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# DYNAMIC PARAMETERS OF THE ENDLESS COLUMN

**(or how the science can prevent hazardous decisions in heritage protection)**

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**SUMMARY**

The Endless Column was erected in 1937 at Targu-Jiu, in a seismic and wind-prone zone, according to Brancusi's direct guidance. Technical solution belongs to Stefan Georgescu-Gorjan (1905-1985), who was the chief engineer of the team of specialists and workers on the site.
The column consists of 17 double truncated pyramid modules in cast iron, threaded on an internal structure made of steel profiles. It is a guilt structure of 29.33 m height. In 1983 and 1984, INCERC investigations were carried out, and the condition of the column, of the core steel and the exterior cast iron modules were checked, while its fundamental dynamic characteristics were determined by calculation and experimentally, using seismometers.

After a highly debated and biased decision, in 1996 the Endless Column was dismantled, restored and reassembled in 2000. Comparison of dynamic measurements made by INCERC in 1984 and by others in 2000, as well as all physical testimonies, are proving that the INCERC measurements of 1984 and conclusions were close to the reality, they correctly indicated that the core situation was not as critical as claimed by some consultants and the dismantling of 1996 was arbitrary.

Such a situation could have been avoidable if the advise of properly chosen scientists would have been taken into account. Thus, the advanced theoretical and experimental methods can help the structural health assessment of heritage items, and conservation decisions, using instruments and laboratory tests.

## 1. PRESENTATION OF SITE AND ENVIRONMENT OF THE ENDLESS COLUMN

**General data about location**
Targu -Jiu is located in Oltenia, in the South-West of Romania in a zone of hills, under Southern Carpathian Mountains of Parang. The climatic and environment site surveys in 2000-2001 have put into evidence the specific air and humidity regime of the place, as threats of $SO_2$ and $NO_2$ acceptable values, with slightly increased values of $NH_3$ and very low acid rains

**Wind zonation**
Romanian Standard STAS 10101/20-90 allows for Targu-Jiu the zone A, under 800 m altitude, that means a mean velocity on 2 min. of 22 m/sec. and a base dynamic pressure stabilized at 10 m of 0.30 kN/m$^2$ . The Column site is of type I, Ch (z) = 1.4 for H=30m, with an aerodynamic coefficient Ct of 1.5 (?)
=1.5 ?
The dynamic characteristics are necessary for evaluating:
–Seismic spectral amplification – resonance, under Vrancea long-period motion ?
–Sensibility to wind: gusting ?

The quoted Romanian standard STAS 10101/20-90 may allow to consider the Column in the category C2 of wind sensitivity ? ! But since it is rather difficult to find for other code factors a proper correspondence between the Column and the construction types of the standard, the questions that arise are:

- What kind of artefact is the Endless Column…It is a building ? Most probably not ! , But it has a finished envelope…
- It is a special structure ? Somehow ! (inside)
- It is an object / monument of art with a special engineered structure ?! More likely !

**Seismicity**

According to the zoning map of the Earthquake Design Code P100-1992, Ks = 0.12, return period is Tc = 1.0, I equivalent MSK = VII, while according to the zoning map of seismologists from SR 11100/1-1993 , I = 7 MSK, all for a return period of 50 years

The new zoning map of the Code P100-2004, for 100 years return period indicates aPGA = 0.12g at Targu-Jiu.

Past Vrancea earthquakes produced at Targu-Jiu intensities as:

| | |
|---|---|
| –10. XI.1940 | I = VI |
| –4. III. 1977 | I = VII |
| –30. VIII.1986 | I = V |
| –30. V.1990 | I = V |

without visible damage.

## 2. PRESENTATION OF THE THE THEORETICAL AND EXPERIMENTAL DYNAMIC ANALYSIS AND FIELD SURVEYS PERFORMED IN 1983 AND 1984 AT TARGU-JIU TO EVALUATE THE STRUCTURAL HEALTH OF THE ENDLESS COLUMN

**The history of The Endless Column**

The Endless Column is a monument of modern Romanian and world art specifically integrated in the Targu-Jiu complex together with The Silence Table and The Gate of Kiss and has been for several decades subject and object of discussion for the art critics and historians who are concerned with the creation of the famous Romanian sculptor Constantin Brancusi. [1,2]. (The information must be regarded as that avilable in 1984, [4], although in the mean time some other data changed).

Stefan Georgescu-Gorjan (1905-1985) was the author of the technical conception of the column erected at Targu-Jiu and the chief engineer coordinating the team of specialists and workers who contributed in 1937 in erecting the monument in ca. 3 months.

In 1934-1937 Brancusi discussed and accepted the technical conception suggested by eng. Stefan Georgescu-Gorjan. The final variant that was to be designed by Eng. N. Hasnas and G. Somlo from A.C.P.; according to this project the Endless Column consisted of an inside steel core and 17 pyramid modules threaded on it. The work was finalized in November 1937.

**Information on the geometry, detailing, structural and dynamic characteristic of the Endless Column**

The Endless Column is made of 17 superposed modules (15 identical modules, double pyramid frustums, a pyramid and prism, frustum base module and a pyramid frustum top module). The total height is 29,33 m. Structurally, the column consists of a steel tubular core / spine with the 17 cast iron modules threaded on it. The foundation is made of a concrete block where the bottom section is embeded (adapted to foundation height and tied) up to a depth of 3 m. The central core consists of three sections: their cross sections decrease up to the top in three steps corresponding to the sections.

The base section is made of profiles and welded steel plates on both sides of the profiles. The middle section in made of profiles and welded steel plates only on the external part of the profiles. The top transom is made of profiles jointed with the interaxis by welded plates on the external part of profiles. The free core / spine height is 28,33 m.
The pyramid frustum modules are empty inside and have the following external dimensions:

- height 1,80 m
- cross-section at half-height: 90 x 90 cm
- cross-section at ends: 45 x 45 cm
- wall thickness: 2,5 cm

The modules were processed on the joint cross-section with in the core in order to ensure reduced mounting tolerance. The test mounting was also performed (using fastening wedges) in the work-shop on the core section; the modules were numbered in view of the actual mounting.

The cast iron modules were sand blasted and afterwards covered with zinc and gold-yellow brass. The following technological process was used in erecting the column:

- mounting of bottom section of the core;
- casting of concrete foundation and socle;
- mounting of the base module and of the first 3 similar modules;
- mounting and fastening of middle section of the core;
- mounting of the following similar modules
- mounting of the following of the top core section
- mounting of remaining modules, the top one included.

**The theoretical dynamic characteristics** of this unusual structure were determined assuring a constant cross-section cantilever (equal to the usual cross section of the bottom section) and under uniform loading. Only the inertia moment of the steel core was therefore taken into account, but considering the mass of the module and of the core.
The usual expressions for circular frequency were used:

$$\omega = \frac{\alpha_i^2}{l^2}\sqrt{\frac{EI}{\mu}}$$

and the following values obtained for pulsations and natural/fundamental periods:

$$\omega_1 = 2.48 \qquad T_1 = \frac{2\pi}{\omega_1} = 2.53\,\text{sec}$$

$$\omega_2 = 15.59 \qquad T_2 = \frac{2\pi}{\omega_2} = 0.40\,\text{sec.}$$

$$\omega_3 = 43.60 \qquad T_3 = \frac{2\pi}{\omega_3} = 0.14\,\text{sec}$$

Considering the wedge mounting of the modules on the central core calculations were performed; the hypothesis of modules and core co-working was also considered, taking into account the inertia moment of the smallest module cross-sections as well, tne period $T_1$= 1.93 sec. was obtained.

These calculations are only orientative as:

- the expression does not take into account the variable cross-section of the core sections and modules of column, the special co-working between modules and core and the actual foundation conditions;
- this expression does not take into account the fact that concrete was cast in the base core section up to a certain height in 1937 in order to provide anticorrosive protection and this provides a certain stiffening.

An accurate calculation would imply a more sophisticated model, a large working volume and the adopting of alternative hypotheses, the validity of which is hard to explain.

**Experimental research studies**

The topographical measurements performed at INCERC in 1983 attested the existence of a remanent top deflection having the value of 21.5 cm. Although this situation is not obvious at first sight, the possibility that this effect combined with corrosion could endanger the column stability and durability was considered.

In order to determine the condition of the column in 1984 one should take into account that beside natural agressiveness (wind, earthquakes, corrosion) the column was also subjected, during the years' 50 to an unhappy tentative of demolishing by cable traction acting in the top third zone.

E.S. Georgescu inspected the top of the Column (using a crane) and the top plate was found perforated by thunder, thus explaining the water penetration between modules and core.

Therefore a first hypothesis was even suggested that the modules should be dismantled in order to examine, improve and possibly consolidate the central core, proposal which was in 1984 considered as highly sophisticated and with uncontrollable effects.

**To determine the condition of the cast iron modules** an orifice of $\phi$ 80 mm was drilled [ by the decision of authorities of that time] in the external wall of the first base module. The cast iron was not corroded during the 47 years of column existence [1984], although a large quantity of rain water was found in the space between module and core. The cast iron had a remarkable crystalline structure and a high resistance.

**To determine the condition of the core steel**, an orifice of $\phi$ 16 mm was drilled in the side plate at the column base, but it was noticed, that the core was indeed filled with concrete. The condition of the space between the core and the bottom module was satisfactory as compared to the usual durability of lead minium painting.

Thus the painting applied in 1937 was still largely preserved but corrosion and exfoliation of the original painting occurred on plates and on screws. For the first time these surfaces could be photographed by E.S. Georgescu introducing a flash in the $\phi$ 80 mm orifice.

The in situ research on the Endless Column constituent materials rendered evident their satisfactory condition, with no serious corrosion processes, after 47 years of exposure to natural and artificial aggressiveness. The studies that were performed were useful in suggesting core specific anticorrosive protection measures (by introducing an oil painting substance under pressure in the slightly corroded zone between base module and core) as well as in excluding the corrosion source (periodical draining of the bottom module).

It was considered that core control by the orifice drilled in 1984 as well as the future periodical measurements on oscillation eigenperiods (under the effect of permanent microtremors) will allow, by comparison to the data obtained in 1984, the study on the evolution of the column condition.

**Experimental dynamic characteristics.** In order to obtain the oscillation eigenperiods, 12 seismometers type RANGERS SS-1 were used, with the following characteristics:

- oscillation eigenperiod: T = 1 sec.
- frequency range: 1,5 – 100 Hz.
- maximum measured amplitude: ± 2 mm
- sensitivity: 340 $V.m^{-1}s$

A number of 10 seismometers were mounted on the column and other on the ground, using special supports, a firemen sliding ladder and a MITSUBISHI-KATO telescopic crane with a jib of 34 m. Filters and amplifiers were used and for the magnetic recording a RACKAL tape recorder with 12 channels was used (3).

Using the Fourier spectral analysis the following oscillation period was obtained on two orthogonal directions:

$$T_1^{exp} = 1,8 \text{ s}$$

The experimental result is closer to the calculation in the theoretical hypothesis of co-working between modules and column, with a considerable influence on concrete presence in the core base section.

The dynamic characteristics of the Endless Column proved a uniform behavior on height (the same oscillation period in all points), indicating the stiffening effect of concrete in the base section, as well as the co-working between the core and the pyramid modules at least under the effect of permanent microtremors. The spectral amplification was very reduced at the socket, while increasing on height, indicating a motion induced by Column, through soil – structure interaction. The periods at some distance from the Column were completely different, in another range of values.

The possibility and requirement to use in situ engineering research methods (especially dynamic characteristics measurements) was confirmed even in case of unique structures such as the column under study.

Although such an investigation implies high difficulties, the result was much more conclusive and efficient than the variant suggesting the module dismantling in order to determine the condition of the core.

## 3. PRESENTATION OF FOLLOW-UP STUDIES AND MEASUREMENTS THAT CONFIRMED THE 1984 DYNAMIC CHARACTERISTICS

As it is well known, the INCERC suggestions of conservation and repair of Column have been postponed, but in the mid of 1990's it was dismantled and repaired, after a highly criticized decision.

At the end of 1990, the National Commission of Monuments and Historical Sites was alerted by the local county boards of Targu-Jiu, became concerned about the situation of Endless Column and asked INCERC to submit an offer. The team that has investigated the Column in 1984 sent a detailed plan of investigations, to be done before any decision, considering that the protection is possible without dismantling. E.S. Georgescu defended this idea in front of the National Commission of Monuments and Historical Sites (14.09.95).

However, it seems that the international activity, lobby and fund raising of a well-known critic of arts influenced the National Commission of Monuments that his team has the professional capacity and funds to do the job (and convinced also some other INCERC staff) to agree with dismantling.

In 1996, the World Monuments Fund listed the Column on a special list, involved the World Bank, UNESCO, foundations and donors. [5]. Some members of the team involved in the Project "Save the Column", declared that the metal of the interior core is already corroded and is ready to "explode", so it will be better to replace the core by some stainless steel column. They undully used the necessity to repair the cast iron modules and the need of remetallizations with a brass-like cover as argument for the alleged "corroded core" replacement, and even for the necessity to replace the foundation !!!.
The Project team invited some "specialists" in metals from Sweden and USA to defend their solution; it seems that they were not engineers, but perhaps specialists able to appreciate the metal artifacts of historical ages.

Mrs. Sorana Georgescu-Gorjan, daughter of Eng. Georgescu-Gorjan, addressed a protest to the Ministry of Culture and made public the danger posed to the monument by this approach, contrary to the Venice Charter, INCERC surveys and common engineering sense.
But the Column was dismantled and during this works some modules. After dismantling some cuts from the modules and core have been done in order to test metal properties, whose results were not known.

Since the dismantling of Endless Column in 1996, the matter became politically driven and subject of a great public scandal. Many art specialists were against this idea, while some strange debates have been held even at national TV, to defend the dismantling.

Thus, when a new government (of oposition) went to power in 1997, the Romanian minister of culture asked UNESCO to evaluate the project and in 1998 this board decided that preservation of the Column is necessary but in its integrity. In the mean time, the bare structure of the core remained exposed to hazards.

In June 1999, WMF followed the recommendations of UNESCO to organize a conference of experts, to discuss and decide about a less distructive and invasive intervention.
On the other hand, the Ministry of Research provided funds for a program of studies since 1994, and the specialized institutes in metal sciences made tests and they found (1999) that the core low-carbon steel was able to resist cracks and can be welded, (as it was well known since 1937 !).

**After new tests, it was decided that the core is not deteriorated at all as claimed (only 2 % corrosion detected !!!). [5].**

Separately, E.S. Georgescu has seen in 2000 [unofficially] the photograps of the bare central core, and the corroded ares were very reduced as areas and superficial as depth, therefore past affirmations about "explosive corrosion" were completely false.

**All these data proven behind any doubts the capacity of Eng. Stefan Georgescu-Gorjan to ensure since 1937 long-term solutions for Brancusi's masterpiece durability.**

World Bank organized a bidding for finishing the works and in October –December 2000 the work was completed. The available data [5] inform us that "the modules have been not soldered back into place, only sealed with silicon joints in order to better withstand wind and movement, since Targu-Jiu is in an earthquake-sensitive zone". The intrusion of wind-driven water between modules was known and also the difficulty of draining after rusting of joints. It is hard to evaluate the true relationship between this sealing and the behaviour of modules to dynamic motions, but further

measurements of fundamental periods may indicate what happens. In case this sealing was also done between core and modules, it can be partly positive and partly negative, since the water may remain captive in exterior, between modules and core.
Concerning the water penetration in the superior interior sections of the core, the top plate was devised with an opening, to provide ventilation of the inner space and avoid condensation.

Lungu et al. made some dynamic measurements before and after modules assembling on the core, in November 2000 (Lungu et al., 2002). The vibration characteristics of the Endless Column without cover modules were measured by his team on November 3, 2000, while these with cover modules were measured on November 14, 2000, obtaining the natural periods and damping ratios.

While for the first situation the period $T_1$ = 1.205 s. we do not have term of comparison, the period T1 = 1.949 s. in the final situation is between calculated and experimental values of INCERC 1984.

The possible explanation of a value between these given under INCERC hypotheses of 1984 is the new pattern of contact and/or sealing between modules and core after the recent cleaning of rust, although it is not known if the sealing was done at that time.

Some other wind tunnel tests (Lungu et al., 2002) allowed to conclude that the Column's modules structural shape have an excellent aerodynamic performance; it offers a limited drag resistance to wind, involves a vortex shedding strongly mitigated by avoiding straight corners and due to its joint aerodynamic and mechanical properties, galloping probability is practically negligible.

Sofronie (2001) emphasized the geometrical and topological thinking, the antropomorphism, automorphism and isomorphism of the Column, as being s typical for the whole creation of Brancusi, and its role in structural concept of the Column. He considers the Column as a suggestion of transcendence, releasing the mankind from the gravity, providing time through the repetition of space.

Safta (2002) proceeded furthermore and analysed from the dynamic point of view the Column as a flexible construction extremely sensible to wind action as its aerodynamic resistance is almost twice higher than that of a circular cylinder with the same dimensions. From the view point of the aeroelastic stability, the Column is high enough that above a certain level, as 10 m e.g., the ground roughness to be felt and influence the flowing regime of winds. The Column's modules, by their special shaping definitely modify the flowing regime of winds preventing any aeroelastic instability. The author concluded that in its automorphic infinity the Column is *ab initio* essentially stable to wind, and no matter how many modules are involved its stability always subsists.

The only aeroelastic phenomenon identified as dangerous could be created by Kármán's alternant vortices, as many steel chimneys and suspension pipelines have been damaged in this way by wind. But due to the particular shapes of decahedral modules it was found out that the flow of wind is such changed so that no eddy shedding ever occurs. Therefore, the Endless Column is by its conception essentially stable to wind, as decades of resistance proved it.

**Conclusions**

Engineering was a partner for Brancusi in many works of art, more obvious in the creation of Endless Column and Gate of the Kiss, both at Targu-Jiu [4, 6, 10].

From the presented data it results that the advanced theoretical and experimental methods can help the structural health assessment of heritage items and conservation decisions, using instruments and laboratory tests.

The experimental data and other true physical testimonies are proving that the core situation was not at all critical as it was claimed by some consultants and the dismantling was arbitrary and it could have been avoidable if a properly chosen team of scientists would have been consulted in due time.

The INCERC dynamic measurements of the Endless Column of 1984 were realistic, since the vibration periods were:

- INCERC 1984, T=1.93 sec. - by calculation, considering co-working core-modules
- INCERC 1984, T=1.80 sec. - experimental, under co-working given by wedges and rusting
- Lungu, 2000, T=1.949 sec. - experimental, after core polishing, local repairs and strengthening etc..

The most important is that instrumental data will be useful for future surveys of behaviour and maintenance of the Endless Column.

The high wind effects can impact the Column rather often, and some recent tornades occurred in Romania too, while large earthquakes only at some decades.

But the environment conditions at Targu-Jiu, mainly the air pollution and its effects on the monument aspect and durability, are perhaps more important than wind and earthquake.

**The challenge of the future in the i**nternational context and globalisation is that for built heritage protection we need a interdisciplinary cooperation of specialists from:

- Earthquake and Wind Engineering
- Environment Monitoring
- Heritage Conservation Boards
- Academic and Research institutions
- Cultural and Humanistic Studies

**Ackowledgements**

Several INCERC specialists contributed in performing the experimental works in 1984; may we mention a few of them: Dr. Eng. Horea Sandi, Eng. Zareh Kehaian, Eng. Constantin Praun.

Some original photographs concerning the construction of the Endless Column in 1937 were provided by the regretted Stefan Georgescu – Gorjan to INCERC in 1984 and we pay again our respects to him.

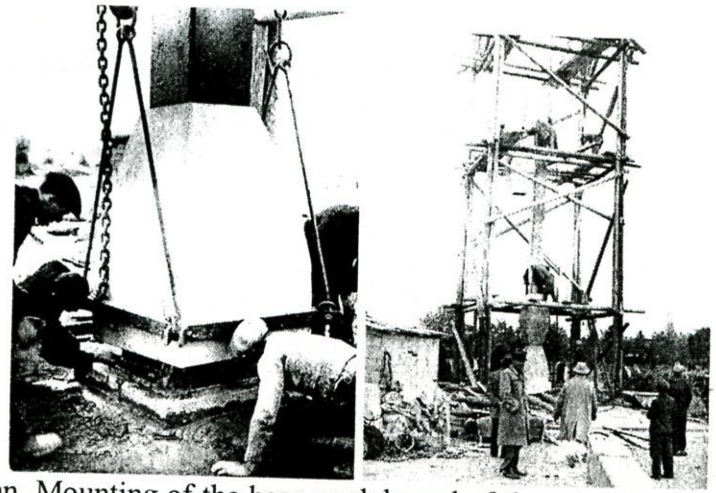

Fig. 1 Endless Column. Mounting of the base module and of the other 2 modules in the year 1937 . Remark the last painting of the steel core, behind module (left) and Sculptor Brancusi going towards the Column (1937) (right).

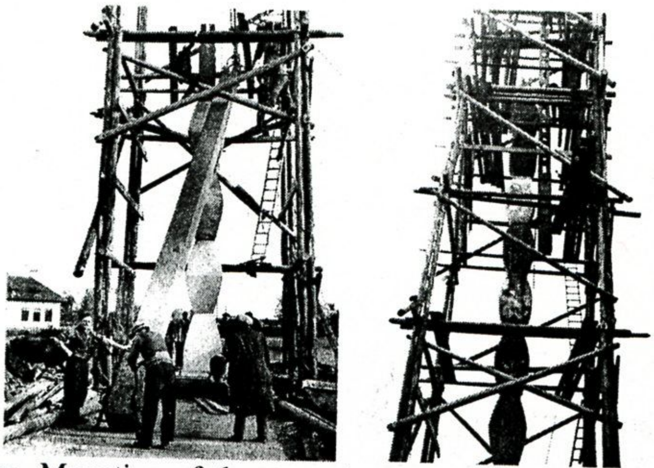

Fig. 3 Endless Column. Mounting of the second and third core section (1937). Note the square welded tube structure (left) and the open structure (profiles with welded plates) (right).

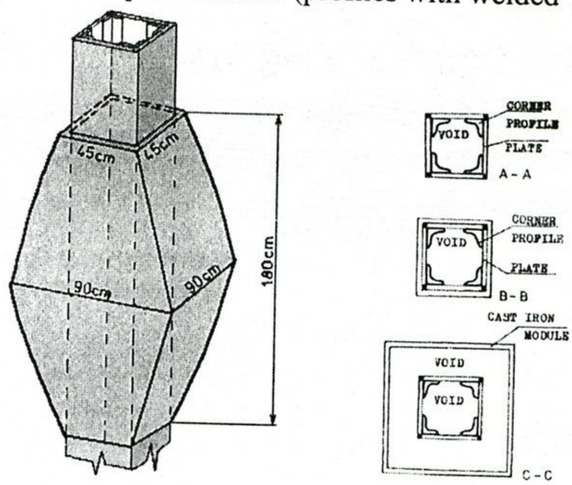


Fig. 5 Detailing and typical cross-sections of the core and modules

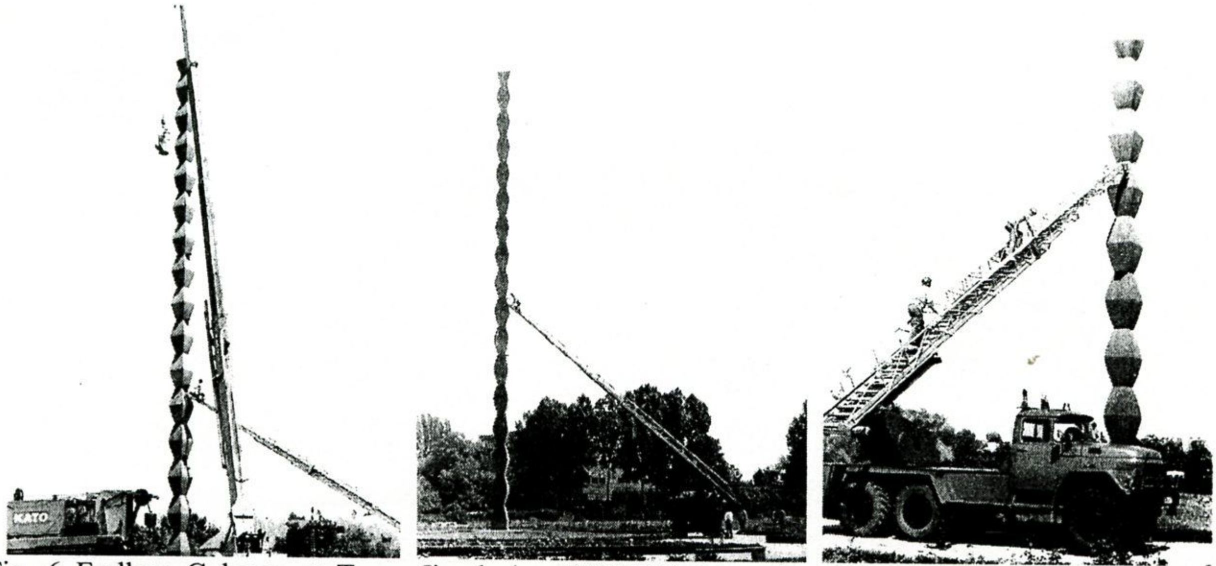


Fig. 6 Endless Column at Targu-Jiu during INCERC dynamic measurements in 1984. Note the telescopic crane and the firemen sliding ladder used for installation of 10 seismometers on Column.

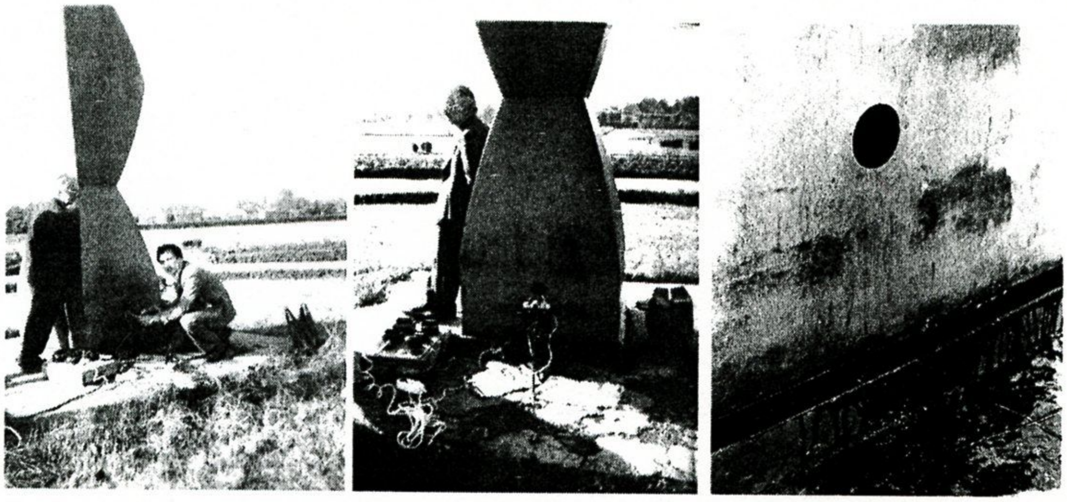

Fig. 7. The orifice made in the shell of base module in 1984 in order to see the state of the core steel

Fig. 8. The image of the good state of core painted surface (the base flange and the bolt) after 47 years of water action. The hole in the left upper side was drilled in the core plate steel and the concrete was found inside.

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