A Review on Hyperbolic Cooling Towers

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ABSTRACT: This research provides a complete overview of the research articles published in the subject of cooling towers, as well as an update on natural draught cooling towers. The advantages and disadvantages of various modelling, analysis, and design approaches are explored. The 118 references in this study are primarily focused on reviews of papers that were published after 2005. Hyperbolic cooling towers are most commonly linked with nuclear and thermal power stations, although they are also utilized in some major chemical and other industrial plants to some extent. They are high-rise reinforced concrete buildings in the shape of doubly curved thin-walled shells with complicated geometry, and their analysis and design are similar. The current article is a comprehensive compilation of cooling tower studies that will provide academics and design engineers in the field of hyperbolic cooling towers with up-to-date information.

KEYWORDS: Buckling, Cooling Tower, Earth Quake, Hyperbolic Cooling Towers, Non Linear Behaviour

INTRODUCTION

In addition to being an important part of power production systems, cooling towers have a role in environmental preservation as well. In addition to nuclear and thermal power facilities, hyperbolic cooling towers are utilized in several major chemical and other industrial operations. Structurally, they are tall reinforced concrete buildings in the shape of double-curved thin walled shells with complicated geometry, and their analysis and design are no different in that regard either. As a result of these unique features, the in-plane membrane activities are largely responsible for resisting the applied pressures, whereas the bending is secondary [1]. Because of its structural strength and minimal material consumption, hyperboloid cooling towers, also known as hyperbolic cooling towers, have established the design standard for all natural-draft cooling towers. The hyperboloid form also helps to speed up upward convective air movement, which improves cooling efficiency. Condensers were employed with steam engines in the 19th century, which led to the development of cooling towers. As early as 1918, the Dutch engineers Frederik van Iterson and Gerard Kuyper erected a 35 meter tall cooling tower in Heerlen[2]. Liverpool, England, was the first city in the United Kingdom to build a 68-meter-high tower. Soon, cooling tower heights and capacities grew, and High Markham Power Station in Britain built the first cooling tower with a height of more than 100 meters. As of June 2012, the development of the Kalisindh thermal energy plant in Rajasthan, India, had finished its construction of a 200-meter-high hyperbolic cooling tower in Niederaussem, Germany. Use, construction, heat transfer techniques, air-flow generation methods, and air-to-water flow mechanism are all used to classify cooling towers. Natural draught cooling towers, mechanical draught cooling towers and fan assisted natural draught cooling towers are the three types of air flow generating technologies for cooling towers. For better understanding of these structures' behaviours, this presentation will focus on the research done so far in the areas of modelling, analysis, design, and the newest theoretical and practical advancements. Research published between 2005 and 2014 has been the focus of the current effort. In NDCT (Natural Draft Cooling Towers), the cooling process is natural because the moist air within the chimney has a lower density than the dry and colder air outside at the same pressure. Positive Gaussian curvature gives hyperbolic geometry an edge over straight towers when it comes to stability. Large fill is installed in the tower's enlarged bottom to assist evaporative cooling of the thin coating of water[3]. While the tower's narrowing impact accelerates evaporation laminar flow, the diverging top encourages turbulent mixing, which enhances the interaction between heated interior air and cool outside air. Every part of the structure is built of high-strength Reinforced Cement Concrete (RCC) in the shape of a thin hyperbolic shell that rests on a series of diagonal or meridional supporting columns and radial supports The top and lower edge components of the shell provide enough stiffness to the shell[4]. Large cooling tower shells can be reinforced with extra internal or exterior rings, which can also be employed as a repair or rehabilitation technique, in order to ensure enough resistance against instability. Fig. 1, Illustrates the constriction of Kalisindh thermal energy plant in Rajasthan, India containing cooling tower.

Fig. 1: Illustrates the constriction of Kalisindh thermal energy plant in Rajasthan, India containing cooling tower [5] .

There are either a large number of single columns with variable or constant cross sections, or a pair of column types that are either linked at the tower base or foundation level concentrically, or not attached at any level whatsoever. Aerodynamics, strength, and stability are enhanced by the hyperbolic shape of thin-walled structures. It is only the hyperboloid that may degenerate into a cylinder, cone, or plane under general rules of rotation. There are numerous ways to depict the generic hyperbola, leading to the optimal design of the tower under varied stress circumstances. There are a variety of geometries that may be discovered in research that have focused on selecting the optimal form of the tower shell[6]. In this article, we will discuss the form optimization, design, and construction of Niederaussem's 200 m high natural draught cooling tower shell. Tower's form is the outcome of optimization calculations based on optimum load bearing behaviour, lowest meridional stress and maximum buckling safety[7]. A meridian curvature rises from base to neck level results in optimal load-bearing performance, according to one source, and the curvature increases steadily from there. The first cooling tower shell was studied using a shell bending theory in 1967. Later, a fourth order ordinary differential equation for the normal displacement was employed, disregarding the tangential displacements and derivatives in the geometrical equations of a bending shell theory[8]. Because of the complicated geometry of cooling towers and the limitations of traditional techniques of shell structure analysis, the Finite Element Method is the method of choice for modelling and analysis of NDCT (FEM). The FEM began to be used in the study of hyperbolic cooling tower shell constructions in the 1970s. There are a variety of finite element models and simulations available to represent and simulate the geometry and loading conditions of such complicated structures. The first step was to employ flat triangular finite elements.

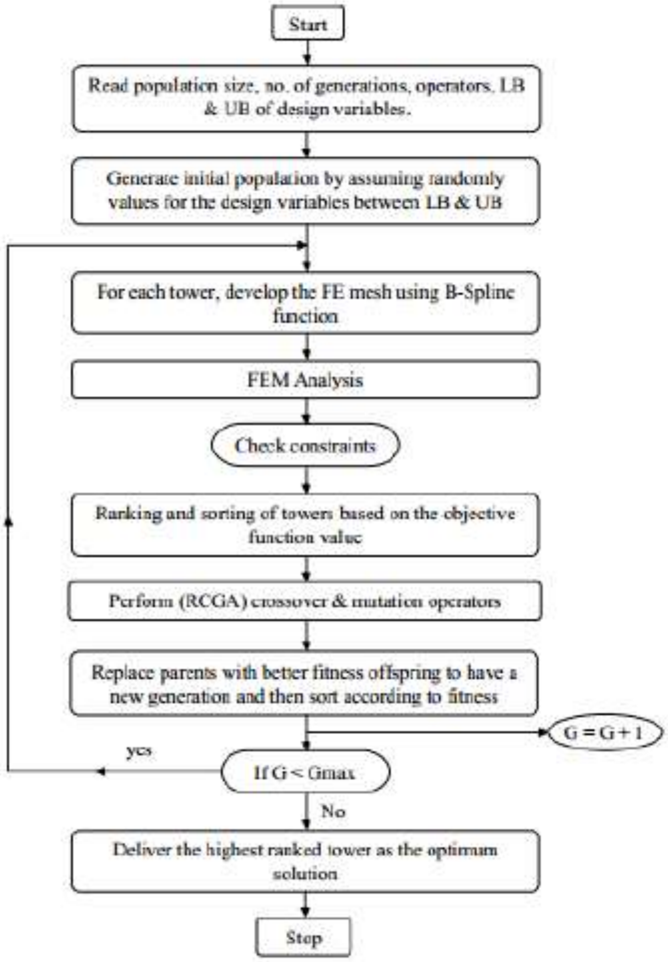

Fig. 2: Illustrates the flow chart followed for the optimum shape and design of cooling tower [9].

Tensile cracking in concrete has been used in finite element studies of RC structures over the past four decades. The discrete cracking model and the smeared-cracking model have both been used to this goal, both of which are difficult and time intensive. One of the study objectives for structural engineers is to determine the ultimate strength of cooling towers in nonlinear static analysis exposed to severe quasistatic wind loads. Diverse nonlinear variables, including concrete and reinforcing steel material nonlinearities, tensile cracking, concrete-to-steel bond effects, known as tension stiffening, significant displacement effects and others, must be taken into consideration when examining the final behaviour of such structures. A significant displacement, concrete cracking, steel yielding and inelastic behaviour of concrete were all taken into account in the analysis of the cooling tower's shell According to their findings, a full nonlinear analysis should be done when determining the ultimate strength of the cooling tower shell, because the ultimate load factor derived from the nonlinear analysis is significantly lower than that obtained from the buckling analysis. It turns out that nonlinear buckling analysis yields a far higher ultimate load than linear buckling analysis does. According to this study, the failure of a tower would be caused by the spread of fractures in the tensile zones [10].

DISCUSSION

Loads for earthquakes have a dynamic character. Ground motion is transmitted from the foundation to the supporting columns and lintel, where it is absorbed by the shell. An earthquake-induced force's amplitude and distribution throughout a hyperbolic tower's length is determined by the tower's mass, its dynamic characteristics (natural frequencies and damping), and the magnitude of the earthquake at its base. Under static seismic design load, to determine resulting stresses in the shell and associated deformations Tables and charts were used as design aids. The recommended technique for the static load scenario produced acceptable results. The impact of column geometry on seismic design was examined parametrically in order to identify the optimal seismic design. They concluded that under seismic excitation of a cooling tower with stiffening rings that these rings had no effect on modal characteristics of structures. However, the stiffening rings did help to increase the resistance of a cooling tower with stiffening rings that had no effect on modal characteristics of structures under such excitations. On several occasions, different techniques with varied degrees of precision had been used to model discrete columns and include their impacts into the cooling tower study. Due to wind, the tower's shell might buckle and collapse due to buckling instability. Experimental and theoretical studies on the stability of hyperbolic shells were conducted after the sudden collapse of three enormous cooling towers at Ferry-Bridge Power Station in England in 1965, in order to study the parameters increasing the wind resistance and buckling safety of the cooling towers. Assessment of the wind loads on cooling towers utilizing a novel technique based on individual equivalent static loads, as well as design of the reinforcement in the meridional circumferential direction and the design to prevent buckling Wind load study of cooling towers with column support. Column supported hyperbolic cooling towers with improved 3D finite element formulation and realistic circumferential wind pressure distribution were investigated. As a result, meridian membrane forces were shown to be more sensitive to pressure changes for various wind pressure distribution patterns. Depending on the shape of the cylinder, the homogeneous external pressure at which a cylindrical shell buckles is very variable. A buckle's buckling strength decreases fast as it grows in length, therefore larger cylinders have an increased critical buckling pressure (CBP). Thinner cylinders have lower critical pressures for buckling while thinner cylinders have higher critical pressures. Large cooling tower analysis using iterative wind pressure technique. An iterative pressure technique was suggested with fluid-structure interaction and compared to a design code-based wind load analysis and a rigid body method that assumed the tower structure was a solid in CFD analysis without fluid-structure interaction. Conclusion: code-based technique is conservative and relative error between iterative and code-based methods increases with increasing mean wind speed, according to a previous study. novel way to analyses wind-induced reactions and comparable static wind loads based on random vibration theory. Initially, the improved analytic technique was given as a CCM to correct for the coupling component between background and resonant components in this research. A case study of a super-large cooling tower in Jiangxi nuclear power plant was conducted to examine the modal coupling mechanism of ESWLs and to verify the precision of CCM for super-large cooling towers. During a wind tunnel test, the changing wind pressures acting on the cooling tower's shell surface were measured. Normally, cooling towers are intended for air that is stagnant, however research has shown that cooling towers may also be used for air that is moving.as a function of crosswind speed. Natural draught cooling tower (NDCT) cooling efficiency is cross-wind situation and might be adversely influenced reduce by 75% in the region of medium to high wind speeds condition. Flow separation at the rear. As well as the deflected plume coming out of a tower stack, diminishes the cooling performance. Fig. 3, Illustrates the different parts of a cooling tower with full specification of parts with scalable dimension.

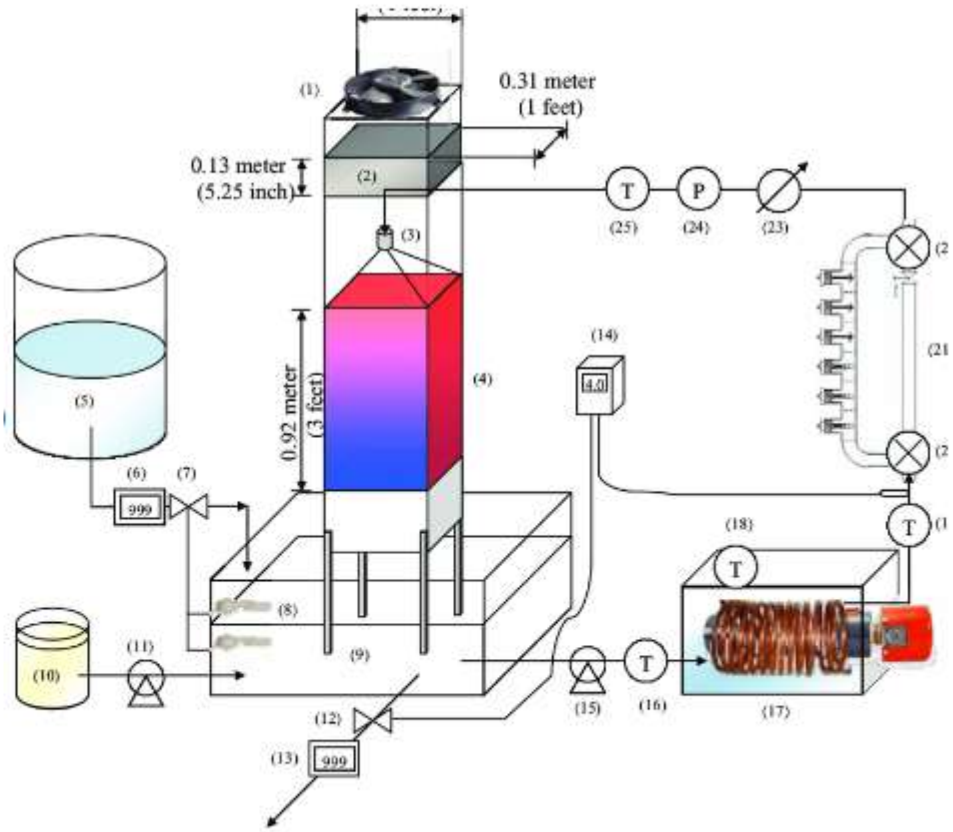

Fig. 3: Illustrates the different parts of a cooling tower with full specification of parts with scalable dimension [11].

According to both experimental and computational results, the cooling tower's heat transfer capacity rose proportionately with wind speed up to 3 m/s and subsequently declined at higher wind speeds. Diverse scholars have examined the influence of wind on cooling tower efficiency and the techniques of development for cooling towers in general. Other researchers found the same thing: flow acceleration at the sideward radiators trailing with a flow separation alongside the rearward radiators, and plume deflection at the exit plane of the tower stack were the two reasons of the lower cooling efficiency. The increased flow near the sideward radiators has attracted the attention of many scientists. They utilized wind breakers that were stretched in the direction of the wind to slow down the air flow. A wind breaker notion was initially presented, but it was not tested. Another group of researchers put this hypothesis to the test mathematically and found that windbreakers enhanced cooling efficiency by up to 16 percent at a commonly examined wind speed of 10 m/s. However, when the extreme value distribution of wind speed at 10 m and the log-normal distribution of ground roughness were taken into account, the simulated probability density functions of buckling capacity were deformed and far from normal. They also discovered that the mean values of the studied cooling tower, when considering both random material characteristics and random wind loads, were near to the deterministic buckling bearing capacity in terms of first and second order statistical moments. The two types of cooling towers' thermal performance and cooling efficiency are quantitatively evaluated. Under high-speed wind moving normal to the longitudinal diameter of the elliptical cooling tower, numerical simulations demonstrated that a cooling tower with an elliptical cross section enhances cooling efficiency compared to a cooling tower with a circular cross section. Because the wind direction is not always the same, the effectiveness of the suggested elliptical shape must be investigated for varied wind blowing angles. The cooling efficiency is an attempt to decrease the plume deflection's throttling impact. An elliptical departure plane for the tower was built and quantitatively examined in this study by crossing an oblique plane of 27 and 45. It was determined that the suggested shape may be employed to decrease the throttling impact in locations with unchanging wind direction. Because the wind direction can alternately vary, it has been proposed that the tower stack be made up of two parts: a fixed lower component and an upper section that must be rotated appropriately in relation to the wind direction. However, the issue here is one of practical application and constructability of such extra spinning components. It was also claimed that while the suggested geometry cannot enhance cooling efficiency as substantially as wind breakers, the combination of the proposed geometry with wind breakers will greatly improve cooling efficiency in windy conditions.

CONCLUSION

The most recent theatrical and experimental advancements, as well as new breakthroughs in natural draught hyperbolic cooling tower analysis and design, are briefly reviewed. In this study, the different elements in the analysis and design of cooling towers were monitored. This review is a comprehensive collection of cooling tower studies that will provide researchers with current and sufficient resources to do study in this subject. Which suggested a that there is dire need of efficient design of cooling tower to withstand the load provided during earthquake or high-speed wind. If the cooling tower will not withstand the load than it will be devastating both in terms of economy. Although there has been conducted extensive research in the sector of cooling towers but this domain is not limited and more research is demanded to explore the full potential of the cooling towers and its design to overcome the disturbance effect generated on the cooling tower due to earthquake or high-speed wind.

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