

# ENGINEERING AND ENVIRONMENTAL IMPACT OF DREDGING FOR CONTAINER TERMINAL, BAY PORT, HAIFA, ISRAEL

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## ABSTRACT

The Israel Ports Plan includes the development of two focal points of sea trade along the Mediterranean Sea: at the city of Haifa located about 90 km northern to Tel Aviv and at the city of Ashdod located about 40 km southern to Tel Aviv (Figure 1).

The development plan was based on the forecast of cargos demand growth (import/export) and the raise of the global trade. One of the plan purposes was to enable huge vessels enter the Israeli ports. Logistics areas, transportation roads and railways were also taken into account.



Figure 1: Haifa City Location in Israel

Bay Port, the new development stage, phase “A”, is adjacent to the existing port of Haifa (Figure 2) built in the thirteen of the past century along the southern part of Haifa Bay. Further development stages of the port allowed berthing of 10 m draft cargo vessels in the sixteen, Panamax bulk carrier of 12 m draft in the eighteens and Post Panamax Container vessels of 14 m draft in 2007 including deepening of the entrance channel to -17.5 m.

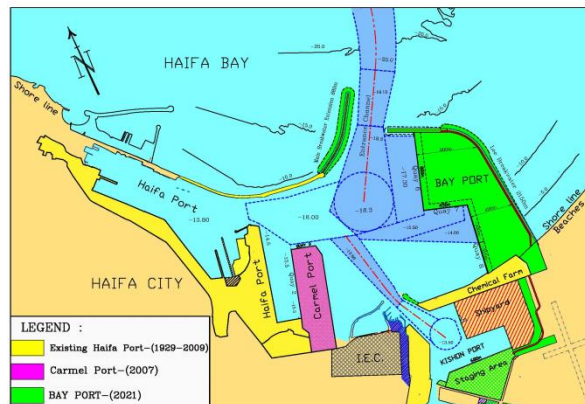


Figure 2: Bay Port Layout

Start order of Bay Port now under construction was on January 2015 and will be operational in 2021. Bay Port is designed for EEE container vessel (400x59x16m, 18,000 TEU) with an entrance channel of 20.5 m depth below Israel Land Survey Datum (ILSD). Total project cost is approximately 1 billion USD. The

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project is executed concurrently with "Hadarom Port" project in Ashdod. Both projects are commissioned for Israel Ports Company Ltd (IPC), designed with the supreme supervision by HPA Engineers P.C.(USA) (ref.1). Bay port is under construction by the Contractor Ashtrom-Shapir Construction of a new Port Ltd. (Israel) and supervised on site by A.D.Y.R Constructions (Israel).

The location of the new port in a natural bay created engineering and ecological challenges during the design and construction phases especially in dredging and soil compaction aspects.

In this paper the following aspects which will be described are:

- Sand sea resources for fill reclamation,
- Deep compaction of the fill,
- Seismic impact and soil liquefaction,
- Impact of the new port on the adjacent beaches.

## PROJECT DESCRIPTION

Bay Port includes the following main structures (Figure 3):

- 882 m extension of the existing Main Breakwater of the rubble mound type at water depth up to 16.5 m.
- 2,150 m of Lee Breakwater (1550 m of rubble mound and 600 m of rectangular cellular concrete caissons) at water depth up to -15m.
- 805 m main container Quay 6 for EEE vessels with design water depth of 17.3m. (Figure 4).
- 447 m secondary container Quay 7 for Post Panamax vessels with design water depth of 15.5m. (Figure 5).
- 715 m secondary Quay 8, of which 420 m for Panamax vessels with design water depth of 14.0m and 310 m with design water depth of 10.0 m for smaller cargo ships.

All depths are related to Israel Land Survey Datum (ILSD).

- 15,0 million m<sup>3</sup> dredging(10.5 million m<sup>3</sup> sand for the reclamation area of 840,000 m<sup>2</sup> , 3.1 million m<sup>3</sup> of unsuitable material for fill (clay and silts) to be dumped offshore in Haifa Bay.
- For breakwaters, a total of 43,200 armor units of concrete Antifer cubes of 4,7 and12 m<sup>3</sup> each and 5,500,000 ton rock of different sizes(0-1 ton,1-3 ton,3-6 ton)are required.
- A staging harbor 650 m long, with an area of 210,000 m<sup>2</sup> and water depth of 11.0 m and staging areas were allocated for contractor's work.

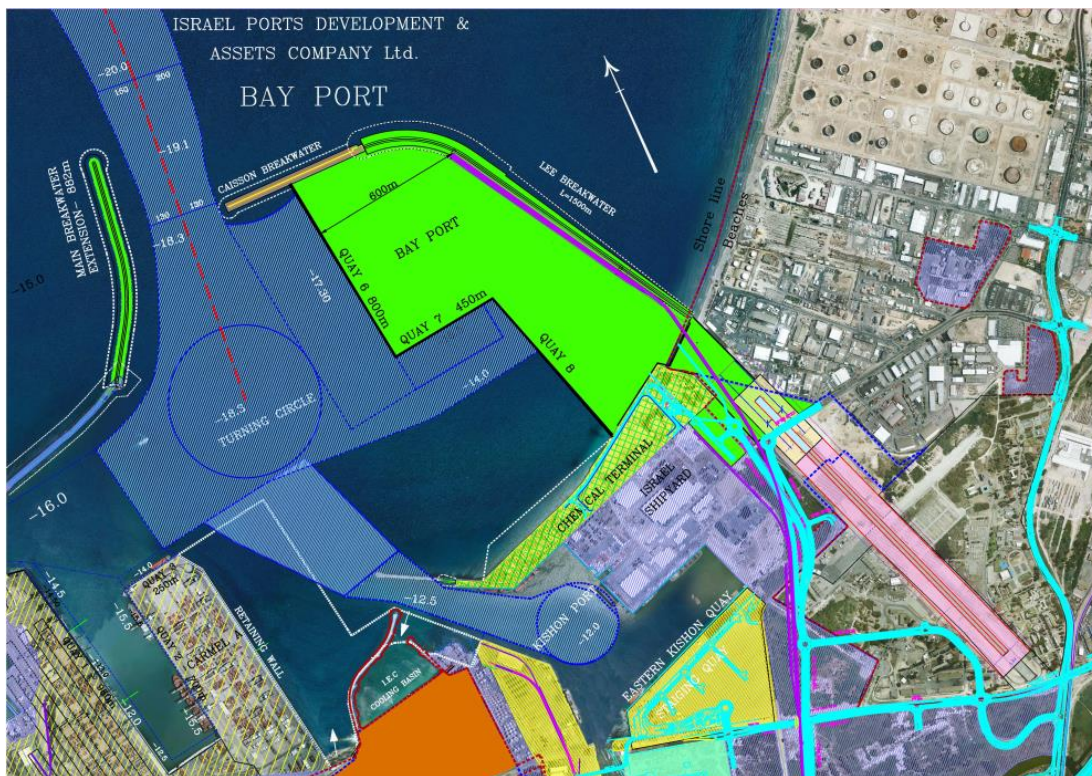


Figure 3: Bay Port Project Layout

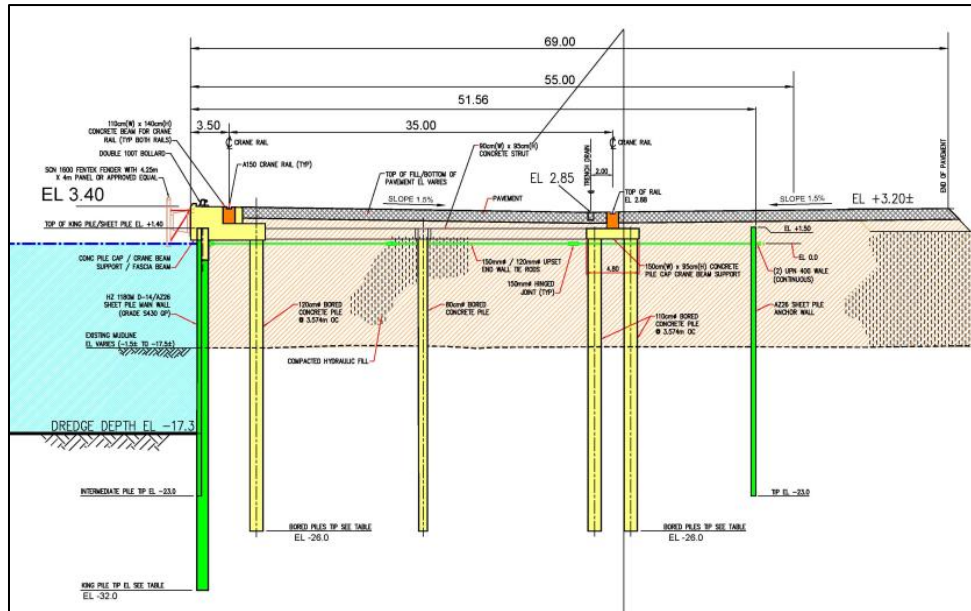


Figure 4: Quay 6 - Typical cross section

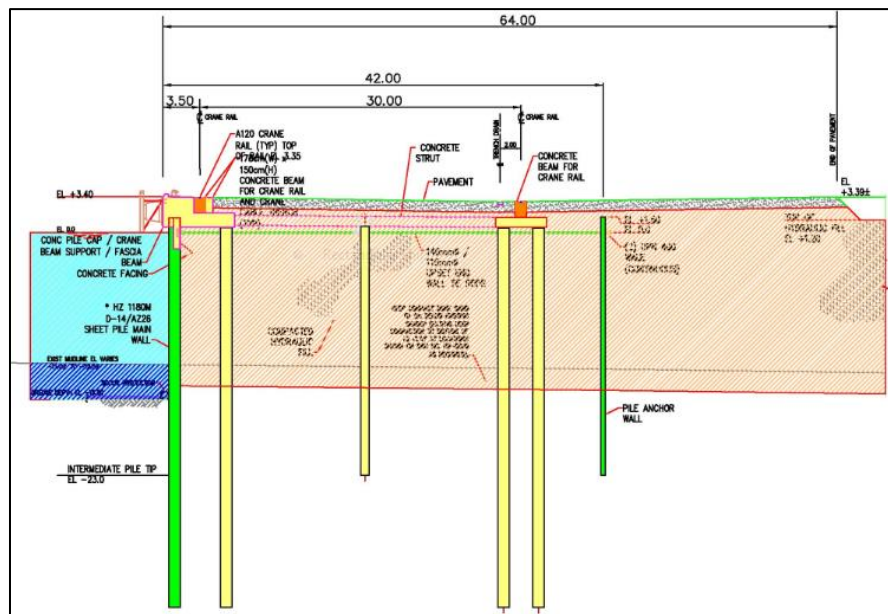


Figure 5: Quay 7 - Typical cross section

## DESIGN

During the design phase of port's structures, extensive marine and land surveys were carried out. These mainly included: 135 exploratory boreholes, 66 CPT and 20 Vibro cores for soil investigations to depths up to -180 m below sea bottom; seismic and magnetometer surveys; soil laboratory tests; 2D and 3D hydraulic physical model tests of breakwaters stability; harbor wave agitation and ship motion numerical models; wave patterns at different construction progress scenarios; fast and real time maneuvering simulations for nautical design.

Four design features required a special study and attention for the proper and economic design of the project:

- 1) sand sea resources for fill reclamation,
- 2) deep compaction of the sand fill and settlement,
- 3) seismic impact and soil liquefaction,
- 4) short and long-term impact on the adjacent beaches of Haifa Bay due to the Bay Port new breakwaters,



entrance channel and the area of sand mining close to the project.  
This paper shall focus on the above issues.

## DESIGN FEATURES

### 1. Sand resources for fill reclamation

The extension of Bay Port involves the construction of new container stacking yard, mostly reclaimed over the sea by walls and retaining structures.

For the reclamation area, huge quantities of fill material were required. An economic solution is to use fill material to be found as much as possible in an area close to the reclamation site.

The quantity of the sand fill material to be reclaimed inside the perimeter of the sheet piles walls is ca 10.50 million m<sup>3</sup>. This quantity includes 3.65 million m<sup>3</sup> of sand to be dredged in an area delimited from the deepening to the operational depth in the entrance channel and in the approach channel, turning circle, along quays 6, 7 and 8. The remaining quantity of 6.85 million m<sup>3</sup> of sand has to be dredged from a borrow area outside the port in Haifa bay. The suitability of the sand was determined on the basis of the following criteria:

- The sand fill must be able to withstand the designed loads.
- Start of operations immediately on completion of the fill and other works.
- Supply of the sand according to the planned schedule and fill procedures within a period of two years.
- Environmental considerations.
- Minimum price
- Statutory and legal aspects.

1.1 Following the National Master Plan for Marine Structures Works instructions, IPC prepared an Environmental Impact Assessment (EIA) including an Environmental Monitoring and Management Plan (EMMP) for dredging works. The EIA was approved by the Ministry of Environmental Protection (MOEP). Extensive studies were performed by international experts (ref.2) as well as Israeli specialists (ref.3) in the fields of hydrodynamics, sedimentology, biology and chemistry. The EIA is implemented during the construction.

The (EIA) of Shallow Water Dredging has included the following main issues:

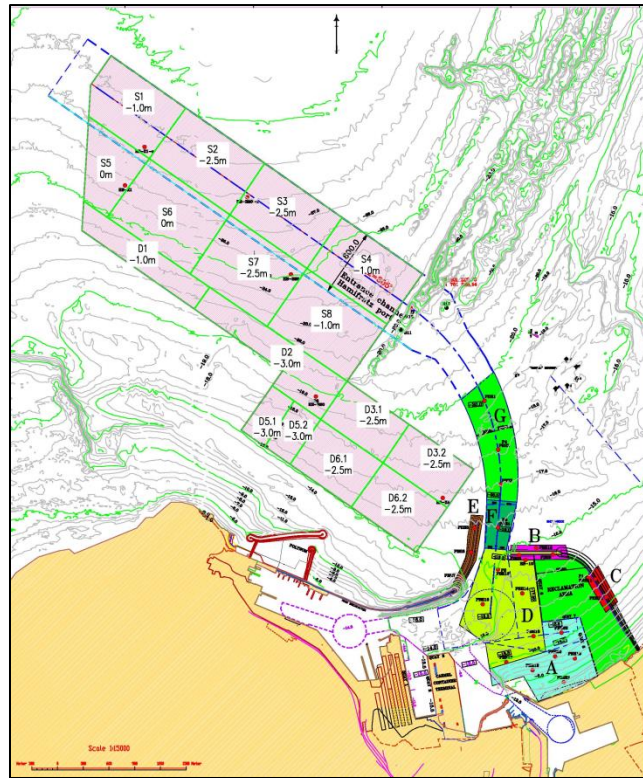
- Baseline Investigations and Surveys;
- Modelling in the field of waves, hydrodynamics and sediment transport (2D), sediment spill and water quality;
- Short-Term Impact of dredging at alternatives sites using various technologies;
- Long Term Impact on the marine environment after completion of the dredging work;
- Selection of the preferred alternative;
- Monitoring, Management and Mitigation plan to ensure compliance with the environmental quality objectives defined for the project.

Along the Israel coast sand deposits to be considered as potential borrow areas generally contain high fines content (i.e. the percentage of material passing 0,075 mm sieve) which is unsuitable for engineering purposes as hydraulic fill for reclamation when low fines content is required. Two sand mining alternatives for the construction of Bay Port have been examined:

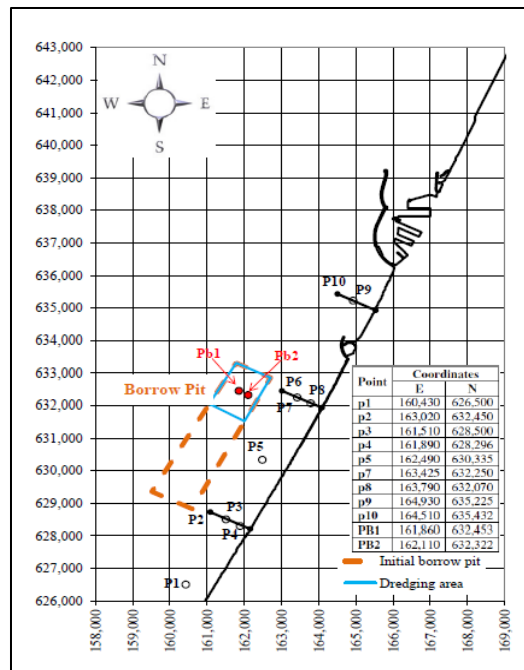
- Alternative 1- Sand mining solely from the Haifa site.
- Alternative 2- Sand mining from Haifa and Nitzanim site.

Dredging in each of the following sites was examined:

- a) Haifa site is close to the reclamation area situated in the Bay where a unique ecological system exists (Figure 6), The granulometry of material to be dredged in this site mainly consist of very fine sand. The sand layer overlies grey dense clay in most of the survey area. The composition of the material is mostly quartz sand with some silt and local clay lenses. In addition to 9 boreholes and 18 vibrocores executed in the borrow area, an accurate Seismic survey was also executed in the same area to verify the sand thickness layer.
- b) Nitzanim site lies south to Ashdod Port, distant from Haifa Bay Port about 140 km (Figure 7). The granulometry of material to be dredged in this site consist of fine to medium sand. To verify the sand thickness layer, 16 vibrocores were executed in this site.



**Figure 6: Borrow Area at Haifa Bay Site**



**Figure 7: Borrow Area at Nitzanim Site**

Some 1.25 million m<sup>3</sup> of dredged material was estimated to be available from Nitzanim site and the quantities to be dredged from the Haifa borrow pit thus can be reduced accordingly.

The total quantities of fines (in tons) from spillage due to dredging and reclamation, computed from the two dredging sites, were compared for short-term as well as for long-term impacts .

After having examine technical, environmental and economic aspects of the two alternatives for sand dredging, Haifa site alternative was chosen taking into account its advantages and was implemented in

the construction works.

The sand from Haifa borrow area adjacent to the reclamation works was dredged at water depths of -16.0 to -18.0 m below the Israel Land Survey Datum (ILSD); the dredged layer thickness varied between 1.0 to 3.0 m (Figure 6). Dredging, for the whole project, was executed by TSHD equipped with green valve.

### 1.2 Water turbidity control

The execution of the Works has been carried out in such a way as to minimize adverse impacts on the existing sea water quality and marine ecology.

The dredging works specifically included partial loading (reduced capacity) of TSHD to limit the quantity of soil spilled during dredging and reclamation.

The Turbidity Monitoring includes:

- Satellite Images Monitoring: monthly at high resolution and daily at low resolution.
- Continuous On-Line Monitoring by Sensors during all the dredging and reclamation period. Eleven on line turbidity sensors were deployed as indicate in Figure 8 .The records are every ten minutes and transmitted to shore station.
- Daily Turbidity Monitoring by boat were performed at 7 points, at 2 depths at each station (1 m below surface, mid-depth). (Figure 9).

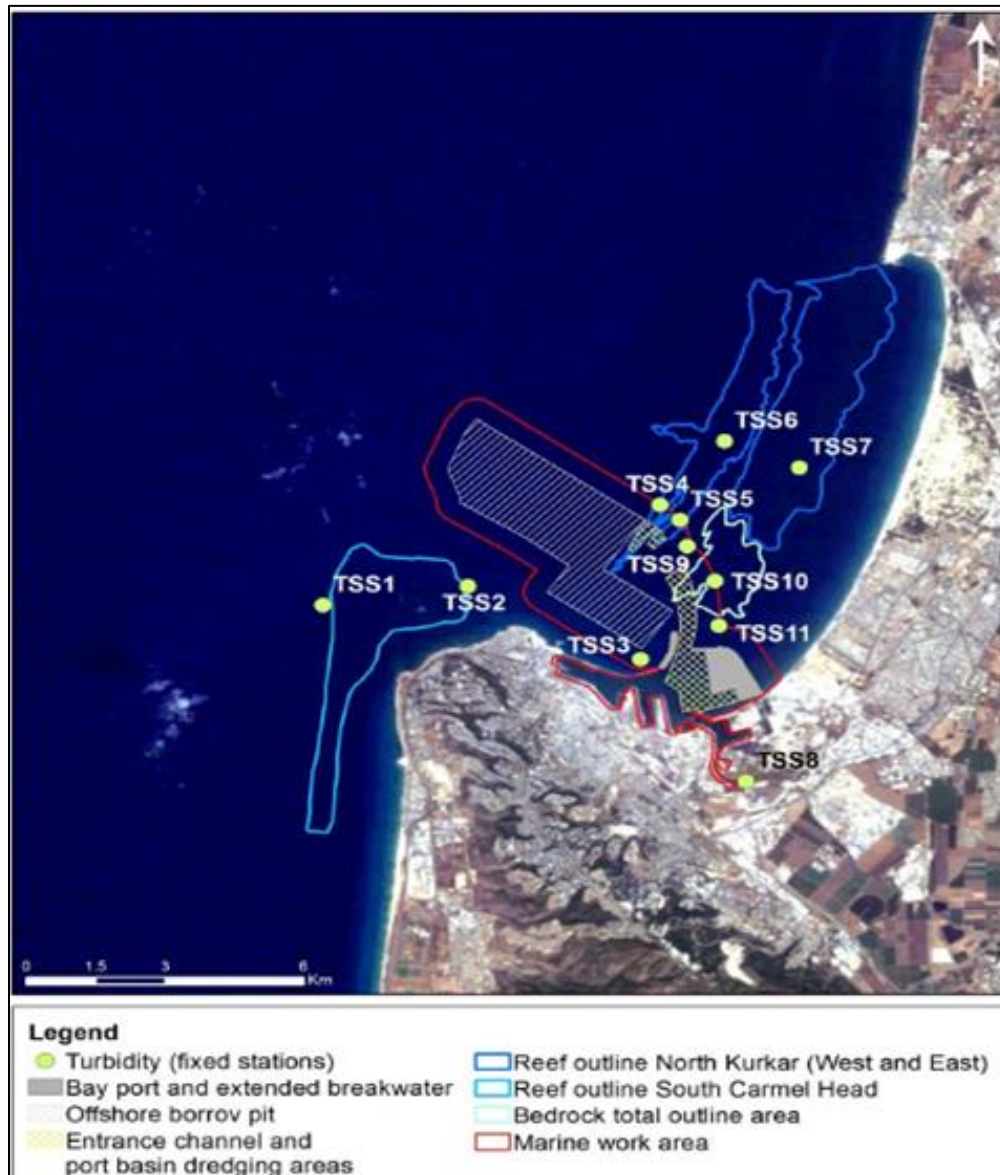
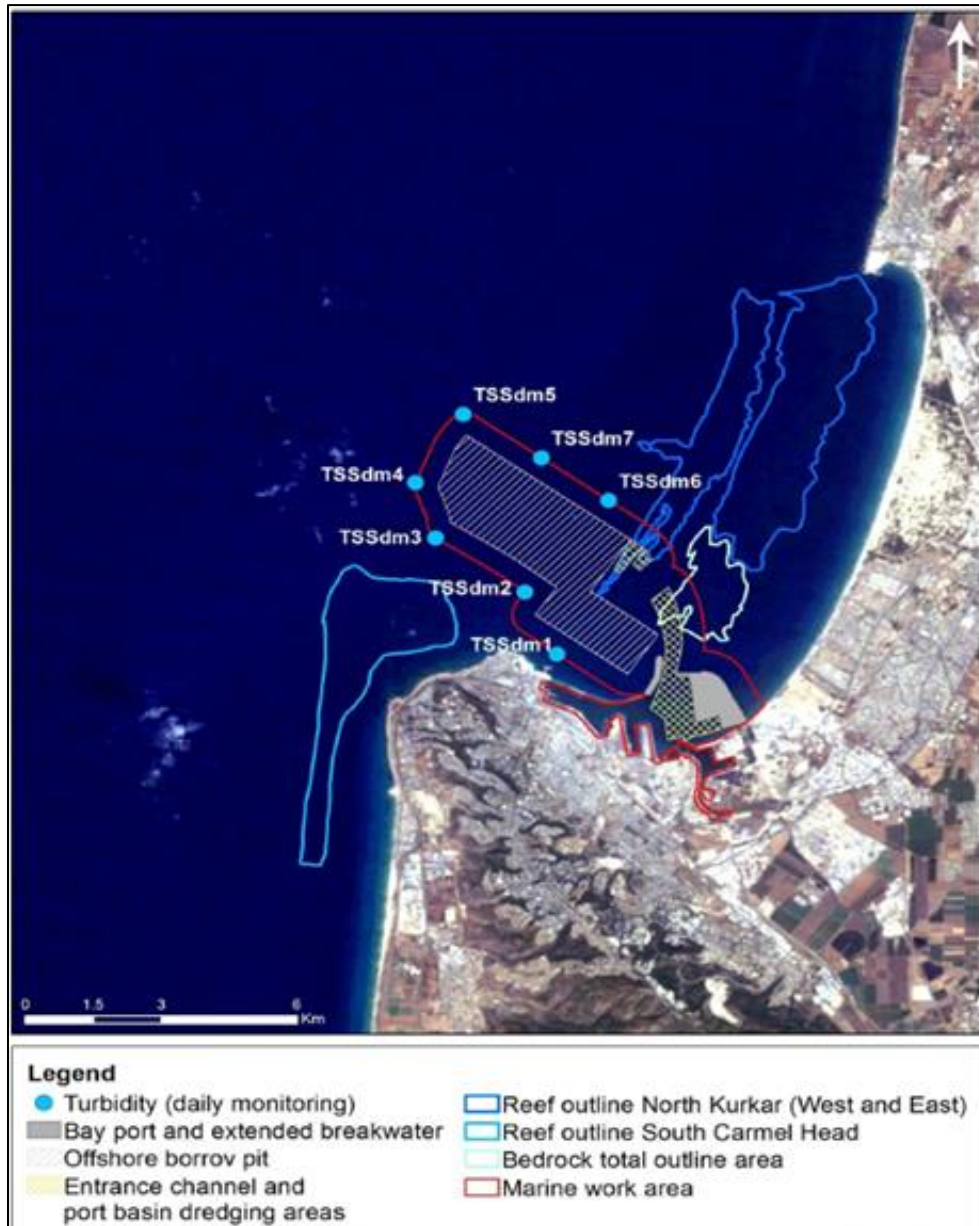


Figure 8: 11 turbidity sensors for on-line monitoring dredging





**Figure 9: 7 Monitoring stations for daily turbidity monitoring by boat**

The maximum sediment spillage fully compliant with the allowable spillage was defined in the EMMP as follows:

For stations TSS9, TSS10 and TSS11 (at half depth) continuously monitored: 30 mg/l.

For stations TSSdm1 to TSSdm7 (1 m below surface and mid-depth) monitored by boat: 30 mg/l.

### 1.3 Procedure placement of suitable loads in the TSHD hopper.

According to the Specification of the Work, the average fines content in the reclamation fill should not exceed 23%. Suitable materials in the hopper were considered loads that have a fines content not exceeding 27%. Loads containing fines whose content exceeds 23% but not exceeds 27% are allowed to be placed selectively in the reclamation in order not to exceed an average fines of 23%. When the sample contains less than 23% fines the load will be placed in the reclamation according to the placement schedule. When the sample contains more than 27% fines, the load will be disposed offshore, in disposal area "Epsilon" approved by the MOEP for unsuitable-not contaminated materials. The distance of Epsilon site from shore is about 22.5 km. For contaminated materials, the disposal area is "Alpha" also approved by MOEP at a distance from shore of about 40 km. (Figure 10).

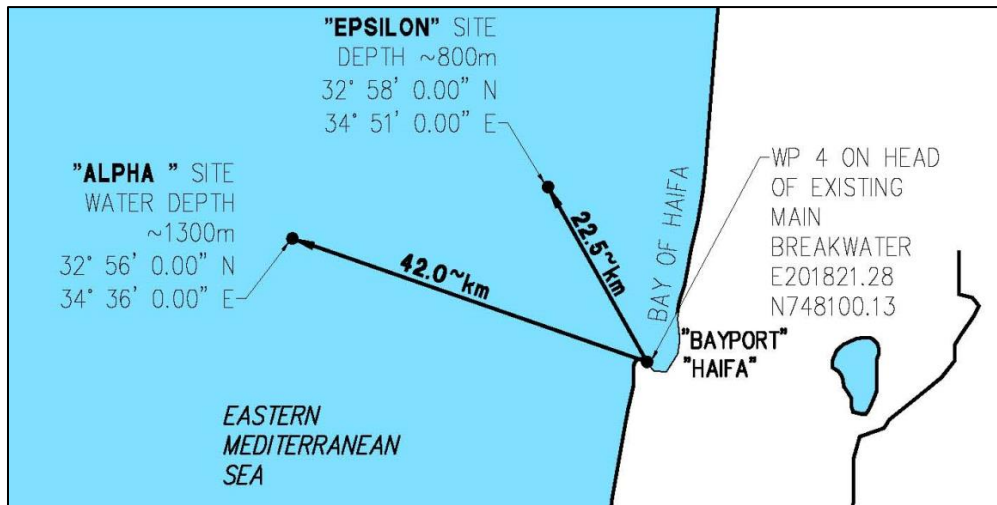


Figure 10: "Epsilon" and "Alpha" disposal sites opposite Haifa coast

**2. Deep compaction of the sand fill in Reclamation Area – Settlement calculation and monitoring**

The reclamation behind the new quay walls required the use of ground improvement works to accelerate and mitigate the ground movements associated with reclamation works, reduce future settlements and mitigate the risk of liquefaction in case of seismic event.

Two typical geotechnical sections of the various layers underneath the reclamation area are shown (Figures 11 and 12).

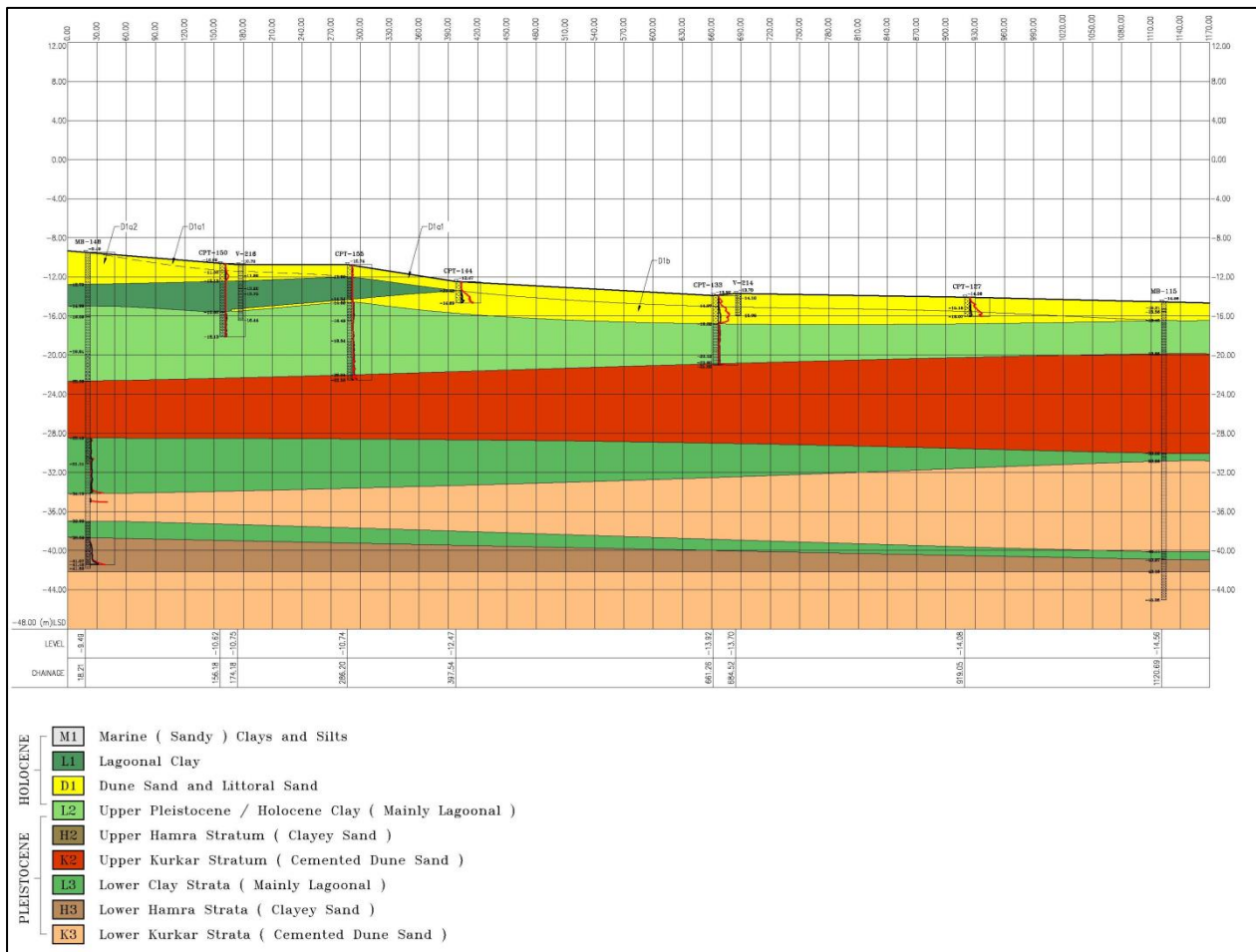


Figure 11: Geotechnical section along Quay 6



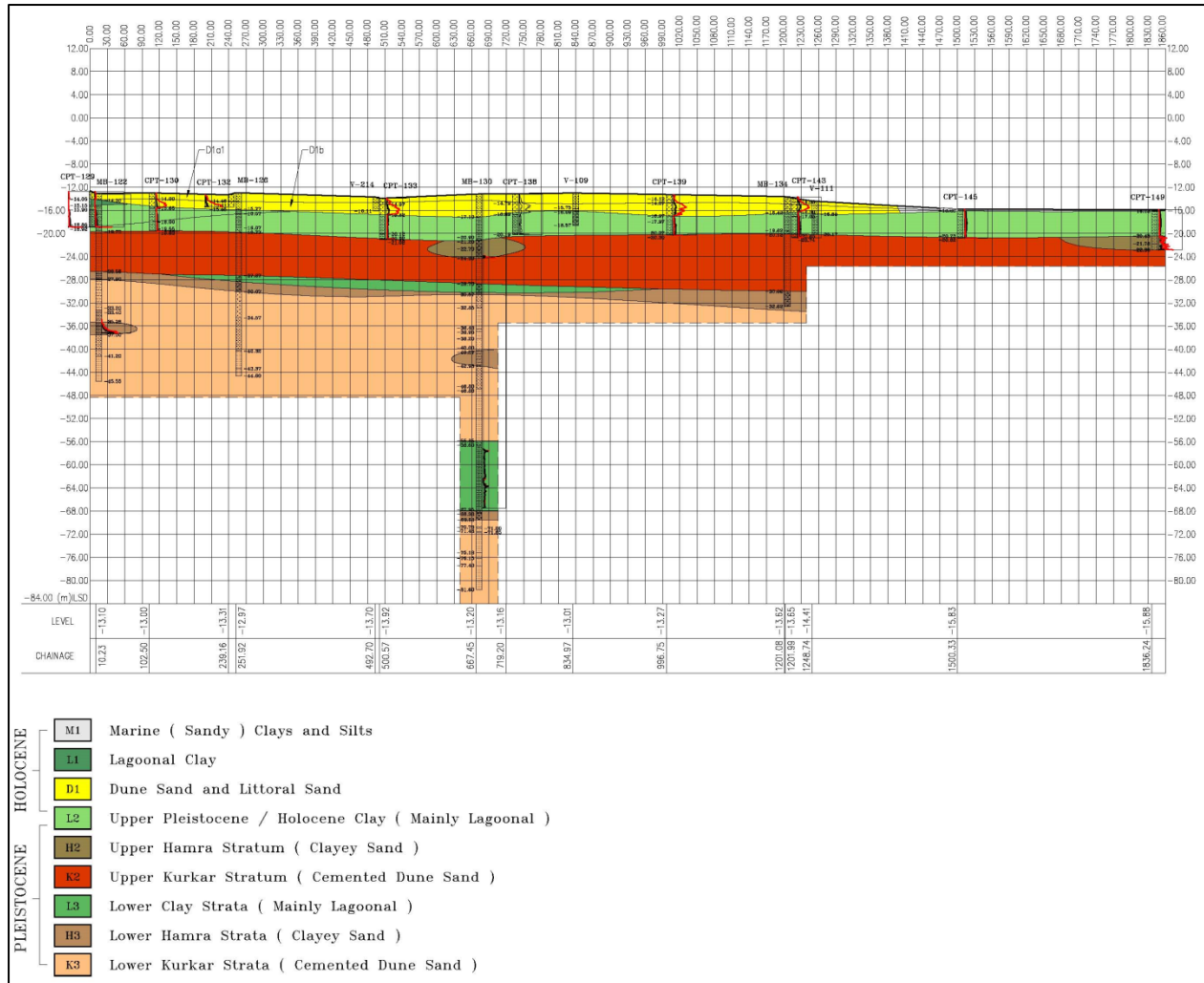


Figure 12: Geotechnical section perpendicular to Quay 6

Based on the results of soil investigation program, the stratigraphy of the project site is typically as follows: Dune sand, Upper Lagoonal Clay (L1), Upper Hamra (local term for clayey silica sand, cemented), Upper Kurkar (local term for uncemented sand to strong calcareous sandstone), Lower Lagoonal Clay (L2), Lower Hamra, Lower Kurkar.

Reclamation fill is expected to undergo elastic settlement as well consolidation settlement due, to the upper lagoonal clays L1 of very soft consistency and L2 stiff clay.

With the aim to minimize expected settlements due to primary and secondary consolidation of the sea bottom clay layers and liquefaction of the sand due to seismic effects, ground improvement techniques of deep compaction like Vibrocompaction and /or Vibrostone columns(using the wet top-feed process) were implemented from 2 m below the existing seabed up to +0.5 m ILSD..

Preparatory works like Boreholes and Proof Testing 30 by 30 m grid were performed for data analyses and determining compaction methodology.

If Fines Content (FC) in the fill area was found less than 23%, works were carried out according to Specification. If FC was found more than 23%, Proof Testing with grid 10X10 m were performed for data analyses and determining compaction method and grid .If (FC) was found more than 10% but less than 23%, or less than 10% and based on laboratory test results, (PSD ,carbonate content, pCPTs) choice was made between vibrocompaction and Vibrostone columns.

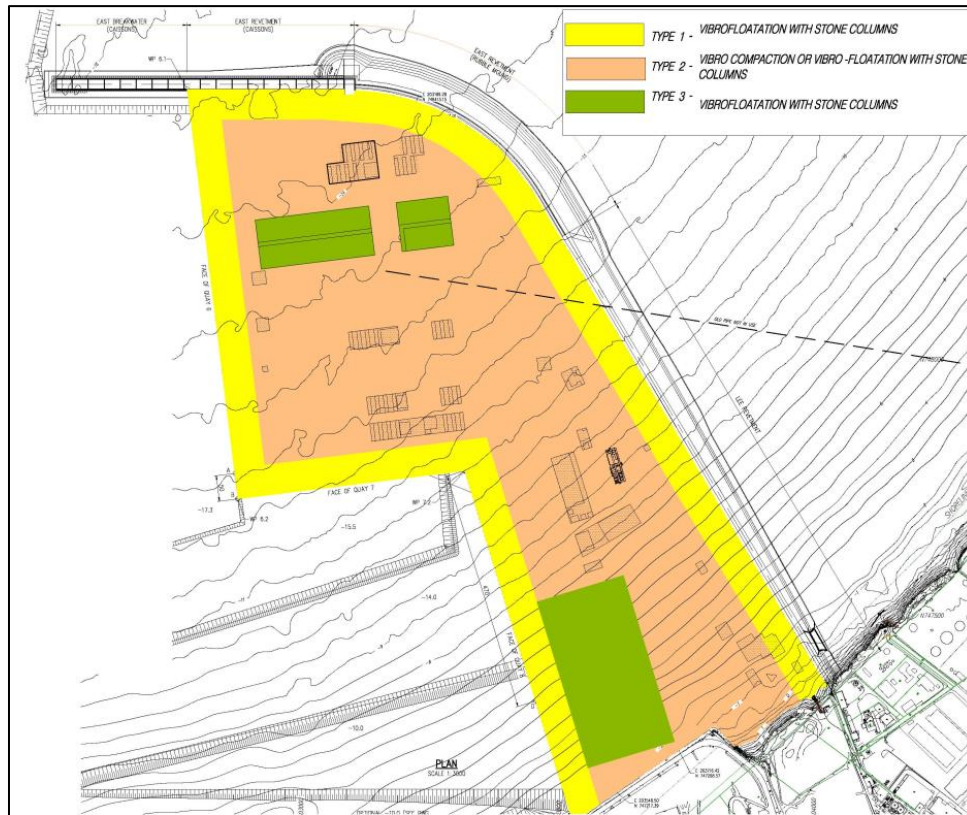
The criteria for compaction were divided into three main types (Figure 13) based on Area Replacement Ratio (ARR) which includes both static and seismic considerations. ARR is defined as the ratio of the stone columns area to the total area of the soil/stone matrix. The three types were:

Type 1 - along quays no.6, 7 and 8 and buildings foundations was compacted by Vibrostone columns with ARR of 23%.

Type 2 - the biggest internal area for containers storage, roads etc. was compacted by Vibrocompaction (70% relative density) and/or Vibrostone columns with ARR of 12%.

Type 3 - intended for dangerous and hazardous containers storage was compacted by Vibrostone columns with ARR of 25%.

The fill behind the quays and revetments was compacted to mitigate the effects of liquefaction under the 475 year return period earthquake and beneath the dangerous and hazardous container area was compacted to mitigate the effect of liquefaction under the (2/3) of 2,475 year return period earthquake.



**Figure 13: Ground improvement Areas (Type 1, 2 and 3)**

Stone columns in area Type 1 were placed on a triangular grid with center to center of 2.5m or rectangular grid of 2.40 x 2.25m due to tie rods position between main and anchor walls and stone column dia. of 1.26m. In area Type 3 a triangular grid of 2.5m was adopted and stone column dia. of 1.32m executed. Vibrostone columns area Type 2 was carried out with a triangular grid, center to center 2.5m and dia. of 0.91m.

After a series of additional Proof Testing by means of pCPT, the values of 23% ARR in area Type 1 and 25% in area Type 3 were reduced to 20% ARR, provided the FC distribution within the reclamation shall be found within 10% to 12%. Stone column diam. was 1.17m.

Time dependent settlements were estimated at a total 35 boreholes and CPT locations spread over the reclamation area. These settlements arise as a result of consolidation as well as secondary compression. For the calculation of the ultimate settlement total overburden stress applied at the mud line and a permanent surcharge of 25 kPa were taken in account. It was assumed that construction time to reach the required fill height is about 1 year.

The potential remaining settlement 2 years after reclamation fill placement due to upper lagoonal clay. This 2-year post-construction settlement is largely confined to the south portion of the reclamation area. Elsewhere, barring a few locations at the East Lee Breakwater, the settlement is practically nil. Some of the total 31 settlement plates for settlement monitoring have been already installed in the reclamation area. Surveys of elevations of the settlement plates have been carried out on a monthly basis including cumulative settlements.

Up to date positive and acceptable results were achieved by both compaction methods, Vibrocompaction or Vibrostone columns.

### 3. Seismic impact and soil liquefaction

3.1 The northwestern coast of Israel lies in a seismically active eastern Mediterranean region and Haifa Bay is the most active zone along the Israel coast. In the past several large earthquakes have occurred up to a magnitude of 5.3. The main reasons for seismic risks are the proximity of the Carmel (Yagur) fault. Its location within the Kishon graben is shown (Figure 14).

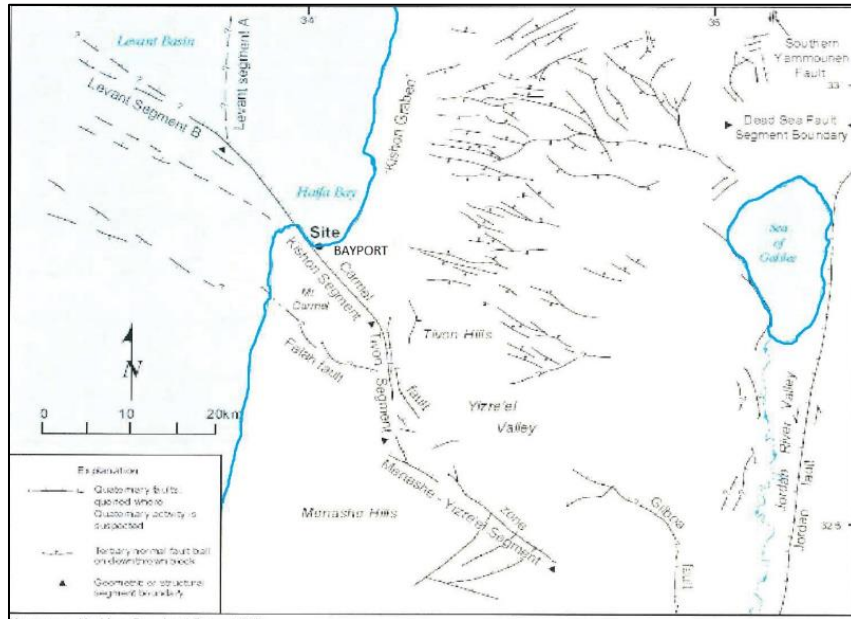


Figure14: Carmel fault location (ref.4)

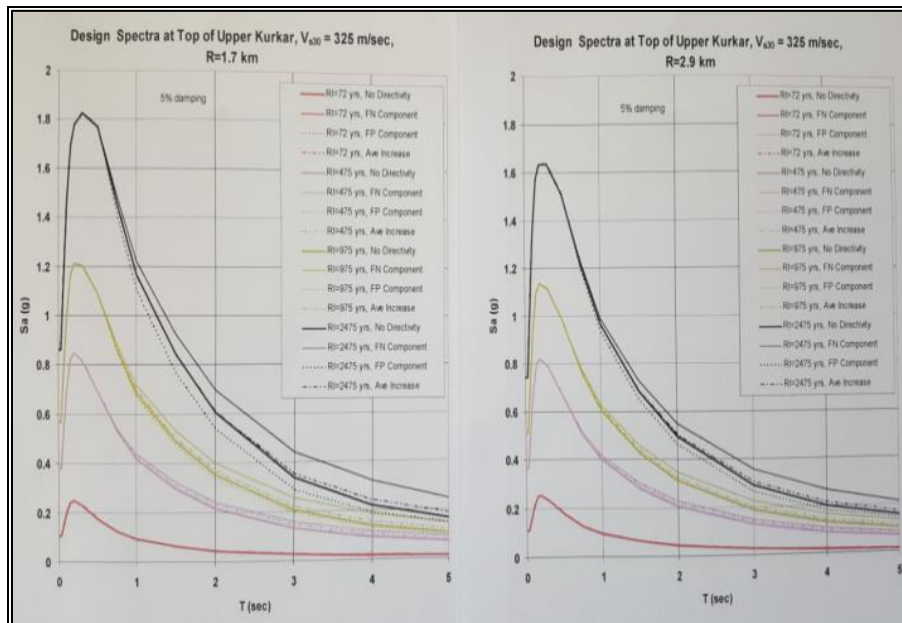


Figure15: Design spectra for OLE and CLE

The primary goal of the ground treatment due to an earthquake is to minimize ground deformations to acceptable levels near to critical structures like breakwaters, quays, ship to shore cranes, utilities systems, hazardous cargo storage facilities, upland utility corridors etc.

For the development of Bay Port, (IPC) decided to implement ground treatment over the whole terminal area. The extent and degree of ground improvement were planned in such a way to reflect the importance of the specific location and resources to repair the facility following seismic events.



Design response spectra were developed by the Designer (ref.1 and ref.4) based on seism-tectonic studies and ground shaking analyses and time histories developed for two design levels of return probability, the Operating level earthquake (OLE) with a return period of 1 in 72 years, 50% probability of exceedance in 50 years and a Contingency level earthquake (CLE) with a return period of 1 in 475 years, 10% probability of exceedance in 50 years. For the OLE event, a PGA near the top of the upper rock stratum of 0.11g and for the CLE event a PGA of 0.38g were used for the design of Bay Port structures.

Hazardous and Dangerous Container area was located sufficiently upland of the quay face so that this area will not be subjected to a quay related damage. The adopted PGA was 0.57g. Plots of the design spectra for seismic events are shown in Figure 15.

3.2 Soil Liquefaction and its control was a major design consideration in Bay Port project due to the use of hydraulic sand fill for reclamation and the relatively severe design earthquake conditions at Haifa Bay. A relatively density of at least 70% was assumed to be required to prevent liquefaction. Sand placed underwater has very low density and therefore generally is subjected to liquefaction.

In order to eliminate the potential for liquefaction, the soil at any given depth must have a Cyclic Resistance Ratio (CRR) greater than Cyclic Stress Ratio (CSR) at the same depth. A safety factor (SF liq) of 1.15 has been adopted in developing the required CRR.

As part of the Liquefaction Assessment as required by the MOEP, cyclic loading due to CLE quake motion and cyclic resistance of reclamation sand fill were tested in laboratory and analyzed. The Liquefaction Assessment used standard empirical methods and assumed soil parameters for the hydraulic fill and natural sand layers. The conclusion was that liquefaction will occur under the design earthquake conditions: a) in the sand fill reclamation: and b) along parts of the foundation of the main and lee breakwater unless appropriate mitigation measures should be implemented.

For sand fill reclamation, deep compaction techniques were used as described in design feature 2 (Deep compaction of the sand fill in Reclamation Area – Settlement calculation and monitoring). For foundation of main and lee breakwaters, replacement of liquefiable upper Dune sand layer with stone of “E” class (0-1000kg) was executed along the main breakwater extension and partially, where considered necessary, along the lee breakwater. (Figures 16 and 17).

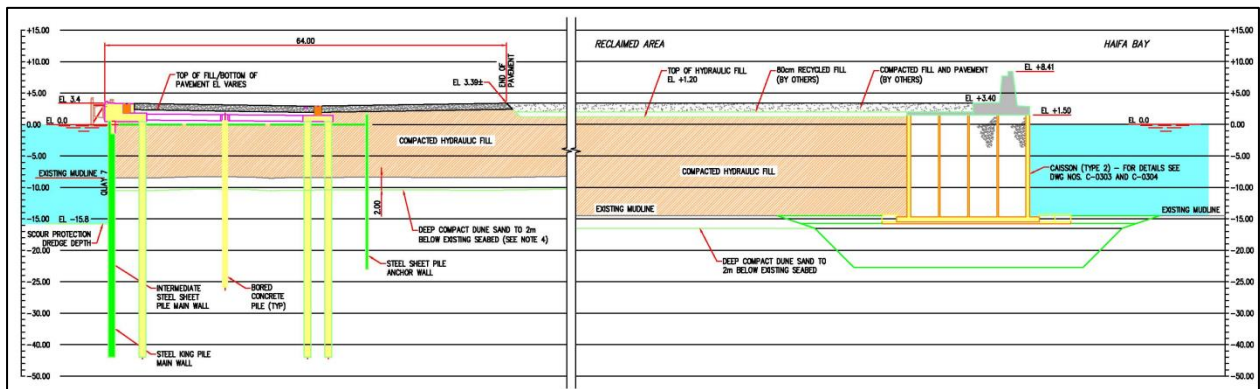


Figure 16: Typical section of reclamation area parallel to Quay 6

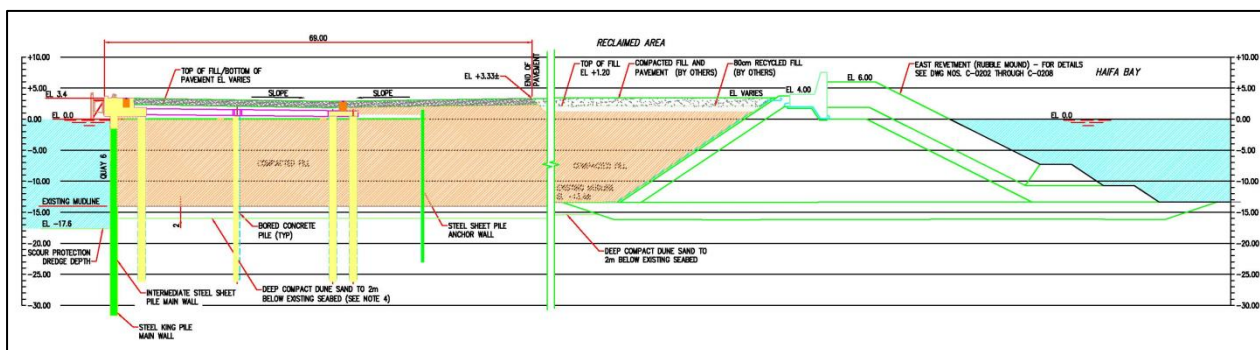


Figure 17: Typical section of reclamation area perpendicular to Quay 6

#### 4. Short and long term impact on the adjacent beaches of Haifa bay

4.1. Haifa Bay can be considered as the end of the Nile littoral cell. The input of Nilotic quartz sand into Haifa Bay is therefore smaller in quantity in comparison with other parts of the Israeli coast, In Haifa Bay due to its location in the sheltered area of the Carmel headland the wave energy is reduced by a factor of 3-4 compared to the Haifa southern coast. **The annual sand transport which enter the Haifa Bay from the south coast is estimated at 80,000 m<sup>3</sup>.** For the present layout, the amount of sediments that bypasses the Main Breakwater and possibly enter into the littoral zone of Haifa Bay is ca. 3900 m<sup>3</sup>/year. Stirring and movement of sediment in the Haifa region is primarily generated by longshore currents induced by breaking waves as well as turbulent velocities generated by the breaking. The direction of sediment drift depends on the angle of the incoming waves measured relative to the coast normal.

The Environmental Impact Assessment (EIA) submitted by the IPC to the Ministry of Environmental Protection (MOEP) dealt with the impacts in Haifa Bay due to the extension of main breakwater, building of the lee breakwater, dredging at the entrance and approach navigation channel and sand mining in the borrow site to be used for fill in the reclamation area.

The study of those impacts commissioned by IPC to CAMERI (ref.3) included:

- comparison of bathymetric and topographic maps and ortho-photos,
- comparison of cross shore profiles,
- changes in wave climate conditions due to the construction of the new structures,
- location of strong currents,
- changes in sediment transport,
- coastline evolution,
- erosion close to marine outlets,

The most advanced and update models for flow and morph dynamic computations were used by CAMERI (ref.3).

The study considered two layouts of the Haifa Port- existing port used, as reference state, and designed port–Bay Port.

The area of interest in terms of sediment transport modeling stretches along the shore from the northern port of Atlit ruins in the south to Old Acre town in the North (a length of ca.25 km) with the western boundary limited by the 30 m water depth (Figure 18).

The wave climate conditions utilized are based on wave instrumental measurements by Datawell wave rider positioned at Haifa site, at water depth of 24 m. The wave dataset covers 16 complete hydrographic years. Based on the analyses of wave data, ten representative waves were selected to represent adequately sediment transport potential within the area of interest (Figure 19) and cross profiles (F1 to F9) drawn in predetermined locations and compared among them (Figures 20 and 21).

The coastline evolution has been assessed during a 30-year period after the Haifa Bay Port construction (Figure 22). Results of the coastline evolution were also assessed every 5 years. The extension of the main breakwater by 882 m was expected to reduce the bypass rates already small at present and consequently to increase beach erosion along the bay since the north-going transport would no longer be compensated, even partially. In such conditions **sand nourishment, of about 35,000 m<sup>3</sup>/yr, was anticipated based on models results.**

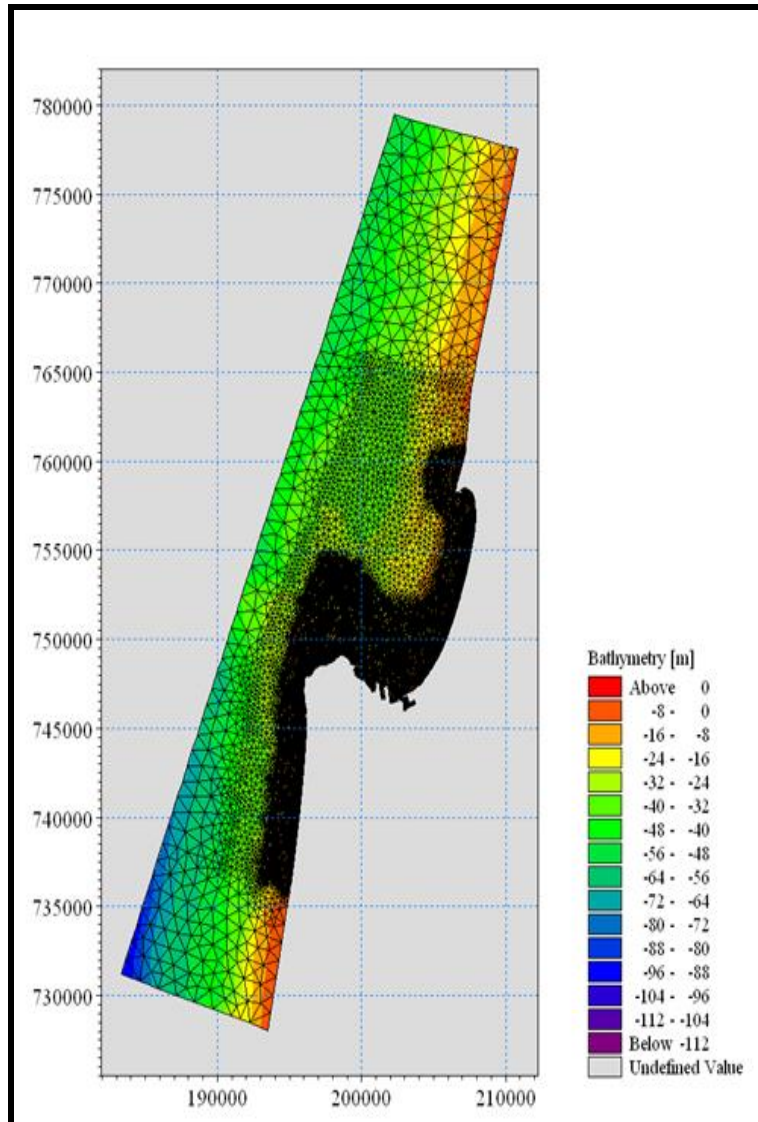


Figure 18: Mike 21 model shore flexible mesh and bathymetry

No.	Waves			Wind	
	Significant height, $H_{m0}$	Direction, $Dir$	Peak period, $T_p$	Speed	Direction, $Dir$
	m	°N	sec	m/s	°N
W01	2.5	245	7.7	7.5	240
W02	2.6	252	6.7	8.2	250
W03	2.8	259	11.1	8.5	259
W04	3.1	264	10.0	8.0	270
W05	3.6	268	9.1	9.0	268
W06	4.7	272	11.8	9.5	274
W07	3.2	285	11.1	6.0	220
W08	4.2	291	11.8	11.0	260
W09	2.9	299	9.1	8.9	299
W10	2.6	310	8.3	10.0	330

Figure 19: Representative waves parameters in deep water



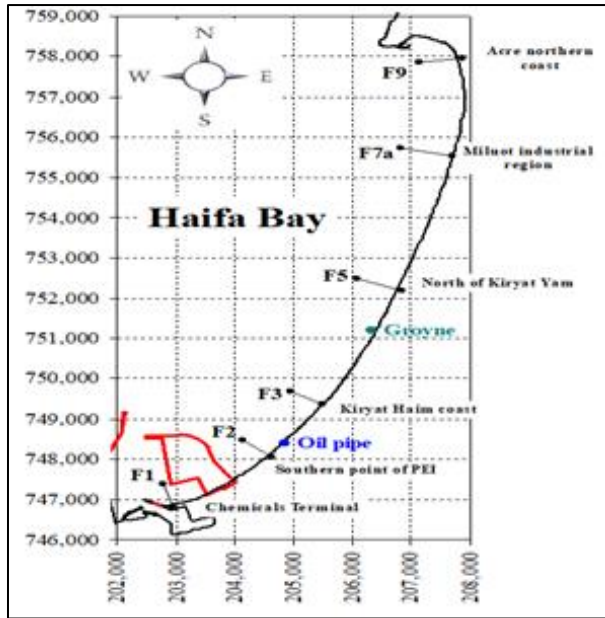


Figure 20: Location of cross profiles

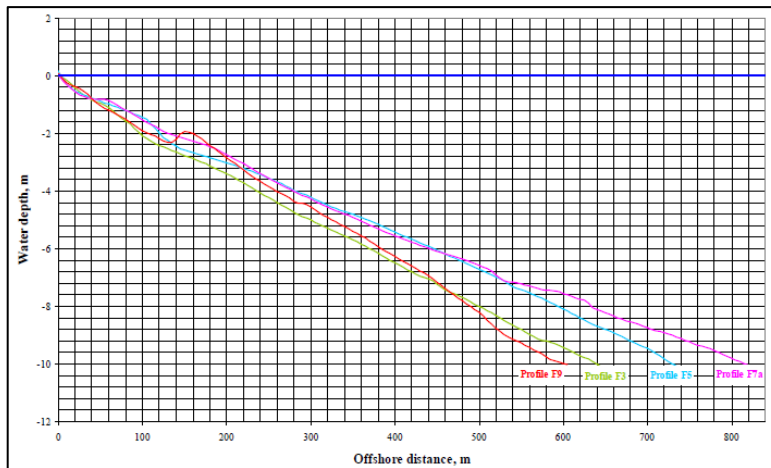
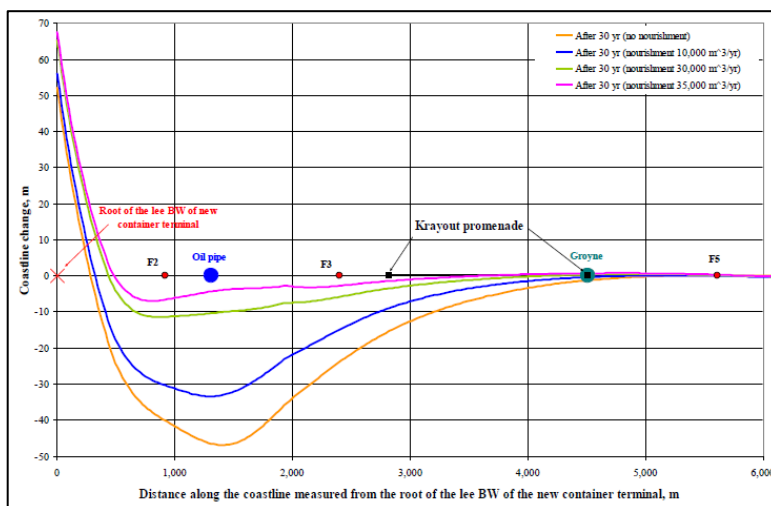


Figure 21: Comparison of cross shore profiles in Haifa Bay



\*Negative values refer to coastline retreat, positive refer to coast line advancing.

Figure 22: Coast line alignment 30 years after the Bay Port completion

4.2 The sedimentological issue and impacts were part of the short and long-term Sedimentological Monitoring Program.

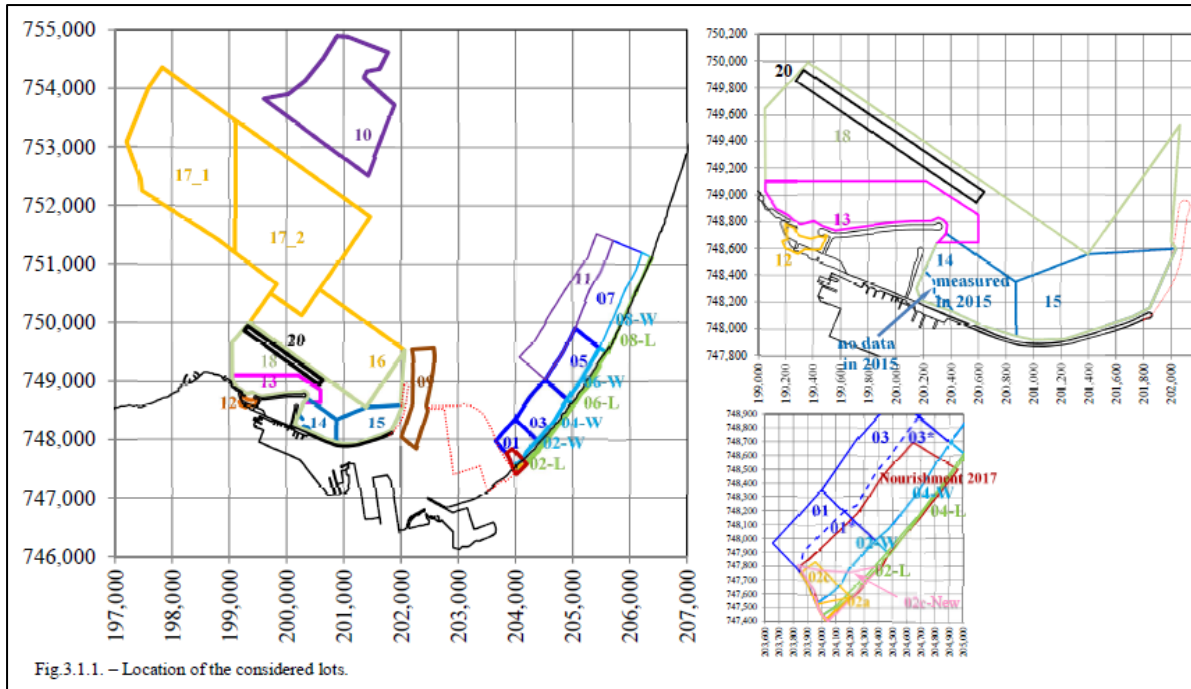
The Monitoring phase of sand nourishment yet started along the Haifa Bay beaches during the construction phases due to some erosion along the beaches northward to the lee breakwater, especially in front of rigid structures close to the shore line like long concrete fences, promenades, ramps, drainage outlets etc. Result of natural sand accretion northward to the Lee breakwater is shown in Figures 23 and 24. Artificial sand nourishment was carried out by TSHD pumping sand on the shore by means of floating pipe from the dredger and diffuser moved along the beach, following a predetermined nourishment plan. Borrow areas of sand of similar quality and gradation to that of Haifa Bay beaches were found opposite the old main breakwater in water depths of 10 to 16 m (Figure 26).



**Figure 23: Starting the construction of the new Lee Breakwater (June 2015)**



**Figure 24: Beach accretion northward to the Lee Breakwater (February 2017)**



**Figure 25: Haifa Bay and Bay Port - Location of the considered lots**

Analyses of bathymetric maps considered the changes occurred during summer and winter of years 2016, 2017 and partially 2018 and comparison of predetermined lots (i.e those lots that cover the borrow area and the dumping area). Volumes, active area and average depth changes in each lot were computed and analyzed thus obtaining sand accretion or erosion in each lot. Topographic and bathymetric surveys were executed along the coast using single-beam and multi-beam echo sounder.

The following sand nourishments campaigns were carried out, close to the shore line, until the end of 2017 in the following lots (Figure 25):

- April-May 2016                    70,870 m<sup>3</sup>    along lots 06-08
- September-October 2016    100,050 m<sup>3</sup>   along lot 06
- May-June 2017                    179,110 m<sup>3</sup>   along lots 05-06
- September-October 2017.    7,600 m<sup>3</sup>     along lots 05-06

Results obtained through comparison and analyses of differential maps indicate on sand accretion, as expected, close to the northern part of the Lee Breakwater under construction and some seasonal beach width improvement along the remainder shore where sand nourishment was carried out opposite the eroded sectors.(Figures 27 and 28).



**Figure 26: Trailer suction hopper dredger pumping sand ashore**





**Figure 27: Beach width in front of concrete fence before sand nourishment**



**Figure 28: Beach width in front of concrete fence after sand nourishment**

## **CONCLUSIONS**

The construction of Bay Port is not yet fully completed, but the following preliminary conclusions can be reached:

1. The sand from Haifa borrow area adjacent to the reclamation works was dredged in such a way to minimize the existing sea water quality and marine ecology following a predetermined strictly monitoring.
2. Positive results were achieved for reclamation works by both compaction methods i.e Vibrocompaction or Vibrostone columns although the fines content in the sand to be dredged for the reclamation fill sometimes reached 25%.
3. The foundation of Main Breakwater and Lee Breakwater (rubble mound) were treated by removing the liquefiable Dune sand layer and in such a way minimizing soil liquefaction during earthquake.
4. During the construction phases, sand nourishment along the Haifa Bay beaches lied northward to the Project together with continuous monitoring carried out by hydrographic, topographic mapping and aerial photos improved the width of limited previewed eroded sectors along the sea shore northward to the Project.

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