CICIND

A Customer's Guide to Specifying Chimneys

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FOREWORD

When it was first formed in 1973, the 'Comité International Des Cheminées Industrielles' (CICIND) adopted as a major goal the harmonisation of national codes for the design of industrial chimneys. To this end it has published Model Codes for Steel and Concrete Chimneys including brickwork and steel liners. At their 1987 General Assembly in Paris, the members of CICIND decided that there also existed a need for a document to provide guidance to customers buying and specifying chimneys. Accordingly, a small committee was charged with developing such a guide. This document is the result of their work. The members of the committee were:

B.N. Pritchard	Great Britain (Chairman)
M. Beaumont	Great Britain
K.R. Jackson	Great Britain (Part time)
H. Van Koten	The Netherlands

INTRODUCTION

CICIND has published Model Codes for the design of concrete and steel chimneys (Ref. 1,2) and Model Codes for the design of chimney liners(Ref. 3,4). Provided the requirements of these codes and the customer's needs are followed a competent and experienced chimney builder can be expected to design a chimney that is safe, fully operable and which should provide trouble-free service throughout its design life. It should be emphasised that this expectation can only be realised if the designer is fully aware of the customer's needs, which, by implication, includes all relevant information about the operation of the plant served by the chimney.

Unfortunately, in the past, customers have often not been aware of the necessity to convey this information to the chimney builder at the time of placing an order, or, in a competitive situation, at the time of inviting bids. Also, while preparing their bids, the chimney builders have often been reluctant to risk jeopardising their competitive position by enquiring more closely into the customer's needs. As a result, many chimneys have performed badly and/or have not satisfied the customer's expectations, purely because the builder was never fully aware of the customer's requirements and the full extent of the operating conditions.

The means by which the chimney builder is made aware of the customer's needs is contained in the specification of the chimney, which accompanies the purchase order and invitation to bid. It is, therefore, very important that the specification of a new chimney should contain a clear statement of the customer's needs and a complete description of the full range of the operating conditions to be expected.

The purpose of this document is to assist the specifiers of new chimneys in ensuring that the chimney's designer and builder will be fully aware of the owner's requirements and the operating conditions that are expected. The document is in three main parts:

Part A provides guidance for a Customer contemplating installing plant which includes one or more chimneys. Its purpose is to bring to his attention, in general terms, the issues that must be addressed, particularly those for which a decision will be required of him. It is assumed that this customer has little knowledge of the principles underlying the design of chimneys.

Part B is aimed at engineers involved in the preparation of specifications for new chimneys. Its purpose is to help prepare specifications that provide all of the data necessary to ensure that the chimney builder is fully aware of the customer's requirements and of the complete range of operating conditions.

Part C provides back-up detail, covering the causes and effects of the hazards faced by a chimney, together with guidance on some of the options available to counteract these hazards.

Appendices provide sketches of typical chimney systems, information on the interaction of the various disciplines involved in chimney design and the relationship between the type of specification used and the responsibilities of the various parties involved.

PART A

Al Why do I need a Chimney?

A chimney is needed to conduct the flue gases away from a fired heater (either a boiler, furnace or incinerator). In so doing, the chimney may be required to provide sufficient draft to assist combustion. Also it is required to discharge the gases sufficiently high above the surrounding area to limit their effects at ground level. This implies compliance with National and local regulations. Thus it will be necessary to consult the relevant Authority before a height can be set.

A2 What types of Chimney are available?

Chimneys can be of reinforced concrete (cast-in-situ or precast), brickwork, steel plate or plastic. They are usually self supporting and designed as cantilevers fixed at the base. Sometimes, however, steel chimneys are supported within steelwork structures or by guy ropes or are stayed against an adjacent building. Plastic chimneys often rely on external support in this way. The choice of chimney type will be determined by cost and construction timetable considerations and by its suitability for the required duty. (Appendix 1 illustrates the various options.)

Because it is usually the tallest structure in a plant, an architect is often tempted to modify a chimney's shape in order to express it as a 'feature'. Such treatment should be used with caution and should avoid departing too far from the basic cylindrical or conical shape. The use of complex shapes can have severe effects on the operation of a chimney and upon its response to winds. It can also significally increase the cost of the chimney .

Reinforced concrete chimneys are usually equipped with one or more liners to isolate the concrete from the effects of the hot and often aggressive flue gases. Steel and brickwork chimneys are also sometimes fitted with one or more liners, but more usually are unlined. Liners may be of brickwork, steel plate, plastic or refractory (applied to the inside of a chimney, or to a steel liner in a concrete chimney).

A3 Who should I appoint as my advisor?

The design of chimneys is a multi-discipline effort, requiring input from specialists in combustion, chemistry, metallurgy and other material sciences and mechanical and civil/ structural engineering (see Appendix 2). As the most important effect of a failure in any of these aspects will be structural failure, it is probably best if the team leader is a Civil, Structural or Mechanical Engineer.

The chimney's specifier should preferably be a professional engineer, either a specialist himself in chimney design, or advised by specialists in the various disciplines listed above.

Specifications can range in detail from a skeleton 'duty Specification' (which nevertheless should contain all of the information required by a designer), to a fully detailed design, merely requiring construction by the chimney builder. Appendix 3 lists the available options, together with the responsibilities of the various parties.

A4 What decisions are required of me?

Prior to the preparation of a specification for a new chimney, certain decisions are required of the owner. These include:

A4.1 Compliance with air pollution requirements can mean that a choice has to be made between the provision of a Flue Gas Cleaning unit and a taller Chimney (to discharge the untreated gases high enough to avoid local pollution at ground level). This choice will be based on: Regulations, cost considerations and the company's attitude to public relations.

A4.2 Generally speaking, assuming no mistakes are made in the design, the cost of future maintenance will be an inverse function of inspection frequency and of the capital cost. A decision will therefore be required on the owner's inspection and maintenance philosophy. This will depend on:

- How often the operation will permit shutdowns for internal inspections.
- The economic consequences of an unplanned shutdown for emergency repairs.

A4.3 An assessment should be made of the possibility that a change of operation may occur in the future. If such a change is considered possible, the designer should be able to advise the owner of the impact that such a change would have on the proposed chimney. He may also be able to recommend a change to the chimney design that would reduce the necessity for future modifications, required to accommodate the change of operation. Typical changes of operating condition are:

- Installation of a new (or removal of an existing) FGD (flue gas desulphurisation) or other pollution control system.
- Installation of an air preheater, or its removal.
- Change of fuel.
- Turndown or upturn of the combustion unit served
- Change of operating mode, from continuous to intermittent, or vice-versa.

A4.4 In the layout of the plant, the chimney should be as close as possible to the combustion unit that it serves. Also, the chimney should be positioned as far away as possible from tower-like structures of similar or greater height. The purpose of this is to avoid aerodynamic interference effects which could dramatically increase the chimney's response to wind loads.

A4.5 When more than one boiler or heater is to be served by a single chimney, the use of multi-flues should be considered. This would allow the dedication of each chimney liner to a single service. Similarly, when an energy conservation or flue gas cleaning device is capable of being by-passed, separate liners should be considered, one for normal service, the other for by-pass service. The initial cost would be greater than that of a chimney with a single liner, but this could be worthwhile in terms of increased integrity of the plant and minimising the effect of a chimney liner failure.

PART B

B1. What are the hazards faced by a chimney and how are they normally overcome?

Flue gases are usually at high temperature and often contain aggressive chemicals. Unprotected concrete would not normally tolerate continuous contact with such conditions. Therefore a concrete chimney is normally provided with one or more liners, which contain the flue gases and isolate them from the concrete. Similarly, liners are sometimes provided in steel and brickwork chimneys. Generally, however, steel chimneys do not require a liner as they are able to withstand moderately high temperatures and, if maintained above Acid Dewpoint Temperature (ADP - see section Bl.l) by external insulation, can avoid acid corrosion when exposed to flue gas. Exceptions occur when the flue gas itself is below ADP, or if occasional very high temperatures are expected, or the risk of internal fire is high. Steel chimneys and liners may be protected against fire by addition of a refractory concrete lining bonded to the steel (provided the temperature of the inner face, in contact with flue gas, is above ADP).

In the course of its operation, a chimney is subject to many hazards. The purpose of this section is to outline these hazards so that a chimney owner will be aware of them and their implications on the chimney design before he specifies a new chimney. Given a full briefing, a competent, experienced chimney designer will be able to ensure that a new chimney operates trouble-free and unaffected by these hazards.

The most typical of these hazards are:

B1.1 Chemical Attack (e.g. acid corrosion, etc.)

Flue gases contain many chemicals and, depending on the materials burned, these may attack structural elements with which they come in contact.

The most common form of chemical attack is 'Acid corrosion'. This can occur when acid, condensing out of the flue gases is deposited on vulnerable surfaces, such as concrete or steel. The most common form of acid corrosion occurs when the fuel contains sulphur in excess of 0.5% by weight and burns in the presence of more than about 4% excess air. In these circumstances, the flue gases will contain significant quantities of SO_3, in addition to SO_2. The acid corrosion takes the form of attack by sulphuric acid, formed by the combination of SO_3 and water, which condenses out of the flue gas when its temperature falls below the 'Acid Dewpoint' (ADP). Acid corrosion can also occur when relatively hot flue gas is in contact with a cool surface whose temperature is below ADP. The ADP of flue gas is related to the concentration of SO_3, increasing with increased concentration. Its value in a given flue gas condition may be determined from the literature (Ref. 5,6,7). CICIND Codes classify the chemical effects on a chimney component in terms of the total number of hours per year that it is exposed to condensing acid from the flue gas. Time spent during start-ups and shut-downs, when the flue gas is at low temperatures, should be taken into account when assessing the exposure to gases below ADP.

The effects of acid attack are accelerated if any chlorides are also present in the gases.

Masonry is permeable to gases. The flue gas will penetrate the masonry, its progress being driven or resisted by both pressure and temperature differences. Therefore condensation can occur within masonry linings. If the masonry is not resistant to acid attack, it can be damaged by the condensing acids. Liner support components and insulation are also susceptible to attack by this acid. Gas that has passed through the liner without condensing may condense as acid on the inner face of the shell.

The addition of flue gas desulphurisation (FGD) equipment has generally been found to increase the hazard of acid corrosion in the chimney despite the removal of all but a small fraction of the sulphur oxides from the flue gas. This is because, even though the concentration of SO_3 (and therefore the ADP temperature) is very low, the FGD process reduces the flue gas temperature to such low values that sulphuric acid continues to condense. In addition, at the very low flue gas temperatures often associated with FGD, sulphurous acid formed by the combination of SO_2 and water can condense.

Other forms of acid corrosion are caused by the presence of Chlorine, Hydrochloric acid (HCl) or Hydrofluoric acid (HF) in the flue gas. Attack by these acids can occur at all temperatures. Alkalis in the flue gas can also affect chimney liner materials, usually at high flue gas temperatures (above about 750ºC).

B1.2 High Temperature

High temperature in the flue gas may be planned, either as the basis of normal operation or as the result of a temporary abnormal situation. In these circumstances, the chimney design can be arranged to suit (for instance the liner may be of refractory bricks, capable of operating at high temperature). Sometimes, however, high temperatures occur unexpectedly due to an internal fire or a sudden, unplanned temperature excursion.

Should a tube rupture in a furnace heating a flammable fluid (for instance, in an oil refinery), large quantities of this fluid will be released and will immediately ignite. Should there be insufficient oxygen for complete combustion, unburned fluid will be carried into the chimney. Here it will probably come into contact with air and will reignite. Another source of fire in the chimney is the build-up of soot and other flammable solids.

B1.3 Uneven temperature distribution

When more than one flue gas stream enters a single-flue chimney, mixing can be quite slow and may not be complete until the gases have moved vertically about 6 diameters (10 diameters, if streamlining guides are fitted). As a result, the liner in such a chimney may be subjected to differential temperatures, which can induce distortion and severe thermal stresses. This is particularly the case with steel liners which are prevented from responding to thermal distortion by radial restraints. Design rules are now available to accommodate these effects (Ref 8).

B1.4 Explosion or other sudden increase in pressure

The difference between a rapidly propagating fire and an explosion is difficult to define. Therefore, if a risk of internal fire exists, the possibility of internal explosions should also be considered. The effect of an explosion is a sudden increase in internal pressure in the chimney, which is capable of destroying part of an unreinforced brickwork liner. Another cause of sudden pressure rises is the rupture of a major tube in a boiler (for instance the economiser supply tube).

When the risk of sudden high pressure or internal explosion is high, it is often advisable to specify a steel liner or chimney.

B1.5 Wide range of operating conditions

A chimney serving different items of plant may experience widely differing flue gas conditions, depending on the combination of equipment operating at a given time. Similar wide variations in flue gas condition could arise in plant equipped with FGD or energy conservation equipment which may be by-passed. As a design suitable for one set of operating conditions is usually not compatible with widely differing conditions, the risk of damage is increased.

It is normally best to provide the chimney with a number of separate liners in these circumstances, each dedicated to a flue gas stream having more or less constant conditions.

B1.6 Continuous operation

Often a chimney is required to operate continuously for many years, without shutting down. In these circumstances, personnel access for regular internal inspections is not possible. Consideration should be given in such cases to using specialised on-line inspection techniques, such as the 'Hot camera'. If made aware of this requirement, the chimney designer will be able to offer advice and can ensure that the chimney is equipped with fittings which simplify the use of these techniques.

B1.7 Wind Effects

B1.7.1 Along-wind Effects

In the along wind direction a chimney is subject to horizontal loads proportional to the (wind speed)^2. For the purposes of design the CICIND Model Codes use the wind speed at a height of 10m, averaged over a period of one hour, which has a return period of 50 years. The use of safety factors in these codes ensures, for instance, that the theoretical probability of a concrete chimney's collapse in high winds is no more than between 1 in 5,000 and 1 in 10,000 during its lifetime, depending on its shape. In practice, safety would undoubtedly be better than this in a properly designed chimney.

The CICIND design rules take into account the effects of both the steady wind and gusts.

B1.7.2 Cross-wind oscillation

When wind blows past a chimney, vortices are shed at regular intervals, alternately from one side and the other. As these vortices are shed, they create a pulse of differential pressure, causing an alternating force in a direction normal to the wind direction. The frequency at which these vortices are shed depends on the wind speed and chimney diameter. When the frequency of vortex shedding is near to a natural frequency of the chimney, resonance effects can magnify the response of the chimney and, if its mass and structural damping are low, very large oscillations can occur. If another chimney of similar or greater height is nearby, buffeting and other interference effects can further magnify this response. At worst these oscillations have been known to cause collapse of the chimney. At best, they are alarming to bystanders.

Generally, concrete chimneys possess sufficient mass and structural damping to ensure their response is minimal. Self-supporting steel chimneys are, however, very susceptible to this phenomenon. The CICIND Model Codes contain rules which, if followed, will normally ensure that a chimney will not respond excessively to these cross wind forces. It is essential, however, that the designer be made aware of any nearby chimneys or structures of similar or greater height.

B1.8 Earthquakes

The CICIND Model Code contains rules that will ensure that a reinforced concrete chimney will possess an acceptable safety factor against collapse in an earthquake. Brittle construction, such as unreinforced, single brick thickness brickwork, is however very vulnerable to damage and should be avoided if possible in areas subject to strong earthquakes. The CICIND Model Codes for linings, contain a basis of rational design for brickwork liners in earthquake areas.

The stresses in a steel chimney, due to design wind load, are usually greater than those due to an earthquake. Consequently, normal steel chimneys can usually resist earthquakes up to about intensity 10 on the modified Mercalli scale, without serious damage. However, in cases where a heavy mass (such as a water tank or heavy lining) is fitted to the upper part of a chimney, a special investigation is warranted.

B2 Operating data required by the chimney designer

The design of a chimney is a complex business, requiring a great deal of skill and experience from the designer. For a given set of operating conditions, specification is simple and a satisfactory design can usually be found. Unfortunately, constant operating conditions are rarely found and, in practice, operating conditions tend to vary over quite a wide range. In these circumstances, the designer is required to develop a design which consists of a series of compromises, which are balanced between the requirements of the different conditions within the range of operations. In order for him to do this, it is essential that the specification provides the designer with information about the full range of anticipated operating conditions.

This information includes:

B2.1 Environmental Control Data

- Limitations on output of sulphur oxides, nitrogen oxides and particulates. Governed by National/Local Regulations.
- Minimum permitted chimney height.
- Maximum permitted chimney height.
- Minimum permitted flue gas exit velocity.
- Maximum permitted flue gas exit velocity.
- Existence of aggressive gases from other sources in the vicinity of the new chimney.
- Requirements for testing flue gas condition, such as constituent analysis, particulate content, temperature, velocity, ADP. Responsibilities for provision of this equipment should be defined.
- Requirement for aircraft warning lights.
- Requirement for lightning protection on all chimneys, except those fabricated of metal.

B2.2 Description of Plant

- Type of heater being served (e.g. boiler, furnace, incinerator, etc.).
- Existence of nearby chimneys or other tall structures.
- Presence of FGD or other pollution control equipment.
- Presence of Air Preheater or other energy conservation equipment.
- Definitions of anticipated abnormal operations, if any (e.g. overload operation, steam/air decoking of furnace tubes, by-pass of air preheater, turn-down, etc.).
- Presence of water quenching or tube washing equipment.
- Location(s) of flue gas entry point(s) into the chimney.

B2.3 Operating Conditions

- Nature of chimney operation, whether continuous, intermittent or occasional
- Maximum and minimum mass flows of each flue gas stream during normal and abnormal operations.
- Desired draughts at entry of flue gas ducts into chimney during normal and abnormal operations
- Maximum and minimum flue gas temperatures at entry of each flue gas duct into chimney during normal operation.
- Maximum and minimum temperatures of each flue gas stream during each anticipated type of abnormal operation, together with the probable duration and frequency.
- Maximum anticipated rate of change of temperature with time and associated total temperature change. This should include start-ups and shut-downs.
- Maximum and minimum temperatures of ambient air.
- Type of fuel being burned and anticipated composition of the flue gases.
- Anticipated concentrations of deleterious chemicals in the flue gases. In particular, the contents of: SO_3, NOX, HF, HCl, Chlorine and alkalis.
- If known, the range of maximum acid dew point temperatures of the flue gases during the various operating conditions.
- Concentration of abrasive dust in the flue gas.
- Planned frequency of shut-downs for internal inspection and maintenance.
- Altitude and any special local topographic features (nearby hills, cliffs, etc.).

B2.4 Future change of operating conditions

An assessment should be made of the possibility that a change of operation may occur in the future. If such a change is considered possible, the designer should be able to advise the owner of the impact that such a change would have on the proposed chimney. They may also be able to recommend a change to the chimney design that would reduce the necessity for future modifications required to accommodate the change of operation. Typical changes of operating condition are:

- Installation of a new (or removal of an existing) FGD or other pollution control system.
- Installation of an air preheater, or its removal.
- Change of operating mode from continuous to intermittent, or vice-versa.
- Change of fuel.
- Turndown or upturn of the combustion unit served.

B2.5 Unplanned hazards

The Specifier should consider the likelihood that unplanned hazards could occur and also should assess the effect that a consequent shut-down of the chimney for repairs would have on plant operation. If the risk is high and a prolonged chimney shut-down would be unacceptable, the designer should be required to provide a chimney capable of withstanding the hazards without the requirement of a subsequent, prolonged shut-down for repairs. Alternatively, they could advise on other steps that could be taken. The hazards include:

- Excessively high flue gas temperature, due to a fire or to mal-operation.
- High flue gas pressure, due to an internal explosion or a sudden accidental release of fluid into the gas stream due to a tube rupture.

B3 What types of chimney are available?

Chimneys can be constructed of reinforced concrete (cast in-situ or precast), brickwork, steel plate of plastic. They are usually self supporting and designed as cantilevers, fixed at the base. Sometimes, however, steel chimneys are supported within steelwork structures or by guy ropes or are stayed against an adjacent building. Plastic chimneys often rely on external support in this way. The choice of chimney type will be determined by cost and construction timetable considerations and by its suitability for the required duty.

Reinforced concrete chimneys are usually fitted with one or more liners to isolate the concrete from the effects of the hot and often aggressive flue gases. Steel and brickwork chimneys are also sometimes fitted with one or more liners, but are often unlined. Liners may be of brickwork, steel plate, plastic or refractory (applied to the inside of a steel chimney, or to a steel liner in a concrete chimney).

Chimney liners of brickwork or plastic may be supported at the bottom or at intervals from the concrete shell. Steel liners are best supported at their bottoms, with lateral support at intermediate levels, as necessary. Steel or plastic liners may also be suspended from the top. When steel liners are suspended from the top, or when they are in sections, each base supported, great care is necessary to provide expansion joints that are gas tight. If possible, the space between the liner(s) and the concrete should be accessible, to allow periodic inspection and maintenance.

Appendix 1 contains sketch layouts of the various types of chimney in common use throughout the world.

PART C

C1 What sort of chimney should I choose?

The choice of chimney type is normally determined by economic considerations. The cost of a steel chimney is greatly influenced by its diameter, which governs the ability to transport it in complete prefabricated sections. If its diameter is too great to allow such prefabrication, its construction will require considerable expensive field welding.

If its diameter places no restrictions on prefabrication, a self supported steel chimney is usually more economical than in-situ reinforced concrete up to a height of about 70 to 90m, and is competitive with the other types listed in Section B3.

If the required height exceeds 90m an in-situ reinforced concrete or a guyed or structure supported steel chimney will normally be most economic. If the required height exceeds 150m a cast in-situ reinforced concrete chimney usually becomes the only economic choice.

If the required diameter exceeds the limits for transporting prefabricated complete sections, a more detailed economic analysis is required, based upon site conditions.

In addition to economic considerations the choice of chimney and, more particularly, the lining system will be governed by technical factors. This is, of course, the province of the chimney designer, but the owner would be well advised to be generally aware of the most important of these factors, listed below. Many of these are based upon the results of an extensive survey (covering 332 chimneys of all types, world-wide), carried out by CICIND (Ref. 9).

- If the concentration of sulphur in the fuel burned exceeds 0.5% (weight) and the flue gas temperature is below 300ºC, a reinforced concrete chimney should be protected by an acid resistant brickwork liner. A ventilated airspace should be provided between liner and concrete and the liner should be externally insulated as necessary.
- Fibre reinforced plastic (FRP) has a good service record in contact with condensing flue gases. However, plastic liners or chimneys lose their strength at quite low temperatures. Before this material is chosen, therefore, expert advice should be sought about its temperature limitations, both long and short term and in wet or dry service.
- Providing the flue gas will always be above ADP and metal temperature will always be below 400ºC, a steel chimney, or steel liner in a concrete chimney (both externally insulated) has been found to give good service. At metal temperatures higher than 400ºC, stainless or alloy steel would be required.
- If the flue gas temperature will normally be above 400ºC, the lining in a concrete chimney should be of refractory brickwork (with a ventilated airspace), or stainless or alloy steel. In both cases the liner should be externally insulated.
- If the risk of internal fire is high, a steel liner or insulated steel chimney should be protected by at least 50mm of refractory concrete. In these circumstances, the temperature of the inner face (in contact with flue gas) should be maintained above ADP.
- If the risk of internal explosion is high, a brickwork liner is vulnerable to damage. Consideration should be given to providing a steel chimney or liner, protected against fire damage as outlined above.
- If the plant is equipped with FGD or an energy conservation device, both capable of being by-passed, consideration should be given to providing separate flues. One flue should be dedicated to normal service, the other to by-pass service.
- In the environment inside a chimney handling condensing sulphurous flue gases (i.e. at temperatures below ADP), the only metals that give satisfactory long term service in contact with such gases are the relatively exotic and expensive Nickel-Chrome alloys such as 'Hastalloy', or 'Incoloy', or Titanium.
- The resistance of stainless steel to attack by the relatively strong sulphuric acid condensing in a chimney environment is about the same as that of carbon steel. Therefore there is little to be gained by using stainless steel in chimneys. An exception occurs inside and outside the chimney near its top. Here any acid condensate will be cool and weak. In these circumstances, type 316L or 317L stainless steel has significant advantages over carbon steel. It should, however, be avoided if alkalis or chlorides are likely to be present in the gases.
- Galvanised steel is of little use where it can be exposed to flue gas inside a chimney or outside, near the top. External platforms and ladders may, however, be of galvanised steel when further than about 10 diameters from the chimney top.
- The effect of an internal fire or unplanned temperature excursion is a very rapid increase in temperature, which can damage the chimney or its liner. This damage could take the form of cracking in brickwork, softening and/or buckling in steel and, normally, total destruction of a plastic liner. Provided it is not externally insulated or close to a reflective surface, a self-supported steel chimney will not normally suffer

excessive damage when subject to an internal fire.

C2 Detail Design Issues

Besides the information contained in section C1 the chimney designer must also consider a number of detail design issues. These include:

C2.1 Location of Chimney

Location of a chimney close to another chimney or cylindrical structure of similar or greater height should be avoided. The limiting distance is 8 diameters of the new or existing structure, whichever is greater. If such a location is unavoidable, the chimney designer will need to provide additional structural damping, such as: guy ropes, damping pads under the base or a pendulum damper. Providing aerodynamic damping by fitting helical spoilers is of little benefit in these circumstances. (Note - existing chimneys can also be affected).

C2.2 Effects of low flue gas exit velocity

If the flue gas exit velocity is less than about 4m/sec, undesirable effects can occur during certain weather conditions. These include 'Downwash', in which the flue gas moves down the outside of the chimney. Another effect is 'Inversion', in which winds passing over the top of the chimney mix with and displace the flue gases inside the chimney. In both cases, the flue gases can be cooled below their ADP, so that acid is deposited.

C2.3 Venturis

Sometimes, in order to increase the flue gas exit velocity to avoid the problems described above, a designer will add a venturi-like restriction to the top of the chimney. Great care is required in designing this feature, as it increases the pressure of the flue gas below the restriction. This can lead to a situation of 'Overpressure', in which the flue gas can be pushed outwards through joints or a pervious liner, to condense acid on cold surfaces.

C2.4 Effects of high flue gas velocity

As resistance to flow is related to (gas velocity)^2, excessive velocity can require the use of a forced draught fan. This would introduce overpressure in the flue gas, with the consequences described in C 2.3 above.

Another consequence of excessive flue gas exit velocity is the generation of noise.

C2.5 Turn-Down Ratio

If a single chimney serves a number of units, or if it serves a single unit with a wide operating range, the flue gas flow rate can vary considerably. This variation is called the 'turn-down ratio'. If turn-down ratios are too large, it becomes difficult to reconcile the conflicting requirements of avoiding too low and too high velocities.

Probably the best means of avoiding problems associated with a high turn down ratio is to specify a multi-flue chimney, each liner being dedicated to the whole or part of the flue gas from a single appliance.

C2.6 Access for inspection and maintenance

In designing access facilities for inspection and maintenance, either on-line or during a shutdown, great care is required to ensure the safety of the people involved. Issues requiring particular attention include: the risk of exposure to high temperature and/or flue gas, the risk of corrosion damage to ladders, platforms and their fixings and the provision of alternative escape routes.

C2.7 Security of equipment at the top of the chimney

The consequences of equipment at the top of the chimney coming adrift and falling can be very serious. Therefore the design of all equipment at the chimney top should pay particular attention to its integrity and that of its fixings. Such equipment includes: Rainshields over the annulus between liner(s) and shell; Platforms; insulation around projecting liner sections; lightning conductors. Hazards include acid corrosion and fatigue induced by oscillations and 'fluttering' in high winds.

Rainshields over the annulus should be fixed to the outer shell, with allowance being made at the junction with the liner for liner expansion.

C2.8 Quality Control

In the history of industrial chimneys there are very few cases of collapse. It can therefore be said that chimneys have generally proved to be safe structures. On the other hand chimney damage or failure of chimney components has not been uncommon. While these effects have not seriously affected the overall safety of chimneys in terms of collapse, they have often led to very expensive unplanned shut-downs and repairs. In order to avoid these problems, the following requirements are of paramount importance:

- The design of the chimney must be carried out by a qualified engineer, experienced in chimney design and in possession of all the facts relating to its operation.
- The construction of the chimney must be carried out by a firm experienced in chimney design and construction, with a qualified engineer being responsible for supervision.
- The provision of quality control at all stages of shop fabrication and field construction. This should be entrusted to an independent agency.

REFERENCES

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(3) Model Code For Concrete Chimneys, Part B: Brick Linings - CICIND, Dec 1991

(4) Model Code For Concrete Chimneys, Part C: Steel Linings - CICIND, Dec 1995

(5) Influence of fuel oil characteristics and combustion conditions of flue gas properties in W- T boilers - G. Bunz, H. Diepenberg and A. Rendle, Jnl of the Institute of Fuel, September 1967

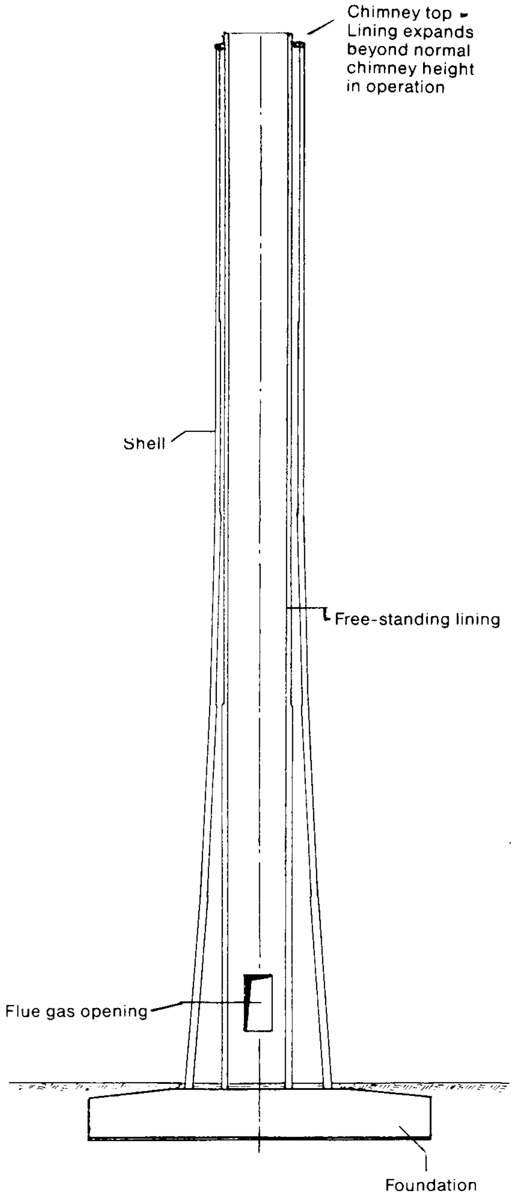
(6) Prevention of cold end corrosion in industrial boilers - Lech and Lewandowski, 'Corrosion', March 1979, Atlanta, U.S.A.

(7) Estimating Acid Dewpoints in Stack Gases - R.R. Pierce, 'Chemical Engineering', April 1977

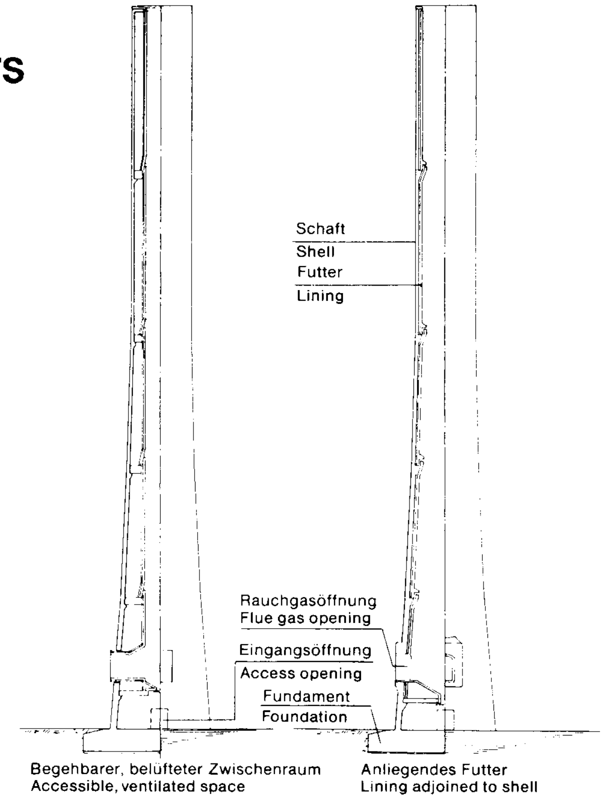
(8) Design and Construction of Steel Chimney Liners - ASCE, 1975

(9) Performance Survey of liners in concrete chimneys - B.N. Pritchard, Paper presented at 3rd International Chimney Congress, Munich, October 1978

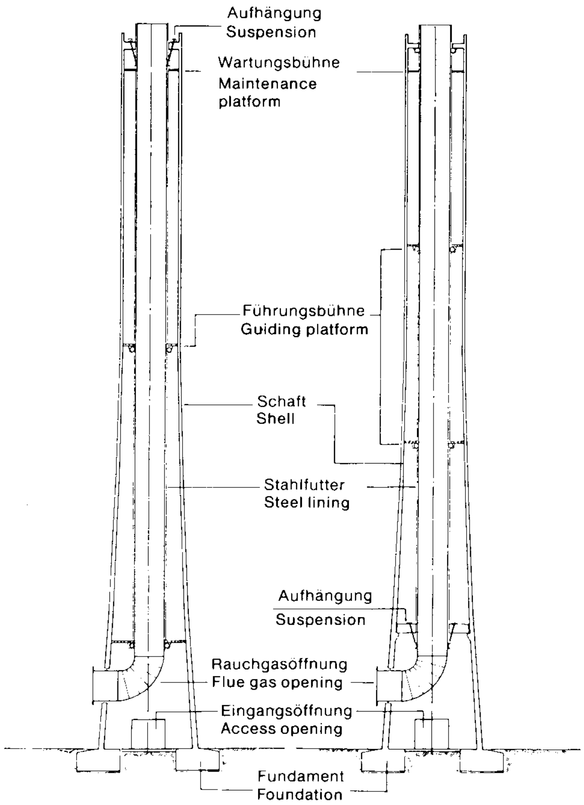
APPENDIX 1
TYPICAL CHIMNEY ARRANGEMENTS



Chimney with free-standing lining.

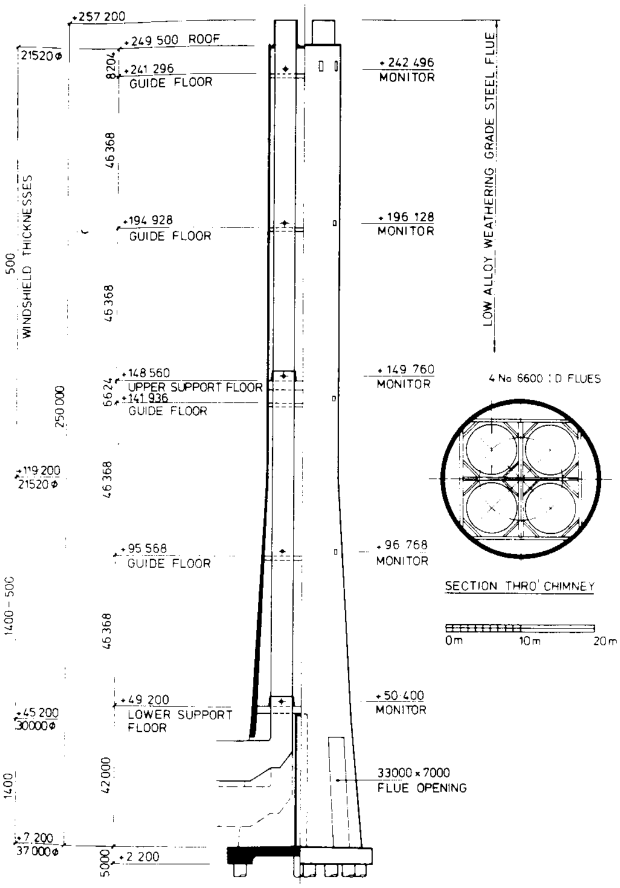


Schornstein mit Etagenfutter.
Chimney with sectional lining.



Schornstein mit Stahlfutter.
Chimney with steel lining.

Figure 1 - Typical Concrete Chimneys with Single Liners



Concrete Chimney

Steel Chimney

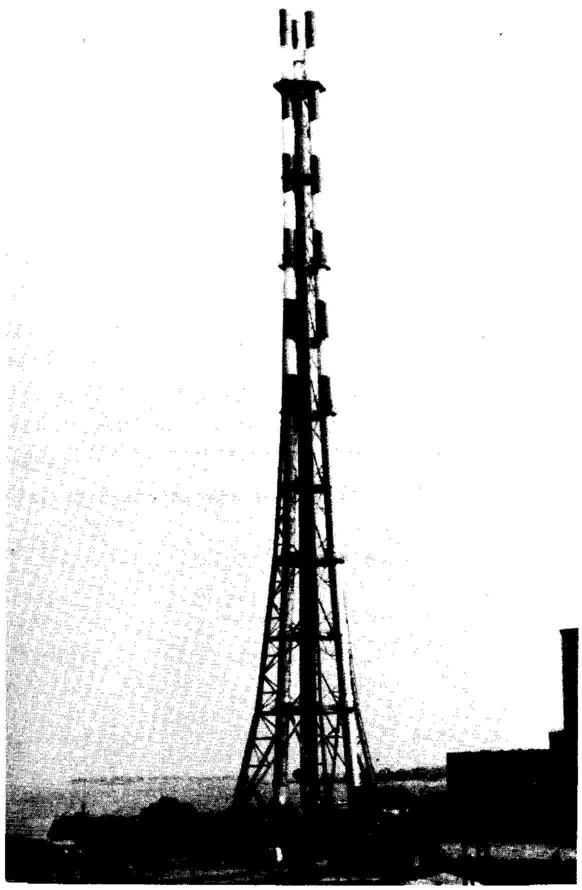


Figure 2 - Typical Multi-Flue Chimneys

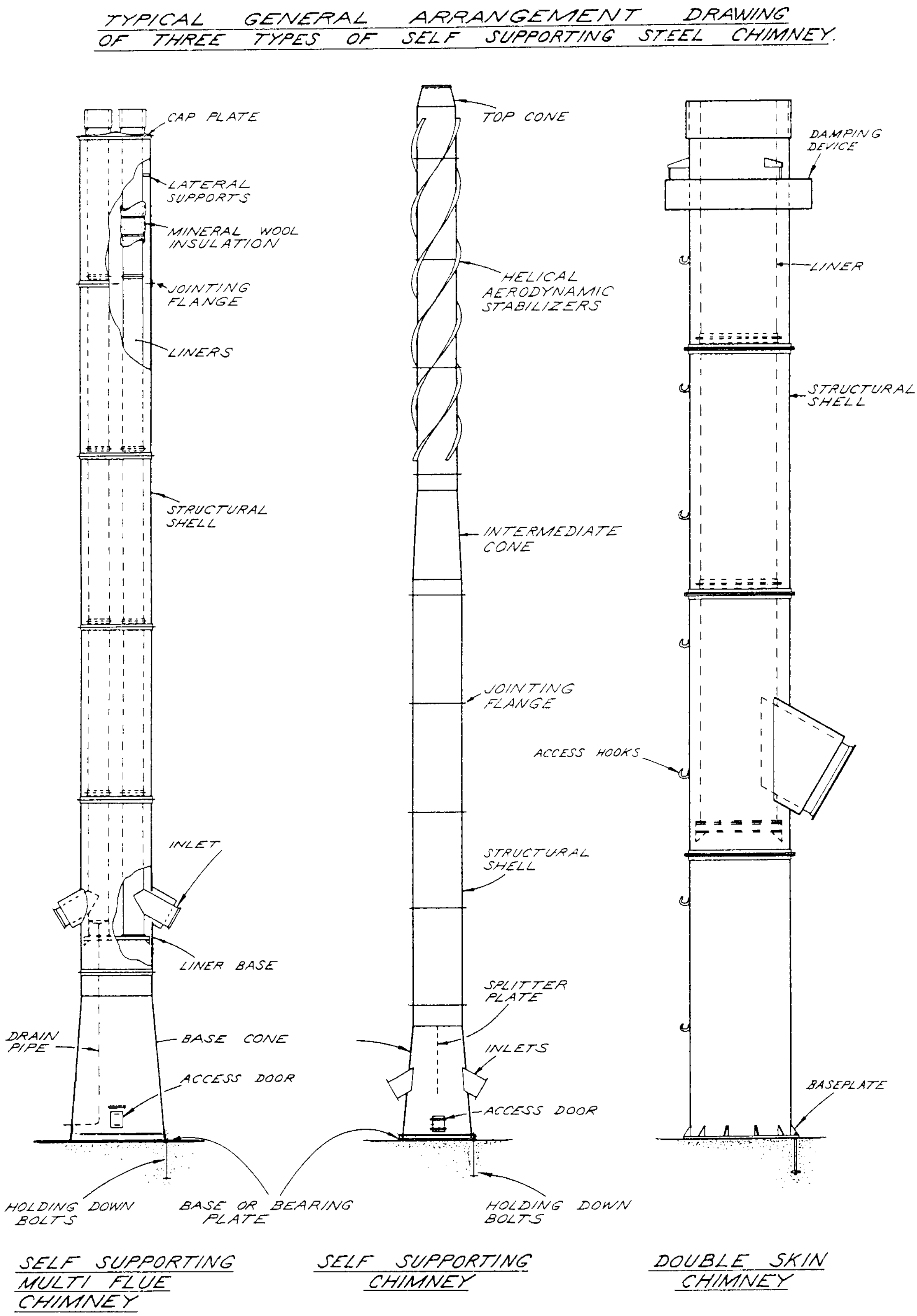


Figure 3 - Typical Self Supporting Steel Chimneys

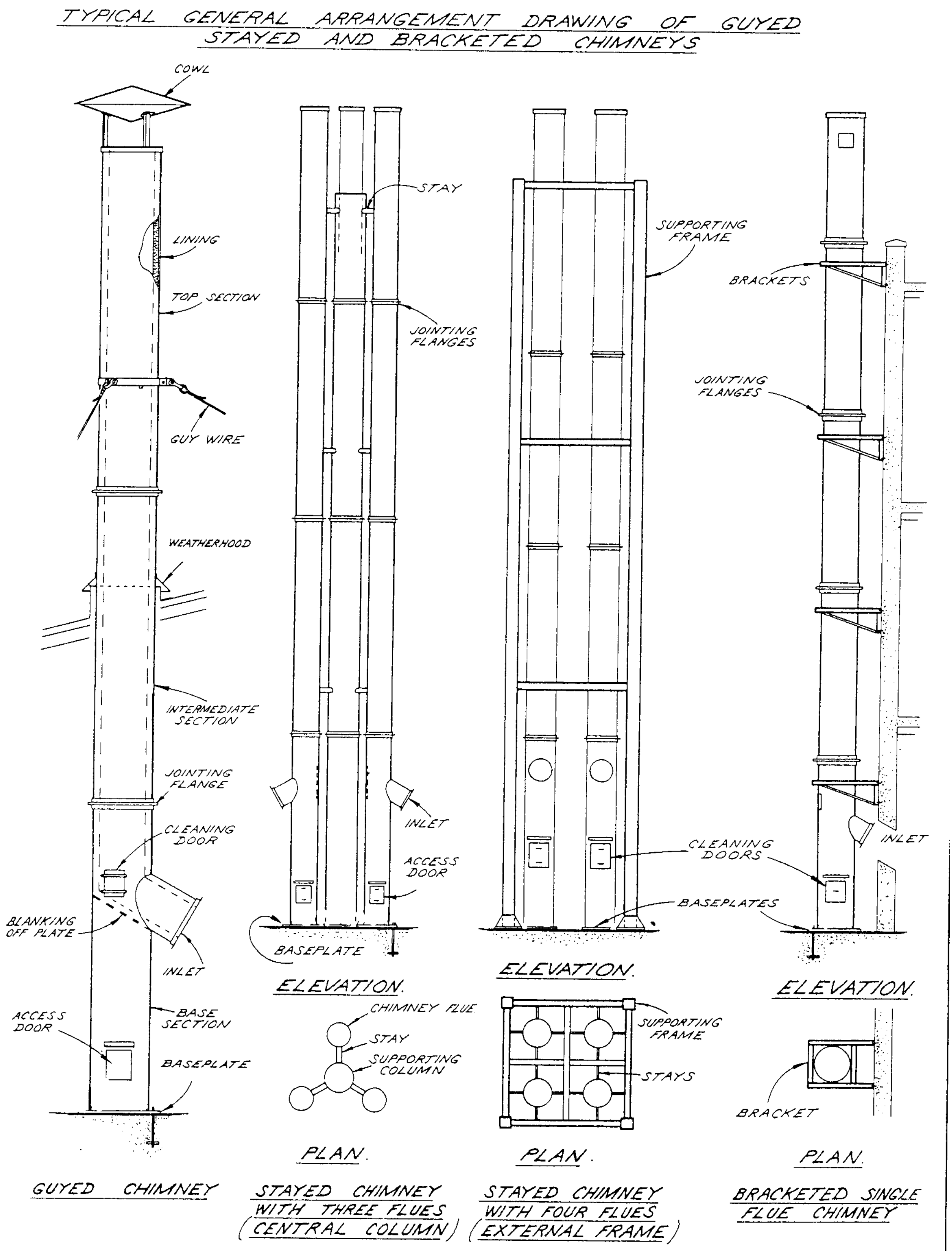


Figure 4 - Typical Steel Chimneys Externally Supported

APPENDIX 2
TYPICAL ORGANISATION CHART FOR A CHIMNEY DESIGN

DESIGN STAGE	REQUIRED INFORMATION	DISCIPLINES INVOLVED
• Height • Diameter • Pollution control	• Government regulations • Flue gas quantity, quality & temperature	• Management • Physicist • Chemical engineer • Combustion engineer
• Windshield material	• Economy	• Architect • Civil/structural or mechanical engineer
• Lining and/or insulation	• Operating conditions • Earthquake risk	• Heat transfer specialist • Material specialist • Civil/structural or mechanical engineer
• Openings in shell and lining	• Duct design	• Heat transfer specialist • Mechanical engineer
• Windshield structural design	• Wind/earthquake data • Design codes	• Civil/structural or mechanical engineer
• Foundation	• Soils investigation	• Civil/structural engineer
• Construction	• Drawings specification	• Contractor • Civil/structural or mechanical engineer

APPENDIX 3

TYPICAL SPECIFICATIONS

<table>
<tr><th>Type of specification</th><th colspan="4">Responsibilities/duties of parties</th></tr>
<tr><th></th><th>Owner</th><th>Specifier</th><th>Designer</th><th>Builder</th></tr>
<tr><td>Skeleton 'Duty specification'</td><td colspan="2">• Usually one and the same
• Must provide data per Section 4
• Responsibility for accuracy of data given in A4</td><td>• Must elicit information in Section B2 from plant designers
• Must comply with codes and take account of data
• Not responsible for A4 data</td><td>• Prime responsibility
• May design in-house or sublet design
• Must construct per codes</td></tr>
<tr><td>Complete specification</td><td>• Appoints specifier (may be in-house)
• Must provide data per Section A4
• Responsible for accuracy of data given in A4</td><td>• Lists data in Section B2
• May choose shell material
• Responsible for accuracy of data given in B2</td><td>• Must comply with codes and take account of data given
• Not responsible for B2 data</td><td>• Prime responsibility
• Maya design in-house or sublet design
• Must construct per codes</td></tr>
<tr><td>Full design</td><td>• Appoints designer
• Must provide data per Section A4
• Responsible for accuracy of data given in A4</td><td colspan="2">• Must elicit B2 data from plant designers
• Must calculate height/diameter
• Chooses chimney type/materials
• Designs chimney
• Prepares contract drawings/specs
• Responsible for all design aspects
• Not responsible for A4 data
• Should invite alternatives</td><td>• Construction only: Must construct per codes
• If alternative chosen:
- Responsibilities as for 'Complete spec'
- Not responsible for B2 data</td></tr>
</table>