

# **Guide to the Inspection and Maintenance of Reinforced Concrete Chimneys and Natural Draught Cooling Towers**

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**(The Association of Technical  
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# Foreword

*At the majority of industrial sites continuous operation of chimneys and cooling towers is essential for the operation of the plant and removing any item from service will obviously cause significant disruption to the plant output capacity.*

*The purpose of this booklet is to give plant owners, contractors and engineers responsible for maintenance guidelines on areas that should be considered when carrying out routine inspection and maintenance works.*

*It is essential that inspection works are undertaken to an appropriate standard so that reports which follow are as comprehensive as possible. This will help ensure that any likely areas of failure are highlighted allowing repairs to be planned to suit normal plant maintenance shutdowns. Similarly, it is very important that repair works, once identified, are repaired to a technically adequate specification and are of a high quality to ensure that an early failure in service does not occur resulting in the need for rework once the plant is back on line.*

*This booklet is intended to be an “aide memoire” when planning inspection and maintenance works to ensure that essential points are considered, rather than a detailed technical reference. British Standards and Codes of Practice have been referred to within the text, where relevant, but content has not been included for reasons of Copyright. In the absence of a British Standard then European, American or International Standards have been quoted. The International Committee on Industrial Chimneys (C.I.C.I.N.D.) produces Model Codes and various detailed technical papers on topics covering initial design through to maintenance and refurbishment of existing structures and readers seeking further technical information on these rather specialised structures can find details on their web site at [www.cicind.org](http://www.cicind.org)*

# **1. The Need for Inspection**

- 1.1 Industrial chimneys and cooling towers often operate under extreme conditions in a wide range of ambient temperatures with additional stresses imposed by wind loading and the operating temperature of the plant which is served. These factors are often combined with aggressive chemicals present in the gases or vapour produced by the plant process which can cause rapid deterioration, particularly when any relatively minor defects to the structure occur which reduces the effectiveness of the measures included by the designer to resist the effects of stress, heat or chemicals.
- 1.2 A regular inspection regime, when combined with the provision and retention of adequate reports for future records, will often identify areas which are beginning to deteriorate before any significant structural damage has occurred. This will allow maintenance staff responsible for the structure to plan the works to be undertaken during a periodic shutdown for plant maintenance rather than as an unplanned maintenance task. Many of the materials utilised for chimney and cooling tower construction (e.g. shaped refractory bricks, alloy foils and GRP packings) are increasingly less likely to be held as stock items by manufacturers. Therefore planning maintenance works on the basis of information obtained as a result of frequent inspection will also help ensure that the materials which are most suitable for the required application are available well in advance.
- 1.3 The frequency of inspection of reinforced concrete chimneys and cooling towers is generally tailored to match the operational cycle of the plant served but several other factors should also be considered. These include status of the structure as noted during the last inspection, the nature of any defects noted & their bearing on the overall well-being of the structure and, where a series of previous inspection reports are available, rate of deterioration of any defects present. The operating conditions of the plant served should also be borne in mind as a chimney which operates under fairly constant load will not suffer from the effects of repeated expansion and contraction as a chimney operating under constantly varying loads. Any unexpected incidents which may have significant effects on the structure (i.e. lightning strike or boiler explosion) may also trigger the requirement for an inspection depending on the nature and severity of the individual event.
- 1.4 The C.I.C.I.N.D. Model Code for Chimneys sets out recommendations for frequency of inspection for various types of chimney and this is reproduced in table format as Appendix A.

# **2. Preliminaries to commissioning an inspection**

## **2.1 Collect and assimilate Documentation and Records**

- 2.1.1 The owner of the structure has a duty of care to gather and hand over adequate information and the as-built design drawings to the appointed Inspection Contractor to allow them to fully understand the nature of the structure of the chimney or cooling tower and any ancillary fitments. If this documentation is not available the Inspection Contractor should be advised and the inspection planned to enable the required information to be compiled for future use. Inspection of a chimney or cooling tower without design and construction information will require a particularly detailed risk analysis and may require the use of access techniques not normally associated with works of this nature.
- 2.1.2 A record system should be maintained by the owner of the plant summarising previous inspection results. This should clearly state the date of last inspection, modifications undertaken to the process plant, boiler, fuel or other changes, which may effect the operation and stability of the chimney or cooling tower, along with details of previous remedial works. Relevant information within this record system should be made available to the selected Inspection Contractor as appropriate.
- 2.1.3 Obtain and make available to the Inspection Contractor copies of previous inspection reports

- 2.1.4 Details on the type of fuel being burnt by the plant served by the chimney should be available with particular emphasis on sulphur content. In addition details of the gas temperature at the point of entry to the chimney and the boiler running conditions, i.e. steady state or non-steady state, will help the contractor or consultant determine the effect this may have on the future performance of the structure.
- 2.1.5 Older chimneys and cooling towers may have asbestos present as insulation, gas seal or packings and the Inspection Contractor should be advised that asbestos may be present so that they can arrange sampling and testing, unless the plant owner can categorically confirm that the structure is free from asbestos.
- 2.1.6 Details about the planned operating life of the plant as well as information regarding the future shutdown regime of the plant should also be available to assist those responsible for planning and executing remedial works arising as a result of inspections.
- 2.1.7 Shutdowns tend to damage brickwork and refractory concrete linings much more than continuous running. Therefore, inspections should be planned to coincide with shutdowns required for other purposes.

## **2.2 Evaluate the Nature of the Process and the Effect this may have on the Works**

- 2.2.1 Many chimneys vent fumes and substances which are acidic and/or toxic and/or pyrophoric and the Inspection Contractor should be advised on the nature of any deposits likely to be encountered to allow appropriate control measures to be included within the method statement and risk assessment for the works
- 2.2.2 Cooling Towers have long been associated with the Legionella Bacterium and the Inspection Contractor should be advised as to what, if any, bactericides have been added to the cooling water to enable him to assess the risk to health of his workforce.

## **3. Selection of a Suitable Contractor for Inspection & Maintenance Works**

- 3.1 Inadequate inspections and low standards of workmanship can be costly and may well reduce the service life of a chimney or cooling tower by causing damage and promoting deterioration.
- 3.2 It is, therefore important to establish the competencies required of the organisation that will have responsibility for:
- the inspection;
  - interpretation of the inspection report;
  - the required maintenance of the chimney or cooling tower.
- 3.3 An organisation competent to inspect and carry out the maintenance of a chimney should:
- Be able to demonstrate they are competent to both undertake the inspection using appropriate access techniques and are also able to correctly interpret any information obtained.
  - Hold membership of an approved trade body and/or hold membership of an approved engineering body and/or have a documented history of carrying out works of a similar nature.
  - Be able to make available on request copies of previous chimney or cooling tower inspection reports and references from clients for whom they have undertaken similar works.
  - Provide detailed method statements and risk analyses for the proposed works. (The standard of these items may be used as an additional indicator when assessing the competency of the inspection company)
  - Indicate the level of formal training undertaken by their staff in N.D.T. techniques where N.D.T. forms part of the required work scope

- 3.4 Information about suitable inspection and maintenance companies may be obtained from organisations such as the Association of Technical Lightning & Access Specialists.

## **4. Chimneys**

### **4.1 Inspection Techniques**

- 4.1.1 Internal inspections during plant shutdown are best made from powered suspended platforms by operatives experienced in chimney inspection works, where possible accompanied by a qualified Engineer. Before full access is given the internal lining should be viewed from a safe vantage point. i.e. duct entry or over the top rim to ensure that entry at the base of the stack can safely be undertaken
- 4.1.2 A photographic or video record should be always be made of any damage seen. This should particularly show any areas of collapsed or spalled brickwork or refractory. The inspector should also record the number of cracks, their width and any profile or radial irregularities either in brickwork or refractory linings. If immediate remedial action is not deemed to be necessary such records made during successive inspections will provide information on the rate of propagation of damage. If the annulus between a brick liner and concrete shell is inaccessible, or if no airspace is present, bricks should be removed to reveal the state of the insulation and the inner face of the concrete shell. These bricks should be removed at sample locations (the number depending upon the chimney size) at various elevations and positions around the periphery and in any "dead space" below duct entries. As chimney shells tend to be thinner in the upper third it is worthwhile selecting more areas for removal of brickwork in this location than at the relatively thick lower levels. Borescope surveys can also be considered for a visual evaluation of the annular space. This can be undertaken working from either the chimney exterior or interior.
- 4.1.3 Core Drilling – 100mm diameter core samples can be cut from the concrete shell working from a suspended external platform using a diamond drilling rig. Examination of the samples extracted will give information about the thickness, quality and pH value of the concrete. More detailed analysis of the core samples can also provided information on the cement, chlorides and sulphate content of the concrete as well as the material density. (Core extraction can often be carried out with the stack or cooling tower on load and can be used to obtain detailed information on the condition of the concrete shell prior to shutdown.)
- 4.1.4 Where core samples have been extracted for analytical purposes, material testing should be undertaken by a UKAS accredited laboratory in accordance with the recommendations contained in BS 1881
- 4.1.5 Thermography - Infra red images obtained with the stack on load will indicate loss of insulation or collapse of part of the liner. Where loose fill insulation fills the airspace between a brickwork lining and concrete shell, thermography can indicate brickwork cracks as well as consolidation, loss and contamination of insulating material.
- 4.1.6 The use of hand held video cameras now provides a useful aid to inspection. The images obtained can be carried by cable or radio link from the camera to a ground based V.D.U. or be recorded on a cassette or DVD carried by the operator. The direct cable link allows instant viewing at ground level by more than one person and the camera operator can be directed by radio link for more detailed examination of particular areas. Cassettes can be filed for subsequent comparison at future examinations. In addition to hand held equipment technology now exists to lower a remote camera down an operational chimney which allows a degree of advance planning for maintenance works rather than having to wait for the plant to shutdown to determine the condition of elevated structures which invariably requires that materials which are increasingly less likely to be held on stock must be procured at short notice. The varied type of remote equipment which are available do, however, all have the same drawback in that personnel must be in fairly close proximity to the top of the live stack in order to erect and set the equipment. This activity must be very carefully considered at the risk assessment stage to ensure that the hazards associated with heat wash wash-over and potentially noxious fumes are adequately addressed.
- 4.1.7 Limited Visual Inspection - Provided adequate precautions are in place to protect staff against heat and noxious gases, and provided a safe access is available, the top part of the lining may be viewed over the

rim of the chimney.

- 4.1.8 External examination of the shell may be made from abseil equipment or a bosuns seat by suitably qualified staff. A powered suspended platform is preferable for larger structures as it ensures that full coverage of the surface is achieved. This method also permits Engineers not normally trained in using minimum rig access techniques to either carry out the inspection jointly with the specialist access staff or view any salient points reported to him. A powered platform also better facilitates the transportation and use of the many items of test equipment which are available for use on concrete inspection works.
- 4.1.9 Where the internal face of the stack lining is obscured by a build up of combustion by products it will be advisable to clean the lining so that its condition can be seen clearly for inspection. High pressure water washing, providing the lining is reasonably resistant to water penetration and the effluent produced can be contained, remains the quickest and most effective way to clean. If the lining system is not able to withstand the application of water under pressure then a dry manual clean may be carried out by operatives using stiff hand brushes.
- 4.1.10 Due to the highly absorbent nature of diatomaceous clay, as used in the manufacture of insulating brickwork, then lining systems containing this material should always be cleaned using the dry process.

## **4.2 Single flue reinforced concrete stacks**

- 4.2.1 Single flue reinforced concrete stacks came into general use in the late 1940's superseding the traditional solid brick stack. The reinforced concrete windshield generally accommodated a refractory or engineering brick lining constructed in independently supported sections, each about 10m high, supported on offset corbels cast integrally with the windshield. Single stacks often have the capacity to carry gas from several boilers each of which can generally be isolated from the main ducting by dampers. The brickwork linings were generally separated from the windshield by ventilated cavities although chimneys with high operating temperatures often had unventilated cavities which were filled with granular insulation.
- 4.2.2 Stacks normally serve plant burning fossil fuel and where the sulphur content of the fuel is high, such as in some heavy oils, problems can arise because of low dew-point temperature of the gas where it comes into contact with colder surfaces causing precipitation of sulphuric acid.
- 4.2.3 Experience has shown that ventilated cavities, even with minimum air flow, prevents acid formation on the inside face of the windshield. Where cavities are insulated and ventilation of the cavities is not installed, problems may arise once cracks in the lining appear allowing contamination of the insulation with flue gas deposits.
- 4.2.4 Thermal stresses on the brick linings, which are normally 110mm thick, bring about problems particularly where operation is intermittent. Cracks will occur either vertically, where a thermal shock has been imposed due to quick start up of plant, or as stepped cracks through the bed and cross joints which indicate a more gradually imposed stress. Once these cracks appear they will never return closed after cooling and will tend to extend after each thermal cycle.
- 4.2.5 The presence of acids, oxides and vapours in the gas stream may have an adverse affect on mortars. It is well known that sodium silicate based mortars react to  $H_2SO_4$  by expanding due to crystalline growth and in sections of brickwork linings of 10m high growths of 75mm have been recorded.
- 4.2.6 Potassium silicate mortars can, under damp operating conditions, also expand resulting in limited growth within individual brickwork sections although this tends to be less pronounced than for sodium silicate mortars.
- 4.2.7 Any internal inspection programme for single flue stacks should include examination of the whole of the lining, arches and reveals at duct entries. In addition inspection ports should be formed at critical points through the lining to examine the inside face of the windshield and a check on the accuracy of line of the brickwork should be carried out. The condition of any expansion joint filling at corbels should be closely examined along with the general condition of installed gas seals, bricks and mortar with samples to be brought to ground level for further testing if suspect.
- 4.2.8 Externally the concrete surface of the stack particularly on the side away from the prevailing wind at the top should be examined for acid attack due to downwash. The condition of any protective coating

applied smoke band at the top should also be noted. Cast iron segmented capping is normally used to cover the top of the windshield with internal flanges covering the top of the brickwork of the top section and this should be examined for fractures or corrosion.

- 4.2.9 Reinforced concrete windshields are either constructed by slip-forming or conventional jump-form shutters and each method has its drawbacks. The slip-forming process, if not properly managed, can produce plastic settlement cracking due to frictional forces between the placed concrete and the formwork whereas jump form shuttering produces circumferential construction joints which form an inherent weakness in the structure and this may affect the long term durability.
- 4.2.10 External inspection of the windshield should always include a complete and thorough visual examination. In addition it is prudent to carry out a "sounding" survey whereby the inspector continually taps the surface with a small hammer to identify any hollow areas or potential spalls which are not yet visible on the surface. A covermeter survey should be carried out to determine the depth of the installed reinforcement at sufficient locations to determine the average depth of cover. This should also be combined with carbonation testing to check that the concrete surrounding the reinforcement remains above Ph 7.0 thus maintaining the natural passivation of the steel.
- 4.2.11 If doubts exist about the verticality of the structure this should be checked and recorded at set orientation at each inspection, subject to normal considerations for solar exposure bending.

### **4.3 Multi-flue reinforced concrete stacks**

- 4.3.1 Multi flue stacks generally contain either sectional brick linings or metallic flues but some of the smaller stacks constructed at hospital sites or similar in the past have utilised lightweight concrete or diatomaceous clay linings have been installed. Where lightweight linings were used a recurring history of troubles due to gas filtration through the porous material has occurred.
- 4.3.2 In larger stacks the air space around the flues is generally ventilated and accessible allowing examination of the external face of the brickwork. Any insulation removed to permit this type of examination should be carefully replaced on completion.
- 4.3.3 The manner in which the successive sections of lining are supported and the number of diaphragm floors provided depends on individual designers, but the inspection of the interior of the windshield should include all the ancillary parts of the structure such as handrails, open grid flooring, stairs, landings and any permanent lifts. Where tension rods are used to support intermediate floors a correct tension testing procedure should be followed with advice to be sought from the designers and manufacturers as to correct loading and means of measuring the load.
- 4.3.4 The interface between metal ducts with the brickwork at the base of the stack should be checked for leakage.
- 4.3.5 The exit stubs for each flue which discharge at the top of the stack must be subject to careful examination for defects. Early multi-flue chimneys were generally built with solid brick stubs and these tended to crack due to thermal stress. If replacement becomes necessary consideration should be given to more satisfactory methods of construction and an external shell for the stub with an independent liner has proven to be a much more durable arrangement.
- 4.3.6 The roof slabs of multi-flue stacks are normally surfaced with acid resisting tiles or bricks. These should be examined for evidence of damage due to chemical attack and sounded for loss of bond with the substrate. Any handrails installed at roof level and their fixings should also be carefully examined.
- 4.3.7 Where steel flue linings are installed careful examination of the restraint system provided must be carried out to ensure the linings are free to move under expansion and contraction within the designed tolerances. Where lateral restraints are fitted care must be taken to ensure that the surfaces of the restraint and contact area of the lining are not binding.
- 4.3.8 Where localised damage has occurred within the insulating materials, all defective insulation should be removed and replaced as to prevent the corrosive and thermal stresses attributable to localised cooling



- 4.3.9 Where steel lining sections are bolted together the bolts should be checked for tightness and any installed gaskets checked. It is worthwhile considering the removal of a representative sample of bolts for testing after a stack has been in service for more than 4 years to ensure that they are still able to meet the rated ultimate tensile stress. Expansion bellows and seals should be checked and resealed where necessary.
- 4.3.10 Any interface between dissimilar metals should be carefully examined for evidence of corrosion.
- 4.3.11 The reinforced concrete of the stack windshield should be periodically examined as described above for single flue chimneys

## 5. Natural Draught Cooling towers

### 5.1 Inspection Techniques.

- 5.1.1 Cooling towers, as with any other form of reinforced concrete structure, require routine inspection to ensure good operational serviceability and durability.
- 5.1.2 Historically, several natural draught cooling towers have collapsed in the UK largely due to a variation of reasons ranging from design flaws to construction irregularities.
- 5.1.3 As a result of the above, the inspection of these type of structure requires detailed surveys to determine structural defects such as:
  - Shape imperfections
  - Meridional and circumferential crack development.
  - Spalling development
  - Honeycombed concrete
  - Moisture penetration through shell
- 5.1.4 Inspection of cooling towers primarily comes in two forms, triangulation survey undertaken at ground level and high level surveys which permit hands on contact with the cooling tower shell.
- 5.1.5 Triangulation surveys are carried out to determine the extent of any shape irregularities within the tower shell which will have a significant bearing as to how the structure reacts under high wind loads. Many early cooling tower shells were constructed with inherent shape imperfections and it has subsequently been noted that any irregularities within the profile of a radial structure can have a dramatic affect on circumferential bearing stresses at these points. If an irregular profile is suspected then the tower should be checked using triangulation surveying techniques to determine the deviation from the design profile. Specialist surveying companies should be employed to undertake this work and all results be evaluated by suitably qualified engineers.
- 5.1.6 Once this type of survey has been undertaken it is unlikely that it will need to be repeated as shape imperfections are generally inbuilt rather than an in service occurrence.
- 5.1.7 Hands on inspections are generally carried out to determine the extent and severity of cracks, spalling concrete, honeycombed concrete and moisture penetration through the shell. As these types of defect tend to develop and/or deteriorate in service then hands on inspections need to be carried out at regular intervals to monitor and react to changes in the condition of the tower shell.
- 5.1.8 This type of inspection generally requires access to the full height of the structure, employing specialist access methods as appropriate. A frequently used technique is to install suspended platforms from the summit of the tower using special brackets which can be relocated around its full circumference. Tensioned vertical profile wires enable access into the throat of the tower when inspecting the tower exterior, or throughout the lower half of the shell if inspecting the tower interior.
- 5.1.9 When inspecting the internal surface of a tower provision must be given for safe access across the drift eliminators to facilitate access to the cradle landing position and to the profile wire anchor locations.

- 5.1.10 Inspection of the tower should be undertaken by a competent person experienced with this type of structure.
- 5.1.11 Interpretation of any observations noted during the course of the inspection should be carried out by qualified engineers, again with experience of structures of this type
- 5.1.12 The tower owner should always supply detailed construction drawings of the tower shell, packs and basin. If available the owner should also supply developed elevation drawings of the tower on which the inspection company can plot all physical defects found during the inspection.
- 5.1.13 During the inspection it is important that all defects listed in clause 5.1.3 are individually measured and documented and accompanied with height and radial coordinates. It is essential that all cracks are measured using a crack gauge at regular locations throughout the length of the fracture. This to enable future monitoring of crack growth.
- 5.1.14 Where cracks are detected, plastic survey targets should be fixed to each end to enable later monitoring from ground using triangulation theodolites.
- 5.1.15 Where spalled or delaminated concrete is present, it is essential that depth of lamination, concrete cover, size and volumetric loss of exposed reinforcement is recorded.
- 5.1.16 In the event that spalling penetrates the full shell depth, the overall thickness of the wall should be measured, recorded and compared to that of the design thickness.
- 5.1.17 Where concrete core samples are required to determine concrete strengths and other material parameters, clauses 4.1.3 and 4.1.4 to be applied.
- 5.1.18 All defects observed during the inspection to be measured, documented and plotted on a developed elevation drawing. Dimensional properties of each defect to be catalogued on a defect schedule, with each individual defect having a unique identification number.
- 5.1.19 Throughout the inspection high resolution colour digital photographs should be taken. Each photograph should incorporate a discrete identification marking which accurately collates to its location on the structure or defect schedule.
- 5.1.20 Thermographic surveys carried out from ground level have also been successfully used to detect physical defects within tower shells. For this method of surveying to be carried out it is essential that the tower remains in service and is most effective when undertaken at night.
- 5.1.21 Where a tower shell has received additional strengthening by the installation of an external reinforced concrete jacket, checks should be made to determine physical separation between the mating surfaces. This form of separation can usually be determined by shrinkage cracking around the summit of the jacket and water seepage on the surface of the jacket exterior.
- 5.1.22 In the event structural separation is detected, it is beneficial to employ the services of a specialist survey company to carry out an impulse radar inspection to determine the extent and magnitude of lamination between the jacket and underlying tower shell.
- 5.1.23 There is no recognised standard for inspection intervals on cooling towers and this may be dictated to some degree by the availability of the unit under shutdown conditions. Cooling tower owners should attempt to build up an historical record based on previous inspections and necessary remedial works and draw conclusion from this record as to future inspection intervals. As a general guide all cooling towers should undergo a thorough hands on inspection at a maximum interval of 4 years until an adequate record has been obtained which will enable competent persons to determine if this interval can be extended or should be reduced dependant on the nature of the defects observed and the remedial works undertaken

## **5.2 Reinforced concrete shell**

- 5.2.1 Commonly in the UK, natural draft cooling towers are hyperboloidal or conetoroid in shape and consist

of a thin reinforced concrete shell supported on a radial array of diagonal support legs. The base and summit of a tower shell is generally stiffened by an increase in wall thickness

- 5.2.2 The method of construction varies but towers constructed post 1970 have in some cases been slip formed in a continuous pour system. In other cases conventional jump shutter construction has been used creating circumferential construction joints at regular intervals in the height of the shell. Shell thickness may vary but early towers are usually about 125mm thick and generally singly reinforced whilst towers constructed post 1980 frequently have a shell thickness greater than 200mm with a twin reinforcing cage installed.
- 5.2.3 Faults in construction usually found include honeycombing at shutter joint levels arising from poor compaction at the bottom of the lifts resulting in the formation of spalling concrete caused by corroding reinforcement placed with insufficient cover. Spalling will occur more readily on the external face of the concrete due to concentration of pollutants from adjacent plant causing accelerated carbonisation of the concrete with a corresponding lowering of the pH. Internally the surface of the concrete usually becomes coated with algae or a mineral salt precipitated from the water vapour and this generally obscures clear examination of the shell. In some cases the internal surface requires high pressure water jet cleaning prior to repair in accordance with current best practice. The general comments made for inspection of the reinforced concrete chimney shells also apply to cooling towers.
- 5.2.4 The support legs and bottom ring beam of towers usually vary in their shape and arrangement but suffer deterioration due to constant saturation coupled with the destructive effects of ice formation. Remedial works to legs by casting or gunning on a protective mesh reinforced concrete skin can be undertaken successfully but decreasing the draught area between the legs may present a problem. Access to the ring beam, particularly internally, may be difficult due to the proximity of the internal packing. If the concrete quality of the legs and ring beam has not deteriorated too far protection by suitable waterproofing coatings may be advisable to arrest further deterioration.
- 5.2.5 Thin shell structures often suffer meridional and circumferential cracking of varying lengths and widths. Depending on the imposed stresses, these cracks can penetrate the full depth of the shell or be partial penetration fractures with the former becoming evident due to permeating moisture inducing localised water staining on the external face of the shell. If the cracks persist and are known to extend a pressure applied injection system of low viscosity resin guaranteed to seal the cracks and prevent eventual corrosion of the reinforcement is available. The particular resin used should have high bond strength and offer some additional stability to the crack whilst retaining a degree of elasticity. It should be borne in mind that cracks which are heavily contaminated with salts may prove difficult if not impossible to fully fill with resin.
- 5.2.6 If the quality of the concrete of the shell is abnormally poor in that it is over porous for depths reaching the reinforcement external waterproofing treatment may have to be resorted to in order to reduce continuous spalling problems. A percussion hammer test of the concrete face may be advisable to provide factual evidence. Any waterproofing system should permit evaporation of coolant saturating the shell but at the same time present a barrier to wind and rain.

## **5.2. Cold Water Basin**

- 5.2.1 The cold water basin which acts as a reclamation area for the circulating water is usually constructed directly under the pack area of the tower. The size of the basin floor generally emulates that of the tower base and includes a continuous reinforced concrete wall around its periphery. A common fault is the formation of cracks through the wall extending into the floor of the pond. These cracks are usually caused by unequal settlement of the tower and can be made good either by resin injection or cutting out and repairing with high bond mortar.
- 5.2.2 The cleanliness of the basin is important and it is generally contaminated by dislocated laths and silts. Debris accumulating in the basin will tend to clog screens or damage pumps whilst large accumulations of silt will reduce the effective operating capacity of the basin. Regular cleaning by suction lines with the basin full or hand cleaning if drained should be carried out on a regular basis to prevent this occurring.

### **5.3. Packing**

- 5.3.1 Packs are usually constructed of timber laths, corrugated fibre cement sheets or more commonly prefabricated PVC modular units. The packing generally starts at the top of the shell support legs and rises up the inside of the tower for several metres. Early cooling tower design adopted wooden laths to break up the cooling water droplets into a fine mist, commonly referred to as splash packing.. Evolution in pack design and efficiency has led to the retrofit of most cooling towers with PVC packing. PVC packs use their corrugated profiles to disperse the cooling water across their surface area thus forming a thin film which encourages evaporation. This system is normally referred to as film packing.
- 5.3.2 The timber laths are more susceptible to deterioration and damage. BS 4485 lays down standards for preservative impregnation of timber which have improved the life cycle of this material but nevertheless a life in excess of 20 years is rarely achieved. In timber which has not been treated or has been treated to a poor standard a very much reduced life expectancy will result. It is desirable therefore to set out guide lines for regular inspection and replacement of packs to ensure the continuing efficiency of the tower. It should be noted that high dosage levels of chlorine in cooling water can also accelerate the deterioration of timber packs.
- 5.3.3 PVC packing is largely maintenance free due to its inherent resistance to algae growth and fouling. Where damage has occurred individual units can be replaced with minimal disruption.

#### **5.3.4 Fungal attack**

- 5.3.4.1 The only important type of fungal attack in cooling tower timbers is soft rot caused in the very wet conditions prevailing by the type of fungi classified under the generic name of fungi imperfecti and ascomycetes. These can be air or water borne and the spores are always present.
- 5.3.4.2 The soft rot problem has made it essential for cooling tower timbers to be treated, and various processes to minimise the effects of soft rot are currently available
- 5.3.4.3 The toad stool fungi (basidiomycetes) which attack window frames can be discounted in cooling towers as the pressure impregnated system of preservative correctly applied affords complete protection whereas in the case of soft rot the rate of attack is considerably reduced but is not stopped altogether.

#### **5.3.5 Mechanical damage**

- 5.3.5.1 Continual impingement of water droplets onto the water from the water distribution system wears away the timber laths, with the arrises generally being the first area to be affected.
- 5.3.5.2 As timber sections dry out, they shrink and warp and in some designs where there is no positive fastening they can fall out of their locating slots.
- 5.3.5.3 In spite of the use of preservatives cooling tower timbers can deteriorate primarily due to soft rot and both types of pack, together with the supporting structure can suffer from mechanical damage. Such damage can also affect the distribution system and these factors can contribute to a reduction in tower performance. Regular inspections of the pack, eliminators, support structure, distribution systems, spray nozzles, splash cups, de-icing systems and walkways can identify the extent of deterioration and damage during service and enable remedial works to be put in hand to minimise further damage.
- 5.3.5.4 Timber which has been treated with preservatives may require disposal at a registered disposal site. Disposal of asbestos cement sheets must also be to a registered disposal site with due regard to current legislation for handling, storage and personnel protection.

#### **5.3.6 Recommendations for routine inspection are as follows:**

- 5.3.6.1 A general inspection of the pack, eliminators, support structures, walkways together with the water feeder system, spray nozzles, splash cups and de-icing system should be carried out at approximately 2 year intervals.

- 5.3.6.2 Six years after initial installation of a timber pack and thereafter at 6 year intervals a more detailed inspection of the pack should be carried out. During this inspection the full area of the pack top should be examined, if necessary by provision of temporary access. Random samples of the eliminator and packing timber should be taken across the diameter of three levels (top of eliminator, top and bottom of pack) and 5 samples per level are suggested.
- 5.3.6.3 A special inspection may be required if an excessive amount of broken laths are noticed at the coarse screens or any other irregularity becomes obvious.
- 5.3.6.4 A check should also be made to ensure that the distribution and de-icing systems are not blocked with silt or other debris and that end caps are secure with all nozzles properly positioned.

## **5.4. Packing supports**

- 5.4.1 Packs are supported on timber or concrete frames. The timber supports fail for reasons already described and concrete frames suffer deterioration for the same reason as any reinforced relatively thin section exposed to continual saturation and exposure. Spalling concrete and erosion to hardened cement paste are the principal defects found within concrete packing supports.
- 5.4.2 Failures of under-designed connections between pre-cast sections and peripheral connections to the lower shell also gives rise to problems in that adequate consideration to ice loading has not been included in the designers calculations and the connections and fixings fail due to the increased weight. Strengthening measures for inadequately designed connections have been developed over time and can be successfully retro fitted in these circumstances.

## **5.5. Internal Walkways**

- 5.5.1 The recommendations with regard to the inspection of packs referred to in Section 4 should also include the internal walkways and handrails. In the interests of safety the structure and deck of the walkways should always be carefully examined and cleaned of slippery algae growth. Timber slats should be sounded by hammer and handrail fixings at the base tested.

## **5.6. Water distribution pipes, culverts and pipe entries**

- 5.6.1 There are three main types of water distribution systems generally adopted in natural draught cooling towers.
- Central riser with radial feeder
  - Diametric culvert with chord feeder pipes
  - External culvert with radial feeder pipes
- 5.6.2 During a tower inspection, the inspector should give particular attention to blockages within the feeder pipe sprinklers, jointing “O” rings and pipe damage
- 5.6.3 At no time should access be allowed into culverts or risers unless the system is completely isolated and access included in the permit for work

## **5.7. External access stairs and doors**

- 5.7.1 For reasons of safety the concrete steel or timber structure to the access stairs should be examined for defects along with internal access doors, hinges, locks and seals.

## **5.8. Drift eliminators**

- 5.8.1 Although they do not contribute to the thermal efficiency of the tower the function of the drift eliminator is to capture large droplets enabling finer droplets to be discharged in the downstream plume.
- 5.8.2 Drift eliminators are installed above the splash packs, the arrangement of which consists of pre-manufactured elements installed in a horizontal grid formation. The eliminator slats are installed inclined to the normal direction of the air flow.
- 2 layers of timber louvers at 70mm horizontal and 13mm vertical spacings
  - 1 layer of PVC aerofoils at 60mm horizontal spacing.
- 5.8.3 Considerable nuisance to the immediate environment of the tower may be caused if precipitation reaches unacceptable proportions. Significant loss of water from the system will also occur as a result of inadequately maintained drift eliminators.
- 5.8.4 Due to the fragile construction of drift eliminators, initial inspection should be carried out from permanent walkways located at and below the drift eliminator level. Where access is required to individual elements, temporary access systems should be installed across the eliminators. Ensuring no additional loads are placed on the eliminator louvers or corrugations.

## **5.9 Levelling**

- 5.9.1 If records of the level of the tower taken at the time of construction are not available it is recommended that at the first inspection a level survey is taken around the pond wall recorded against a suitable fixed datum on the site. Future inspections should include a level survey to check any movement of the tower in service.
- 5.9.2 Where possible the client should give access to all historical data for the cooling tower under examination to assist all parties in evaluating potential deterioration

## **6. Lightning Protection**

- 6.1 Lightning protection systems in the UK are currently designed to comply with BS 6651 : The Protection of Structures Against Lightning. This standard is shortly to be superseded by a new European Standard but the basic requirement for inspection and testing of the system will be similar to the existing and can be summarised as follows:
- 6.1.1 Personnel carrying out inspection and testing works must be competent to do so and be able to produce documentary evidence of training.
- 6.1.2 BS6651 states that visual inspections should be carried out at fixed intervals, preferably not exceeding 12 months.
- 6.1.3 Inspection should include detailed examination of the mechanical condition of all conductors, bonds, joints and earth electrodes. Any part not being exposed for inspection should be noted on the report/certificate.
- 6.1.4 During inspection, newly installed services should be given particular attention to ensure they are adequately bonded.
- 6.1.5 The resistance to earth of each local earth electrode and the complete earth termination system should be measured using calibrated instrumentation to ensure the overall effectiveness of the system. Although BS6651 requires inspection and testing at 12 monthly intervals it is best practice to fix these intervals at 11 months thereby ensuring that over a 12 year period the testing will have been carried out

throughout the year and will reflect seasonal variations on the resistance of the electrode system. The method of testing is given in BS7430:Earthing.

- 6.1.6 The resistance of each electrode should be no more than 10 times the number of electrodes on the whole system and these should provide an overall combined resistance of no more than 10 ohms. If the resistance of the individual earth electrodes and the whole system exceed the maximum levels, measures should be put in place to reduce the resistance to tolerable levels.
- 6.1.7 A test certificate should be raised following the inspection and testing, a copy of this should be kept on site and provide the following information;
1. Scale drawings showing the nature, dimensions, materials and position of all component parts of the lightning protection system;
  2. The nature of the soil and any special earthing arrangements;
  3. The type and position of the earth electrodes, including reference electrodes;
  4. The test conditions and results obtained;
  5. Any alterations, additions or repairs to the system;
  6. The name of the person responsible for the inspection.

Where details are unavailable or unobtainable due to site conditions this should also be noted on the test certificate.

A pro-forma lightning conductor test certificate form is attached as Appendix B to this document.

## Appendix A Frequency of Inspection

The International Committee on Industrial Chimneys Model Code sets out the following recommendations for the frequency of inspections for various types of chimney and linings

<b>CHIMNEY TYPE</b>	<b>INSPECTION FREQUENCY</b>	<b>CHECKLIST</b>	<b>REMARKS</b>
All types	Frequently, no less than annual. Also after earthquakes and high winds	External surface of shell and permanent access ladders (where fitted)	From ground level using binoculars
Steel liners	Annual  Annual  Annually for first two years after commissioning or after significant change of operation. Thereafter, every 3 years and immediately following fire or explosion	Lateral guides  Insulation  Refractory Top, incl. rainshield Lightning conductor External concrete face Duct entry / expansion joint Turning vanes	Where airspace accessible  Where airspace accessible  (if present)  (if present)
Brickwork linings with accessible airspace	Annual  Annual  Annually for first two years after commissioning or after significant change of operation. Thereafter, every 3 years and immediately following fire or explosion	Insulation  Concrete inner surface  Corbels / ring beam  Brickwork inner face Duct entries Top, incl. rainshield Lightning conductor Turning vanes	} If airspace access not permitted on-stream } carry out this activity during planned outage } for internal inspection       (if present)
Brickwork linings without access between lining and windshield	Annual  Annually for first two years after commissioning or after significant change of operation. Thereafter, every 3 years and immediately following fire or explosion	External signs of damage  Brickwork inner face Insulation Windshield inner face Duct entries Top, incl. rainshield Lightning conductor	       } achieved by removing } bricks from lining

As a general comment, where stacks are maintained at steady load without intermittent shutdown damage to linings is reduced and the periods quoted above can be extended by 100%.