Analytical Model to Find the Best Location for Construction of New Commercial Harbors

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ABSTRACT

An analytical model to find the best location for construction of new commercial harbors is proposed. For this model a global formula is proposed. The transportation price, the distribution of population, capacity of the existing harbors and import/export cargo demand are the main parameters in the proposed formula. As a case study, the formula is applied to Iran. This case study shows that the location of Imam Khomeini Harbor is selected correctly. This is why that at the present time about 60% of the goods imported to Iran passes through this harbor. Applying this case study and a comparison of the results obtained from the proposed model shows a very good agreement between the results obtained from the application of the model and the actual situation of the harbors in Iran. The final location of the new harbor is determined by considering the local environmental conditions including the wind, waves, current, sedimentation conditions, and also by the distance from the quarry of stones and materials to the harbor. A computer program has been developed to find the best location to construct the new harbor and to simulate the wave characteristics and wave loads applied to rubble mound structures. Wave characteristics have been simulated by applying Bretschneider formulas and wave theories for deep waters and shallow waters. Wave characteristics are simulated numerically by considering mainly the fetch lengths, wind velocities and durations, difference between sea water and air temperatures, refraction, shoaling, seabed friction and different conditions of waves. An application of numerical simulation of wave characteristics is also presented.

Keywords: Numerical Simulation, Harbor, Best Location, Wave Characteristics

INTRODUCTION

Ports and harbors are important infrastructures that have big impacts on the economy level and industrial progress of a given country. Furthermore, harbors have very important roles in linking cities of a country to overseas harbors and to the import and export of goods in any country. Therefore, special attention should be directed to the planning and management of coastal zones and harbors.

Well organizing the planning phase of a new harbor construction and considering the transportation aspect in order to minimize the transportation time and fuel consumption, during the life of a harbor (about 75 years) is essential to the construction of new harbors.

This paper presents how the best location of a new harbor can be found by entering specific data into a computer program that can give guidance to coastal managers about developing coastal zones and harbors in the framework of a master plan of any country. The significant points presented in this paper are listed below:

- Proposing a new formulation to evaluate the best location to construct new commercial harbors considering the distribution of people, cities, cargo

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transportation, existing harbors capacities, and the amount of annual imported/exported goods.

- Describing a computer program to find the best location of new harbors and to calculate the waves and the layers of breakwaters to estimate the quantity of materials needed to construct a harbor's breakwaters.

Computer program

To find the best location of a new harbor, a computer program entitled Harbor Numerical Analysis Program "HaNAP" has been generated by the authors (Nouban, 2014). HaNAP has three main sub-programs: Harbor Location Finder (HaLoFin), Wave Simulation Computer Program (WSCP) and Material Rough Estimation (MRE). HaLoFin finds the best location for new harbors globally, and WSCP has been developed to simulate the wave characteristics and wave loads applied to breakwaters in order to tune up the location of the new harbor locally. MRE is applied to find the rough estimation of materials needed to use in the core, filter and armor layers of breakwaters.

Proposed Formulation To Evaluate The Best Location Globally

Coordinates Of Points

The formulation proposed by the authors is to find the best location of harbors globally. In the proposed formulation the distribution of people in the country and the followings are considered:

- The spherical coordinate system is used to find the distances between the harbor, cities and the overseas harbors in other countries.
- The coordinates (altitude, longitude and latitude) of all the required points are found from the Internet (e.g. by using the Google Earth Website or the like).
- The coordinates of the center of cities (or provinces) inside the country (i.e. the center of gravity of distribution of a population in a city (or province) or a consumption center) is chosen as (R_j, Θ_j, ϕ_j).
- The coordinates of different points examined as locations of the new harbor are taken as (R_i, Θ_i, ϕ_i).
- The coordinates of overseas harbors (the ship destination/departure points for export/import) are selected as (R_k, Θ_k, ϕ_k).
- The distance between harbor i and city j (D_{ij}) and also the distance of the harbor i and the overseas harbor k in other countries (D_{ik}) are calculated by using formulas given in in this paper and the coordinates extracted from the Google Earth or Google Maps websites or the like.

Distances Between Two Points Using Spherical Coordinates

To find the distance between the points on the surface of the Earth, the spherical coordinate system is adopted. The length of an element between two points i and j is written as follows:

Spherical coordinates are as follows:

$$x = R\ \sin\theta\ \cos\phi \qquad (1)$$

$$y = R\ \sin\theta\ \sin\phi \qquad (2)$$

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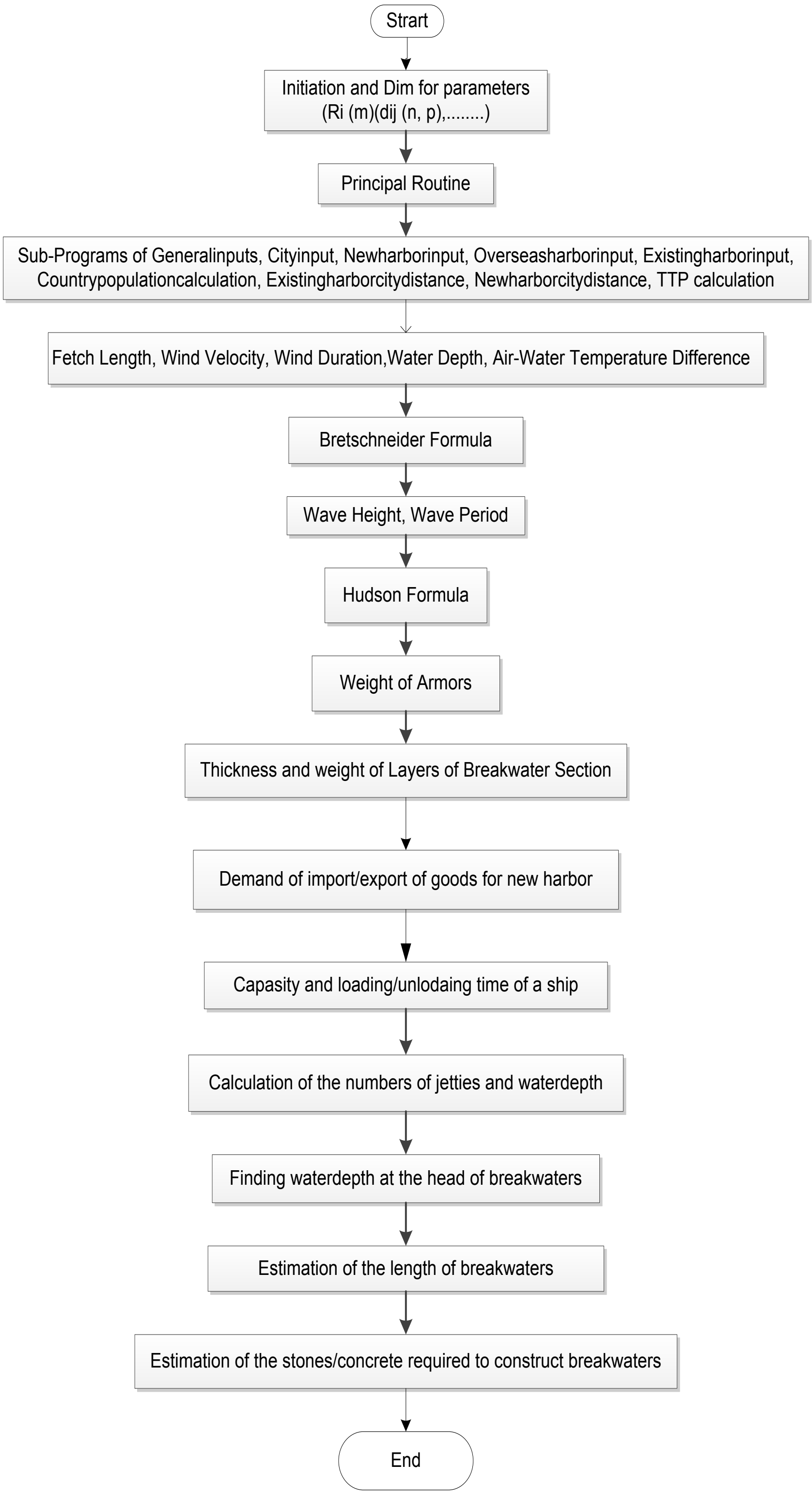

Fig. 1. Flow chart for main part of HaNAP

$$z = R \cos\theta \quad (3)$$

The orientation of this coordinate system is:

- The origin is at the Earth's center
- The x-axis passes through the prime Meridian (0° longitude)
- The xy-plane contains the Earth's equator
- The positive z-axis passes through the North Pole.

Note that the angle $(\frac{\pi}{2} - \theta)$ is the measure of latitude, and the angle ϕ is the measurement of longitude, where, $0 \leq \theta \leq \pi/2$ and $0 \leq \phi \leq 2\pi$. And $\theta > \pi/2$ that is for negative latittudes correspond to points in the Southern Hemisphere, and $\theta \leq \pi/2$ (i.e. positive latitudes) correspond to points in the Northern Hemisphere (Surowski, 1989).

It is typical for the radial distance R to vary from Ri to Rj, but since the values of (Rj-Ri) comparing the average radius of the Earth (R = 6,378 Km) - specially for the elevations of cities in a country - is less than 3/1000 and its square value is smaller than 1/1000000, the values of (Rj-Ri) may be neglected.

Two points $P_i(\Theta_i, \phi_i)$ and $P_j(\Theta_i, \phi_j)$ determined in spherical coordinates can be determined in the Cartesian coordinates of $P_i(x_i, y_i, z_i)$, $P_j(x_j, y_j, z_j)$. The Euclidian distance d between Pi and P_j is given by the three- dimensional Pythagorean Theorem:

$$d_{ij} = \left\{\left(x_j - x_i\right)^2 + \left(y_j - y_i\right)^2 + \left(z_j - z_i\right)^2\right\}^{1/2} \tag{4}$$

Converting the Cartesian coordinates to spherical coordinates, gives:

$$d_{ij} = R\{2 - 2sin\theta_i sin\theta_j \cos(\phi_i - \phi_j) - 2cos\theta_i cos\theta_j\}^{1/2} \tag{5}$$

The distance D_{ij} between Pi and Pj along the surface of the Earth (i.e. the arc length along the indicated sector) can be found as follows (Surowski, 1989):

$$\sin\left(\frac{\alpha}{2}\right) = \frac{d_{ij}}{2R} \tag{6}$$

Where α represents the angle between the lines joining points i and j to the center of the Earth. Since:

$$\sin(\alpha) = 2\sin\left(\frac{\alpha}{2}\right)\cos\left(\frac{\alpha}{2}\right) = \left(\frac{d_{ij}}{R}\right)\left[1 - \left(\frac{d_{ij}}{2R}\right)^2\right]^{1/2} = \left(\frac{d_{ij}}{2R^2}\right)\left[4R^2 - {d_{ij}}^2\right]^{1/2} \tag{7}$$

Therefore:

$$D_{ij} = R\alpha = R\, sin^{-1}\left[\frac{d}{2R^2}\left(4R^2 - {d_{ij}}^2\right)^{1/2}\right] \tag{8}$$

All these formulas are for the calculations on the basis of a spherical Earth (ignoring ellipsoidal effects) which are accurate enough for most purposes. [In fact the Earth is very slightly ellipsoidal; using a spherical model gives errors typically up to 0.3%]

In order to consider the effect of the difference between elevation R_i and R_j (R_j-R_i), the authors propose to use the value of R average (R_{ave}) instead of R, therefore:

$$d_{ij} = R_{ave}\{2 - 2sin\theta_i sin\theta_j \cos(\phi_i - \phi_j) - 2cos\theta_i cos\theta_j\}^{1/2} \tag{9}$$

The distance D_{ij} between Pi and Pj along the surface of the Earth (the arc length) is:

$$D_{ij} = R_{ave}\, sin^{-1}\left[\frac{d_{ij}}{2R_{ave}^2}\left(4R_{ave}^2 - {d_{ij}}^2\right)^{1/2}\right] \tag{10}$$

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With:

$$R_{ave} = \frac{R_i + R_j}{2} \quad (11)$$

Where:

R_i represents the distance between points i and the center of the Earth,

R_j represents the distance between point j and the center of the Earth,

θ_i represents the angle between the line joining point i to the center of the Earth and Z axis passing the Earth's poles. The latitudes of point i (λ_i) equals ($\pi/2 - \theta_i$),

θ_j represents the angle between the line joining point j to the center of the Earth and Z axis passing the Earth's poles. The latitudes of point i (λ_j) equals ($\pi/2 - \theta_j$),

ϕ_i represents the longitude of points i,

ϕ_j represents the longitude of point j (Nouban, 2014).

The distance D_{ij} between the local harbor i and consumption center j in the country (city) is calculated by using Eqs. (10), (9) and (11). The distance D_{ik} between local harbor i and overseas harbor k is found by substituting subscripts j with subscripts k in Eqs. (10), (9) and (11).

Total Transportation Price Index Formula

The Total Transportation Price Index (TTPI) per year for the new harbor that is supposed to be constructed at point Pi (new demand) is submitted below. The roads, seaways and air transportation and also the capacity of existing harbors are considered in TTPI calculations. Since the real lengths of the roadways, railways and seaways between two points on the Earth are more than the minimum mathematical distance between these two points, a distance factor is introduced to approach the real lengths.

The following proposed formula is to be minimized to find the best location of a new harbor at position $P_i(R_i, \Theta_i, \phi_i)$:

$$TTPI_i = \sum_{j=1}^{j=n}(n_j w_j)\sum_{j=1}^{j=n}(P_{Road}K_{Dij}\,D_{ij}) + \sum_{j=1}^{j=n}(n_j w_j)\,\sum_{k=1}^{k=p}(P_{Seaway}K_{Dik}\,D_{ik}) - \sum_{l=1}^{l=q}(W_l) - W_O \quad (12)$$

With:

$$K_{Dij} = \frac{L_{ij}}{D_{ij}} \quad (13)$$

$$K_{Dik} = \frac{L_{ik}}{D_{ik}} \quad (14)$$

Where:

$TTPI_i$ represents total transportation price per year for new harbor that is supposed to be constructed at point Pi (new demand),

i represents a number for a location to be examined to build a new harbor,

j represents the number of cities in the country,

k represents the number of overseas harbors (export/import destinations),

l represents the number of existing harbors,

n represents the total number of cities in the country,

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p represents the total number of overseas harbors (export/import destinations),

q represents total number of existing harbors,

n_j represents the population number of city j,

w_j represents the weight of consumption for one person per year (in tons),

P_{road} represents the transportation price per ton per km for the roads (in USD/ton /km),

P_{Seaway} represents the transportation price per ton per km for the seaways (in USD/ton /km),

D_{ij} represents the distance between harbor i and city j along the surface of the Earth (see Eq. (10)),

D_{ik} represents the distance between harbor i and overseas harbor k along the surface of the Earth.

K_{Dij} represents the distance factor between harbor i and city j,

K_{Dik} represents the distance factor between harbor i and city k,

W_l represents the capacity of existing harbor number l,

W_O represents the total weight of goods import/export via airports or land border gates.

L_{ij} represents the real roadway length between harbor i and city j,

L_{ik} represents the real seaway length between harbor i and overseas harbor k. (Nouban, 2014)

The distance factor K_{Dij} is a factor greater than one and smaller than 2.5. Its average value is normally between 1.25 and 1.75.

The required capacity of a new harbor equals the total demand for the country minus the amounts transported from other harbors, airports and land gates.

By changing the location of a new harbor, we find different values for $TTPI_i$ while i vary between 1 and m (the number of tested locations on the coastline of a country). A minimum value of $TTPI_i$ indicates the best location for the construction of a harbor.

Since the real distance between the harbor and the cities should be calculated from the trajectory of the roads, railways or waterways, for more accuracy, several coordinates of points on the trajectories may be selected and the summation of distances gives the distance between a city and the harbor or between the local harbor and overseas harbor. When enough accurate information from the real roadway, real railway and the real seaway lengths (L_{ij} and L_{ik}) are available, these values may directly be used in the following equation:

$$TTPI_i = \sum_{j=1}^{j=n} n_j\, w_j \sum_{j=1}^{j=n} P_{Road} L_{ij} + \sum_{j=1}^{j=n} n_j\, w_j \sum_{k=1}^{k=p} P_{Seaway} L_{ik} - \sum_{l=1}^{l=q} W_l - W_O \quad (15)$$

Since to find the minimum value for TTP, a comparative method is used, in most cases, using the real lengths or using the mathematical distances along with the distance factors give similar results to the found location for the new harbor.

Calculation of WAVE to FIND the best location locally

Assumptions and steps

The numerical simulation is performed based on recorded environmental data, the

Bretschneider formulation, different wave theories and the Rayleigh distribution (Sadeghi, 2001) for the prediction of wave characteristics.

Bretschneider formulas were selected in this study because in the Bretschneider formula, the important parameter of difference between seawater and air temperatures is considered.

Since there is insufficient available wave characteristics data for some parts of the Mediterranean Sea to evaluate the sensitive operations such as installations of marine and offshore structures, a simulation of wave characteristics was carried out as a case study. The zone considered in the case study is located between Turkey and North Cyprus waters.

Wave characteristics in shallow waters have been simulated by applying the Solitary wave theory for the case study.

In the numerical simulation the followings are applied:

- Sea water temperature, wind velocity, direction of wind, wind duration, air temperature and fetch lengths are used in the numerical simulation as main parameters.
- Wave theories and formulas.
- In this study the Rayleigh ratio for H_{max}/H_s is used (i.e. $H_{max}/H_s = 1.85$) (Sadeghi, 2001).
- Significant wave height, significant wave period and Peak Period are calculated based on the Bretschneider formulation that considers the difference of air and seawater temperatures.
- To find the validity of wave theories in different water depths and for various environmental conditions, the graph presented by Le Mehaute is used (Sadeghi, 1989).
- To calculate the hydrodynamic force applied on the circular sections of piled structures, the Morison formula is used (U.S. Army Coastal Engineering Research Center, 1980).
- To calculate the armor layers of breakwaters, the Hudson formula (US Army Corps of Engineers, 2002 and OCDI, 2002) is used.

Formulas Used in HaNAP

Wave generation mechanisms and its effective factors, sea state, wave height and period distributions, progress procedures of waves toward shoreline, wave prediction methods for shallow and deep waters are implemented in the numerical simulation.

The Bretschneider equations are used in the simulation to predict wave height (H) and wave period (T) in constant water depth (d) conditions for different durations of wind (t) and fetch length (F) are as follows (Sadeghi, 2008, 2007, 2007, 2013):

$$U_A = 0.71 U^{1.23} \quad \text{(U in m/s)} \qquad (16)$$

$$U = R_T \cdot U_{(10)} \qquad (17)$$

$$\frac{gH}{U_A^2} = 0.283\tanh\left[0.530\left[\frac{gd}{U_A^2}\right]^{\frac{3}{4}}\right]\tanh\left\{\frac{0.00565\left[\frac{gF}{U_A^2}\right]^{\frac{1}{2}}}{\tanh\left[0.530\left[\frac{gd}{U_A^2}\right]^{\frac{3}{4}}\right]}\right\} \quad (18)$$

$$\frac{gT}{U_A} = 7.54\tanh\left[0.833\left[\frac{gd}{U_A^2}\right]^{\frac{3}{8}}\right]\tanh\left\{\frac{0.0379\left[\frac{gF}{U_A^2}\right]^{\frac{1}{3}}}{\tanh\left[0.833\left[\frac{gd}{U_A^2}\right]^{\frac{3}{8}}\right]}\right\} \quad (19)$$

$$\frac{gt}{U_A} = 5.37\times10^{2}\left[\frac{gT}{U_A}\right]^{\frac{7}{3}} \quad (20)$$

Where: U represents wind speed, d represents waterdepth and R_T represents the Stability Factor (defined by Resio and Vincent, which allows consideration for the difference of air and sea temperatures).

The Bretschneider equations used for the prediction of spectral wave height (H_{m0}), peak spectral period (T_m) in time duration of wind (t) for a limited fetch length (F) in deep water conditions are as follows:

$$\frac{gH_{m0}}{U_A^2} = 1.6\times10^{-3}\left[\frac{gF}{U_A^2}\right]^{\frac{1}{2}} \quad (21)$$

$$\frac{gT_m}{U_A} = 2.857\times10^{-1}\left[\frac{gF}{U_A^2}\right]^{\frac{1}{3}} \quad (22)$$

$$\frac{gt}{U_A} = 6.88\times10\left[\frac{gF}{U_A^2}\right]^{\frac{2}{3}} \quad (23)$$

In fully developed wave cases, the following equations are used:

$$\frac{gH_{m0}}{U_A^2} = 2.433\times10^{-1} \quad (24)$$

$$\frac{gT_m}{U_A} = 8.134 \quad (25)$$

$$\frac{gt}{U_A} = 7.15\text{x}10^4 \tag{26}$$

The effects of sea bottom on the wave characteristics such as refraction, shoaling and wave breaking conditions are also considered in the simulation in HaNAP.

Equations of Airy, Stockes' (second and fifth orders), Stream Function, Cnoidal, Solitary and Trochoidal wave theories are used in the simulation.

APPLICATIONS

Evaluation of The Best Location of Harbors Globally for Case Study 1 (Iran)

Some Data Inputs

Some data inputs to apply to the proposed formulation for finding the best location of harbors globally for case study no. 1 (Iran) are submitted below. Table 1shows the input data of Iran provinces (National Geoscience Database of Iran, 2014; National Weather Service, 2014; Latitude and Longitude, 2014).

Table 2 presents the coordinates and capacities of the important Iran harbors in Persian Gulf Coasts (PMO, 2014; PMO, 1995; PMO, 1974; Distances From, 2014).

Table 1(Part-I). Altitudes, Longitudes and Latitudes of provinces of Iran

Item	Name of State	Population	Altitude (km)	Longitude (°)	Latitude (°)
1	Tehran	12,183,391	1.189	51.0000° E	35.1667° N
2	Alborz	2,412513	1.430	50.5800°E	35.4800°N
3	Khorasan Razavi	5,994,402	0.985	59.6057°E	36.2980°N
4	Isfahan	4,879,312	1.590	51.6692°E	32.6577°N
5	Fars	4,596,685	1.484	52.5333°E	29.6167°N
6	Khuzestan	4,531,720	0.017	48.6940°E	31.3273°N
7	East Azarbaijan	3,724,620	1.351	46.2800°E	38.0766°N
8	West Azarbaijan	3,080,576	1.330	45.0759°E	37.5528°N
9	Mazandaran	3,073,943	0.076	53.0588°E	36.5656°N
10	Kerman	2,938,988	1.755	57.0679°E	30.2907°N
11	Gilan	2,480,874	0.007	49.5890°E	37.2774°N
12	Sistan and Baluchistan	2,534,327	1.352	60.8669°E	29.4924°N
13	Kermanshah	1,945,227	1.371	47.0869°E	34.3176°N
14	Lorestan	1,754,243	1.183	48.3538°E	33.4871°N
15	Hamadan	1,758,268	1.813	48.5146°E	34.7982°N
16	Golestan	1,777,014	0.144	54.4444°E	36.8393°N
17	Kurdistan	1,493,645	1.537	46.9960°E	35.3113°N
18	Hormozgan	1,578,183	0.008	56.2667°E	27.1833°N

Table 1(Part-II). Altitudes, Longitudes and Latitudes of provinces of Iran

Item	Name of State	Population	Altitude (km)	Longitude (°)	Latitude (°)
19	Markazi	1,413,959	0.174	49.6909°E	34.0954°N
20	Ardabil	1,248,488	1.2250	48.2973°E	38.2514°N
21	Qazvin	1,201,565	1.299	50.0029°E	36.2693°N
22	Qom	1,151,672	0.934	50.8798°E	34.6456°N
23	Yazd	1,074,428	1.215	54.3570°E	31.8948°N
24	Zanjan	1,015,734	1.646	48.4845°E	36.6751°N
25	Bushehr	1,032,949	0.007	50.8382°E	28.9184°N
26	Chahar Mahaal and Bakhtiari	895,263	1.250	50.8546°E	32.3275°N
27	North Khorasan	867,727	0.940	57.3317°E	37.4761°N
28	Kohgiluyeh and Boyer	658,629	1.165	51.6000°E	30.6700°N
29	Ahmad	622,534	1.473	59.2164°E	32.8653°N
30	South Khorasan	631,218	1.132	53.3953°E	35.5769°N
31	Semnān Ilam	545,093	1.404	46.42278	33.6367°N

Table 2. Characteristics of Iran harbors in Persian Gulf Coasts

Item	Name of port	Altitude (m)	Longitude (°)	Latitude (°)	Harbor capacity/year (Ton)
1	Khorramshahr	4	48.2269563	30.3641484	3,500,000
2	Abadan,	4	48.9899790	30.5769211	4,000,000
3	Imam Khomeini	5	49.1055556	30.4355556	50,000,000
4	Bushehr	5	50.8333333	28.9666667	20,000,000
5	Asaluyeh	4	52.6166667	27.4666667	18,000,000
6	Lengeh	4	54.8805556	26.5580556	840,000
7	Shahid Bahonar	4	56.2091237	27.1520753	10,000,000
8	Shahid Rajaey	4	56.2666667	27.1833333	70,000,000
9	Chahbahar	4	60.6300000	25.2866667	15,000,000

Cost of logistics

Truck transport in Iran is the cheapest in the world (2 cents per ton/Km); railroad transportation costs are equally low but not cheaper than road, which is exceptional.

Shipping rates to Iran ports are not excessive. This, results from a combination of factors: fast growing traffic volumes (especially for containers) which makes the port develop as a quasi-hub connected to major destinations and aggressive pricing by national shipping lines (World Bank, 2000).

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Sources are not fully consistent, but it seems that rates in Iran ports are now close to that of Dubai. Export rates are much cheaper (50%) than imports rates. Also the shipping costs with Asia are much lower than with Europe. For example, typical freight rates for Bandar Abbas (40' container: 26780 Kgs) are given in Table 3. The seaway distances are extracted from Internet (Sea-Distance, 2014)

Table 3. Typical freight rates for Bandar Abbas for 40' container

	Export freight rates (USD)	Export freight rates (USD/ton/km)	Import freight rates (USD/ton/km)
Dubai	350	0.0561	0.1122
Shanghai	520	0.0018	0.0035
Kobe	580	0.0020	0.0039
Singapore	600	0.0036	0.0072
Jakarta	650	0.0036	0.0072
Rotterdam	1750	0.0508	0.0116
Gothenburg	2000	0.0123	0.0062

Shipping a container from Bandar Abbas to Tehran costs typically 750 USD. Half price on the export direction.

Obtained results

To examine the validity of the proposed analytical model - to find the best location of new harbors globally - , first, the locations of the existing harbors in Iranian coastlines in Persian Gulf (9 existing important harbors as listed in Table 1) were examined as case study no. 1.

Fig. 2 shows the distance factor K_D and its average value for Imam Khomeini Port versus 31 states of Iran (as listed in Table 1).

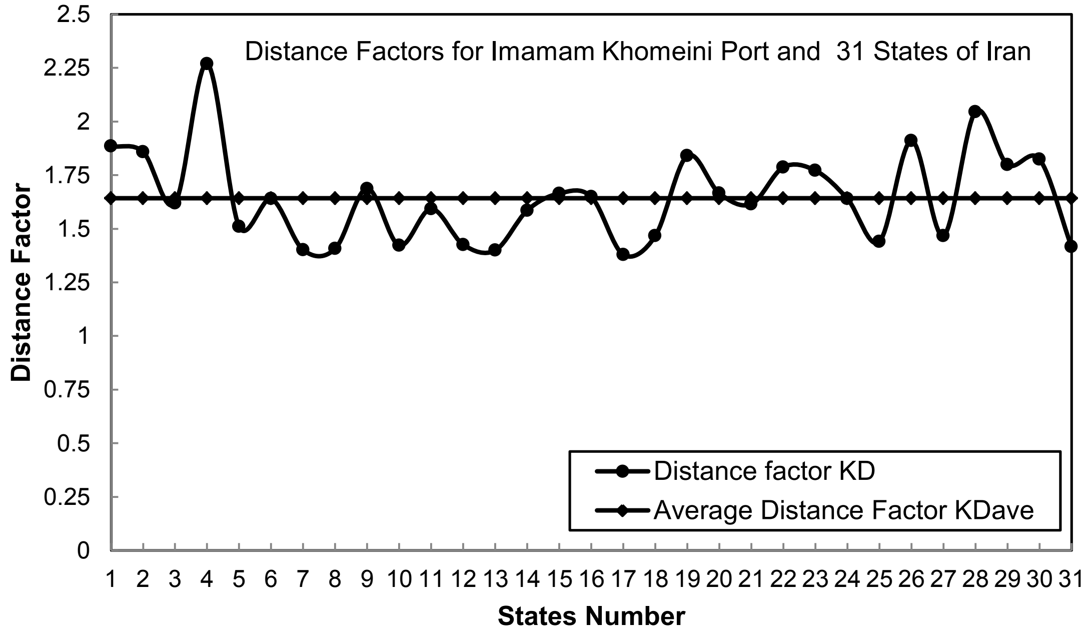

Fig. 2. Distance factor K_D from different provinces of Iran for Imam Khomeini Port

As Fig. 2 shows the average value of distance factor is about 1.64 when the roads connecting Imam Khomeini Port (port no. 3) to the centers of 31 states of Iran are considered. According to the performed calculations using HaNAP, the average distance factors for Chahbahar Port, Shahid Rajaey Port, Bushehr Port are 1.37, 1.37 and1.52, respectively. A comparison of these average distance factors shows that the roads connecting the Chahbahar Port and Shahid Rajaey Port to the consumption centers of Iran are shorter than those compared to the Imam Khomeini Port and Bushehr Port. Therefore considering the population distribution, the roads connecting the Imam Khomeini Port and Bushehr Port should be improved and should be shortened.

Fig. 3 shows Transportation Price indices versus port numbers (as listed in Table 2).

As Fig. 3 indicates the best location (minimum Total Transportation Price Index "TTPI") is found for the Imam Khomeini Port (port no. 3). The obtained result has a very good agreement with the harbor actually selected by the merchants and trade centers. In reality, about 60% of goods are imported/exported to/from the Imam Khomeini harbor. Port no. 2 (Abadan Port) due to other factors such as being located along the Arvand Rood River and due to the limitation of its jetties capacities, it is not the most popular selection.

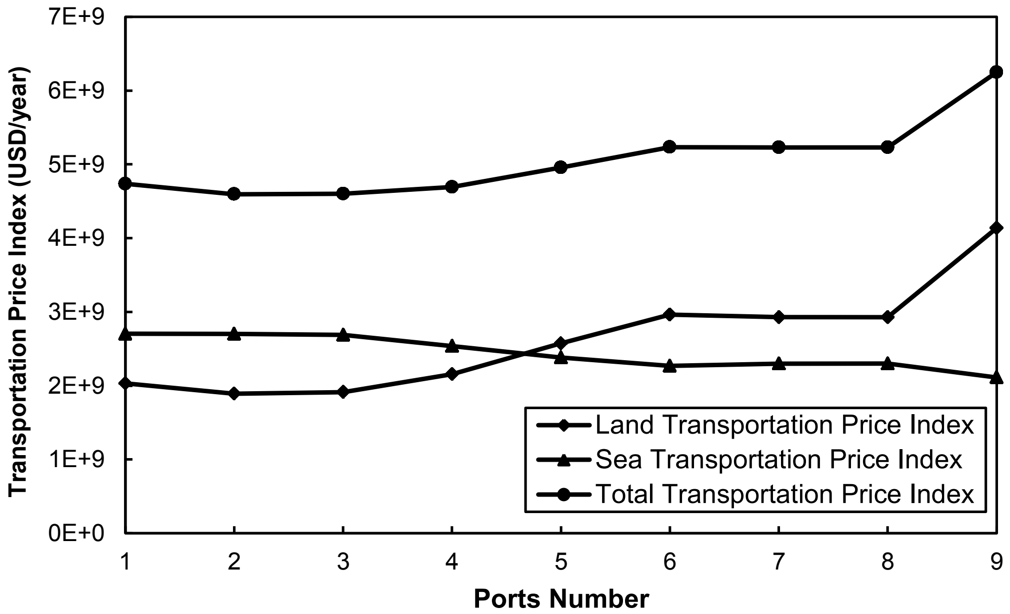

Fig. 3. Transportation price indices for different ports of Iran in the Persian Gulf

Application of wave simulation for case study no. 2

In the case study no. 2 performed for the Mediterranean Sea waters (near Lapta in North Cyprus), the numerical simulation shows that the Solitary wave theory fits the wave theory suitable for the studied nearshore zones.

Environmental Data

General environmental data used in the numerical simulation for the location of case study no. 2 for the waterdepths between zero and 5.2 meters with a return period of 25 years extracted from the "British Admiralty Booklet" (British Admiralty, 2008) is given below:

- HHWL-LLWL: 37.3 cm
- Sea water density: 1028-1036 kgf/m^3
- Wind directions: 71% from WNW, 24% from NE and 5% variable

- Wind Force: max 67 km/hours at the region
- Wind Duration: max 4 days
- Wind Period: 5 times a year (high wind) over 45 km/h
- Surface Currents: mostly west to east (95%) 2.2 knots max
- Deep Currents: mostly west to east (87%) 1.9 knots max
- Seawater Temperature: Min. 16.3º C and max. 29.7º C
- Air Temperature: min +1 Cº and max +46 Cº
- Wave Period of about 4.5 seconds for shallow water.

Simulated Values

Some examples of outputs from the wave characteristics calculations in shallow waters for the location of case study no. 2 for the rubble mound structures carried out by HaNAP are submitted below.

Figure 4 presents the comparison between the calculated significant wave height (H_s or $H_{33\%}$) and breaking wave height (H_b) versus the waterdepth for wind directions from the North (zero degree angle). To calculate the significant wave height in shallow water, the deepwater significant wave height (H_{s0}) and shoaling K_s with refraction factor (K_r) equal to 1 are considered. Since the maximum wave height is breaking wave height, as shown in the figure, breaking wave governs the other phenomena in the estimation of the wave height.

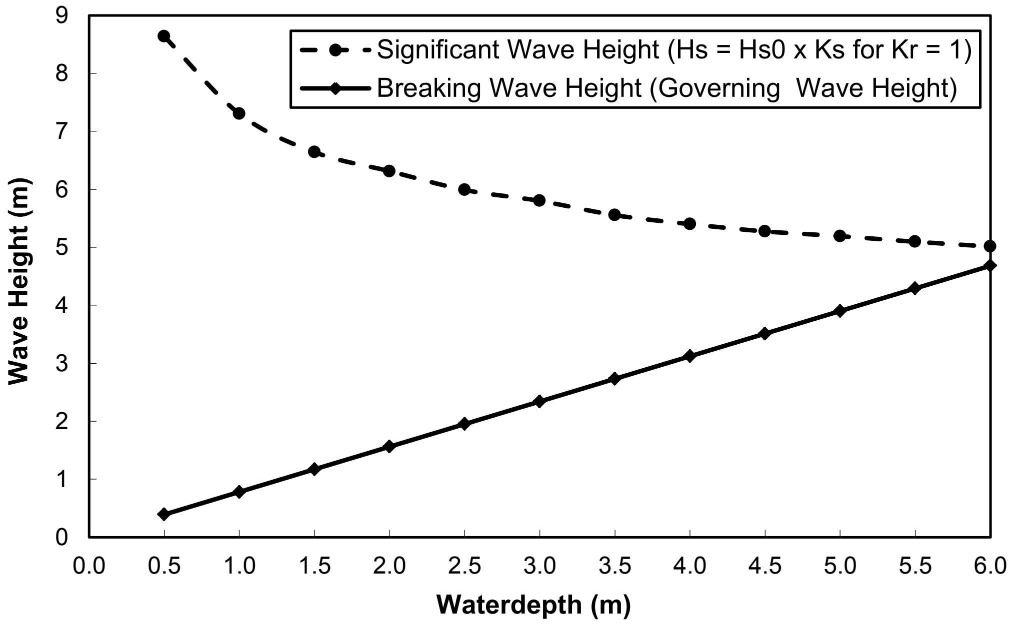

Fig. 4. Wave heights for wind from North (zero degree)

The calculations show that the wave height in the direction of +15º is maxim compared to other directions.

Fig. 5 shows the weight of armor (quarry stone and concrete Dolos) units needed to be used for the construction of rubble mound structures (breakwaters) in the zone of case study no. 2 (Lapta coasts in North Cyprus).

Comparing the weights of different types of armor units indicates that using Dolos armors reduces considerably the armor weights and facilitates the placement procedure especially for waterdepths of more than 4 meters.

In general, there is a good agreement between simulated and observed results.

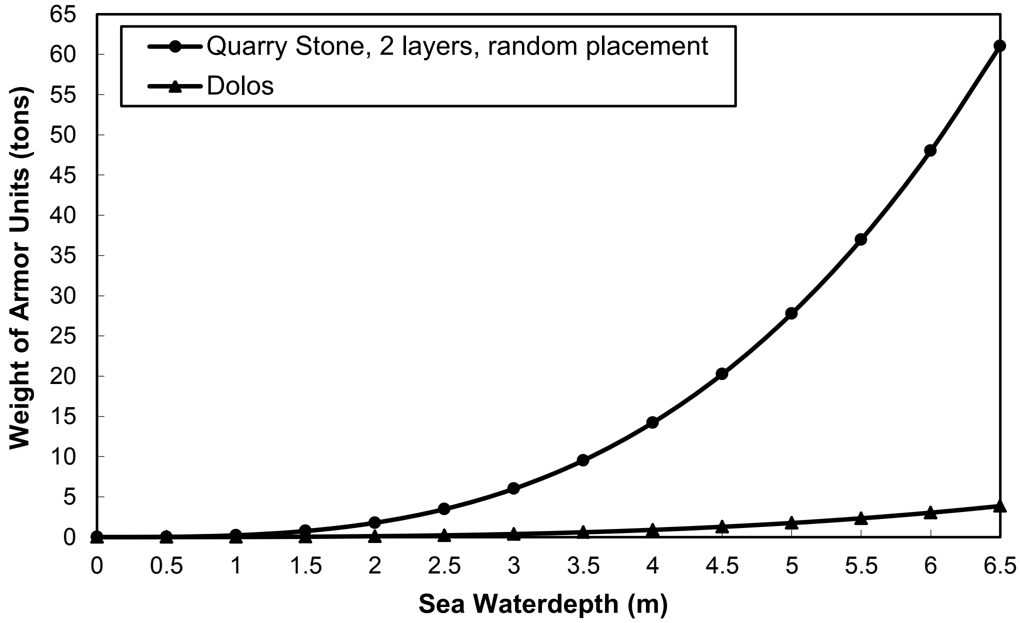

Fig. 5. Weight of quarry stone armor units versus waterdepth

CONCLUSION

The analysis performed by applying the proposed formulas and the computer program designed (HaNAP) indicates that the best location for a new harbor is found at Imam Khomeini Port in Iran (case study no. 1). The obtained result has a very good agreement with the harbor actually selected by the merchants and trade centers. In reality, about 60% of goods are imported/exported to/from the Imam Khomeini harbor.

Wave characteristics simulated by applying the designed computer program (HaNAP) indicate that the Solitary wave theory for shallow waters fits the environmental conditions and the bathymetry of North Cyprus nearshore zones close to Lapta (case study no. 2). Applications of the proposed numerical simulation of wave characteristics in deep waters and shallow waters of the Mediterranean Sea in North Cyprus show that there is a good agreement between simulated and observed results. Using the newly developed computer program (HaNAP) to simulate numerically the wave characteristics and wave loads applied to rubble mound structures is suitable to use for the preliminary designs and rough estimation purposes in future project proposals.

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