Monitoring of the anchorage system of the harbour structure of Shahid Rajaei port third phase development project using fiber optic sensor

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ABSTRACT

The design and construction of the harbour structure takes a lot of time and cost to be put into operation, and its regular safety, surveillance and evaluation is no less important than the design and construction stages. The importance of this matter is revealed from the fact that in case of any defects and problems, it will lead to damage to this structure or in a critical condition, it will cause failure and the impossibility usage it. In addition to the loss of huge capital, it may also cause irreparable injuries. In this paper, while introducing the instrumentation of the structural health monitoring system, the investigation and monitoring of the strand anchorage system of the Shahid Rajaei port harbour (phase 3), which is the first project of the harbour structural health monitoring project in Iran, has been discussed. Among the various control instrumentation used in the structural health monitoring system of the mentioned project, strain gauges with Fiber Bragg grating (FBG) mechanism have been introduced and the obtained results have been analyzed. According to the evaluation on the measurement data and the graphs of control parameters, it can be concluded that the anchorage system of the harbour structure is in a desired condition.

1. Introduction

In the early 1970s, health monitoring systems were used to monitor the infrastructures and large elements of industrial plants in order to ensure the durability of the structures over time. Later, health monitoring systems were used to monitor all civil structures. Structural Health Monitoring (SHM) systems play a crucial role in detecting unusual structural behavior at an early stage. By utilizing SHM, the risk of sudden collapse can be reduced, thus ensuring the safety of human lives, preserving the financial costs of assets. Over time, SHM has shown its usefulness in reducing surveillance costs and optimizing rehabilitation actions. Geotechnical and structural monitoring in civil engineering, as a suitable method to control the behavior and increase the reliability of the safety of the structure and to modify the construction methods and finally, the possible arrangements for remedial operations in time, is one of the main components of every major engineering project. On the other hand, SHM includes the integration and usage of sensors that allow the loading conditions and damage of a structure to be recorded, analyzed and predicted [1, 2]. The strategy of SHM depends on several parameters such as the purpose of monitoring, the type of structure, the dimensions and materials of construction, loadings and how they are combined. Safety, assurance of the completed designs and evaluation of its efficiency and optimization, calibrating the used analysis model, evaluating the efficiency of the equipment and maintenance method used, predicting the behavior of the structure, are the main goals of instrumentation and monitoring [3].

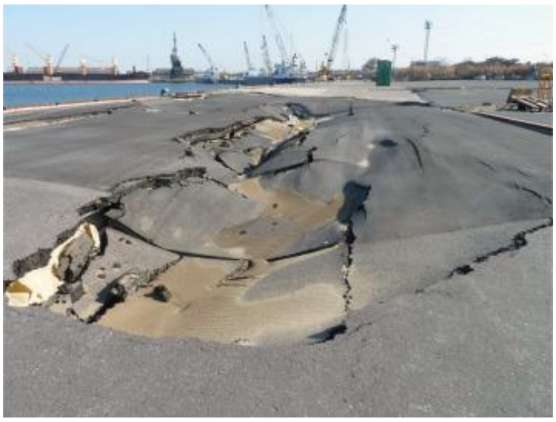
The success of a health monitoring system depends on the following two steps:

• Designing and implementing health monitoring based on a multidisciplinary team

• Extracting knowledge and making decisions with the support of health monitoring data

In addition to non-destructive testing methods such as tomography and acoustic emission methods, the use of sensor devices is essential for assessing the structural condition. Various types of sensors, either embedded within or attached to the structure, can be employed for this purpose. These include strain gauges, load cells, accelerometers, acoustic emission sensors, tiltmeters and among others.

The harbour are hydraulic structures that are used for ships to transport, load or unload cargo and passengers. These types of structures are one of the most important infrastructures in the transportation network of any country and one of the foundations of its economy. These structures, like other structures, often show behavior and warning signs before any type of instability, and the main goal of their behavioral analysis is to recognize these signs and predict instability in time. Numerous examples of damage to harbour caused by various loads, including earthquakes, etc., have been recorded all over the world. [4, 5] Figure 1 shows examples of harbour damage and failure.



(a

(b

Figure 1. Examples of harbour damage and failure, a) Wharf Area at Kashima Port, b) the Third Wharf Area of Onahama Port [4]

In general, damage identification in SHM are classified in four levels as follows [2, 3]:

First level: detecting the presence or absence of damage in the structure

Second level: the first level + determining the location of failure

Third level: the second level + the amount of severity of failure

Fourth level: the third level + estimated remaining life

The most important role of SHM is to obtain the safety status of the structure and maintain safety in operation. Therefore, by using the SHM (including observational methods, use of instrumentation, methods of laboratory or field tests), in addition to the knowledge of the stability, safety and durability of the structure, it is possible to ensure the quality of maintenance and operation.

2. Harbour structure of Shahid Rajaei port third phase development plan

Ports & Maritime Organization of Iran started the third phase development project of Shahid Rajaei Port based on the possibility of berthing with a capacity of EU18400 and increasing the port's capacity by 1.2 million TEU from the end of June 2017. The target project is located in Hormozgan province and 23 km west of Bandar Abbas. The harbour structure includes a row of T-shaped quay wall adjacent to the water, a row of piles in order to bear the loads caused by the rail of the crane and a row of restraining and anchorage piles to control the displacement of the quay wall by means of strand anchors. The main forms of failure of this type of coastal wall are the sliding of the shield wall (or quay), the general deflection of the coastal wall, the lack of proper compaction of the back embankment and the rupture of the strand anchors system. The reasons and factors affecting this type of failure are the following:

1. High depth of dredging in front of the wall and subsequent rotation of the wall.

2. High loading under which it can increase the bending moment in the wall and its failure, increase the displacement of the wall and failure of the strand anchors.

3. Increasing the life and aging, corrosion and failure of metal components and complex structural members, which may lead to a decrease in the capacity of structural members.

4. Unbalance of anchorage quay wall [6].

To calculate the changes created in the wall, from the analytical and numerical modeling methods, it is possible to calculate the values of the bending moment created in the desired cross section and the corresponding post-tensioning force from the side of the restraining and anchorage system. Also, the displacement caused by each of the forces in the state of operation and the state of dynamic loads such as the collision of water waves, the movement of machinery, the impact caused by the ship's mooring, seismic loading and other possible loads are also calculated. The main parameter involved in these calculations is the force in the anchorage system. Therefore, knowing the post-tensioning load in the anchor, its value can be compared with the predicted values at any moment.

In this project, the quay walls have T-shaped sections, which are sewn to the row of anchorage piles with a bracing row as shown in Figure 2. Strand anchors consisting of 19 strands of 7 cables, which according to the design report, have a final capacity of approximately 510 tons, which are stretched and tensioned to a maximum of 30% of the final capacity to control the movement of the wall, and often according to the pre-tensioning tests, about 138 tons are pulled.

3. Instrumentation and structural health monitoring system of harbour of Shahid Rajaei port (phase 3) development

Instrumentation to monitor the structural health of Shahid Rajaei port harbour include fiber optic strain gauges, fiber optic thermometers, electric piezometers, accelerometers, tiltmeters/inclinometer and meteorological stations. This plan for instrumenting and monitoring the health of the harbour structure is the first plan in Iran, and the type of equipment and mechanisms used are also used and measured for the first time. Figure 3 shows the cross-section of the instrumentation and health monitoring system drawing of the harbour structure. In recent years, with the progress made, one of the methods for detecting structural damage is the methods based on dynamic and vibration based approach. In this way, during the operation of a structure, the induced cracks of the structure may increase continuously and finally cause the structure to be destroyed. The impact of cracks in the structure is in the form of local changes in stiffness, and these changes have a significant effect on the dynamic characteristics of the structure, which causes the natural frequency of the structure and shape modes to change, and by analyzing these changes, it is possible to identify cracks or damage. By using accelerometer sensors, the health monitoring of structures is based on this basic idea, that the dynamic characteristics of a structure are a function of its physical characteristics. Therefore, changing the physical characteristics of the structure caused by the damage caused to it can change its dynamic characteristics. As a result, the vibration data of the structure is collected, and it is used to identify the damage of the structure. For this purpose, triaxial accelerometers have been considered and installed for the harbour structure of this project at certain intervals along the harbour, so that the vibration changes and natural frequency of the structure can be investigated. Considering the type of quay wall structure and its burial in the soil, the location of the accelerometers on its crown is installed inside the manholes.

Another instrument of the project monitoring system plan is a biaxial titlmeter on the quay wall, so that by using it, the changes in the inclination of the wall crown due to displacements are measured. In this way, in case of deflection from the wall or rotation of the wall, you can use this instrument to monitor the changes in the inclination of the wall. In order to check the changes in the displacement of the quay wall under the influence of the displacements on the upper side of the wall and on the sea side, biaxial are monitored online by tiltmeters. The tiltmeters have been installed in the vicinity of the accelerometers in the manhole located on the top of the quay wall. Both of these instruments have integrated data loggers and are of wireless data transmission type. The reading is done automatically and the collected data is transmitted to the control room as wireless.

Other control parameter of the quay wall is changes in water height and piezometric level behind the wall and sea water level. In order to obtain the pattern of water changes behind the wall with the sea water level, as well as predicting the state of the structure and the possibility of failure by comparing the water head changes by installing piezometers installed behind the quay wall, it is checked. Considering the water level on both sides of the wall, one side of which is the level of sea water and the other side of the water level behind the wall, and its connection can be checked. Piezometer measurement data is transmitted to the control room as wireless by installing a wireless data logger inside the manhole.

In this paper, among the various instrumentation, the method of installation and measurement results of fiber optic strain gauges have been investigated and discussed. It should be noted that the wireless data logger and wireless data transmission of instrumentation have been launched for the first time in monitoring and instrumentation projects in Iran.

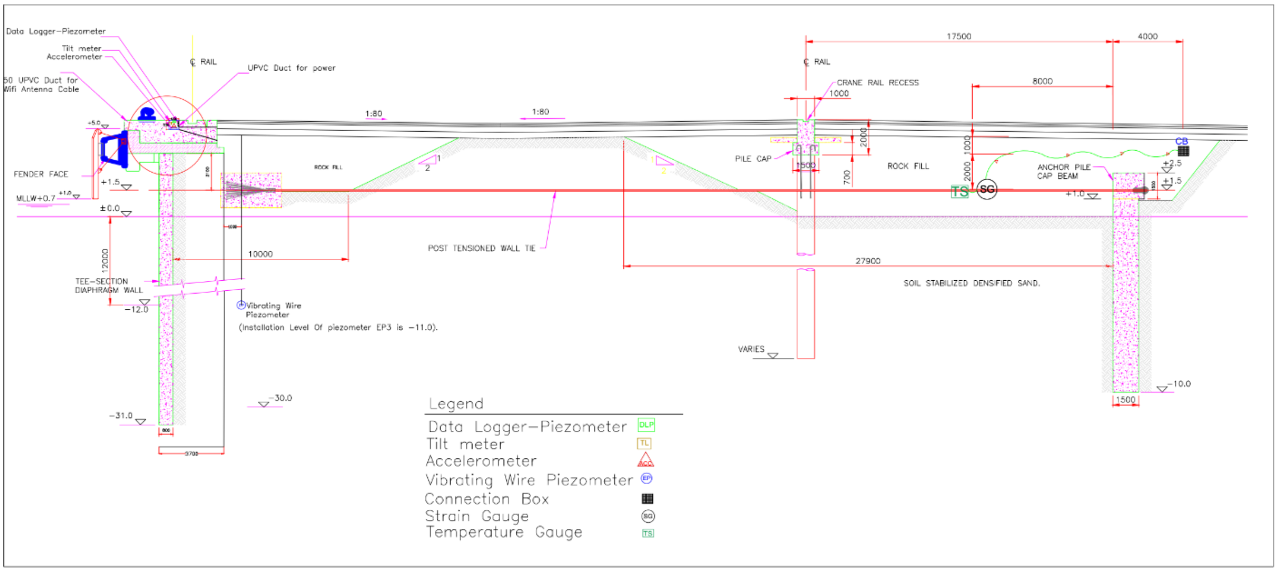


Figure 2. Cross-section of SHM drawing of harbour structure of Shahid Rajaei port (phase 3) development

4. Monitoring the anchorage system using a strain gauge sensor

4-1 Fiber optic sensor (FOS)

One of the most common consequences of applying a force in any structural element is its deformation. The measurement of the strain is one of the possible forms to measure the deformation of an object, and is usually sensed by using strain gauges [7]. The application of SHM systems based on Fiber Optic Sensors technologies has been widely explored in the field of Civil Engineering. Typically, these systems are implemented in large concrete or steel structures such as bridges, power plants, high-rise buildings and transmission capabilities. Optical fiber sensors offer numerous advantages, including immunity to electromagnetic interferences, chemical inertness, high-temperature resistance, and potential for compact and lightweight designs. Additionally, multiple measuring points can be multiplexed along a single optical fiber, allowing for fully distributed measurements with high spatial resolution [8]. One crucial attribute of this technology is the ability to multiplex numerous FBGs in the wavelength domain, facilitating the development of highly effective quasi-distributed sensor systems. Furthermore, FBG technology enables the creation of sensors with linear output, increased sensitivity, wide dynamic ranges, high resolutions, immunity to electromagnetic interference, and flexible sizes (ranging from 0.1mm to several centimeters), among other desirable characteristics [9].

In recent years, fiber optic sensors, specially Fiber Bragg Grating (FBG) type, have been widely used in various fields as they allow for both static and dynamic monitoring of strain and temperature. Fiber optic sensors have been used for more than a decade in civil engineering applications in SHM of bridges, and other structures. The fiber Bragg grating (FBG) technology has been rapidly applied in the sensing technology field. Among these applications, we can refer to its use in civil engineering structures, aerospace, marine, oil and gas, composites and smart structures [10]. FBG sensors have many advantages for strain sensing in structural health monitoring applications including the ability to measure localized strain and temperature and the potential to multiplex hundreds of sensors with a single ingress/egress fiber. FBG is a permanent periodic modulation of the refractive index in the core of a single-mode optical fiber [11]. FBG sensors are characterized by light weight, small size, resistance to neutralization and corrosion, immunity to electromagnetic interference, ease of multiplexing, and versatility (they can measure strain, temperature, pressure, and vibration) [12]. When a broad spectrum of wavelengths is passed through the FBG, a narrow bandwidth of wavelengths is reflected, while all others are transmitted. The principle of operation and mechanism of FBG sensor is shown in Figure 3. Any change in the control parameters such as force, temperature, etc., changes the index of refraction of the core and the grating period time, and then causes a change in the wavelength of the reflected light [13]. Due to the mechanical deformation of the fiber, period of the fiber Bragg grating will change. Bragg wavelength is essentially defined by the period and refractive index of core. This alteration is related to variation of the refractive index modulation spatial period using Bragg's law. The Bragg condition is calculated through the following expression:

$$\lambda B = 2neff\Lambda \tag{1}$$

Where in Eq.(1) λB is the central wavelength of the reflected light, $neff$ is the effective refractive index index of the fiber core, and Λ is the grating spacing. When incident broadband light travels through an FBG, a narrow spectrum S(λ) is reflected backward, while the remainder of the spectrum travels through the FBG. The sharp reflection peak is centered at the Bragg wavelength λB [14].

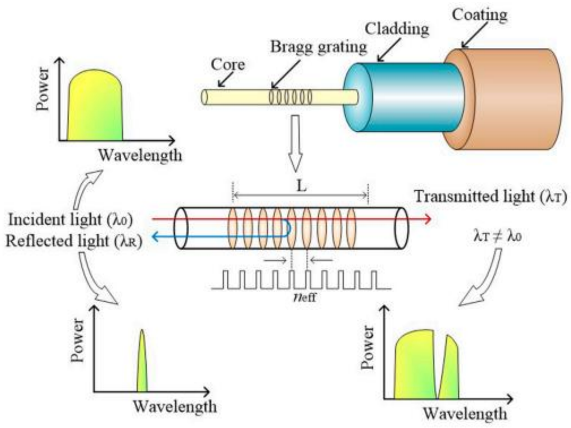


Figure 3. Principles of FBG sensor technology and mechanism [14]

As mentioned before, in recent years, various researches have been studied on the applications of fiber optic sensors, especially the technology and mechanism of FBG sensors, in the production of instrumentation and their performance, some of which are mentioned below. In 2009, Huang et al. studied on harbour health monitoring. As a result of their research, they indicated that fiber optic sensors are a suitable option for harbour health monitoring [15]. In 2011 Habel and Krebber investigated different types of fiber optic sensors to determine different control parameters including strain distribution and soil anchors [16]. In 2014, Liu used fiber optic sensors to determine the strain as well as the damage mechanism of pipes used in drilling in oil fields [17]. In 2014, Ye et al devoted to providing a summary of the basic principles of various fiber optic sensors, innovations in measurement and calculation methods, development of new fiber optic sensors, and the status of practical application of thier technology in SHM for civil infrastructures [18]. FBG sensors have been employed to monitor the structural health of bridges by measuring strain, temperature, and deflection. They provide valuable data on the behavior and integrity of bridge components, such as beams, girders and cables. An example of FBG monitoring can be found in the circular pedestrian steel bridge in Aveiro, Portugal. In this case, metallic transducers were welded to the bridge structure, forming a star configuration with 32 strain transducers and eight temperature transducers distributed across eight branches. Another instance is the monitoring of the Viaducte des Vaux Bridge, a concrete bridge equipped with 12 FBG-based strain transducers. These transducers were affixed to the interior walls of a section of a box girder [19, 20]. Li et al. in 2009, used the FBG sensors for minoring of the deformation and strain of the cable into the stay cables in the Tianjin Yonghe Bridge in China [21]. Other notable structures, such as the Taylor Bridge and the Navas viaduct, have also been equipped with (FBG)-based sensors monitoring systems. In the Taylor Bridge 63 FBG transducers have been installed at various locations along the girders. Similarly, the Navas viaduct, comprising ten identical sections separated by two piles each, incorporated a SHM system developed by the University of Cantabria. This system featured 42 FBG transducers capable of measuring both temperature and elongation. These transducers were positioned on top of one pile and between two piles of the sections [9].

In 2015, Huynh et al., conducted a research with the aim of monitoring the prestressing force in pre-stressed concrete (PSC) beams, and estimating the effect of temperature on the changes of prestressing forces. They used fiber optic sensor for this purpose. They stated that this type of instrumentation monitors well the prestressing force and the effect of temperature on it [22]. Dewra et al., in 2015 reviewed various FBG applications, including their use in determining strain in structures such as bridges [23]. In the same year, Chen et al., investigated the use of FBG sensors to determine the strain in single-headed beams and compared it with the results of other strain determination methods. The results of these researchers showed that the use of fiber optic sensors leads to more accurate results [24]. Harmanci et al., used FBG sensors to determine the strain in a concrete structure in 2016 [25]. In 2017, Kim et al., used fiber optic strain gauges to determine the strain in the strand anchors. They proposed a method to increase the strain measurement range using polyimide tubes [26]. The research conducted by Zhang et al., in 2018 showed that the use of fiber optic strain gauges provides reliable results in determining the axial strain in anchors [27]. In 2019, Fu et al., used FBG sensors to determine the force in anchors. They stated that the use of these sensors in large structures provides reliable results [28]. Lecieux et al., reviewed the wharf health monitoring system in France in 2019. They used fiber optic instruments for this purpose [29]. Kwon et al., used fiber optic strain gauges to determine the axial force applied to the strand anchors used in soil slopes. They also provided a method to increase the correlation coefficient between the anchor force and the strain field [30]. In 2021, Braunfelds et al., used strain gauge sensors and fiber optic thermometers for installation in asphalt road and investigated the effects of traffic on it

[31]. The research results of Yang et al., in 2021 showed that the strain change and crack propagation in reinforced concrete beams are well controlled by FOSs during the loading process [32]. In 2022, Guo et al. used FOS to investigate the strain mechanism and determine the axial stress characteristics of anchor bolts in a rock media. They emphasized that these sensors are a reliable to determine the strain in bolts [33]. The use of FOSs on the smart strands of the bridge and the investigation of the effects of temperature on the results were carried out by Jeon et al., in 2022. They provided a relation for the temperature correction [34]. A great influence of FBG technology can be observed, due to the substantial improvement in terms of reliability that can generate [35].

These examples showcase the versatility of FBG-based monitoring systems in different types of structures, providing valuable data for assessing structural behavior and ensuring their long-term integrity.

According to the instrumentation plan in 900m length of Shahid Rajaei port harbour, 66 FBGs type FOS strain gauges and also fiber optic thermometers for thermal correction of strain values in 17 loops have been installed. The accuracy of the used sensor was < 2μm .It is possible to take reading the sensors in the connection box manually as well as online and automatically in the control room datalogger. These instruments and its accessories such as data logger are made by Sylex company. Figure 4 shows the locations of the strand anchors and the sensors and routing cables. As seen in this figure, the strain gauges and temperature gauges have been connected to a connection box using fiber optic cables and from there they have been connected to the located automatic data acquisition system in control.

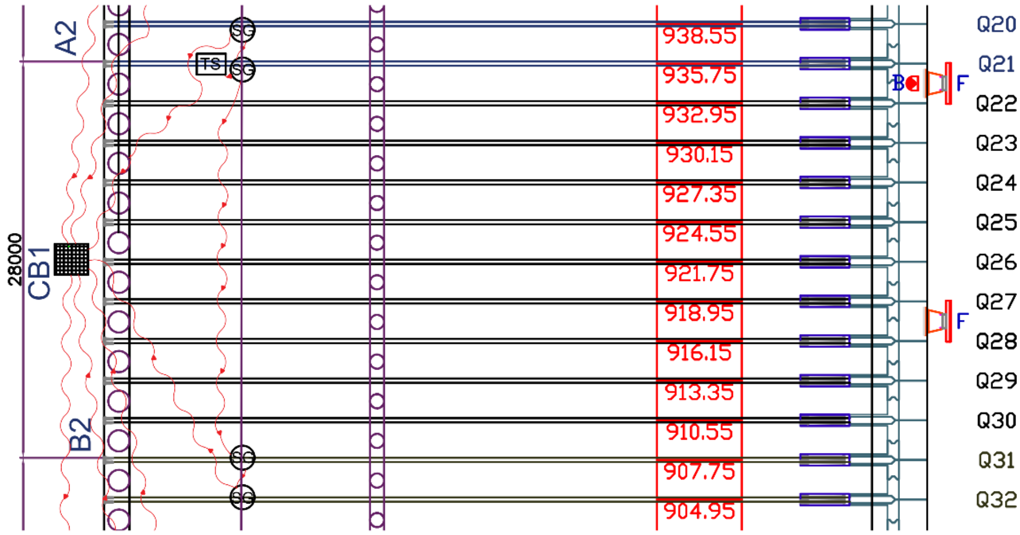


Figure 4. Plan of a part of the harbour and location of strain gauges, thermometers and routing cables

Finally, the installed sensors are automatically take reading in the control room. The datalogger comes with Sentinel software to record readings and data analysis. Data collection is one of the most important parts of modern monitoring systems. This software provides facilities for analysis, collection, storage, management and transmission of FBG-based measurement data and allows the user to set data logging at specific time intervals.

4-2 Installation procedure of FOS strain gauge

Installation procedure of FOS strain gauge, which is innovatively designed and carried out, includes the following steps:

1- The strands of the anchorage system have a HDPE protective sheath and are placed inside the sheath. At a distance of about 8 meters from the retaining and anchorage pile, in the position of the strain gauge sensors on the desired strand, about 1.5 meters, the diameter of the protective sheath has been increased. The increase in diameter, as seen in Figure 5, has been done by using two trumpet sheath tubes. Before connecting the 180 mm diameter sheath to the trumpets, a 225 mm HDPE sheath with a length of about 90 cm was placed around the 180 sheath. The larger 220 mm diameter sheath moves telescopically.

2- At a distance of about 10 cm of the trumpet, about 90 cm length of the upper part of the 180 mm diameter sheath has been cut and removed.

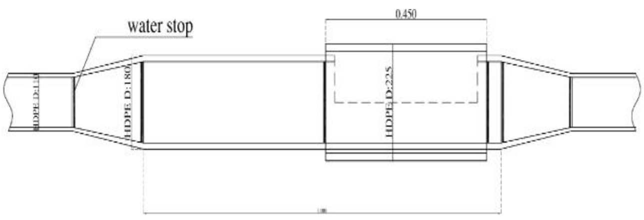


Figure 5. The sheath used for installation of strain gauges

3- Spacers (steel spacers) which were designed and prepared according to Figure 6, have been installed inside the sheath dia.180mm and at a distance of 90 cm in the place of the removal sheath. Spacers had a galvanized coating and the purpose of using them is to separate one strand from the cluster of 19 strands, so that the strain gauge sensor can be installed on one strand.

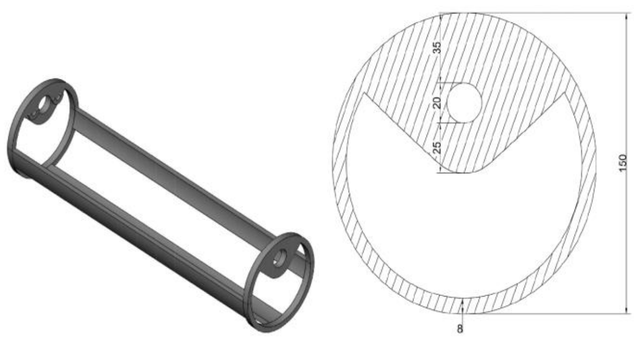


Figure 6. Spacer of Strands

4- The next step is the filling of materials on the sheaths of the anchoring system, and connecting the beginning and end of the strands to the structures, and then stretching and prestressing them.

5- at this stage, the embankment materials of the cutting region of the sensors installation position are removed and the sheath is moved telescopically. Therefore, the cutting part is exposed to access the strand for installing the sensors.

6- The strain gauge sensors have been installed on strand number 19, which is separated from other strands by a spacer. The sheath dia. 225 mm are re-installed on the removal region. Two holes have been created on the sheath dia. 225 mm, to transfer the fiber optic cable to the ground surface. If both the strain gauge and the thermometer are installed on the strand, the fiber optic cable is connected in series from the strain gauge to the thermometer inside the sheath, and finally the two cables inside the protective PVC tube. Then they were connected to the corresponding connection box through the protective tube.

7- All the connections of the hoses and the outlet of the sheath and tubes were blocked using foam.

8- In order to prevent possible damage to the cables, they were protected by a sheath connected to the mentioned protective tubes.

9- Between the trumpet tubes and the 180 mm sheath, as well as the 180 and 225 mm sheaths, are sealed with glue. Also, for more reassurance, a waterstop has been implemented around the sheaths at the connection of the trumpet to the 180 sheath and the 180 and 225 sheaths to each other. Finally, to further protection the sheath and cable protective tube, concrete has been poured on them.

10- Then the operation of injecting the corrosion protection grouting inside the sheath of the strands is performed. To ensure that the sheaths are completely filled with the grout material, after the air inside the sheath is discharged and the grout exits from the air hose, the injection operation continues for 10 seconds, and then the air hose outlet is blocked. Figure 7 shows the installation steps of fiber optic strain gauge sensors.

Figure 7. Installation steps of fiber optic strain gauge

4-3 principles of strain measurement and calculation

The following expressions are used to measure the amount of strain:

$$\Delta\varepsilon = \frac{\Delta\lambda - B.\Delta T}{A.\Delta l} + \Delta T \cdot CTE_{SS304} \cdot \Delta l_2 \qquad (2)$$

$$\Delta\lambda = \frac{\lambda_{act} - \lambda_0}{\lambda_0} \qquad (3)$$

$$\Delta T = \left(T_{act} - T_0\right) \qquad (4)$$

$$\Delta l = \frac{l_{FAL}}{l_{FFL}} \qquad (5)$$

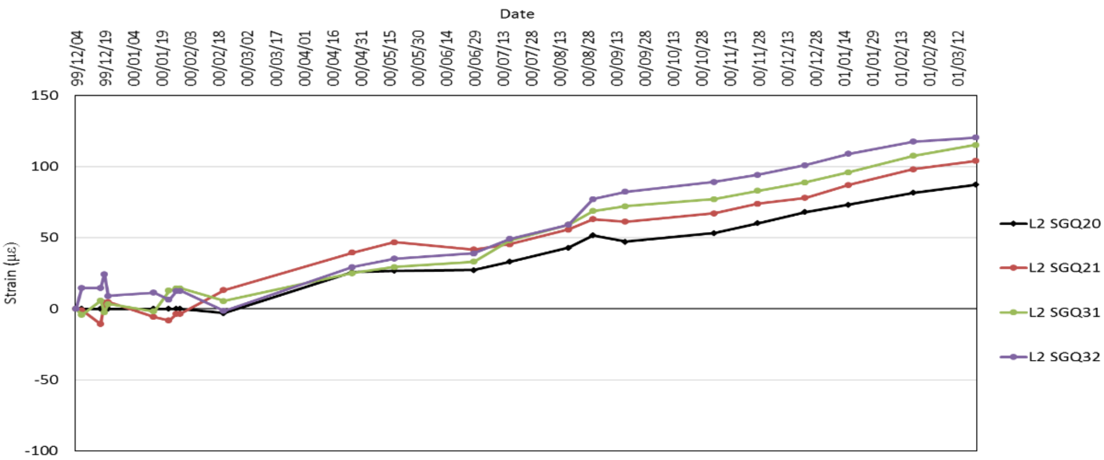
$$\Delta l_2 = \frac{\left(l_{FAL} - l_{FFL}\right)}{l_{FAL}} \qquad (6)$$

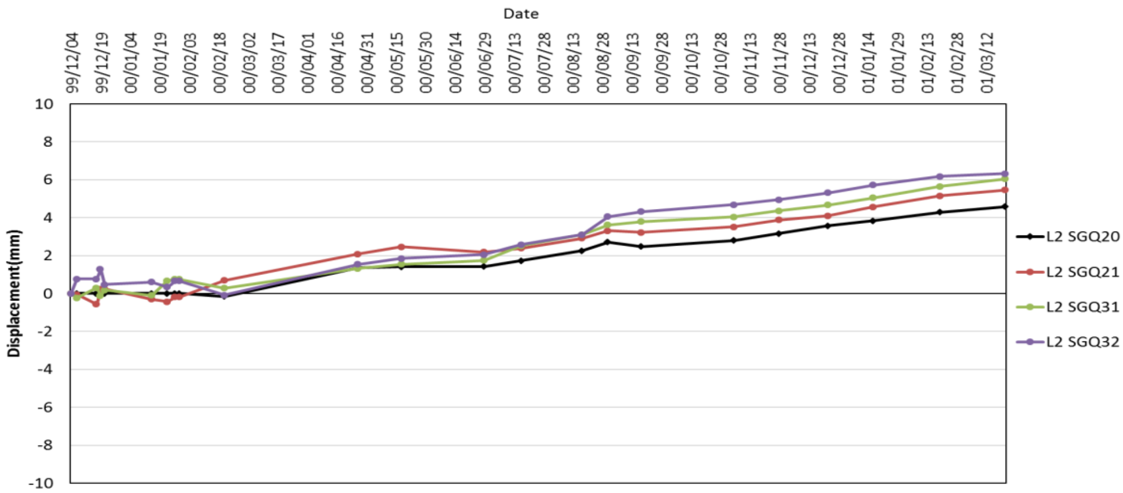
Where the parameters of the above expressions are as follows: $\Delta\varepsilon$ Strain change [$\mu\varepsilon$], λ_0 initial strain wavelength [nm], T_0 initial temperature [$^\circ C$], L_{FAL} anchorage length [m], T_{act} actual temperature [$^\circ C$], λ_{act} actual strain wavelength [$\mu\varepsilon . ^\circ C^{-1}$], L_{FFL} free fiber length [m], CTE temperature correction factor] [nm and A and B are the strain coefficients whose values are provided in the instrument calibration sheets.

4-4 Results and analysis of strain measurement data

As mentioned earlier, strain gauges have been designed and installed in 17 loops along the harbour. In this paper, the diagrams of strain, cumulative displacement and changes of applied axial force are presented for monitoring the strand anchorage system. Temperature and strain are obtained directly from the measured data from the sensors. After applying the thermal correction, it is possible to calculate the amount of displacement and changes of force applied in the strands using the relevant calculations. By comparing the measured force and the allowable force of the strands, the condition and behavior of the structure can be investigated and evaluated. In the following, as an example, the graphs of cumulative strain changes, displacement and daily displacement rate (mm per day) for Loop 2 have been evaluated (Figure 8). According to Figure 8, as can be seen in the figure, the process of increasing the strain in the strands has started after the dredging operation of the front deck has started. Also, after the earthquake near Bandar Abbas city, the strain values have been increased, however, these values were not significant, and after that, the change process was relatively constant and stable. In general, dredging in front of the quay wall and earthquake (Aban 23, 1400, solar calendar) can be mentioned among the factors affecting the occurrence of strain increase and displacements. Considering that the readings of the sensors were done before and after the start of dredging, therefore, the effect of dredging operation on the behavior of the strands can be investigated. Moreover, displacement may not occur immediately after the start of dredging and its impact can be seen gradually over time. Also, the distance of the dredging site from the quay wall and the speed of the dredging operation are important factors affecting the behavior of the strands. The dredging operation started on 3/12/2019 (solar calendar), and according to the planing, readings and measurements of the sensors were recorded at the mentioned time. The dredging operation first started from the 900 kilometer location, which affected the sensors installed near this location.

As mentioned earlier, the installation of strain gauges and fiber optic thermometers has been done after pre-tensioning. According to the results of strand quality control tests and based on the design report, the final capacity of each of the strands of the restraint system is about 26 tons. In this case, the final capacity of each strand of the anchorage system, which includes 19 strands, will be approximately equal to 510 tons. In the pre-tension, about 30% of the final capacity of the strands, that is, approximately 138 tons, are pulled out. By measuring the changes in the axial force applied to the strands, it is possible to calculate the amount of axial forces in the strands during different stages of the project and compare them with the allowed load capacity.





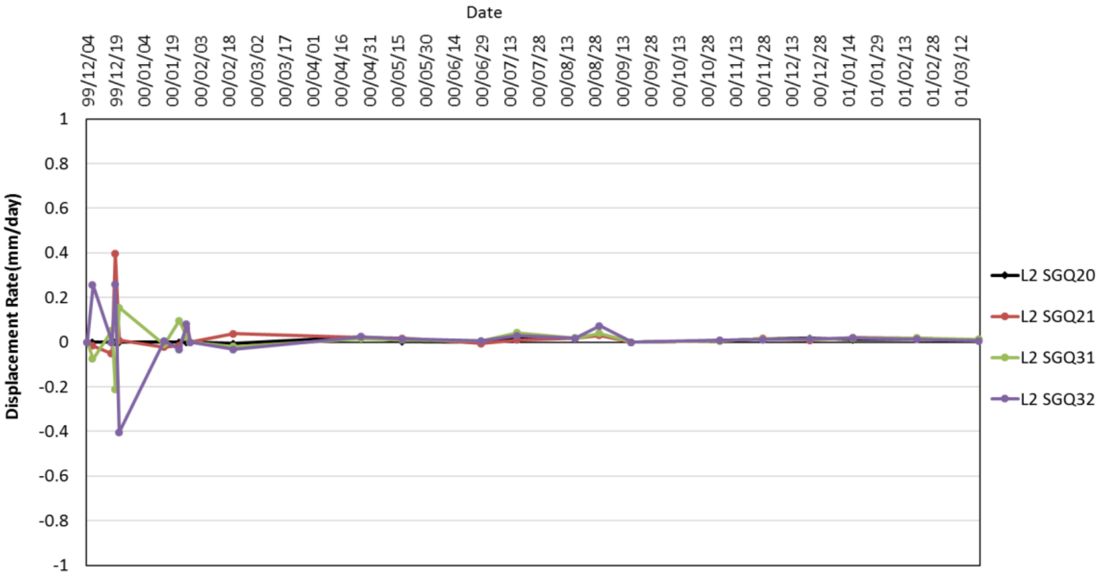


Figure 8. Change diagram of (a) cumulative strain, (b) displacement, (c) daily displacement rate (mm/day) for loop 2

Figure 9. shows the graph of the axial forces applied to the anchors for loop 2 as an example. It should be noted that the amount of axial forces obtained from the installed strain gauges are all within the allowable limit. The amount of changes in applied axial forces can vary according to the dredging in front of the deck wall as well as the step-by-step construction phase.

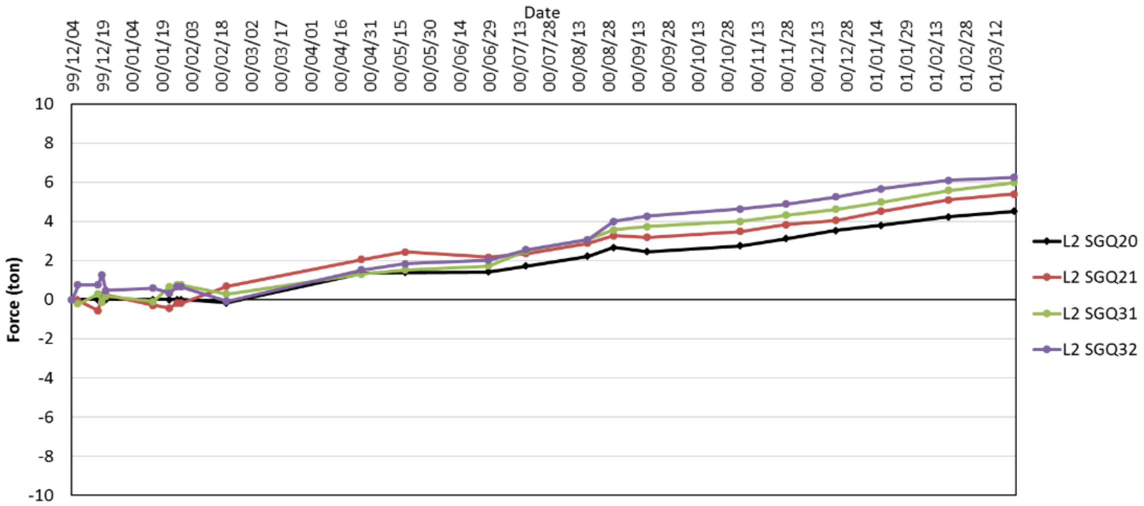


Figure 9. Change diagram of the axial forces applied to the anchors for loop 2

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5. Conclusions

Based on the assessment made on the data obtained from the monitoring of the strand anchorage system using optical fiber strain gauges and the different drawn graphs, it can be concluded that the habour structure of Shahid Rajaei port third phase development project is in a favorable condition in terms of safety at the end of construction. In this paper, the behavior of harbour structure has been analyzed based on the data of the fiber optic sensors during the construction and the operation. The following results can be mentioned that the values and trends of the strain changes and displacements in the anchorage system obtained from the measurements of the strain gauges' data show that this control parameter in terms of values and trends are acceptable and indicate the acceptable performance of the anchorage system. Also, no significant increase in axial force is observed in any of the measurements even after the earthquake occurred during the construction. It is recommended to use the innovative method as well as the instrumentation plan of the structural health monitoring system of harbour for similar projects. The fiber optic strain gauges offer a promising solution for monitoring anchorage systems in harbor projects, providing reliable and real-time data on structural health.

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