



COMPARATIVE STUDY OF MECHANICAL BEHAVIOUR OF LIGHTING POLES WITH FLAT AND STAMPED FLANGES

Zakaria EL MASKAOUI

ENSEM, Hassan II University of Casablanca, Morocco

Salah Eddine JALAL

ENSEM, Hassan II University of Casablanca, Morocco

Lahbib BOUSSHINE

ENSEM, Hassan II University of Casablanca, Morocco

ABSTRACT

This paper presents a comparative study of mechanical behaviour of two types of steel lighting poles. The first type has a thick flat flange plate and the second type is with thin stamped flange. For this purpose, an experimental program was performed in order to apply bending load to the poles. Applied load and deformations of the tested poles and those of the flanges were fully measured. In parallel with the experimental study a numerical modelling program has been carried out to investigate further the structural behaviour of poles under loading. The numerical models, which were developed using the nonlinear finite element package MSC NASTRAN, showed the capability to replicate the key test results and the full experimental load–deformation. Both experimental and numerical results revealed that using stamped flange reduces overall manufacturing cost of lighting pole than flat flange plate ensuring at the same time compliance with international standards.

Key words: Zakaria EL MASKAOUI, Salah Eddine JALAL and Lahbib BOUSSHINE.

Cite this Article: Zakaria EL MASKAOUI, Salah Eddine JALAL and Lahbib BOUSSHINE, Comparative Study of Mechanical Behaviour of Lighting Poles with Flat and Stamped Flanges, *International Journal of Mechanical Engineering and Technology* 9(6), 2018, pp. 1241–1250.

<http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=9&IType=6>

1. INTRODUCTION

Today's street lighting market, in Morocco and in several African countries, is a major one, in a context of heavy international competition. The choice of lighting poles is determined by a variety of factors such economic and environmental aspects, safety and quality requirements

in respect of existing norms, standards and techniques related to the design, construction and operation.

Lighting poles structures are comprised of an octagonal conical column welded to flange. Pole is subjected to two kinds of forces, wind load and dead load due to the weight of the bracket, lanterns, etc. The flange transfers the loads applied on the pole to the foundation. The verification of the pole design calculation should be made in accordance with European Standards EN 40 [1]. There are several explicit methods for design of flat flanges, which can be found in the Eurocode 3 steel design guide and in many other books [2], but an explicit method has not yet been presented for design of stamped flange.

On the other hand, several lighting poles with flat flange plate collapsed in-service. The results of the ensuing investigation concluded that the collapse was due to fatigue cracking at the pole-to-flange connection [3–5]. Fatigue of lighting poles is caused by wind-induced oscillations due to the aero-elastic phenomenon of vortex shedding and the aerodynamic vibrations of natural wind gust [6]. The results of the research show that the flange flexibility of welded pole-to-flange connections must be considered in order to produce fatigue designs that are efficient, economic and safe [7]-[8].

This study investigates the effect of flange shape geometry on the flexibility of steel lighting poles and the stress behaviour in the lighting pole. Two types of flange are tested. The first with thick flat flange and the second with thin stamped flange. During the test, the poles were erected transversally and applied load and deformations of the tested poles and those of the flange were fully measured.

In conjunction with the experimental study a numerical modelling program was performed using the Finite Element (FE) analysis package code MSC/NASTRAN SOL400 [9]. The aims of the numerical investigations were initially to replicate the full experimental load–deformation histories and to generate further structural performance data to supplement the experimental results. The results of the calibration study show that relatively FE modelling techniques are able to provide reasonable results, when compared to experimental data.

2. TEST LIGHTING POLES SPECIFICATIONS

In order to investigate the effect of flange shape geometry on the performance of lighting poles structures, two specimens comprised of an octagonal conical pole without hand access hole, welded to flange were manufactured from steel sheets. The design of lighting pole specimens structures follows the EN 40 Standard Specifications [1]. The poles had an initial length of 6m and they were cut to have 2.5m in length. The first pole has a flat flange made of a steel plate with a thickness of 14 mm by oxy-fuel cutting process. The second pole has a steel stamped flange with a thickness of 10mm. The flange is cut-out to allow the pole to fit inside of it. Two fillet welds connect the flange to the pole. The first and most structurally significant is applied at the top of the flange. The second fillet weld is applied inside the cut-out of the flange, between the bottom surface of the pole and the sides of the cut-out in the flange. Fig. 1 and 2 show the geometric features of the two pole specimens and the flanges. The measured dimensions are presented in Table 1.

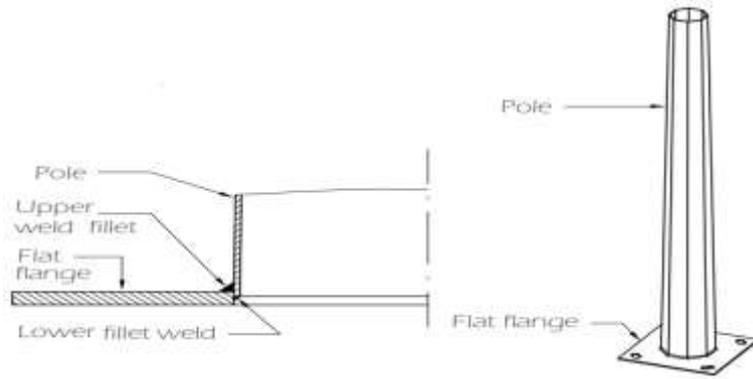


Figure 1 Lighting pole specimen with flat flange

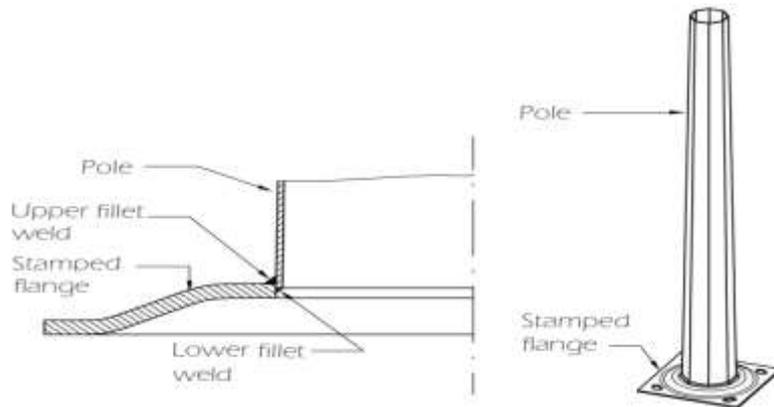


Figure 2 Lighting pole specimen with stamped flange

Table 1 Poles dimensional characteristics [m]

Height of the pole	Base diameter	Top diameter	Thickness	Flange dimensions
2.50	0.191	60 at 6	0.003	0.4x0.4

3. EXPERIMENTAL PROGRAM

The study based on experimental analyses has been carried out at Laboratory of Technologies of Constructions and Industrial Systems (LTCSI) at ENSEM of Casablanca. The objective of the experimental test fixture is to erect the pole horizontally for loading test and measure displacements at specific points. The test set-up is shown in Fig. 3 and 4.

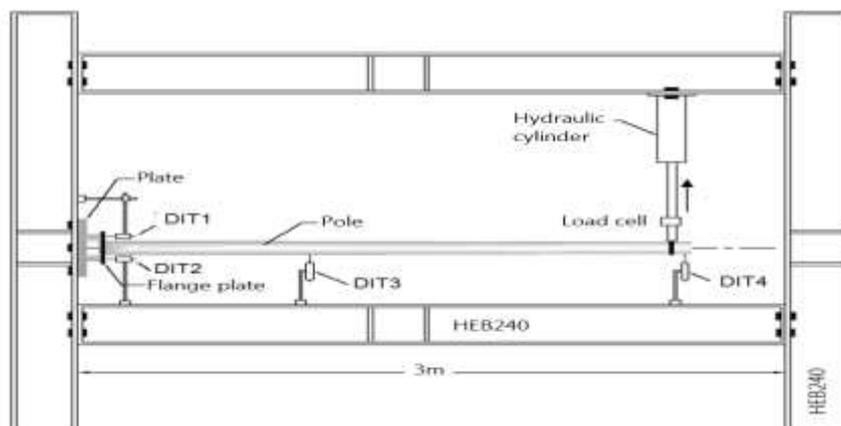


Figure 3 Test set-up showing test frame and lighting pole



Figure 4 Pole mounting



Figure 5 Displacement inductive transducers DIT1 and DIT2 positions

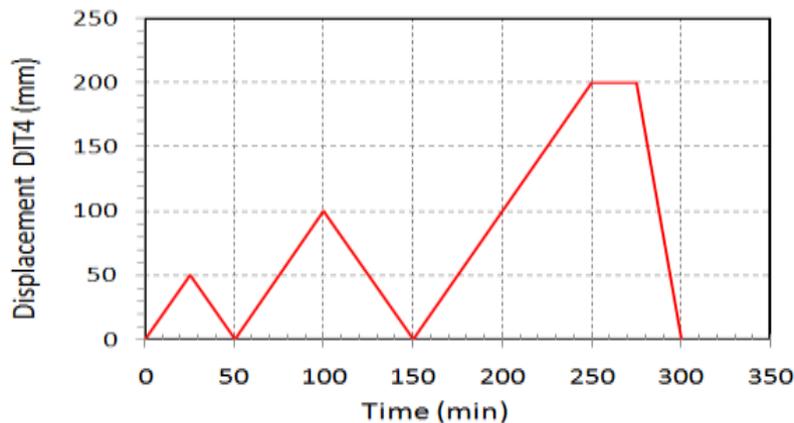


Figure 6 Loading protocol

In the field, the structures are supported by a reinforced concrete foundation which extends below ground. Since the experimental investigation was not concerned with the dynamic properties of the structures, the soil interactions were neglected. Therefore, the flanges are clamped to a rigid cover plate with four M28 bolts grade 6.8. The elastic limit of the connections was predicted analytically.

The loading is applied by hydraulic cylinder through a loading cell at the top of the pole. All displacements are recorded by inductive transducers connected to a data acquisition system. Indeed, displacement inductive transducers DIT1 and DIT2 were used to measure the flange deflection on the compression and tension sides as indicated in Fig. 5. To measure

transversal displacement of the pole, displacement inductive transducers DIT3 and DIT4 were installed respectively 1m and 2.48m away from the flange.

The test was carried out under displacement control in order to detect any local failure during the test. The loading protocol is divided into several displacement steps: loading to 50mm, unloading, reloading to 100mm, unloading and reloading until 200mm (see Fig. 6). The average displacement speed of the cylinder rod is approximately 2mm/min.

4. FINITE ELEMENT MODEL

In conjunction with the experimental study described before a numerical modeling program was performed using nonlinear FE analysis. A FE model of specimens structures created using the graphical preprocessor MSC PATRAN and the analysis was carried out using the code MSC NASTRAN SOL400.

Shell element type (*CQUAD4*) was used for flange plate and pole, which is a kind of four nodes element with six degrees of freedom each node, and applicable to nonlinear analysis with large deformation (see Fig. 7). Preliminary studies are performed to select the parameters of the finite element meshing. Then, the nodes and elements were distributed in such a way that a finer mesh was created at the critical region of the structures and a coarser mesh elsewhere.

Multi-point constraint (*MPC*) element, or specifically NASTRAN's Rigid beam element *RBE2* is used to connect nodes at the top of the pole. The load is applied at master node of the *MPC* element. The bolts are represented by rigid elements (*RBE2*); the center of the rigid elements is constrained with respect to any translational displacements.

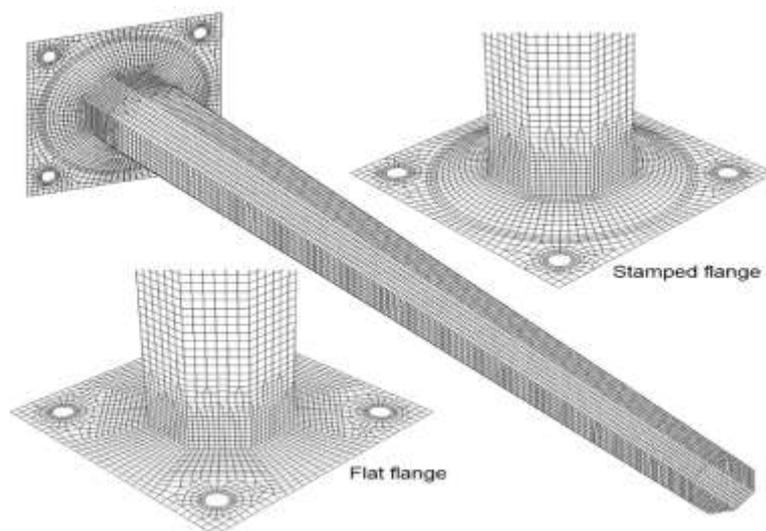


Figure 7 Specimens mesh

Instead of nominal stress-strain ($\sigma_n - \varepsilon_n$) curve obtained from tensile coupon test, true stress-strain ($\sigma_t - \varepsilon_t$) curve [9] is used to introduce the material nonlinearity portion before inputting into MSC NASTRAN (see Fig. 8). The material elastic portion is defined by providing the Young's Modulus, $E=190400\text{MPa}$ and Poisson's ratio $\nu=0.3$ with density $\rho=7850\text{kg/m}^3$.

The calculation is performed with displacement control considering geometrical and material non-linearity. This allows providing the load-displacement curve including the descending branch that represents the post-critical range.

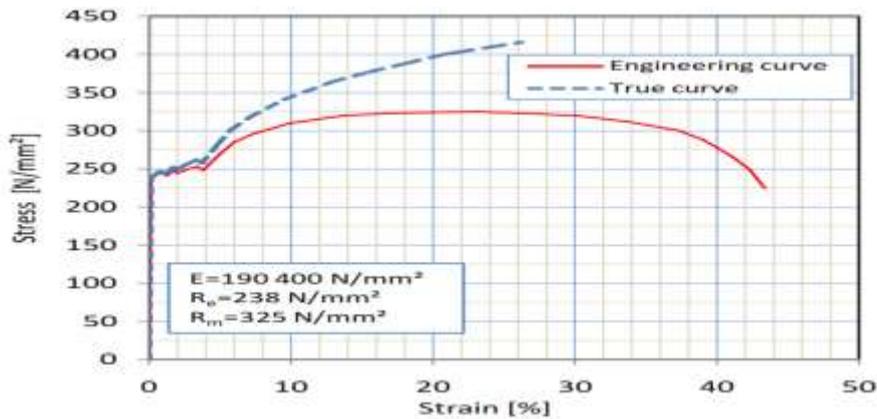


Figure 8 Engineering and true stress–strain curves

5. ANALYSIS OF EXPERIMENTAL AND NUMERICAL RESULTS

As detailed in section 3, specimens were erected transversally to determine the behavior of specimens under applied load. Fig. 9 and 10 show respectively experimental and numerical results of the applied load against the transversal displacement at the top of the pole. The curves given by the FE model showed the same tendency as the experimental results. Both specimens present a typical elastoplastic response. The global load–displacement curves agree well with the experimental curves during the first stage of loading. At the end of the curve, the test load is growing continuously because the FE models does not take into account the residual stresses due to cold-forming and welding introduced during the production process what resulting in significant changes in material behavior [10].

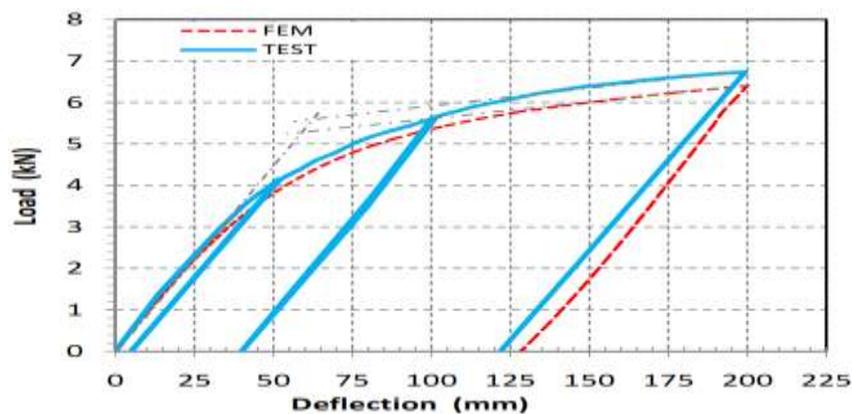


Figure 9 Experimental load-deflection curves at the top of the pole with flat flange

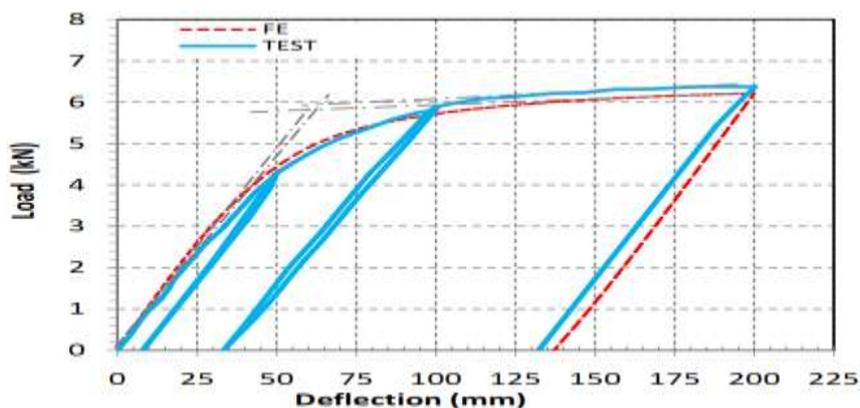


Figure 10 Numerical load-deflection curves at the top of the pole with stamped flange

To obtain some usual characteristics for the structural analysis and design, we define the plastic resistance value F_y as the intersection between the initial stiffness (S_o) and the tangent stiffness at the final part of the load–displacement curves (see Table 2).

The pole with stamped flange have a slightly greater residual deflection than the pole with flat flange. These deflections are mainly due to plastification at the flanges.

The flexural stiffness at the loading and unloading phases is almost identical for the two specimens. That shows an elasto-plastic behavior without damage.

Comparatively to the flat flange, the plastic resistance is enhanced for the stamped flange by more than 5% for experiment results and then 8% for numerical results.

Table 2 Final Data Comparison

Pole type		Plastic resistance F_y [Kn]	Displacement u_y [mm]	$S_o = F_y/u_y$ [kN/mm]	Residual deflection u_p [mm]	Max load F_{max} [kN]
With Flat flange	FE	5.3	59.0	0.0896	128.6	6.4
	Test	5.6	63.6	0.0884	122.1	6.7
With Stamped flange	FE	5.8	59.5	0.0975	137.3	6.2
	Test	5.9	64.7	0.0917	132.4	6.4

Fig. 12 and 13 shows the experimental and numerical load-displacement curves in the flange measured as indicated in Fig. 5.

The experimental result flange deflection is slightly different to the FE results. This slight disagreement is acceptable due to the measuring tolerance of the experimental test setup.

The numerical deflection of stamped flange is slightly greater than the experimental results due to non-consideration of the residual stresses due to cold-forming introduced during the stamping process. At the plastic stage, deflected shape at DIT1 position is greater than DIT2 position by more than 45% for stamped flange and is smallest by more than 7% for flat flange. The same tendency results are nearly obtained by FE model showed in Fig. 14.

Fig. 15 and 16 show respectively plastic stain and Von Mises stress distributions in flanges. The plastic deformations and stress are much higher in the flat flange at the intersection with the pole at the corner regions fold. However, fatigue only occurs in locations of highly localized plastic deformation [4]. Stamped flange also influences the stress distribution through the pole and flange connection. However, the stress distribution at welded connection areas is better in the stamped flange than flat flange.



Figure 11 Deflected shape of flange under maximal load

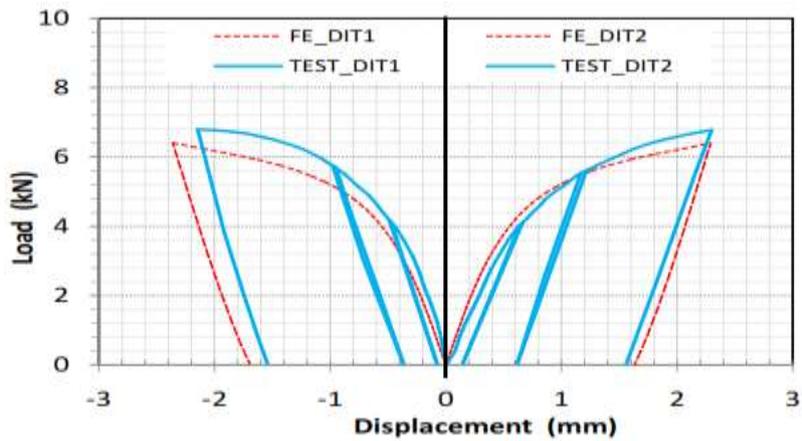


Figure 12 Experimental and numerical load-displacement curves in the flat flange

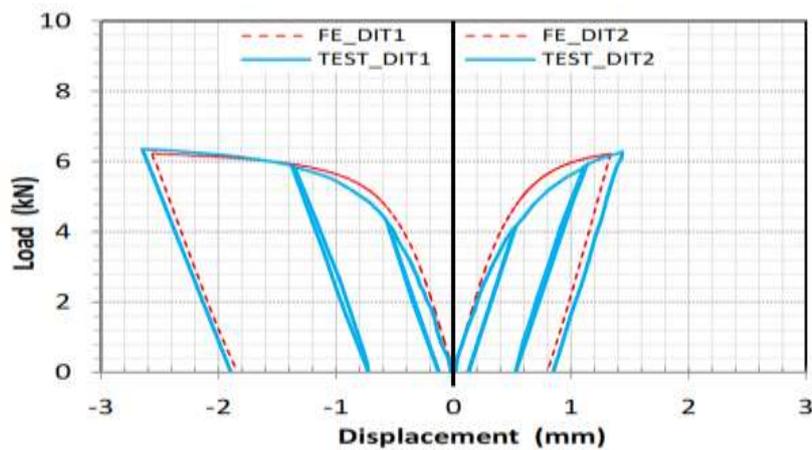


Figure 13 Experimental and numerical load-displacement curves in the stamped flange

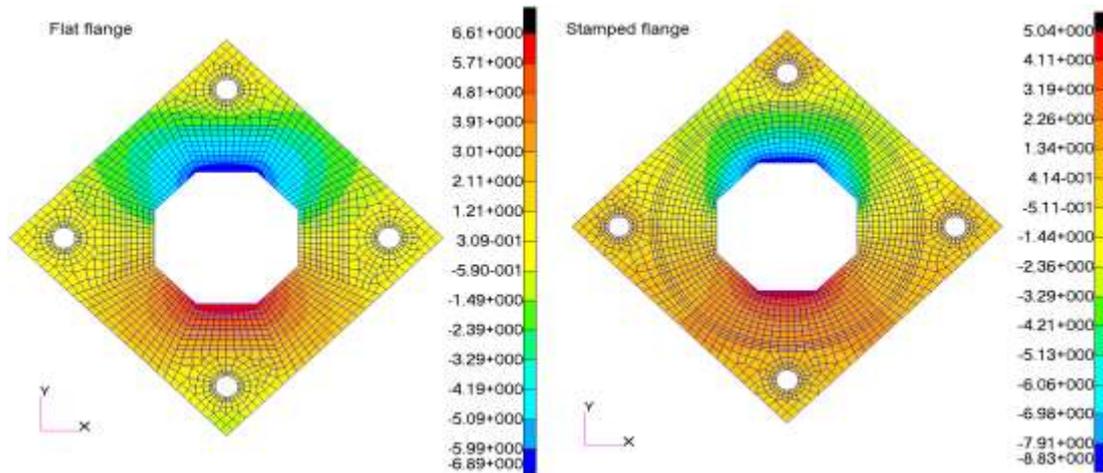


Figure 14 Flange plate displacements, Z component [in mm]

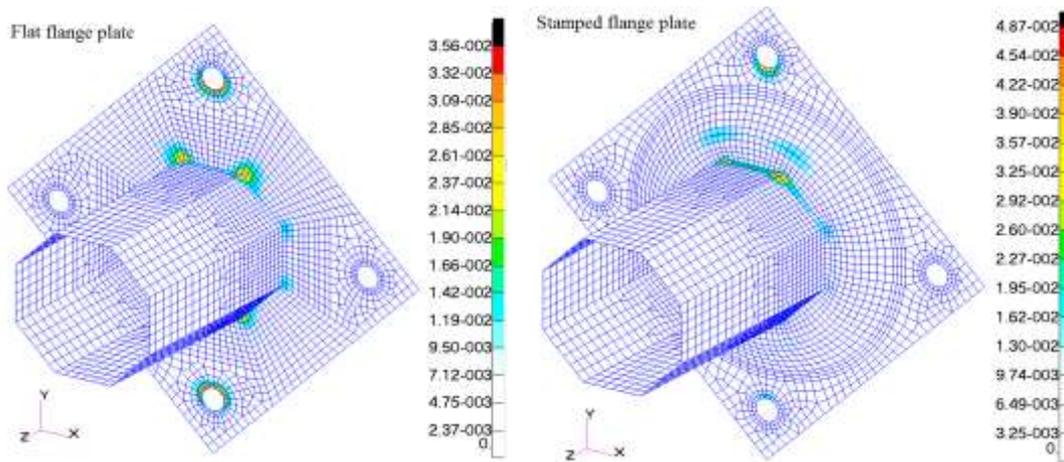


Figure 15 Plastic strains

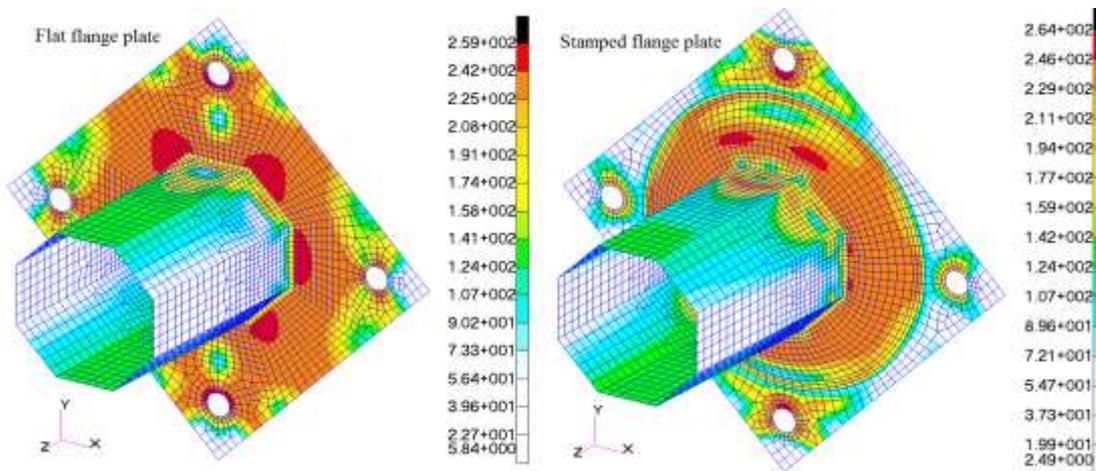


Figure 16 Von Mises stress tensor [in N/mm²] in the flanges at Plastic resistance load

6. CONCLUSIONS

In this work a comparative study between two types of steel public lighting poles was carried out. The first pole has a flat flange with a thickness of 14 mm. The second pole has a stamped flange with a thickness of 10mm. A FE model was developed to simulate the nonlinear behaviour of the poles and verified through comparison with the experimental result. From the observations and analyses of the experimental and numerical results, the following conclusions can be drawn:

- The results given by the FE model showed the same tendency as the experimental results.
- The flexural stiffness at the loading and unloading phases is almost identical for the two poles. That shows an elasto-plastic behaviour without damage.
- The pole with stamped flange have a slightly greater residual deflection than the pole with flat flange. These deflections are mainly due to plastification at the flanges.
- Stamped flange enhances the resistance and gives a more ductile behaviour compared with the flat flange.
- At the plastic stage, deflected shape in the stamped flange is more important than flat flange.
- Stamped flange has a considerable influence on the distribution stress and plastic stain in the pole wall adjacent to the welded connection of a lighting pole. However, stress and plastic

strain are much higher in the flat flange at the intersection with the corner regions fold which increases the risk of fatigue failure in these areas.

Through this study, we can confirm using stamped flanges could reduce overall manufacturing cost of lighting pole than flat flanges by reducing the thickness, ensuring at the same time compliance with international standards. On the other hand, both the experimental investigation and numerical study could provide valuable information and could be extended to study of the effect of the residual stresses due to cold-forming and welding introduced during the production process on the lighting pole behaviour.

REFERENCES

- [1] European Committee for Standardization. EN 40-3-1: Lighting columns. Design and verification. Specification for characteristic loads. BSI. 2013.
- [2] Lescouarc'h, Y. "Les pieds de poteaux encastrés en acier." CTICM. 1988.
- [3] Kaczinski, M. R., Dexter, R. J., and Van Dien, J. P. "Fatigue-resistant design of cantilevered signal, sign and light supports." Nchrp. 1998.
- [4] Miki, C., Fisher, J. W., and Slutter, R. G. Fatigue behavior of steel light poles. State of California, Department of Transportation. 1981.
- [5] Aichinger, R., and Higgins, H. "Toe Cracks in Base Plate Welds? 30 Years Later." Electrical Transmission Line and Substation Structures, Proceedings. 2017.
- [6] Thompson, R. W. "Evaluation of High-Level Lighting Poles Subjected to Fatigue Loading." Master of Science, Lehigh University. 2012.
- [7] Hall, J. H., and Connor, R. J. "Influence of Base Plate Flexibility on the Fatigue Performance of Welded Socket Connections." Journal of Structural Engineering, American Society of Civil Engineers, 134(6), 911–918. 2008.
- [8] Warpinski, M. K., Connor, J. R., and Hodgson, C. I. "Influence of Flexibility on the Fatigue Performance of the Base Plate Connection in High-Mast Lighting Towers". J. Struct. Eng., vol. 136, no. 3, pp. 324–329, Mar. 2010.
- [9] MSC Software, MSC Nastran 2014 Nonlinear User's Guide. MSC Software Corporation, 2014.
- [10] Ashraf, M., Gardner, L., and Nethercot, D. A. "Strength enhancement of the corner regions of stainless steel cross-sections." Journal of Constructional Steel Research, 61(1), 37–52, 2005.