DEVELOPMENTS IN CHUTE DESIGN FOR HIGH CAPACITY MULTI PRODUCT CONVEYING

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1. INTRODUCTION

Seeing an extensive demand for raw materials in China, India and to a lesser extent in Europe prompts an ever-increasing need to transport high volumes of base metals, coal and similar commodities.
Servicing the growing demands for bulk transportation of such materials to fuel this exploding global infrastructure expansion, the development of belt conveyor systems has seen an unprecedented increase in popularity.
Simply increasing size, speed and related capacity is today totally unacceptable because in an environmentally sensitive world, issues such as dust generating, spillage and the associated pollution is permanently under the scrutiny of the developers and operators alike.
Today we see Ports clogged with bulk vessels waiting to load their cargo and there is not a single port considering, preparing or developing its facilities to meet this growing worldwide demand.

To this end, we, as designers have a duty to make the systems we develop stand up to the rigours of providing truly well designed equipment which offer high availability, coupled to the associated ease of maintenance in a breakdown situation.
To be able to guarantee quick and simple start up, to rapidly identify failures and to predict the possible future failure before they occur. This has been identified as introducing intelligence into the equipment we provide.

Over the years, we have seen the introduction of many “innovative” solutions to materials handling problems; the “Pipe Conveyor” to eliminate transfer points and reduce blow off dust emissions.
The “Triangular Gantry” and “Maintenance Trolley” to allow cost effective elevation of conveyors away from the problems of Port sterilization and quick access to the maintenance area.
Presently we are developing idlers with temperature sensors, which will warn of pending failure, and coupling this to the Maintenance Trolley we will be able to send the trolley to automatically monitor and replace damaged idlers.

These new innovations are helping with the required improvements in system availability but we are still to fully address the biggest cause of damage, wear and serviceability, this being referred to as the transfer point.

The normal requirement at a typical Port can be the transportation of 2,000 to 15,000 tons of ore per hour, transport as much as 30 different products through the same system of conveyor belts and transfer points.
These products can vary from pellets, to fine high moisture ores, to dusty powders.
Consideration must also given to conveying high impact materials which are not very forgiving to poor chute design making prediction of flow paths of immense importance.

This paper sets out to show the processes being applied to the development of transfer points at three of South Africa’s export terminals namely Saldanha Bay, Port Elizabeth and Richards Bay Dry Bulk Terminal.

To highlight the work being undertaken, this paper concentrates on the following aspects of chute development:-

- The effect of flexibility on the availability of associated equipment
- Transfer point complication
- Computer modeling of material flow
- Wear protection
- Dust emission
- Maintenance and finally
- Condition Monitoring

This focus is an ongoing development of what has been termed “Condition Monitoring” normally associated with belting, pulleys, idlers and drive components.

However this need to effectively transfer different materials on the same conveying system results in the need for the establishment of a totally defined procedure to operate and maintain the transfer points, including simple methods of defining liner wear and undertaking inspections resulting in the achievement of predictive scheduled maintenance.

2. TERMINAL LAYOUT - THE EFFECT OF FLEXIBILITY ON AVAILABILITY

Terminal layout is considered to offer the biggest challenge to the designer especially when the upgrades are proceeding with abundance, sketches figures 2.1 and 2.2 below show the measure of expansion one can see in many of our ports.

However, how do we approach this requirement for upgrade, do we simply increase the number of storage beds with the increase of infrastructure or do we investigate the cause and effect of an additional transfer point as related to system flexibility and availability.

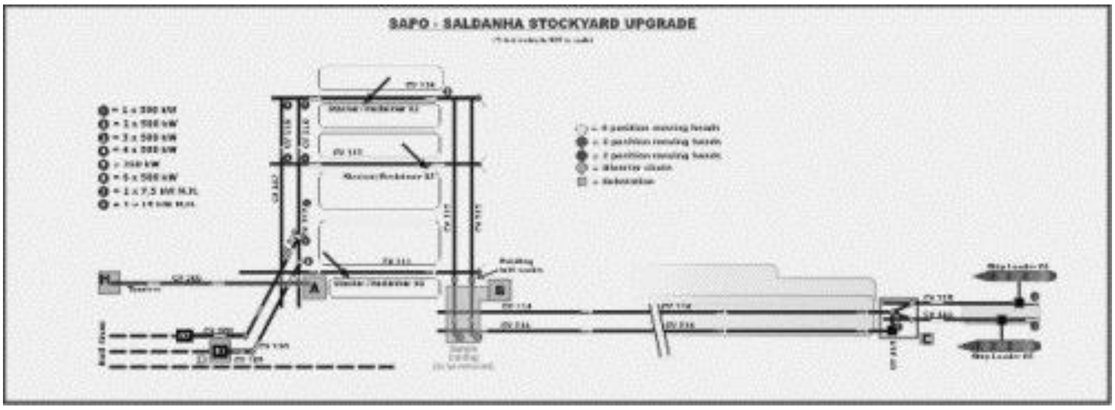


Figure 2.1 – present Layout

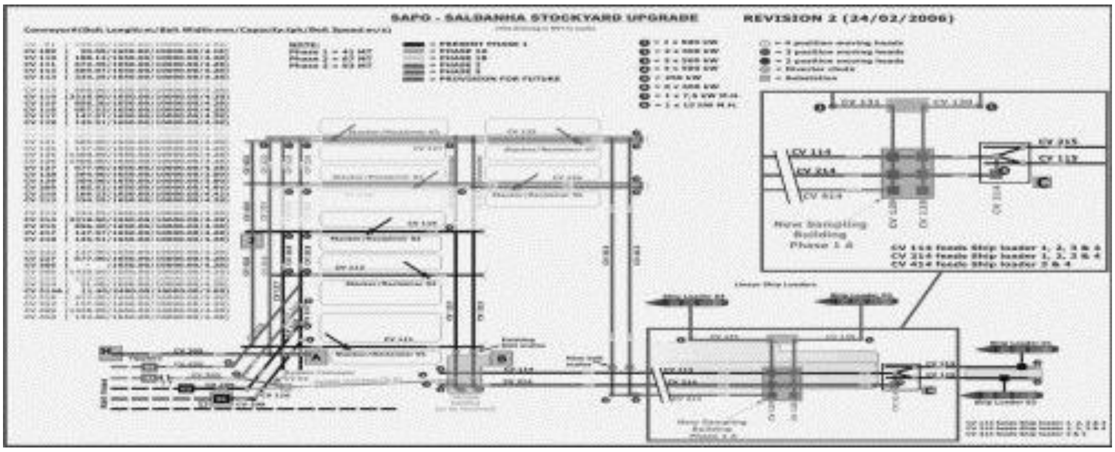


Figure 2.2 – Possible New Layout After Upgrade

Today a large amount of work is being done to understand the philosophy of flexibility as related to availability, any self respecting operator / owner when asked about flexibility will always answer that the first rule is total flexibility, not understanding that total flexibility results in unworkable operating solutions, meaning very poor availability.

This is no more significant in a terminal or power plant where even when one calls for total redundancy, often one should read that as totally redundant, or inoperable. For the purpose of this paper we considered that in transfer point design, having the ability to place product on any conveyor from any transfer point to ensure flexibility is possibly a “nice to have” but the requirements of the transfer chute then becomes very extensive and a real compromise on the design itself, certainly negating the guarantee of eliminating the compromises we try to design out of a transfer point.

Therefore, one should use extensive simulation modeling to help understand the effect of adding in that additional conveyor and related transfer point.

2.1. TRANSFER POINT LAYOUT - TRANSFER POINT COMPLICATION

One of the projects under investigation, offered the writer an opportunity to understand the acute effects of obtaining a “flexible” solution; the terminal conveys 30million tons of iron ore per year and over the next 10 years it is proposed to increase this to 90million tons per year. Which will increase the number of transfer points from the present 24, (chutes), to 68 transfer points. Each of which will, at some time in their operation, see all 12 different products. Theoretically it offers over 1000 different routes to go from the tippler station to the ship loader and without computer modeling it is totally impossible to understand what “flexibility” actually entails, in fact in one case we see consideration being given to introducing an additional conveyor line to overcome the loss of availability caused by the many “flexible” transfer points.

Figure 2.3 following shows the effect of meeting the “flexibility” requirement, it shows a multi-position moving head chute which offers extensive improvements on “bifurcated” or “shuttle” transfers, but being able to guarantee accurate positioning, requires extensive instrumentation control and repeatable placement complications.

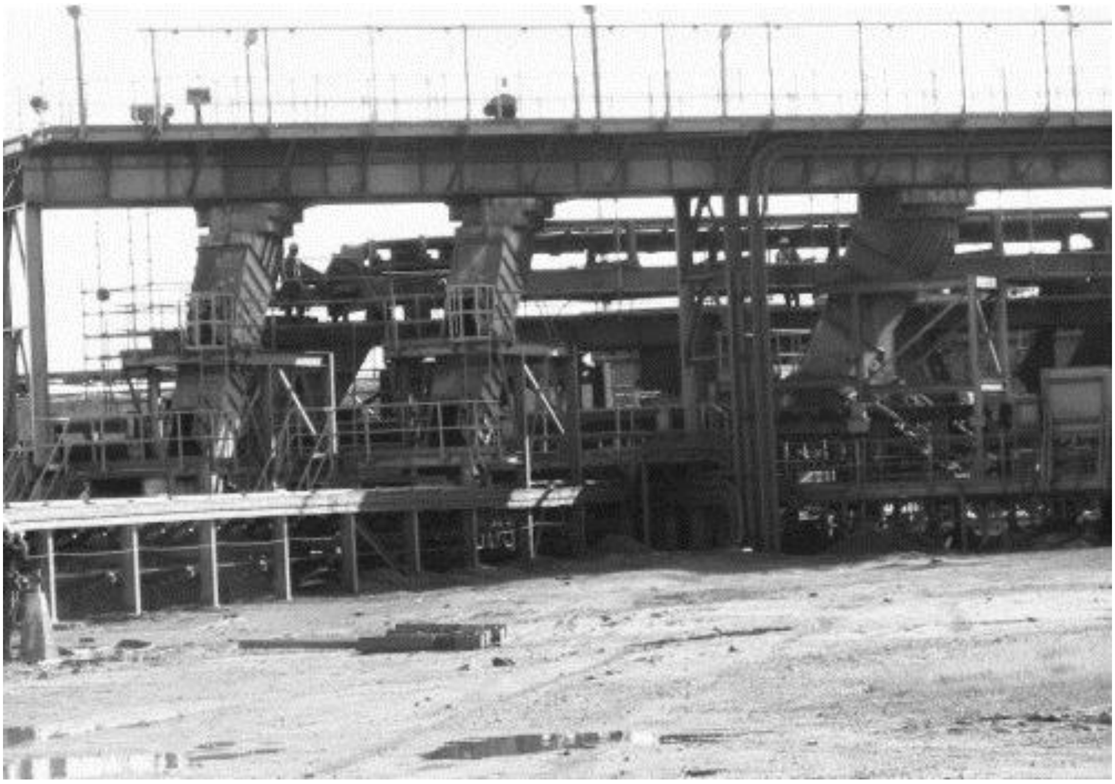


Figure 2.3 - Typical Moving Head Transfer

Another solution for a simple two-way transfer is the diverter car shown below figure 2-4. It offers simple transfer with generally lower height requirements between incoming and outgoing belts.

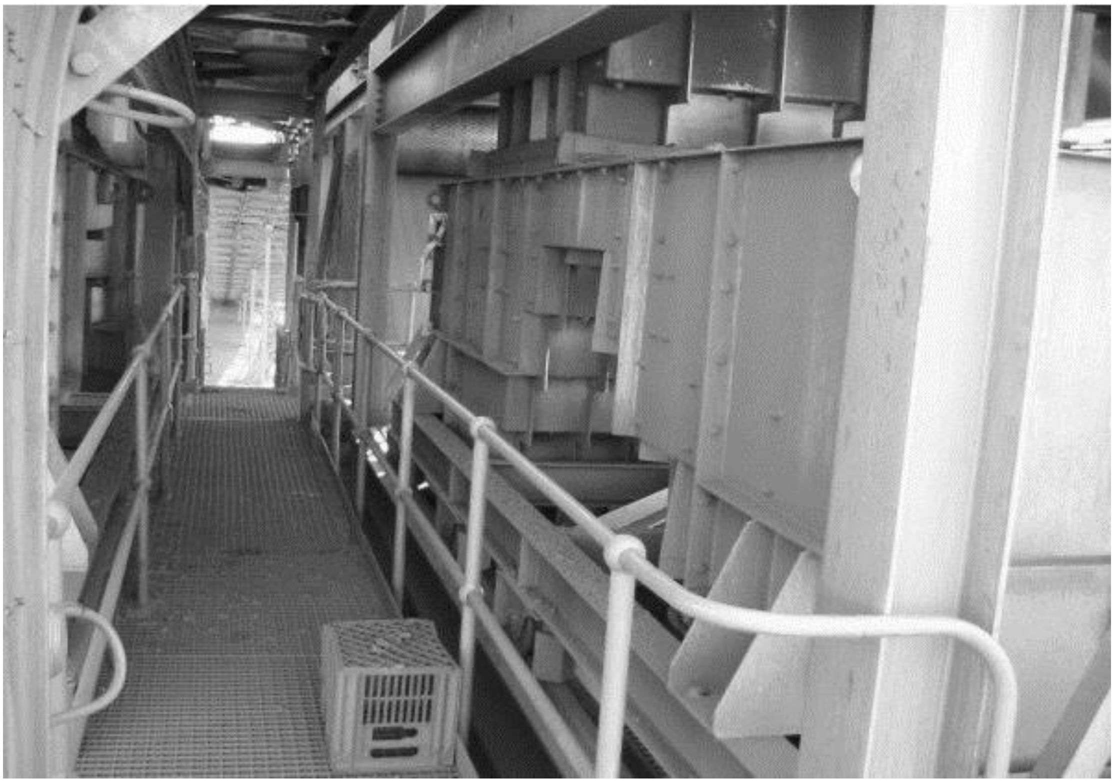


Figure 2.4 – Typical Diverter Chute

3. PRESENT DEVELOPMENTS IN CHUTE FLOW CRITERIA - COMPUTER MODELING OF MATERIAL FLOW

3.1. INTRODUCTION

When one embarks on the development of a transfer point, there are a number of expected norms considered essential in perfecting the design. Firstly, one has to consider the materials being transferred and with typical Terminals as stated above, multiple products are the order of the day.

So what do we design for? The answer is to design for the worst product, but what is the worst product? Is it flow ability, dust generation or abrasion? We generally have a combination of all aspects in our chute design so a typical approach will be as follows:-

- Material Testing
- Chute Layout
- Computer Modeling of Material Path and
- Computer Modeling of Material Velocity
- Physical Model Building.

3.2. MATERIAL TESTING

Initially one would attempt to produce a set of laboratory tests on the materials being transferred, however, this is realistically only carried out on the worst material, (generally the "stickiest"), possibly with various degrees of moisture content.

These tests produce a schedule as indicated in Table 3.1, which highlights "friction angles" and recommended "minimum chute angles" for various "impact pressures" over different liner types.

Liner Types	Impact Pressure KPA	Friction Angle Deg	Chute Angle Deg
VRN500	0.00	35	45
	2.10	37	47
	3.50	39	49
	5.50	41	51
Ti-Hand	0.00	37	47
	2.10	40	50
	3.50	42	52
	5.50	44	54
Chromonite-1	0.00	36	46
	2.10	38	48
	3.50	40	50
	5.50	43	53
Chromonite-180	0.00	29	39
	2.10	31	41
	3.50	33	43
	5.50	35	45
Mild Steel	0.00	34	44
	2.10	37	47
	3.50	39	49
	5.50	42	52
Ceramic	0.00	33	43
	2.1	36	46
	3.5	38	48
	5.5	40	50
Dead Boxes (Material sliding on material)	0.00	38	48
	2.10	40	50
	3.50	42	52
	5.50	46	56

Table 3.1 – Liner types under consideration

It is not normal for the laboratory to recommend the best liner type for the application; this is generally a function of layout and impact characteristics of both chute and liner material.

3.3. CHUTE LAYOUT

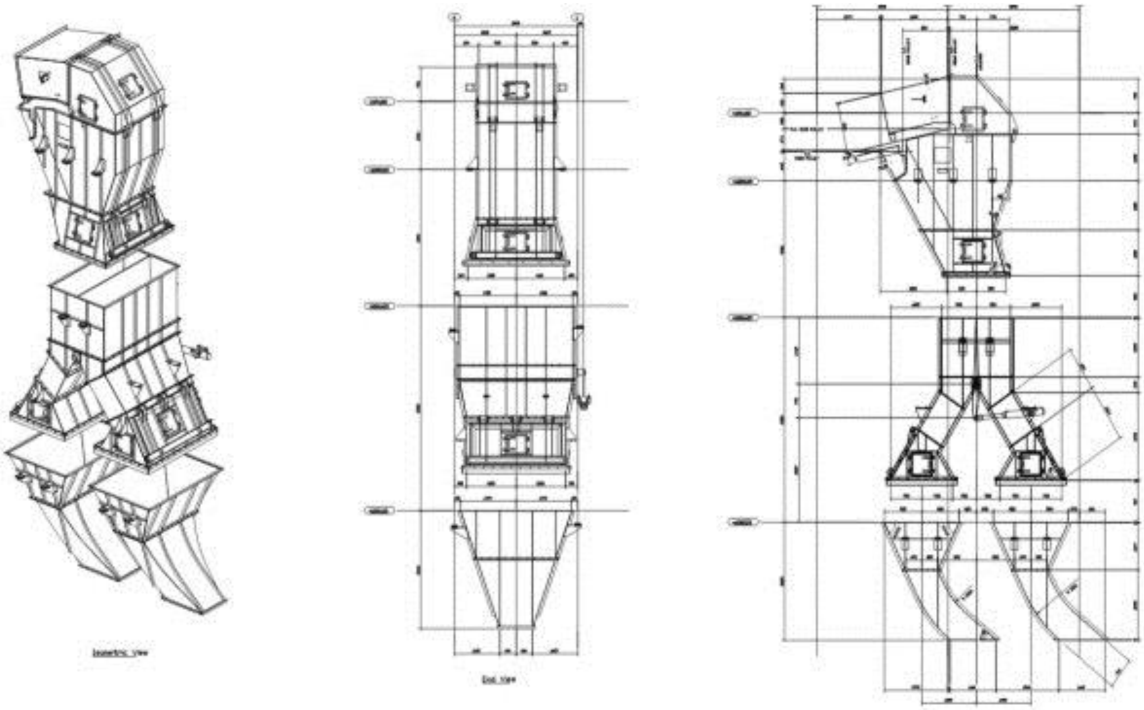


Figure 3.2– Chute Layout

The tests indicated in section 3.2 above, generated the friction angles and recommended chute angles for the material application in question. This is used to develop the 2 and 3 dimensional layout of the proposed chute. Figure 3.2 above is an application with conveyor feed too and collection from a primary and twin secondary crusher application.

The next stage in the development of the chute is the introduction of a mathematical model, which produces chute flow predictions, (routing) and material velocities and impact pressures to allow correct liner selection and positioning.

3.4. COMPUTER MODELING OF MATERIAL PATH

The last 6 years has seen unprecedented developments in chute flow predictions using subject matter such has DEM, (Discrete Element Method), theory where predictions of material flow direction and velocity are considered to be standard practice. Below is a graphical representation of a modeling technique as demonstrated by Mr. LK Nordell in his Beltcon 12 paper refer figure 3.3.

This is a mathematical tool, which is now being employed extensively to assist with material flow problems and predictions.

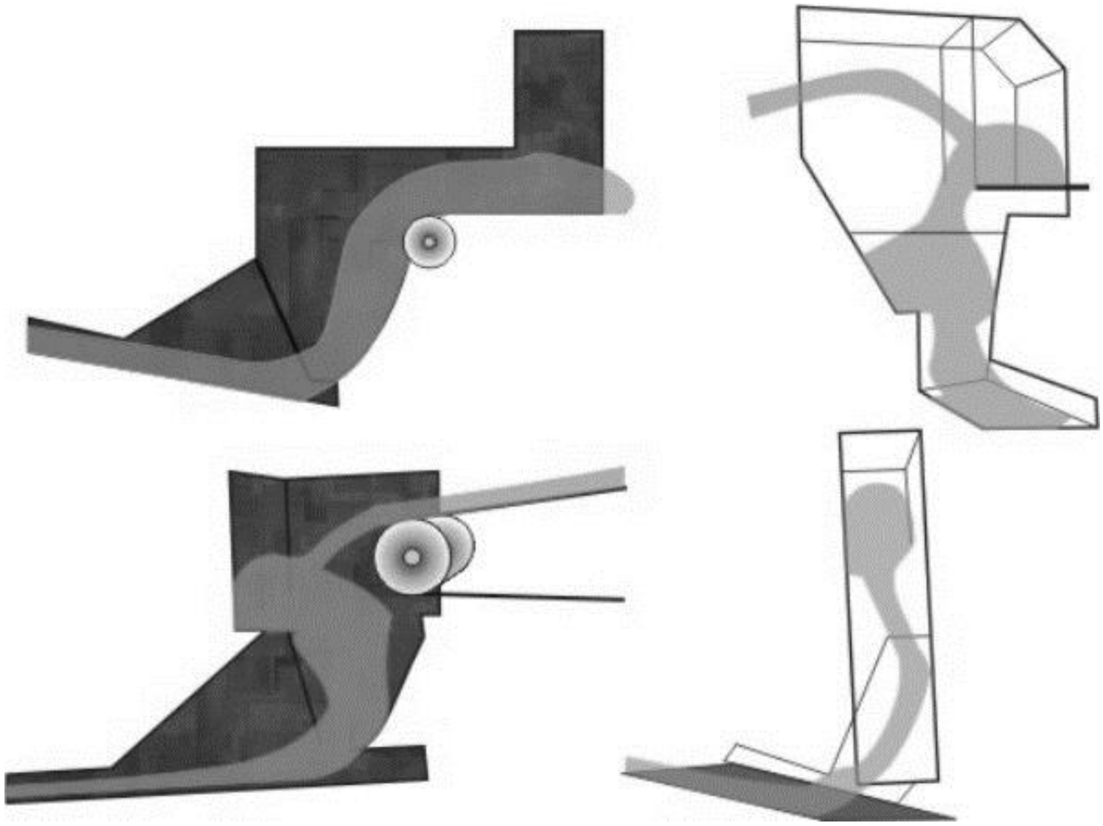


Figure 3.3 – DEM method as considered by Mr. LK Nordell in his Beltcon 12 paper

Here one is able, (using sophisticated computer modeling techniques), to define the total path of a material through a chute and calculate the material velocity and impact forces on itself and contact surfaces.

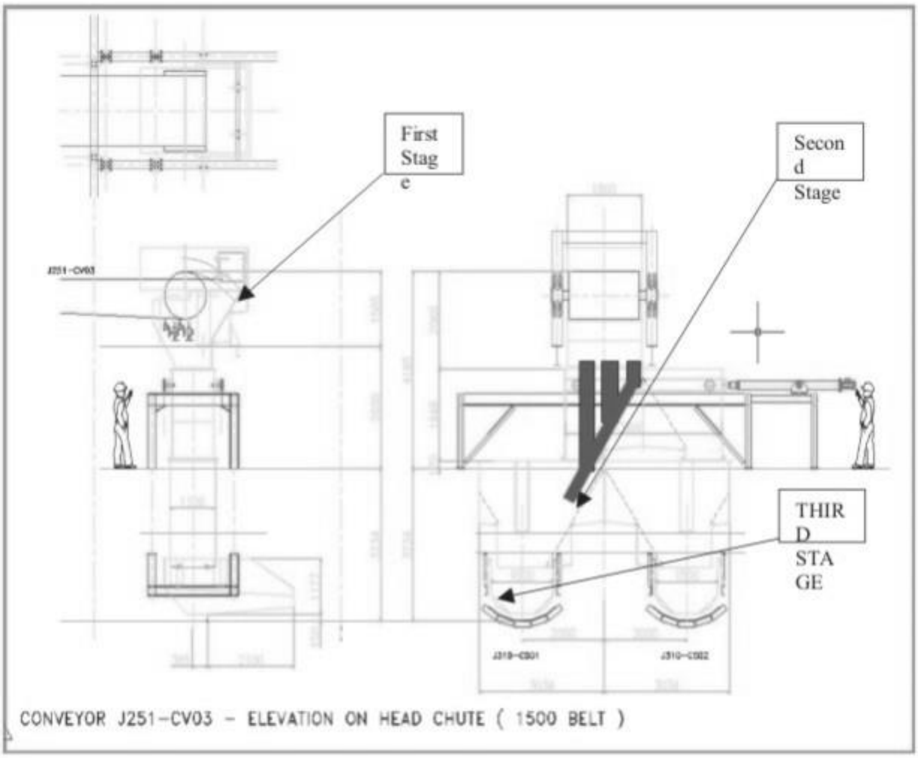
However, typically a conveying system will not have a standard homogeneous product passing through it "requiring that many variations of chute layout must be considered". As noted above at a typical Terminal there will be a multitude of different products transferred on a daily basis with variations in every attribute, including size, moisture content and dust emissions and abrasion gives the products significant flow property variations.

So the confidence associated in computer model predictions, although a basis for the design "is far from acceptable in obtaining a total solution to the acceptance of a total solution".

Obviously discrete element modeling systems can be used at this time in place of the simplified spreadsheet approach adopted for most purposes as seen in figure 3.5.

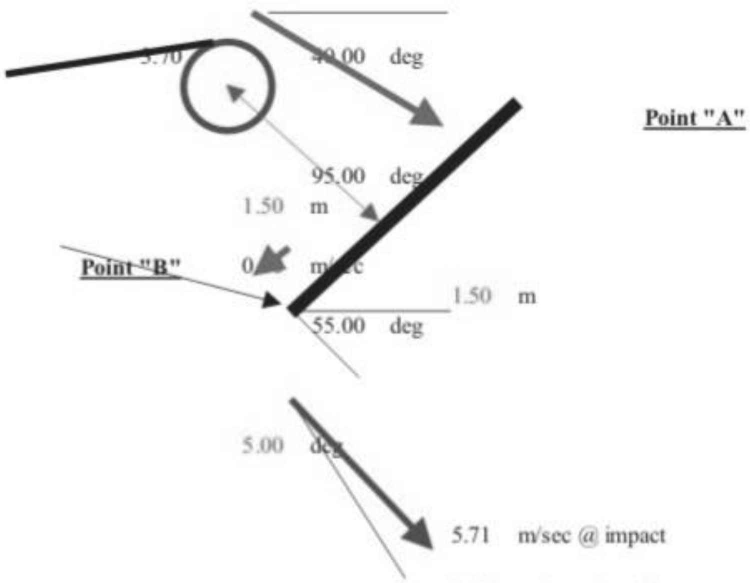
Chute Flow Design

Conveyor J251 Cv 03 on to J310 Cv301 / Cv 302



Input Data :-		**Cv 251 Cv 03**			
	Material Type	Iron ore, crushed			
	Conveyor Length	191.80	m		
	Conveyor Lift	22.40	m		
	Design Belt Capacity	4700.00	tph =	1305.56	kg/sec
	Material Density	2200.00	kg/m3		
	Belt Speed	3.70	m / sec		
	Material Lump Size	-25.00	mm		
Belting :-					
	Belt Width	1500.00	mm		
	Belt Type	Fabric			
	Top Belt Cover Thickness	10.00	mm		
	Bottom Belt Cover Thickness	5.00	mm		
	Rating	1250.00	4.00	ply	
	Fill Capacity	63.99	%		
	Edge Distance	199.01	mm		

First Stage

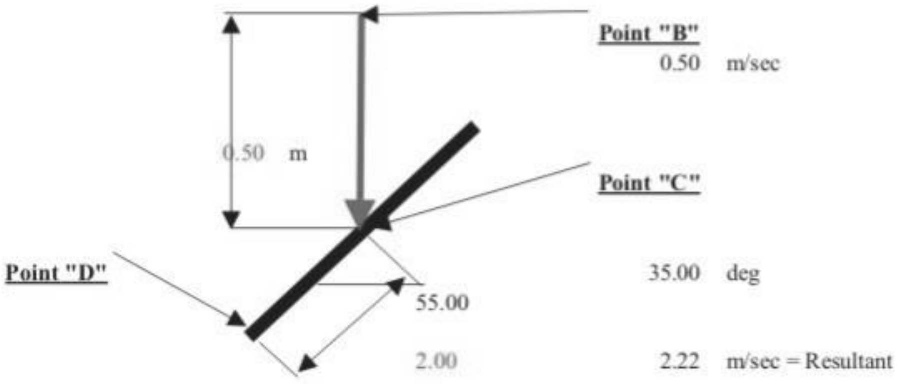


Calculation @ Point "A"
Velocity at Impact = 5.71 m/sec
Resultant velocity = 0.50 m/sec

Force Down Slope = 0.00 N
Acceleration = 0.00 m/sec^2

Calculation @ Point "B"
Velocity @ "B" = 0.50 m/sec **Required CSA Sq m = 1.19**

Second Stage



Calculation @ Point "C"

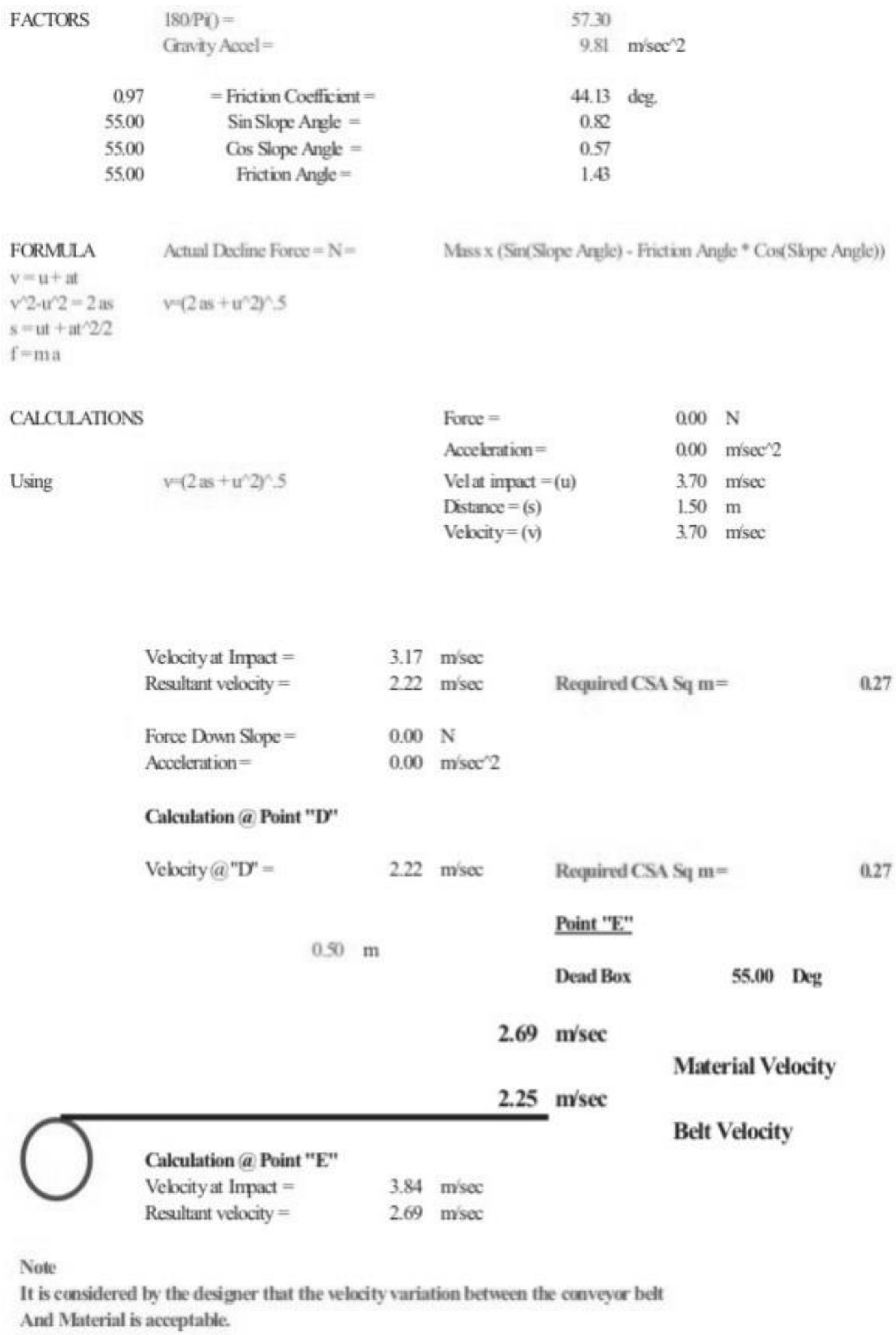


Figure 3.4 – Spread Sheet Approach to Material Flow Analysis

However, with the number of tests, that must be undertaken for a multi product Terminal, one can understand that the required variation in velocity and trajectory, (path), cannot be catered for in an individual design.

The approach of designing for the worst case can often be to the detriment of the overall material flow. To explain this, consider a product range from fine material to lumpy ore. Suggesting that chute angles to prevent build up of fine material will be significantly steeper (70 degrees) than lumpy ore (50 degrees), you may be able to design for the chute to eliminate fine material blockage but applying the same 70 degree chute angles to the lumpy ore will produce high chute exit velocities, uncontrollable spillage and high belt wear.

Using this data provided from material testing Table 3.1, the spread sheet calculations figure 3.4 a velocity profile through the chute can be prepared as follows:-

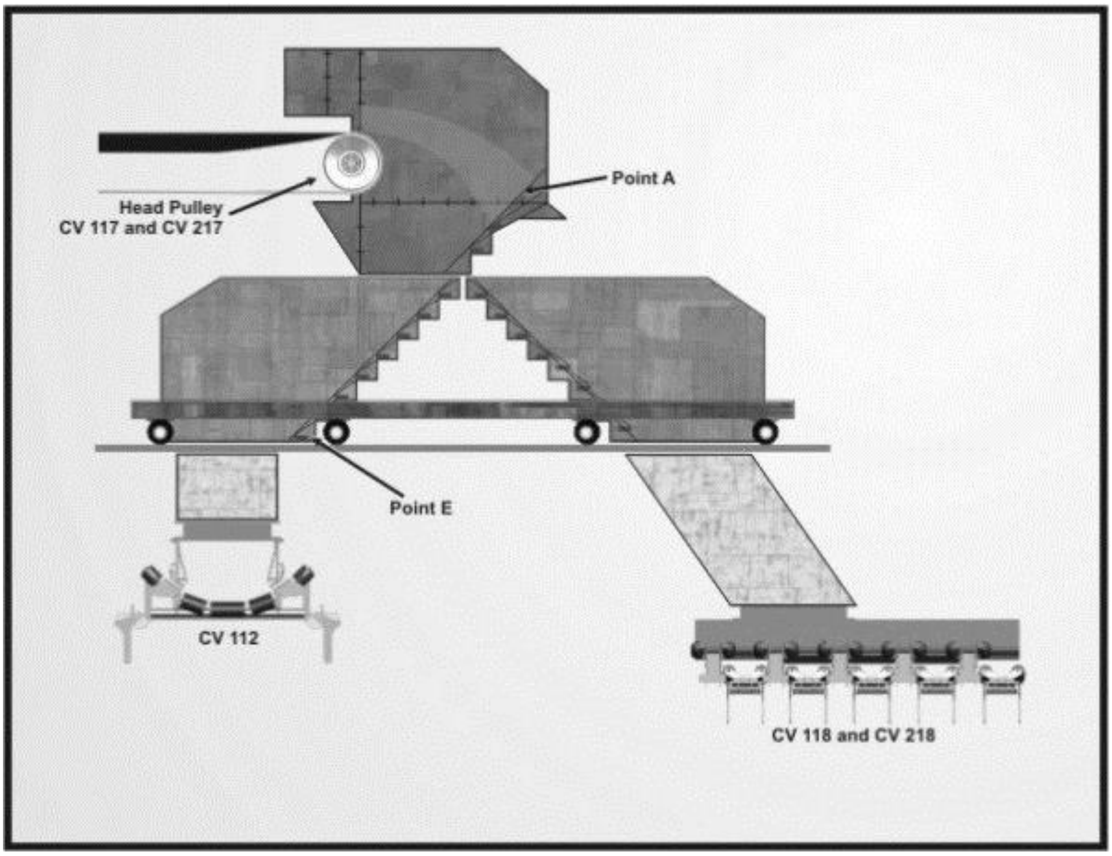


Figure 3.5 – Computer model of chute Cv117 to Cv116 and Cv 117

3.5. TYPICAL MATHEMATICAL OUTPUT

3.5.1. CV 117 to CV 112

The design data employed was obtained from data sheets and drawings provided as follows:

3.5.2. Incoming Conveyor CV117:

Belt width	1650 mm
Velocity	4.2 m/s
Capacity	10 000 tph (at p = 2500 kg/m^3)
Head pulley diameter	1020 mm
Design density	2500 kg/m^3
Inclination angle (discharge end)	2°

3.5.3. Receiving conveyor CV 112

Belt width	1650 mm
Velocity	4.28 m/s
Toughing angle	45°

Capacity	10 000 tph (at p = 2500 kg/m³)
Design density	2500 kg/m³
Inclination angle (receiving end)	0°

The velocity, impact pressures and required areas are as follows:

Point "A"	The stream impact pressure is 19.33 kPa
	The velocity after impact is 0.1 m/s
Point "E"	The velocity is 5.26 m/s
	The requires material section is 0.2112 m²
Point "F"	The stream impact pressure is 6.62 kPa
	The velocity after impact is 2.93 m/s
Point "G"	The velocity is 3.11 m/s
	The required material section is 0.3573 m²

The conclusions from this type of analysis will be as follows:-

- The material velocity in the direction of the receiving conveyor is 1.79 m/s and the kinetic energy caused by a maximum particle of 30x30x30 mm is less than 1 Joule. The pressure on receiving belt is 6.49 kPa.

- From the trajectory plot it was seen that the material impacts low down in the chute on the left hand side. An oversized dead box will be required in this area to guide the material to the centre of the belt.

- At the point of impact on the belt, the material section is 0.65 m² and the available area is 0.9 m². The front part of the chute need to be brought forward to create more space in the acceleration area.

While respecting that there is an analytical procedure available in the market place, we are still in the infancy stage and as stated above applying this approach to multiple products will produce multiple answers, which cannot be catered for with a "one size fits all" approach.

We are in the process of comparing the on site observation and the theoretical results from a typical DEM model but we are far from convinced of the success.
This comparison exercise is considered to be significant in attempting to provide some form of credibility to the new art and not let it drift into the realms of other so-called new technologies, which have no on site benchmarking backup.
The spreadsheet approach indicated above can be considered as a real hands on tool, allowing multiple tests, (materials), to be undertaken quickly and above all cost effectively. The analysis utilizes the application of material trajectory theory which was extensively applied to the free fall portions of the chute. Coupling the analyses techniques, (of material testing and flow velocity calculation), together we were able to prepare a model which allowed us to predict the routing through the chutes and place the necessary liners in the correct places.

4. ALTERNATIVE APPROACH TO CHUTE DESIGN

Section 3 above showed the difficulty in developing a correct solution to the problems of multi product transfers. The end user who, being totally familiar with the problem, still insists on a bottom dollar solution does not assist this problem.
Today we are often reminded that conveyors have not changed in the last hundred years, but, when attempts are made to effect change, we get confronted with, "it's worked for years so why change it" well, we as designers are striving for new developments, as note above, so why not the "intelligent chute".

This is not really a new concept; ship-loading chutes have for years had an adjustable spout. But to now introduce an intelligence level relating chute mass to blockages is a must when one is trying to optimize chute flow to outlet velocity and therefore belt wear.

Figure 4.1 following shows a typical transfer chute expected to transfer the many different products at the port.

Figure 4.1 – Typical Multi Product Transfer Chute

By redesigning the chute to make it flexible at the lower portion one is able to change the material flow angles and make it respond to variations of mass of chute, which will equate to build up in the chute and can then be equated to flow velocity.
Methods of measuring the changes in chute mass can be as simple as pressure measurement on the hydraulic cylinder or for more accuracy a load cell positioned under and supporting the chute. See figure 4.2.

Figure 4.2 – Chute Re designed to Allow it to Pivot with Hydraulic Cylinder

Figure 4.3 – Cut Away of Chute in Back Position (Maximum Flow)

Figure 4.4 – Cut Away of Chute in Front Position (Minimum Flow)

One can see that this type of approach will lend itself to improved control on chute flow, will offer a far more accurate chute blockage warning and will assist with optimization of material flow, even giving inline adjustment to rapid changes in moisture variations.
Also it could have alleviated such catastrophic failures as the one attributed to a possible blocked chute as seen in figure 4.5 below.

Figure 4.5 – Machine Failure May Have Been Caused By a Blocked Chute

5. WEAR PROTECTION

A short section on wear protection of chute work with the aim of defining the correct liner material is discussed, not to advise on the best liners, but to indicate what has been considered in the present projects. The method of minimizing wear was also considered with an extensive review being given to the use of liner materials which protected the chute plates.

The liner materials considered included the VRN range of VRN 400-500-600, (refer to appendix for details). Consideration was also given to lining some areas with Ceramic tiles because of their good wear properties. (Details are given in the Appendix). However due to the difficulty in fixing and relocation of ceramic tiles we do not recommend their use.

Therefore the use of “dead boxes” is considered the most practical method of wear protection; generally the lip liner method was preferred as it allowed ease of replacement and positioning see figures 5.1 to 5.6 following.

Figure 5.1 – Typical head end box

Figure 5.2 – Vertical and Horizontal Shelf Liner (Note the Abrasive Wear Areas)

Figure 5.3 – Funnel Design Step Chute (Used to centre material in long drop areas)

Figure 5-4 – Wear Caused by free fall of ore

Figure 5.4 above shows two liner placements of VRN 400 material, one can clearly see the effect of operating in high wear areas, however what the focus of the above pictures are the ability to see the wear in situ and the ease with which the liner can be modified and replaced.

Figure 5.5 – Wear on high capacity chute allowing material flow routes to be clearly demarcated to allow flow analysis

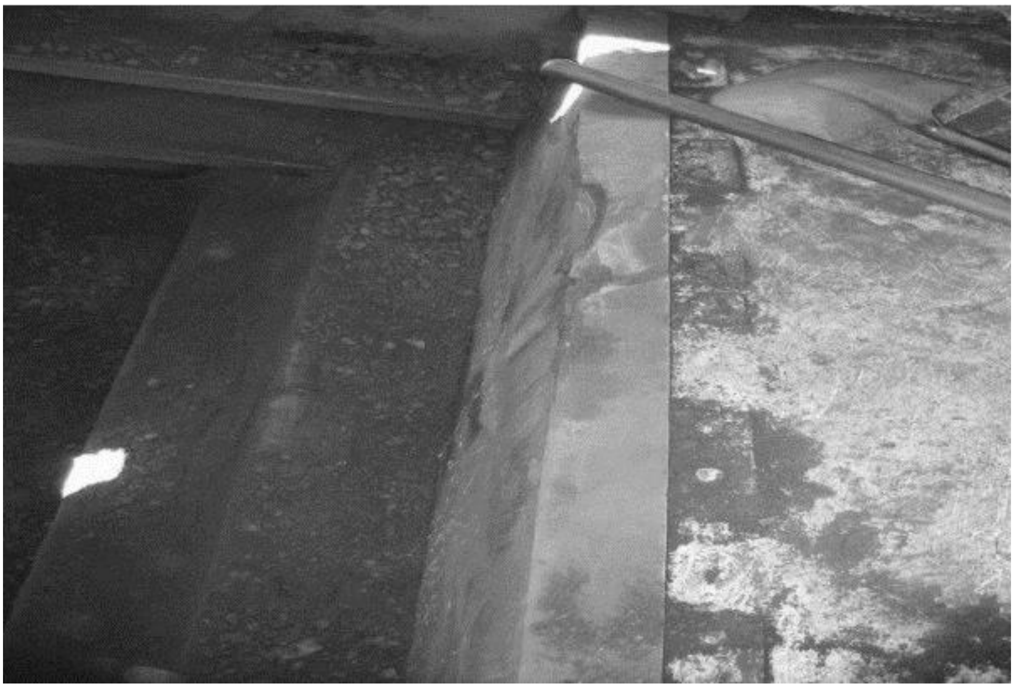


Figure 5.6 – Wear on high capacity chute

6. CONDITION MONITORING

We are all aware of condition monitoring to drives, pulleys and belting, we are about to introduce the idler into this range, but to condition monitor a chute, apart from the ability to check its mass there is little that can be done.
Except to go back to the tried and tested method of visual inspection. However, we all know that a typical chute installation allows little or no access to carry out true inspections.

Access doors appear to be the exception rather than the rule; in fact, one generally sees more of a peephole into a dark chasm rather than a true viewer / inspection / access door.
To day, we are trying to educate the client and engineers into the need for easy removable panels, which lift off, or swing away from the access area allowing the inspector to literally walk into the chute view the wear areas and "effect changes or modifications under easily accessible working areas".

Figure 6.1 – Man access doors for maintenance

Figure 6.2 – Man access doors for maintenance

So understanding that there may be a need to undertake extensive commissioning work, (modifications), on the chute liners it is important to make the inside of the chute easily accessible.
All the chute liners are removable to allow accurate positioning and replacement, with dead boxes being preferred to sliding faces. Obviously when contamination is a problem and chutes must be cleaned between shipments one must be prepared to offer adjustable chutes as proposed in figures 4.2 to 4.4 above.

Typically, we need to feed the centre roll only to obtain a central feed into the conveyor, with these high capacities any off centre feeding will result in belt run of and the associated spillage.
Figure 6.3 below shows a combination of moving head chute to multiple outlets together with a funnel chute for correct material positioning onto the following belt.

Figure 6.3 – Design to feed centre roll

7. ENVIRONMENTAL IMPACT - DUST EMISSION

There were two major considerations when applying the Environmental Impact Assessment, firstly dust emission and secondly noise. Here we will only consider the dust emission problems.

There are four factors, which cause dust; we have long drop heights, poor containment, complications of flexibility and belt speed.

When considering a layout, one is always constrained by the footprint available for construction; normally height is a compromise, which is usually dictated by operatives who have little or no understanding of the complexities of transfer point design.

We are often met with the same constraints which make us opt for moving head constructions for multiple transfers, (in excess of two), as opposed to bifurcated chutes, where constraints were released, we did however utilize diverter cars, (two way transfer), with their associated dead box constructions to effect two way transfers.

However even with moving heads, layouts dictated that we were forced to build some very large chutes with long falls as seen below:-

Figure 7.1 – High chute design to accommodate layout constraints

Convention suggested that for this type of design a more vertical shelf design, (cascade layout), should be implemented, however the variations of product dictated that speed could not be compromised and that applying stops to the material flow may cause blockages.

Also the issue of containment was extensively discussed, operator experience of dust collection units was at best considered to be poor, with the iron ore dust having a considerable impact on equipment life. Therefore, we adopted the containment option of water sprays where possible.

The use of water sprays however had some drawbacks, firstly we are normally restricted to 2% water in the ore, (considering Port Headland in Australia is working with 5 to 7%) and we could not add water after the Sampling Plant.

As one would expect, the addition of water at the transfer point, resulted in the reduction in the dust emission, however it is still considered a major concern, dust on the stockpiles is contained to some extent with water cannons but as we approach the sampling plant and continue on to the Ship Loaders real concern with dust and spillage emissions was evident.

Also after Sampling no water can be added to the ore again making the suppression at the Ship Loader very difficult.

This in itself is detrimental to good materials flow and the associated diversity of the product being transferred through the chute requires too many compromises to make the chute an effective transfer facility.

When opting to use a high belt speed even though this could have a beneficial capital cost the effect on the environment is considered to be unacceptable bearing in mind the high winds and associated high belt speeds causing blow off of dust particles.

Presently we are experimenting with what are commonly known as “Calming Tunnels” which we position directly after the feed in the skirt area. This has the effect of giving the dust laden air a place to escape to but in a controlled environment.

Consideration is being given to variable speed drives for conveyor systems and the possibility will then exist to vary the conveyor speed for the different materials, (high speed for fine ore and low speed for lumpy ore), in principal this concept is worth considering, however variation in material trajectory, (with variation in speed), will introduce further complications in chute layout predictions, especially the correct location of dead box and liner plate.

Shown below, the impact bed has been employed with tremendous success at transfer points, giving consideration to the ability to change the impact idler rolls without any disruption to the skirt / chute arrangement and allowing the rolls to be replaced easily and quickly.

Figure 7.2 – Typical impact arrangement

Also to reduce the amount of spillage between the skirt rubber and the belt, a simple sliding pad arrangement is used, again, with a quick release feature to allow for quick replacement.

The words we as designers are always confronted with are, “zero spillage”, probably we could achieve this but would have to eliminate the transfer point itself. We rather suggest a compromise of spillage containment and look to the operator to instill discipline into its “clean up team” and look to total maintainability in place of total flexibility.

8. CONCLUSION

Environmental Impact Assessments are to-day the norm when considering any new developments, attacking the concerns of the assessment no longer fall on simple design procedures but extensive mathematical modeling to assist in predicting the outcome of the system layout.

Two such models are the DEM material flow model and Dynamic Simulation model. The work undertaken at Saldanha Bay has done much to support the cause of material flow modeling and the work by Bulk Solids Flow has been seen to offer a very acceptable start point in transfer chute layout.

Concerning Dynamic Simulation of plant layout and the concepts of flexibility, as opposed to availability, one must consider flexibility often inhibits the total availability of the system by necessitating the need for highly complex transfer point layout.

The complexity of layout also contributes to excessive spillage, conveyor belt damage, chute blockages and often major structural damage. Even consideration of speed variations for different products may solve some problems but can introduce other more severe issues of incorrect trajectory analysis and dust emission.