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TECHNICAL SOLUTIONS AND ASSESSMENT OF ECONOMIC EFFECTS OF CONSTRUCTION OF AN OFFSHORE TERMINAL

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Abstract: *With the increase in the volume of work in container traffic, the occurrence of ever-larger ships with the big draft, the growing demands for the shorter timing of distribution of materials, products, and containers, etc., there appeared also demands for new technological solutions in the organization of container shipping. One of the rationalization options is offshore Floating Container Storage Terminal (FCST) located near the hub port on the open sea, which can unload the warehousing and warehouse work of the port and which are used to transfer containers from large container ships or to load other cargo on a short-stay platform, and later shipping them to smaller ships for shipment to end-users. There are very complex requirements for locating of such terminals, such as convenience of locations with sufficient depth of the sea, favorable climatic and hydrographic conditions, the closeness of smaller ports, sufficient sea surface for maneuvering, approaching, leaving the port, etc. In this regard, in the work are presented some characteristics of the offshore FCST terminals, the principles of their construction, alternative constructive solutions of supporting structures with special emphasis on FCST. Based on the experience, there are shown advantages and disadvantages of FCSTs, risk factors that are very important for the construction of such terminals, and economic assessment and justification of their construction.*

I. BASIC FUNCTIONS OF AN OFFSHORE FLOATING CONTAINER STORAGE TERMINAL

There are several functional concepts for the construction of floating terminals, such as floating cranes, floating displaced ports (FCST, TNG, TPG), the lighter aboard ship (LASH), mobile port, offshore transshipment structures, Roll-on/Roll-off (RORO) ships and terminals, separated crane and transfer units (separate CUTU), hybrid mobile floating port, a floating city (living), a floating green-houses (cultivation), a floating airport (transportation) etc.

Offshore Floating Container Storage Terminal (hereinafter: FCST), or a floating platform for temporary storage and maintenance of the container, is the classic platform stabilized and equipped with the necessary number of mobile cranes or portal cranes (usually, with four or more; for Feeder technology up to three cranes, and for large ships up to six), traffic trails, temporary storage trays, additional equipment for horizontal overload Rubber Tyred Gantry (RTG), Rail Mounted Gantry (RMG), Automated stacking cranes (ASC), lifeboats, offices, etc., Figure 1 [1]. When building an offshore terminal, it is necessary to satisfy certain requirements, such as the appropriate location with sufficient depth of the sea and good climatic and hydrographic conditions, proximity to smaller ports in the gravitational area, which can be easily reached, and which can serve as a shelter because of weather disasters. In addition to these general requirements, offshore FCST has specific requirements in terms of providing sufficient space for temporary storage of containers, the existence of transshipment machinery, the possibility of increased mobility, the possibility of using of other intermodal transport technologies, etc. [2].

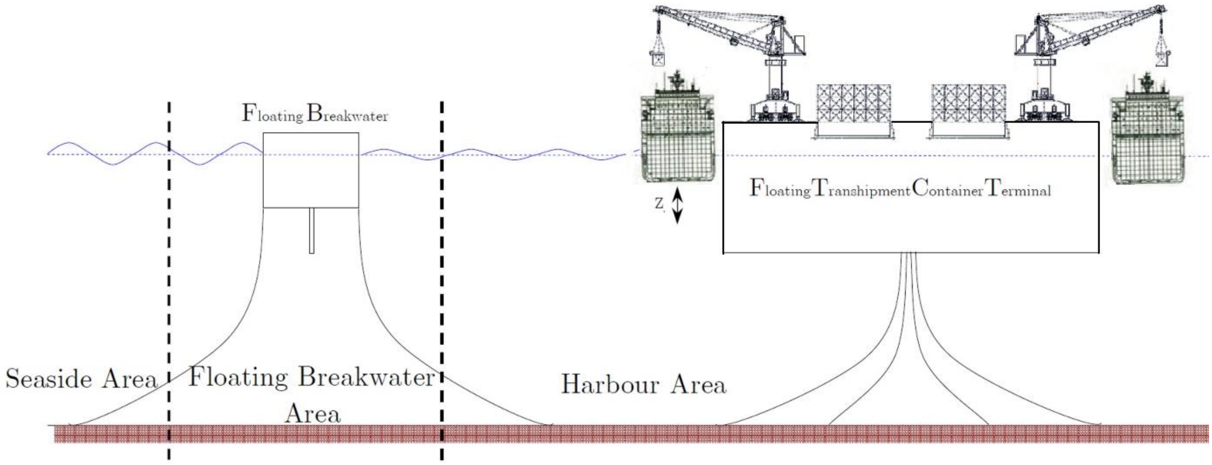


Figure 1. The floating harbor system [1]

There are several key situational requirements when alternative solutions are imposed on conventional ports:

- the inability to expand the port at the existing location,
- extremely large costs of upgrading existing or building a new port,
- the existence of several small ports in the gravitational area of large "hub" ports,
- inaccessibility in terms of inadequate terrain and depth of water, etc.

If there is no possibility of expanding the port area and there is an increase in the scope of work, offshore FCSTs are one of the solutions. However, even if there is a possibility of expanding the port area, it is necessary to know that the costs of the land lease on the operational coast and thus the costs of building the berth are very significant. Therefore, locating an offshore FCST in the immediate vicinity of the port, and in the water area, is a much more favorable variant due to the shorter time the ship is operating in the harbor, and therefore the reduce to pay high harbor fees. The location requirements to be fulfilled by offshore container terminals are given in Table 1.

Table 1. Equipment and conditions for locating offshore FCST

Equipment / Conditions	Great construction costs	More small ports nearby	Inaccessibility
Buffer for containers	-	yes	-
Container crane	yes	yes	-
Fixed connection	yes	-	yes
Mobility	-	yes	-
RoRo technology	-	-	yes

From the aspect of transport, each offshore FCST has several basic functions that relate to mobility, capacity, and equipment. Observing the interdependence of these elements, different technological operations can be realized:

- replacement of basic and supplementary services of conventional ports due to the increased volume of work with containers in the port,

- transportation of containers between offshore FCST and smaller gravitational ports,
- container transshipment from ship-to-ship (STS).

Mobile offshore FCST with container storage (buffer) can be used as a feeder ship between *"hub"* and local, smaller, harbors at shorter distances, in several ways, Table 2. It can be noted that all forms of offshore FCST must have a storage space for the temporary storage of containers and be mobile, and in addition, they may be equipped with a container conveyor and/or capable of RoRo technology.

Table 2. Equipment and use of offshore FCST

Equipment / Conditions	Feeder ship	RoRo feeder ship	Distribution of operation in two ports	Mobile port structure
Buffer for containers	yes	yes	yes	yes
Container crane	-	-	yes	yes
Fixed connection	-	-	-	-
Mobility	yes	yes	yes	yes
RoRo technology	-	yes	-	yes

Additional functions relate to the existence of buffers, the possibility of increased mobility with the need to shift FCST, servicing and other Ro-Ro vessels, achieving delivery of containers beyond regular shipping lines and establishing a connection with the land in emergency situations. An important additional service is also provided when the offshore terminal can be used as a berth for containers' and other ships outside the hub port, which is often due to the increased number of ships and the hub port inability to simultaneously receive and manipulate multiple vessels within the port. So, an offshore terminal becomes an additional "server" of the hub port. They can also be used in the sense of a double-sided transshipment system, thereby increasing the efficiency of all berths in gravity ports, resulting in time savings in reducing the time of the container and ships turnover. The cost of these savings should be compared with the costs of locating such FCSTs.

Table 3. Estimation of the FCST's transshipment capacity based on four cranes

Number of transshipments per hour	Number of working hours per day	Number of transshipments per day	Number of transshipments per year	Number TEU per year	Capacity %
20	4	298	108,624	184,661	17
20	8	595	217,248	369,322	33
20	12	893	325,872	553,982	50
20	16	1190	434,496	738,643	67

The annual capacity of the FCST can be estimated based on the number of cranes (in this case, four), their working hours and the possibility of storing of minimum 4,000 TEU (Twenty-foot Equivalent Unit), with an average time loss by 7%, and an if the container is kept on average for 2.5 days on FCST, in each year. Based on the average operating time of the crane at the level of 12 h/day, in the case of 12 working hours per day, FCST can expect a capacity of over 550,000 TEU/year, as shown in Table 3 – row 3.

II. OFFSHORE OPERATING CONCEPTS

Different combinations of technological elements define the offshore FCST equipment and thus the technology of operation. Basically, there are several configurations, and the following text will show some solutions collected from literature, primarily [3]. The basic configurations consist of the following concepts:

- ***A Hybrid Quay wall (HQW)***, located in the immediate vicinity of the port, where the ship is located between the existing port and FCST. The transshipment (loading, unloading and/or pure transshipment) of containers is done on the principle of (S/S, ship-to-shore) partly by the harbor and partly by crane, as it is described in [4];

- ***Integrated Terminal Ship System (ITSS)***, consisting of two parallel floating pontoons, like the modified monolithic structure of offshore FCST. This system is described in Johannes March patent proposal [5];
- ***Mobile Harbor (MH)*** or mobile floating port is a standalone mobile barge with a container buffer, built-in crane and a platform for RoRo technology. This operating system combines operations between the feeder ship and the barges. Details about MH are presented in [6];
- ***Offshore FCST with or without a buffer for containers;*** without the buffer represents a typical STS structure, and it differs from the floating crane because it supports a larger number of cranes and is used exclusively for STS. It is often used transshipment of barges with containers; so-called, the "lighters" barges continue to embark on a large LASH ship. If it has a buffer, its basic function is the STS container transshipment, but it also provides all the other functions provided by the classic container harbor terminal. More detailed about offshore FCTS can be found in [7];
- Finally, as always, hybrid solutions ***(HFP - Hybrid Floating Port)*** are considered, which would represent a combination of RoRo feeder ship and floating displaced ports with ramps to manipulate the vehicles. The system can be mobile. More about this, but also some other solutions can be found in [3].

Intensive work is being done on new solutions for floating FCSTs to reduce the vessel's stay-time in ports. A new RoRo container ship called the Interbarge and Enisys and RoRo terminal called Improved Port/Ship Interface (IPSI) are constructed [8], [9]. Containers are lined up on stands with wheels (like the LUF system) using RTG conveyor riders or port cranes that are further driven to and/or pulled from the RoRo ship with the help of the AGV vehicle or a special loco-tractor. The RoRo vessels act as feeder ships.

III. ECONOMIC ASSESSMENT OF OFFSHORE FCST

A deeper economic assessment is not at this time feasible due to the lack of structure of all costs in a particular location, the choice of bearing structure, the cost of mechanization by type of technological operations and manipulation points, the scope of work by type of container, possible cost savings, and the implementation of the entire project.

Variable costs can be roughly estimated based on the following costs for a total of 2600 h/y):

- amortization and work (linear, 15 years, other income, etc.) EUR 1.7 million;
- Maintenance (5% of the investment) EUR 0.9 million;
- insurance (0.5% of the investment) EUR 0.09 million;
- indirect administrative costs of EUR 0.16 million;
- direct costs of executive workers (five workers 250 EUR/h · 2,600 h) 0.65 MEUR;
- cost of power energy (2600 h) EUR 0.25 million;
- the rest EUR 0.25 million, which totally amounts to about EUR 4.0 million, with an average utilization of the capacity of 39%.

An estimating of fixed costs, it starts from the construction cost of FCST, Figure 2. Of the other fixed costs, it is necessary to specify:

- the price of the crane of about EUR 7.5 million;
- the barge with the crane of about EUR 2.2 million;
- the supporting structure EUR 1.2 million, the pontoon EUR 3.6 million;
- machine compartment EUR 2.0 million;
- winch and other equipment EUR 1.5 million;
- which totals around EUR 18.0 million.

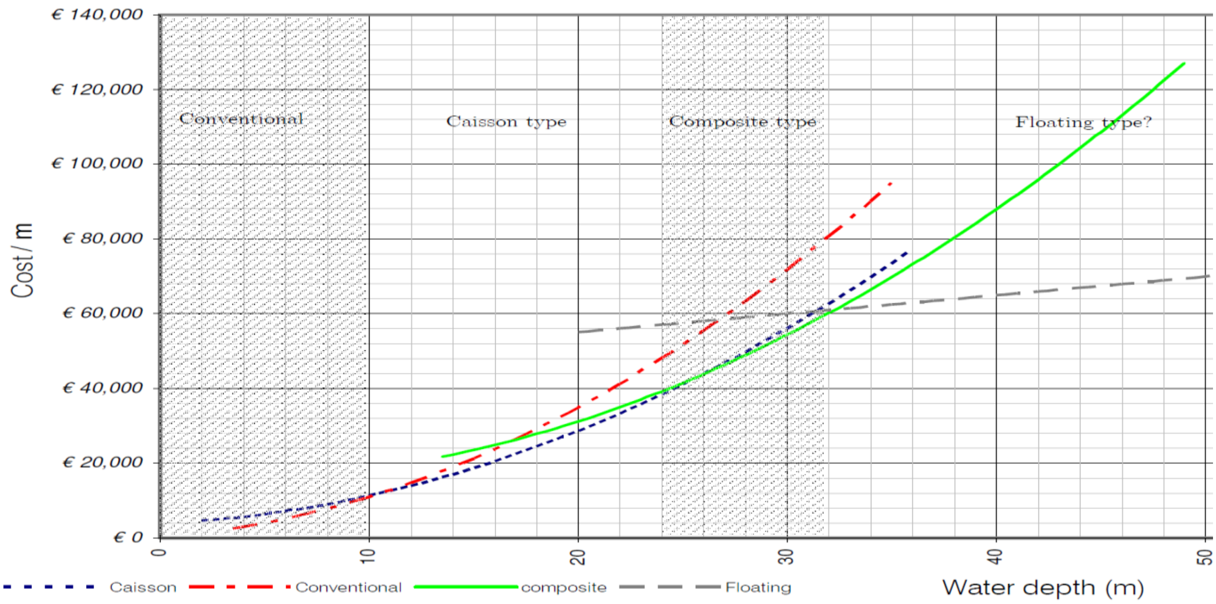


Figure 2 Comparison of construction cost /m1 depending on the water depth [1]

The price of manipulation per container can be estimated. If it is possible to accomplish 25 manipulations, that is to tranship 25 containers per hour, then in 2600h, the average price of transshipment of one container is about EUR 62 [10]. This estimation should be considered conditionally, as there will be some changes in the number of operating hours, average capacity (cont./h), interest calculation, etc., which surely will affect the price of the transshipment of one container. For a more detailed analysis, it is necessary to determine the number of cranes on the offshore FCST, whether all the containers from the ships will be loaded onto the terminal or will have a clear transshipment from the ship to the barges and vice versa.

Based on the presented costs and existing experience, preliminary conclusions can be made that:

- investment costs amount to about 18 million EUR/year,
- Operating variable costs for 2600 operating hours are around 4 million EUR/year.
- Manipulation costs per container 62 EUR/TEU (reduced to 20 minutes) and this price is 50% lower than the price in classic ports, where on average it is 130 EUR/TEU for a full, and about 110 EUR/TEU for an empty container (in Serbia stands EUR 75 for 40 minutes, and EUR 50 for 20minutes),
- Lower manipulative costs remain, which generates savings of around 100 USD/TEU together with environmental protection costs for zero-emission ports,
- the rapid development of the port and its mobility,
- there is no cleaning of the bottom of the port from the sludge, etc.

All these estimates should be considered as the first preliminary estimate because each situation requires a more detailed analysis of costs and savings, as well as other implementation costs. It is undoubtedly that use of offshore FCSTs can generate some potential savings, indicating that all stakeholders in the construction of this type of FCST should be included in the analysis.

Bulgaria plans to receive gas from an offshore terminal near Greece's Aegean port of Alexandroupolis [11]. This will significantly improve Bulgaria's energy security while providing the opportunity for Bulgaria to differentiate its sources and natural gas supply routes. The facility would supply the gas market of southern Europe through the Interconnector of Greece-Bulgaria and the National Natural Gas Transmission System of Bulgaria, which is managed by Bulgartransgaz. The LNG facility is designed to work in tandem with the planned Greece-Bulgaria gas interconnector (IGB) to bring gas from Azerbaijan to southeastern Europe via the TANAP/TAP gas pipeline system [12]. Estimated capacity is 700,000 cubic meters per hour, or 6.1 bcm/year. The Alexandroupolis terminal will cost about EUR 370 million (about $ 413 million) [13] and it is expected to be operational by the end of 2020 [12]. The oil fleet LNG terminal would include a floating LNG storage and re-gasification unit (FSRU) with an initial LNG storage capacity of 135,000 to 170,000 bcm and the possibility of expanding gas deliveries to 13 bcm/year [14].

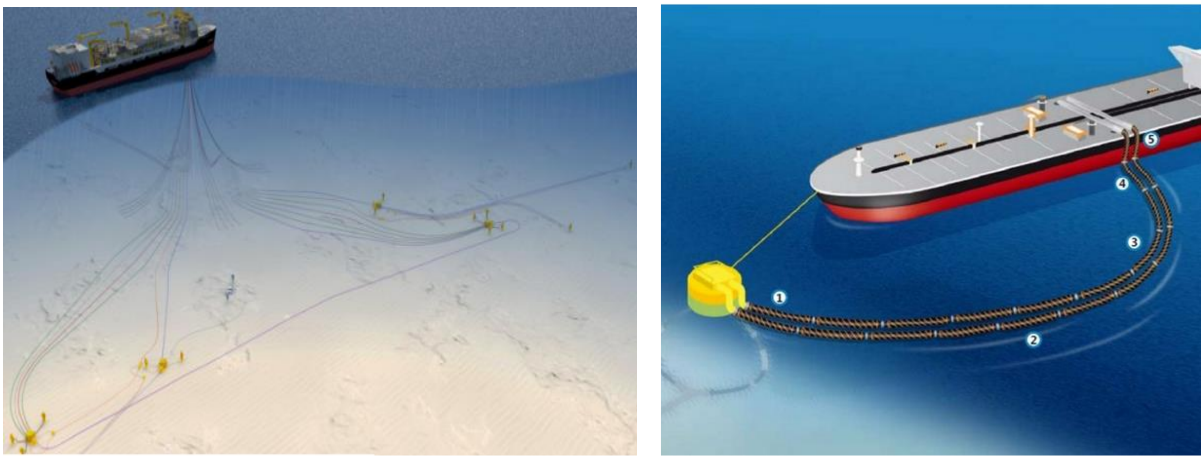
IV. SECURITY OF OFFSHORE FCSTs

Many internal and external factors affect the safety of offshore FCST work in the SPM binding system. Particularly typical hazards and risks are strong winds and tsunamis. They and the power of the waves, which are significantly larger and stronger than in the port, can cause swinging and thus overload due to oscillatory movement and stability change. In addition, accidental collisions of vessels and/or submarines with pontons, etc., are possible. Potential consequences of an accident by unprotected SPM can include oil spillage, environmental pollution, the costs of collecting and cleaning the oil, staff injuries, damage of the property and repair costs, terminal downtime, negative media attention, greater insurance premiums, terminal integrity endangering, costs of reduced reputation... All this requires that the seafloor is free of abrasion, and rocks and bulges, that has no sudden lowerings and that the depths are not too large for the stable positioning of the necessary installations. It is necessary to have sufficient free sea surface in terms of free space for maneuvering, approaching and abandoning the dock.

To increase security, different platform anchoring systems and links to ships are used [15]:

- ***Spread Moorings*** - a system for direct connection to the platform hull, or conventional, through the so-called Conventional Buoy Mooring (CBM) on the surface of the water, through multiple points using chains, wires or ropes of synthetic fibers.
- ***Dynamic Positioning System*** (***DPS)***, it is a key system for ships and barges piloting to make it easier to change their positions within the port. One of the key requirements for the DPS computer is the ability to easily and safely integrate various already existing ship systems.
- ***Single Point Mooring (SPM) system***, figure 3, a system that has the advantage of allowing the terminal to move in order to obtain an optimal orientation towards the predominant direction for the LNG terminals. There are also some other systems as: Single anchor leg mooring (SALM), Jacket type, Spring pile type, Exposed location single buoy mooring (ELSBM), Articulated loading platform (ALP), SPT (Single Point Turret), STL (Submerged Turret Loading) and HRT (Hybrid Riser Tower), etc.

From the perspective of external influences to the safety of the FCST platform, there are various cyber threats, thefts and terrorist activities that can cause problems with shipping and receiving of cargo and containers, increase the degree of vulnerability or even the disappearance of goods. Many countries have cybersecurity strategies that protect their networks and security systems. However, networks are vulnerable to cyber-attacks, depending on what protection measures have been established. A significance was given to the importance of face recognition, cyber securities and the identification of suspicious situations in financial transactions and the engagement of software specialists to identify, analyze and exploit information in data exchange within and between the FCST users. Integrated "end-to-end" control systems are needed in a combination of the necessary measures to combat these threats, based on scientific innovations in preventing cybersecurity threats.



a. Turret mooring [16] **b. CALM buoy [17]**

Figure 3. Single Point Mooring (SPM)

Basic attention is focused on technical solutions for the fight against terrorist threats and theft of property or goods in FSTS such as classic Closed-Circuit TV (CCTV) systems, thermovision, infrared cameras or other video surveillance systems, but also to the alternative methods (e. g. use of dogs to detect unauthorized drug trafficking) that can be successfully integrated into some of the traditional forms of prevention and detection [18]. More and more PIDS (Perimeter Intrusion Detection Systems) systems are being used in the outside environment to detect the presence of an attacker trying to break through the perimeter. The adoption of distributed acoustic sensing (DAS) technology with optical fibers is rapidly growing as part of PIDS's strategies for many companies in a number of industries. Network perimeter is used to isolate servers and resources both internally and from the Internet. In most cases, servers that should be accessed by Internet clients are placed in the perimeter of the network, behind the firewall (ISA Server 2004).

V. CONCLUSIONS

When an offshore terminal is mentioned, the first association are containers, container ships, and cargo cranes. Together with the development of containers and container ships, the ports in which these ships are served are also developing [19]. As large container ships often cannot be serviced in coastal ports, offshore platforms (on the open sea) have begun to develop for container transshipment. Although there are also offshore terminals for the transshipment of oil and other cargo, the most common terminals are for the transshipment of containers from larger to smaller container ships or for containers unloading to the platform. Offshore terminals vary by purpose, size and equipment they own, and in their mobility, but their common problem in transshipment on the offshore FCSTs is impacts of waves and winds. Based on the performed analyzes, and considering all the advantages and disadvantages, these terminals represent potential sites for the rationalization in the supply chains.

So far, the offshore terminals have not been in large numbers, but with the increase of containerized and other cargo worldwide and the construction of larger ships, their faster development is expected.

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ТЕХНИЧЕСКИ РЕШЕНИЯ И ОЦЕНКА НА ИКОНОМИЧЕСКИТЕ ЕФЕКТИ ПРИ ИЗГРАЖДАНЕ НА КРАЙБРЕЖНИ ТЕРМИНАЛИ

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Ключови думи: *крайбрежен терминал, плаващ терминал за съхранение на контейнери, технически решения, икономически ефекти.*

Резюме: Н*арастващия обем на контейнерните превози, нуждата от кораби с по-голяма товароподемност и търсенето на срочни доставки, определят необходимостта от иновативни технологични решения при организацията и превозите на контейнери. Една от възможностите за рационализиране на тези дейности е да се създадат крайбрежни плаващи контейнерни терминали, разположени в близост до морските пристанища, така че да бъде улеснено претоварването и обработката на контейнерите от контейнеровозите и тяхното доставяне до крайния получател. Като цяло процесът при изграждане на подобен тип терминали е сложен, тъй като е свързан с определени изисквания, като: подходяща дълбочина на газене на корабите;благоприятни климатични и хидроложки условия; подходяща дълбочина за акустиране, извършване на маневрени и други дейност и т.н. В тази връзка в настоящата разработка са разгледани някои от характеристиките на крайбрежните плаващи контейнерни терминали, изискванията за тяхното изграждане и др. Освен това са представени предимствата и недостатъците на тези терминали, както и е направена оценка на икономическите ефекти от тяхното строителство.*