Časopis Pomorskog fakulteta Kotor – Journal of Maritime Sciences (JMS)
god. 24, br. 1/2023; Vol. 24, No. 1/2023; May, 2023

DOI: https://doi.org/10.56080/jms230508 UDC: 629.545.2:614.84
Review paper

Contribution for the Fire Protection Improvement on RO-RO Ships

Sanja Arko Kariolić, Đani Šabalja, Renato Ivče, Astrid Zekić

Abstract: Fire is one of the most dangerous types of an accident that might happen to a ship, highly harmful to the crew as well as to the ship itself, high temperature, toxic vapours and gases are created (generated) by the combustion of a combustible material. In addition to human casualties, a material damage was also included in the fire. Therefore, a significant role of the fire protection is timely notification of fire, enabling the quick intervention, the damage reduction and engagement of people and equipment. The possibilities of fire protection improvement are carefully studied by the authors on RO-RO ships. The aim is to point out the importance of fire protection preventive measures. The analysis of the article is based on the road tunnels fire alarm system and the possibilities of application on RO-RO ships. The authors have been suggesting the use of an optical sensor cable in garages on RO-RO ships as the main type of fire alarm system detectors.

Keywords: Fire protection, Road tunnels, RO-RO ships, Optical sensor cable.

1. Introduction

Fires can take hold quickly and spread rapidly, yet RO-RO ship crews are relatively small in number while detecting, locating and accessing a fire within a deck is time-consuming. Roll-on roll-off (RO-RO) car carriers are back in the spotlight following the total loss of the Felicity Ace. The Felicity Ace sank in March 2022 with 4,000 vehicles worth an estimated $400-$500 mn on board while being towed by salvors, two weeks after a fire broke out en route from Germany to Rhode Island, US. Recently, there has been an increasing number of ship accidents caused by fire, some of them need to be highlighted:

- MV Honor suffered a fire on its upper vehicle deck in February 2017, which led to extensive damage to the vessel, as well as to its cargo of about 5,000 vehicles,
- Sincerity Ace caught fire in the Pacific on New Year's Eve, 2018 with more than 3,500 cars on board. The crew had to abandon the vessel, and five tragically died,

- The Diamond Highway had to be abandoned by its crew in the South China Sea in June 2019, due to a fire, while carrying more than 6,000 cars, and
- The Höegh Xiamen, caught fire in June 2020 in Jacksonville, Florida, resulting in the total loss of the vessel and its cargo of 2,420 used vehicles [1].

The subject of this research is related to the fire protection of RO-RO ships, where fire alarm systems play a significant role. The aim is to indicate the possibility of using an optical sensor cable in garages on RO-RO ships. Recently, optical cables have been used in road tunnels.

The article is structurally divided into six basic parts. In the second part of the article, following the introduction, the road tunnels fire protection measures and the application of the optical sensor cable in the fire alarm system in tunnels are presented. The characteristics of RO-RO ships are described in the third part, while fire protection measures are listed in the fourth part. The fifth part discusses the possibility of using the optical sensor cable in garages on RO-RO ships. The last, sixth part of the article summarizes the concluding remarks.

2. Protection in the Road Tunnels

Although accidents occur not so frequently in road tunnels than on the open road, there is no doubt that a fire in a tunnel may cause far more serious consequences than a fire in the open. According to the French statistics, there will only be one or two car fires (per kilometer of tunnel) for every hundred million cars pass through the tunnel [2]. However, fire risk is a serious problem causing death for many people during past decades.

In addition to human casualties, an enormous material damage was also caused by the fire [3]. In many countries, the direct annual fire losses amount to about 0.2% of a gross domestic product (GDP), but if the costs of intervention services, fire protection measures, premium of the fire insurance and consequent losses in the production and trade are added to this, the total costs of fires rise to approximately 1% of GDP [4]. It should be mentioned, during the fire in the Burnley tunnel in Australia, the operator lost about AUD 3 million in toll revenue, due to the closure of the tunnel for four days, and each subsequent day would probably mean the loss of an additional AUD million [5].

Fire protection systems are installed in road tunnels, where automatic detectors are of special significance. For the automatic detection of tunnel fires and the subsequent initiation of cost intense fire ventilation and fire brigade alarm, linear heat detectors today are the only 100% reliable

detector with a minimum of fault alarms [6]. The accident site can be located with an accuracy of 7-10 m (a temperature sensor cable), or 1-2 m (an optical sensor cable).

Lately, the linear detectors with a light beam have often been used. This type of the fire alarm detector has a sophisticated system that correctly directs the light beam and maintains the position of the detector during the exploitation.

One of the solutions for automatic notification of fire is laying of a linear sensor cable with a laser - flowed optical conductor based on the principles of changing the parameters of the laser beam caused by deformation of the conductor due to the increase in temperature. The cable is placed on top of the tube, along the central axis of the tunnel tube (Figure 1).

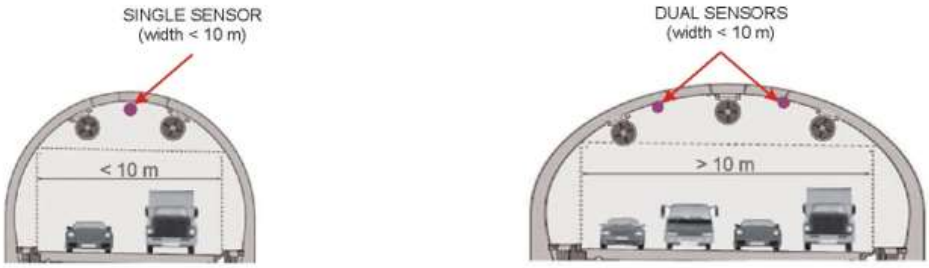

Fig. 1 – *Cable configurations in the roof of the tunnel.*

The optical fiber sensor measures the temperature gradient and the maximum set temperature, enabling the detection of fire within a sector of 4 m, as well as the direction and speed of its progress. The advantage of this sensor is the high resistance to atmospheric and aggressive environments, electromagnetic influences, physical shocks, vibrations etc., with low maintenance costs [7]. They are characterised by high resistance to aggressive chemicals, mechanical influences, road salt, accumulation of dust and dirt, splashing with water and regular cleaning of tunnels [8].

In the following text, the features of RO-RO ships are listed and the possibility of using an optical sensor cable in garages on RO-RO ships is analysed.

3. Significant Characteristics of RO-RO Ships

The RO-RO was defined in the November 1995 amendments to Chapter II-1 of the International Convention for the Safety of Life at Sea (SOLAS), 1974 as a passenger ship with RO-RO cargo spaces or special category spaces [9]. The cargoes in the ship are loaded and unloaded over the built ramps. RO-RO ships are usually equipped by stern or quarter ramps. In some ships, they are also found on the bow as well as the sides. Such ramps can become

damaged or twisted due to due to improper commercial operations of the ship (loading and unloading). Damage to the ramp endangers watertightness and makes extinguish fires difficult, especially when using CO_2 system.

RO-RO ships are ideal for transporting different kinds of cargo and loading and unloading operations of the cargo is very effective. Cargo may remain on vehicle or it may be discharged from vehicle and stowed on deck.

The variety of cargo sizes on RO-RO ships is unregulated [10]. The world fleet of RO-RO ships have one or more RO-RO decks consists of a wide range of different kinds and sizes. Merchant ships under the International Convention on Load Lines are generally divided into two main types:

- Type A ships which are assigned lower freeboards, and
- Type B ships which are assigned higher freeboards than type A ships.

Type A ships are better protected from the sea and they have more internal subdivision and limited numbers and sizes of deck openings. RO-RO ships are belonging to type B with higher freeboards and they have weaker requirements for subdivision and damage stability. On type B hull is divided into a certain number of separate spaces (holds) by transverse bulkheads. Main transverse bulkhead should be watertight. In the event of the ingress water into hold (hull being holed), the bulkheads may prevent the ship from sinking or they will limit or delay the inrush of water enabling enough time for the evacuation. Fire in cargo space also may be limited by transverse bulkheads. Firefighting is also limited fire on certain cargo space and fire prevention measures are more effective. On the contrary RO-RO ships haven't fixed transverse bulkhead above main deck because the installation of fixed transverse bulkheads would prevent drive cargo on to the ship at one end to the other. Below main deck RO-RO ship is equipped with the watertight bulkheads prescribed by SOLAS. The huge decks on RO-RO ships enable water to enter very rapidly and fire may also spread very quickly for the same reason. New generation of RO-RO ships are equipped by movable bulkheads. Cargo spaces are subdivided by mentioned bulkheads when ship is at sea. Bulkheads are opened during commercial operations at port.

Stowage spaces on RO-RO ships are determined in Section 17 of the International Maritime Dangerous Goods (IMDG) Code and in Chapter II-2 of SOLAS as a space not normally subdivided in any way and extending to either a substantial length or the entire length of the ship in which goods, in or on rail or road cars vehicles (including road or rail tankers), trailers, containers, pallets, demountable tanks or, in or on similar stowage units or other receptacles that are loaded and unloaded, normally in a horizontal direction. There are, in general, three types of RO-RO spaces on board these vessels:

- Closed RO-RO spaces,
- Open RO-RO decks (openings are typically aft and in sides, but deck is above), and
- Open RO-RO decks/weather deck (with no deck above).

Closed RO-RO cargo space is a RO-RO cargo space that is neither an open RO-RO cargo space nor a weather deck. Open RO-RO decks is a RO-RO cargo space either open at both ends, or open at one end and provided with adequate natural ventilation that is effective over its entire length through permanent openings in the side plating or deckhead, to the satisfaction of the Administration. Open RO-RO decks/weather deck is a deck that is completely exposed to the weather from above and from at least two sides. It is the main feature which distinguishes the RO-RO ship from other types of ships. This deck (or more of them) run the full length of the ship between bow and stern. It is crucial for she efficiency and also the whole RO-RO concept. This is one of its most controversial features, since it has led to considerable concern about the safety of RO-RO ships is their stability (both the intact and damaged condition) [11]. Mentioned features have also great impact on spreading fire and demand additional requirements for installed firefighting equipment on this kind of ship.

RO-RO ships are equipped with powerful drainage water system on RO-RO deck. This kind of ship on navigating bridge have been supplemented by an audible alarm indicating any change of state of the doors under surveillance. Audible alarms should be equipped for presence of water in deck bilge. Firefighting by water also require water level monitoring in deck bilge. Circuit television system is on the navigation bridge as well as in the engine room to leakage monitoring. The sudden ingress of water due to damage of the hull or failure of watertight doors may have serious impact on ships safety.

RO-RO decks are generally known to introduce safety vulnerabilities. A Fire safe study which was carried out by European Maritime Safety Agency (EMSA) found that some 30% of fires have happened on RO-RO decks [12]. RO-RO spaces (closed and open) should be protected by a minimum one of following fixed fire-extinguishing system:

- Foam system,
- Water system,
- Gas system,
- Deluge system,
- CO_2 system,
- Rarely a high-expansion foam system, and

– Water mist have been developed as an alternative system.

Foam systems are specifically engineered and designed to protect areas where flammable and combustible liquids are present and where traditional water-based systems are not adequate. Foam systems fall into three categories: Low Expansion, Medium Expansion and High Expansion foams. Water has been the traditional firefighting agent for centuries, but too much water combined with inappropriate firefighting techniques has had disastrous results. Gas systems are able to combat fires automatically in sensitive areas where it is best to avoid using water. Deluge systems have been used for open RO-RO cargo spaces (cannot be sealed) and they can be used as an option for closed RO-RO spaces. A deluge control station is often located at an outside from navigation bridge, engine control room and crew accommodation and the release is initiated from this place [13]. Closed spaces on RO-RO ships are usually protected with a low-pressure or high-pressure CO_2 system. Relevant safety checks should be carried out prior to the release of CO_2. CO_2 systems are more effective firefighting medium but those systems are not suitable for open vehicle deck and they have limited effectiveness in boundary cooling [14].

4. Fire Detection and Alarm System on RO-RO Ships

Analysis of reports casualty data in maritime accidents in recent years has identified several sources of fires within RO-RO vehicle decks (Figure 2) [15].

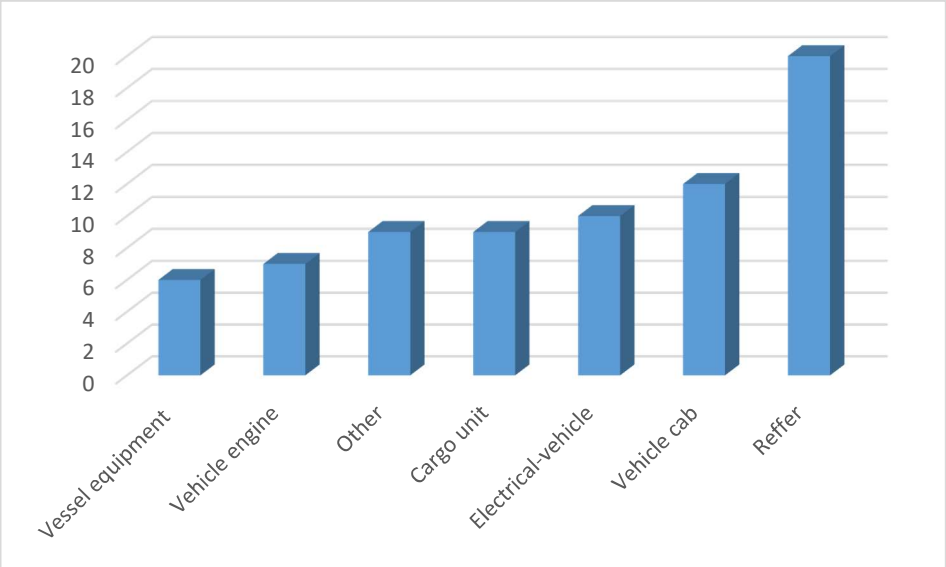

Fig. 2 – *Fires on RO-RO vehicle decks 1994-2011.*

The key finding in cases of fire incidents on car/RO-RO passenger vessels is that attention should be given to response time in the event of a fire incident. For quick action in fire cases, it is very important to have appropriate fire detection equipment.

The response of the detection and reporting system in time means reducing the scope of the fire and reducing the danger to passenger and cargo. System maintenance has an impact on the overall safety of the RO-RO ship. Today a typical fire detection systems on board RO-RO ships are consist of sensors and an alarm panel in fire station and on navigational bridge. That sensors can be with smoke, heat, flame and gas detectors. Detectors are provided a visible and audible alarm indicating the location of a fire on board ship. The detectors are wired to a fire control panel on navigational bridge and fire station. Fire detection systems on RO-RO ships can generally use:

- Thermal sensors,
- Smoke sensors, and
- Light (Photo) sensors (Flame detectors).

Thermal sensors react to the ambient air temperature and start to exceed the set value. They are used exclusively in spaces where a layer of heated air can appear on the ceiling. Smoke sensors are switched on and activated when smoke appears in the initial stage of fire development. These sensors are activated before the flame or heat sensors are activated. Light (photo) sensors detect flames by measuring the part of the light spectrum that appears in the flame. Since the signal reaches the detector at the speed of light, these sensors report in real time.

The mentioned systems have certain disadvantages. Therefore, the authors have been suggesting the use of optical sensors (fiber optic sensors) for the detection of fires in closed spaces on RO-RO ships.

5. Application of Optical Sensor Cable for Fire Detection and Alarm in Garages on RO-RO Ships

The optical fiber is increasingly being imposed as the most promising transmission medium because it was noticed a long time ago that there is a huge information capacity enabled by transmission systems that work at the frequencies of electromagnetic waves of light (information transmission capacity increases proportionally with the operating frequency of the system). Due to the characteristics of optical fibers, the application of optical technology in the field of sensors is increasing today. The optical technology must have properties of resistance to the specific conditions of the ship's environment (influence of salt, chemicals, temperature changes, humidity, vibrations, etc.) used on the ship.

Likewise, the lifetime of the optical fiber system will generally outlast the lifetime of a modern ship. The property of simplicity of self-diagnosis is also very important (the place of fiber optic damage is determined on the basis of light scattering with the use of a reflectometer). The optical fiber technology system has high reliability, which is of the particular importance on ship. It is also resistant to the effects of electromagnetic impulse interference, EM interference and radio frequency interference.

Depending of the sensor location, the optical sensor may be divided in two main groups: intrinsic or extrinsic. Optical fiber sensors for the fire detection in the cargo space of RO-RO ships proposed by Authors will be intrinsic sensors which are directly use an optical fiber as the sensitive part and also as the conductor to transport the optical signal with the measured information. In this type of sensor, physical perturbations modify the characteristics of the light carried by the fiber.

Starting from the use of optical fiber sensors for the fire detection and alarm in tunnels, the authors have been proposing the fire detection and alarm system be applied in closed spaces on RO-RO ships (garages) according to the principle. An optical fiber sensor would be installed on the ceiling of the RO-RO ship's garage. The fiber would be placed longitudinally above the center section of each parking lane as shown in Figure 3.

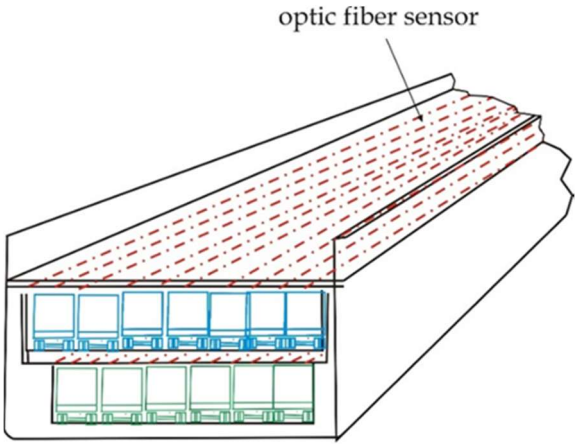

Fig. 3 - *Positioning of fiber optic sensors in the garage of the RO-RO ships.*

In this case, the fiber optic sensors would measure the temperature gradient and the maximum set temperature. This would enable the detection and progress of the fire within the sector of the parking lane, as well as the direction and speed of its progress. The advantage of this sensor is resistance to all harmful influences on the ship, it can also be an obstacle to the functioning of existing ship fire sensors. The fire alarm would be carried out

by a fiber optic cable, which would enable obtaining information about the fire in real time.

Fire optical sensors detection systems are long-term investments on ship's safety having benefit but also significant costs that are incurred for procurement and installation this system. It is therefore reasonable to assume that introduction of proposed fire detection should not be based solely on the expected benefits. A more obvious decision-making approach involves considering both the benefits and the costs of considered system. Cost-benefit analysis provides a systematic means of determination the benefits of the system against the associated costs. If the benefits and costs can both be expressed in monetary units, mentioned analysis provides an objective basis for determining if this investment is justifiable in the case of the considered RO-RO ship, the benefit can be considered through preventing the development of fire and possible harmful consequences. Because optical fiber sensors are immune to electromagnetic interference and do not conduct electricity, they can be used in hazardous environments where high-voltage electricity or flammable material such as jet fuel may be present. Optical fiber sensors can also be designed to resist high temperatures [16].

A Raman-OTDR is used for distributed temperature measurements. Sensing systems based on Raman scattering are used to detect temperature, allowing the monitoring of large area with a single instrument, which is applicable for cargo space on RO-RO ships. Also, he ability to measure temperatures at thousands of points along a single fiber is particularly interesting for monitoring cargo space on RO-RO ships [17]. Table 1 shows the basic characteristics the Raman-OTDR optical fiber sensors.

Table 1 - *Basic characteristics the Raman-OTDR optical fiber sensors.*

Type of optical fiber sensor	Raman-OTDR
Measurand	Raman scattering
Field	Engineering
Sensing Application	Real-time monitoring, distributed temperature sensing
Network Config.	Distributed sensing
Performance	Temperature accuracy of 0.5 °C at a sensing distance of 11.5 km, temp. range -200°C to +700°C depending on fiber cable, testing wavelength 1550 / 1625 nm, pulse width 5 ns to 1μs [18,19]
Procurement and installation costs	About $50,000 [20]

This type of sensor is increasingly present on ships and replaces the current sensor technology. Fire optical sensors detection systems is

especially suitable for places on board ship with high temperature (engine room) and vibrations. Advantages and disadvantages of fire optical sensors detection systems applicable on board ship are shown in Table 2.

Table 2 - *Advantages and disadvantages of fire optical sensors detection systems.*

ADVANTAGES	DISADVANTAGES
- Small size, - No requirement of electrical power at the remote location, - Precision in terms of detection location is very good even at long distances, - Resistant to electromagnetic and radio frequency interference, - Safe and suitable to be used in extreme vibration and harse environments, - Excellent flexibility, - Lower attenuation in the visible range, - Measure very small temperature changes, - Highly resistant to impact, extreme conditions, temperature and demanding environments, - Wide dynamic range and large bandwidth, and - Easy handling.	- Very expensive, - Detection systems may be complex, - Unfamiliar to the user and hence it requires basic training before they start using it, - Requires precise installation methods or procedures, -Complex to develop usable measurement systems using fiber optic sensors, and - Production of these types of sensors is quite complex.

The high procurement and installation cost of these sensors is the main optical sensor technology disadvantages and it is one of the main obstacles to the greater application of this system on board ships. Safety (based on the potential reduction in fatalities and injuries) and environmental protection enhancements due to a reduction in failures should be the main reason for installing these systems on board ships.

6. Conclusion

Car/RO-RO passenger vessels are specific in their construction as well as like the cargo they carry. The frequency of fires in the car/RO-RO passenger vessel segment is increasing and is currently at a level twice the frequency of fires on most other vessel types.

Adequate fire protection measures are necessary in order to reduce fire damage and prevent their spread and occurrence. The fire protection measures should enable quick intervention to reduce damage, as well as the engagement of people and equipment.

The use of optical fiber sensors has proven to be very successful in fire protection in road tunnels. Therefore, such an application in RO-RO ships

would certainly be very efficient, since it enables prompt notification, which is of great importance for fire protection. Especially in this regard, fires are one of the most dangerous types of accidents that might happen to a ship because they cause great material damage, also the loss of human life. High price of fire optical sensors detection systems can be the main reason why these systems have not found wider application on board ships.

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Submitted: 20/11/2022
Accepted: 29/04/2023

Sanja Arko Kariolić
Polytechnic of Rijeka, Occupational Safety Department,
Vukovarska 58, Rijeka, Croatia,
Email: arkosan@yahoo.com

Đani Šabalja
University of Rijeka, Faculty of Maritime Studies, Department of Nautical Sciences,
Studentska 2, Rijeka, Croatia,
Email: danisabalja@pfri.uniri.hr

Renato Ivče
University of Rijeka, Faculty of Maritime Studies, Department of Nautical Sciences,
Studentska 2, Rijeka, Croatia,
Email: renato.ivce@pfri.uniri.hr

Astrid Zekić
University of Zadar, Maritime Department
Mihovila Pavlinovića 1, Zadar, Croatia,
Email: astrid.zekic@gmail.com