Guidance to Prevent Over-pressurisation of Storage Silos during the Delivery of Powder in the Cement, Concrete and Quarrying Industries.

Produced by:-

British Cement Association

The British Precast Concrete Federation

HSE Health & Safety Executive

Quarry Products Association

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EXECUTIVE SUMMARY

This document addresses the problems of over-pressurisation of storage silos during the pneumatic delivery of powder (see Appendix E – Silo incidents). These problems have been recognised by the cement/quarry industry, who have produced the following guidance in conjunction with the Health & Safety Executive/Laboratory, in order to identify the best industry practice for the operation of silos in order to prevent such incidents. The information contained in this document is designed to identify the key issues associated with delivery, provide guidance on preventing over-pressurisation and improve the over-all operation of silos.

The following recommendations are made:

- Ensure adequately sized Pressure Relief Valves (PRVs) are fitted to silos and that they are maintained and operated correctly, so as to mitigate any over-pressurisation.
- Automatic shut-off systems are used to prevent over-pressurisation from occurring. These should be used with all new installations and, where reasonably practicable, existing installations should be modified.
- Operate in accordance with the guidelines detailed in this document, which outlines the best industry practice.

FOREWORD
from the Metals and Minerals Sector, Health and Safety Executive.

This guidance arises from requests to the Metals and Minerals Sector of the Health and Safety Executive to assist in identifying the risk factors which give rise to over-pressurisation of silos used in the Cement, Concrete and Quarrying industries and methods of controlling them.

The contents represent best industry practice and are commended to everybody associated with this activity.

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1 INTRODUCTION

1 The cement/quarrying industry handles many millions of tonnes of powder every year. It is common practice for these powders to be transported by road in tankers. The loads are discharged by fluidising the powders and blowing them into a silo (pneumatic conveying). The air used to carry the powder is vented from the top of the silo through filters. If the air entering the silo is not vented adequately, delivery in this manner may result in over-pressurisation and consequent rupture of the silo, or ejection of the filter system or the silo lid. Suitable pressure relief devices should be fitted to all powder silos.

2 Pressures above 6.9[†] kPa (1 p.s.i.) may be sufficient to damage silos. Although the discharge pressure at the outlet of the delivery pipe at the top of the silo will be of this magnitude, the pressure at the tanker end will be much greater and will vary depending on the silo height, length of pipe, number of bends in the pipe, powder density, etc.

3 Over-Pressurisation of a silo can occur due to one or more of the following:

- Increase in flow rate of air from a tanker during delivery or at the end of discharge;
- Overfilling of silo;
- Failure of Pressure Relief Valve to vent air at the rate of flow from the tanker;
- Inadequate flow of air through the filters;
- Inadequate maintenance or design of the above equipment; and
- Uncontrolled discharge of residual air from the tanker.

4 A rise in air flow to the silo occurs when the density of the fluidised powder is reduced, especially at the end of delivery. This transition stage is short, but could result in a catastrophic pressure rise in the silo. The maximum instantaneous flow rate of air may be as high as 3.25 $m^3\ s^{-1}$ (~6900 cfm) (see Appendix A).

5 This document applies to all silo installations used for the storage of non-flammable powders (for which there are no explosion risks) in the cement and related industries. The aims are to:-

- Prevent silo over-pressurisation, and if this is not reasonably practicable, mitigate the effects;
- Advise on the equipment used in the delivery process and any short comings in their operation;
- Identify the potential hazards associated with the delivery of cementitious material to silos;
- Provide guidance on assessing the risk associated with the delivery process;
- Provide guidance on the choice, assessment and fitting of protective devices; and
- Provide guidelines for designing new installations and improving existing sites.

6 Legal requirements include Health and Safety at Work etc. Act, the Management of Health and Safety at Work regulations, the Pressure Systems Safety Regulations, the Provision and Use of Work Equipment Regulations and the Environmental Protection Act. Guidance on these can be found in the publications listed in Section 9 and from the appropriate enforcing authority.

[†] all pressures are given as gauge pressures (i.e. pressure above atmospheric) and not absolute pressure

2 DESCRIPTION OF TANKERS

2.1 Road tankers

7 Both tipping and non-tipping (belly) tankers can be pressurised and operated in a similar way to deliver powders. The tankers have a blowing system, which provides air to transport powder into the silo. Tankers currently operate at up to 200 kPa (29 p.s.i., 2 bar). A modern tanker, designed exclusively for use in the industry, typically has a volume in excess of 36m^3 when operating at 41 tonnes.

Figure 1. Modern, non-tipping tanker.

2.2 Air-discharge

8 A compressor (blower) mounted on the tanker lorry provides a supply of air. This air:

- Pressurises the tanker vessel. The tank is pressurised at the start of the blow and maintained at operating pressure during the course of discharging;
- Fluidises the powder around the distributor plate; and
- Transports fluidised powder from the tanker, along the connecting pipework to the silo.

2.3 Interconnecting hoses and feed lines

9 The feed line, which takes the powder from ground level to the top of the silo, is a 100 mm (4") rigid pipe. The tanker is usually connected to the feed line *via* a flexible hose using a cone type coupling. The hose is typically rated to a pressure of ~ 500 kPa (72.5 p.s.i., 5 bar) and the couplings to > 800 kPa (116 p.s.i., 8 bar) providing the coupling is sound and a good connection is made.

10 There are alternative fittings, which incorporate a positive locking action. These couplings are rated to 1000 kPa (145 p.s.i., 10 bar) and above, depending on the material from which the coupling is made. The fittings and blanking caps are also available with protective locking mechanisms and pressure-activated locking devices, which ensure that connections cannot be broken if there is residual pressure in the system.

3 RECEIVING SILOS

11 Silos can be of varying styles, sizes and shapes, and some are divided into a number of compartments. The height of a silo and length of inter-connecting pipework affects the rate at which powder may be delivered from a road tanker. The higher the silo and the longer the pipework, the further the powder has to be conveyed. This alters the ratio of air to powder required to maintain the powder flow.

12 On entering the silo from the feed line, the velocity of air/material decreases rapidly, allowing the powder to fall from suspension. The powder is deposited in the silo whilst the air is vented from the silo, through filters, to atmosphere.

3.1 Filter systems

13 Not all of the powder transported into the silo settles out of suspension rapidly. Therefore, the air leaving the top of the silo needs to be filtered to prevent emissions of powder to the environment. This is achieved using:

- *Filter bag systems* - these filter the air through a cloth bag, which removes particulate material.
- *Filter cartridge systems* - these contain a series of cylindrical cartridges of pleated filter material. The pleats in the material greatly increase the surface area of the filter.

14 Filter cleaning systems are essential for reliable operation and to maintain filter efficiency. In general, this is achieved either by:

- *Reverse jet cleaning* - short blasts of air are fired against the normal direction of flow though the filter. These blasts last for a fraction of a second and dislodge any powders that have been deposited in the filter material. This procedure is repeated at frequent intervals during the filling process to prevent the build up of deposits.
- *Mechanical shaking* - filter bags are mechanically shaken for a predetermined length of time (e.g. 30 seconds - 5 minutes) depending on the powders involved. This procedure should be carried out in accordance with manufacturer's recommendations.

Figure 2. Filter housing on top of silo installation.

3.2 Warning systems

15 Since it is not easy to determine either the level of fill inside a silo or the internal pressure, silos should be fitted with warning sensors, which activate audible and visual alarms. Typical sensors are:

- *High pressure sensor* - usually a pressure sensor, located at the top of the silo. The sensor monitors the pressure in the silo and, if pre-determined levels are exceeded, activates alarms or fill pipe shut-off valves; and
- *High powder level* - either a mechanical device, which detects the presence of powder by interference with a moving sensor, or an electrical device (probes or optical sensor) which detects the presence of powder. The location of the sensor determines the degree of warning given by the alarm; the lower the sensor, the earlier the warning.

16 The high level warning system is designed to prevent the silo from being over-filled by providing the tanker and silo operators with a warning when the level in the silo approaches the maximum fill level.

3.3 Pressure relief valve (PRV)

17 Although silos have a degree of inherent strength, they are not designed as pressure vessels and therefore they must be protected against a build up of pressure. Pressure relief valves are mechanical valves or vents which open at a pre-set pressure in order to allow excess air to vent from the silo. Frequently used designs are:

- *Dead weight valve* - the weight of the lid of the vent usually keeps the pressure relief device closed. When the pressure in the silo exceeds the designed lift-pressure, the force on the underside of the vent overcomes the weight of the lid, which lifts and vents the excess air to atmosphere. Once the pressure subsides the lid reseats, thereby resetting the valve.
- *Spring loaded valve* - the resistance to opening comes from a spring acting on the valve rather than the weight of the valve cover. The valve opens if the pressure exceeds the design pressure and resets once the internal pressure has fallen.

4 DISCHARGE PROCESS

18 Discharge of powder from the tanker must be carefully controlled by the tanker driver. During steady-state delivery of powder, the delivery rate should be maintained by the driver by regulating the flow of air and powder in the delivery line. A rise in airflow at the outlet will occur when the powder density is reduced, especially at the end of delivery, thereby producing a surge of air into the silo from the tanker. Correct operation of the valves by the driver will minimise the excess air entering the silo.

19 During delivery:

- The flow of material into the silo can be checked by the noise and movement of the flexible hose;
- The end of delivery can be detected by a sudden pressure decrease in the tank, accompanied by a changing tone of the compressor.

20 A surge of air into the silo from the tanker can result from:

- Inadequate monitoring of the powder level in the tanker. If the last of the powder from the tanker, or from a single pot, is discharged without any action being taken to control the flow, large flow rates of air into the silo may occur.
- At the end of the discharging procedure, the tanker will contain residual air at pressures significantly above atmospheric pressure. High flow rates will be generated by the sudden discharge of this residual air through the silo.

21 If no action is taken to stop the discharge of air, the flow of air will continue until the pressure in the tanker falls to ambient. For a typical silo, the maximum flow of air into the silo can be as high as 3.25 $m^3 s^{-1}$ if sudden discharge from the tanker occurs. Appendix A gives the information required to calculate the maximum flow rate of air into a silo and Appendix B gives a worked example.

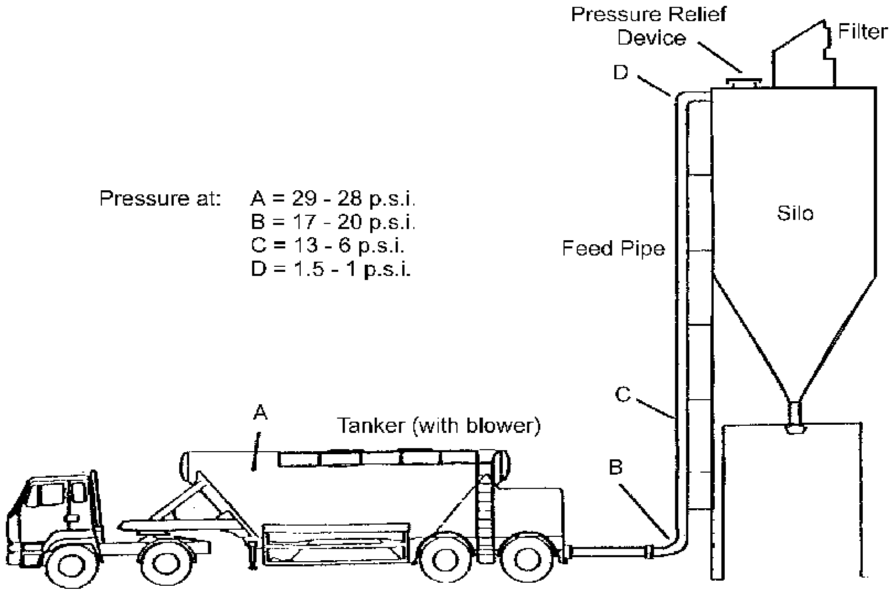

Figure 3. Schematic representation of the delivery system, with typical pressures measured in the delivery pipe.

5 MAINTENANCE OF EQUIPMENT

22 Experience from reported incidents of over-pressurisation (see Appendix E) indicates that one of the major contributory factors is the poor maintenance of equipment. All equipment used in the discharge process must be maintained regularly so that it functions correctly at all times.

23 Maintenance procedures, including routine examinations of equipment, are required to ensure:

- Safe operation of the equipment;
- Early detection of faults or impending faults;
- Identification of on-going maintenance needs; and
- Identification of components which cause repeated problems and which may require re-design or re-specification.

24 Table 1 identifies some key areas which require a well planned maintenance schedule, in order to ensure the delivery system operates safely and efficiently. The table is not a comprehensive list of areas to check, but contains key components related to the safe operation of the delivery system. The responsibility for maintenance will lie with the equipment owner. In all cases, a detailed maintenance record should be kept.

Table 1. Maintenance checks.

Location	***Component***	***Checks***
Tanker	Pressure system	Has tanker been examined under Pressure Systems Safety Regulations?
	Hose and couplings	Correctly rated hoses and couplings are used. Hose and couplings are not worn or damaged. Seals are not worn or damaged. Clamps are not worn or damaged. Correct grade seals are fitted.
	Discharge valves	Valves operate correctly. Valves do not leak.
	Pressure relief valves	Valves operate correctly. Set pressure is suitable for the installation. Set pressure is suitable for the safe operating limit of the tanker.
Silo	Structural integrity	Filter housing is free from corrosion. Filter housing is secured to silo. Silo lid is free from corrosion.
	Hose couplings	Couplings are not worn or damaged. Correct seals are used. Clamps are not worn or damaged. Lock-off devices operate correctly.
	High level/pressure alarms	Warning system circuit operates correctly. Sensor operates correctly. Sounder and lamp operate correctly.
	Pressure relief valve	Valve operates at correct pressure. No leaks from valve. No build up of powder in or around valve. Lid is not seized. Hinges are not faulty. Springs are not seized or powder-laden.
	Filter system	Correct filter fitted. Filter not blinded. Cleaning system operates correctly.
Site	Compressed air	Correct pressure is maintained at all times. Air is dry/ moisture traps emptied. Air lines are not discoloured (e.g. no oil/water contamination). System examined under Pressure System Safety Regulations.

6 RISK ASSESSMENTS

25 A risk assessment of the whole delivery process must be undertaken to identify the hazards, assess the risk and identify the steps required to control the risks. Appendix A contains guidance on the information that may be required to carry out a risk assessment and methods of determining operating conditions for the delivery process. Appendix C contains a checklist of some of the frequently encountered issues which are important to consider. Each silo installation must, however, be considered individually.

7 RISK CONTROL MEASURES

26 There are a number of factors which affect the likelihood of over-pressurisation occurring and the possible failure of the silo or silo fittings. Guidance on some of these are outlined below:

7.1 Silos

27 The following features of any silo may contribute to over-pressurisation problems:

28 **Size -** The risk of over-filling is greatest in small silos where the volume of the silo may be similar to the volume of material in a single delivery. For this reason, larger silos are better than small or compartmentalised silos. Replacement or carefully engineered modification (to remove the compartments) of small or compartmentalised silos should be encouraged.

29 **Maximum Silo pressure** - Storage silos are not manufactured as pressure vessels and are only designed to withstand the load due to stored material. For this reason, silos will generally not be able to withstand any internal pressures much above atmospheric. There will be some residual strength built into the silo itself, but this will not typically be specified by the manufacturer. Connections on the silo to additional equipment (e.g. filter systems) can be weak points in the structure. The maximum pressure that such vessels can withstand may be as low as 6.9 kPa (1 p.s.i.) and can only realistically be assessed in collaboration with the silo manufacturers or competent engineers.

30 **High level alarms -** High level alarms must give the tanker operator sufficient time to shut down the delivery system and clear delivery lines before the silo becomes full. The sensor must, therefore, not be located too close to the roof of the silo, as there will be insufficient warning before the silo is full.

31 The location of the high level sensor will depend on the material being stored. For example, in the case of paddle sensors, used with low density materials, more of the paddle has to be immersed in powder before there is sufficient resistance to stop the paddle. In addition, the top surface of material in the silo is unlikely to be level. The sensor should be located so as to measure the highest level of powder in the silo. This will provide the best warning.

7.2 Filters

32 Any filter system used must be capable of handling the large flow of air that is generated during the delivery process, without increasing the pressure in the silo. It is therefore important to calculate the required filter size to match the flow rates of air through the silo.

33 For filter systems to operate effectively, the filters must be cleaned to prevent both blockages and loss of efficiency due to accumulation of powder in the filter material. All types of cleaning system shall operate according to the original manufacturers specifications. In particular:

- Mechanical shaking systems should be checked for correct operation.
- Reverse jet systems require compressed air at a minimum pressure. The pressure of the air supply should be checked when other plant equipment is operating as this may cause a drop in supply pressure.

34 The filter housing must be adequately secured to the silo. The securing flanges and filter housing must be engineered to withstand the forces that may act upon them at the maximum allowable working pressure of the silo.

7.3 Maximum rate of material transfer

35 The rate of delivery of powder to the silo should be set to a maximum allowable rate to allow sufficient time for the delivery to be stopped once the high level alarm has sounded. In addition, the maximum allowable rate of delivery of powder to the silo determines the maximum pressure at which the tanker needs to operate.

7.4 Tanker venting

36 In order to significantly reduce the risk of over-pressurising a silo, residual air should only be discharged (where allowed) to the silo in a controlled manner, through, for example, small bore pipes, bleed valves or other flow restrictors or, alternatively discharged to atmosphere through filtering equipment fitted to the tanker.

7.5 Pressure Relief Valves (PRVs)

37 All silos should have pressure relief valves fitted to prevent over-pressurisation. These must be correctly sized to meet the maximum flow rates that can be attained (see Appendix A).

38 The operating characteristics of PRVs differ significantly with size and style of design (e.g. spring loaded, dead weight, hinged, etc.). Therefore, it is not possible to specify a particular design/model that would be suitable for all silos. The choice of the PRV required must be made using the following data:

- Required lift-pressure
- Maximum operating pressure of the silo
- Maximum flow of air into the silo
- Venting capacity of the PRV at specific over-pressures
- Compatibility of PRV material with silo contents.

39 The PRV chosen must:

- Have a lift-pressure below the maximum operating pressure of the silo, but high enough that the device will not open due to pressures experienced during normal delivery; and
- Be able to vent the maximum attainable flow of air into the silo at a relatively small over-pressure, such that the total pressure in the silo does not exceed the maximum operating pressure.

40 Flow characteristics may be obtained from the manufacturer or by testing the valve to be used if the information is unavailable. The silo operator must be able to demonstrate that they have evidence that the PRV they are using is adequate for the silo to which it is fitted and for the method of discharge utilised.

__WARNING:-__ It is possible that the maximum flow rates, quoted by manufacturers, for PRVs may only be achieved at pressures in excess of the maximum allowable operating pressure of the silo. This may mean that the flow rates that are obtainable at the maximum allowable operating pressure are not sufficient to prevent over-pressurisation (see Appendix B).

Figure 4. Shut-off valve located close to connection point, which is labelled.

Figure 5. Shut-off valve, located mid-pipe, and alarm to indicate activation of system.

7.6 Automatic Shut-off systems

41 As a method of preventing silo over-pressurisation, **it is recommended** that when installing new silos, automatic protection systems, which stop the delivery of material from a tanker to the silo when alarm conditions are reached, are also installed. It is also recommended that, where reasonably practicable similar systems are fitted to existing systems. Any automatic shut-off system should contain the following features:

- Delivery to the silo should only be possible if a valve, located between the tanker distributor and the silo, is open;
- The valve should be operated by a control system which respond to conditions in the silo;
- The system should include both high level sensors and pressure sensors;
- The controls should receive signals from the sensors and the valve should be closed if alarm conditions are reached. However, it may be suitable in some cases (i.e. in response to the high level alarm) to give an audible warning for a short length of time before the valve is closed, thereby allowing the tanker operator to manually stop the delivery;
- Delivery to a silo should be allowed to continue, by the valve re-opening, once it has been established that it is safe to do so and the alarm conditions have subsided; and
- The system should be designed to be "minimum fail to danger", i.e. it is "fail-safe". This means that delivery to the silo should be impossible if any of the alarm conditions exist, if the system is not energised or if power (or compressed air) to the system fails.

42 Suitable automatic protection systems are already in effective, day-to-day operation. There appear to be very few operational difficulties and, once installed, there are significant financial benefits to be achieved in the form of reductions in the costs of maintenance of filters and pressure relief devices (because they become less powder-laden) and in costs of repairs due to over-pressurisation. Also, the protection system provides an early warning of potential operational problems associated with a silo. For example, repeated activation of the shut-off valve is an indication of silo pressure increases, which may occur if the filter is not operating correctly.

43 There may be other suitable methods of preventing over-pressurisation, but they would need to achieve the same level of protection as this automatic shut-off system.

7.7 Operating procedures

44 Silo operators must develop safe operating procedures for the delivery process.

45 After consultation with the delivery company, information must be displayed at each silo filling point. This must give instructions on:

- Reporting to the control point before delivery commences;
- The maximum pressure the tanker can charge to the silo;
- The maximum flow rate of material allowed;
- Ensuring all connections are securely fitted to the charging point;
- Stopping the delivery should the high level alarm operate;
- Stopping the delivery if any discharge to atmosphere is observed;
- The procedures to follow in the event of any spillage;
- Venting of the residual pressure from the tanker;
- Locking the fill point when delivery complete; and
- Reporting to the control point when delivery is completed.

Figure 6. Delivery from tipping tanker. Note signs close to delivery point.

7.8 Duties

46 Tanker drivers, silo operators and companies responsible for delivery have specific duties which contribute to the safe operation of the delivery and storage systems. Thus, with respect to the management and operation of silos:

Companies responsible for delivery will ensure that:

- Tanker drivers are trained to deliver the products they supply (Appendix D is an example of a syllabus for driver training);
- Deliveries are undertaken according to an operating procedure agreed between the silo operator and the delivery company;
- Delivery equipment is properly maintained and compatible with the silo installation;
- They produce and operate a policy on safe operation of tankers, etc.; and
- Notify silo operators of changes to delivery equipment (e.g. tanker size and performance).

Silo operators will ensure that:

- Charging procedures are displayed at each silo filling point;
- The plant operative has been trained in the safe operation of plant equipment and silos;
- A policy on safe operation of silos is prepared and operated;
- Access to the fill points is under the control of the plant operative; and
- Silos are designed and operated to prevent over-pressurisation (see Sections 7.1 - 7.6).

Tanker drivers will:

- Report to a suitable point to ensure that the load is delivered to the correct silo and there is sufficient space in the silo to accept the load;
- Discharge according to a written procedure for safe operation;
- Remain with the tanker at all times;
- Monitor the level of powder in the tanker; and
- Carry documentary evidence of training.

8 RECOMMENDATIONS

47 In order to protect storage silos from the risk of over-pressurisation during the pneumatic delivery of powder, duty holders should ensure that, where they apply, the following recommendations are followed:

- Drivers are provided with training in the safe delivery of powder;
- Silo operators shall maintain effective control of filling activities by, for example, fitting access control devices to filling pipes;
- Venting at full pressure through the silo is prohibited;
- A filter of sufficient size to allow the excess air to dissipate to atmosphere, without entrained dust, is fitted to the silo;
- Adequately sized Pressure Relief Devices are fitted to silos and that they are maintained and operated correctly, so as to mitigate any over-pressurisation;
- A high level alarm, positioned to give sufficient ullage space above the cement level to prevent the filter from blinding, is fitted;

- Other equipment (e.g. air filters) should be selected with consideration given to the prevailing operating conditions;
- Silos are operated in accordance with the guidelines detailed in this document, which outlines the best industry practice;
- Where reasonably practicable, taking into account the outcome of risk assessments, automatic shut-off systems are used to prevent over-pressurisation from occurring. These should be used with all new installations or those undergoing major refurbishment

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10 ACKNOWLEDGMENTS

48 The leading organisations involved in the production of this guidance are the British Cement Association (BCA), British Pre-Cast Concrete Federation (BPCF), Quarry Products Association (QPA), the Health and Safety Laboratory (HSL) and the Health and Safety Executive (HSE). In addition, the Environment Agency of England and Wales, pressure relief valve manufacturers, silo manufacturers, tanker manufacturers and suppliers of silo fittings have been consulted.

49 The authors are grateful for the supply of photographs to illustrate the document.

APPENDIX A: INFORMATION REQUIRED

50 The safe operation of a silo and the associated powder delivery system will only be achieved if the processes involved are understood and adequately assessed. In order to undertake such an assessment (as identified in Section 6) the following information is needed:

51 ***Flow rate of air into a silo during the conveyance process.*** The rate of air flow into the silo during steady-state delivery of powder must be known so that the correctly sized filters can be selected. The rate of air flow can be determined from the capacity of the blowers used.

52 ***Rate of delivery of powder to the silo.*** In order to determine the rate at which available space within the silo will be filled during delivery, it is necessary to know the rate of delivery of powder. Typical loads of about 26 tonnes can be discharged into a silo in about 20 minutes, but can take as little as 12 minutes. Thus the delivery rate may be as high as about 2 tonnes per minute. In the case of cement, with a density of 1400 kg/m^3, approximately 1.4 m^3 of material is delivered per minute. However, before the powder has completely settled in the silo, the volume occupied will be greater than this.

53 ***Filter selection.*** The filter material and size should be selected such that the volume of air passing through the silo during steady-state delivery can be filtered at an adequate rate and without a significant pressure drop (e.g. < 0.34 kPa (0.05 p.s.i.)) across the filter. The characteristics of the specific filters used should be obtained from the filter manufacturer.

54 ***Forces acting on silo.*** In order to assess the maximum allowable operating pressure of the silo, it may be necessary to know the forces acting on the walls/lid of the silo as a result of internal pressure. This can be calculated from the equation: "Force on wall (N) = Pressure in silo (N/m^2 (or Pa)) *x* area of contact (m^2)". The forces may be very large and require significant strength in the components holding the lid in place. In addition, similar forces also act on the inside walls of the silo and the filter stacks fitted to the silo.

55 ***Maximum flow of air into a silo.*** The pressure within a silo will increase if air is allowed to enter the vessel at a rate faster than it can vent to atmosphere. This may occur due to one or more of the following:

- If the filter is blocked,
- If the pressure relief device is blocked or seized, or
- If the rate at which air entering the silo is greater than the venting capacity of the PRV fitted.

56 The maximum flow of air into a silo is most likely to occur at the end of the delivery process. At this point, the tanker may be pressurised up to 200 kPa (29 p.s.i., 2 bar), there may be little or no powder in the delivery line and no powder in the tanker. If the tanker discharge line is opened (or is left open at the end of the delivery) the tanker at 200 kPa (29 p.s.i., 2 bar) will then be connected directly to the silo, with little resistance to the flow of air. The tanker contents (i.e. air) will therefore flow very rapidly, through the silo, to atmosphere. The rates of air flow that may be produced are much greater than are experienced during the steady discharge of powder from the tanker during the delivery process.

57 The maximum rates of flow can be calculated using methods based on compressible flow of air from a pressurised reservoir (*i.e*. the tanker), through a pipe, to atmosphere (*i.e*. the vented silo). The maximum discharge rate depends on several factors:

- The pressure in the tanker;
- The length of the delivery pipe (assumed to be 100 mm (4") diameter) from the tanker to the silo;
- The number of 90° bends, *N*, in the discharge pipe; and
- The roughness (*f*)of the delivery pipe.

58 Figure A1 shows the calculated maximum discharge rates that may be achieved for a range of configurations of silo and tanker. Each line represents a specific configuration having up to three 90° bends (i.e. N = 0, 1, 2, or 3) in the delivery pipe and tanker pressures of 100 or 200 kPa (1 or 2 barg, respectively); the maximum flow is read off the line at the point corresponding to the length (m) of the delivery line. In each case, the co-efficient of friction, f, is assumed to be 0.0025. The maximum discharge rates for other configurations may be derived by extrapolating the data shown.

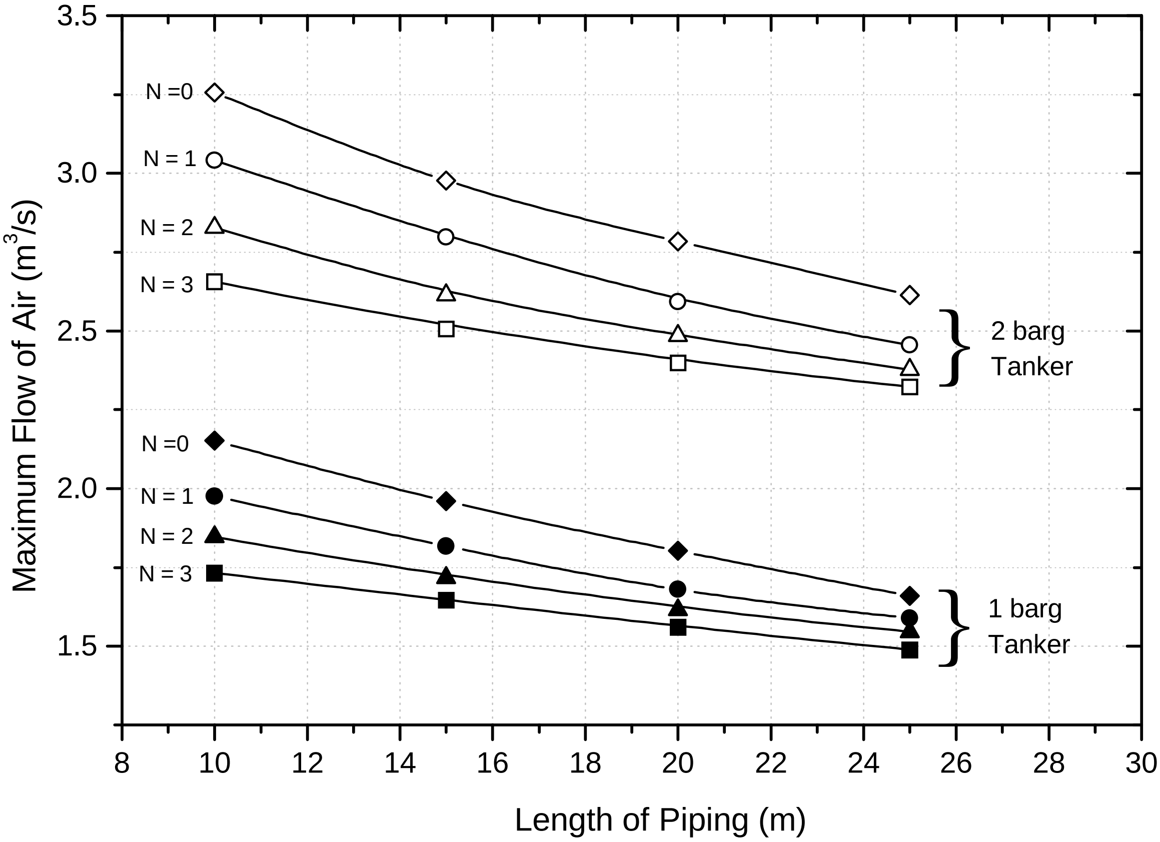

Figure A1. Plot of maximum discharge rates against length of piping (diam. = 4" (100 mm)) for tanker pressures of 1 and 2 barg, and for pipes containing up to three 90° bends (N = 0, 1, 2, or 3).

59 The pressure in the tanker will decrease as air is released through the silo. This in turn will lead to a decrease in the discharge rate of air from the tanker. However, it can be seen from Figure A1, that in the case of a tanker at 200 kPa (29 p.s.i., 2 barg), with a relatively short, straight delivery pipe, the rate of air flow will be in well excess of 2.0 m^3 s^{-1} until the pressure in the tanker drops to significantly below 100 kPa (14.5 p.s.i., 1 bar). This may take several (>10) seconds. If at any stage this flow rate is greater than the venting capacity of the PRV the pressure in the silo will increase.

60 ***Pressure relief valves.*** Pressure relief devices generally open at a pre-set pressure, at which point they will vent air from the silo. The rate at which air may be vented increases with an increase in the pressure within the silo, because higher pressures increase the height to which the lid is lifted and thus increase the venting area. Therefore, in order to vent air from the silo at a greater rate, it is necessary for the pressure in the silo to increase.

61 To prevent the pressure inside the silo from exceeding the maximum working pressure of the vessel, the PRV must:

- Open at a pre-determined pressure in order to release excess air from the silo; and
- Vent air at a rate greater than or equal to the rate at which air is entering the silo, at a pressure which does not exceed the maximum operating pressure of the silo.

62 For each silo and PRV configuration, it is necessary to determine:

- The maximum rate of air that may be delivered to the silo (see Figure A1);
- The pressure that is required to allow the PRV to vent air at this rate; and
- The maximum operating pressure of the silo.

63 Thus, for a specific PRV, if the pressure required to open the PRV sufficiently to vent air at the rate it is entering the silo is greater than the maximum operating pressure of the silo, that PRV is unsuitable. It will be necessary to use a different PRV (which requires a lower pressure to provide the required venting rate) or to use more than one PRV, thereby increasing the venting capacity at a given pressure (see Appendix B – Example calculation).

64 ***Rate of transfer of material.* –** Ideally, silo operators and tanker drivers need to know the minimum pressure that is required to deliver powder to a specific silo, and conversely, what flow rates can be achieved for a given operating pressure in the tanker. However, this cannot be derived from simple calculations or tabulations, because the behaviour of pneumatically conveyed powder is not simple and depends on many factors, such as height of the silo, length of the delivery pipe, the number of bends in the delivery line, the roughness of the delivery pipe, etc.

65 In order to provide some guidance, a large number of silo operators were asked to provide information relating to the rates of material transfer that are actually achieved during delivery to their silos. The following table contains information, relating to the delivery of cement, recorded at a selection of silos. The table shows the delivery rates achieved, for different tanker pressures and for different silo configurations (height, length of pipework, etc.). This information may be used as a *rough guide* to the flow rates that may be expected for similar configurations.

WARNING: ***If operators find that, for a similar silo configuration, they are having to use much higher pressures to achieve a specific flow rate, or they are achieving much lower delivery rates for a similar pressure, this may be an indication of problems with their system. This should be investigated.***

Table A1. Measured delivery rates.

Pressure (bar)	Flow (tonne/min)	Height (m)	Total length of piping (including height) (m)
0.75	0.97	11.0	23.5
1.00	0.44	20.0	38.0
1.00	0.87	10.0	23.0
1.00	0.90	9.1	19.7
1.00	1.00	7.0	19.0
1.10	0.90	11.0	24.6
1.20	0.88	7.5	43.8
1.25	0.70	30.0	40.0
1.40	0.92	20.0	38.0
1.50	0.84	15.0	37.5
1.50	0.70	20.0	38.0
1.50	0.87	15.0	31.0

APPENDIX B: EXAMPLE CALCULATION

66 The following section gives a worked example to assess the suitability of a specific Pressure Relief Valve (PRV) for use on a silo installation. The example outlines the information that is required and shows the stages of the assessment to be undertaken in order to determine if the PRV is suitable. The silo configuration chosen is taken to be representative of a typical installation; it is chosen to be similar to the arrangement shown in Figure 3 of the main guidance.

67 This example assumes the worst situation, i.e. the filter is blinded and there is very little ullage space in the silo.

Step1: Information required

68 In order to assess the suitability of a PRV for use on a given silo, it is necessary to know the following information about the installation.

Details required	*Specification of example silo*	
Height of silo:	15 m	
Length of flexible delivery pipe from tanker to silo:	10 m	
Total length of delivery pipe:	25 m (10 m + 15 m)	
No. of 90° bends in delivery pipe:	2	
Operating pressure of tanker:	200 kPa	(29 p.s.i., 2 bar)
Maximum operating pressure of silo:	10.3 kPa	(1.5 p.s.i., 0.1 bar)
Opening pressure of PRV:	5.17 kPa	(0.75 p.s.i., 0.05 bar)

69 It is also necessary to have the characteristic operating details of the proposed PRV to be fitted to the silo. These should be provided by the manufacturer and may be similar to the sample data shown in Table B1 and Figure B1.

Test pressure (p.s.i.)	Flow rate ($m^3 s^{-1}$)
< 0.75	0.0
1	0.85
1.5	1.40
2	1.70
3	2.00
4	2.25
5	2.50

Table B1. Details of PRV (as supplied by manufacturer)

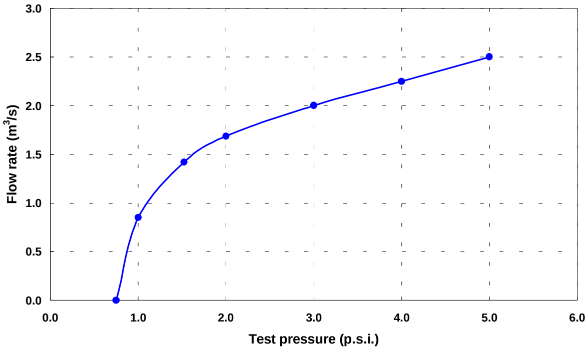

Figure B1. Plot of PRV operating characteristics (based on information from manufacturer).

Step 2: Calculate maximum flow of air to silo

70 The maximum flow of air to the silo is determined using the information displayed in Figure A1. The flow rate is derived by reading from the graph at the point corresponding to the conditions of the silo. In the example given, the length of the delivery pipe is 25 m, the tanker operating pressure is 200 kPa (29 p.s.i., 2 bar) and there are two 90° bends (i.e. N = 2) in the delivery system. The flow rate read from the graph for these conditions is ~2.4 $m^3 s^{-1}$. Hence the maximum flow rate of air into the silo is 2.4 $m^3 s^{-1}$.

Step 3: Determine maximum allowable silo pressure

71 The maximum allowable internal silo pressure has to be determined either from the silo manufacturer or from an independent assessment of the silo. If the silo has been modified since it was installed, if the strength of any component is likely to have reduced due to wear or if there is any doubt to the maximum allowable internal silo pressure, an independent assessment should be undertaken by a suitably qualified and experienced engineer. In the example given, the maximum permissible pressure has been given as 10.3 kPa (1.5 p.s.i., 0.1 bar). Hence, the pressure in the silo must not be allowed to exceed 10.3 kPa (1.5 p.s.i., 0.1 bar).

Step 4: Characterise flow properties of the PRV

72 The venting capacity of the PRV must be known before it is possible to determine whether it is suitable for the silo. The characteristic flow properties of the PRV must either be obtained from the manufacturer or obtained experimentally. Table B1 shows data as they may be supplied by the manufacturer. The same data are shown graphically in Figure B1. Typically, values of flow rate of air through the PRV at different pressures are given.

Step 5: Determine if PRV is suitable

Criterion: Can the PRV vent air, at a rate greater than the maximum rate of air flow into the silo, at a pressure which is below the maximum operating pressure of the silo?

73 The data supplied by the manufacturer of the PRV, as listed in Table B1 and shown graphically in Figure B1, show that the venting capacity of the PRV at 10.3 kPa (1.5 p.s.i., 0.1 bar) is only 1.40 $m^3 s^{-1}$. This means that the PRV selected is not capable of venting the required flow of air (i.e. 2.4 $m^3 s^{-1}$) at pressures below the maximum silo operating pressure (10.3 kPa (1.5 p.s.i., 0.1 bar)) and should not be used. Figure B1 shows that the pressure in the silo would have to be > ~33.1 kPa (4.8 p.s.i., 0.3 bar) before the PRV could vent air at the rate at which it is entering the silo. This pressure is far in excess of the maximum permissible pressure and is likely to result in failure of the equipment.

74 If two of the PRVs are fitted to the silo, the venting capacity at a given pressure is double that for a single PRV. Hence, at 10.3 kPa (1.5 p.s.i., 0.1 bar), there would be two PRVs, each capable of venting up to 1.40 $m^3 s^{-1}$. The combined venting capacity is therefore 2.8 $m^3 s^{-1}$, which is greater than the rate at which air may enter the silo (namely 2.4 $m^3 s^{-1}$). In this case, two PRVs would provide sufficient venting capacity for the silo.

75 With two PRVs fitted, each would be required to vent 1.2 $m^3 s^{-1}$ (i.e. half of 2.4 $m^3 s^{-1}$). Figure B1 shows that the pressure required to achieve this rate of venting is 8.6 kPa (1.25 p.s.i., 0.08 bar). Therefore with two PRVs fitted, the pressure in the silo should be maintained below 8.6 kPa (1.25 p.s.i., 0.08 bar), which is below the maximum allowable pressure.

76 Notes:

1. Identifying a single PRV which has venting capacities suitable for the silo will provide an alternative solution. In this case, a venting capacity of 2.4 $m^3 s^{-1}$ at a pressure of less than 10.3 kPa (1.5 p.s.i., 0.1 bar) is required.
2. Reduced tanker operating pressures will reduce the maximum volumetric flow rates (see Figure A1) and may provide an alternative solution.
3. The PRV must be properly maintained in accordance with the manufacturer's instructions to ensure the operating characteristics are maintained.
4. In order to do this calculation and demonstrate that the PRV fitted to the silo is adequate, it is necessary to know the characteristics of the valve.

WARNING . ***The data given in this example are theoretical and do not necessarily represent those of a typical silo or PRV. The results must not be used as a general solution. The characteristics of PRVs vary considerably. However, the methodology used is suitable for assessment of silo installations and PRV selection.***

APPENDIX C: HAZARD CHECKLIST

77 *The aim of this table is to assist the silo operator (and if necessary the tanker operator) to assess whether an installation is operated and maintained to the best standards, based on the recommendations in the main document.*

In the table below, the following definitions are adopted:

Silo operator:	Person(s) responsible for silo maintenance and delivery procedures.
Tanker driver:	Driver/operator controlling tanker discharge
Delivery company:	Person or organisation responsible for the delivery of the powder.

ISSUE		***SOLUTION*** ***If the answer is not "yes", take the following action:***	***Section Ref.***
Control of activity			
Are there site procedures, which are in accordance with Process Guidance note IRP3/1 (Ref 3), in place, describing the operations of the tanker from arrival to departure?	❑	Produce a set of operating procedures, which are agreed between the silo operator and delivery company, detailing the delivery process and the actions to be carried out by the tanker driver and silo operator.	7.7/7.8
Are there copies of the site procedures available for the tanker driver?	❑	Issue site procedures to the tanker driver and delivery company and display procedures on site.	7.8
Does the tanker driver follow site procedures?	❑	Monitor the delivery process and ensure operating procedures are followed. If procedures are not followed, ensure there are systems in place to: Check the tanker driver is aware of the procedures; and Take action to ensure the procedures are enforced.	
Is the tanker driver fully trained and have documentary evidence?	❑	The silo operator shall be satisfied that the delivery company has a training and assessment procedure for tanker drivers. On completion of suitable training, the tanker driver should be issued with Photo- I.D. to indicate that they have been assessed. Systems should be in place to: Verify driver has valid photo I.D; and Re-assess drivers at suitable intervals.	7.8
Has the tanker been tested in accordance with PSS Regulations?	❑	Ensure the delivery company has suitable evidence.	5/7.8
Are suitable maintenance and checking procedures for the silo and associated equipment in place?	❑	Prepare a maintenance schedule for the equipment and arrange for maintenance to be undertaken accordingly. Maintain a record of actions/checks undertaken	5/7.8
Delivery procedure.			
If there is a local limit on the agreed operating pressure of the delivery tanker, is the maximum allowable operating pressure clearly displayed?	❑	Display the maximum tanker operating pressure close to the delivery point. Ensure the tanker operator takes action to limit the pressure of the tanker to the maximum specified delivery pressure.	App.A/ 7.1
Is the transfer rate of material clearly displayed?	❑	Display the transfer rate close to the delivery point. Ensure the tanker driver is aware of the specified rate.	7.3/7.7

ISSUE	***SOLUTION*** ***If the answer is not "yes", take the following action:***	***Section Ref.***
Is the operating pressure of the tanker the minimum required for adequate delivery? ❑	Reduce operating pressure to a level at which adequate delivery rate is achieved.	7.3 App. A
Is pressure required to deliver powder to the silo greater than expected? ❑	If the tanker driver is using excessive pressure in the tanker to achieve reasonable delivery ensure there are systems in place to: Remove obstruction in the delivery line; Check the filters are clean and operating correctly; and Investigate if delivery can be achieved at a lower pressure.	7.5
Personnel Training		
Is the silo operator fully trained? ❑	Ensure in-house training procedures cover the silo operator and silo operations. (Check documentary evidence of training)	7.8
Is site-specific information suitably displayed? ❑	Display operating procedures that are site-specific and which may differ from general procedures.	7.7
Pressure Relief valves (PRV)		
Is the PRV correctly sized to handle maximum flow of released air? (Is there documentary evidence?) ❑	Undertake suitable assessment of the delivery system and silo equipment to determine the maximum flow of air into the silo and the maximum operating pressure of the silo. Select a PRV that operates within the conditions identified. Document the assessment.	7.5 App. A App. B
Is the PRV regularly maintained? ❑	Produce and follow a maintenance schedule for the PRV system	5/7.8
Is there a record of PRV maintenance? ❑	Maintain a log of PRV maintenance as part of the operating procedure.	5/7.7
Is the PRV checked in accordance with Ref. 3? ❑	Ensure there is a system in place to check the operation of the PRV in accordance with regulations.	5 7.7/7.8
Ullage Space/ High level sensor		
Are high level/ pressure sensors fitted? ❑	Fit suitable high level/pressure alarms to the silo	3.2
Does the sensor operate correctly and is it regularly maintained? ❑	If possible, use systems which have test facilities which indicate any failure of the sensor system. Maintain a log of maintenance and checks of correct operation as part of the operating procedure. Ensure the maintenance procedure includes testing the operation of the sensors.	5
Does the high level warning give the tanker driver sufficient time to shut down the delivery before the silo is over- full? ❑	Ensure the high level alarm is located at a height and position within the silo to give adequate warning. Ensure the length of warning given is sufficient for the tanker operator to respond and to stop a delivery.	7.1

ISSUE		SOLUTION If the answer is not "yes", take the following action:	Section Ref.
Alarms/warning lamps			
Are warning indicators clearly audible and visible?	❑	Alarm should be located sufficiently close to the delivery point and be audible and visible to the driver.	
Are the warning indicators clearly labelled?	❑	All warning lamps and sirens should be labelled to indicate the alarm condition they are displaying. (e.g. high level, high pressure)	
Are alarms regularly checked?	❑	Maintain a log of maintenance and checks as part of the operating procedure.	5
Filters			
Is the filter sized correctly for the flow of air through the silo?	❑	Use the manufacturer's information to determine the size of filter required to filter the flow of air passing through the silo during steady state delivery of material.	7.2 App. A
Is the filter regularly maintained and replaced?	❑	Maintain and check any automatic cleaning system, such as reverse jet cleaning. Maintain a log of maintenance, operation and checks of manually operated cleaning systems as part of the operating procedure.	3.1
Silo Structure			
Is the maximum operating pressure of the silo known?	❑	Assess the strength of the silo and any fittings onto the body of the silo. The maximum operating strength of the silo may be obtained from the silo manufacturer or assessed independently by qualified engineers.	7.1
Is the maximum operating pressure of every silo fitting known?	❑	Special note should be taken of fittings (e.g. filter system housings.), which may be significantly weaker than the silo itself.	7.1/7.2
Material			
Is the product in the silo compatible with material used?	❑	Ensure material used for pipes, hoses, silo vessels and seals is compatible with the material being stored/transferred and is not overly-susceptible to corrosion/wear.	
Is the temperature of the product compatible with the silo/delivery equipment?	❑	Ensure materials used in the delivery system are compatible with the temperature of the material being delivered. Take particular note of hot materials (e.g. PFA) which may not be compatible with some seal and filter materials)	
Tankers			
Is there sufficient clearance space above the tanker?	❑	Ensure there is suitable clearance above the tanker to allow clear passage. If there is limited space ensure the tanker position is clearly marked. Particular care is required with tipping tankers, for example clearance from overhead power lines.	

ISSUE	***SOLUTION*** ***If the answer is not "yes", take the following action:***	***Section Ref.***
Is the ground flat and level. ❑	Prepare suitable flat, level platform for the tanker during the delivery process. Mark the area clearly and maintain the area in clean condition.	
Time of delivery Are any deliveries made when site personnel may not be present? ❑	Procedures should be in place to cover deliveries made outside normal operating hours. These should include: • Points of contact (if any) for tanker driver; • Procedures for ensuring delivery to correct silo; • Safety procedures; and • Lone working.	7.7/7.8
Temporary Sites Have the above assessments been addressed? ❑ Are site-specific procedures in place to cover operation? ❑	Follow the above assessments, which apply to all silo installations Display operating procedures which are specific to the temporary site and which address any issues which may differ from permanent sites, such as location of site operators office, etc.	

WARNING: This table only includes the main areas associated with the delivery of powders to silos, and is therefore not exhaustive. There are other aspects which should be included in a full assessment (e.g. Transport, routing around site, personal protective equipment, etc.).

APPENDIX D: DRIVER TRAINING

78 The following table is an example of a syllabus used for the training of drivers.

Process	Required Key H&S Training Skills
Introduction.	• General Duty of Care of Employer to Employee, and Employee to himself and others. [S2,3,7&8 HASWA 74]. • Hierarchy of compliance [Strictest of two instructions applies if they differ]. • Use of Personal Protective Equipment
Maintenance & Inspection.	• Safe access onto the top of tanks. • Routine inspection of vehicle etc. • Examinations under the Pressure Systems Regulations, normally by insurance company of tank, PRV, etc. • Entry into confined spaces and necessary precautions.
Travel to bulk cement loading point.	• Safe driving techniques. • Site induction, including site safety rules. • Use of high visibility clothing.
Loading bulk cement.	• Safe access onto top for loading & maintenance. • Product information and precautions:- Knowledge of product Data Sheets. Including: - OPC very caustic when hydrated because of the presence of hexavalent chrome. An irritant, harmful to eyes, causes dermatitis. Need to wear and use PPE including eye & skin protection including gloves. [Goggles required for pneumatic discharge]. - OES opc dust = $10 mg/m^3$ [8hr] Total inhaleable dust. RPE. Protection factors.
Arrival at customer's site	• Site induction, including safety rules to be followed on site and the location and operation of loading points.
Discharge bulk cement	• Principles of pressure discharge and associated plant. This is to include all aspects from the tanker to the silo, including safety functions, (i.e. pressure relief valves, filters, high level alarms, automatic shut-off and flow control valves). • Silos are not pressure vessels. • Consequences of silo over-pressurisation. • Types of tanks including tipping tanks and body characteristics, their valves, pipes, couplings, sealing lids. The Dangers of tipping tanks over-turning and the precautions to take. • Noise levels:- Noise induced hearing loss etc. – wear ear protection. • Hazard of OPC and precautions to follow – as defined above.
Loading procedures including what to do if overloaded.	• Routine inspection, e.g. flexible pipes and couplings, pressure relief valves, etc. • Every driver is to be provided with written procedures for safe discharge. • What to do if dust is discharged to atmosphere, i.e. reporting procedure on return to base. • Stop loading if high level /pressure alarm on silo sounds. • Emergency shut-down procedures:- Shut down compressor, close valves, de-pressurise, and report faults and any damage.

APPENDIX E: SILO INCIDENTS

79 Below are examples of incidents similar to those which this document aims to prevent.

80 ***Incident:*** A road tanker was blowing cement under pressure into a 25 tonne silo at a concrete batching plant. The bag filter unit on top of the silo became blocked because of overfilling. Air pressure in the silo built up and the relief device failed to operate. The bolts holding the filter unit in place pulled through the metal retaining flange causing the filter unit, which weighed ¼ tonne, to be blown upwards. It cleared the handrails around the top of the silo and fell to the ground below.

81 ***Outcome:*** The movement of the pressure relief device was greatly restricted. The company was prosecuted as a result of this incident.

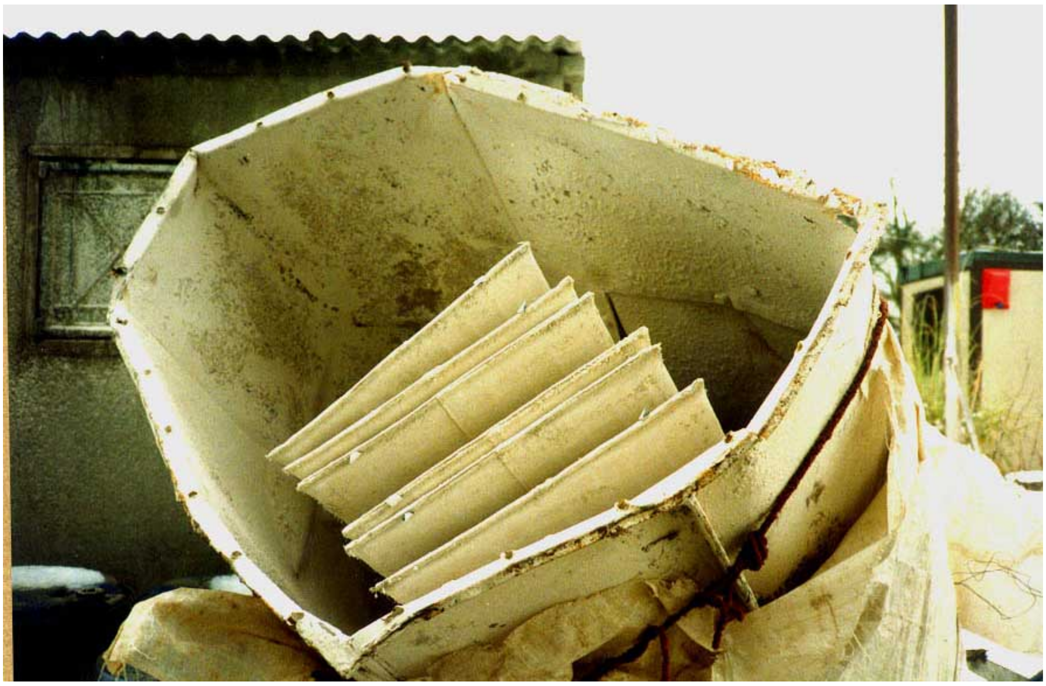

Figure E1. Filter housing which has been ejected from the top of a silo. The bolts holding the housing in place have been torn through the metal flange.

82 ***Incident:*** One compartment of a two-compartment cement silo split along a weld. The silo roof was so heavily encrusted with cement that the access doors to the filter compartment had become obstructed.

83 ***Outcome:*** The filters were blocked and clearly had not been cleaned for some considerable time. The silo was not fitted with a pressure relief device.

84 ***Incident:*** Due to a misunderstanding between a cement tanker driver and a plant operator, cement was delivered into a silo which had been filled the previous day. The high level alarm on the full silo had been muted when it activated during the delivery on the previous day. In normal circumstances, once the cement level fell below the level of the detector, the high level alarm automatically reset. However, because the cement still covered the detector, this had not happened. During the second delivery, a loud explosion occurred and the filter unit was ejected from the silo roof.

85 ***Outcome:*** The air filter was not operating correctly due, firstly, to a considerable build up of cement within the filter body and, secondly, to it being incorrectly reassembled after maintenance. Over a period of time, cement powder had built up in the pressure relief device and hardened causing it to seize up.

Figure E2. Poorly maintained PRVs. The build up of cement powder around the PRV indicates a lack of maintenance and incorrect operation. The PRV should only lift in an emergency, whereas the one pictured above appears to have been routinely lifting during delivery, resulting in the observed accumulation of powder.

86 ***Incident:*** A 24 tonne cement tanker operating at 200 kPa (29 p.s.i., 2 bar) discharged 10 tonnes of cement into a 15 tonne silo. Just as the high level alarm went off, the last of the cement was discharged from the tanker. Whilst the driver was in the process of closing the cement delivery valve the retaining clip between the filter body and the location upstand failed. As a result, the filter body was blown off the top of the silo, landing on the ground below.

87 ***Outcome:*** Although the pressure relief device operated, it seems likely that it was not sufficiently large and was overwhelmed by the volume of air involved.

APPENDIX F: CONTACT DETAILS

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