Guidelines and Considerations for Open Pit Designers

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Purpose

It is recognised that some of the course participants on the Deswik software "Design for Open Pit Metals" course may be new to pit design and may need some advice on how to undertake a pit design.

This article has been written with that requirement in mind, and has been written specifically for assistance with the aspect of computer aided pit design – i.e. geometric design guidelines. It is not intended to be all encompassing on general pit design and operating principles.

Remember, the software assists the design process not the design itself. The design is controlled by the engineer doing the design.

If you are an experienced pit designer reading this document, and you note a "pearl of wisdom" not included, or believe further explanation or a modification is required, feel free to e-mail me at julian.poniewierski@deswik.com, and I will be happy to include in subsequent updates.

DISCLAIMER

The content in this white paper is intended as a general reference and is made available on the basis that neither the author or Deswik are providing mining engineering, operational or professional advice.

Pit design is, by its nature, driven by site-specific circumstances, including local guidelines and legislation as well as equipment manufacturers' recommendations. Although the information in this white paper was prepared with reasonable care and attention, neither Deswik or the author take any responsibility for the accuracy and completeness of the material contained herein. It may be incomplete or inapplicable to your particular circumstances, conditions or desired outcomes, equipment types, or local mining safety regulations. Users must exercise their own skill and care when using the information, and to the extent the user is not qualified any use of this information should only be done in conjunction with a qualified and experienced professional who can take into account your specific needs and outcomes, and all the surrounding circumstances and factors. Neither Deswik or the author accept any liability resulting from your using, relying on or acting on any information in this white paper. Finally, the material in this white paper may include views or recommendations of third parties, which do not necessarily reflect the views of the author or Deswik.

Introduction

Your company may have a haul road/pit design manual – use it if it exists.

For those that do not have a design manual, or only have limited guidelines, then this article may help you in the process of designing your first pit.

References (most downloadable off the web) are given at the end of the article for more information.

The end-purpose of your pit design will likely be

- Determining Ore Reserves
- Inputting into a schedule for Life-of-Mine planning
- To provide the guidance for the excavation of the pit to be detailed and laid out by the short-term design engineers.

As such your design needs to focus on

- Operational Efficiency (trucking and digging, and maybe drilling)
- Cost Minimization / Value Maximization (less waste, more ore).
- Schedule flexibility (is it practical to schedule and maintain productivity)
- Safety (don't build hazards and risks into the design!)

Expect the process to be iterative – the design may need several attempts to come up with a satisfactory final design. Design may need to be done bottom-up, top-down, or a combination of both.

It's a skill to juggle many competing factors and come up with good designs. You will get faster and develop better designs with practice and experience. Familiarity with process and an operation will improve your ability to design quickly.

On the topic of safety: A good design can contribute to the safety of an operation. A poor design may add unnecessary safety risks. When diverting from standard good practice design principles (e.g. a dual carriage way running width of 3.5 times truck width) – be prepared to defend your design criteria in a warden's court in the event of an accident or even a fatality in the pit.

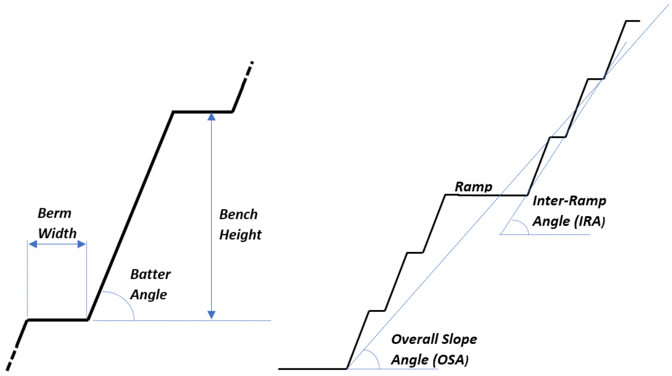
Documenting your design principles and reasoning will help you and future pit designers. Additionally, make running notes during design steps (which will help final documentation, and capture steps that worked and did not work).

First-up: Pit Design Parameters

Before starting a pit design, you will need to know the general expected pit design parameters by material type and/or geotechnical domain, specifically the following:

- Berm width
- Safety Berm width and placement intervals (if requested or required)
- Batter angle (bench face angle)
- Bench Height
- Inter-ramp angle (IRA) limits
- Overall slope angle (OSA) limits
- Ramp width
- Ramp gradient
- Switchback width and gradient
- Minimum Radius for Curves
- Truck Stopping Distances (Loaded & Unloaded – at maximum allowable or achievable speeds)
- Drainage planning needs, including drainage gradients for benches and berms
- Minimum mining width – pit bottom, bench ends, stage cut-back widths
- Preferred effective bench mining width.
- Safety Features required (e.g. safety ramp run-offs; etc.)
- Geotechnical zones to avoid for ramp placement.

Figure 1 Pit Design Terminology Used



Also know the pit optimisation assumptions (Whittle/Psuedoflow):

- How was Overall Slope Angle (OSA) derived?
- Did it include an allowance for the pit ramp? Where in design, how wide a ramp, how many widths of the ramp in a section of wall?

  It may occur that the pit optimisation assumptions no longer match the design parameters very well (e.g. ramp location adjustment to OSA). Thus, it will be difficult to follow such an optimisation shell. And depending upon difference between the pit optimisation shell and the final design, it may be necessary to re-iterate through the pit optimisation stage using the new OSA parameters from the just completed design.

- Check any pit optimisation shells you've been given to base your design on for "vertical edges". These are caused by the pit optimisation process being run on a block model that has not been extended out far enough to encompass the shell that is being created. (It's happened! – if noted return the shell to the pit optimisation person with a polite "fix and re-run" request)
- Check the given pit optimisation shell actual slopes against the OSA that was used in the optimisation process. There is likely a difference – called the "slope error". The optimisation slope values entered into the pit optimisation may not be able to be achieved using the block model dimensions, as slopes are defined by connecting centroids and blocks are then "in" or "out". A large "slope error" may make it impossible to match the shell with the pit design parameters, as the shell slopes themselves may be wrong. (If this is noted – discuss with pit optimisation person, it may require re-running the pit optimisation process with "dependency heights" increased; or it may be considered OK to continue with pit design).

Some things to think about up-front and to think about through-out the design process:

- Generally, design will start from bottom and work its way up.
- Sometimes you may have to do some of design from top down and work out how to join the two designs. This will almost certainly happen where you have a preferred pit exit point for a ramp.
- Look at previous designs to see what previous designers have come up with
- Think about where ramp should exit bottom to access areas higher up with minimal waste stripping.
- Where should ramp(s) exit at top of pit?
- Should I have multiple ramps for productivity and safety (but at what extra stripping cost)?
- Can I backfill an area with waste to avoid haulage to a surface dump?
- Can I use backfill to access an area?
- Can I place a ramp in an area/wall that will be long-life and used for multiple stages/cut-backs (e.g. the footwall of a stratiform deposit) for which it will then be worthwhile building good quality roads (e.g. good road base and sub-base)?
- Some ramps may be temporary (e.g. providing access for drill rigs and blast trucks or access to pumps and infrastructure – not just for haulage)
- Think about scheduling implications if cutting off access to an area with a later stage design (first area must be completely mined before being cut-off, which may result in scheduling problems).
- Slice pit optimisation shells to have as a guide contour for each bench
- Similarly, be able to have a block model slice of ore – colour coded for value or grade – for each bench

- Slice significant geology wireframes (shears, faults, dykes) by bench for use in design process.
- Potentially may want to design a "good-bye" cut at bottom (an excavation "trench" of ore by a backhoe excavator without an access ramp, dug retreating from the excavation with trucks backed up to excavator).
- Design pit and ramp to minimize loaded truck travel times and minimize trucking costs from a maintenance perspective as well as an operating perspective (and accept that this is a compromise for unloaded truck return hauls).

String Number and Conventions

- Determine site conventions for pit design polyline colours and line-types.
  - For example, different colours and line types for crest lines, toe lines, mid-wall lines, survey actual lines (topography), and ramp edge lines. For example, may use dashed lines for toes, solid lines for crests, dotted lines for mid-height design lines.

Berms and Safety Berms

- In large deep pits, a safety berm (extra wide berm) may be required intermittently (every say 6 benches) and being of a width to allow access for rill spillage clean-up

Ramp Design

Just to re-iterate, this article deals with computer-aided pit design, and the inclusion of the ramp in that design. It does not deal with details of construction, maintenance and operation of a ramp – except where the computer-aided pit design impinges on those aspects. Nor does this article deal with the requirements for design of high speed surface roads. A number of references at the end of this article can be consulted for this type of information.

A good criterion for a good haul road design (and maintenance) is the operator should be able to leave the loading face and drive to the dump location with their foot flat to the floor for the whole trip (except where reaching imposed safety speed limits).

Design requirements for line-of sight on horizontal and vertical curves are touched upon, but have not been considered in detail in this article. For more information on this see USBM IC 8758 and Thompson (2015). The stopping distance of trucks (loaded uphill and unloaded down-hill) should however be known and considered if pit design walls are obstructing the view ahead. Note that "line-of-sight" may also need to take into account the "sight" of lasers and other sensors being used in autonomous truck navigation (specifically this can be a problem at pit ramp exit and a gradual change from pit ramp gradient to flat will be required).

Some of the following listed design items will change if using automated trucks and/or trolley assisted systems – these have not been considered in the following list of guidelines.

OVERALL LONG-TERM PIT DESIGN VS. OPERATIONAL DESIGN

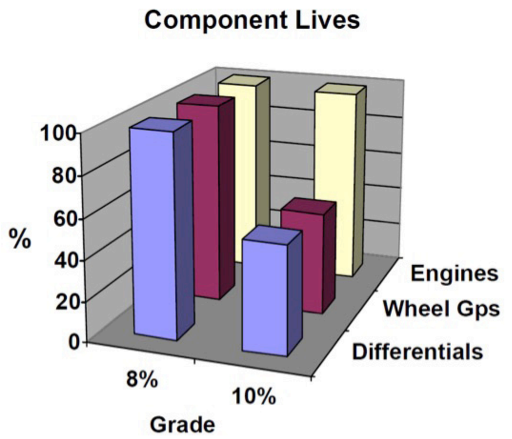
- In long-term pit design we generally do not worry about operational details such as road camber and cross-fall, but we need to make sure these issues can be dealt with within our design at an operational level.
- Pavement Thickness: While normally not necessary to consider in most pit design exercises, in poor ground conditions (particularly wet tropical deep weathered soils and clays), the road pavement depth for a properly constructed road can be up to 3 m deep. This will need to be accounted for in the geometric pit design (road will need to be cut lower than the road as built).

RAMP GRADIENT

- Check for any laws or regulations controlling permissible gradients in the local jurisdiction of the mine (State/Provincial/Federal)
  - For example: the Western Australian DMIRS traffic management audit guidelines (DMIRS, 2016) point 3.5 states: "Confirm that road gradients do not, so far as is practicable, exceed 10%."
- Find out what gradient the operation wants, or insists on.
- 10% (1 in 10) gradient is a general accepted standard in Australia for rigid body dump trucks. However, in North America, an 8% (1 in 12) ramp gradient is common for operational and maintenance reasons.
  - The 10% gradient commonly used may be causing significant unrecognized maintenance costs. For many mechanical drive trucks (e.g. a Cat 793C), a 10% grade, with a 2.5% rolling resistance will place the truck in a rimpull curve position such that with just minor aberrations/variations in the road surface (e.g. 10 cm "bump" over a 5.9 m wheel base that results in grade change of 1.9%), or variations in the load, the truck will be hunting for a gear change (down to 1st gear, or up to 2nd gear). At 8% gradient, the truck speed is right in the middle of the 2nd gear range and can thus handle road surface aberrations better.
  - On a 10% gradient ramp that is suffering from gear "hunting", the operators will be required to lock the truck into 1st gear which will then impact on the overall average travel speed.

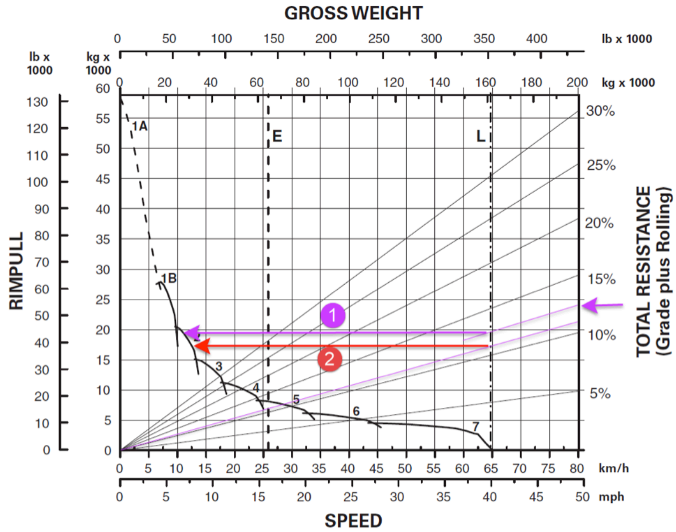
This gear change issue and resulting power surges are the likely cause of a major recognised component cost difference shown in Figure 2. The component life of differentials and "wheel group" components (bearings, breaks, axle, etc.) are halved when ramp gradient is increased from 8% to 10% (so costs are doubled, and availability reduced).

Figure 2 Change in Component Lives for Truck Major Maintenance Cost Components for Ramp Gradient of 8· vs 10· ·Source· Caterpillar·



- If using a gearless electric drive truck, then this 8% vs 10% issue disappears.
- Use of 8% vs 10% ramp will likely result in increased stripping ratio (or a different OSA for the pit optimisation input and therefore a different selected design shell), but truck operating costs for a deep pit (and therefore mining costs input into the pit optimisation) with an 8% ramp will be lower (primarily due to the lower maintenance costs, as the higher speed along an 8% ramp is countered by the extra travel distance – resulting in similar cycle times). A full scenario analysis of pit optimisation, design, scheduling and costing would be needed to determine which is more cost effective over the Life-of-Mine.
- In summary, if you know the truck type being used, and the rolling resistance of an operation, take a note of gear change speeds in the truck rimpull curve and avoid a steady state gradient that would result in a speed that "hovers" around a gear change location. Avoid such a gradient for long sections of ramp in the design. For example, Figure 3 below, a 10% ramp with 2.5% rolling resistance is shown by line "1" (total resistance = 10% + 2.5% = 12.5%) that it is near the gear change point, whereas the centre of the 2nd gear position shown by line "2" is around 11% total – so for a 2.5% rolling resistance road, implies a 8.5% to 9% ramp is a good choice for a constant grade ramp for a 777D.

Figure 3 777D Rimpull Curve · Comparing Total Resistance of 12.5· vs 11·



- Articulated 6-wheel drive trucks can handle higher gradients of say 12% (or 1:8.)
- Intersections of ramps should be flat with lead in sections (one truck length) flat also. Note that Western Australian DMIRS traffic management audit guidelines (DMIRS, 2016) point 4.4 states: "Gradients greater than 2-3% are to be avoided" for intersections.
- Do not design 12% final bench access ramps in pits using rigid trucks. Some designers will design a 12% ramp for the final couple of benches in a pit, thinking that it will help increase ore recovery in pit bottom, for minimal inefficiency with the trucks. However, a 12% ramp will result in two unintended consequences:
  - (a) Light loading of trucks due to truck otherwise reaching stall conditions on high rolling resistance sections.
  - (b) Light loading of trucks due to increased rock fall off back of trucks if full loading attempted.

  Leave the 12% option for the operation to decide upon when they get to the bottom. Don't build it into the long-term design.

RAMP WIDTH

- Width is a function of largest truck in truck fleet to be used – specifically the truck width.
- Design recommendations (Holman, 2006; DMIRS, 2016 - point 3.2, Kaufman W.W. & Ault J.C. 1977.) for minimum road “running width” are

  = 3.5 times truck width for 2 way ramp straight (see example in Figure 4)

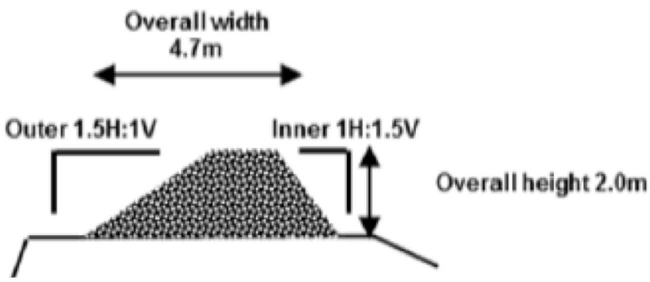
  = 4 times truck width for 2 way ramp corners.

  = 2 – 2.5 truck width in one way straights and corners.

  - Note; Origin of these recommendations is US Bureau of Mine Information Circular 8758 (Kaufman W.W. & Ault J.C. 1977), originally published in 1977.
- Add provision for safety bund – at minimum of half tyre height (see example in Figure 4)

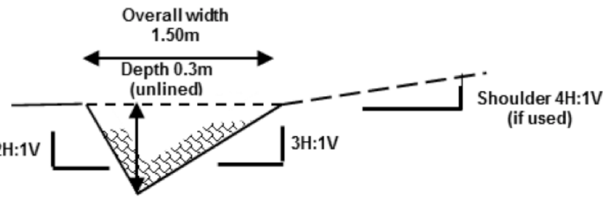
  NB DMIRS (2016) audit guidelines point 3.14: “Any windrow should be determined by risk analysis, but should be at least half (50-66%) the wheel height of the largest vehicle operating on that road.”
- Add provision for drain: width allowance will be a function of rainfall to be dealt with. Drains are typically V-ditches, with side slopes typically 3H:1V on the inside against road shoulder and 2H:1V on the outside, with a minimum depth of 0.3 m (giving a 1.5 m width – see example in Figure 6). Depth and width however are functions of rainfall environment and could need to be much greater.

Figure 5 Example of a windrow design



(source: Thompson, 2015)

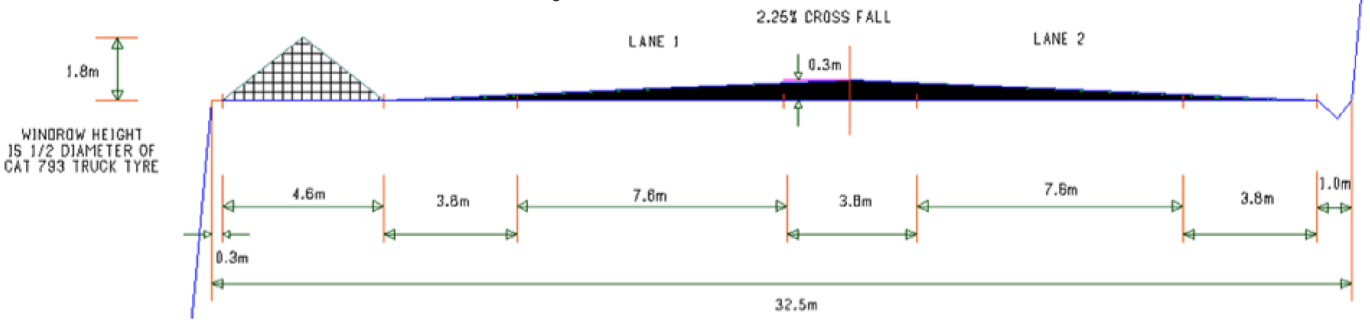
Figure 6 Example of a drain width design



(source: Thompson, 2015)

- Further width allowances may be required to allow for:
  - Consistently wet and slippery roads (wet tropic mines)
  - Inexperienced drivers (high turn-over mines; non-traditional mining jurisdictions with large local workforce)
  - Foggy conditions
  - Erosion and potential fall-off
  - Potential to add a median windrow for traffic separation.
- Bottom 2-3 benches are often designed at one-way ramp width. If doing this, consider parking and passing areas for trucks awaiting access to shovel (on switchbacks for example).

Figure 4 ·below· Example of a ramp width design for a Cat 793 ·7.6 m truck width·
·Note smaller drain width than recommended in this set of guidelines·



DIRECTION OF TRAVEL / DIRECTION OF SPIRAL DECLINES

- Where possible (and it is not always possible), design ramps in a pit to be clock-wise upwards (when loaded-hauling upwards).
  - This allows the trucks (which are left hand drive) to drive loaded upwards against the pit wall (with trucks driving on left-hand side of road). Having the driver's cabin on the outside of the road allows the driver to spot the road edge – especially important during night shift. Having the loaded truck against the wall means that less weight is placed on the likely less stable ramp edges. Additionally, truck components such as steering, wheels, axles, bearings, brakes are more likely to fail under full load and being further from pit edge is safer with respect to uncontrolled movements when such failures happen.
  - Obviously, switchbacks will reverse this design intent, but the trucks will still be running such that the driver can easily see the road edge. Maximise the time/distance trucks are travelling clock-wise upwards.
  - Some pits, in countries that use left-hand drive cars and therefore drive on right hand side of the road, will prefer trucks follow the general road-rules convention (avoids confusion). But this is still recognised as not being as safe as driving on left hand side of road – such that some right-side driving countries will swap convention to left-hand side of road in their open pits in order to increase safety.

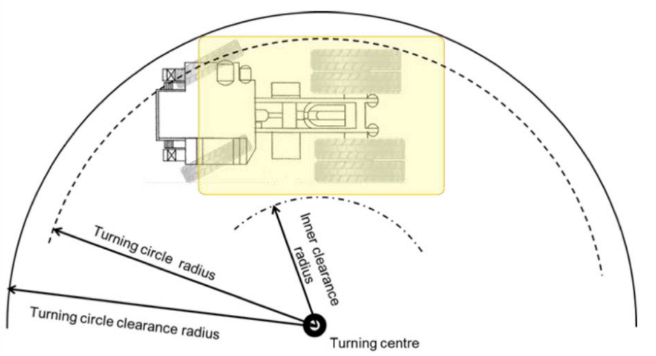
GEOTECHNICAL FACTORS

- Talk to the geotechnical engineer. Know the geotechnical risks. Especially weak shear zones with a high risk of failure that are best avoided putting a ramp in.
- Jointing in an area may mean that the crest of ramps in that area are regularly lost, requiring extra width in the ramp for safety.

SWITCHBACK/CURVE WIDTH AND GRADIENT

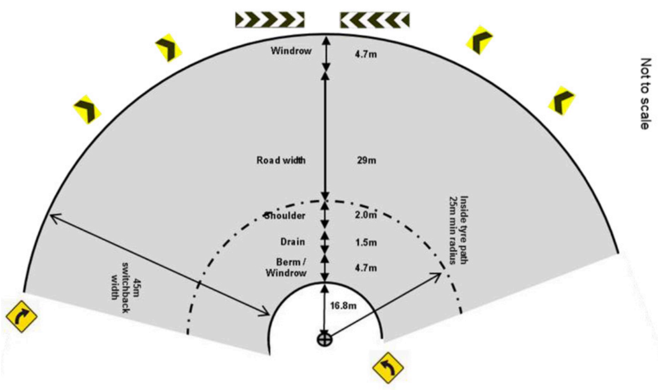
- Switchbacks should be designed with an inside ramp string radius to give a minimum inside tyre path radius of at least 150% of the minimum turning circle inner clearance radius of the truck being used in the pit. (See Figure 7 for definition)
- Flat switchbacks are preferred. But still check that they have sufficient turning circle room on the inside lane. Flat switchbacks provide the least load on the trucks drive train, and in a mechanical drive truck will likely still cause a gear change but this is at least fairly non-aggressive.
- If a switchback is designed on grade, the gradient on the inside windrow curve radius should be set to a gradient flatter than the ramp grade by 2-3% to compensate for increased curve rolling resistance.
  - Think about how a loaded truck is going to negotiate the inside of any switchback
  - The geometry of a graded switchback will still cause gear changes simply because it is not possible to have a constant grade on both drive wheels.
- Where possible design switchbacks co-incident with a berm so that the turning radius is increased without penalizing the waste stripping ratio more than necessary.
- Width of a switchback is usually increased by 0.5 to 1.0 truck widths greater that the width of the straight ramp sections. This is to avoid collisions of overhanging parts of trucks.
- In practice these flat switchbacks will be built up in use with some super-elevation or at least 2% cross-fall for drainage.
- A larger radius curve can be far more operationally efficient that a sharp switchback – particularly for long life ramps. Use largest radius possible, and keep constant and smooth.
- Note that poorly designed curves result in slower cycle times and higher overall costs.
- An example of all the design elements required to be considered for a switchback are shown in Figure 8.

Figure 7 Turning radius definitions



(source: Thompson, 2015)

Figure 8 Example of Switchback design elements all considered ·7.25 m wide truck·



(source: Thompson, 2015)

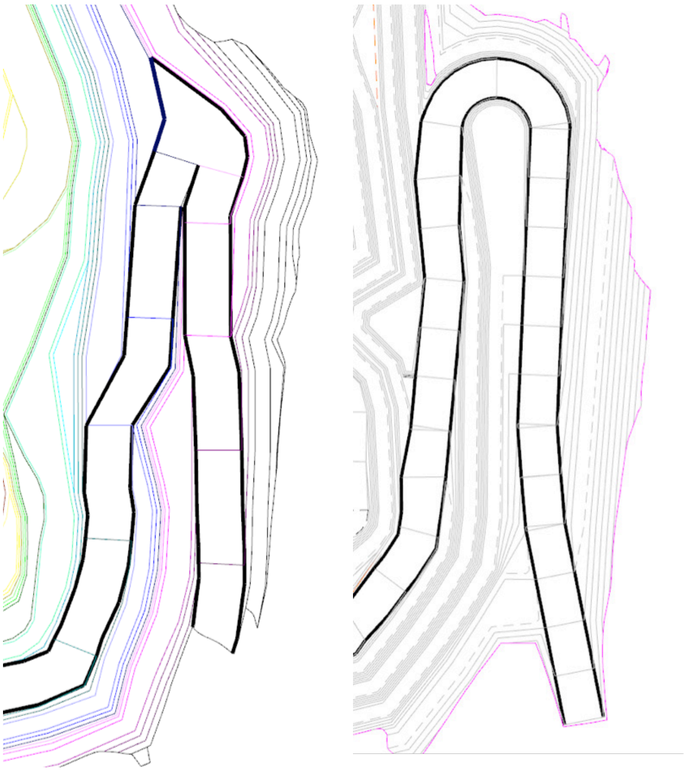
CENTRE-LINE VS SHORTEST-EDGE LINE

- As a default - use the shortest edge option in 2-way ramp design. Using centre-line based design options around curves and switchbacks can result in extremely high gradients on inside lanes of a dual carriage ramps. (see https://www.linkedin.com/pulse/truck-says-centre-line-gradient-ramp-designs-julian-poniewierski/)
- Centre-line option can be used in single-lane ramp design (although still better to consider the inside tyre path radius as the design gradient)

STRAIGHT ROADS / STRAIGHT WALLS

- Keep ramps and walls straight or at least as smooth curves. When designing a pit and following pit optimisation shells, the expanded projections can start to feature "wobbles" and "kinks"– straighten or smooth these out before continuing the design process, as shown in Figure 9.

Figure 9 Example of ·wobbly· ramp ·left· straightened out ·right·



RAMP-BERM INTERSECTION

- Design crest and toe strings for a ramp-bench intersection that reflects reality at an operation. Recommendation is to flare the ramp width such that it provides access onto a berm.

RAMP RUN-OFFS

- May be a required safety feature. Ask. May be covered as an intermittent extra wide "safety berm".

OTHER RAMP SAFETY CONSIDERATIONS

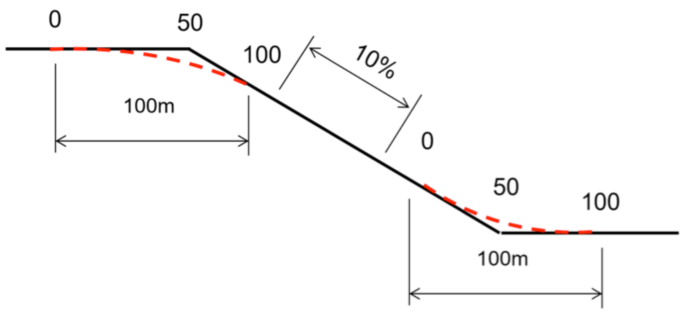
A number of safety issues in design have been discussed already.

"A safe system acknowledges that humans are fallible, error is inevitable, and that when it does occur the (mine haul) road system makes allowance for these errors so as to minimize the level of hazard associated with the risk." (Thompson, 2015)

Some additional safety issues for consideration in the pit ramp design are

- Sight distances along the ramp must ALWAYS be more than the stopping distance (rule-of thumb: use twice the stopping distance). The issue will be obstacles on the ramp in the same lane as the path of the truck – such as broken-down equipment (trucks, graders, passenger vehicles, etc.) or a large fall of rock that could take out a sump!
- In particular, corners and crests (see Figure 10) must be designed such that machine operators are capable of seeing and avoiding hazards when travelling at normal operating speeds
- Intersections should be made as flat as possible and should not be constructed at the top of ramps.
- Sharp horizontal curves should be avoided at the top and at the bottom of ramps.
- To maximize safety, corners and crests must be designed such that machine operators are capable of seeing and avoiding hazards when travelling at normal operating speeds.

Figure 10 Example of a vertical curve change at ramp gradient change to maintain line of sight



(source: Caterpillar design presentation)

OTHER SCHEDULING CONSIDERATIONS

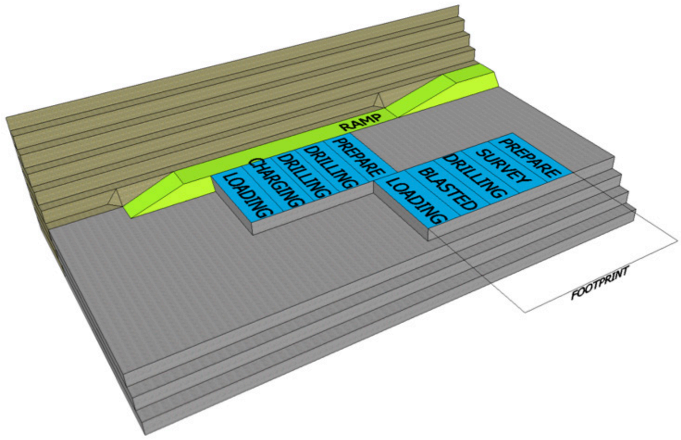
- A ramp that accesses a bench mid-way along its length will allow mining on at least two fronts - in opposing directions - increasing the rate at which the bench can potentially be mined. If there are any extra-large benches in a cut-back – then such ramp positioning will help pit productivity.

Pit Ramp Exit Location

- Close to waste dump – to minimize waste haulage? Waste tonnage likely to be much higher than the ore tonnage.
- Close to mill – to minimize ore haulage?
- Two exits? One for waste, and one for ore?

Hilly or Mountainous Topography

- In hilly or mountainous terrain, if a ramp is placed in a wall that is on the uphill side, or below steepest slope, a significant amount of waste will be added to your design. Where possible put the ramp on the downhill side, or under lowest rise in topography.



(Source: Jordaan, 2011)

Minimum Mining Widths

- Three issues to consider:
  - Pit bottom minimum width,
  - Stage minimum width
  - Specific area in a bench access width – ends of benches etc.
- Geometry provides for the relative number and productivity of available working areas
- What is the truck turning circle? What is shovel swing radius?
  - One suggested minimum mining width (pit bottom) = truck turning circle + width of safety berm
  - Another = swing circle of a shovel + a ramp width + width of safety berm
  - A suggested minimum bench width = swing radius of a shovel + truck turning circle + width of safety berm. Double this will allow two working faces in the cut-back bench.
  - A truck must be able to clear a loader under full acceleration.
- Is there room for the working room and a temporary bypass ramp? (allowing multiple benches in cut-back to be mined? Or designating it as a single bench only mining area)
- Bucket width limits/Bucket reach limits?
- Are trim blasts being used, and at what width? May need to be added to width of working room on the primary blast in a bench.
- A suitable work area size calculation can be done by determining and summing the safe and efficient areas required for all related activities in the pit, as per Figure 11.

Figure 11 Example of set-out for of working room calculation in a pit for Minimum Mining Width

Curved walls or Straight Walls.

- Some people like walls in straight sections (Note: these are easier to layout, blast and dig)
- Some people like smooth curved walls (Note: can be relatively easy to do in oxide material, but how do you blast a curved wall in hard rock? Blast hole spacing may be 5+ metres, so your curve is really a set of straight lines)

Stage Designs

- In general, design the final pit first, then deal with the earlier stages. May requires some iterations as potential stage synergies are understood.
- Examine if sections of current final ramp can be used for any of earlier stages as well.
- Can stage interactions be separated by alternately designing successive stages on opposing sides of pit?
- Can staging be designed to allow in-pit backfilling – avoiding hauling all waste to surface?
- Is a “launch pad” for and underground portal required, and at what stage of mining will such access be required?
- Avoid thin triangle intersections or “wedges” between the edge of one stage to the edge of a subsequent stage or final pit (see Figure 12). These can be unsafe to excavate.

Figure 12 Unsafe Stage Intersection ·left· vs. Safe Stage Intersection ·right·

- Talk to the geotechnical team. It may be desired to use an internal stage to test and trial more aggressive slope parameters prior to committing to a final design. Back analysis of slope failures in an early pit stage will provide a more reliable understanding of slope stability limits.

- Running operating ramps under rill slopes or scree filled berms caused by cut back staging is not recommended. There is an inherent safety risk, or a cost penalty from running small equipment to clean up berms. If the issue cannot be scheduled out or designed out, then placement of large scale catchment berms is required. One solution is to design a "fat" ramp in the inner stages – as used at Cadia (Mumme and Pothitos, 2006). This is to design the ramp to be a combination of "catch berms and ramp to maximise the time benefit of catch capacity, allow schedule flexibility and remove the risk of access to normal berms for clearing by allowing for contingency" (Mumme and Pothitos, 2006).
- Ensure stages have mining dimensions that allow for efficient equipment utilization.
- Is a stage wide enough to allow placement of a temporary ramp to allow multiple bench mining in the stage? If not, a whole bench will need to be mined before next bench can be mined, significantly reducing the mining capacity of the pit.

Pit Dewatering and Drainage

- Are there any design requirements to establish a successful pit dewatering strategy?
- Examine terrain map and design for surface water drainage to be kept away from pit.
- In high rainfall environments, it is recommended to use inclined benches and inclined berms (latest versions of the software include this option in the design tools). A 3% incline appears to work well (e.g. at Lihir).
- Think about where sumps and drains may be required to be placed – and if design changes are needed to accommodate these. It is common to locate a sump at the end of a drain at a switchback, and to allow safe access to that sump for pump maintenance.
- Think about how a water catchment may be able to be established early in the pit development.

Checking the Design Surface triangulation

- Colour the surface triangles by dip (Draw | Solids | Triangle Slope Markers). This will highlight areas that may be out of specification. (see example in Figure 13)
- Cut a set of close contours – say every 1 m – and inspect contours to see if there is a triangulation aberration (see example in Figure 14)– especially with the ramps where contours should be parallel on straights and systematic in changes elsewhere. (Draw|Solids|Slices: Plan/Fixed Spacing/Increments = 1.0/Data Extents)
- Rotate designs in 3D to confirm all looks OK.
- Compare Ore and Waste tonnes to pit optimisation shell. Provide feedback to pit optimisation person/team.

Figure 13 Example of coloring a pit design to check on application of design slopes

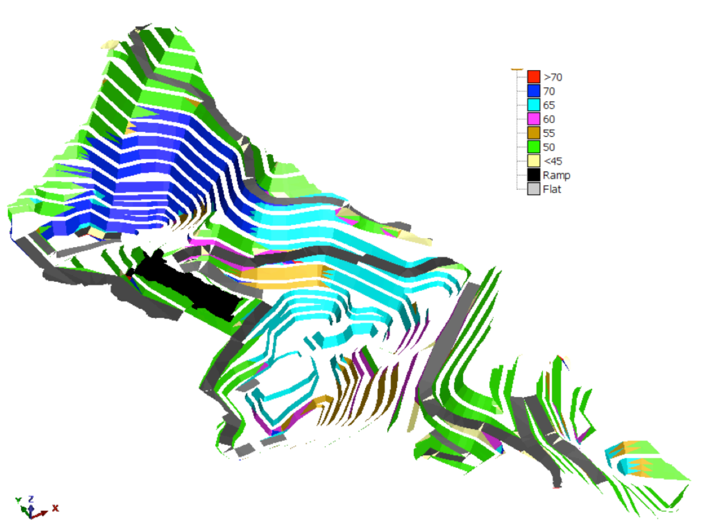
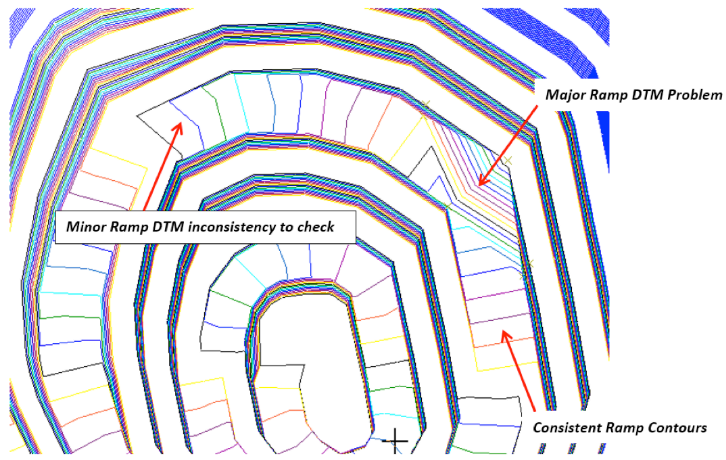
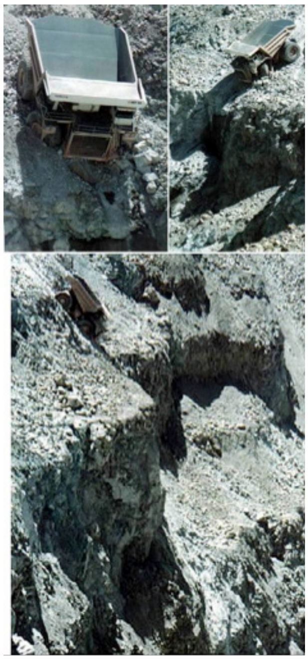


Figure 14 Example of slicing a pit design to check on triangulation and ramp



Photographic Examples of Issues

Why we have windrows



Source of above photos: unknown

Truck damage from poor ramp designs causing stress on steering frame and axles

Source of above photos: unknown

LEFT-SIDE LOADED PIT RAMPS AGAINST WALL

This is the preferred arrangement when possible:

(St. Ives Gold mine, Australia)

(Freeport-McMoran site, USA)

LEFT-SIDE LOADED PIT RAMPS AGAINST THE VOID

This is the less preferred arrangement (but can be unavoidable due to switchbacks)

(Chuquicamata).

(Kalgoorlie Super-Pit)

Source of above photos: unknown

RIGHT-SIDE LOADED PIT RAMPS AGAINST VOID

This is the least preferred (least safe) arrangement:

(source: Mining Mayhem website, site unknown)

FLAT GRADIENT SWITCHBACK

(Oyu Tolgoi) - Source: unknown

A POOR SWITCHBACK

(unknown and best left anonymous)

BUNCHING

An example of truck bunching up a ramp:

(Grasberg, Indonesia) - Source: unknown

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