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Geomonitoring of the foundation of a high-rise building applied fiber optics

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ABSTRACT: New technologies in building and high-rise monitoring make it possible to track damage and defects in existing structures and infrastructures. The need for timely detection of defects in building structures using fiber optic sensors is increasingly prompting planners, builders and facility managers to use the capabilities of a powerful system such as DFOSS. In addition to the well-known advantages, they are the most reliable in conveying the stress-strain state of the structure in the long term. The main objective of any construction project is safety for people, which can only be ensured by proper monitoring of the condition of the building, where the presentation and management of the resulting information on changes in the system and structure can be ensured with DFOSS.

1 INTRODUCTION

The condition may deteriorate over time, resulting in a serious and ongoing issue for the operating company. Evaluating the genuine state of crumbled structures is important for opportune distinguishing proof of deformities and settling on conclusions about suitable fixes.

Because of the enormous number of maturing frameworks, including noteworthy designs, observing the state of designs has started to assume a powerful part during the activity and upkeep period of the primary life cycle the board interaction.

SHM works with the observing and assessment of primary properties, which streamlines underlying upkeep costs and further develops underlying wellbeing [Buranbayeva, 2022].

Structures have various responses under various burdens during their life cycle, which can be estimated by utilizing SHM frameworks and sensors to acquire data about the changed boundaries and components. Observation and measurement of design, condition assessment, information management, planning and decision-making, repair execution, and evaluation of repair and maintenance performance are the primary stages of condition monitoring [Agdas, 2016], [Huston, 2016].

Utilizing a distributed fiber optic monitoring system will make structural condition assessment in sanitary monitoring more efficient and accurate. The construction sector can benefit greatly from DFOSS's use.

The limitation of a structure's deformations and/or stresses is frequently the foundation for engineering design standards. This is significant because deformation indicates the potential degree of damage that has occurred and is a measure of how close the construction material is to its strength capacity. This is significant on the grounds that disfigurement is a proportion of how close the material of development is to its solidarity limit, and hence shows the likely level of harm that has happened.

There is a long history of applying solid checking strategies to take care of structural designing issues. For instance, vibrating wire or metal foil strain checks are notable devices for estimating resist individual focuses in a construction. Because the strain distribution is a function of the end conditions and the applied load, they are typically suitable for determining the

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complete strain profile within structural components like beams or columns. However, foundations, tunnels, and pipelines—all of which interact with the ground—are exempt from this.

Since the soil loads are dispersed in these situations, it is impossible to fully comprehend the structure's state without knowing the entire site strain profile [Soga, 2015]. Problems caused by soil heterogeneity, such as deformations, rotations, and unevenly distributed soil and structural force interaction forces, can be identified with the assistance of knowledge of the continuous deformation profile. Conventional pinpoint strain measurements can miss such problematic areas [Soga, 2014]. FO distributed strain sensing became a tool to provide continuous strain profiling and, as a result, enhance our comprehension of civil structures around the middle of the 2000s.

For more than a decade, DFOSS has been used to measure the strain in civil engineering structures. It is now used worldwide to monitor a variety of structures, including diaphragm walls, tunnels, bridges, piles, dams, embankments, and bridges.

DFOSS depends after backscattering when lights communicated along an optical fiber. One standard ticular part of the backscattered light is created by Brillouin dissipating. Anytime along a fiber, the recurrence of Brillouin backscattered light relies on the strain and temperature by then. Considering the impact of temperature thusly, the strain anyplace along a fiber can be reasoned by communicating beats of light down the fiber and dissecting the recurrence of backscattered light.

DFOSS presents a novel approach to strain measurement in comparison to the utilization of isolated strain gauges in that:

1. The continuous strain profile along a structural element is returned by DFOSS. It is possible for strain gauges to miss vital strain variations between gauges because they can only provide discrete pointwise readings.
2. Electromagnetic interference does not affect optical fiber backscattering.
3. Pure, inert and extremely stable silica forms the core of optical fibers. The filaments in this manner oppose consumption, don't taint the neighborhood climate and have a design life estimated regarding many years.

Optical filaments can work over a lot more extensive scope of temperatures than most electronic gadgets.

Because of their small size and lack of intrusion, optical fibers are simple to incorporate into both new and existing structures.

The total strain profile can be recuperated for a fiber extending a few kilometers, potentially supplanting a huge number of discrete sensors. Installation is greatly simplified by using a single cable.

Because of the continuous improvement of DFOSS read-out units, a DFOSS framework inslowed down presently can profit from potential upgraded estimation capacities later on.

2 ENGINEERING-GEOLOGICAL INVESTIGATION OF THE CONSTRUCTION SITE

The site of the experiment was in Astana city, in the basement of the tallest building complex in Central Asia - Abu Dhabi Plaza, 320 meters high. Abu Dhabi Plaza is a complex high-rise building with a retail and leisure podium and a hotel cluster at the base that rises to form a series of office and residential towers to the north – a creation of the famous British architect Norman Foster (Figure 1).

The raft construction process is shown in Figure 2, the complex consists of several buildings, where fiber optic cable monitoring was carried out in 3 of them, blocks R, Z, Y. Block R is the tallest building in the complex and is a 75-storey residential building with a 4-storey underground parking at the base. The foundation structure of the building consists of a pile raft including Auger Cast Piles 1,125 m and boring piles with a diameter of 1.2 to 1.5 meters (Figure 2).

The length of the piles varies depending on the height of blocks from 13 to 25 m from high-strength concrete with an exposure durability of 40 MPa. The raft is built form the C28/35 concrete. The maximum design excavation level for the construction of a raft for block R was 19.30 m. The basement floors consist of 4 levels from B1 to B4 of the lowest.

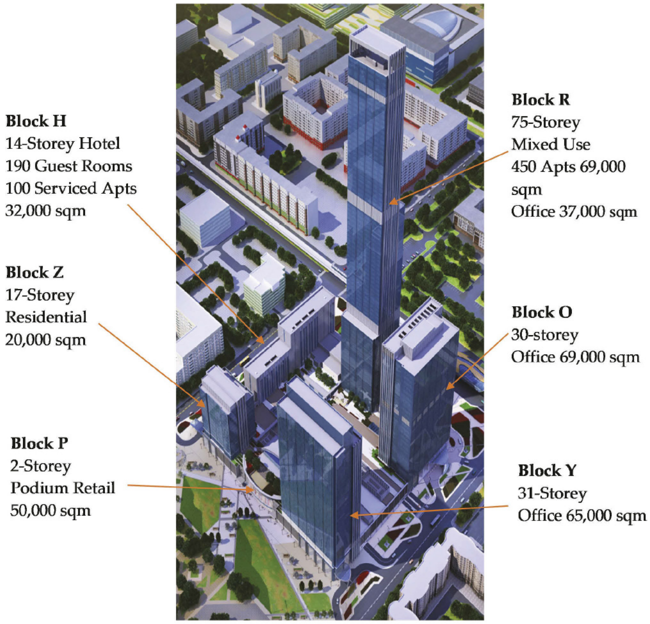

Figure 1. Abu Dhabi plaza building complex.

Figure 2. Construction site.

3 FIBER OPTIC MONITORING SYSTEM

3.1 *Design of distributed fiber optic strain sensing system (DFOSS)*

The proposed DFOSS system comprises a grid of fiber optic cable bonded to the B4 slab linked to an analyzer located in a temperature- and humidity-controlled room at B1 level.

On the B1 level, there is an analyzer of the monitoring system for temperature and strain data collected via distributed fiber optic strain sensing system (DFOSS) from B4 level (Figure 3). The applied DFOSS system transmits the signal via a grid of fiber optic cable to the B4 raft linked to an analyzer located in a temperature- and humidity-controlled room at B1 level.

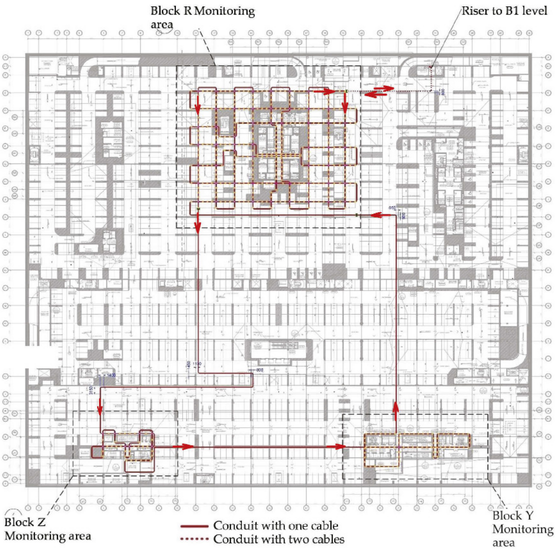

Figure 3. Part plan of cable routing in block R monitoring area on B4 raft.

3.2 *Analyzer and analyzer room*

The analyzer must operate within specified environmental conditions and so must be located inside a room whose temperature and humidity are controlled. The analyzer room will also accommodate the logging system and computer required to interface with the Internet and as such the room must be supplied with uninterrupted electrical power and a high-bandwidth Internet connection and must be sufficiently spacious for two operatives to work comfortably inside. A summary of the analyzer specification is presented in Table 1.

Table 1. Specification for analyser.

Parameter	Value
Spatial resolution	≤ 1.5 m
Optical budget	≥ 11 dB
Measurement resolution	≤ 22με
Distance range	≥ 2.09 km
Gauge length	≥ 2 m
Measurement range	≥ 1.5 %
Measurement interval	≤ 3hrs
Operational period	≥ 70 yrs
Data acquisition	Remote control and transmission via internet

Note – Optical budget includes both strain and temperature measurements cables configured in a loop

Particular consideration must be given to the routing of the fiber optic cables into the analyzer room from the riser used to route the cables to B4 level. The cables may be routed in channels cut into the B1 slab in a manner similar to the channels in the B4 slab. Running the channels through doorways instead of under walls would remove the need to demolish portions of blockwork wall to enable cable installation. Alternatively, the cables may be routed overhead via cable trays into the analyzer room (Figure 4); in this case blockwork at ceiling level will need to be removed for the cable to pass through any walls. Regardless of the routing method it is essential that the allowable curvature of the cable is not exceeded.

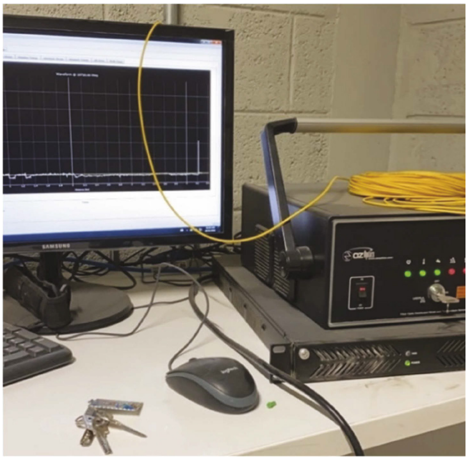

Figure 4. Monitoring room with typical analyser.

3.3 *Field results*

Emphasis in obtaining the results of the fiber optics was given to high-rise blocks, namely block R, where, as expected, the highest strain values of the fiber optic cable were obtained. C_T was found as 1.113MHz/°C, and Cε was equal to 0.054MHz/με. At the time of the measurements, the temperature field distribution was relatively stable and varied within + 4 +8°C over the entire area of the B4 level of block R (Figure 5). The location of areas with lower temperatures in the center of the building along the load-bearing walls of the core is explained by the greater thermal conductivity of reinforced concrete structures. Considering the depth of the raft -19 m and the allocation of the block R in the middle of the complex of buildings the ambient temperature did not affect to the results of the FO strain measurements during recording. Considering that the measurements were taken in February 2021, as well as the cold climate of Astana.

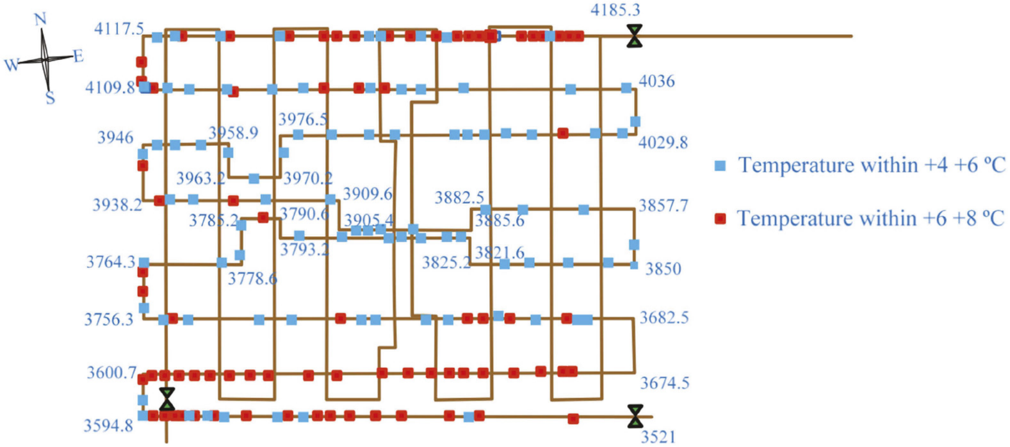

Figure 5. Temperature field distribution in block R.

As can be seen in Figure 6, the fiber optic results show alternating strain signs along the length of the fiber optic cable embedded in the raft of the lowest level B4 of block R. Compression deformations prevail in the central part of the building core, in the zone of

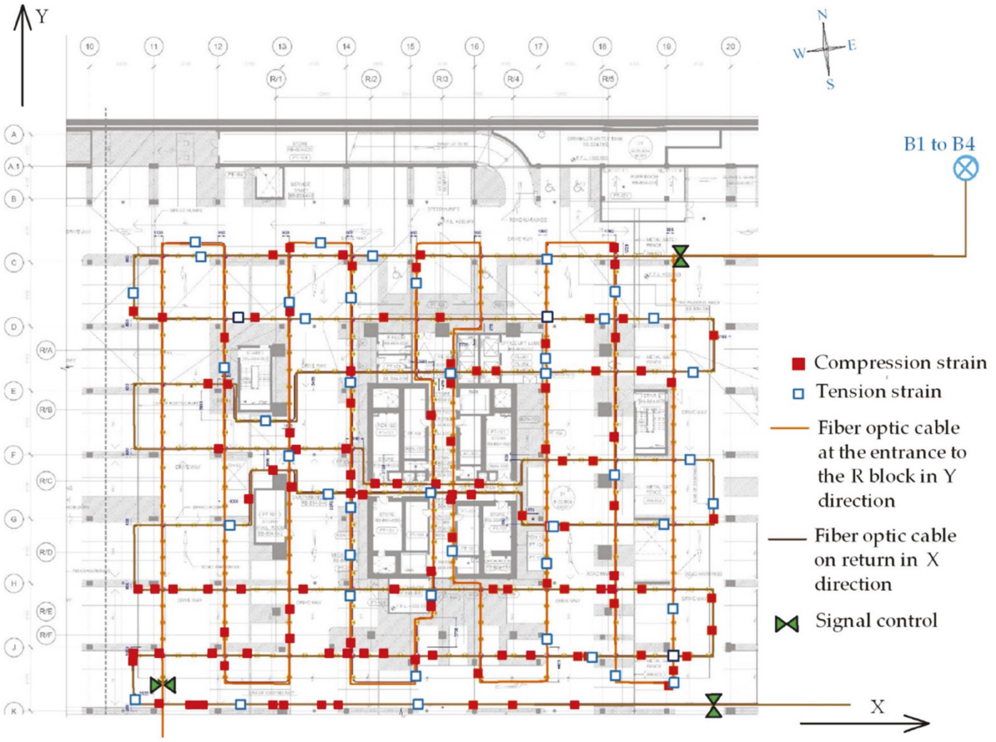

Figure 6. Fiber optic strain along the cable layout in the block R, level B4.

increased load from reinforced concrete load-bearing walls. Tensile deformations are most focused on the extreme axes, as well as near the joints of the columns. The interpretation of compression zones by values is shown in Figure 7 and tensile zones in Figure 8.

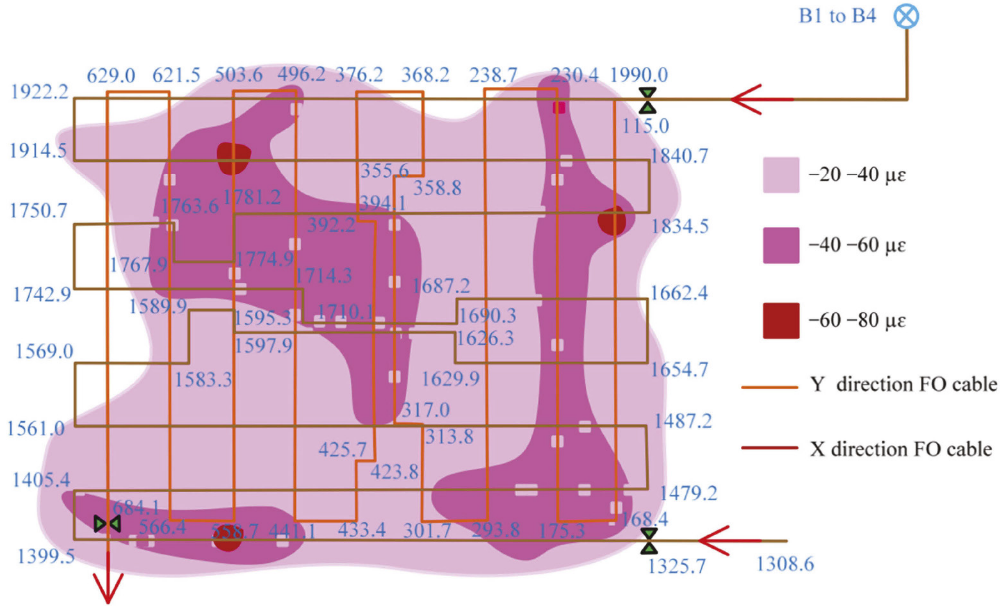

Figure 7. Zones subjected to compression strains.

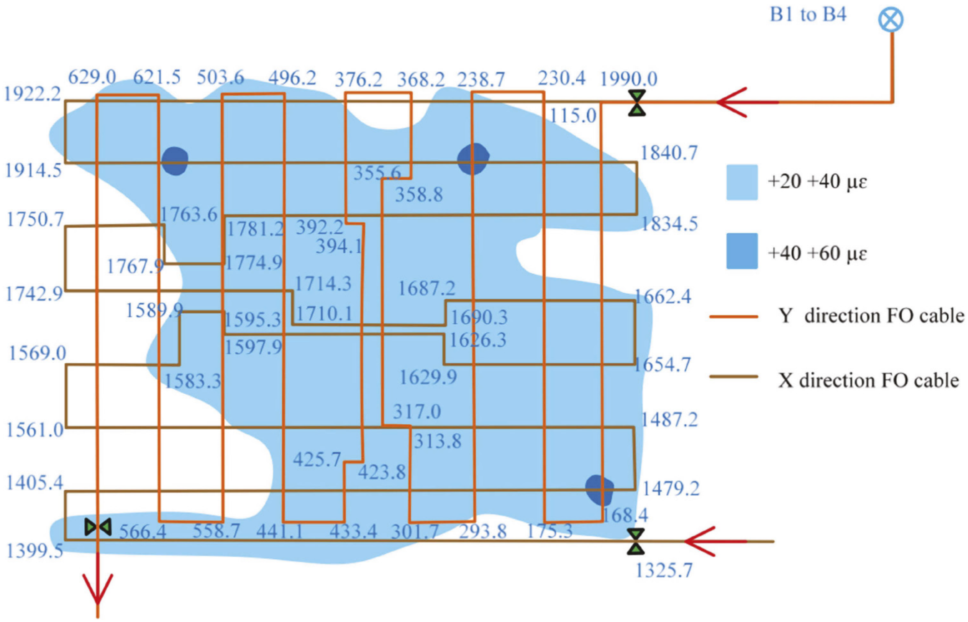

Figure 8. Zones subjected to tension strains.

Tension zones as indicated by Figure 8 are uniformly disseminated over values from −20 to −40 με, with a slight transcendence on the right (east) side of the structure. Individual spots of −40 to −60 με are once in a while situated along the external shape of the structure. Tensile stresses accumulate in more stable patterns in the building's center, north, and east [Buranbayeva, 2022].

4 CONCLUSION

The authors considered whether the distributed fiber optic strain sensing system technology could be used to monitor structures, using the Abu Dhabi Plaza complex's underground parking lot as an example in Astana's soil conditions. The technology enables you to evaluate the outcomes of geomonitoring in real time, ensuring the safe operation of underground buildings in the challenging engineering and geological conditions of Kazakhstan's capital.

The following conclusions were drawn as a result of the evaluation of the data used for structural health monitoring that was embedded in the raft plane of pile-raft foundations of a high-rise building at the beginning of its operation:

1. Fiber optic's monitoring made it possible to provide actual results of strains in the upper layer of the raft at the lowest level B4 of the high-rise 75-storey block of the Abu Dhabi Plaza building on multilayer soils of Astana city.
2. The compression strains were observed over the entire area of the building with values -20-40 με. A greater values of compression strain, -40-60 με, were registered in the center in the Y direction and along the eastern facade of the block R in the building core with some points up to - 60-80 με.
3. The tension strains are concentrated along the extreme axes of the building, with a predominance in the southern part of the R block, as well as in the immediate vicinity of the columns, in a range of + 20+40 με, with separate spots +40+60 με.
4. Individual patches of tension strains near the columns have been explained by the increased deflection of the raft under the application of a concentrated load (columns).

5. When a strain above 1000 με (1%) occurs, a basic structural analysis is recommended, above 1500 με (1.5%) a detailed structural analysis is required.
6. Fiber optic monitoring results at the time of testing did not exceed the permitted values for high-rise building operation; however, they characterized the general picture of the strain in the raft plane and make it possible to determine the initiation of cracks in concrete at an early stage.

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