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Geo-monitoring of basement slab at Abu-Dhabi Plaza in Nur-Sultan City, Kazakhstan

Abstract. In modern architecture, there is an increased need to design constructions in conditions of dense development. It is important to implement a project without hitches. However, during the construction process, design flaws or environmental impacts can often arise in the end result. Therefore, proper design and monitoring allow taking preventive measures that helps to avoid overhaul of buildings in the future, which also affects to the cost of project, and sometimes-human casualties.

During and after the construction of high-rise permanent structures often-unacceptable cracking can occur in the external walls and at the base slab of the basement. Respectively, groundwater starts to leak through the cracks of basement, compromising the serviceability and durability of the basement and rendering it unusable. The paper presents the use of fiber-optic sensor technologies geotechnical engineering. In this paper, it has been established the possibility of foundation monitoring system using fiber optic sensors during the construction process.

The monitoring system includes a distributed fiber-optic voltage measurement system using a fiber-optic cable, which allows you to control deformations that occur on the surface of the plate.

This study involves an investigation of the foundation system in a high-rise buildings and structures in Nur-Sultan city.

Keywords: strain, basement slab, high-rise buildings, fiber-optic sensors, civil engineering.

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Introduction

High-rise buildings (buildings with a height of more than 75 m) pose new challenges for engineers, especially in the field of calculations and design of above-ground structures, bases and foundations. Therefore, designers of both above-ground and underground parts of the building are forced to resort to more complex methods of calculation and design. Especially this applies to geotechnicians, who are involved in the design of foundations for high-rise buildings. By complexity, problematic design, erection, operation, impact on the environment and people, high-rises can be attributed to the structures of increased danger and complexity.

Many megaprojects are being built in Nur-Sultan. One of the unique projects is the "Abu-Dabi Plaza" (ADP) complex which was started to the construction from July 2011 in Nur-Sultan. This will be the highest building in Central Asia. "Abu-Dabi Plaza" - a complex from several towers, united around the main building with a height 320 meters - 75 floors here are used several heavy crane for construction stage (see Figure 1).

Before you start laying the foundation, you need to decide on its technology and depth. It depends on the expected load on it and the features of the natural conditions, namely the type of soil and the depth of the groundwater. ADP residential skyscraper consists of 5 main towers (see Figure 1):Block R - offices and living quarters (75-Storey, Mixed Use 450 Apts 69,000 sqm, Office 37,000 sqm);Block O- office building (30-storey, Office 69,000 sqm);Block H- hotel and furnished rooms (14-Storey Hotel, 190 Guest Rooms, 100 Serviced Apts, 32,000 sqm);Block Y- offices of class «A» (2-Storey, Podium Retail, 50,000 sqm) and Block Z-residential apartments (17-Storey Residential 20,000 sqm).

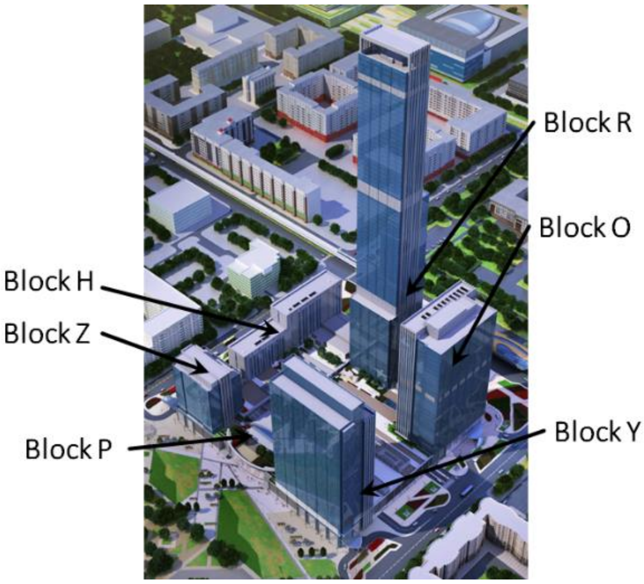

Figure 1. Project ADP in Nur-Sultan city

During and after construction of the permanent structures unacceptable cracking occurred in the external walls and base slab of the basement. Groundwater has been leaking through the cracks, compromising the serviceability and durability of the basement and rendering it unusable.

Construction site Company has since engaged Golder to review the design of the basement to establish the likely cause of the cracking and to propose methods for rectification. The chosen method comprised an internal drainage system maintaining a dry interior whilst collecting and draining water leaking through the walls and floor. Golder developed the system into a conceptual design consisting of a voided slab covering the floor and a façade for the walls [1-2].

Subsequent to the conceptual design Golder was made aware of the need for detecting and monitoring potential expansion arising from delayed ettringite formation (DEF) and alkali-aggregate reaction (AAR) in particular areas of the base slab. The possibility for DEF and AAR was highlighted by accelerated expansion tests and concrete chemical tests.

The voided slab obstructs visual observation of the slab and access for monitoring. Golder therefore developed a conceptual design for a slab monitoring system enabling the detection and monitoring of DEF- and AAR related expansion and cracking during operation of the basement. The primary element of the slab monitoring system comprises a distributed fibre optic strain sensing (DFOSS) system employing fibre optic cable to monitor strains developing on the slab surface. This paper presents the detailed design of the DFOSS system.

Design of distributed fibre optic strain sensing system. DFOSS has been employed for measuring the strain in civil engineering structures for over a decade. It is now harnessed worldwide for monitoring a wide range of structures, including tunnels, bridges, piles, dams, embankments and diaphragm walls.

DFOSS relies upon backscattering when light is transmitted along an optical fibre. One particular component of the backscattered light is produced by Brillouin scattering. At any point along a fibre, the frequency of Brillouin backscattered light depends upon the strain and temperature at that point. Making allowance for the effect of temperature therefore, the strain anywhere along a fibre can be deduced by transmitting pulses of light down the fibre and analyzing the frequency of backscattered light.

Compared to the use of isolated strain gauges, DFOSS offers a new paradigm for strain measurement in that:

- DFOSS returns the continuous strain profile along a structural element. Strain gauges can provide only discrete pointwise readings and can miss vital strain variations between gauges.
- The backscattering from optical fibres is unaffected by electromagnetic interference.
- The core of optical fibres is made from pure silica which is very stable and inert. The fibres therefore resist corrosion, do not contaminate the local environment and have a design life measured in terms of decades.
- Optical fibres can operate over a much wider range of temperatures than most electronic devices.
- Optical fibres are small and unobtrusive, and hence are easy to integrate into both new and existing structures.
- The complete strain profile can be recovered for a fibre stretching several kilometers, potentially replacing tens of thousands of discrete sensors. The single-cable approach greatly simplifies installation.
- As a result of the ongoing development of DFOSS read-out units, a DFOSS system installed now can benefit from potential enhanced measurement capabilities in the future.

Most analyzers require the installation of an additional optical fibre to measure temperature alongside the strain sensing fibre so that the effect of temperature can be eliminated from the Brillouin frequency shift.

The proposed DFOSS system comprises a grid of fibre optic cable bonded to the B4 slab linked to an analyzer located in a temperature- and humidity-controlled room at B1 level (see Figure 2 for "General plan of cable routing on B4 slab" and Figure 3 for "Part plan of cable routing in Block R monitoring area on B4 slab").

Gauge length. Fracture of the fibre must be prevented since installing the fibre below the voided slab renders any remediation of the fracture practically unfixable. Fracture at a localized crack in the slab is prevented by fixing the fibre only at discrete points rather than bonding the fibre to the slab continuously along its routing. An unbonded length between two adjacent points of fixture is called a gauge length. Prevention of overstraining relies upon the fibre undergoing the average surface strain of the slab along a gauge length instead of experiencing the maximum localized strain adjacent to a crack.

An alternative to discrete fixing is to bond the fibre continuously along its length but to allow the adhesive bond to yield beyond a predetermined shear stress. However, achieving consistent yielding of the adhesive under site conditions is difficult in practice and risks either inaccurate representation of strain in the case of premature yield or fibre fracture if yield is retarded.

Strain resolution. The degree to which an analyzer can resolve the strain in a fibreis limited by noise and so resolution decreases with measurement distance. Strain resolution may be augmented by improving the signal-to-noise ratio with a more powerful analyzer or by successively taking many measurements and averaging.

The averaging of strain along a gauge length places a more stringent requirement on the strain resolution compared with the case of a continuously bonded fibre. Furthermore, the spacing of the fibre optic grid determines the distance of fibres from an expansion event and influences the required strain resolution.

The lowest strain in a gauge length that would be induced by any conceivable expansion event was determined to be 22 $\mu\varepsilon$ through assuming:

A requirement to detect surface strains as low as 0.06%, equivalent to the strain of 0.6 mm m-1 explains the determination of the lowest induced strain which is summarized as follows:

1) For each expansion event, interpolate the relationship of applied volumetric expansive strain and maximum induced surface strain obtained by numerical analysis to determine the critical value of expansive strain required to induce the lowest detectable strain of 0.06%.

2) For each expansion event and for a range of gauge lengths and grid spacings evaluate the maximum strain induced across a gauge length by the critical value of expansive strain.

When considering expansion events across the entire conceivable range of events the lowest induced strain is 22 με. Although specifications for most analyzers state a strain resolution in the order of 2 to 5 με this refers to the condition of uniform strain along the entire fibre. Under irregular strain conditions the resolution of typical analyzers increases to around 20 to 30 με which is adequate to detect practically all expansion events considered. Therefore, strain resolution is not a governing factor in the DFOSS design.

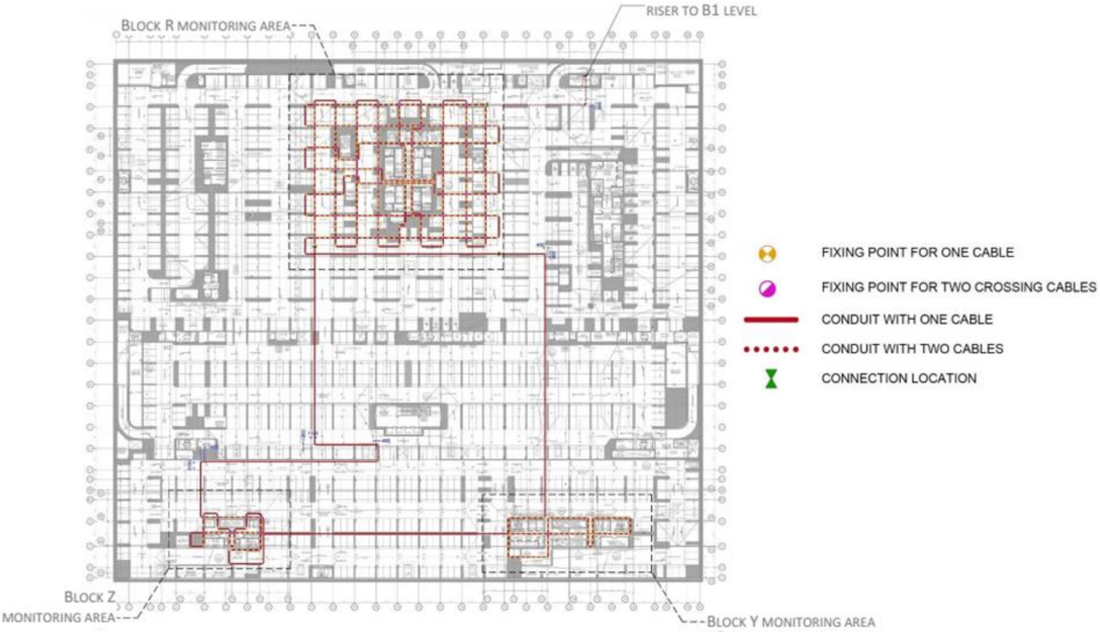

Figure 2. General plan of cable routing on B4 slab

Figure 3. Part plan of cable routing in Block R monitoring area on B4 slab

At certain areas the base slab is thickened by casting additional concrete above the structural floor level and in places steel mesh is cast into the thickened section to prevent surface cracking. To reduce the risk of installing the cable at a curvature exceeding the allowable curvature the elevation of the cable should be maintained in the thickened sections and instead the channel depth adjusted to accommodate the change in slab thickness.

Producing the channel at the thickened sections would necessitate cutting through any steel mesh that might be present and additional time and tooling should be provided for this task.

Fixing points within the monitored areas in Blocks R, Y and Z are depicted at intervals of approximately two meters or longer to create gauge lengths. Of the 525 fixing points 450 of them clamp a single cable and the remaining 75 clamp two perpendicular cables. A fixing solution similar to that illustrated in Figure 4may be employed to clamp either one or two cables.

At most intersections both cables are clamped but at six intersections, namely four at the centre of the Block R core and two within the Block Y monitoring area, the intersections are spaced significantly closer than two meters. At these six locations only, a single cable is clamped to avoid creating gauge lengths shorter than two meters.

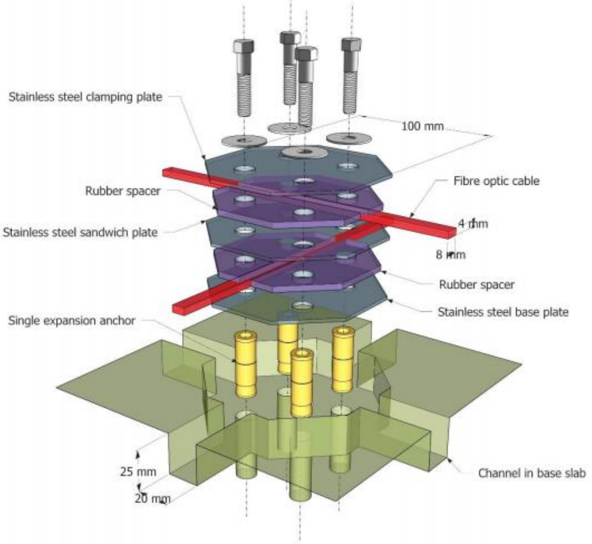

Figure 4. Conceptual design of cable fixing point (contractor to provide design)

The analyzer measures strain by transmitting pulses of light down the fibre and analyzing the frequency spectrum of the backscattered light. The optical budget of an analyzer may be increased by extending the pulse width measured in nanoseconds, which reduces its attenuation. If the pulse width is too long however, backscattered light from the leading edge of the pulse begins to interfere with backscattered light from the trailing edge of the pulse and the analyzer is unable to differentiate between the two. This places a limit on the minimum distance over which a value of strain can be interpreted by the analyzer. This distance is termed the spatial resolution and may be likened to the width of an averaging window for a sampling point [2-3].

A spatial resolution as short as 2 cm is achievable by some analyzers on the market but due to the trade-off between optical budget and spatial resolution this comes at the expense of the optical budget which at such a low spatial resolution would be only around 2 dB. To achieve the required optical budget of 11 dB the spatial resolution would typically be no lower than around 0.5 m [3].

Even though the spatial resolution limits the minimum distance over which a value of strain can be interpreted, the analyzer is still able to take multiple measurements at small intervals along the fibre. The shortest interval between two sampling points is termed the sampling resolution and depends upon the number of measurements made by the analyzer. Cable lengths and connectivity as portrayed in Figure 5.

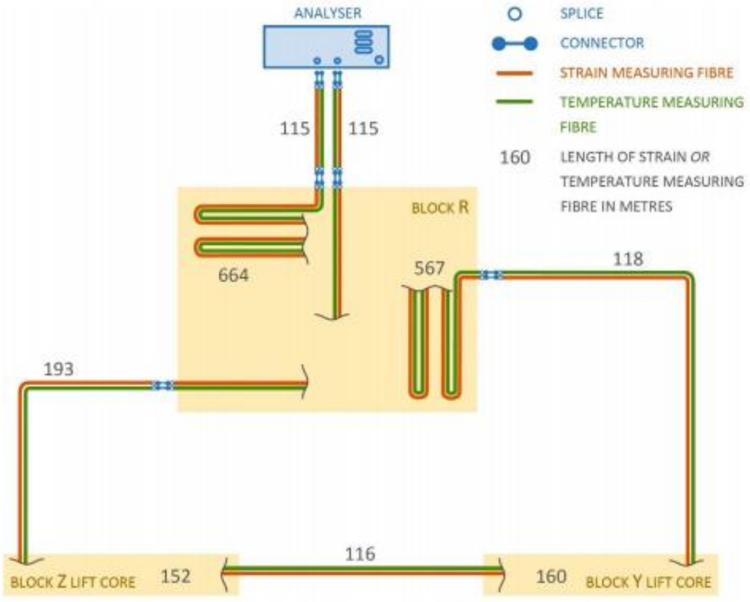

Figure 5. Schematic diagram of distributed fibre optic strain sensing system

The commission test results were able to capture temperature changes caused by curing of concrete during the testing as shown in Figure 6 and Figure 7. The temperature changes were significant at certain locations at Block R where slab casting process were ongoing during the measurement time. Similar measurement trends between both temperature and strain sensing cables indicates that the strain changes were caused by change in temperature rather than structural movement [7].

As slab casting and repair works were ongoing during the test, the temperature changes affected the recorded strain measurements which increased the standard deviation of both fibre optic cable at certain locations along the monitoring route.

By comparing the standard deviation of the first and second test, the results has shown that both tests have very similar magnitude of standard deviation except for those areas where there were significant changes in temperature. Therefore, for the current analyzer used, the thermal shift in electronic components does not affect the precision error when the analyzer is powered off.

Up to date, the slab casting and repair works at the monitoring area (Level B4) are still ongoing. Long term monitoring work will start after the completion of the slab casting and repair work at the monitoring area [4-5].

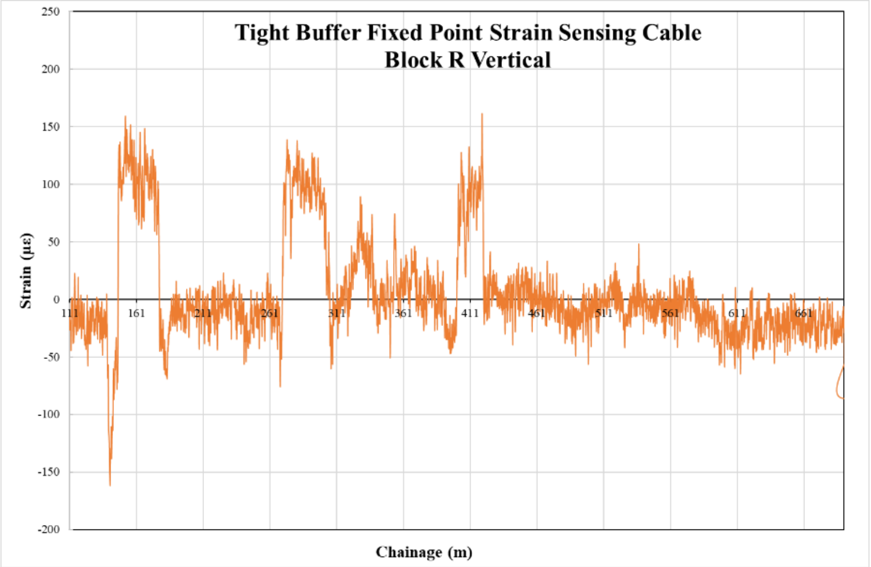

Figure 6. Strain measured at Block R vertical on 18/2/2020 16:45 (result of geotechnical monitoring)

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Нұр-Сұлтан қаласындағы Абу-Даби Плаза жертөлесінің тақтанегіздерінің геомониторингі

Аңдатпа. Заманауи сәулетте көп жағдайда тығыз құрылыс жағдайындағы құрылымдарды жобалау қажет етеді. Жобаны жүзеге асыру өте маңызды, бірақ құрылыс барысында көбінесе жобада қателіктер туындауы немесе қоршаған ортаның соңғы нәтижеге әсері болуы мүмкін.

Сондықтан, дұрыс жобалау және уақтылы бақылау болашақта ғимараттардың күрделі жөнделуін болдырмауға мүмкіндік беретін алдын-алу шараларын, сонымен бірге жобаның өзіндік құнына, кейде адамдардың қаза болмауына алып келеді.

Көп қабатты стационарлық ғимараттарды салу кезінде және одан кейін көбінесе сыртқы қабырғалар мен жертөле тақтасынан жарықтар табуға болады. Жер асты сулары жертөледегі жарықтар арқылы өте бастайды. Бұл жертөле қабатының ұзақтылығы мен беріктігіне қауіп төндіріп, оны пайдалануға жарамсыз етеді. Мақалада талшықты-оптикалық сенсорлы технологиялардың геотехникалық инженерияда қолданылуы көрсетілген. Құрылыс процесінде талшықты-оптикалық датчиктерді қолдана отырып, іргетастың мониторинг жүйесін құру мүмкіндігі қарастырылған.

Мониторинг жүйесіне пластинаның бетінде пайда болатын деформацияны басқаруға мүмкіндік беретін талшықты-оптикалық кабельді қолданумен таралған оптикалық кернеуді өлшеу жүйесі кіреді.

Осы зерттеу аясында Нұр-Сұлтан қ. (Қазақстан) орналасқан биік ғимараттар мен имараттардың негіздер жүйесін зерттеу болып табылады.

Түйін сөздер: кернеу, іргетас тақтасы, биік ғимараттар, талшықты-оптикалық датчиктер, азаматтық құрылыс.

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Геомониторинг подвальной плиты в рамках проекта Абу-Даби Плаза в городе Нур-Султан

Аннотация. В современной архитектуре все чаще возникает необходимость проектирования конструкций в условиях плотной застройки. Важно реализовывать проект без заминок, но в процессе строительства часто могут возникать ошибки проекта или влияние окружающей среды на конечный результат. Поэтому правильное проектирование и своевременный мониторинг позволяют принимать превентивные меры, которые помогают избежать капитального ремонта зданий в будущем, что также влияет на стоимость проекта, а иногда и на человеческие жертвы.

Во время и после строительства высотных стационарных зданий могут возникнуть часто недопустимые трещины во внешних стенах и на фундаментной плите подвала. Соответственно, грунтовые воды начинают протекать через трещины в подвале, что ставит под угрозу работоспособность и долговечность цокольного этажа и делает его непригодным для использования. В статье представлено применение волоконно-оптических сенсорных технологий геотехнической инженерии. В данной работе установлена возможность создания системы мониторинга фундамента с использованием волоконно-оптических датчиков в процессе строительства.

Система мониторинга включает в себя распределенную волоконно-оптическую систему измерения напряжения с использованием волоконно-оптического кабеля, что позволяет контролировать деформации, возникающие на поверхности плиты.

В рамках данного исследования проводится исследование системы фундаментов высотных зданий и сооружений в г. Нур-Султан (Казахстан).

Ключевые слова: напряжение, плита фундамента, высотные здания, волоконно-оптические датчики, гражданское строительство.

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