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Autor: Sniatkov, Serguei V.

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Monitoring of Granite Structures

Surveillance des ouvrages en granit

Ueberwachung von Granit-Bauwerken

Serguei V. SNIATKOV
Technical Advisor
Russian Engineering Academy
St. Petersburg, Russia

Serguei V. Sniatkov, born in 1956, was educated at the Leningrad Institute of Civil Engineering. For about 10 years he was involved in long span roofs for places of assembly. Since 1989 he has been studying the problems of monitoring, maintenance and restoring of historic monuments.

SUMMARY

The paper presents a programme for monitoring granite structures of architectural monuments. The programme is of particular importance for St. Petersburg, where numerous historic monuments are built with the use of Finnish granite "rappakivi". The necessity of monitoring these monuments is demonstrated by the continuous supervision of the Alexander's Column, one of the largest monolithic granite structures in the world. Practical results of the implementation of modern flaw detection methods are illustrated by the reconstruction of the Petrovsky Bridge in Schlisselburg, near St. Petersburg.

RÉSUMÉ

L'article expose le programme de surveillance structurale des monuments en granit. Ce programme est d'une importance capitale à St-Pétersbourg qui abrite tant de monuments historiques construits avec du granit finlandais "rappakivi". La nécessité d'un tel contrôle est explicitée à partir d'un exemple, la colonne d'Alexandre qui est l'un des plus grands monuments en granit monolithique, dans le monde. A partir de la reconstruction du pont Pétrovsky à Schlisselbourg, près de St-Pétersbourg, l'auteur illustre les résultats pratiques obtenus par l'application de méthodes modernes de détection de défauts.

ZUSAMMENFASSUNG

Der Beitrag äussert sich zum Ueberwachungsprogramm für historisch bedeutsame Granitbauwerke. Dieses Programm ist besonders für St. Petersburg wichtig, wo viele Baudenkmäler aus dem finnischen "Rappakivi-Granit" bestehen. Die Notwendigkeit der Ueberwachung dieser Denkmäler wird am Beispiel der Alexander-Säule, eines der weltgrössten Granitmonolithe, aufgezeigt. Praktische Ergebnisse der Ausführung moderner Fehlstellensuchmethoden werden anhand der Rekonstruktion der Petrovsky-Brücke in Schlisselburg, in der Nähe von St.Petersburg, veranschaulicht.

1. INTRODUCTION

Granite is an intrusive igneous rock material, one of the most plentiful in the Earth's crust; it has been widely used in building since antiquity. Baltic granite "rappakivi" rich deposits are abundant in Finland, Sweden and in the north-west of Russia. Rappakivi is considered a valuable facing and structural material thanks to its porphyry-like structure with large-sized rounded orthoclase formations, rich gamut of colours and easy workability despite its high structural strength.
St.Petersburg, Russia's former capital (1712-1918), is internationally known for the extensive use of granite in its architectural monuments and ensembles. Granite became most popular here in the first half of the 19th century [1]: it was used for facing the embankments of the Neva, minor rivers and channels, bridge abutments; it was also widely used as structural material in cathedrals, palaces and private residences. Among the most spectacular examples of the rappakivi use are the 17m high antium columns of St.Isaak's Cathedral (Fig. 1) built in 1818-1858 to the design and under supervision of architect A.Montferrand; interior columns of the Kazan Cathedral (1801-1811, architect A.Voronikhin); columns of the Mikhailovsky Castle (1797-1800, architect V.Brenna), etc.

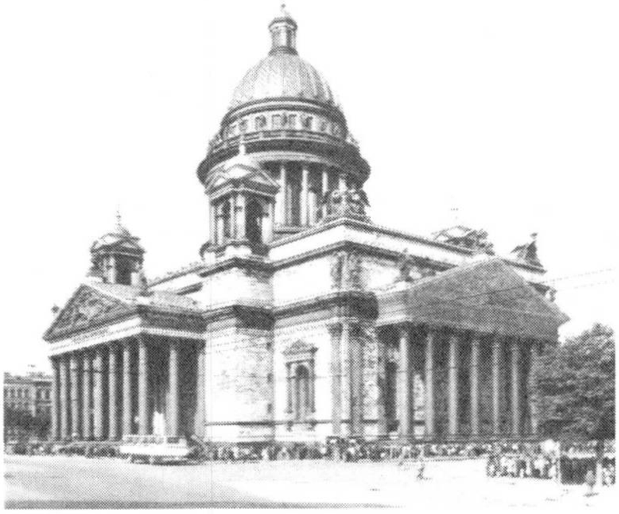

Fig. 1 St.Isaak's Cathedral in St.Petersburg

Granite is reasonably considered one of the most durable building materials. Yet there exist various environmental effects, both of climatic and technogenous origin, which gradually destroy it. Granite being a friable material, is subject to crambling, the most dangerous and destructive flaw for it. Noteworthy also is that crambling, generally of an orderly pattern, is inherent in granite, even in natural beds [2], and practically every large-sized granite element has cracks susceptible to extend in course of time. The history of monitoring the Alexander's Column throughout its lifetime provides a vivid example of the necessity for supervising crack extention in vital elements of constructions, especially those of architecture and historic interest.

2. ALEXANDER'S COLUMN: ERECTION, REPAIRS, DURABILITY FORECASTS

The Alexander's Column (Fig. 2a) was erected in the Palace Square in St.Petersburg in 1832 to the design of A.Montferrand in honour of Russia's victory over Napoleon. The fust of the column is made from pink rappakivi; being 25.6 m high and 3.6-3.2 m in diameter, it is one of the world's largest granite monoliths. It was cut from a boulder extracted from the same natural deposit in the neighbourhood of Vyborg as earlier the columns for St.Isaak's Cathedral. Even when selecting the monolith Montferrand was aware of the Vyborg granite tendency to crack (Finnish "rappakivi" means "rotten stone"), specifically to temperature fluctuations. But his confidence in the monument's durability was based on the absence of visible natural cracks in the monolith as well as on careful surface treatment by means of polishing and soaking with special compositions [3]. Nontheless, as early as in 1836, a few years after the erection of the column, its fust became a subject of concern due to the obvious expansion of surface cracks. In 1838 the Super-

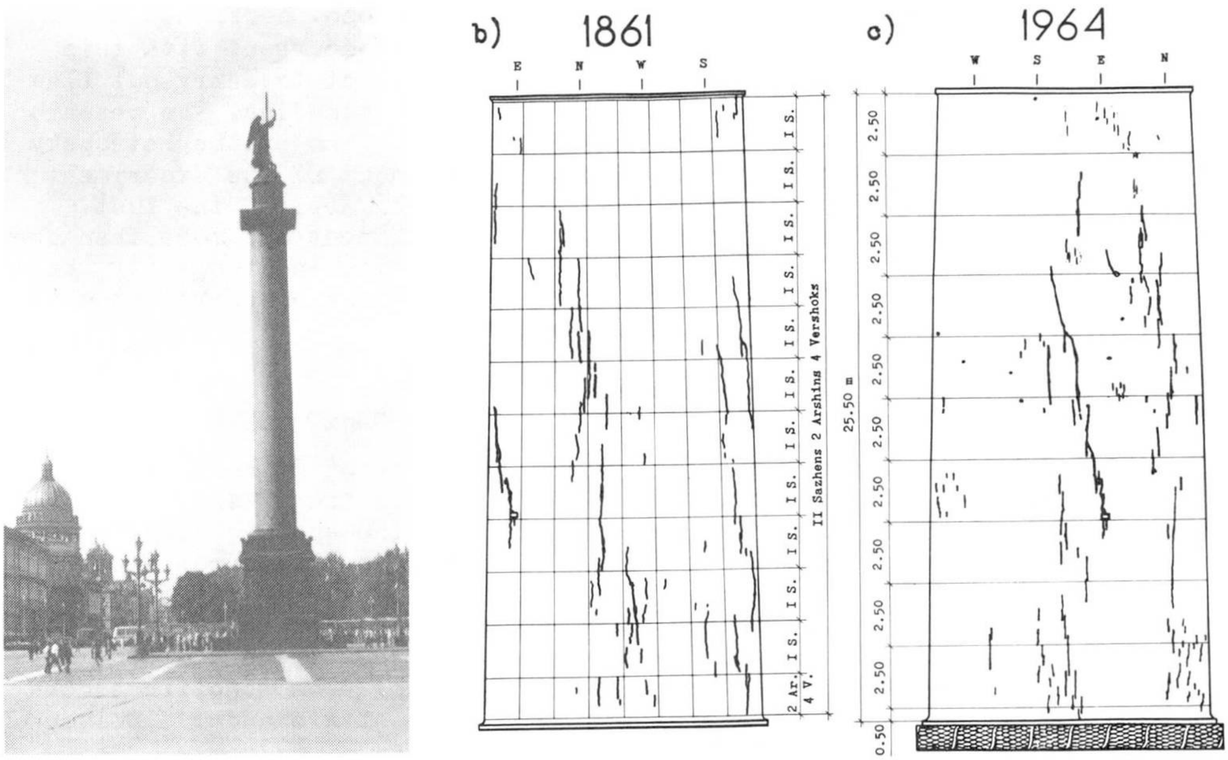

Fig. 2 **Alexander's Column :** a)- **general view;**
b,c)- granite fust **flaw fixing** drawings

vising Commission responsible for the erection of St.Isaak's Cathedral was charged with the research of these cracks, and later, in 1841, a special State Commission was set up for the examination of the column. In course of discussion, top-level Russian experts put forth quite contradictory predictions regarding the construction future. Among others, there was even a proposition to line the column with copper sheets in order to secure passers-by. Yet, largely due to Montferrand's high prestige, the Commission confined to recommendations on minor repairs of the monument.

In 1860 obvious degradation of the granite fust surface caused a new team supervised by colonel-engineer Pauker to turn to the rigidity of the monument; in doing so the commission discovered an error committed in 1841 - at that time no more or less objective data concerning the condition of the granite were fixed. In 1861-1862 photos of the column fust and a set of detailed drawings fixing its surface flaws were made (Fig. 2b, [4]). However these drawings also appeared unadequate for the analyses of crack expansion because they carried no information about the width of crack divergence. This new burst of public attention to the monument gave impetus to close research of the properties of rappakivi [5] and new debates about the expected moment of the column collapse [6]. This time the column fust was repaired more carefully, the cracks were cleared and filled with portland cement based composition.

In the early 1880-s another examination of the column was carried out by a commission of academicians and famous architects and engineers. Examination and restoration of the column were also taken in 1911, 1954 and in 1963-64. But despite permanent controversies as to the column's future [7,8], it was not until the last repair that a thorough drawing of surface flaws layout was performed. However, a comparison of said drawing with the one performed in 1861 (Figs. 2b,c) shows that its authors not only missed a unique chance to follow the crack expansion in the course of the elapsed century, but what is more, they obviously had no intention to make their drawing compatible with the former one as evidenced by the coordinate grid.

In October 1991 a team of mountaineers lead by M.Yu.Anosov performed an examination of the bronze angel crowning the column. Concurrent with this work the author of the present paper pioneered an attempt to carry out flaw inspection of the column's granite fust by ultrasonic sounding. The research was based on the method used in the studies of the columns of the Petrovsky Bridge in Schlisselburg. But lack of adequate background of the experiment made it possible to gain only a few data about a small area of the fust. Thus, despite tremendous unique importance of the monument and more than one--and-a-nalf-century debate as to its technical condition and longevity there has not been performed any thorough research with the use of current methods of flaw detection up to the present.

3. PETROVSKY BRIDGE IN SCHLISSELBURG: RESEARCH AND RECONSTRUCTION

The Petrovsky Bridge in Schlisselburg (in the vicinity of St.Petersburg) resting on granite columns provides a unique sample of the extention of civil architecture order to bridge architecture. In the epoch of classicism there were built no more than a few bridges of the type all over the world, and the Petrovsky Bridge is the only one that has survived to the present day [9]. The bridge was built in 1820-30-s after the project of French architect P.Bazin; 18 columns and 8 semi-columns of the bridge abutment (Fig. 3) were made by a famous stone-cutter S.Sukhanov from monolith blocks of pink rappakivi structurally allied to the granite of Alexander's Column and the columns of St.Isaak's Cathedral.
Reconstruction of the bridge in 1988-90 revealed notable crambling of the fusts of the columns which cast serious doubt upon their longevity and caused another more sophisticated study of their condition. Ultrasonic sounding detected regular non-uniformity ("orthotropy") of the column material in reference to the velocity of the ultrasonic signal passing through it (Fig. 4), said non-uniformity being much more obvious than that found in the literature [10,11]. The phenomenon is associated with peculiar to the granite monolith mutually parallel microcracks which tend to spread under external loads and other actions in course of time.
To estimate such crambling effect on the overall rigidity of a column, samples of granite identical to the material of the columns were subjected

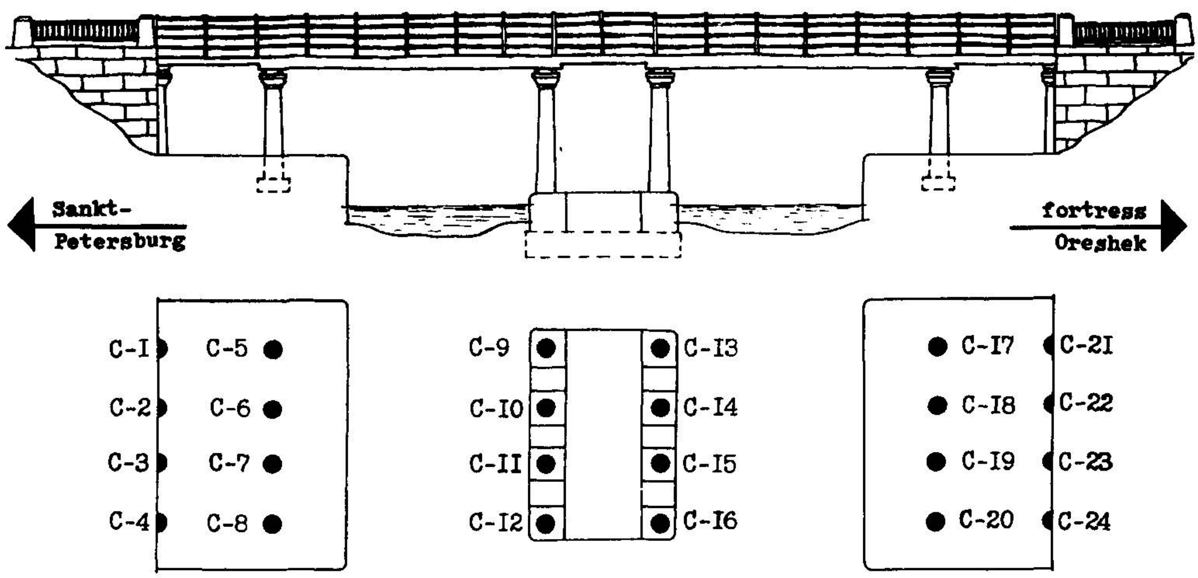

Fig. 3 Petrovsky Bridge in Schlisselburg: construction scheme

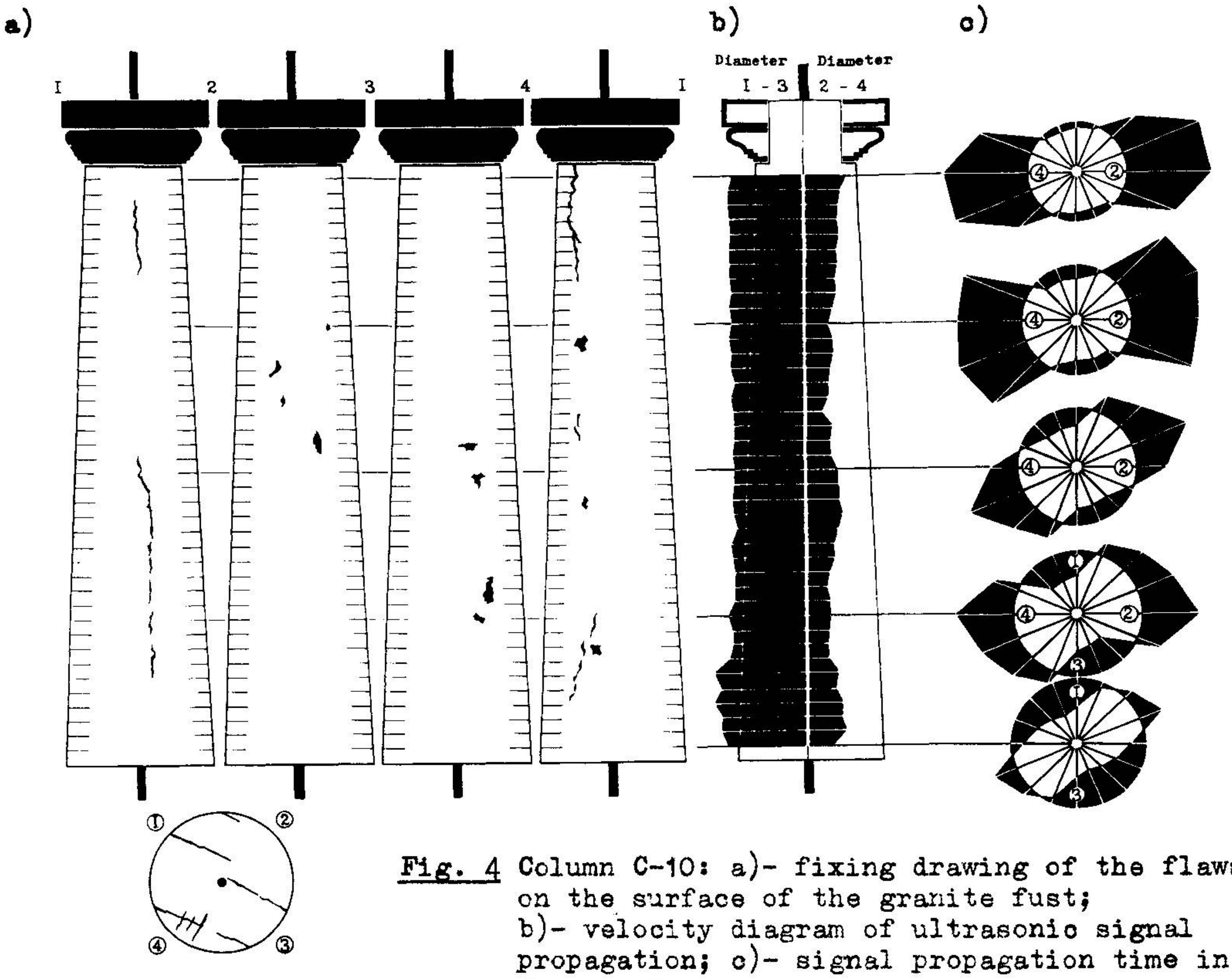

Fig. 4 Column C-10: a)- fixing drawing of the flaws on the surface of the granite fust; b)- velocity diagram of ultrasonic signal propagation; c)- signal propagation time in fust sections

to laboratory mechanical testing, and besides, a full-scale testing to local failure on column end surfaces was performed. The analysis of thus obtained data lead to the conclusion that 23 out of 24 columns could remain valid and only one that had a through lateral crack was substituted. The heads of the columns were strengthened by means of special-purpose casings enclosed in hollow cast iron caps, and in addition, the original design of the bridge span support on the columns was revised in order to reduce bending moments transmitted to them [12,13].

The results of the investigation enabled conservation of the granite elements of the unique historic construction as well as possibility of taking adequate steps regarding their future service.

4. CONCLUSION

The present paper is aimed at substantiation of the development and execution of a wide-scale program for monitoring major bearing granite elements of historic constructions with the use of currently-available flaw detection methods, specifically ultrasonic ones.

Structure disruption (crambling) is the most hazardous for the rigidity of material as friable as granites. On the other hand, essentially every large granite monolith has more or less tangible primary ("born") cracks. Finnish granite rappakivi is particularly typified by crambling. That is why granites unlike other building materials need not only appropriate detection of inner flaws but also feasibility of their evaluation in time. For this

purpose, a system of basic data readily correlated with the results of subsequent measurements should be built up. Such correlation would make it possible to decide adequately whether the construction needs repair, strengthening or substitution of individual elements before the onset of an emergency situation. Another line of this work should involve thorough strength investigation of granites with inner flaws, and revealing the dependence of granite strength on such flaws qualitative and quantitative parameters.
The importance of such research is dictated by high architecture value of numerous historic buildings and constructions with granite principal bearing elements. In this regard St.Petersburg presents a striking evidence. Experience has shown that the problem can be solved on base of up-to-date technical facilities.

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