Considerations on the behavior of Incheon Bridge, Seul, South Korea to the action of un uniform sunshine, comparison study to the extreme temperature’s exposure periods

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Abstract: - Structural monitoring has become a current activity in the life of constructions. In terms of responding to stress and the required frequency for determinations, structural monitoring can be classified into three segments: static, quasi static-quasi dynamic and dynamic, with specific tools, technologies, methods to each group, some of these being common. The analysis of a building’s construction must also include a good knowing of the characteristic environmental factors in the location area, but in order to optimize the design solutions, the behavior models provided by the data banks (future) become a must. In setting up these data banks the main information is provided by the topo-geodesical activity, which must coordinate the entire monitoring process for the tracking of the behavior after the action of environmental and exploitation factors. The case study, in continuous quasi-static condition, was performed on Incheon Grand Bridge South Korea. At 12.3km long with a main cable stayed span of 800m the new Incheon Bridge will be one of the five longest of its type in the world.

VCE Vienna Consulting Engineers ZT GmbH is an independent, high tech oriented consulting firm with its head office in Austria. The company operates in four principal lines of business:
- the transportation sector (including bridges, tunnels and railways)
- the building and industrial sector (general design and management as well as specialized technological expertise)
- the development sector (from research and development to feasibility and environmental studies, financial engineering, to development aid)
- the structural health identification (BRIMOS®) and Life Cycle Engineering

Key-Words: - monitoring, permanent quasi-static regime, Incheon grand bridge

1 Introduction
Development of completion of special constructions of more and more performing dimensions and constructive features, experienced an unprecedented expansion in history, during the last 30 years. Against this background, the monitoring activity of the time behavior of the constructions became a stage in the life of these structures, started since the completion of foundations, and running their entire life cycle. In this context, techniques and instruments that are considered classics have been partially replaced, appearing new methods, new equipment and also genuine monitoring manager systems of land and constructions. In most cases, new technologies have emerged from specific needs, monitoring the execution and then the time behavior of a very high bridge or construction, but many of them may become universal in so far as they are known, tested and validated. Lack of systematization of information on specified topics at national and global level, makes that this latter goal to be practically impossible to fulfill. Measurement and instrumentation techniques for strains monitoring under static and quasi-static conditions, have been traditionally categorized into two groups, according to the field of the professionals who use these techniques:
- Topographic-geodetic measurements, which include the conventional methods (Land surveying leveling technology or planimetry), photogrammetric methods, some unconventional techniques (laser instrumentation, hydrostatic leveling, alignment method), and satellite methods of the GPS category.
- Structural and geological methods of investigation, which particularly aim the
mechanics of land and the destructive processes produced over time upon the strength structure of the monitored constructions; these do not fall within the theme of this paper.

2 The three segments of structural monitoring

During execution and then, after completion of the works, all buildings over two levels should be monitored for behavior in time under the action of loads, starting from the effect of personal weight on the subsoil, the effect of uneven sunshine, wind or of a convoy of vehicles on a bridge (Radulescu 2003). In Romania, Norm P 130 states that all buildings with more than two levels are required to be monitored in time. Legislation in all countries, in various forms, contains such rules, but in many cases it is constantly violated. The fact that this work is very expensive, takes a long time, years, sometimes up to 20 years, and especially because it does "not show" - meaning that only if something happens to the structure it will be found that the necessary studies for prevention have not been conducted - reinforces this assertion.

Since the construction of the Gothic cathedrals in the center of Europe, to the erection of the first "skyscrapers" in the U.S. (SkyScrapers 2011) hundreds of years have passed, and monitoring techniques have evolved from the lead wire to today's sensory techniques.

Depending on the nature of the applications and the speed of the structure's response, two main groups of measurements emerge on monitoring behavior in time of constructions (Radulescu 2011, Radulescu 2004):

A. Monitoring in static regime,
B. Monitoring the kinematic regime.

The measurements of the first category particularly analyze the subsidence of the land under the foundation of the monitored building, usually using the geometric leveling means method and the analysis of slips produced in plan, using angular intersections.

The measurements of the second category can also be classified into two categories:

B 1. Monitoring in:
   a quasi static regime,
   b quasi dynamic regime,


The techniques and instruments used for measurements of quasi static category, presented in the paper, the Beska Danube Bridge case, can be common with those used in the static method, only the frequency is greater, from one minute to one hour, compared to static samplings made monthly or yearly. In the case of quasi dynamic and dynamic methods, we usually use sensory techniques, are, accelerometers and GPS with continuous recordings with wire or wireless transmission of data taken over the entire monitoring period. The goal remains the same, to analyze the structure's response to stress, the methods and tools are different. Engineering Topography (Radulescu 2004) was set for measurements in categories A and B1.a. and entered, through the new branch called Dynamic or Kinematic Topography in the area of activity of measurements in categories B1.b. and B2.

3 Monitoring a structure in quasi static continuous regime

Fig. 1. Compact, highly sensitive SONARANGE® ultrasonic sensors for distances of 2.5 and 5.0m

Ultrasonic sensors SNT Sensortechnik AG are mainly used in structural monitoring, machine manufacturing, process control for distance, height and level measurement and monitoring. The proximity type sensors work after the principle of time of flight measurement of sound. The time of flight in air (forth and back) is approx. 6ms per meter. The new innovative ultrasonic fork sensors however work after the principle of sound amplitude evaluation. Compared to other measuring principles ultrasound is very robust. It passes dirty environment as well, and it is reflected by almost all surfaces. Thus it is independent of material, colour and surface structure of the target to be detected. On the right one sees the remarkable influence of ultrasonic frequency on the sensor characteristics. The SONARANGE ultrasonic transducers are Independent of material, surface, colour, size, Works under dust, dirt, fog, bright light, Detects transparent and shining objects, Wide measuring ranges from few mm up to >5m. The outstanding feature of the UPK series is its high acoustic power combined with small sensor size.
4 Incheon grand bridge South Korea

The Incheon Bridge (also called the Incheon Grand Bridge) is a newly-constructed reinforced concrete bridge in South Korea. At its opening in October 2009, it became the second connection between Yeongjong Island and the mainland of Incheon. The Incheon Bridge is South Korea's longest spanning cable-stayed bridge. In comparison, the Incheon Bridge is the world's seventh longest cable-stayed bridge as of October 2010. At 12.3km long with a main cable stayed span of 800m the new Incheon Bridge will be one of the five longest of its type in the world. Its 33.4m wide steel/concrete composite deck will carry six lanes of traffic 74m above the main shipping route in and out of Incheon port and link the new Incheon International Airport on Yongjing Island to the international business district of New Songdo City and the metropolitan districts of South Korea’s capital, Seoul. The cable stayed section of the crossing is 1,480m long, made up of five spans measuring 80m, 260m, 800m, 260m and 80m respectively, and the height of the "inverted Y" main towers is 230.5m(19). The sea crossing bridge section, whose concessionaire is Incheon Bridge Corporation, is funded by the private sector. Korea Expressway Corporation and the Korean Ministry of Land, Transport and Maritime Affairs (MLTM) managed the project(19).

5 Monitoring system

It consists of 6 UPK category sensors, i.e. 4 UPK500 sensors and 2 UPK2500 sensors, as follows:
1. Ultrasonic sensor UPK2500 for measurement of bridge gap-South carriageway;
2. Ultrasonic sensor UPK500 for measurement of gap at first lamella-South carriageway;
3. Ultrasonic sensor UPK500 for measurement of gap at second lamella -South carriageway;
4. Ultrasonic sensor UPK500 for measurement of gap at 24- lastlamella -South carriageway;
5. Ultrasonic sensor UPK500 for measurement of gap at first lamella -North carriageway;
6. Ultrasonic sensor UPK2500 for measurement of bridge-North carriageway;

There are also temperature sensors for concrete and steel structures, a registration sensor for weather conditions and a solar panel for power supply, all located on the "south carriageway".

One of the most important parts of the monitoring system is the ROBO CONTROL box also located on the south side of the structure.

As an example of monitoring in quasi static regime, the Incheon Grand Bridge, South Korea (Figures 1 and 2 ) was chosen, work performed by Vienna Consulting Engineers in Vienna, Austria. From the presentation site we quote: " In order to measure the movement of the cable stayed bridge section and the performance of the modular expansion joints of type LR24, a ROBO®CONTROL remote monitoring system was installed at one at the expansion joint locations. This serves to measure the movements of the first, second and last lamella beams of the joint, as well as the entire gap width and air and structure temperatures."(Brimos, VCE 2009-2012). Figure 2 shows the sensor location on the backbone of the bridge, RoboControl box, ultrasonic and temperature sensors mounted on the structure and figure 6 shows the position of the RoboControl box, mounted on the structure.

6 Monitoring period, Monitoring results

Structural monitoring of Incheon Grand Bridge South Korea began on 01.06.2009 and continues today.

Tables 1-4 show some significant results for some extreme periods, as follows:
1. The extreme values obtained for the 9 monitoring positions, of which three temperatures and six movements of structural elements, 4 in the south and 2 in the north;
2. The extreme values obtained for the period 01.08.2009-30.01.2010, a complete cycle of movements due to a full cycle of temperature variation;
3. Similar to the period 01.08.2012-30.01.2013;
4. Similar to the period 30.01.2012-07.08.2012; period considered for analysis in this paper.
As a general line for the position of the various structural elements analyzed, it is noted that the maximum values are obtained in January, corresponding to the minimum temperatures and the minimum temperatures in August corresponding to the maximum. With the exception of the "Bridge the gap" component, representing the distance between the two sides that open in order to facilitate the passage of large ships, the other movements, although important, remain constant between 50 and 100 mm.

In these circumstances, the choice of the analysis period 30.01.2012-07.08.2012, 190 days, a period considered for this study as a "trial" period presented in Table 4, can be considered significant because it reproduces the same pattern encountered in the other periods of 183 days listed in Tables 2 and 3.

Although considered normal for large metal parts, the expansion values produced by temperature differences are significant. Thus, by choosing the two-day period at the end of the trial monitoring period, it is observed that the effects are almost synchronous, the strain following the temperature evolution shortly after that. For example, on 30.01.2012, the day with the lowest temperature within the trial period, at a change in temperature of approximately 5°C, there are displacements of 50 mm for the second lamella, 100 mm for bridge gap and 25 mm for first lamella, all in the South Line; in the North Line, 100 mm for bridge gap and 25 mm for first lamella. For the period with the highest temperature in the test period, 06.08.2012, at a temperature variation of about 13°C, there are displacements of 65 mm for the second lamella, 180 mm for bridge gap and 33 mm for first lamella all in the South Line; in the North Line, 180 mm for bridge gap and 31 mm for first lamella. Figure... shows the temperatures and displacements for the entire trial period and figures.... accurately show the progress of movements due to contraction-expansion for the monitored components, relative to the temperature variations.

![Fig. 3. The position of the RoboControl box, mounted on the structure](image)

![Fig. 4. Temperature evolution for all monitoring period 23.06.2009-07.05.2012](image)
5 Conclusion
We are experiencing one of the most remarkable engineering achievements of all time. It is known that bridges, along with tall buildings, have been, in the last hundred years, among the world’s greatest structural achievements. It can be seen that the deformations of monitored elements are constant. The extreme values are within close limits for all periods of extreme temperature variation. This paper falls in the area of quasi-static monitoring although it is continuous and permanent. The premises created by the data viewed here are that such a construction falls into the category of construction works having a permanent nature, throughout the period of use, thus making the construction fit into the "smart structure" category.

The answer of the metallic elements monitored under the action of temperature variations is almost immediate. The figure illustrating the entire trial period clearly shows that small variations in temperature, regardless of the interval, whether they are extreme temperatures that are positive or negative, almost immediately produce significant deformations due to the expansion-contraction process. These values must be known, communicated to the engineer and kept under control. Only such a SHM action can give this guarantee.
Fig. 9. Movement of structure in the interval 30.01.2012, 00.00.00-30.01.2012, 24.00.00

Fig. 10. Movement of structure in the interval 06.08.2012, 00.00.00-06.08.2012, 24.00.00

References:


