 2):

Phase I - Haifa East "A" and Haifa East "B" by the year 2003.

Phase II - Haifa East "C" and "D" future developments based on demand.

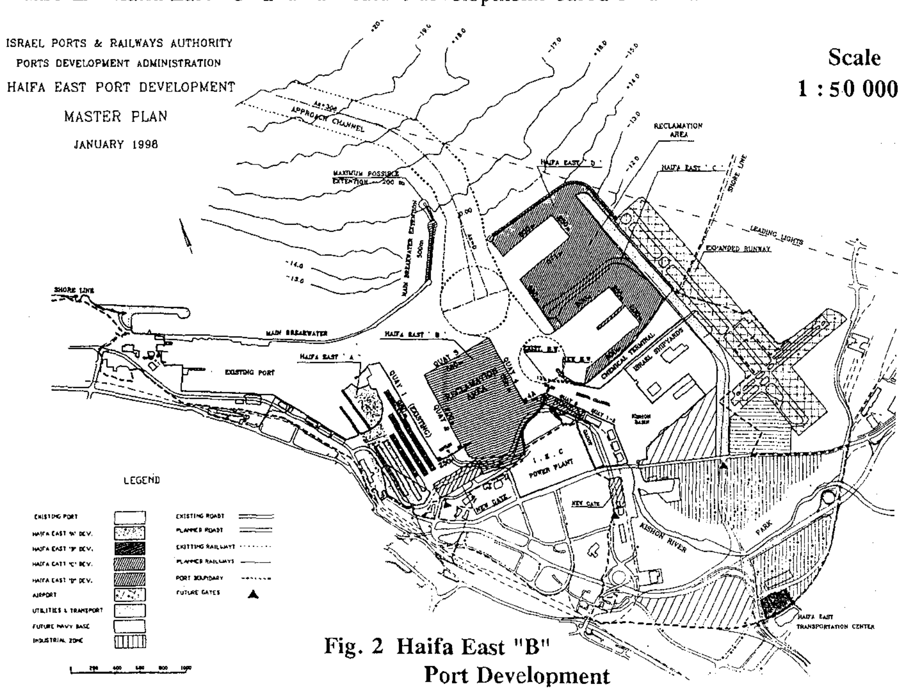

Fig. 2 Haifa East "B" Port Development

With the completion of works envisioned under the development plan, the port would have a total of 6 500 m of operational quays (plus another 900 m of service quays) and 245 ha of operational area.

Phase I calls for the construction of 700 meter of container quay and 1 900 meter of general and dry bulk cargo quays in Haifa East "B". Container operational areas will be expanded by 50 ha, general and dry bulk cargo areas by 15 ha. The quays in the western sector of the port (1 600 m) are to be used by passenger ships and ships serving the Dagon grain silos. The western end of the port will then be designated as a passenger ship port and will be integrated into the city's urban fabric. This transformation will have a sweeping impact on the development of the City of Haifa.

The main breakwater must be extended by 500 m to allow Phase I development. The existing Kishon north breakwater must be removed and replaced along a new alignment, with a 200 m long breakwater, refer Figure 2.

Upon the completion of Phase I, the container terminal will be centralized in the area including Haifa East "A" and the western side of Haifa East "B". The western end of the Port will no longer be used for container handling operations. General cargo will be handled in the Kishon Port (as it is currently) and on the northern and eastern quays of Haifa East "B". A transport corridor physically connecting the Kishon Port with the main Haifa Port is planned. The water inlet of the Electric Power Station's cooling basin will be maintained as a bridge in the transport corridor. The warm water from the Electric Power Station will be canalized in a closed conduit and its outlet will be located between Quays nos 1 and 2.

Phase II is intended for expansion of the existing chemical terminal as an alternative to the fuel jetty and tankfarm and for handling general cargo and bulks by grabs (Haifa East "C" and "D"). Expansion of the existing airport is planned, as shown in Figure 2.

The mix of ships using the Port, has impact on two primary aspects of the port development plans :

- the physical layout of the port including quay length, water depth, basin size, operational areas, breakwaters and entrance channel dimensions
- the design of the operational concept, including personnel and handling equipment plans and work procedures.

The following **design vessels** (LoaxBxT) were used by the planners for the Haifa Port extensions :

a) Post Panamax Container Vessels up to 84 000 dwt (318x42,8x14).

b) Bulk Ships 60 000 dwt (225x32x12,5),Bulk Ships 100 000 dwt (280x40x15) and Coal Ships 150 000 dwt (295x44x17).

c) General Cargo Ships 25 000 dwt (190x25x10,6).
d) Chemical Tankers 12 000 dwt (160x18,4x8,3).
e) LPG Tankers 22,000 dwt (170x23x9,7).

The following development plan characteristics were set based on the above design vessel assumptions :

- entrance channel water depths (max. 20 m);
- quayside water depths, 14 and 16,5 m for Bulk and General Cargo Ships, 15,5 m for Post Panamax Container Ships, 19 m for Coal Carriers, 12 and 10 m in the Kishon Port to be used by smaller Bulk Carriers and General Cargo Ships;
- basin width between quays 250 m;
- turning circle diameter 600 m.

WAVE PENETRATION AND MOORING STUDIES

Both numerical and physical model studies were done to optimise the harbour layout with respect to limiting wave agitation. Due to the semi-protected position of the Port of Haifa (see Figure 1), storm waves from the dominant W'ly and WNW'ly directions become mainly NW'ly but also NNW'ly. Because ships must approach from the same NW'ly direction, due to the presence of the Talbot Reef, protection against wave penetration becomes rather problematic and several layouts have been studied in the numerical model before physical model tests were done.

The **numerical model** studies employed three separate modules, a non-linear shoaling module, the linear DHI agitation model MIKE 21 EMS and a linear wave-ship interaction module developed by the Coastal and Marine Engineering Research Institute (CAMERI) in Haifa. For more details on this approach, refer to Di Castro *etal* (1997). The **physical model** was built to a scale of 1 in 150 at the CAMERI laboratory in Haifa. As a first step, the numerical model results were compared with those of the physical model for the **existing** harbour conditions. Acceptable agreement was found, both in the short and long wave heights and in the downtimes for the 60 000 dwt bulk carrier and the 30 000 dwt container ship moored at the existing eastern quay (refer Di Castro *etal*). Operabilities were found to be **97,0 %** and **96,1 %** for the numerical model and **97,9 %** and **96,7 %** for the **physical** model (limited prototype data suggests 2 % to 4 % downtime which is in close **agreement**).

After calibration, three basic layouts were modelled in the numerical model, namely the '**original**' design (Figure 3) with four different alignments of Quay no. 4 from maximum skew (kinked extension of Quay no. 5) to 90° square (parallel to Quay no. 2), the '**alternative**' design which provides maximum protection against wave penetration (Figure 4) and the '**final**' design (Figures 4, insert, and Figure 2).

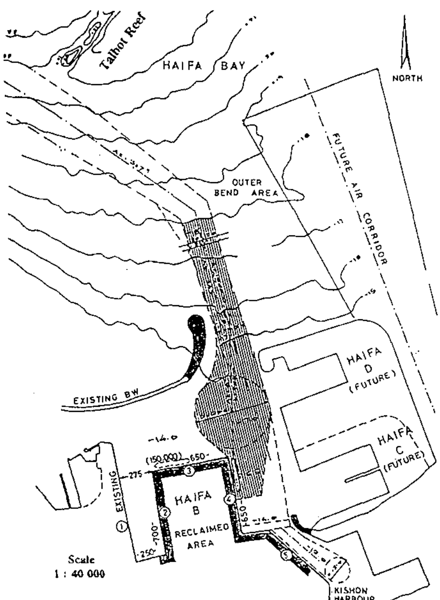

Fig. 3 **Initial Layout**
Haifa Port Extensions

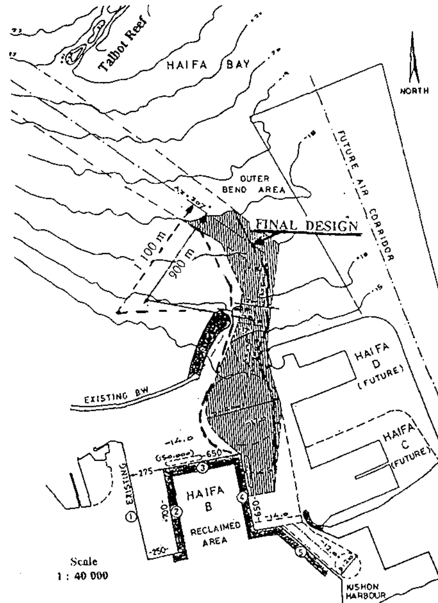

Fig. 4 Alternative Layout
Haifa Port Extensions

The test results for the original layout showed that the 'parallel' Quay no. 4 has the lowest downtimes and this quay-wall layout was therefor used for all further modelling. The 'alternative' design, with the head of the breakwater extension moved about 150 m east, was found to be significantly **better** in the eastern part of the port extension, including the Kishon Port, although conditions at Quays nos 1 and 2 became slightly worse. Mainly based on navigational considerations the entrance channel of the 'alternative' layout was revised, without changing the position of the breakwater head, which resulted in the 'final' design. The 'final' layout was studied, both with the numerical models and the physical model and the results showed generally **acceptable downtimes** for all the berths of Haifa East "B", namely operabilities for the various design ships moored at the relevant Quays nos 1 to 5 from **95,2 % to 98,8 %** for the **numerical** model and from **96,6 % to 99,6** for the **physical** model. Considering that these operabilities assume 100 % occupancy of design ships (sensitivity studies showed that downtimes for smaller ships are generally significantly less), these results were considered **acceptable**, based on present experience in the port.

NAUTICAL HARBOUR ENTRANCE DESIGN

The nautical design efforts were concentrated on the Post Panamax **container** vessel of 84 000 dwt (maximum draught 14,0) loaded to **12,5 m** draught (**71 900 dwt**) to berth at Quay no. 2, a **150 000 dwt** coal carrier to be berthed at Quay no. 3, the **100 000 dwt** bulk carrier to berth at Quay no. 4 (north) and the **25 000 dwt** general cargo ship entering the Kishon Port.

Wave conditions in the approach and entrance area are rather mild and the swell direction is mainly NW. The following refracted design data (in %) apply to the entrance area in 16 m depth (the 'long term' data are largely visually recorded data) :

Wave Direction	$H_{mo} > 1{,}5$ m	
	'Long term' wave data '58 -'96	Directional Waverider '93 -
NW	3,43	0,77
NNW	0,53	0,10
All directions	3,96	0,87

Thus, since the available 30 t bollard pull Voith-Schneider tractor tugs can be made fast in waves up to H_{mo} = 1,5 to 1,8 m (refer Halber *etal*, 1985), these tugs could **assist outside** the protection of the breakwaters for **at least 96 % of the time**.

The dominant **wind** directions are W, NW and SE while the strongest winds come mainly from W'ly, E'ly and SE'ly directions. Wind speeds in excess of 10 m/s (20 knots) occur only 2,9 % of the time (all directions) while speeds in excess of **15 m/s** (30 knots), which limits ship handling and crane operation, occur less than **3 days** per year.

The 'original' channel alignment shown in Figure 3 was 345° with an approach route of 307°. This design was based on the accepted criterion of a **straight** harbour entrance channel (refer PIANC, 1997 and also Halber *etal*, 1985). However, a more easterly position of the breakwater extension would provide better protection against the NW'ly waves and the 'Alternative' entrance design shown in Figure 4 was developed with the breakwater head moved about 150 m east, an entry channel at 10° with the same approach route of 307° and a nominal 63°-radius bend of 900 m or about 3 ship lengths. PIANC (1997) quotes a minimum of 2,8 lengths for unassisted entry but in the case of Haifa, **tug assistance** in the bend area would anyhow be **possible** up to at least 96 % of the time.

This layout proved to be **superior** from a wave protection point of view but further improvements were made as follows (see insert Figure 4) :

- the head of the breakwater extension remained unchanged but the 500 m extension was made straight
- the turning circle and the head of the future Haifa D breakwater were moved 50 m west
- the entrance channel was revised to have a single-radius (1 100 m) bend of 53°
- the channel design allows a further lengthening of the breakwater due north of 200 m, if found necessary (see Figure 2).

This provided a single-radius entry route into the main port area (container basin) of ample radius. No change was sofar made to the original approach route of 307° into Haifa Bay because it is virtually fixed by the presence of the Talbot Reef and the future air corridor (refer Figures 1 and 3). However, when considering the aids to navigation, it was found that by making a minor change in the approach route from 307° to 306°, the back leading light could be fixed to a very prominent grain elevator building (refer Figure 2).

This 'final' layout was used for the preliminary and detailed ship manoeuvring studies described below.

FULL-MISSION MANOEUVRING SIMULATOR

The MSCN **real-time simulator** with the full mission bridge and a 360° visual image was used for the Haifa Port extension manoeuvring simulation studies. This facility consists of a real **ship bridge** located in the centre of a cylindrical projection wall on which the graphics image is projected. A separate wing console is available for manoeuvring close to berth. Among the standard equipment of the bridge is a software controlled radar with full ARPA functionality.

Behind the bridge is the **simulation manager's** position. He can follow the manoeuvres directly as he has a view on the bridge, but he also controls all aspects of the simulations using a dual-headed workstation. On the left hand screen a **birds-eye view** of the simulation is presented. All environmental conditions can be called up on this screen. The track following target vessels are also controlled from this screen with respect to track and velocity. The right hand screen is used for the **control** of the simulation. It is used for the selection of conditions, control of tugs, control of environmental settings (visibility, wave heights and wind speed/direction) and it gives information about the status of the own ship (velocity, rate of turn and relative wind speed). At any time the simulation manager can halt the simulation and, if required, reposition the vessel. It is even possible to play-back a manoeuvre. During the simulations the simulation manager can follow the conversation on the bridge using the intercom. Tug orders are normally transmitted by VHF.

During the simulation studies the following **instruments** were available on the 'bridge' :

RPM indicators of engine and bow thrusters;	dopplerlog;
rate of turn indicator(s);	sallog;
rudder indicator(s);	wind indicator (speed and direction);
compass and course indicator;	VHF and intercom.

The data base includes information regarding the new **lay-out** of the port according to existing data of surveys, sea charts, local maps and the design drawings of the new situation. Both the 'original' and 'final' designs were included with access channel depths of 16, 18.5 and 20 m, depending on the design ship. All data regarding the critical **environmental conditions** were made available by the Israel Ports and Railways Authority and these data were digitized and imported into the database. For the environment (waves, wind and currents) it is possible to include a so called grid in order to take into account the spatial variation of the environment. Furthermore effects of variations in time are also included in the simulations, for instance, wind gusting and slowly varying drift forces. These variations in time are, like in nature, stochastic which makes every simulation unique.

The **visual image** was prepared using photographs, maps, charts and drawings. For each situation two outside views were prepared, a day and a night version. In the night version special emphasis was laid on the so-called cultural lights. Lights on the quays and in town, producing backlight but also giving additional position information to the pilot. Of course also the **aids to navigation**, buoys and leading lights, were implemented. A so called 'minimum scheme' was applied in order to find out which aids had to be added in order to secure safe manoeuvring. For a number of destinations, moored ships were included at various quays thus reducing the available space and making the manoeuvres more complicated.

The **mathematical models** applied are waterdepth/draft sensitive, consequently the manoeuvring characteristics are depending on the waterdepth, an important aspect of manoeuvring in shallow water. Special emphasis was paid to the wave drift forces calculated for the various ship types. When the vessel runs aground in the simulator the simulation halts sothat the reason for this can be evaluated. A realistic collision behaviour with spring action, damping and longitudinal friction, depending on the properties of the fendering, was included along the quay walls. Bank suction was only included in the Kishon area, as this is a relatively narrow passage with restricted width and depth.

Most realistic is a simulation with **tugs** as own ships sailed from other available bridges. However the own-ship tugs are not always practical and in the Haifa simulation tugs operated by the simulator manager were used. All tug forces are modelled realistically and the transitions between the pulling/pushing directions conform with reality. The forces are dependent of speed, pulling/pushing direction, velocity of own ship and current. The tugs can be positioned in a realistic position awaiting the approach of the vessel. They are also visible in the visual image. When the pilot requests assistance, the tugs will approach and upon command they will make fast. All this is performed with **realistic time delays** including stochastic variation. Pulling/pushing will be effected on order. In the Haifa simulations four 30t bollard pull Voith-Schneider tugs were available for assisting the vessel.

For a new port development, the **selection of the pilots** who should execute the simulations is an important issue. It is beyond doubt that experienced pilots must be used. Local pilots have the advantage that they are familiar with the port and the procedures normally applied. However in case of an increase in maximum ship size they lack the experience with the specific vessels. To overcome this problem in the Haifa port study we have worked with one local pilot and one Dutch pilot who has experience with the specific ship size. This was a successful approach also with regard to knowledge/experience transfer.

PRELIMINARY MANOEUVRING SIMULATIONS

Although tug assistance in the channel bend is considered feasible most of the time, it was decided by the IPRA to carry out a preliminary programme of manoeuvring simulations to check on the **nautical feasibility** of the curved entrance channel which goes against normal harbour entrance design rules.

These preliminary simulations were done on the full-mission simulator at MSCN/MARIN, Wageningen over a period of three days by a Dutch and an Israeli pilot. Only the **largest ships** were used, namely the Post Panamax container vessel (84 000 dwt) loaded to 71 900 dwt and the 150 000 dwt bulk carrier. Also, rather **extreme conditions** were used, namely : Condition 1 with 10 m/s (**20 knots**) W wind, 1 m/7 s NW waves and 0,2 m/s E'ly current, and Condition 2 with 20 m/s (**40 knots**) W wind, 2 m/9 s NW waves and 0,4 m/s E'ly current.

Leading lights were used to define the approach route, the back light being 4,7 km from the start of the bend at a height of 30 m above sea level and the front one 2,9 km away at a height of 15 m (see Figure 2). Four navigation buoys were used, **no. 1** at the Talbot Reef, **nos 2** and **4** at the start of the bend and no. **3** at the entrance, opposite the new breakwater head.

The preliminary simulations included 15 entry manoeuvres (both during daylight and at night) and 4 departures with the container vessel (T = 12,5 m) and 8 entries and 1 departure with the 150 000 dwt bulk carrier (T = 17,0 m). Thus, a total of 28 actual test runs, excluding 5 familiarisation runs. The runs started about ½ mile (900 m) seaward of buoy no. **1** and it was assumed that the **pilot** had boarded before buoy no. 1. The container vessel was berthed at Quay no. 2 (north) and the bulk carrier at Quay no. 3 (centre). Two 30 t tugs joined the ship in the bend area. For condition 1 (H_{mo} = 1 m) the tugs could start to make fast outside, for Condition 2 (H_{mo} = 2 m), they could only make fast when the wave height had reduced to H_{mo} =1,5 m. It was assumed to take 5 minutes to fasten one tug. Two more tugs were waiting inside and could be used, if required.

Although it was intended to also check the 'original' layout, the early results with the 'final' layout were very positive and all the preliminary runs were done for this layout. On the basis of this limited simulation programme it was found that the 'final' layout was indeed **feasible**. Rudder and propeller use were moderate and three tugs should be sufficient, except for the 40 knot (20 m/s) wind condition when the tug capacity was considered marginal for the container vessel. It was therefore decided to reduce this test condition for the further simulations to a more realistic wind speed of 30 knots (15, 0 m/s). Even when the container ship's power was reduced by 25 per cent for some runs, no particular problems were encountered.

Based on the preliminary three-day simulation study it was **concluded** that the 'final' layout was, not only nautically **acceptable**, but probably preferable to the original layout with the straight entrance channel section. This is because the single bend design is such that the entry manoeuvre becomes quite 'natural'. It was also found that the aids to navigation (leading lights and 4 buoys) appeared sufficient but necessary for safe navigation.

On the basis of these results it was decided to continue with the main simulation study using the 'final' entrance design.

COMPREHENSIVE MANOEUVRING SIMULATION STUDY

The main simulation study consisted of two weeks of simulations at MSCN/MARIN by two Israeli and two Dutch pilots. The **purpose** of these studies was to check on the nautical design of the extended port, according to the 'final' design, with particular emphasis on :

- the approach, entrance and turning area layouts and the channel widths
- the location and extent of the manoeuvring areas and mooring basins
- the need for and adequacy of the aids to navigation
- the minimum required tug use and the overall manoeuvring safety vis á vis weather conditions.

The simulations were done with the following ships :

- Post Panamax Container Vessel (T = 12,5 m) to be berthed at Quay no. 2;
- 150 000 dwt Bulk Carrier (T = 17 m and 11,8 m) to be berthed at Quay no. 3;
- 100 000 dwt Bulk Carrier (T = 15 m and 10 m) to be berthed at Quay no. 4;
- 25 000 dwt General Cargo Ship (T = 10,6 m) to be berthed at Quay no. 5 (Kishon).

The following **environmental conditions** were used in the simulations :

Swell	Direction	-		-		NW		NNW	
	H (m)	0		0		1	2	1	2
	T (s)	0		0		7	9	7	9
Wind	Direction	E		SE		W		NW	
	Speed (m/s)	10	20/15	10	20/15	10	20/15	10	20/15
Current	Direction	-		-	W	E		-	W
	Speed (m/s)	0		0	0,20	0,20	0,4	0	0,20
Starting Speed (knots)		5	6	5	6	6	7	6	7
Condition		**1**	**2**	**4**	**5**	**7**	**8**	**9**	**10**

In total, 102 manoeuvring runs were performed as follows (outbound in ballast) :

Runs	Inbound	Outbound	Night	75 % Power	Total
Post Panamax Container Vessel	47	10	9	4	57
General Cargo Ship	13	-	3	-	13
100 000 dwt Bulk Carrier	12	4	2	-	16
150 000 dwt Bulk Carrier	22	4	1	-	26
Totals	94	18	15	4	102

The results of the simulations are shown in Figure 5 where the results are **combined** for the different wind directions W, E, SE and NW and for the three main design ships (excluding the 100 000 dwt bulk carrier). Some minor channel boundery transgressions are noted on the inside of the bend and near the head of the future Haifa D breakwater. MSCN/MARIN recommended straightening of the western channel boundery but since this would come in the way of a possible further main breakwater extension, it was decided to anchor an **additional buoy, no. 6**, here. Also, an additional buoy, **no. 5**, is anticipated to avoid possible transgression of the eastern channel boundery (refer Figure 6).

Apart from these minor changes, the harbour **entrance design** was found to be **effective** and **nautically safe**.

FINAL LAYOUT AND AIDS TO NAVIGATION

Based on the design studies and the preliminary and detailed ship manoeuvring simulations it was found that :

- the approach, entrance, turning and mooring areas are **satisfactory** for safe operation for waves up to H_{mo} = 2 m and 20 to 30 knots (10 to 15 m/s) wind for the container vessel and up to 40 knots (20 m/s) for the bulk carriers
- the **limiting** conditions for operation will be bringing aboard of pilots and the use of service craft, not the channel design
- the revised Kishon entrance was found to be **satisfactory** although, due to the change from the present entry conditions, pilot **training** on a simulator will be advisable
- under adverse conditions, only the **bow-out** manoeuvre of the container vessel is sufficiently **safe** but for the bulk carriers both the bow-out and bow-in manoeuvres can be made safely
- normally **two tugs**, used inside the port, are sufficient although for some conditions three and even four tugs are advisable (also depending on the type of ship and for speed of operation)
- the **aids** to navigation as used in the simulations are generally sufficient but **necessary** for safe navigation and manoeuvring although two additional buoys are envisaged based on the minor transgressions
- the pilot boarding and manoeuvre starting points used are satisfactory

- pilot training is envisaged for the new conditions, particularly for manoeuvring into the container basin and the new Kishon entrance and to confirm the need and effectiveness of the additional buoys nos 5 and 6.

The 'final' design, including all the envisaged aids to navigation are shown in Figure 6. This layout was also used for the detailed numerical and physical model tests described above for the **mooring conditions**. Preliminary numerical model studies did indicate that a longer breakwater extension (600m) would indeed **further reduce** wave heights inside the port sothat this remains a future option, if needed.

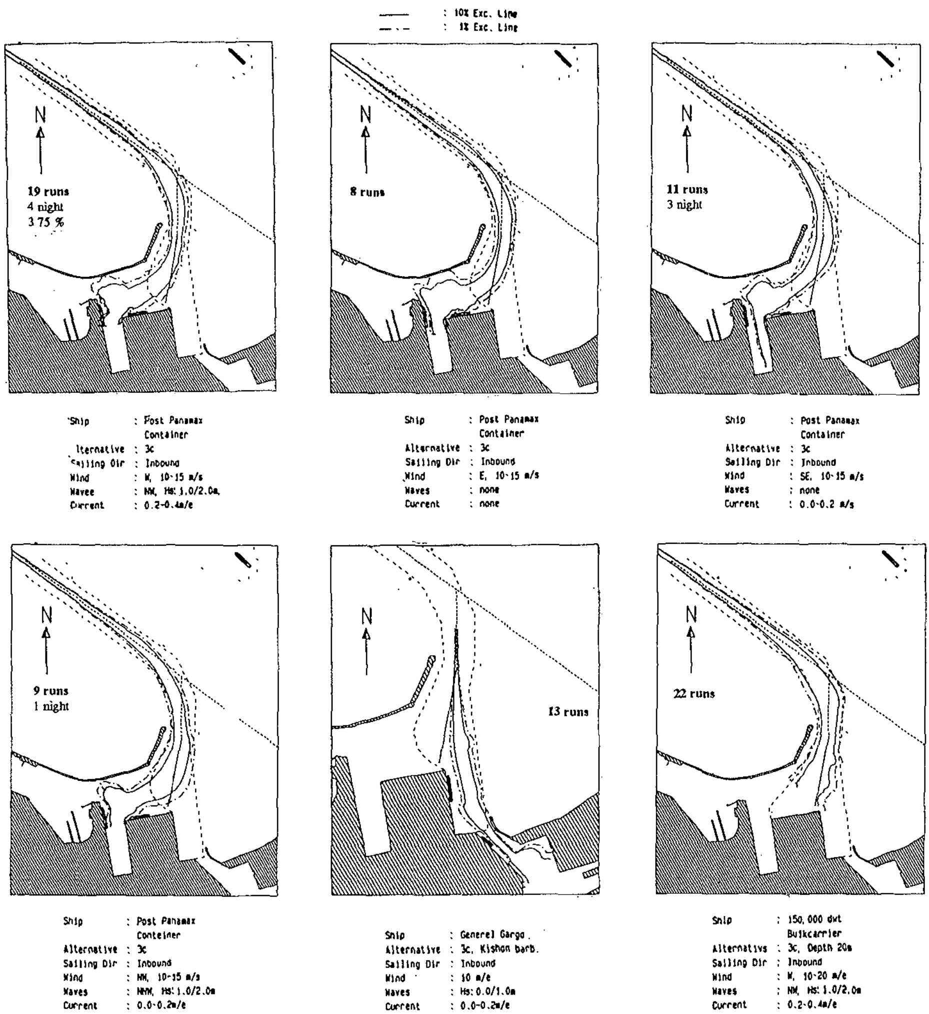

Fig. 5 Combined Simulation Tracks per Wind Direction

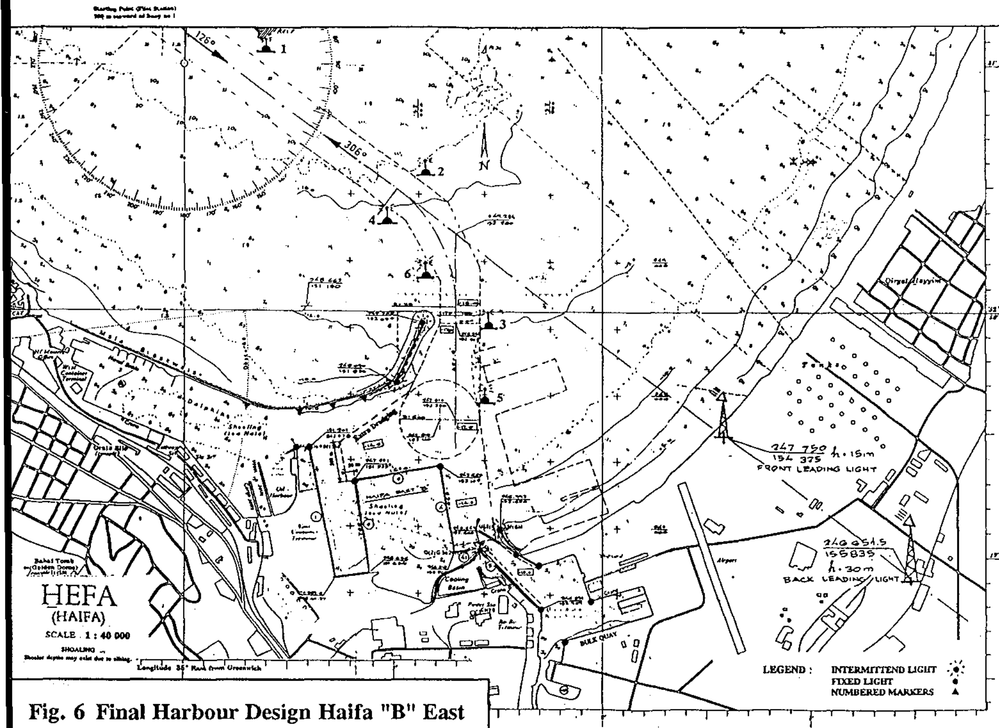

Fig. 6 Final Harbour Design Haifa "B" East

CONCLUSIONS

Forced by circumstances, a **curved approach** to the entrance of the planned extensions to the Port of Haifa, was designed in the 'final' layout. Detailed nautical studies not only proved the adequacy of this layout but they showed the distinct **advantages** of this particular design. At the same time, **maximum protection** against wave penetration was achieved.

These satisfactory results were reached by an **integrated design** process which included a nautical desk study design supported by an extensive programme of full mission manoeuvring simulations and detailed numerical and physical model studies.

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