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A STUDY OF THE LIFE EXPECTANCY OF COOLING TOWERS

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ABSTRACT :

The paper describes the following different tasks of the study whose aim was to extend the life time of cooling towers for French Nuclear Power plants to 40 years.
The aging factors specific to cooling towers were measured and analysed with regard to the external surface, the internal surface and inside the concrete.
The safety coefficient for buckling was calculated and then the stress analysis of the materials (concrete and steel) was done. A special computer program written for cooling towers was used with a model including the soil stiffness and the supports of the tower.

I. Introduction

The importance ELECTRICITE DE FRANCE (EDF) places on the economic management of its nuclear power plants has caused the development of a study programme concerning the life expectancy of certain major components. The cooling towers are one of these EDF has 26 cooling towers on nuclear plants and 2 on thermal plants (see fig.1). These are all exceptional structures for their size (Golfech holds the world record at 178.50 m tall), their structure (relatively very thin) and their severe environment (extreme humidity, strong winds and varying temperatures). (see Fig.2)
They are under a standard surveillance which comprises of :
- a complete inspection before commissioning (elevation levels, photogrammetric survey),
- annual classic topographic surveys. This has now been replaced by an automatic system using a laser and a microcomputer,
- a survey of visual faults (video system).

A complementary study was made on several old towers (Bugey, Dampierre, Cruas and Pont-sur-Sambre) with the aim of determining the physical aging factors, and the safety and durability coefficients.

II. Effects of the aging factors

The factors specific to cooling towers were analysed regarding :
a) the external surface : rate of concrete carbonation and penetration of aggressive ions from the atmosphere.
b) the internal surface : study of the algae and the amount of cement paste contained within fallen algae. Chemical attack by the condensation accounts for a small amount of mineralization.
A systematic study of algicide products has been carried out.
c) inside the concrete :
- examination by a Scanning Electron Microscope in order to determine the structure of the cement hydrates, the identity and the localization of possible products of decomposition and the quality of paste and aggregate
- measurement of the moisture gradient
- measurement of the temperature gradient

The majority of the results have been processed and interpreted and have led to the following conclusions :
- the mineral matter contained within the algae does not affect the towers' life expectancy, (extrapolation indicates 4 mm of concrete lost after 30 years operation).
It is not foreseen to resort to algicide protective coatings.
- concrete carbonation : varies greatly from sample to sample but rarely exceeds 1 cm in 8 years of use. Assuming a relationship of the form $\sqrt{t}$, the average reinforcement cover of 3 cm does not give worries about the loss of protection (confirmed at Pont-sur-Sambre).
The results (temperature, humidity) provide an abundant source of information. Altogether none of the factors of structural degradation are found to affect the expected life time of cooling towers.

III. Evaluation of safety and durability factors

All the cooling towers have not the same level of safety ; the recent regulations are very precise and consider all the aspects of safety. The earlier towers were built following simpler regulations. The analysis of safety factors is only necessary for these older towers and those that have experienced noted deteriorations.
For the first application, EDF has chosen the Pont-sur-Sambre cooling tower, a 30 years old coal power station.
This tower, built for a capability of 125 MW, has a height of 92 m, a base radius of 32 m and an average thickness of 0.1 m. It comprises only of one layer of horizontal and vertical reinforcement bars.
To begin with, the exact state of the tower had to be known, so the following surveys were carried out.
a) soil stiffness (modulus of long term deformation by boring and dynamic modulus by seismic refraction)
b) external deformation (measured by photogrammetry)
c) visible cracking
d) resistance and modulus of concrete (core drilling, sclerometer, sonic velocity counter)
e) reinforcement positioning

f) state of corrosion of the reinforcement (core drilling and surface electrical potential)
The two key safety parameters, ultimate resistance and buckling have been closely examined.

III.1 Ultimate limit state
The risk of collapse is evaluated regarding a defect of resistance of a part of the shell.
The different partial safety factors similar to Eurocode are all calculated (see fig.3).
The elementary load cases are combined according to EDF specifications established following French regulations.
The steel bars were put into five categories according to their state of corrosion (84 % steel remaining near the upper ring and 95 % in the lower part of the shell).
The stress analysis of the materials (concrete and steel) was done using a special computer program writen for cooling towers, with a model including the soil stiffness and the supports.
The stress analysis of the materials (fig.5) shows that :
a) Stresses in concrete assumed homogenous : for the perfect reference structure, the allowed tensile stresses are not exceeded.
For the actual structure, the average stresses in tension exceed the allowed ones (2 MPa), on average over a total area of 220 m^2 on the outside surface and 10 m^2 on the inside, where the total surface is 5800 m^2.
b) Stresses in steel bars
For the reference structure, the allowed limit stresses of steel are exceeded especially in the lower part of the shell, where the vertical cracking is the most important.
In fact, the effect of the corrosion of the steel bars and their off centre positioning calculated by a global statistical approach slightly affect the conclusions drawn.

III.2 Safety coefficient for buckling
The safety coefficient for buckling is calculated from two criteria :
a) Formulae established by the University of Bochum (Dr Mungan)
The criteria are calculated not only at the neck but over the whole section for the reference shell and the real model (see diagram). The shell was not designed with these criteria.
The calculated coefficient shows a notable singularity at level 9.5-11 m. It reaches 2.8 for the theoretical shell and 2 for the real one where stresses are amplified by the deformations.
In the current specifications, the minimum allowable value for the Bochum coefficient is 5.
b) Eulerian buckling
The calculations are done using a finite element three dimensional elastoplastic model based on the theory of plasticity and using criteria of multiple forces ; tension, shear, hydrostatic pressure and those arising from anisotropic cracking.
The real geometry (issued from photogrammetry) is entered with multimodal deformation (from modes 5,6 and 9) of amplitude 27 cm (the maximum observed deformation). (see fig.4)

Values of λ (Eulerian buckling safety coefficient)

load	elastics		elasto-plastic	
	theoretical shell	real shell	theoretical shell	real shell
λ G	8,6	12,25	2,73	2,17
λ (G+V)	8,3	11,05	2,15	1,54
λ (3G+V)	3,3	4,4	1,45	-
3G + λV	21,7	26,9	-	-

G = gravity loads V = normal wind loads

Comments on the calculations
1) For the elastic calculations, the deformations of the tower effectively increase the stiffness and therefore the safety but a failure would be more brittle.
2) The wind slightly reduces the safety factor regarding buckling.
Therefore an average safety factor of the order 1.5 to 2 is found. Obviously, the model does not take into account the reinforcement of the upper ring nor the six external steel cables around the top part of the tower.

III.3 Safety conclusions
The safety has been confirmed but the safety margins are clearly lower than the prescribed ones (see fig.5).
This tower is under regular surveillance from now on. If a local weak area, is found the study will be revised and remedial action will be taken.

IV. Surveillance procedure

EDF expects to complete the monitoring process by testing with a patented machine called LEZARD wich is used jointly by EDF and CEBTP. (Building and Public Works Study Centre). The LEZARD is an automatic machine capable of moving about the surface and assessing the positioning of reinforcement, the rate of corrosion of the steel bars and the surface defects.

V. Conclusion

These different tasks form a complete file of investigations relating to materials, calculations and surveys.No real sign of premature aging has been discovered on various nuclear plants' towers.We have come to the conclusion that the expected life time of 40 years could be reached.
However, an increased surveillance is implemented on a few older towers (for example : Pont sur Sambre).
The method descrided above can be used according to the diagnosis, for all the cooling towers located in France or abroad.

Fig.1 - FRENCH COOLING TOWERS PLANTS

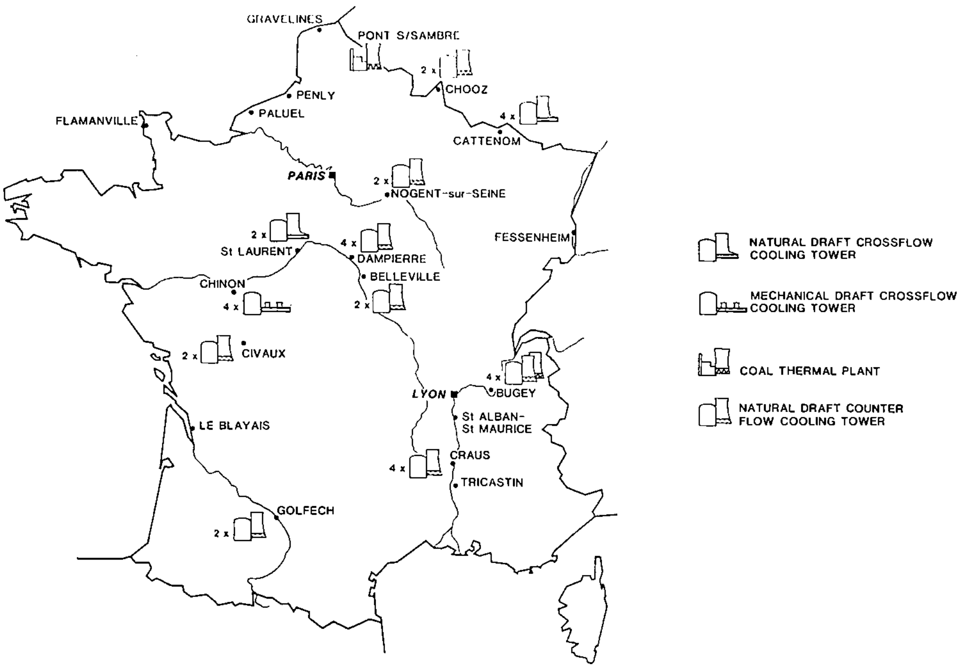


Fig.2 - COMPARISON of CHARACTERISTICS of THE FRENCH POWER PLANT'S COOLING TOWERS

	PLANT			TOWER					
	SITE	Unit	Power	Height	Diameter Throat	Diameter Lintel	Throat thickness	Reinforcement Layers	Reinforcement % Throat section
NUCLEAR	BUGEY	4-5 (1975-77)	900 MW/2	127 m	61 m	95 m	18 cm	2	V:0,34 H:0,13
	DAMPIERRE	1-2-3-4 (1977-79)	900 MW	165 m	77 m	122 m	21 cm	2	V:0,38 H:0,38
	CATTENOM	1-2-3-4 (1983-86)	1300 MW	165 m	84 m	177 m	21 cm	2	V:0,36 H:0,36
	GOLFECH	1 (1986)	1300 MW	179 m	83 m	122 m	20 cm	2	V:0,50 H:0,50
	CHOOZ	1 (1986)	1400 MW	173 m	85 m	138 m	25 cm	2	V:0,50 H:0,50
FOSSIL FUEL	PONT SUR SAMBRE	2 (1961-62)	250 MW	93 m	43 m	63 m	10 cm	1	V:0,19 H:0,17

Fig.3 - LIFE EXPECTANCY INDICATORS

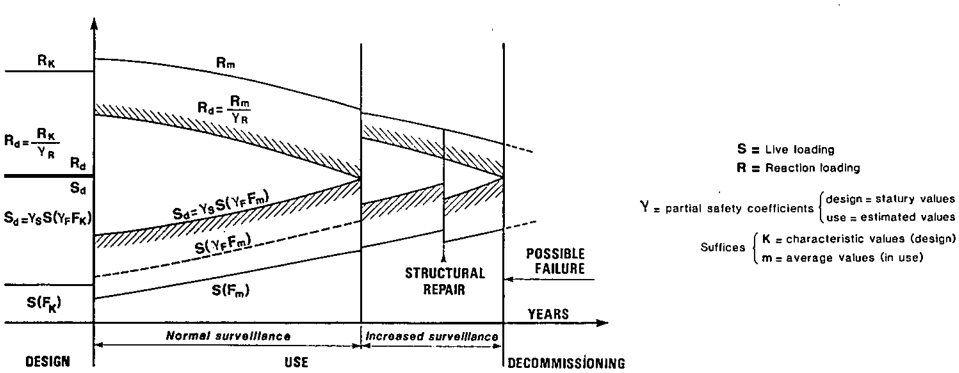
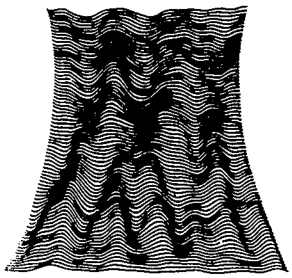
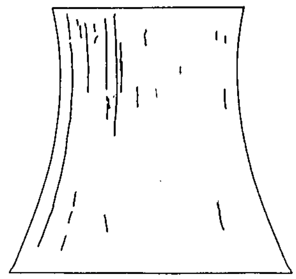
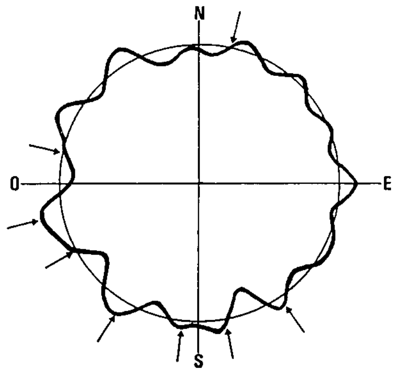


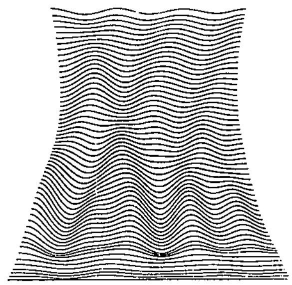
Fig.4 - SHELL DEFORMATION





REAL SHAPE



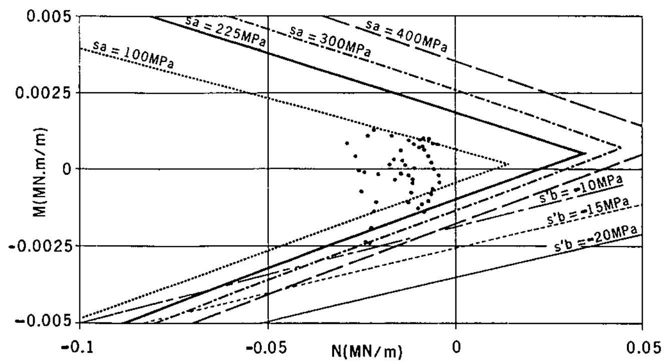


CALCULATION RESULT

Fig.5 - DIAGRAMS M, N - LEVEL 62m

thickness= 0.1m, Ø 8mm, spacing= 0.333m, covering 3.2cm

Actual Structure



Theoretical Structure