

THE SQUAT-EFFECT AND ENVIRONMENTAL PROBLEMS AT REDUCTION SHIP'S SPEED IN SHALLOW WATER AND HARMFUL EMISSIONS

СQUAT-ЭФФЕКТ И НЕКОТОРЫЕ ПРОБЛЕМЫ ЗАЩИТЫ ОКРУЖАЮЩЕЙ СРЕДЫ ПРИ ЭКСПЛУАТАЦИИ СУДОВ

The analysis and generalisation of practical recommendations about maintenance of safe navigation in the conditions of heavy traffic in sea transportations are resulted in the article, in particular a question of safe draught maintenance UKC (Under Keel Clearance).

Analytical calculations of "Squat" effect by a method "UKC" of vessel's safe draught in the conditions of "shoal" and "deep" water are made. Calculations are executed according to IMO requirements and a policy of the Company and are originality and practicality in use.

According to the Kiotsky Protocol requirements as for decreasing in issue of components of hotbed gases, concrete recommendations about decreasing of carbon dioxide CO₂ are formulated during operation of ship's power installations.

For the first time calculations of the vessel's Low Sulfur Diesel Fuel (LSDF) bunkering in the areas of the air pool special pollution control by sulphurous connections SECA, ECA are executed. As it is shown by the calculations, that the transition from heavy into light fuel has not any bases as to make clearing of fulfilled gas of the ship power installations from sulphurous anhydride directly onboard a vessel in engine-boiler department by the simplified technology much more cheaply, than expenses for acquisition LSDF.

Practical recommendations about protection of air pool from sulphurous connections are developed. Recommendations — are economically proved and ecologically safe, protected by patents, a principle "Know How".

В статье приведены анализ и обобщение практических рекомендаций по обеспечению безопасного судовождения в условиях повышенного трафика морских перевозок, в частности вопрос обеспечения безопасной осадки UKC (Under Keel Clearance).

Произведены аналитические расчеты Squat-эффекта по методике "UKC" безопасной осадки судна в условиях мелководья и глубокой воды. Расчеты выполнены согласно требованиям ИМО и политики компании, обладают оригинальностью и практичностью в использовании.

В соответствии с требованиями Киотского протокола по снижению эмиссии компонентов парниковых газов сформулированы конкретные рекомендации по снижению эмиссии диоксида углерода CO₂ при эксплуатации судовых энергетических установок.

Впервые выполнены расчеты целесообразности бункеровки судов на Low Sulfur Diesel Fuel (LSDF) в районах особого контроля за загрязнением воздушного бассейна сернистыми соединениями SECA, ECA. Расчетами неоспоримо показано, что этот переход с тяжелого на легкое топливо не имеет под собой никаких оснований, поскольку производить очистку отработанного газа СЭУ от сернистого ангидрида непосредственно на борту судна в машинно-котельном отделении по упрощенной технологии намного дешевле, чем приобретение LSDF.

Разработаны практические рекомендации по защите воздушного бассейна от сернистых соединений. Рекомендации экономически обоснованы и экологически безопасны, защищены патентами, принцип "Know how".

Key words: Squat-effect, UKC, SECA, ECA, low sulfur, fuel, calculathion, technology, carbon dioxide, IMO Requirements.

Ключевые слова: осадка судна, безопасность судовождения, парниковые газы, сернистые соединения, отработанные газы, судовые энергетические установки, расчеты.

Introduction.

Squat is a serious problem for ships are entering harbors with small underkeel margins. The squat effects are that the ship acquires sinkage and trim. Due to this sinkage and trim UKC (under keel clearance) decreases. The distance between bottom and ship becomes very small and measures must be taken to avoid contact of the ship with the bottom. The pressure distribution that develops around a ship moving through the water, distorts the waterline by raising the level of the high pressure regions ahead of the bow and aft of the stern whilst lowering it along the length of the hull, particularly in midships. When a ship moves forward through shallow water, the displaced water is not easily replaced, thus resulting the ship to move vertically down. This bodily sinkage of the vessel is known as squat. This effect is imperceptible and irrelevant in deep water but it does become significant when the ship moves into shallow water. The risk of going aground due to squat must obviously be considered when operating in shallow and restricted waterways so formulae have been developed to estimate the degree of squat that a ship will suffer. On most occasions, the forward motion of the ship causes squat, but squat will also occur with a moored ship alongside a jetty if a tide is present.

It is difficult to calculate the magnitude of squat accurately. However, theoretical and empirical methods of varying reliability exist.

The analysis of last publications. General.

The water depth H and the ship draught T are used as the parameters to define shallow water. If the H/T drops below 1.5, one will, in general, experience a measurable change in the draught of the ship (sinkage). As H/T approaches 1.0 (grounding), the effect of shallow water increases significantly.

The ship's speed is another parameter of importance for the effect of shallow water. The wave pattern created when the ship travels forward depends upon the ship speed relative to the water depth, as there is a maximum depth at which a free-standing wave can travel. If the power to the engine(s) is maintained at the same setting as in deep water, the ship will slow down in shallow water.

Shallow water effect is normally measurable when the under-keel clearance ($H-T$) drops below 50 % of the static mean draught.

As the ship is generally not symmetrical about its half-length and because of the viscous effects of water, the changes in pressure are not identical for the fore and aft parts of the hull. This causes the ship to trim forward or astern depending on the hull shape. Thus, the magnitude of squat depends on the hull shape, the side and under-keel clearance and the speed through the water.

When the ship approaches shallow water it will experience sinkage and trimming — squat — due to changes in the vertical forces acting on the hull. Squat varies in proportion to the square of the speed. A ship with a large block coefficient (greater than about 0.70) will normally tend to squat by the bow.

Different approaches for predicting squat have been suggested in technical literature. The methods cover both theoretical and empirical investigations. The theoretical methods (Tuck & Taylor) generally requires detailed information about the geometry of the hull as well as a computer with adequate software. The empirical methods (Dr. Barrass) are normally based on data from model tests or full-size ships and use the leading hull parameters, the speed of the ship, and the principal geographical data.

Based on a review of ship squat in the literature and comparison of the different empirical methods available, it has been found that the method proposed by Dr. Barrass appears to provide results of reasonable accuracy.

Any draft measurements taken whilst the vessel is moving, either from the shore if the ship is moving in a canal, or by onboard pressure sensors in the hull, will not indicate squat. The raising of the waterline at the bow and stern draft will give a very exaggerated impression of an increase in draft. A large ship experiencing about 50 cm of squat may produce 2 m high bow wave, the fore draft would appear to increase by about 2.5 m, were as UKC has only decreased by a 50 cm. The water level can also rise at the stern but, this will depend upon how the bow and stern wave systems interfere with each other. Mistaking an indicator's increased readings of a ship's draft at the bow and stern for squat does at least to make a master or pilot error on the safe side with regard to the ship's navigation in shallow water. There are some

situations when it may be imperative to increase speed, such as to improve steering control, and idea of the squat effects could deter the master from taking this essential action in shallow water.

A ship tied up to a river berth with a current will also suffer squat and were making with their accompanying distortion of the waterline, even draft reading of the ship alongside may give a false impression of the ship's true draft, trim and deadweight. This can lead to disputes as to how much cargo has been loaded if the vessel is chartered to load a specific tonnage. A master must avoid sailing with insufficient UKC to allow for squat. If a ship is at even keel in deep water and then moves into shallow water of uniform depth, the change of trim depends upon the followings factors [1, 2]:

— if a ship's centre of buoyancy is forward of midships, the hull is fuller in the bow than the stern there is more immersed area and greater convergence of the streamlines forward than aft. Squat will produce a head trimming moment;

— when the centre of buoyancy is aft of midships, as is generally the case in finer lined hulls, squat causes a stern trimming moment;

— the local acceleration of water flow through the propeller creates a stern trimming moment;

— the ship trims by the head as the bow passes over the shoal squat forces concentrate under the forward hull;

— the ship trims by the stern as the stern passes over the shoal squat forces concentrate under the after hull;

— a small list in the deep water or a slight heel due to side wind will increase in shallow water due to squat as the heel angle increases the low side's closer proximity to the seabed will further enhance the heel or at least sustain it.

A ship moving in shallow water with an angle of heel will experience an increase in the list due to the squat forces concentrating in the region of least UKC. Upright vessel will suffer a squat induced list if it moves over a shelving seabed that becomes progressively shallower under one side of the ship.

Shallow water effect and his sign:

1) wave making increases, especially at the forward end of the ship;
2) ship becomes more sluggish to maneuver. A pilot's quote, 'almost like being in porridge';
3) draft indicators on the bridge or echo sounders will indicate changes in end drafts;
4) propeller RPM indicator will show a decrease. If the ship is in 'open water' conditions, i. e. without breadth restrictions, this decrease may be up to 15 % of the service RPM in deep water. If the ship is in a confined channel, this decrease in RPM can be up to 20 % of the service RPM;

5) there will be drop in speed. If the ship is in open water conditions this decrease may be up to 30 %. If the ship is in a confined channel such as a river or a canal then this decrease can be up to 60 %;

6) the ship may start to vibrate suddenly. This is because of the entrained water effects causing the natural hull frequency to become resonant with another frequency associated with the vessel;

7) any rolling, pitching and heaving motions will be reduced as the ship moves from deep water to shallow water conditions. This is because of the cushioning effects produced by the narrow layer of water under the bottom shell of the vessel;

8) the appearance of the mud could suddenly show in the water around the ship's hull say in the event of passing over a raised shelf or a submerged wreck;

9) turning circle diameter (TCD) increases. TCD in shallow water could increase 100 %;

10) stopping distances and stopping times increase, compared to when a vessel is in deep waters [2; 5].

Ais data and squat effect.

The ship's data, received in VTS service via AIS, can be used for many purpose other than identification and traffic surveillance. Such AIS data processes improve work of VTS and increase safety at sea.

Implementing real time analysis of ship squat, it is intended to monitor and predict squat by VTS being prevention of grounding.

Ships equipped with AIS system transmit a series of data, which are divided into three categories: static, dynamic and information about voyage and cargo. VTS receives the necessary waterway data

such as depth, underwater cross section and width from the relevant hydrographic institutes and vector electronic charts which include vector data of the seabed and depths. With the help of computers, depth information can be corrected for tide oscillations in real time. Given that squat is dangerous for ships only in certain circumstances, there is no need to calculate it for all vessels in all areas of navigation and thus unnecessarily spend and slow down computer system resources. It is therefore necessary to introduce conditions which would automatically start the calculation, tracking and prediction of squat and UKC.

Speed and depth/draft ratio should be the basic starting conditions for squat calculation. The reason for that is the fact that squat is primarily caused by the movement of the ship through water and grows approximately proportional to the square of ship speed. Depth/draft ratio indicates an area of shallow water and therefore danger regarding to ship draft.

VTS has to continue to monitor the ship and predict the possible critical situation in shallow waters with the help of computers. To make this possible it is necessary to determine the criteria for calculating the minimum UKC, taking into account the squat effect. The critical UKC alarm is activated if the observed UKC reduced for the calculated squat value is equal or smaller than the minimum allowable UKC. Squat is obtained by calculation using real time ship data and selected adequate empirical formula [1; 2; 5].

Squat Calculating:

$$\text{Maximum Squat} = \frac{C_B \times S^{0,81} \times V^{2,08}}{20}, \text{ m.} \quad (1)$$

C_B = Block co-eff.

$$S = \text{Blockage factor} = \frac{\text{Submerged cross section area of ship}}{\text{Submerged cross section area of channel}} = \frac{b \times d}{B \times D}, \quad (2)$$

where b & d — breadth & draft of ship and B & D ; breadth & depth of the channel respectively;

V — Vessel's speed relative to the water, in knots.

If the vessel is in open shallow water, B = Breadth of the channel is taken as:

$$B = \{7.7 + 20(1 - C_B)^2\} \cdot b, \text{ known as the width of influence.}$$

The width of influence ranges from 8.25b for supertankers, to about 9.5b for general cargo ships to about 11.75 ship breadths for container ships.

The presence of another ship in a narrow channel may cause the squats to double in value as they pass/cross the other vessel.

Short — cut Formulae:

$$\text{Maximum Squat} = \frac{C_B \times V^2}{100}, \text{ m} \quad (3)$$

(for open water conditions only, where $D/d = 1.1$ to 1.4).

$$\text{Maximum Squat} = \frac{C_B \times V^2}{50}, \text{ m} \quad (4)$$

(for confined channels only, where $S = 0.100$ to 0.265).

For example: Under Keel Clearance calculation:

Voyage	43d	Date	02.09.2013
Port	Port of Murmansk	Time of Transit	0:51
Vessel Block Coefficient (Cb)	0.781		

Speed (Knots)

Sea Passage	14
Pilotage/Port Approaches	6
Transit areas	6

Height of Tide (Meters)

Transit Area	2.97
Pilotage/Port Area	1.12

A. Vessels Draft (Meters)

At Sea Passage

Maximum Draft (SW)	12.15
Squat	1.53
Deepest Draft (Dynamic)	13.68

In Port Approaches

Maximum Draft (SW)	12.15
Increase (Due density)	0.00
Squat	0.40
Deepest Draft (Dynamic)	12.55

B. Minimum Water Depth (Meters)

Transit Area

Maximum Draft (SW)	12.15
Increase (Due density)	0.00
Squat	0.40
Deepest Draft (Dynamic)	12.55

Sea Passage	100
Port Approach	21
Transit	24
Anchorage	24
Alongside	21

C. Under Keel Clearance:

	Policy	Required	Actual
Sea Passage	30 %	4.15	86.32
Port Approach	15 %	1.9	8.39
Transit	20 %	2.66	11.39
Anchorage	10 %	1.27	11.39
Alongside	5 %	0.63	8.39

But it is not necessary to forget about environmental problems at reduction ship's speed in shallow water and harmful emissions thus.

According to traditional researches, navigation is the reason of formation of 2,7 % of world hotbed gases that makes to 400 million tons CO₂ in a year. For comparison the aircraft emits 650 million tons CO₂ a year [3].

New researches have shown, that actually emissions of “hotbed” gases by sea and river transport can be three times above, than was considered earlier. If conclusions of scientists are true, annual emissions by a world merchant marine fleet have already reached 1,12 billion tons CO₂, or about 4,5 % of all world emissions of “hotbed” gases. Irrespective of, whether calculations in the given research are correct, in many works necessity to begin reduction of emissions of the fulfilled gases in navigation for avoidance of dangerous changes in a climate which are accompanied by increase of mid-annual temperature of a planet is underlined.

It is expected, that public pressure will increase by ship-owners on transition to ecologically pure grades of fuel, and to EU — the account of negative influence of navigation in the scheme of “trade” in emissions.

In April, 2011 IMO have returned to work on a question of reduction of “hotbed” emissions in working group of Committee on Protection of the Sea Environment (MEPC). The committee has considered offers from the governments of the countries, including the tax to bunker fuel or methods of trade in limits of emissions, however the early stage of reforms on reduction of emissions for increase ship’s energy efficiency has been excluded from necessary offers [3; 4].

EU plans to regulate emissions of sea navigation if IMO cannot independently promote in this question. The Eurocommission has stated transport strategy till 2050 in which the purposes directed for more effective and long-term work of transport system on all types of transport contain. Among other, strategy demands transition of transportation of passengers and cargoes with road on railway and sea ways, and also reduction of emissions CO₂ by sea types of transport to EU on 40–50 % in 2050 in comparison with 2005.

The unwillingness was one of deterrents from developing countries to co-operate in question of the EU acts while as unique motive power for the new purposes of reduction of emissions of “hotbed” gases then as the USA have rejected a mention of the bunker extra charge, and China, India and Saudi Arabia have declared, that debate about market measures should be suspended until the new agreement concerning a planetary climate will be entered into.

EU declares, that will operate independently if IMO, “climatic” negotiations do not achieve the object in reduction of quantity of emissions from ships.

Navigation — the most effective type of transport, however, if sector will grow, as it is supposed, on 150–250 %, it can become a problem for environment [3; 4].

If other industrial sectors continue to reduce quantity of emissions in atmosphere, and navigation is not present, the contribution of “hotbed” gases from ships in world emissions will stably grow.

The international chamber of navigation has created a web site devoted to navigation and issue CO₂ in which readiness of branch to reduce world emissions of “hotbed” gases is reflected. Some ship-owners support idea of use of the scheme of “trade” in components “hotbed” gases whereas others consider the tax to ship fuel as more effective way of smoothing of negative tendencies in climate change on a planet.

Some considerations on the special zones emission control of sulfur dioxide (SO₂) from ship power engine.

Annex VI to MARPOL 73/78 put forward requirements for limiting emissions of sulfur compounds. In the area of SECA (Sulfur Emission Control Area) more than 5 degrees West longitude (Baltic, North Sea, English Channel), you must [3]:

- 1) produce low-sulfur bunker on diesel fuel, no more than 1 % by weight (based on Methyl — Mercaptane — MC) from June 1, 2010, 0.1 % by weight. MC — in January 1, 2015;
- 2) maintain overall emissions SO₂ (after the main and auxiliary engines) no more than 6 g/(kW × h).

On August 1, 2012 to join the North American zone SECA 200 — mile zone off the coast of the U. S. and Canada — ECA areas in which valid only diesel Low Sulfur concentration with MC in it an order of magnitude lower than in the area of SECA, — 0,1 % wt. MC.

From 1 January 2016 to join the district ECA areas of the Caribbean, the United States, Puerto Rico, the Virgin Islands.

In the rest of the world uses heavy fuel oil containing , wt% MC:

Since January 1, 2012 — 3.5;

Since January 1, 2020 — 0.5.

Low-sulfur diesel fuel (0.1, 1.0 wt% MC) is much more expensive than the heavy (3.5–4.5 % by weight. MC) as its production caused significant costs, hydrocatalytic stage desulfurization and fractionation [4].

Here is a comparison of damage avoided air basin in connection with the transfer of diesel fuel with high sulfur (4.5 % by weight. MC), low sulfur (0.1 wt% MC).

The calculation of the cost of low sulfur marine and high sulfur fuel.

Calculation of damage avoided air basin is made according to the method described in [6; 7].

Initial data for calculation:

Diesel fuel consumption, *t*/year. — 65.000, MC concentration in diesel fuel, wt%, 4.5 and 0.1.

Damage prevented air basin by switching from high-sulfur to lower sulfur fuel is:

$$P = Y_{4,5\% \text{ MC}} - Y_{0,1\% \text{ MC}} = 26119821.61 - 19278326.56 = 6841495.08 \text{ UAH/year, or}$$
$$6,84 \times 10^5 \text{ USD/year (10 UAH/USD — as of April 2014).}$$

At the same time, additional material costs for the acquisition of low-sulfur diesel fuel will be:

$M3 = 65\,000 \cdot (1200 - 600) = 390 \times 10^5 \text{ USD/year}$, where 1200 and 600, respectively, the value of 1t sour Low Sulfur fuel (0,1 % by weight. MC) and Heavy Diesel Fuel (4.5 wt% MC), USD/*t*.

As a result, the material costs for the purchase of low Sulfur diesel fuel (0.1 wt% MC) exceed prevented damage to the air in the pool:

$$\frac{M3}{P} = \frac{390 \cdot 10^5}{6,84 \cdot 10^5} = 57 \text{ times.}$$

As a result, the following conclusions.

Summary.

1. The basic purpose is the ship's squat calculating and his using in VTS services for predicting the danger of grounding. Calculations and conditions are proposed for predicting and alarming the critical under keel clearance in real time.

2. As an example of the further care of environment protection on July, 15th 2011 amendments to addition VI to MARPOL on reduction of emissions of hotbed gases from ships have been approved. The resolution has come into force on January, 1st 2013. One of the basic requirements is presence on vessel SEEMP — Ship Energy Efficiency Management Plan, Energy Efficiency Design Index(EEDY).

3. Use on board a vessel for Main Propulsion (MP) cheap high sulfur diesel fuel without the additional step of catalytic hydrotreating and fractionation (4.5 % by weight. MC);

4. Clean the exhaust gas from sulfur dioxide MP directly on board in engine and boiler room on the simplified technology to minimize level of maximum permissible concentration and emission limits for sulfur dioxide. Simplified exhaust gas cleaning technology from MP SO₂ can be created for practical implementation based on the technical solutions described in [4].

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