Scientific Journals
Maritime University of Szczecin

Zeszyty Naukowe
Akademia Morska w Szczecinie

2012, 32(104) z. 2 pp. 41–47

2012, 32(104) z. 2 s. 41–47

Integrated dynamic UKC assessment system for Polish ports

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Key words: dynamic UKC, mobile communication system, navigation safety

Abstract
In this article an integrated system for dynamic under keel clearance (UKC) assessment is presented. The system was created to improved navigation safety and economic effectiveness in Polish ports. In this paper principle of model operations and utilization with modern, available mobile devices in integration with wireless data transmission technology was introduced.

Introduction

Navigation on restricted areas is connecting with ship's hull touching the bottom. Under keel clearance of a ship is the main factor which determines safety of navigation and maintaining the proper, safe under keel clearance is the basic task for navigator. Up to this time general method for safe under keel clearance determination for ships which enter Polish ports was method of constant clearances. It consists in determination under keel clearance as a sum of several components, which are calculate too general. This method is characterized by relatively big predetermined margin of error assessment, which during some conditions could exert an influence for too protective decisions. In this situations additional costs of ship's waiting for road are generated, and could be steer clear of them without unnecessary risk.

As an alternative, developed in Maritime University of Szczecin, probabilistic model for under keel clearance assessment was proposed [1]. This model can be useful at practical decision problems of Captain of harbor work during big draught vessels entering. In this situations, both caused potential profits / losses and possibility safety operation assurance should be taken into account [2].

Most often making decision according to entrance big draught vessel occurred on the basis of analysis of maximal dimensions and draught of particular ship with reference to actual port regulations.

Integrated system UKC assessment

Integrated UKC model is based on dynamic UKC assessment system and decision model, which will cause decision making according to port entrance simplify. UKC model was implemented on computer platform and is available via Internet. This type of application enables transfer data to pilot by using GPRS-UMTS technology, or optionally WiMAX. Integrated system for dynamic under keel clearance assessment takes into account:

- differential vessel type (bulk carriers, container vessel, product tanker, chemical tanker, gas carrier, e. c.);
- actual hydro-meteorological conditions (automatic download water level data, wave height introduce by user);
- actual bathymetry of port entrance (for each port there are different model of bathymetry with additional parameters which are important for squat).

For user-friendly application, interface of model was created, which is presented in figure 1.

Mobile communication system

The mobile communication segment in dynamic under keel clearance assessment system allows remote use of the DUKC model by an officer on the ship via available mobile devices. Those devices can be e.g.: mobile phone, PDA, smartphone, tablet, notebook, netbook, or the ordinary desktop computer with access to a wireless network.

Fig. 1. Main page of interface and page for data introduce and choosing water area

Marine segment

The system is based on wireless data transmission technology using contemporary techniques of radio communication available on the Polish telecommunications market. Depending on the user's access point and the type of mobile device (the software), among other types, the following technologies are used:

– GPRS/EDGE;
– UMTS (HSPA) / CDMA2000;
– WiFi / Wi-Max / HiperLAN.

Wireless communication is used within the ship – land communication. The rest of the data from the operator's server of wireless transfer of information to the server at the Maritime University of Szczecin is wired with DSL technology.

On-land segment

The main system component of the mobile access to DUKC server is located in the main building of the Maritime Academy in Szczecin. The server has been implemented with UKC application, that allows calculations and reply the information which are needed by a navigator, during approach to the port (Fig. 2).

The server is a computer physically connected to an external internet network, characterized by high computational power, enabling the use of the applications implemented on it.

In order to establish external communication with the wireless operator's server is necessary to use dedicated software.

In described mobile system it is Apache HTTP Server. HTTP Server is the software that provides previously created applications based on standard of the mobile device which are used. Communication is bi-directional, i.e. the transmitted data packets are incoming (INPUT DATA) and outgoing (RESULTS), consistent with the HTTP protocol.

The system is dedicated to mobile devices, using different types of so-called internet browsers. From a technical point of view, they differ in display capabilities of information sent to them.

Mobile DUKC has been developed for devices using two mobile protocols WAP 1.0, WAP 2.0 and a standard WWW / HTML.

The assumption of mobile DUKC is intended as a navigation-aid tool to assist the navigator in terms of the available depth of the area at the entrance to the port, or passing through the seaway. The principle of operation is to return relevant navigation information (RESULTS) based on the incoming basic vessel's parameters (INPUT DATA) (Fig. 3).

Once the ship is in range of the wireless network, navigator has the ability to connect to the DUKC server, based on Debian GNU / Linux, thereby obtaining remote access to the DUKC mobile system. By combining the appropriate network address, the input data template appears on the screen of his mobile device, by which, the officer sets significant parameters of his unit. The form of presentation of input template depends on the software installed on the mobile device. At this point, a header type of the browser is identified and the automatic selection of the appropriate protocol is done. For proper operation of the application, the following data is required:

– Length overall;
– Breadth;
– Draught;
– Speed;
– Vessel's Type;
– Destination.

Input data entered into the system are given remotely on the input block of DUKC model. On their basis, in a calculation block the feedback alphanumeric values are generated and given on the mobile device's screen. They contain the following information:

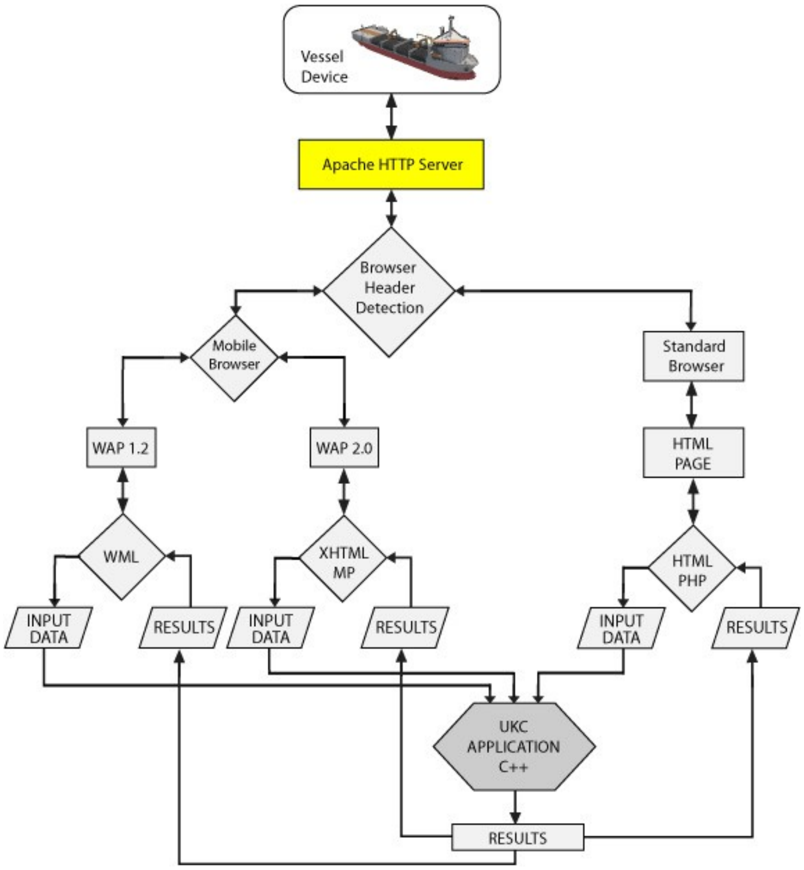

Fig. 2. Flow chart of communication system for dynamic UKC mathematical model

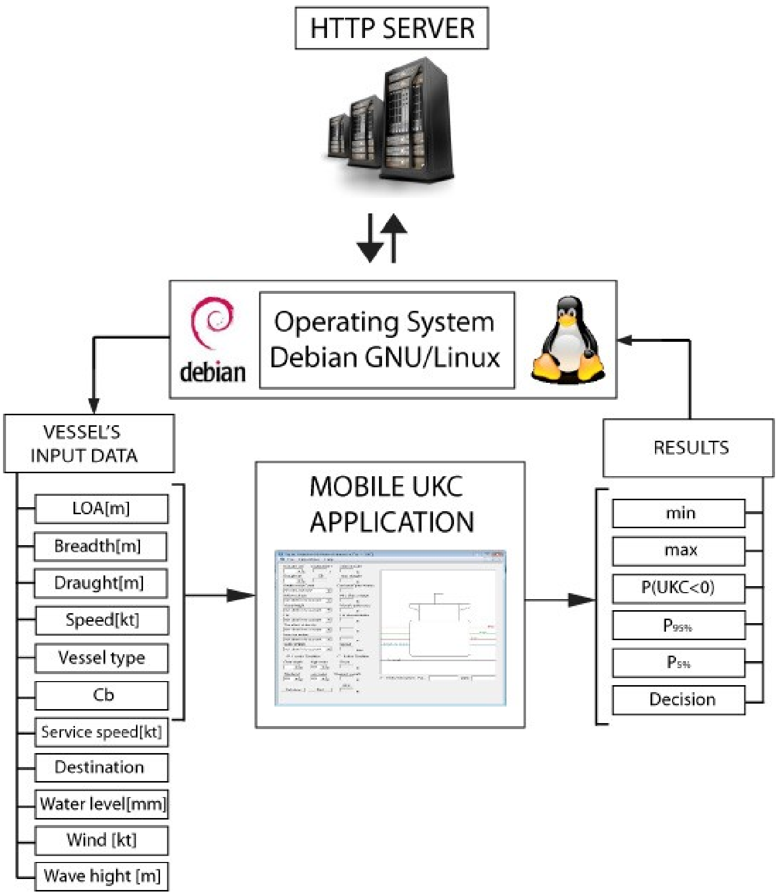

Fig. 3. Algorithm of mobile UKC application

- Water level;
- Squat;
- P(UKC < 0) – probability, that the UKC value will be less than 0;
- P95% – probability at 95% confidence level that UKC < 0;
- P5% – probability at 5% confidence level that UKC < 0;
- Max draught.

In the assumptions, the layout designed for mobile devices using a mobile access to the DUKC is limited to a minimum. The aim is to increase application availability for older devices, maximizing the speed of the program, and to minimize costs of data transfer. If the HTTP header will recognize the standard (not mobile) web browser, the application redirects the connection to the DUKC in the full version.

Installed system

Installed operating system on server is Debian GNU/Linux. Distribution is maintained in stable version, which is updated once a month. System kernel is in version 2.6.26. Server is used also as www server, therefore, apache server with php5 module is installed.

Main database server is PostgreSQL in version 8.3. With this database system one can create databases with unlimited size (limitation is only in available disk space). Maximum size of one table is limited to 32 TB, one row to 1.6 TB, and one field to 1 GB. There is no limitation in number of rows and indexes in table. Maximum number of columns is in range between 250 and 1600, which depends on column type.

For PostgreSQL there is plenty of available interfaces for programmers, like C/C++, Java, .Net, Perl, Python, Ruby, Tcl, ODBC and others libraries. For connection to database in presented application pqxx library in version 2.6.9 from standard distribution repository is used. With this library application can execute SQL statements directly on server.

MySQL server in version 5.0.51a is installed as a secondary database system. It is used for managing users passwords.

Database access

Due to the fact, that www service is available on server, administration tools like phppgadmin and phpmyadmin are installed. With these tools remote connection and database managing is possible. In internal University network PostgreSQL database is available on port 5432, from the outside connection is restricted for security reasons.

In dataset system there for better data handling were created following tables:

- Ship's types table – it contains for each ship with specific type and length over all information about parameters such as length between perpendiculars, hull coefficient of form, breadth, service speed and waving influence.
- Water level table – it contains information about water level for given localization and time.
- Squat table – it contains information for each localization about parameters such as name of method, method symbol, delta, standard deviation and calculation weight.
- Depth table – it contains information about depths in each localization.
- Conversion table – due to the fact that data in squat table are common for some ports conversion table was created.
- Password table – it contains password for used with authorization to use application.

Tables are mostly manually updated. This is caused by integration issues and data specification. Only water level table is automatically updated from website. To provide this update bash script was created.

Applications of probabilistic models components in the system – example

There are a number of factors which during operation of the waterways have an impact on the under keel clearance. These factors are on the both side: the area and ships.

Depth of waterways is a major parameter influencing vessels under keel clearance. The nautical publications such as pilots, port guides, maps, etc. usually give the technical depth and width of individual areas which should be ensured through actions of responsible maritime administration.

From the ship side draft is primarily affected on under keel clearance. Draught of the vessel is constant only for a moored ship unless the cargo or ballast operations are carried out. In the case of a ship in motion we are dealing with dynamic changes in the draught, which is the result of:

- longitudinal movement of the vessel- hydrodynamic force creates on the hull which causes the increase of draft and trim change (subsidence);
- roll of the ship; roll may be caused by a ship rocking on the wave, wind pressure on the lateral surfaces of ship or course alters.

Water area sedimentation model

Model is based on the determination of the depths of the waterway sections. Studied fairway has a trapezoidal cross-section. Measured points and determined fairway axis (designated and received from the maritime office) are as a input data. Following stages can be distinguished:

- The division of the waterway into sections. Due to the varied nature of the Szczecin-Świnoujście fairway appropriate sections were distinguished: the Port of Świnoujście, Piastowski Canal, Zalew Szczeciński, Roztoka Odrzańska, Police Turn, Szczecin and its channels.
- Each of the designated sections was divided into smaller sections of 1 km, for which every 50 m straight lines perpendicular to the axis were established.
- As a center of the coordinate system adopted axis of the fairway.
- For a given cross section (perpendicular line) specified depths on the right and left of center of the track.
- This results in the depth distribution for the sections and depth frequency.
- Determined depths for a given profile are implemented in the model UKC.

The program randomizes one of the presented depth in profile of each loop and for randomly selected depth (distribution) draws a deep value. The number of draws may be variable, which will also change the amount of cross-sections used in the model.

In order to facilitate measurements UTM coordinate system is used.

Knowing the size of the average annual silt layer and the date of recent sounding is possible to reduce the depth and reservoir siltation determined value can be used to determine the actual depth of the area [3]. For this purpose based on surveys of the fairway transverse profiles were determined at specified sections.

Surveys covering the period 2006–2009 are stored in a *.dxf file that information on the depth is presented in the form of a polyline. Each of the polyline represents the appropriate isobaths (Fig. 4).

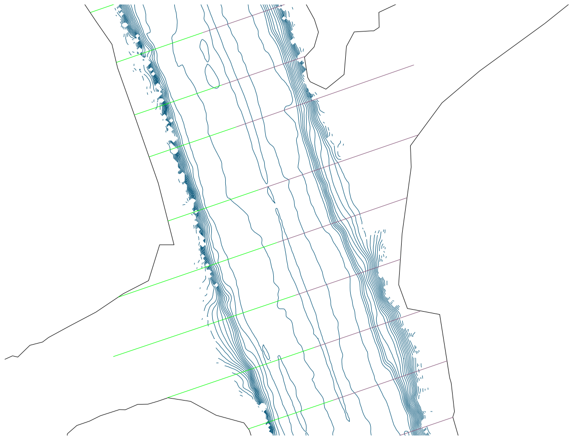

Fig. 4. Soundings of one section of Szczecin–Świnoujście fairway

Profiles were generated using a specially written application that designate points of intersection of the profile of the isobath and additionally interpolates the depth of the bottom of the set discretization (Fig. 5).

Data obtained using this method provide information on the transverse profile of the bottom at each section of the fairway.

Generated data on the bottom transverse profiles of the fairway based on surveys from the last few years, taking into account the time taken in dredging works are the basis for a statistical model of sedimentation.

Model of wave action and ship's response

In the integrated UKC system a ship's motions in waves are calculated based on the linear theory

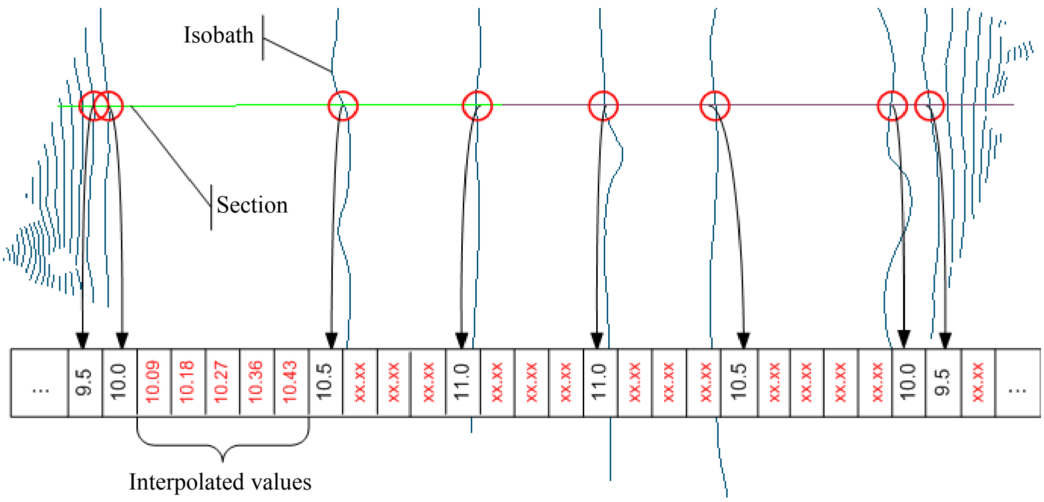

Fig. 5. Method of determining the depth on the cross sections based on *.dxf files

of ships motions. The motions in irregular wave are calculated on the principle of linear superposition of regular wave contributions. In the steady-state conditions (after some time required for stabilising the motions to reach the asymptotic behaviour) the amplitude of regular (harmonic) motions and corresponding phase lag can be solved by means of the following well-known algebraic equation:

$$\left(\left[B_{jk}\right]-\omega_E^2\left[M_{jk}+m_{jk}\right]-i\omega_E\left[N_{jk}\right]\right)\left\{u_{kA}\right\}= \\ =\left\{F_{WV\,jA}\right\},\quad j=1,\ldots,6,\quad k=1,\ldots,6 \tag{1}$$

where:

- u_{kA} – complex amplitude of k-th motion (in direction of k, values {1,2,3} denote translational motions along x, y, z axes respectively, values {4,5,6} indicate angular motions around the axes), the complex amplitude comprises information on the right (real) amplitude and the phase;
- F_{WVjA} – complex amplitude of j-th wave excitation force (in direction of j), in common linear assumptions the wave force real amplitude is proportional to wave amplitude (or height);
- ω_E – encounter frequency (as equal to the frequency of wave excitation force, which according to the linear model of vibration also produces the same frequency of final motions);
- M_{jk} – ship's mass and inertia matrix (6 x 6);
- m_{jk} – virtual (added) mass matrix, represents the surrounding water (as ideal fluid) inertia forces i.e. acceleration-related forces;
- N_{jk} – damping matrix, represents velocity-related forces;
- B_{jk} – restoring matrix, represents the hydrostatic forces i.e. displacement-related forces.

Considering the expression (1) with regard to a given encounter frequency, the resulting real amplitude of motion is proportional (linearly dependent) to the wave amplitude. This leads to a wide adoption of the so-called transfer functions or response amplitude operators. Besides, basically referring to such constant ratios of motion / wave amplitude as function of frequency, the transfer functions (or RAOs) in wider sense should also contain the phase angle between wave and a ship's motion [4].

The developed algorithm and computer application is a dynamically linked library working on the Linux platform – the operating system of a dedicated UKC server. The software computes ship's linear motions in pseudo time-domain for irregular seaway in that the time series of elementary 6 motions (3 linear and 3 angular) are generated as composed of a sum of harmonic oscillations. Each of these harmonic responses is produced by a harmonic wave contribution, the amplitude and absolute frequency of which is taken from an actual wave spectrum.

The wave spectrum is based on a significant wave height and characteristic period. Both terms are correlated to each other and are specific for particular nautical area, also for the Świnoujście–Szczecin waterways. The software's open architecture also allows for an arbitrary wave spectrum definition.

The mentioned harmonic motion is, however, given an encounter frequency (as the real excitation frequency from the wave) that is based on a ship's speed, wave incidence angle, water depth. The latter influences the wave number or wave celerity (in other words the wave propagation velocity). Finally, an amplitude of the harmonic motion is established according to the harmonic wave amplitude and RAO value (treated in narrow sense as the amplitude multiplier). Additionally, a phase angle is determined. Both, RAOs and phase angles have been computed off-line and stored in lookup tables, they constitute a ship's complete and constant hydrodynamic motion response characteristics, though in our pseudo time-domain approach we solely concentrate on asymptotic steady-state oscillations (the transients or the so-called memory effects are disregarded). The RAOs and phases are both functions of 4 arguments – wave absolute frequency, incidence angle, ship's speed and water depth ratio (h/T – water depth divided by ship's draught).

The software package comprises the following files:

sk_dlib1.so – The main simulation dynamic library (in binary format for commercial distribution). The source code was written in C++ and compiled by means of the standard (internal) Linux compiler "g++". The library functions may also be called from a source code of other languages if the function interface compatibility is preserved.

***.rao** – A file type that contains the mentioned ship's specific hydrodynamic database with RAOs and phase angles. Within the considered UKC project scope up to 8 ship models were prepared as typical for Świnoujście and Szczecin. Each [.RAO] file defines the coordinates of ship's gravity centre and 4-argument discrete transfer functions (both for amplitude and phase) for this centre. Here the arguments are: absolute wave frequency ω (40 values, 0 to 1.32, every 0.033), wave incidence angle γ_{WVrel} (13 values, 0° to 180°, every 15°), ship's speed v (5 values, equally spaced from 0 to v=max.), water depth ratio h/T (6 values – 1.05, 1.2, 1.5, 2, 5, 500).

***.spe** – A file type which deals with a normalised wave spectrum for a dedicated nautical area – precisely the wave energy spectral density. The normalisation means dividing the wave energy by the square of the wave significant height $h_{1/3}$. This relation is here discretely stored as function of wave frequency ω (independent variable) and characteristic period T_1 (parameter). The [.SPE] file also includes properly discretised numerical evaluations of the so-called dispersion relation, which provides the wave number k as function of wave frequency and water depth ratio h/T – the computations were made in Mathematica. The dispersion relation is of course independent from a wave spectrum, but is temporarily stored in this file. The wave number k is necessary for converting the absolute (real) spectrum into the encounter spectrum. Due to the water depth reduction in port areas the wave number increases (under the same wave frequency), which means the shorter and slower wave. It shall be here stressed that in oceanographic terms, i.e. relating the wave length to water depth (λ/h), the shallow water wave is called a long wave.

Summarising, the transfer functions (in [.RAO] files) denote a ship's dynamic model, while the wave spectrum (in [.SPE] files) sets a wave environment's model.

The transfer functions for ships motions were determined using a strip method. At the present early stage of research and development works the commercial software SEAWAY was employed. Because the applied reference system is a bit different from that of SEAWAY (strictly it assumes a right-handed coordinate system widely used in ship manoeuvring) a recalculation of phase angles for some degrees of freedom was performed. The assessment accuracy of the transfer functions thus corresponds to the general SEAWAY's accuracy, in particular to both numerical accuracy and adequacy of hydrodynamic assumptions (approximations).

Conclusions

Accommodate big draught vessel without an expensive investment process is possible only by using modern tools which supported process of making decision by Port Captain. Such a tool which is an integrated system of under keel clearance assessment, which could improved Polish ports effectiveness during acceptable draught appreciation. Presented system was built on the basis of probabilistic model of under keel clearance assessment.

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