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TESTING OF CONCRETE OR METAL HOLLOW POLES EMPLOYING PSEUDO-DYNAMIC OR FATIGUE LOADS

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Abstract

Tall slender poles made by either concrete (pre-stressed or centrifugal) or by thin steel plating are used by utilities for various functions. Concrete poles are used by power utilities for electricity transmission cables whereas steel hollow poles are used by transportation authorities for attaching at their top lighting fixtures. These slender columns vary in height reaching 15m are subjected to continuous vibrations during their life time. The main loading condition is that of their own dead weight the forces imposed by the cables they are supporting plus the wind forces. Due to their structural system, being that of a cantilever, the part that develops the largest demands is their lowest part and that of their base and its connections to its foundation. Initially, their observed performance is outlined which demonstrates a number of weaknesses possible leading to unsatisfactory performance or structural damage. Consequently, it is important to check their performance under a number of loading conditions aimed to establish certain levels of resistance. This manuscript presents such loading arrangements employed in order to asses the performance of specific either concrete or metal hollow poles. These loading arrangements were either pseudo-dynamic or fully dynamic in nature. The pseudo-dynamic loading arrangement is employed to establish the inherent resistance of these poles to static loads and especially the limit bending moment value at the base. The fully dynamic loading arrangement aims to establish the limit resistance of such hollow poles under fatigue loading conditions. The testing performed with a number of such hollow poles is presented and discussed. The assumptions adopted for setting up these loading arrangement is outlined. A number of the obtained observations are presented and discussed. It is shown, that such type of testing can reveal manufacturing weaknesses and can thus lead to manufacturing corrective actions. Results from a preliminary numerical analysis are also presented. It is shown that such tests, although they are posing a considerable effort for a testing facility, are very essential; and beneficial for the manufacturing industry and the public utilities.

Keywords: concrete and metal poles, laboratory testing, pseudo-dynamic load, fatigue tests

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1. INTRODUCTION

A variety of poles with a variable cross section are used for transport authorities. These relatively tall and slender poles made by either concrete (pre-stressed or centrifugal) or by thin steel plates are used by utilities for various functions. Concrete poles are used by power utilities for electricity transmission cables whereas steel hollow poles are used by transportation authorities for attaching at their top lighting fixtures (figure 1).

Fig. 1. Slender poles

Figure 2. Concrete poles produced by a centrifugal industrial process at the premises of their industrial production.

The concrete poles are of conical geometry. Figure 2 depicts a number of concrete poles at the site of their industrial production. The metal hollow poles are of various cross section either cylindrical or polygonal, as shown in figure 3 (left). Their cross section also varies along the height, as shown in figure 3 (right) [1].

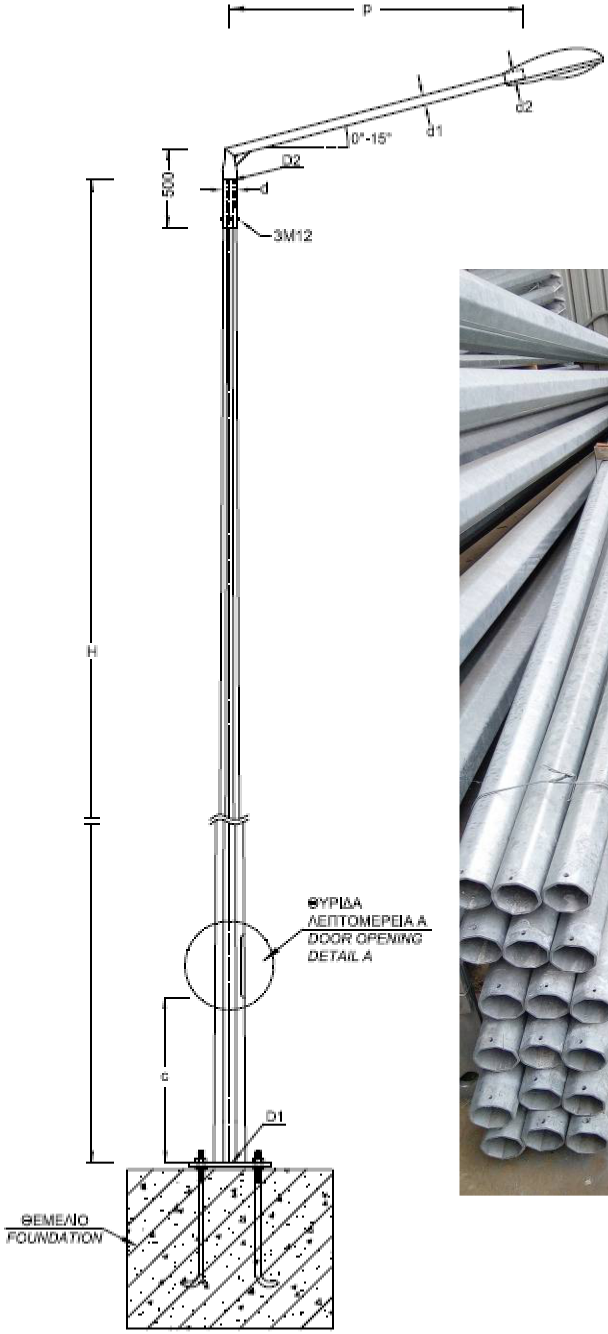

Figure 3 Metal hollow poles. Left. Anchoring at a concrete foundation block. Right. Metal hollow poles at the production facility

All slender poles vary in height reaching 15m and are subjected to continuous vibrations during their life time. The main loading condition is that of their own dead weight, the forces imposed by the cables they are supporting plus the wind forces. Due to their structural system, being that of a cantilever, the part that develops the largest demands is their lowest part and that of their base and its connections to its foundation (figure 3 left). In what follows their observed performance during testing is outlined which demonstrates a number of weaknesses possible leading to a limit-state performance or structural damage. Consequently, it is important to quantify their performance under a number of loading conditions aimed to establish certain levels of resistance. This manuscript presents such loading arrangements employed in order to asses the performance of specific either concrete or metal hollow poles.

2. LOADING ARRANGEMENT USED FOR CONCRETE POLES

The loading arrangement employed to check the performance of concrete piles is described here. Figure 4 depicts the used loading arrangement in order to subject the concrete poles to a dominant pure flexural behaviour. The base end of the pole was rigidly attached to a strong concrete block in a way to simulate fix-end conditions. The other end at the top of the column was left free to rotate with the horizontal force being applied by a strong cable linked with a load cell and a jack monitoring the applied force. In this way the conditions of a free standing cantilever were realized. The resulting deflection at the loaded end was also monitored.

Figure 4. Loading of pre-stress concrete poles being subjected to pure flexure.

Figure 5 depicts the same loading arrangement of figure 4 but with the following modification. A metal frame was attached at the free and enabling the horizontal force to be applied with a considerable eccentricity in order to subject the concrete pole to combined flexure and torsion. By measuring the eccentricity length together with the magnitude of the applied horizontal force the bending moment amplitude and the amplitude of the torque at the fixed end of the cantilever could be found. The applied force was gradually increased until structural damage start to develop, initially through thin cracks and the extending in the form depicted in figure 6.

Figure 5. Loading of centrifugal concrete poles being subjected to pure flexure and torsion

Figure 6. Damage of concrete poles produced by the combined pure flexure and torsion

Three different poles were tested (E-10, M-12 and EB-13) all of them of a conical shape and were produced with a centrifugal industrial production process. The diameter of pole E-10 at its base is 300mm whereas at its top 175mm, with the height of this pole being 10m. The diameter of pole M-12 at its base is 323mm whereas at its top again 175mm, with the height of this pole being this time 12m. The diameter of the third pole EB-13 at its base is 470mm whereas at its top again 310mm, with the height of this pole being this time 13m. The measured load-deflection response of these three poles is depicted in figure 7. The depicted performance is of pure flexure without any torsion and is characterized by almost linear trend up to failure. The maximum load was combined with compressive failure of the concrete thus the limit state performance can be characterized as flexural behaviour of limited ductility.

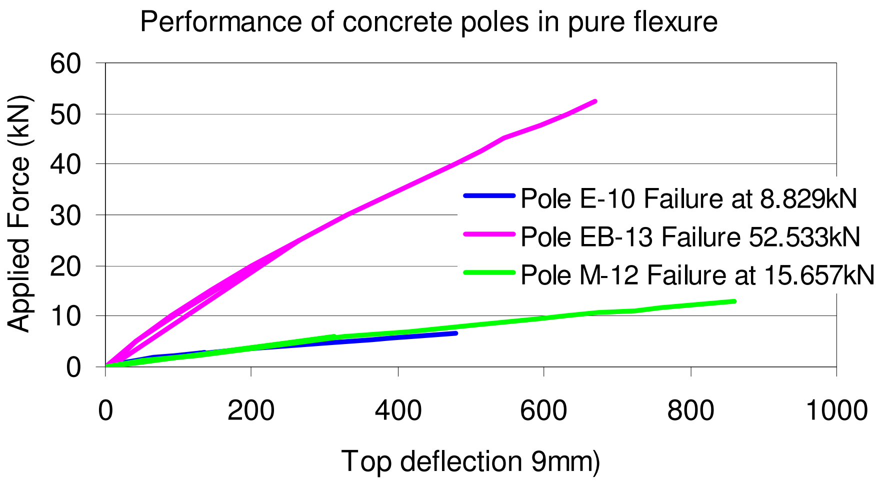

Figure 7. Performance of centrifugal concrete poles being subjected to pure flexure

3. LOADING CHARACTERISTICS FOR METAL HOLLOW POLES

In this section the loading arrangement used to study the performance of metal hollow poles. These poles are composed of a base horizontal plate that is connected with the lower cylindrical part of the pole by welding which is done during manufacturing. The pole of variable cross-sections along its height is composed of a number of parts which are welded along the pole's height. The part that the largest bending moment demand is obviously the base weld. Similarly, it is critical the anchoring of the base metal plate to the foundation concrete block (figure 3, left). The bending moment demands decrease as the distance from them base plate increase; however, the flexural capacity also decreases because of the conical shape. Therefore, it is reasonable to test the lower part of these hollow metal poles.

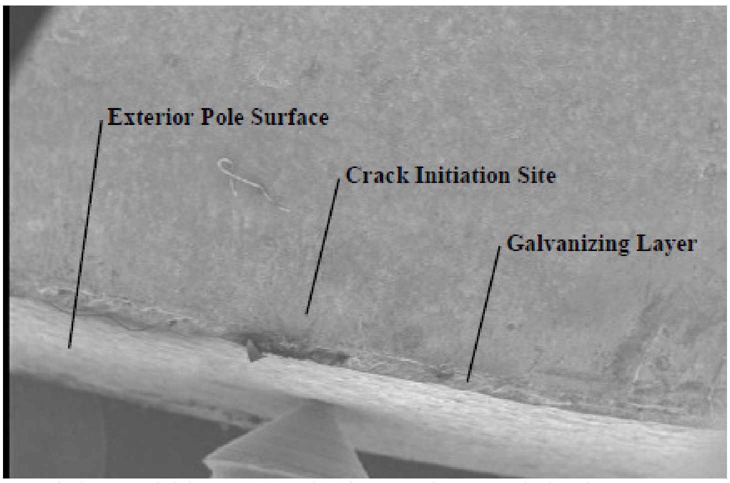

Figure 8. Cracking of the weld between the base plate and the bottom part of the metal pole

Another aspect that must be considered is the dynamic nature of the wind loading. Because of this dynamic nature of the wind it has been established by past observations that the failure of prototype hollow metal poles are dictated by fatigue. Therefore, in order to quantify the long term performance of hollow metal poles it is necessary to study their flexural behaviour both by applying loading simulating pseudo-dynamic conditions as well as conditions simulating fatigue loads. These loading arrangements that were materialized at the laboratory of Strength of Materials and Structures of Aristotle University. Towards this a preliminary numerical simulation was performed in order to asses the dynamic characteristics of the metal poles to under investigation. The obtained results are shown in figure 9 and table 1. As can be seen the first six (6) translational eigen-modes mobilize approximately 50% of the total mass. Moreover, the corresponding eigen-frequencies belong to the frequency range 1.368Hz to 6.308Hz. Including twelve (12) eigen-modes the mobilized mass becomes 62% of the total mass and the frequency range extends up to 38.6Hz.

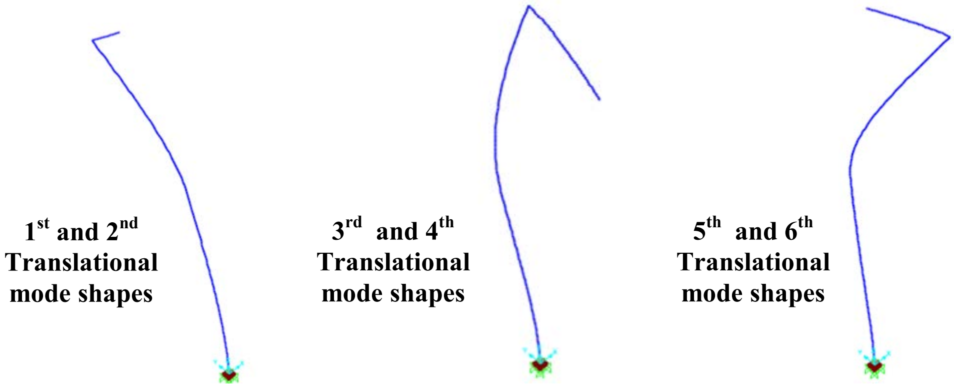

Figure 9. Translational eigen-modes of the metal pole

Table 1. Modal Mass participation ratios

Modal	Frequency	Period	UX	UY	SumUX	SumUY
No	Hz	Sec	Ratios %	Ratios %	Ratios %	Ratios %
MODE 1	1.368	0,731	0	23.5%	0	23.5
MODE 2	1.401	0,714	23.0%	0	23.0	23.5
MODE 3	3.372	0,297	20.7%	0	43.7	23.5
MODE 4	3.536	0,284	0	20.4%	43.7	43.9
MODE 5	5.668	0,176	0	5.9%	43.7	49.8
MODE 6	6.308	0,158	6.5%	0	50.3	49.8

4. LOADING ARRANGEMENT USED FOR METAL HOLLOW POLES

The employed loading arrangement is depicted in figure 11. The bottom part of a hollow metal tube having a height of approximately 2.5m, from a total height of the complete metal pole of approximately 12m, was rigidly attached on the strong reaction floor of a strong reaction frame hosting a servo-hydraulic actuator with force and displacement capabilities sufficient to subject the investigated metal poles to both the pseudo-dynamic and the fatigue loading. For this purpose the base of the pole was secured on the strong reaction floor using the same bolts that are used to secure the prototype metal pole on its foundation block as shown in figure 11 [2]. At the bottom of figure 11 the structural details of the tested hollow metal pole are also listed. The height of the main vertical part of this pole was equal to 9800mm with the external diameter at its base equal to 210mm and at the top 70mm with the thickness at the base equal to 2.5mm. Instrumentation was provided to monitor the applied horizontal load by the servo-hydraulic actuator at a height approximately 2290mm from the base plate. At the same height the resulting horizontal displacement was also recorded. In order to monitor the flexural response of the bottom part of the tested metal pole a set of displacement transducers were attached in order to monitor any resulting vertical displacements of this bottom part.

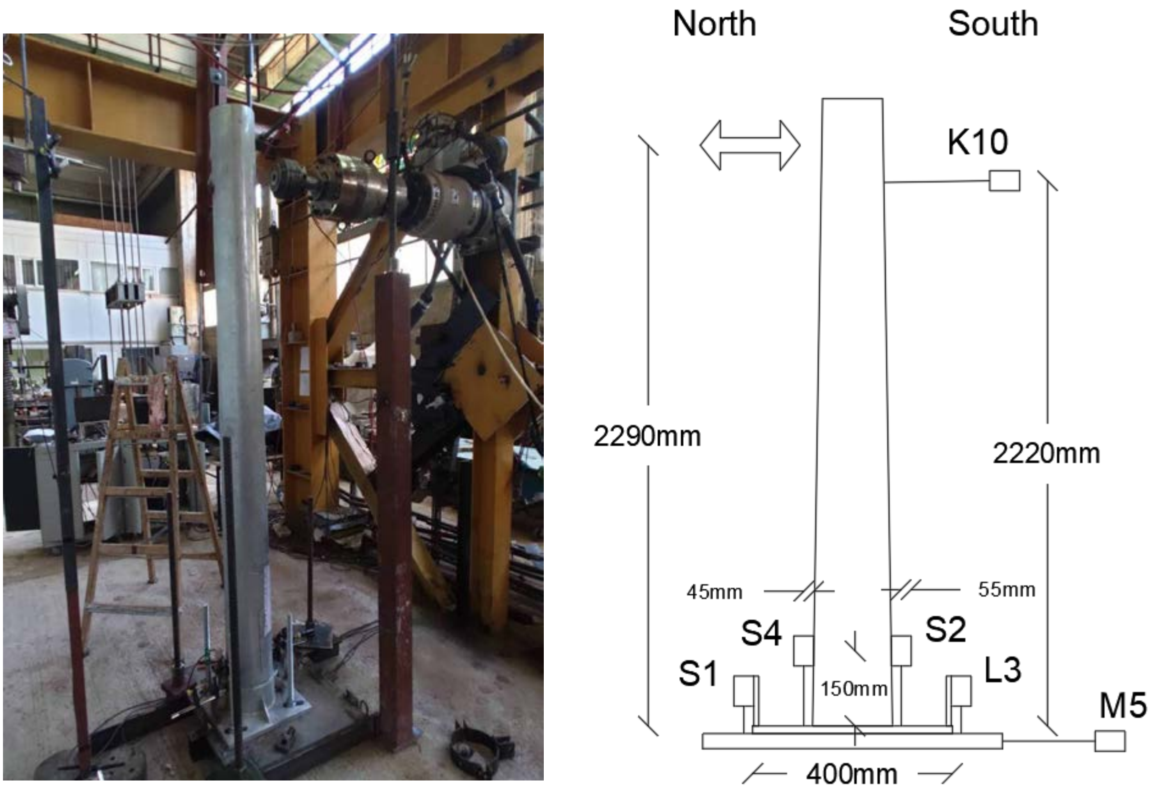

Figure 10. Loading arrangement of the hollow metal pole at the strong reaction frame of the laboratory of Strength of Materials and Structures of Aristotle University

D1 (mm)	D2 (mm)	t (mm)			
210±3	70±2	2.50	400x400x20±1	80x80x8	4 M22 x 600

Figure 11. Clamping of the base of the hollow metal pole on the strong reaction floor.

In order to check the clamping of the base plate at the strong reaction floor apart from the transducers checking the relative vertical displacement between the base plate and the floor an additional displacement transducer was attached at the strong reaction floor in order to monitor the appearance of any sliding of the bottom plate relatively to the floor.

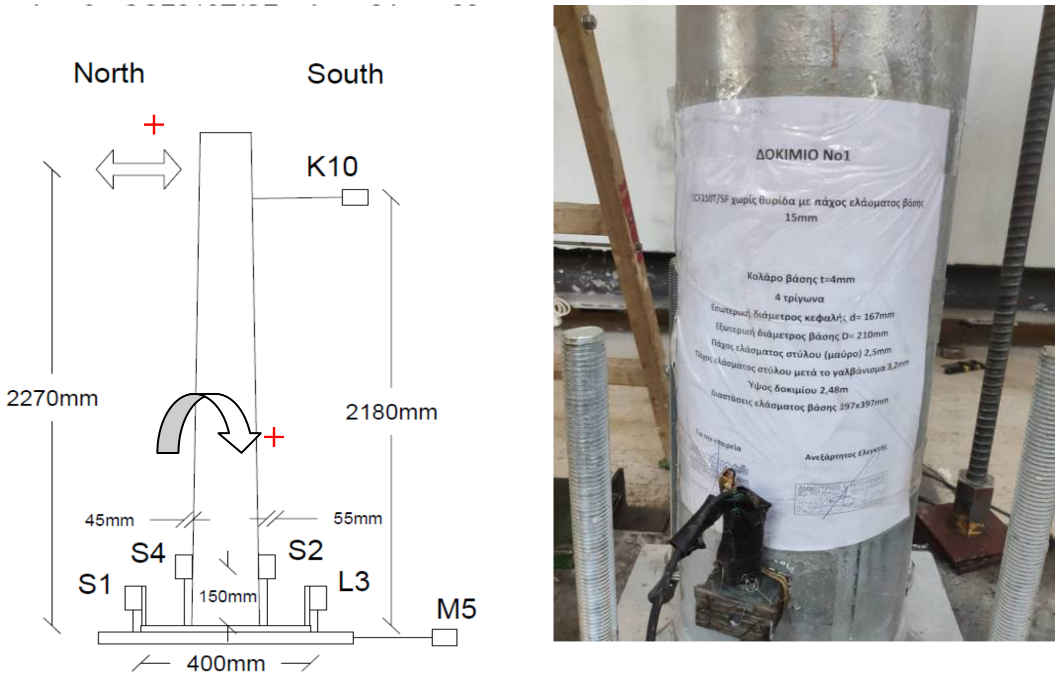

Figure 12. Loading arrangement of the hollow metal pole noting the positive signs for the applied horizontal force and the resulting bending moment at the base.

A special connection was linking the moving part of the servo-hydraulic actuator with the top of the tested hollow metal pole employing a double universal joint in a way that the applied force was of horizontal direction, which was measured exactly by the load cell. All the used instrumentation as well as the servo-hydraulic actuator could effectively perform to the employed frequency which was selected to be equal to 3Hz for the fatigue tests. As can be seen this frequency value is within the frequency range of the first four (4) translational eigen-modes. The obtained results are presented for the two loading sequences.

In figure 13 to 15 the measured flexural response of the tested hollow metal pipe is presented when subjected to pseudo-dynamic load. The variation of the applied horizontal force in time is depicted in figure 13 whereby it can be seen that the loading frequency was 0.03Hz although the cyclic nature of the load is kept. Figure depicts the obtained flexural response of the hollow metal pole in terms of the variation of the base moment and the horizontal force at the top versus the horizontal displacement at the top. Figure 15 depicts the measured flexural response of the hollow metal pole in terms of the variation of the base moment versus the rotation of the bottom part of the pipe relatively to the base plate. The corresponding response of the metal pole to fatigue loading, which followed the pseudo-dynamic load, is depicted in figures 16 to 18. Figure 16 depicts a time window of the fatigue loading when almost 100000 cycles were completed. The loading frequency is equal to 3.0Hz e.g. 100 larger than the loading frequency of the pseudo-dynamic test [3]. Moreover, when comparing figures 14 and 17 it can be seen that the relevant target bending moment values are equal to 15.44kNm and 11.03kNm, respectively. There was no observed structural damage up to this number of loading cycles.

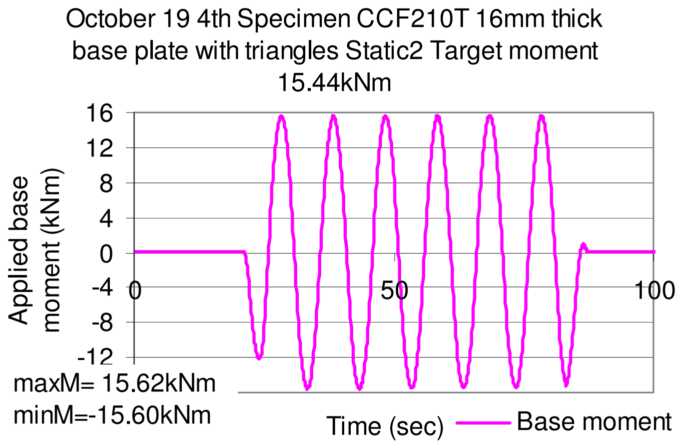

Figure 13. Flexural response of the hollow metal pole noting the variation of the base moment at the base versus time.

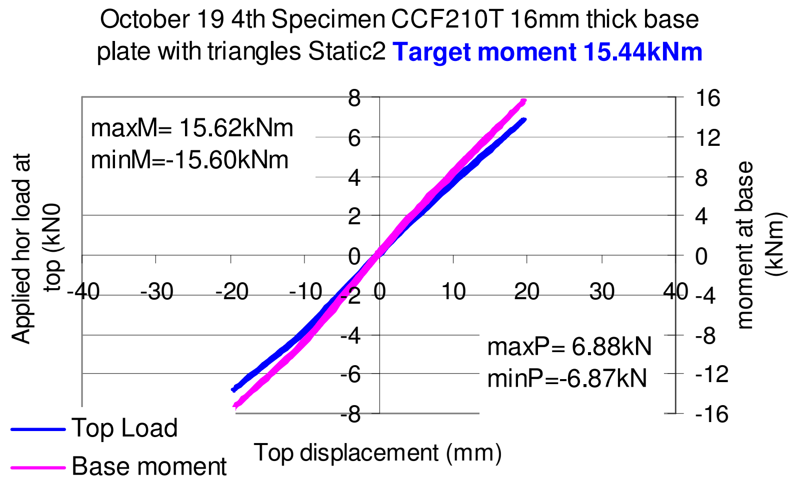

Figure 14. Flexural response of the hollow metal pole in terms of the variation of the base moment and the horizontal force at the top versus the horizontal displacement at the top.

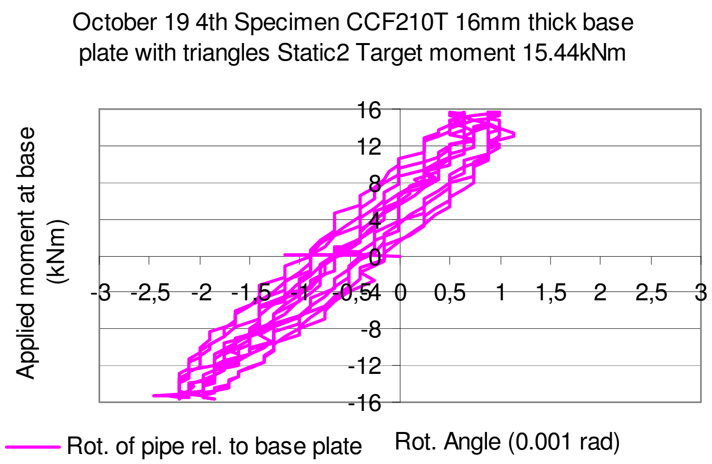

Figure 15. Flexural response of the hollow metal pole in terms of the variation of the base moment versus the rotation of the bottom part of the pipe relatively to the base plate.

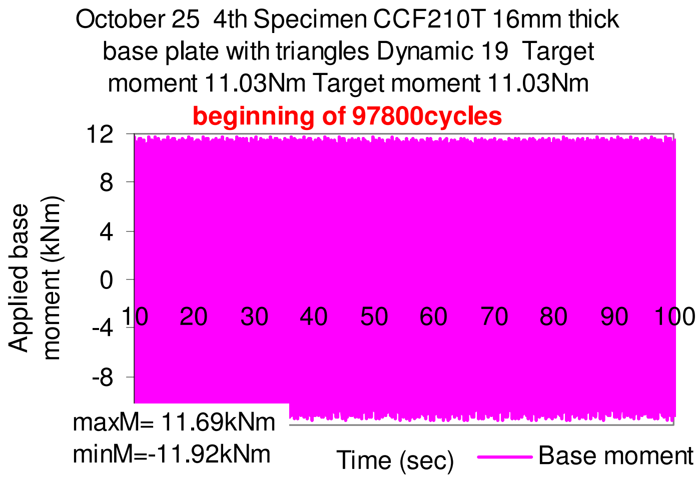

Figure 16. Flexural response of the hollow metal pole noting the variation of the base moment at the base versus time.

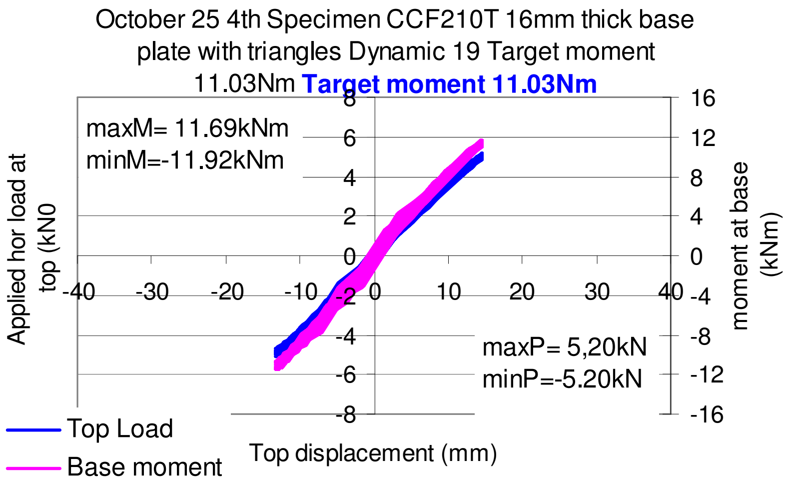

Figure 17. Flexural response of the hollow metal pole in terms of the variation of the base moment and the horizontal force at the top versus the horizontal displacement at the top.

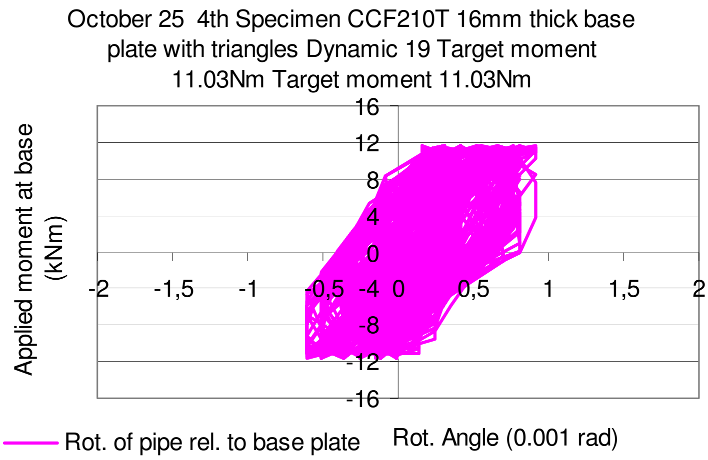

Figure 18. Flexural response of the hollow metal pole in terms of the variation of the base moment versus the rotation of the bottom part of the pipe relatively to the base plate.

5. CONCLUSIONS

Tall slender poles are used by utilities for various functions. Concrete poles are used by power utilities for electricity transmission cables whereas steel hollow poles are used by transportation authorities for attaching at their top lighting fixtures. The main loading condition is that of their own dead weight the forces imposed by the cables they are supporting plus the wind forces. Due to their structural system, being that of a cantilever, the part that develops the largest demands is their lowest part and that of their base and its connections to its foundation. A set of loading arrangements used to test the flexural capacity of these poles are presented in this study. The following are the main conclusions.

- For the concrete centrifugal poles the used loading set up subjected the full length of the pole to either pure flexure or flexure combined with torsion. The obtained response demonstrated that this loading arrangement was effective in reaching the limit state for the studied poles.
- The observed behavior was of limited ductility whereby the maximum load was followed by the compressive concrete failure of the compressive zone. The employed loading arrangement can be used to verify the conformity of these industrial products to the desired performance according to specifications.
- For the hollow metal ties apart for the pure flexural performance under pseudo-dynamic loading an additional requirement is to check the flexural performance under fatigue loading conditions. The later is a quite demanding loading condition both in the ability of laboratory equipment to apply this type of loads as well as in the time that is required to complete such a large number of loading cycles.
- The tests that were performed completed 100000 loading cycles for the specimen presented here monitoring all this time the most significant loading and displacement response parameters. The specified target bending moment at the base of the tested specimen was reached as required throughout the loading sequence. For the specimen presented here no structural damage was observed throughout all the fatigue loading sequence.

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