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Design of Storage Silo Systems

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Die Auslegung von Silo-Speichersystemen
Conception des systèmes d'entreposage en silo
Diseño de sistemas de silo de almacenamiento
貯蔵用サイロシステムの設計
贮仓系统的设计
تصمم أنظمة صوامع التخزين . بقلم جيه . اف . دراي

Summary

Practical design and operational considerations are presented relating to the three main aspects of adopting a bulk powder storage and handling scheme, namely:

- The transport of the powder from the supplier to the customer
- Acceptance of the material and its storage
- The transfer of the stored material to the process.

This paper describes the basic principles and highlights the important features which should be borne in mind when considering the installation of a bulk handling scheme.

PART I: Practical Considerations

1. Introduction

There are many excellent publications expounding the theories of powder technology, but the main concern of the user of bulk powders is the proper integration of the various pieces of equipment used to comprise a complete scheme.

It is most desirable that, when approaching a supplier of equipment for a given project, all the relevant facts be made known. In this way, advantage may be taken of the supplier's previous experience to avoid the many pitfalls and to ensure that the plant is of suitable capacity for the duty required, having provision for future expansion plans.

Broadly speaking a scheme can be divided into three sections:

1. The transport of the powder from supplier to consumer.
2. The acceptance of the material and storage.
3. The transfer of material from storage to process.

In the following sections the basic principles and important features which should be borne in mind when considering the installation of a bulk handling scheme are highlighted.

2. Material Transport from Supplier to Consumer

It is often the case that the consumer does not pay much attention to the method used to deliver the material to his storage silo, other than the fact that he will make a decision to accept loose bulk or pressurised bulk from road or rail vehicle.

However, it is wise to bear in mind one or two basic points about the various methods of transport, otherwise, ignorance of these facts can often lead to incorrect decisions being made and then experiencing subsequent difficulties with the operation of the plant (Fig. 1).

2.1 Loose Bulk

Powders may be delivered in loose bulk by an open tipper lorry or rail hopper wagon. In fact, in certain areas this is a common method used.

The main difficulty with loose bulk delivery is that, when the vehicle arrives at the consumer's premises, the material has to be tipped into an open pit from where it may be transferred by pneumatic or mechanical means into the storage silo. This is often a messy and dusty business and is rather prone to the ingress of moisture and/or foreign bodies.

It also means that the consumer must install a suitable hopper and conveying equipment on his premises which is only used each time a delivery is made. This is normally considered an uneconomic proposition.

However, some consumers feel that since they themselves are using tipper vehicles to deliver their own product in the general direction of the supplier of their raw material that, rather than the vehicles returning unladen, they should bring back a load of the powder, thereby making greater use of the vehicle fleet.

This is false economy since, not only has additional equipment to be installed and maintained at the consumer's premises, it also means that there is a great danger that the product being delivered on the outward journey will contaminate the material being brought back on the return journey. This then often leads to difficulties with the conveying system used to transfer the powder to the silo.

A good example of this situation is where a quarry owner decides to build a ready mixed concrete plant at his quarry site. He will have many vehicles delivering granite or sand to his customers in the surrounding area and normally returning empty.

He may feel that he could save some money on his cement deliveries by not adopting pressurised delivery but using his own open tipper lorries to bring the cement to his ready mix plant on a return journey. The cement is then probably tipped into a hopper at ground level and the cement discharged

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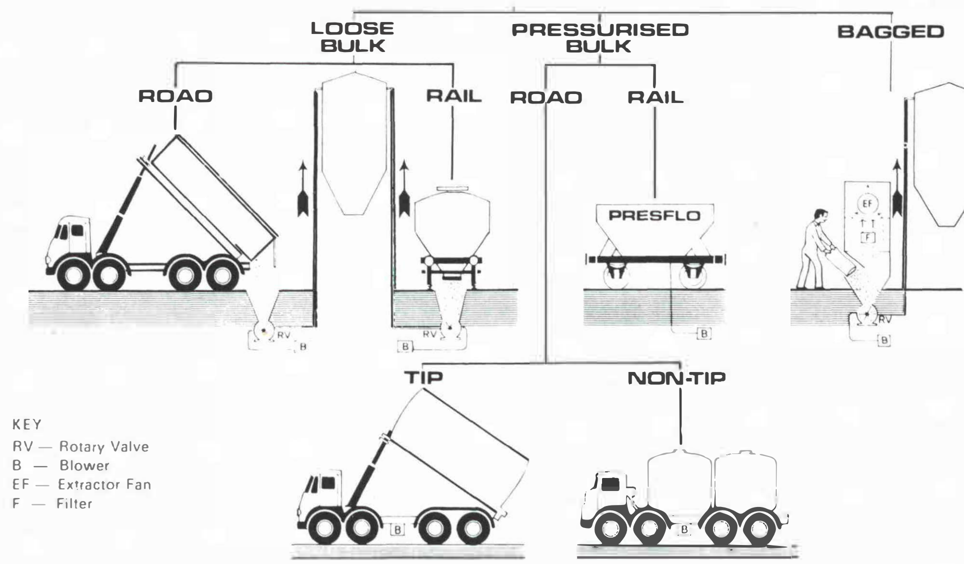


Fig. 1: Transport of material from supplier to consumer

from this hopper by rotary feeder into an airline and blown to the silo at the top of his ready mix plant.

The probability is that the vehicle driver will not completely clear the vehicle of all the granite and he certainly will not go to much trouble to ensure it is perfectly dry before filling with cement. The net result is that pieces of granite, with cement caked around, will be poured into the hopper together with a few lumps of hard cement which have formed with the moisture left on the inside of the vehicle. These will find their way into the rotary feeder, damaging the blades and jamming the whole system.

This does not have to happen more than once or twice before all the savings that the consumer had in mind have been lost on repairs and maintenance to the transfer equipment.

2.2 Pressurised Bulk

The preferred method of transporting powders is definitely by pressurised tanker vehicle, either on road or rail, since no contamination can take place until the material has left the storage silo.

Both road and rail tankers are usually filled by gravity at the supply point via a manhole in the top of the tank, and in the case of road vehicles, then driven direct to a point as close as possible to the customer's silo.

The vehicle driver will then connect the tanker outlet and the silo inlet pipe by a flexible hose. The tanker will carry its own compressor and therefore, without any assistance from the consumer, the material can be transferred from the tanker direct into the silo.

In the case of rail vehicles, they do not usually carry their own compressor equipment and therefore would require a static compressor at the consumer's receiving point to provide the necessary air to transfer the material from the rail tank into the silo.

Some road tankers are provided with facilities so that they may transfer material from a rail tanker into the vehicle tank using its own compressor. In this case a filter must be provided to vent the air from the road tank as the material is blown in.

A further method used is to employ a demountable tank carried on flat trucks.

The advantage of this method is that a rail vehicle, carrying from one to four of these tanks, can be gravity filled at the supply point in the usual way then delivered to the nearest rail head. At this point the tank full of powder is lifted by crane onto a flat road vehicle to complete the journey to the consumer's premises. At this point a static blower provides the air to transfer the powder from this tank into the silo. The tank is then returned to the rail wagon in exchange for another full tank.

The sort of circumstance where this method is employed is where a dam or some other large civil engineering project is being constructed in an out of the way area.

Delivery of cement from the nearest factory may present considerable problems if it were done by road, whereas the nearest railway may not be close enough to the site to fill the silo direct.

The problem is solved by bringing the material by rail as close as possible and then using short haul vehicles to complete the journey.

2.3 Types of Road Tankers

Road tankers usually fall into two basic types.

There is the horizontally mounted tank which discharges via rotary feeder, or venturi pick-up in the blowing line. This type is fitted with tipping gear so that, as the tank becomes empty, it is gradually tipped to ensure complete discharge. This may present a problem at the receiving point since, with the larger tanks, considerable headroom is required to accommodate the fully tipped vessel.

The other basic method used, is to mount vertical tanks on the chassis. The tanks are fitted with fully fluidised floors so that no tipping of the vessel is necessary. This type generally gives a higher discharge rate and has the advantage that, with two tanks fitted on one chassis, dissimilar materials can be delivered in one journey.

Alternatively loads may be delivered to two separate consumers knowing the precise amount given to each.

It was previously the practice to fit to tankers blowers having a capacity of approximately 250 ft^3/min. However, it is becoming more and more common to use 500 ft^3/min compressors to overcome the difficulty of blowing into tall silos or those situated well away from the tanker access point.

This is very relevant to the powder consumer since the size of his silo filter will be dictated by the amount of air being used to fill the silo and the period taken to effect each delivery.

The size of the tanker being used is obviously of prime importance to the consumer since his silo must be of sufficient capacity to receive at least one complete vehicle load.

Vehicles fitted with one vertical type tank may carry as little as 200 ft^3 but the current designs of horizontally mounted tanks have reached capacities of 1,500 ft^3 and it is likely that they will continue to increase in size.

2.4 Bagged Material

If a material is not available in bulk it is often desirable to transfer the powder from bags to a silo.

The advantages are that the material can then be integrated into an automatic process, floor space can be saved and the problem of recirculating the bagged material is eliminated.

The method of transfer is similar to that used for loose bulk, but a small hopper is used and it is usually desirable to fit dust extraction equipment over the hopper to protect the operator.

It is important that the consumer should first of all decide which basic transport method he is to use and that if the material is to be delivered in pressurised bulk by the material suppliers, he should make himself aware of:

- The size of tanker to be employed.
- The type of tanker (whether it be tip or non-tip).
- The size of compressor fitted to the vehicle.

3. Material Acceptance and Storage

There are many factors affecting the selection of the type of equipment most suitable for the reception and storage of bulk powders.

It is impossible to list the features in any order of importance since the order of importance itself will vary considerably according to the type of material being handled and the circumstances in which it is to be used. The following notes are not to be considered as being in any particular order but merely comments on the factors affecting the correct selection of suitable equipment.

3.1 Size of Silo

An obvious factor that most be decided in all cases is that of selecting the most suitable size of silo for the project in mind.

The first point here is to determine the bulk density of the powder to be handled, since this varies enormously from powder to powder, ranging from something like 200 lbs/ft^3 right down to 5 or 6 lbs/ft^3.

It is therefore much better to refer to silo sizes in ft^3 capacity rather than tonnage. This avoids the possible confusion due to varying densities.

One of the main problems found in any storing system is stock control. One must know the usage of material for a day or week, the minimum storage which one can accept to cover for emergencies and the size of each delivery. From these three factors, the minimum silo size can be determined.

3.2 Pressure or Gravity Feed

Probably the next most important feature is to consider the type of silo to be used. There are two basic types of silo, one being the pressure delivery type and the other being the gravity feed type.

The pressure delivery type is more expensive than the gravity feed type since it is, in fact, a pressure vessel having to be made to the appropriate standards and incorporating dished ends, etc.

In order to use this type of silo it is also necessary to provide a compressor to effect the discharge from the silo, this also being a comparatively expensive piece of equipment.

The main use for this type of silo is as additional storage to a working silo, or as a transfer vessel to a further silo some distance away. A tanker can make a delivery into the silo and then it can be sealed off, pressurised and its contents blown quite quickly over reasonable distances.

It is not generally used when feeding direct into a process since the feed rate is not controlled and the rate of transfer is generally capable of more than that which is required.

A gravity feed type silo having a conical bottom or full air slide across the base of the silo is very versatile and can be used in many different ways.

3.3 Permanent, Temporary or Portable

Having made the decision to use conical gravity feed silos for working in conjunction with the rest of the process, it is then important to know whether it will be a permanent, temporary or portable installation. These three factors can greatly affect the economical design of the most suitable vessel.

It is generally accepted with a permanent industrial installation that it is going to be used for a number of years and therefore, at the outset, adequate facilities should be provided for changing requirements in the future.

Dust must be kept to an absolute minimum, access ladders with back guards and safety handrails on the roof of silos are most desirable for permanent structures.

To assist with stock control, probably more sophisticated contents indicator equipment is appropriate.

At the other end of the range, a portable silo must essentially be made as simple as possible to enable the silo to be effective on short-term jobs such as on building sites, etc., and so as soon as the project is finished it can be moved to a new location without difficulty and re-used again.

It is generally accepted for such portable applications that the safety features are reduced by not having back guards to access ladders and handrailing at roof level.

The filtration is usually kept as simple as possible since if the application is only short-term and probably outdoors a small amount of dust can be accepted whereas the complication of fitting electrically operated filter units will impede the portability.

The temporary silo falls in a category between truly portable silos and permanent silos and it is a matter of judgement, dependent on how temporary it is to be, as to what form the silo should take. This may be governed by certain other factors such as its size, the material to be handled and the purpose for which it is being used.

3.4 Material and Method of Construction

The material from which the silo is made is obviously a very important feature to consider. Generally speaking, silos are made in mild steel but in a number of cases this is not acceptable, since corrosion or contamination may result with the material to be stored (Fig. 2).

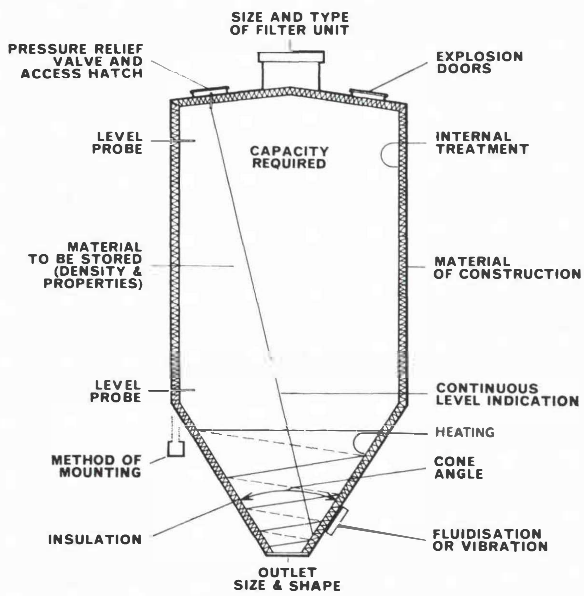


Fig. 2: Principal silo design parameters and considerations

If the silo is to be used for the food or chemical industry a satisfactory method is to manufacture the silo in mild steel and then to have the internal surfaces coated with an epoxy resin or plastic film which will ensure no contamination with the product and no corrosion of the steel.

The method of construction of the silo is dependent on most of the factors so far discussed such as the size, its location and the material to be handled, etc. Generally speaking the small silos, particularly the portable silos, are made in one piece. However it may be necessary, if the silo is to be installed in a restricted space in a building, to be sectionalised to gain access to the final position.

The larger silos may be of too great a diameter to deliver in one piece and therefore have to be erected on site. If the silo is to be a permanent one the preferred method is to site-weld all the preformed plates together. This will ensure that there are no leaks and will give a much more permanent structure although it is slightly more expensive than bolting. If, however, the silo is only temporary and, after a year or two, has to be transferred to a new site, it is obvious that the bolted method has to be used. This can cause some difficulties in sealing off all the joints and bolts but if care is taken a good watertight vessel will result.

3.5 Siting of the Silo

The starting point in deciding where to site the silo is obviously going to be the point where the material is to be introduced into the process.

The silo should be positioned reasonably close to the feed point but, on the other hand, must not be too far away from the point where the tanker can gain access for delivery purposes.

If the delivery line is too long or takes a tortuous route, the period taken to transfer the tanker load into the silo will increase, giving rise to complaints from the material supplier due to the long turnround period of his vehicle. It also gives rise to a filtration problem caused by the fact that the filter is in use for too long a period.

If the process feed point is fairly near to an outside wall of the building there is no problem. The silo can be sited either inside the building feeding direct, with the inlet pipe being brought outside the building. Alternatively, the silo can be sited outside the building and have feed equipment through the wall to process.

If, however, the process is well away from an access road and the silo is to be a large one such that it cannot be accommodated inside the building the user will be faced with using very long feeder equipment. This can be overcome in extreme cases by siting a smaller silo convenient to the process with the appropriate feed equipment fitted and then having pneumatic transfer equipment from the main silo sited convenient to the access point.

It is then a matter of keeping the small silo topped up from the large one whilst the former is being used for feeding the process.

3.6 Intake and Filtering

Most silos are currently fitted with a 4″ diameter inlet pipe terminating in a unicone belled end so that the tanker hose can be connected by use of an instantaneous clamp joint.

The run of the inlet pipe should be such that it has as few horizontal sections as possible and that all bends are of 3 to 4 ft radius. If the material to be handled is abrasive, such as sand, it may be necessary to reinforce the pipe at the bends.

The inlet pipe usually enters the silo tangentially so that the material cyclones round inside the silo separating from the conveying air which then passes out through the filter.

In the case of material consisting of particles of different sizes or weights where it is undesirable to allow separation to occur, it is usual to bring the inlet pipe above the silo and then turn it down vertically, through the roof.

To prevent the conveying air from carrying a lot of dust outside the silo an adequate filter must be fitted.

The preferred type is that where the filtering medium is formed into a number of envelopes which trap the dust. At the end of each delivery a mechanical device shakes the filter returning back into the silo all the filtered out material.

The size of filter and the material to be used for the element depends on the type of powder being handled and the amount of air being used for conveying.

A cotton medium is considered to be the most efficient but if there is any danger of moisture being present in the atmosphere it is probably better to use Polypropylene which does not absorb moisture but, on the other hand, has a reduced filter efficiency.

The speed of the air flow through the filter should not be allowed to exceed 5 ft/min but in the case of fine powders, such as hydrated lime, the speed should be reduced to half this.

This would mean therefore, that if a 500 ft^3/min compressor was being used to transfer lime into a silo, a filter area of some 250 ft^2 would be required.

It must be borne in mind that if material is being transferred for a long time continuously that the filter will gradually become choked.

This reduces its effective area and transfer must be stopped whilst the filter is cleaned. Many filters are fitted with electrical vibrator mechanisms which can quite readily be operated from a remote position.

There are more elaborate filters available for cases where it is not practical to cease the transfer of material into the silo. These filters are fitted with high pressure air cleaning jets which are capable of forcing the dust off the filter element whilst it is still being used.

On portable silos it is not practical to have a mechanically agitated filter and a stocking type filter is sometimes acceptable. This is simply a hollow sleeve, suspended from inside the silo near the roof, so that the dusty air travels down the inside, passing through the medium to atmosphere, leaving the dust collected in the sock. It is necessary after each blow to undo the bottom of the sock and collect the dust in a bag or bucket.

The inefficiency of this type of filter is accepted because of its much lower cost and the probability that it is being used on an external application where the dust is not considered too much of a hazard.

3.7 Ancillary Features

All silos that are to be pneumatically fed must be provided with a safety valve to relieve the internal pressure should this rise above that for which the silo is designed.

It is also obviously desirable to provide an access hatch to the inside of the silo.

These two features can very satisfactorily be combined by making the access hatch into a spring loaded pressure relief valve.

A common use for the access hatch is to see what level of material is in the silo.

However there are many devices available for measuring the contents, varying from simple diaphragm switches, indicating maximum and minimum levels, to much more sophisticated continuous indicators, fitted with recorders and automatic trips to warn the operator when the level is reaching one of the extremes.

Various fixed position level devices are available for temporary or permanent silos, working on the capacity probe principle, the hypersonic sound wave principle, or the use of motorised paddles which stall when they come in contact with the powder level.

The type of indicator that gives a continuous reading of the level of material usually consists of a steel wire rope running from the roof of the silo to a point low down the cone which acts as an electrode. The capacitance is then measured between this electrode and the shell of the silo and converted to a scaled reading on a dial. Contacts can be fitted on the dial to trip off an alarm when the selected limits of level are being reached.

If the contents of the silo are required to be known accurately, the whole silo can be mounted on load cells and the precise weight read off. This method can be quite expensive and where the silo is sited outdoors, problems are created by winds, but it is possible, by mounting the silo on three or four load cells to integrate the signals electronically, to compensate for wind loads.

3.8 Silo Cone Outlet

One very important point not yet covered, is that of the required cone angle and the method of ensuring proper flow through the outlet.

Various therories are offered which show how relationships between particle size, shear strength and coefficient of friction for given materials effect the required cone angle to achieve proper mass flow.

In practice, a particular material will vary considerably due to a number of factors, for example:

- The size of load delivered into the silo.
- The time that has elapsed since the last delivery.
- The rate of usage.
- The temperature.
- The humidity.

Since the cone angle cannot be made to vary to suit these conditions, the only answer is to make the cone angle suitable for the worst conditions.

This could mean providing a very long, slender cone and also a very large outlet which are often unacceptable due to physical limitations of space available and the type of equipment the silo is to feed.

Another very important point which has to be borne in mind when considering the design of silos, is that, wherever possible, a standard design must be used so that advantage can be taken of production runs thereby keeping the cost to an economic level.

Some means has to be found to make a standard cone suitable for as many materials as possible and to ensure that suitable flow would occur under the varying conditions experienced with a given material.

The answer to this problem is to inject a suitable amount of air at low pressure into the cone to fluidise the material.

The effect of this is to bring all materials to a similar type which will have very little shear strength due to the fluidisation and therefore will flow readily in a cone of a moderate angle of 60°—65°.

Unfortunately, not all materials are readily fluidised and therefore, in some cases, special cone angles must be used or alternatively mechanical bin dischargers employed.

Salt is an example of a material that does not readily fluidise when air is injected and it is necessary to use a cone angle that has been established as being satisfactory for this material.

It is also found necessary in this case to heat the cone so that the salt is kept quite dry and free flowing at all times. This is done by providing a double cone with insulation between the two layers which has an electrical heating element wound round inside, controlled from a multi-position regulating switch.

3.9 Insulation

Generally it is not necessary to provide any further protection against weather conditions since the silo body will be completely weatherproof.

However, there are exceptions and one notable example is that of flour. It is essential, in this case, to protect the material either by enclosing the silo in a building or providing insulation over the whole body.

If insulation is used it, in turn, must be protected from rain by additional cladding or, alternatively, have an impervious external surface.

3.10 Hazard

One final point to be borne in mind when selecting a silo is that of hazard. Will the powder give off toxic fumes or be liable to explode.

Pulverised coal stored in an enclosed silo is an example where special precautions are necessary. Explosion doors should be fitted in the roof and it may be desirable to inject nitrogen to keep the oxygen content low.

3.11 Conclusions

The following points are therefore the main ones to which consideration should be given before finally deciding on a silo for a particular project:

1. Is it to be permanent, temporary or portable?
2. What capacity should it be (selecting too small a silo often proves false economy)?
3. What is the material to be stored?
4. From what material should the silo be made and should it be lined?
5. What should be the cone angle, and is fluidisation required?
6. Is it suitably sited, having regard for the length of inlet pipe and the length of feeder to the process?
7. What size filter is required and what should be the filter medium?
8. What ancillary equipment is necessary?
9. Are there any special considerations such as fire or explosion hazards?

4. Material Transfer from Storage to Process

Having transferred the powder into bulk store, the problem now is to get the material from the silo into the process in the most advantageous manner. There are many pieces of equipment available ranging from simple hand operated values to highly sophisticated equipment which can be fully automated with the complete process (Fig. 3).

The following notes will not enable the design of an installation to be undertaken but may serve as a guide to the most appropriate approach to a particular scheme.

4.1 Outlet Valves

If the silo is to be used merely to load a vehicle or to dispense an approximate quantity of material it is only necessary to have a valve, either hand operated or pneumatically operated, fitted direct to the silo outlet.

There are many types of valves each one being suitable for a particular class of duty and it is recommended that advice be sought before specifying a particular type.

4.2 Weighers

Various types of weighers are available to the user and the correct selection is obviously governed by the application and the price that one is prepared to pay.

The conventional mechanical lever weigher is very satisfactory for most applications and can be of either the steelyard type or the dial type but in either case these can be arranged to have automatic trips incorporated to control the feeder equipment and can be remotely controlled for incorporation into a more comprehensive scheme.

Load cell weighers are basically of two types, the superior one being designed on the strain gauge principle, producing an electrical signal which is then used to give a dial indication. These can readily be incorporated into automated systems.

A similar type is a hydraulic capsule which is used to operate a Bourdon type pressure gauge calibrated in lbs. Although

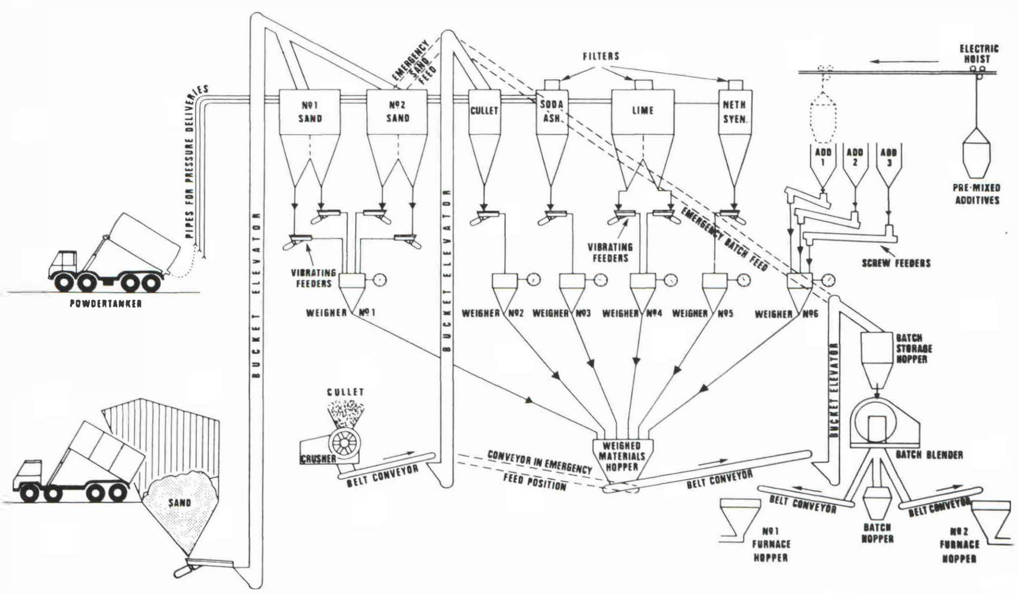


Fig. 3: Typical batch plant flow diagram (glass industry)

this type can be fitted with one or two electrical contacts it is somewhat limited in its application but is a lot cheaper than the strain gauge type.

Another type of weigher which can be used to good advantage is that which relies on air pressure for the load measurement. In this case the weigh hopper is suspended from a conventional lever system which is arranged to impart a load on a freely located cap covering a dashpot. Air at a pressure of about 60—70 psi is then injected into the pot and will escape by lifting up the cap. The pressure required to lift the cap is then measured in the pot and converted to an accurate dial reading.

The advantages of this system are that, since weight is now interpreted as air pressure, the connections between the weigh hopper and the remotely located dial consist purely of air pipes and this pressure can be used to operate diaphragm switches to initiate trips, as required, to control the process. This gives great flexibility and a high standard of automation without resorting to complicated electronic circuitry.

If the material is to be weighed in batches but the circumstances do not justify elaborate weighing systems, various simple mechanical weighers can be used.

The silo may be sited directly over the process and have a weigh hopper mounted on a knife edge lever system mounted directly under the cone. This type is usually arranged so that a valve is opened by hand, allowing the material to fall into the weigher, and when the predetermined weight is reached this valve is automatically tripped off.

An alternative to this is a load cell type weigher similarly mounted beneath the silo but having limited remote control facilities.

One basic problem with weighing direct from a silo is that, since the material is flowing purely by gravity, there is a possibility of fluctuations in the feed rate, particularly if true mass flow does not exist.

The danger is that, just at the crucial point of cut-off when the desired weight is reached, a sudden surge of flow may occur from the silo causing the machine to overweigh. The result is that, no matter how accurate the weighing device, errors may be caused.

The accuracy of a batch weigher is governed by three principle points:

— The accuracy of cut-off of the feeder.
— The basic accuracy of the weighing machine itself.
— The complete discharge of the batch from the weigh hopper.

Weigh hoppers may be discharged from a manually operated door, a pneumatically operated door or an electrically operated door.

In the manual case, it is usually left to the operator to ensure that all the material has been discharged, by agitating the hopper slightly before closing the door.

In the case of pneumatically or electrically operated discharge doors it is common practice to fit a small vibrator to the hopper, operated by a limit switch on the door, to ensure a complete discharge.

In an automatic system it is important that a trip be fitted which prevents the next batch being weighed off until the previous batch has been cleared from the hopper and also that feed cannot commence until the hopper door is properly closed.

One further point with regard to weigh hoppers is that it is most important to ensure that the hopper is properly vented to allow the displaced air to escape readily, so as not to impose false loads on the weigher. This displaced air should pass through a filter, otherwise a considerable dust nuisance will be caused.

If it is considered unsuitable to discharge a complete batch into the process in the few seconds normally taken to empty the hopper, it may be necessary to discharge first into a receiving hopper which has a rotary feeder fitted to spread the discharge over the desired period.

4.3 Feeders

Usually it is undesirable to mount the silo directly over the process and therefore some sort of feed will be required.

Screw conveyors and vibratory feeders are those most commonly used when handling powders and both types can be arranged to give either a constant rate of feed or to feed to a weigher, the weighing machine being used to control the feeder drive motor.

The problem of surges with gravity feed are removed by the introduction of a mechanical feeder, so long as the potential flow from the silo is greater than that demanded by the feeder.

If it is intended that the material shall be fed continuously at a predetermined rate into a process, it is usual to provide a variable speed drive so that the rate of feed can be adjusted to the required amount. The main drawback to this system is the possibility that, for some reason, flow may cease and the operator be unaware of this, thereby causing a fault in the process. A possible cause of this situation may be simply that the silo has been allowed to become empty.

On the other hand, if the conveyor or feeder is used to supply a weighing machine, interlocks can be provided so that the batch cannot be discharged until the predetermined weight has been reached. If a hold up then occurs it is immediately obvious since the batch has not weighed off.

With feeders controlled by weighers, it is a good feature to have a two-speed drive motor so that the bulk of the batch can be fed rapidly into the weigh hopper and then the drive tripped onto dribble feed to top up to the precise amount required.

Another common application for feeders is where the process demands a set rate of feed from a small holding hopper. A conveyor can then be installed between the outlet of the silo and this holding hopper whose feed rate is slightly in excess of the demand of the process. By fitting low and high level trips on the hopper, the conveyor can be arranged to start up when the material level reaches the bottom trip and switch off as it reaches the top trip.

A very important point to watch here is the number of times per minute the conveyor is going to be caused to start and stop. This will be governed by the size of hopper and the feed rate required.

A standard three phase motor is usually capable of some 20 starts per hour but a special rating can be obtained giving 60 starts per hour. However, if a greater rate than this is demanded it could involve considerable complication with the drive and transmission.

In the case of screw feeders, it is desirable, wherever possible, to keep the length of the conveyor down to that where the flight or auger can be supported from either end, so that the danger of the powder interfering with the bearings is greatly reduced.

However, if this cannot be avoided and a longer conveyor is required, the burden must be kept low. This can be achieved by introducing a rotary feeder between the silo outlet and the conveyor inlet or having reduced pitched flighting for the first part of the conveyor. In any event, the capacity of the screw will be greatly reduced.

4.4 Bin Dischargers

If a material does not readily fluidise, is prone to absorb moisture or a controlled feed rate is required, mechanical bin dischargers may be fitted.

Various types are available:

1. Rotary type consisting of an arch breaker arm which rotates in the silo cone, drawing material down into a rotating plate feeder to control the discharge rate.
2. Screw type consisting of one or more horizontal flights pulling material out of a long slot silo outlet.
3. Vibrating disc type consisting of a large diameter shallow cone mounted just above the large circular silo outlet. By vibrating the disc, material is discharged annularly.

4.5 Pneumatic Conveying

Pneumatic conveying systems are commonly employed for transporting powders due to the flexibility and dust tightness of the system.

Pipelines carrying powder can be made to bend round corners, climb vertically or run horizontally over considerable distances if required.

However, a powder conveying line must not be thought of as a water pipe or similar. There are many limitations to its use and advice must be sought before planning a lengthy system.

Various configurations are employed usually based on one of the following:

1. Positive high pressure system, where powder is loaded into a pressure vessel, the vessel closed, pressurised and then opened to the conveying line.
2. Positive low pressure system, where powder is introduced into the airstream by rotary feeder. This gives a constant controlled feed rate.
3. Suction.

In certain cases combinations of the above are employed to meet the requirements of the duty.

There are many factors affecting the design of a pneumatic conveying system; feed rate, horizontal distance, vertical climb, type of material, pipe diameter, filter size, etc., all of these must be properly studied before selecting the best system and deciding on the type of air compressor or blower to be employed.

Another form of pneumatic conveying is the airslide where, by passing powdered material over an inclined fluidised bed it can be conveyed almost horizontally.

The use of airslides is limited but can often be employed to advantage as a discharge or feed chute.

4.6 Mechanical Conveying

Mechanical conveying of powders is commonly carried out using belt, bucket, screw, vibratory and draglink conveyors, but the problem of dust is a most important consideration when selecting suitable equipment.

1. Screw conveyors are very satisfactory, particularly where a controlled feed 10 to 15 ft long is required. Above this distance intermediate bearings are required which necessitate the reduction of the material burden. Screw elevators can be employed to lift powder vertically or inclined at any angle but care has to be taken with the selection of speed and HP.
2. Vibratory feeders and conveyors are extensively used, particularly on granular materials. They can be made to convey moderate distances but are generally more expensive than a screw conveyor. One advantage is that the material being conveyed does not come into contact with any working parts other than the inside of the trough or tube. Vibratory feeders and conveyors cannot normally be used to elevate material and, in fact, require a slight down grade.
3. Belt conveyors are sometimes employed where it is important to prevent segregation of different particles. It is important to keep the burden low or employ a trough type belt. In most cases the conveyor should be totally enclosed to prevent dust nuisance caused by wind or draught.
4. Bucket elevators are frequently selected where a powder is to be lifted from a loose bulk material hopper into a storage silo. The elevator must be totally enclosed and care must be taken to ensure correct feed from the hopper.
5. Draglink conveyors provide a satisfactory alternative to belt conveyors and bucket elevators. Material can generally be conveyed without particle damage or segregation but, in the case of the draglink elevator, cannot be completely emptied.

4.7 Comprehensive Schemes

Complete powder handling schemes can take many forms ranging from the simple silo with hand discharge to the multiple fully automatic installation handling many different materials.

Where more than one material is involved they can be stored either individually in separate silos or in separate sections of a multi-compartmented silo.

Generally speaking, individual silos can be cheaper but it is often desirable to adopt the multi-compartment configuration in order to save space and make a more integrated plant.

The possible layout can be so varied that each case must be treated on its own merits.

From storage, the various materials can be fed to individual weighers and then discharged in sequence or collectively into the process.

Alternatively, the feeders can be brought together to a common weigher and accumulatively weighed. Although the latter arrangement is usually less expensive, it must be borne in mind that the accuracy of weighing is bound to be affected adversely.

Wherever possible the weigher should discharge direct into the process to avoid possible losses in any transfer system otherwise employed.

However, in some cases, particularly where a number of materials are involved, this is not practical due to the lack of space around the process feed point. In these cases it is often practical to group the silos around a weighing machine at a convenient location, possibly even outside the building altogether, and then, having weighed out the batch, to transfer to a receiving hopper convenient to the process inside the building. This should be avoided if possible because there is always the danger that the entire batch is not transferred on each occasion and, without check weighing at the receiving point, this would then not be known.

With a comprehensive scheme, it is comparatively simple to automate all the various functions. In fact it is most desirable to do so in order to ensure that the materials are fed in correct sequence and weighed accurately. Fully automating a scheme also makes full use of the capital cost involved since the bulk of the cost is in the main storage and conveying equipment.

PART II: Case Study

Granular soda ash for the glass industry in Scotland has, for a number of years, been taken up by train from ICI Ltd.'s works in Cheshire, England, to Larbert, situated to the north of and midway between Glasgow and Edinburgh.

The distribution of soda ash from the rail head to the glass manufacturers and other users was carried out by James Hemphill Ltd., Road Transport Contractors of Glasgow. Their road vehicles were back filled direct from the rail wagons, and since each train load was 500 tonnes the rail wagons had to remain at Larbert for a considerable length of time.

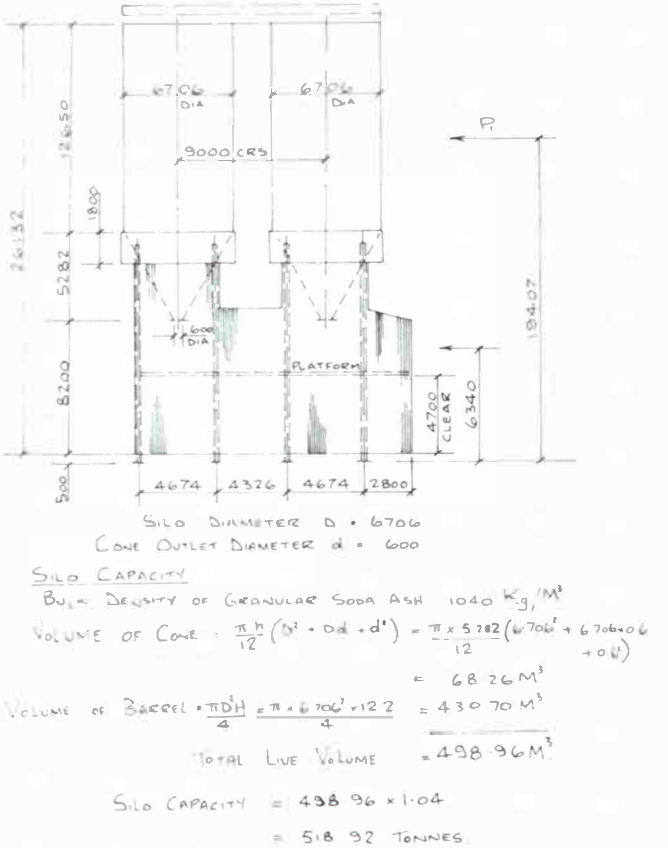
In August 1976, J. T. Scotney Ltd. was approached by James Hemphill Ltd. to put forward proposals for installing silos at Larbert to hold 1,000 tonnes of granular soda ash for outloading into road vehicles.

Initially 4x250 tonne mild steel silos were proposed, but after consultation with ICI Ltd., and James Hemphill Ltd., the final proposal was for a 2x500 tonne silo system.

J. T. Scotney Ltd. received an order for these silos in October 1979, erection work commenced on site in the spring of 1980 and the installation was completed in September 1980. The arrangement of the silos and the sheeted-in supporting structure is shown in Figs. 1 and 2. A shortened set of the design calculations for the silos and supporting structure is given below.

Fig. 1

Fig. 2



LOADINGS

SUPER ON ROOF $= \pi r^2 \times 76.5\ Kg/M^2$

$= \dfrac{\pi \times 3.352^2 \times 76.5}{10^3} = 2.7$ TONNES

SELF WEIGHT SILO + STRUCTURE = 55 TONNES

SHEETING $= 0.053\ KN/M^2 \times 400M^2 = 2.12$ TONNES.

SUPER ON PLATFORM $= \dfrac{255\ Kg/M^2 \times 7 \times 4.5}{10^3} = 8.03$ TONNES

ANCILLARY EQUIPMENT NOT ITEMISED = 1.00 TONNES

PIPE WORK = 1.00 TONNES.

CONVEYOR = 4.22 TONNES

PIPE/FOOT BRIDGE = 1.57 TONNES.

WIND LOAD.

BASIC WIND SPEED = 51 M/SEC.

$S_1 = 1.00$

$S_2 = 1.01$ GR 2. CLASS B

$S_3 = 1.00$

DESIGN WIND SPEED $= 51 \times 1.00 \times 1.01 \times 1.00$

$= 51.51$ M/SEC.

FROM C.P. 3. CHAPTER 5. PART 2. TABLE 5

WIND PRESSURE $q = 166.06\ Kg/M^2$.

COEFFICIENT - BARREL $\dfrac{\text{HEIGHT}}{\text{DIA.}} = \dfrac{14.45}{6.7} = 2.16$

THIS IS MARGINALLY OVER 2. IN TABLE 14. CP3. CH.5. PART 2. WE WILL TAKE AS 0.75

$C_f = 0.75$

STRUCTURE. $\dfrac{\text{LENGTH}}{\text{WIDTH}} = \dfrac{16474}{5330} = 3.09$

$\dfrac{\text{HEIGHT}}{\text{WIDTH}} = \dfrac{11680}{5330} = 2.19$

$C_f = 0.75$ (TABLE 10. CP3. CH.5. PART 2.)

AREA OF BARREL $= 14.45 \times 6.7 = 96.815\ M^2$

WIND LOAD ON BARREL $= 166.06 \times \dfrac{0.75}{10^3} \times 96.815$

$\therefore P_1 = 12.06$ TONNES.

CONSIDERING THE WIND AT AN ANGLE OF 45° TO THE CENTRE LINE OF THE STRUCTURE.

AXIAL LOAD ON FOUNDATION DUE TO WIND ON SILO BARREL $= \dfrac{12.06 \times 19.407}{6.706}$

$= 34.9$ TONNES

WIND PRESSURE ON STRUCTURE

WIND SPEED = 51 M/SEC

$S_1 = 1.00$

$S_2 = 0.901$ GR 2. CLASS B HEIGHT 11.6M.

$S_3 = 1.00$.

DESIGN WIND SPEED $= 51 \times 1.00 \times 0.901 \times 1.00$

$= 45.95$ M/SEC

FROM CP3 CHAPTER 5 PART 2 TABLE 5

WIND PRESSURE $q = 132\ Kg/M^2$

WIND LOAD ON ONE STANCHION. (TAKE $C_f = 1.4$)

$= 132 \times 11.68 \times \dfrac{(4.674 + 4.326)}{2} \times 1.4 \times \dfrac{9.806}{10^3}$

$= 95.25$ KN.

TOTAL WIND SHEAR AT BASE OF STANCHION

$= 95.25 + \dfrac{12.06 \times 9.806}{2}$

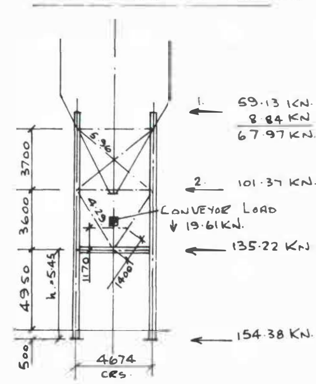
$= 154.38$ KN.

WIND SHEAR AT PLATFORM LEVEL

$= 154.38 - \dfrac{4.7}{2} \times \dfrac{4.674 + 4.326}{2} \times 132 \times 1.4 \times \dfrac{9.806}{10^3}$

$= 135.22$ KN.

CROSS SECTION THRO' STRUCTURE



WIND SHEAR AT 1.

FROM SILO BARREL $= \dfrac{12.06 \times 9.806}{2}$

$= 59.13$ KN

FROM STRUCT. $= \dfrac{3.7}{2} \times \dfrac{4.674 + 0.6}{2} \times \dfrac{132 \times 1.4 \times 9.806}{10^3}$

$= 8.84$ KN.

WIND SHEAR AT 2.

$= 154.38 - 6.5 \times \dfrac{4.674 + 4.326}{2} \times \dfrac{1.4 \times 132 \times 9.806}{10^3}$

$= 101.37$ KN.

UPPER BRACING

LOAD $= 67.97 \times \dfrac{5.96}{4.674} = 86.67$ KN

TRY 152 × 76 [IN TENSION

GROSS AREA $= 22.77\ cm^2$

NETT AREA $= 22.77 - 1.72 = 21.05\ cm^2$

ALLOWABLE LOAD $= \dfrac{155 \times 1.25 \times 21.05 \times 10^2}{10^3} = 408$ KN.

THIS SECTION IS MORE THAN ADEQUATE

HORIZONTAL BRACE AT POSITION 1.

LOAD = 67.97 KN. SPAN = 4674.

TRY 178 × 76 [AREA $= 26.54\ cm^2$ $r_y = 2.25$ cm

$\dfrac{L}{r_y} = \dfrac{0.7 \times 4674}{2.25} = 145.4$ $p_c = 43.5\ N/mm^2 \times 1.25 = 54.38\ N/mm^2$

$f_c = \dfrac{L}{A} = \dfrac{67.97 \times 10^3}{26.54 \times 10^2} = 25.61\ N/mm^2$

$\therefore$ SECTION SUITABLE.

BRACE WITH CONVEYOR SUPPORT.

LOAD IN BRACE FROM WIND (COMPRESSIVE) $= 101.37\ KN \times \dfrac{4.29}{2.34}$

$= 185.8$ KN

THERE WILL BE AN ADDITIONAL LOAD IN THE BRACING DUE TO THE LOAD FROM THE CONVEYOR. THIS WILL BE A VERTICAL LOAD OF 9.8 KN WHICH RESOLVES TO 5.32 KN PERPENDICULAR TO THE BEAM AND 8.45 KN ALONG THE BEAM ADDING TO THE COMPRESSION.

LOAD DIAGRAM OF BEAM SUBJECT TO BENDING

5.32 KN. | 1400 | 2890 | 4290 | L. | R.

REACTIONS ARE

$4.29 R_R = 5.32 \times 1.4$.

$R_R = 1.74$ KN

$R_L = 3.58$ KN.

BM $= 3.58 \times 1.4 = 5.02$ KNM.

REVISED AXIAL LOAD $= 8.45 + 185.8 = 194.25$ KN.

TRY 152 × 152 × 23 Kg U.C.

AREA $= 29.8\ cm^2$, $r_y = 3.68$ cm $Z_x = 165.7\ cm^3$ $D/T = 22.3$

$\dfrac{L}{r_y} = \dfrac{0.85 \times 429}{3.68} = 99.1$ $p_c = 79.7\ N/mm^2$

$\dfrac{L}{r_y} = \dfrac{0.7 \times 429}{3.68} = 81.6$ $p_{bc} = 165\ N/mm^2$

$f_c = \dfrac{L}{A} = \dfrac{194.25 \times 10^3}{29.8 \times 10^2} = 65.18\ N/mm^2$

$f_{bc} = \dfrac{BM}{Z} = \dfrac{5.02 \times 10^6}{165.7 \times 10^3} = 30.29\ N/mm^2$

$\dfrac{f_c}{p_c} + \dfrac{f_{bc}}{p_{bc}} = \dfrac{65.18}{79.7} + \dfrac{30.29}{165} = 0.81 + 0.18 = 0.99 < 1.$

$\therefore$ SECTION SATISFACTORY

CONSIDER THE BOTTOM UNBRACED PANEL OF THE CROSS SECTION THROUGH THE STRUCTURE AS A PORTAL FRAME

FIXED BASE FROM STEEL DESIGNERS MANUAL

$K = \frac{I_2}{I_1} \times \frac{h}{L} = \frac{33388}{40246} \times \frac{5.45}{4.674} = 0.967$

STANCHION ASSUMED 356 × 368 × 129 Kg UC

$N_1 = K + 2 = 2.967$ $N_2 = 6K + 1 = 6.8$

MOMENTS + LOADS DUE TO WIND ON SIDE

$M_A = -\frac{Ph}{2} \times \frac{3K+1}{N_2} = -\frac{135.22 \times 5.45}{2} \times \left(\frac{3 \times 0.967 + 1}{6.8}\right) = -211.4\ KNM$

$M_B = +\frac{Ph}{2} \times \frac{3K}{N_2} = +\frac{135.22 \times 5.45}{2} \cdot \frac{3 \times 0.967}{6.8} = +157.2\ KNM$

$M_D = +\frac{Ph}{2} \times \frac{3K+1}{N_2} = +211.4\ KNM$

$M_C = -\frac{Ph}{2} \times \frac{3K}{N_2} = -157.2\ KNM$

$H_A = -H_D = -\frac{P}{2} = -\frac{135.22}{2} = -67.61\ KN$

$V_A = -V_D = -\frac{2M_B}{L} = -\frac{2 \times 157.2}{4.674} = -67.27\ KN$

MOMENTS + LOADS DUE TO PLATFORM BEAMS

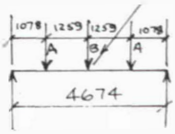
THE 3.58 KN REACTION FROM THE BRACING SUPPORTING THE CONVEYOR RESOLVES TO 2 KN VERT. AND 3 KN. HORIZ.

REACTION ON BEAM FROM CONVEYOR = 2 × 2 KN = 4 KN

THE OUT OF BALANCE LOADING IN 'V' BRACE WILL ALSO INDUCE A VERTICAL LOAD IN THE BEAM

$LOAD = 2 \times 8.45 \times \frac{2}{3.58} = 9.44\ KN$

LOADS ON CROSS BEAM FROM PLATFORM SUPPORTS = 17.66 KN



LOAD A FROM PLATFORM = 17.66 KN

LOAD B = 17.66 + 4 + 9.44 = 31.1 KN

MOMENTS AND LOADS DUE TO CENTRAL POINT LOAD 'B'

$M_A = M_D = +\frac{PL}{8N_1} = \frac{31.1 \times 4.674}{8 \times 2.967} = 6.13\ KNM$

$M_B = M_C = -2M_A = -2 \times 6.13 = -12.26\ KNM$

$V_A = V_D = \frac{31.1}{2} = 15.55\ KN$

$H_A = H_D = \frac{3M_A}{h} = \frac{3 \times 6.13}{5.45} = 3.37\ KN$

MOMENTS AND LOADS DUE TO OUTER POINT LOADS 'A'

$a_1 = \frac{a}{L} = \frac{1.078}{4.674} = 0.23$ $b_1 = \frac{b}{L} = \frac{3.596}{4.674} = 0.77$

$M_A = M_D = \frac{Pab}{L}\left(\frac{1}{2N_1} - \frac{b_1 - a_1}{2N_2}\right) + \frac{Pab}{L}\left(\frac{1}{2N_1} + \frac{b_1 - a_1}{2N_2}\right)$

$= \frac{17.66 \times 1.078 \times 3.596}{4.674}\left(\frac{1}{2 \times 2.967} - \frac{0.77 - 0.23}{2 \times 6.8}\right) + \frac{17.66 \times 1.078 \times 3.596}{4.674}\left(\frac{1}{2 \times 2.967} + \frac{0.77 - 0.23}{2 \times 6.8}\right)$

$= 14.65(0.129) + 14.65(0.208)$

$= 4.94\ KNM$

$M_B = M_C = -\frac{Pab}{L}\left(\frac{1}{N_1} + \frac{b_1 - a_1}{2N_2}\right) - \frac{Pab}{L}\left(\frac{1}{N_1} - \frac{b_1 - a_1}{2N_2}\right)$

$= -14.65\left(\frac{1}{2.967} + \frac{0.77 - 0.23}{2 \times 6.8}\right) - 14.65\left(\frac{1}{2.967} - \frac{0.77 - 0.23}{2 \times 6.8}\right)$

$= -14.65(0.377) - 14.65(0.297)$

$= -9.87\ KNM$

$V_A = V_D = 17.66\ KN$

$H_A = H_D = 2\left(\frac{3Pab}{2LhN_1}\right)$

$= 2\left(\frac{3 \times 17.66 \times 1.078 \times 3.596}{2 \times 4.674 \times 5.45 \times 2.967}\right)$

$= 2.72\ KN$

ADDITIONAL BMs AND LOADS DUE TO WIND ON SIDE

$LOAD = 4.95\left(\frac{4.674 + 4.326}{2}\right) \times 1.32 \times 1.4 \times \frac{9.806}{10^3} = 40.36\ KN$

$M_A = \frac{Wh}{4}\left[\frac{-K+3}{6N_1} - \frac{4K+1}{N_2}\right] = \frac{40.36 \times 5.45}{4}\left[\frac{-0.967+3}{6 \times 2.967} - \frac{4 \times 0.967 + 1}{6.8}\right]$

$= -51.61\ KNM$

$M_D = \frac{Wh}{4}\left[\frac{-K+3}{6N_1} + \frac{4K+1}{N_2}\right] = \frac{40.36 \times 5.45}{4}\left[\frac{-0.967+3}{6 \times 2.967} + \frac{4 \times 0.967 + 1}{6.8}\right]$

$= +27.11\ KNM$

$M_B = \frac{Wh}{4}\left[\frac{-K}{6N_1} + \frac{2K}{N_2}\right] = \frac{40.36 \times 5.45}{4}\left[\frac{-0.967}{6 \times 2.967} + \frac{2 \times 0.967}{6.8}\right]$

$= +12.66\ KNM$

$M_C = \frac{Wh}{4}\left[\frac{-K}{6N_1} - \frac{2K}{N_2}\right] = \frac{40.36 \times 5.45}{4}\left[\frac{-0.967}{6 \times 2.967} - \frac{2 \times 0.967}{6.8}\right]$

$= -18.62\ KNM$

$H_D = \frac{W(2K+3)}{8N_1} = \frac{40.36(2 \times 0.967 + 3)}{8 \times 2.967} = 8.39\ KN$

$H_A = -40.36 + 8.39 = -31.97\ KN$

$V_A = -V_D = -\frac{WhK}{LN_2} = -\frac{40.36 \times 5.45 \times 0.967}{4.674 \times 6.8} = -6.7\ KN$

TABLE I RESULTANT MOMENTS AND LOADS

M_A	−211.4	+ 6.13	+ 4.94	− 51.61	=	− 251.94 KNM
M_D	+211.4	+ 6.13	+ 4.94	+ 27.11	=	+ 249.58 KNM
M_B	+157.2	− 12.26	− 9.87	+ 12.66	=	+ 147.73 KNM
M_C	−157.2	− 12.26	− 9.87	− 18.62	=	− 197.95 KNM
V_A	−67.27	+ 15.55	+ 17.66	− 6.7	=	− 40.76 KN
V_D	+67.27	+ 15.55	+ 17.66	+ 6.7	=	+ 107.18 KN
H_A	−67.61	+ 3.37	+ 2.72	− 31.97	=	− 93.49 KN
H_D	+67.61	+ 3.37	+ 2.72	+ 8.39	=	+ 82.09 KN

FOR THE CROSS BEAM MAX BM = −197.95 KNM

WIND COMPRESSION LOAD = 135.22 KN

TRY 457 × 191 × 67 Kg UB

AREA = 85.4 cm^2 r_y = 4.12 cm r_x = 18.55 cm Z_x = 1296 cm^3

D/T = 35.7

$\frac{L_x}{r_x} = \frac{467.4}{2 \times 18.55} = 12.6$

$\frac{L_y}{r_y} = \frac{125.9}{4.12} = 30.55$ $p_c = 142.5\ N/mm^2$

$\frac{L}{r_y} = \frac{262.5}{4.12} = 63.7$ $p_{bc} = 165\ N/mm^2$

$f_c = \frac{LOAD}{AREA} = \frac{135.22 \times 10^3}{85.4 \times 10^2} = 15.83\ N/mm^2$

$f_{bc} = \frac{BM}{Z} = \frac{197.95 \times 10^6}{1296 \times 10^3} = 152.74\ N/mm^2$

$\frac{f_c}{p_c} + \frac{f_{bc}}{p_{bc}} = \frac{15.83}{142.5} + \frac{152.74}{165} = 1.03$

NEAR ENOUGH TO 1 FOR SECTION TO BE SUITABLE HAUNCH HOWEVER WILL BE ARRANGED FOR DESIGN OF BOLTS

STANCHION DESIGN

LOADINGS	TOTAL LOAD =	110 TONNES 2 NO. SILOS
	TOTAL CONTENTS =	1000
	SUPER ON 2 ROOFS =	5.4
	SHEETING =	2.12
	SUPER ON PLATFORM =	8.03
	EXTRA ITEMS	7.79
		1133.34 TONNES

$LOAD/STAN = \frac{1133.34}{8} = 141.6$ + WIND COMP. 34.9 TONNES

= 176.56 TONNES

= 1731 KN

MAX BM = 249.58 KNM.

TRY 356 × 368 × 153 Kg U.C.

AREA = 195.2 cm² r_x = 15.8 cm. r_y = 9.46 cm. Z_x = 2681 cm³

D/T = 17.5.

$\frac{L_y}{r_y} = \frac{500}{9.46} = 52.85$ p_c = 131.2 N/mm²

$\frac{L_x}{r_x} = \frac{545 \times 1.5}{15.8} = 51.74$ p_{bc} = 165 N/mm²

$f_c = \frac{LOAD}{AREA} = \frac{1731 \times 10^3}{195.2 \times 10^2} = 88.67$ N/mm²

$f_{bc} = \frac{BM}{Z} = \frac{249.58 \times 10^6}{2681 \times 10^3} = 93.1$ N/mm²

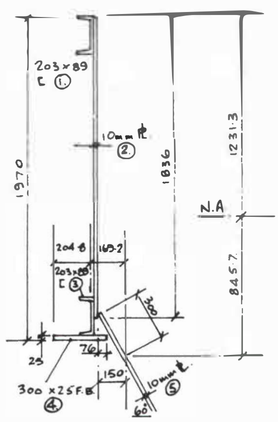
$\frac{f_c}{p_c} + \frac{f_{bc}}{p_{bc}}$ MUST NOT EXCEED 1.25.

$\frac{88.67}{131.2} + \frac{93.1}{165} = 1.239.$

∴ SECTION SATISFACTORY.

SILO DESIGN.

HIP RING BEAM.



NA xx

PART	AREA	DIST.	A × d.
①	37.94	10.1	383.194
②	183	92.1	16854.3
③	37.94	184.4	6996.13
④	75	195.75	14681.25
⑤	30	196.3	5889
	363.88		44804

NA = $\frac{44804}{363.88}$ = 123.13 cm.

NA yy

①	37.94	18.65	707.6
②	183	15.5	2836.5
③	37.94	18.65	707.6
④	75	22.4	1680
⑤	30	7.5	225
	363.88		6156.7

NA = $\frac{6156.7}{363.88}$ = 16.92 cm.

I_{cg} xx

① 2491 cm⁴

② $\frac{bd^3}{12} = \frac{1 \times 183^3}{12}$ = 510707.75 cm⁴

③ 2491 cm⁴

④ $\frac{bd^3}{12} = \frac{30 \times 2.5^3}{12}$ = 39.06 cm⁴

⑤ $\frac{1 \times 30 (1^2 \times 0.25 + 30^2 \times 0.75)}{12}$ = 1688.125 cm⁴

I_{cg} yy

① 264.4 cm⁴

② $\frac{bd^3}{12} = \frac{183 \times 1^3}{12}$ = 15.25 cm⁴

③ 264.4 cm⁴

④ $\frac{bd^3}{12} = \frac{2.5 \times 30^3}{12}$ = 5625 cm⁴

⑤ $\frac{1 \times 30 (1^2 \times 0.75 + 30^2 \times 0.25)}{12}$ = 564.375 cm⁴

I_{xx} SECTION

PART	AREA	h	Ah²	I_{cg}	Ah² + I_{cg}
①	37.94	113	484627	2491	487118.4
②	183	31.03	176203.5	510707.25	686910.8
③	37.94	61.27	142427.25	2491	144918.25
④	75	72.62	395524.8	39.06	395563.9
⑤	30	73.17	160615.5	1688.13	162303.6
					1876815 cm⁴

$Z_1 = \frac{1876815}{123.1}$ = 15246.3 cm³

$Z_2 = \frac{1876815}{84.5}$ = 22210.8 cm³

I_{yy} SECTION

①	37.94	1.73	113.55	264.4	377.95
②	183	1.42	369	15.25	384.25
③	37.94	1.73	113.55	264.4	377.95
④	75	5.48	2252.28	5625	7877.28
⑤	30	9.42	2662.1	564.38	3226.47
					12243.9 cm⁴

$Z_1 = \frac{12243.9}{16.92}$ = 723.63 cm³

$Z_2 = \frac{12243.9}{20.48}$ = 597.85 cm³

HIP BEAM SUPPORT POINT.

LOAD = 1272.13 + 6.62 + $\frac{33 \times 9.806}{4}$ = 1359.65 SAY 1360 KN.

SHEAR = $\frac{1360}{2}$ = 680 KN

BM AT SUPPORT = 1360 × 4 × $\frac{6.706}{2}$ × 0.03415 = 622.91 KNM

BM AT MID SPAN = 1360 × 4 × $\frac{6.706}{2}$ × 0.01762 = 321.4 KNM.

TORSIONAL MOMENT = 1360 × 4 × $\frac{6.706}{2}$ × 0.0053 = 96.67 KNM.

COMPRESSION = 0.5 × 1360 × 4 × cotan 60° = 1570.4 KN.

$f_{bc} = \frac{BM}{Z} = \frac{622.91 \times 10^6}{15246.3 \times 10^3}$ = 40.86 N/mm²

$f_c = \frac{L}{A} = \frac{1570.4 \times 10^3}{363.88 \times 10^2}$ = 43.16 N/mm²

f_t = 0

$\frac{f_{bc}}{p_{bc}} + \frac{f_c}{p_c} = \frac{40.86}{165} + \frac{43.16}{155}$ = 0.53 < 1.

HIP SECTION SATISFACTORY.

AT POINT OF CONTRAFLECTURE BM = 0

f_c = 43.16 N/mm²

$M_T' = \frac{M_T}{d - t_s} \times Kr$ WHERE K = 0.1366, t_s = 200, d = 2077.

$M_T' = \frac{96.67}{2077 - 200} \times 0.1366 \times \frac{6.706}{2}$ = 23.59 KNM.

$f_{bc}' = \frac{23.59 \times 10^6}{0.5 \times 597.85 \times 10^3}$ = 78.9 N/mm²

$\frac{f_{bc}}{p_{bc}} + \frac{f_c}{p_c} = \frac{78.9}{165} + \frac{43.16}{155}$ = 0.75 < 1.

∴ HIP SECTION SATISFACTORY

INTERNAL PRESSURES IN SILO

DENSITY OF SODA ASH = 1040 Kg/M³ = ρ
ANGLE OF INTERNAL FRICTION φ = 40°
HALF CONE APEX ANGLE α = 30°
h = DEPTH BELOW MATERIAL SURFACE
PRESSURE DURING FILLING
ON VERTICAL SIDES Cf = .218
ON CONE SIDE Cf = .413

PRESSURE ON VERTICAL SIDE AT HIP = Cf × h × ρ
= 0.218 × 12.2 × 1040
= 2766 Kg/M²

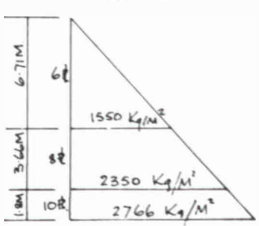
PRESSURE ON CONE AT HIP = Cf × h × ρ
= 0.413 × 12.2 × 1040
= 5240 Kg/M²

PRESSURE ON CONE AT OUTLET = Cf × h × ρ
= 0.413 × 17.5 × 1040
= 7516 Kg/M²

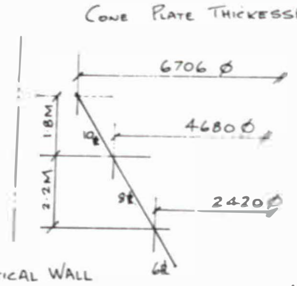
DURING EMPTYING THERE WILL BE A REVERSAL OF PRESSURES IN THE CONE

FOR CONE TAKE PRESSURE CONSTANT AT 7516 Kg/M²

PRESSURE DIAGRAM
VERTICAL WALL



CONE PLATE THICKNESSES



HOOP TENSIONS IN VERTICAL WALL

① AT HIP = 2766 × 9.806/2 × 6.706 = 90944.75 N/M

② 1.8 M. ABOVE HIP = 2350 × 9.806/2 × 6.706 = 77266.9 N/M

③ 5.46M ABOVE HIP = 1550 × 9.806/2 × 6.706 = 50963.3 N/M

HOOP TENSIONS IN CONE

④ AT HIP = 7516 × 9.806/2 × 6.706 = 247122.5 N/M

⑤ 1.8M BELOW HIP = 7516 × 9.806/2 × 4.68 = 172462.5 N/M

⑥ 4M BELOW HIP = 7516 × 9.806/2 × 2.42 = 89179.3 N/M

HOOP STRESSES

① 90944.75 / (10³ × 10) = 9.1 N/mm²

② 77266.9 / (10³ × 8) = 9.66 N/mm²

③ 50963.3 / (10³ × 6) = 8.5 N/mm²

④ 247122.5 / (10³ × 10) = 24.7 N/mm²

⑤ 172462.5 / (10³ × 8) = 21.56 N/mm²

⑥ 89179.3 / (10³ × 6) = 14.86 N/mm²

FOR THE CONE WE MUST TAKE INTO ACCOUNT THE WEIGHT OF CONE AND WEIGHT OF MATERIAL

WEIGHT OF CONE = 8 TONNES
WEIGHT OF MATERIAL 2 × 68.26 × 1040 / 10³ = 142 TONNES

TOTAL LOAD 150 TONNES

AT HIP CIRCUM = πD = π × 6706 = 21070.25 mm

ft = 150 × 10⁴ / (21070.25 × 10) = 7.12 N/mm²

ADDING THESE STRESSES TO RING BEAM

78.9/165 + 43.16/155 + 7.12/155 + 9.66/155 = 0.86 < 1

RING BEAM SUITABLE

IF FOR SIMPLICITY WE TAKE THE SAME LOAD ACTING AT 1.8 M BELOW HIP

CIRCUM = πD = π × 4680 = 14704.6 mm

ft = 150 × 10⁴ / (14704.6 × 8) = 12.75 N/mm²

SUMMATING STRESSES 12.75/155 + 21.56/155 = 0.22 < 1

PLATE THICKNESS SUITABLE.

References

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[5] Steel designers manual. 4th. edition 1975 published by Crosby, Lockwood & Staples.
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