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TREATMENT RECOMMENDATIONS FOR THE BRANCUSI MONUMENTAL ENSEMBLE

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5. STRUCTURAL STABILIZATION AND REPAIR

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I. Introduction

The purpose of the meeting of the structure group was to consider the part of Brancusi's Column referred to as the "Spine." The spine is a carbon steel support structure that cantilevers out of the ground and onto which the cast iron modules are threaded "like a strand of pearls." The *Endless Column* is made up three distinct sections: the first section up to elevation + 10.9m is a steel box section filled up to a 5m level with concrete; the second section up to elevation 20.9m is a similar steel box section without the concrete fill; and the last section up to elevation 28.3m is a lattice-work section. The dimensions of the sections of the Column spine vary from ±42cm square in the lower section to ±40.4cm square in the upper two sections.

Previous investigations were performed by those listed below and findings of these investigations were considered during the meeting:

1. August 1994 site visit by David Scott, a conservator with the Getty Conservation Institute, and Vladimir Kucera and Bo Rendahl, corrosion engineers with the Swedish Corrosion Institute.

2. April 1997 (cf p.10) site visit by Giorgio Croci, Claude Forrieres, and Alessandro Bonci for UNESCO.

3. Structural calculations performed by INCERC, a Bucharest-based engineering concern.

4. Metallurgical studies performed by ICEM, a Bucharest-based metallurgical concern.

5. Non-destructive testing by Laurentiu Gottlieb, Dragos Gheorghiu, Georgica Maftei, Cristinel Nicolae, and Ion Rosu of SC Vulcan SA.

The complete findings of these visits can be found in their respective reports and will only be discussed as necessary in this narrative.

II. Concrete Foundation Systems

Cracking of the poured-in-place reinforced concrete foundations was reported as part of the Getty visits. It was recommended that the foundation systems required further investigation. No foundation cracking was observed during our site visit, however, we were informed that the foundation cracking was assumed rather than visually apparent. We do not know if some cracking repair had taken place prior to our recent site visit.

The concrete foundation for the monument is 3 meters below grade and is not exposed for visual inspection. The concrete that is visible to the eye is the top portion of the concrete counterweight that was formed on top of the foundation and around the base of the initial stage of the spine. In addition it should be understood that concrete, when placed around a steel column, will have a tendency to shrink and consequently crack in a pattern that radiates outward from the steel column. This is a typical phenomenon that occurs in steel-frame buildings with continuous concrete slabs. In these constructions, control joints are introduced into the slabs where they encircle columns to address the inevitable cracking. Such cracks at the *Endless Column*, if observed, do not necessarily indicate distress or failure of the foundations beneath, nor would they detrimentally affect the fixity or counterweight value of concrete.

Based upon our inspection of the concrete at the base of the monument, we do not see a reason to assume that the foundations were damaged when the monument's destruction was attempted in the 1950's, nor do we see the necessity for an investigation of the foundations.

III. Carbon Steel Spine

SC Vulcan SA reported on the results of their recent non-destructive testing to the structures group. They performed magnetic particle and ultrasonic testing to accessible representative plates, welds, and bolts. This testing was performed at elevations 0 to 3 meters and 7 to 9 meters above grade.

No cracks were found in any of the plates tested. Plate thicknesses varied slightly but were generally found to be as thick as or thicker than those originally specified (for example a plate of specified 20 mm thickness was found to vary between 19.8 mm to 21.8 mm). Testing indicated a smooth inside surface of these plates, indicating that they are probably not corroded on the interior. Small inclusions were detected but these were not considered significant.

Eight horizontal welds were tested and no cracking was found. The welds were found to be less than full penetration welds. These welds may require replacement if analysis indicates that they are inadequate. One hundred bolts were tested, and one bolt was found to be cracked. Cracked bolts should be replaced.

Analyses of metal coupons performed by ICEM and reported in the UNESCO report indicate that the steel is composed of .07-.08% carbon, trace amounts of phosphorous (.008%), and .01-.03% sulfur. This is a low carbon steel that is not hard, is easily weldable, and has a low propensity to cracking. The low amount of silicon indicates that it was not used to "kill" the steel during hardening. Low carbon steels would be expected to have a ferrito-perlitic micro structure with the likelihood of sulfur manganese inclusions as reported by UNESCO. In our opinion, this is a good steel material.

Questions remain regarding the actual tensile strength of the steel because all structural calculations to date have been based upon an assumption of the steel strength. A more accurate value for the steel strength can easily be determined by removal of small steel coupons from the spine and physically testing these samples to determine actual yield strengths. Once these values are verified, previous structural analyses of the spine can be revised accordingly and strengthening schemes, if required, can be designed with greater confidence.

IV. Corrosion of the Spine

This is the issue of greatest concern with the monument. After the modules were removed and the spine cleaned of scale, the spine was found to be in better condition than originally feared. The visible corrosion can be characterized as superficial and localized. Areas of visible corrosion include the base, the area behind the sixth and seventh module (as numbered from the base), and at horizontal module joints. The loss of profile in these areas were typically measured at 0.1 mm, but in some areas there are pits that are some 2 to 3 mm in depth, but as they are very localized they are of little consequence.

It is apparent that the corrosion is caused by moisture that is captured in the void between the modules and spine. It is believed that the collection of corrosion product at the base of the monument held moisture against the spine accelerating corrosion in this area. At present there is concern with further corrosion of the spine because the spine is now directly exposed to the elements in a way that it never was prior to removal of the modules. Rain water can presently enter within the spine from the top of the spine that is open to the elements. It is recommended that the spine be protected from rain water on a temporary basis during the time that the modules are disassembled. This can be accomplished by wrapping the spine with plastic sheet and this should be done without delay.

Concern has been expressed regarding corrosion in the spine not open to view, i.e. the interior of the spine. In our opinion this concern should be heeded as the modules were removed and the spine is now exposed directly to the elements with no protection. Endoscopic inspection should be performed by introducing small pilot holes through the plates of the lower portion of the spine where concrete was not introduced into this cavity. Such an examination should address these concerns.

Where concrete is present within the lower 5 m of the spine we do not suspect that there is active corrosion because there are no visible outward signs of hidden corrosion such as failed bolts and welds. Such visible distress would occur from the expanding corrosion product when it is restrained within the concrete and without a void to expand into. Lack of corrosion would not be surprising due to the passivating protection that concrete gives to steel onto which it is in direct contact. If there is reason to believe that steel within the spine is corroded below the level of the concrete based upon the results of the endoscopic evaluation performed from above, then a pilot opening should be introduced through the spine within the concreted area for further visual examination.

V. Inclination of the Spine

Reportedly, the spine received its inclination during the attempt to pull it down in the 1950s, though there are theories that inclination dates from a settling of the foundation in 1937-1938. The Getty report refers to an incline of 7 degrees. As a point of reference the Tower of Pisa has an incline of 5.5 degrees that is highly visible to any viewer. Since the *Endless Column* spine incline is not easily discernible it seems that the 7 degree incline is questionable. Engineers from INCERC report a 131 mm tilt from plumb in one axis and a 195 mm tilt from plumb in the other axis of the spine (relates to an inclination of 0.381 degrees on one axis and 0.256 degrees on the other axis).

Making a visual site line up the spine in both axes indicates that the spine may be bent rather than or in addition to being inclined. The bends may occur at splice points between stages of the spine. These bends were either fabricated in this position or were caused during the attempted destruction. It seems that there is not a sufficiently detailed survey of the progressive incline of the spine along its two axes to make a determination if this incline (or bend) should be addressed, and if so, how. Bends in the Column spine that occur at splices in the Column can be easily remedied in the following manner. Splice connections should be partially or fully disconnected in such a fashion that shims can be inserted in the appropriate areas to straighten the bond. The splice connections would then be reconnected. It is assumed that this would be by a welding or bolting procedure.

VI. Conclusions

Conservation of the existing spine is feasible. Conservation of the spine would entail further investigative testing, revision of the structural analysis taking the results of the testing into consideration, possible strengthening of the spine as directed by the structural analysis and using methods similar to those discussed in the UNESCO report, replacement of horizontal welds with new full penetration welds as directed by the structural analysis, and the choice of an appropriate steel treatment to retard future corrosion. As soon as possible, the interior of the spine should be temporarily protected from water penetration until the actual work begins.

Testing of the spine should include the following:

1. Tensile strength testing of steel coupons to determine the actual yield stress of the steel.

2. Endoscopic investigation of the spine to verify the condition of the steel within the spine in areas not visually accessible.

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3. Further non-destructive testing to confirm the results of the initial non-destructive analysis.

Possible coatings for the steel spine should include either:

1. A two-component organic zinc rich primers with an epoxy coating,

2. An inorganic zinc-rich primer with an epoxy coating (this would require a high degree of applicator skill), or

3. A thermal spray or zinc metallizing coating where molten zinc would beintroduced to the steel surface with compressed air coating (this would require a high degree of applicator skill).

The incline of the spine along both of its axes should be measured with a greater degree of precision. The inclines indicated by the INCERC report may not be significant enough to require repair. Additional measurement will allow the determination of the nature of the incline or bend, whether repair is necessary, and what repair efforts are required.