

# Rock slope stability and snow disposal capacity optimization, St-Michel Quarry, City of Montréal

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## ABSTRACT

The City of Montreal manages large volumes of snow every winter and presently uses a former limestone quarry as snow disposal site. The quarry is more than 60 m deep and have dimensions of around 1500 m long by 300 m large. The disposal method uses docks located on the quarry edges to allow trucks to back-up and dump the snow. An Alternative method is to use larges snow blowing machines that enable to increase potential snow volume but at higher costs. [A1]

The present paper is divided in two sections, the first part addresses the rock slopes stability underneath the docks, while the second part covers snow disposal methods in relation with optimal volume and costs. The slope stability was address using a survey carried out by a drone, and the data interpreted by software in order to identify the structural discontinuities in the rock mass and to identify among other things, potential sliding blocks and long-term stability of the rock wall. Stability results were used to assess existing docks stability and to propose new docks design.

The second part of the study address the snow disposal capacity optimization. The study looks at several punctual docks versus one continuous dock and compare construction costs along with volume capacity available by snow dumping versus snow blowing considering the specific angle of friction of snow.

## RÉSUMÉ

La Ville de Montréal utilise une ancienne carrière de calcaire pour la disposition des importants volumes de neige récupéré annuellement dans les rues de la ville. La carrière a une profondeur supérieure à 60 m et des dimensions d'environ 1 500 m de long par 300 m de large. La Ville utilise présentement des quais qui sont localisé le long de la paroi rocheuse qui permettent aux camions de déverser la neige de façon gravitaire. Une méthode alternative est l'utilisation de souffleuses à haute puissance qui permettent d'augmenter le volume neige entreposés dans la carrière à des coûts toutefois supérieurs à la méthode par gravité.

Cet article est divisé en deux parties, soit l'étude de la stabilité des parois rocheuses servant de fondations aux quais, et la seconde partie implique l'étude des volumes de neige dépendant de la méthode de disposition, du volume optimal et des coûts. L'étude de stabilité des parois rocheuses a été réalisé en utilisant un relevé par drone et les données ont été traités au moyen d'un logiciel qui permet l'interprétation de la géologie structurale de la masse rocheuse de façon a identifier des potentiels plans de glissement et à adresser la stabilité à long terme de la paroi.

La deuxième partie couvre l'aspect optimisation de l'entreposage de la neige. L'étude compare l'utilisation de plusieurs quais ponctuels à un grand quai continu, en regards aux coûts de construction, au volume d'entreposage en tenant compte d'un angle de repos de la neige mesuré au site.

## 1 INTRODUCTION

The St-Michel quarry is located on the island of Montreal, in the Province of Québec, Canada. This former limestone quarry is now used a snow disposal by the city of Montreal. The project was divided in two parts, first a stability study was carried to assess the long-term stability of the rock slopes. Secondly, an optimization study was carried in order to evaluate the volume of snow that can be disposed according to different unloading docks configuration.

This paper describes the geotechnical aspects of the rock slope stability study and the design of the new docks. Also, it describes the volume optimization of the snow compared with different type of docks.

## 2 PROJECT DESCRIPTION

The snow disposal docks are installed along the rock slope of the former Francon limestone quarry, which is now known as the St-Michel quarry located on the Montreal island (see figure 1). The city of Montreal has built since 1981, several structural docks in order to allow snow disposal into the quarry. A total of 14 docks are spread along the quarry edge as showed on figure 2.

The quarry is 60 m deep and the rock slope is divided in three 20 m high ledges. However, the area of dock no. 14 was excavated without ledges. Figure 3 shows a typical rock slope section.

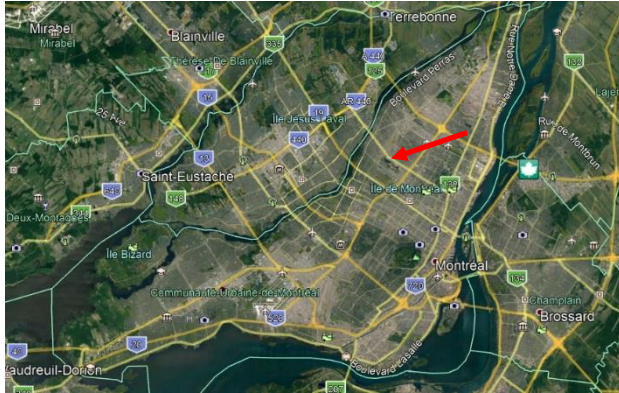


Figure 1. Project location on the Montreal Island

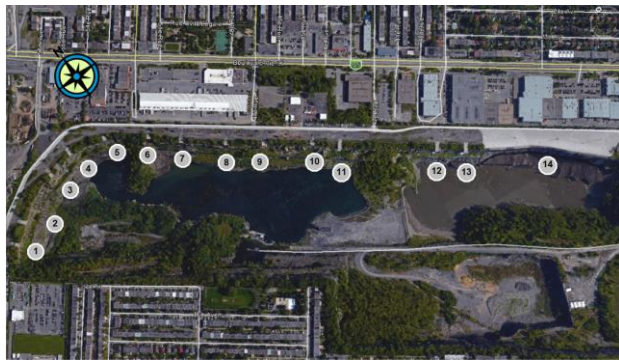


Figure 2. Quarry plan view with dock numbers

For safety reasons, some docks were closed, thus limiting the disposal capacity of the site. The City of Montreal requested a study to increase disposal capacity. The present paper discussed to initial reasons why docks were closed and also showed the results of the volume optimization carried.

### 3 GEOLOGY

#### 3.1 Regional geology

The quarry rock slopes are composed of sedimentary rocks of Ordovician Age from the Montreal formation and part of the Trenton Group [A3] (Globensky, 1987). The rock mass consists of an alternating of shaley limestone with thin black shale (< 5 cm). The rock mass is cut by several sills and dykes of various thicknesses and of Cretaceous Age. These intrusive structures are generally related with the Mont-Royal intrusion. Those geological conditions are usually observed uniformly throughout the site. The water table vary greatly around the site and the quarry form a vast drain that lowers it, as water seepage are observed on the rock slopes as shown in figure 4.

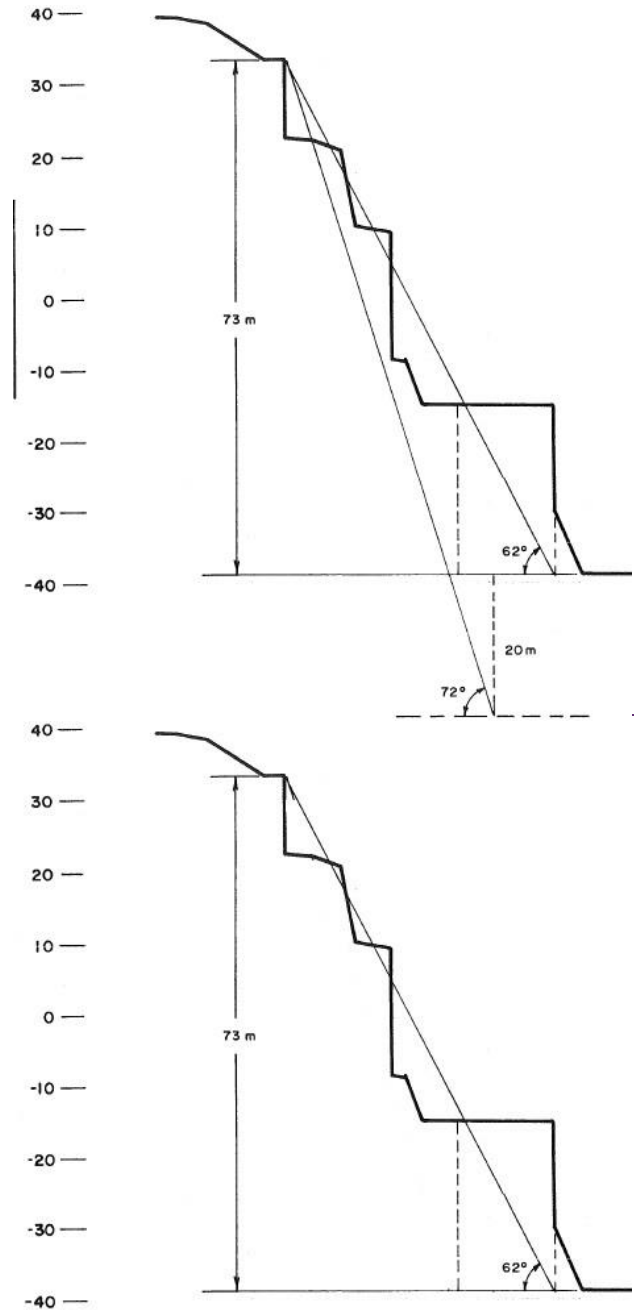


Figure 3. Typical cross section [A4] (taken from SNC, 1983)

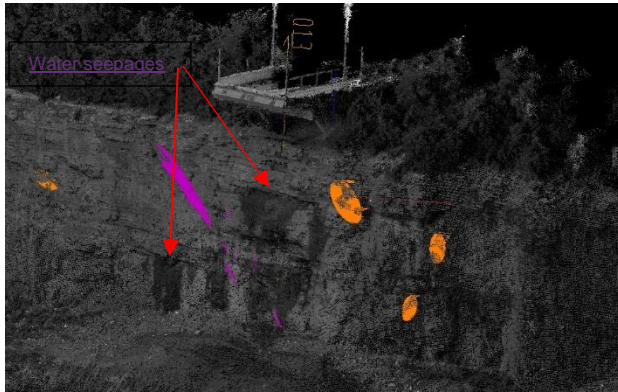


Figure 4 – Water seepage on rock slope, dock 13[A5]

### 3.2 Rock mass structure

The rock mass is cut by at least three joint families that are described in table 1. Families no. 1 and no. 2 are sub-vertical and family no. 3 is sub-horizontal and represent the sedimentary bedding.

Table 1. Joint family

Family	Dip Dir. (°)	Dip (°)	Spacing ± (m)
1	70 - 90	80	0.5 - >3
2	320 - 340	90	1 - >3
3	Sub-horizontal	0	0.1 - 0.5

It can be seen in table 1, that only family no. 1 has a dip of around 80° and may form possible sliding blocks. Family no. 2 is more steadily vertical and more prone to toppling.

Table 2. Summary of rock mass properties

Parameter	Value range	Quality	Recommended value
RQD (%)	82 - 100	Good to excellent	85
C <sub>0</sub> (MPa)	54.9 - 90.5	-	55
RMR (%)	51 - 82	Average to very good	-
Q	1.1 - 14.2	Poor to good	-
Friction (°)	30; 49; 57	-	34

Table 2 present a summary of the rock mass mechanical properties that were observed and measure from geotechnical boreholes and laboratory testing. The rock mass is of poor to very good quality.

## 4 GEOTECHNICAL ASPECTS

Rock slope stability was addressed using existing geotechnical parameters presented in section 3 along with a thorough drone survey to obtain the rock face geometry

with enough accuracy to interpret fracture intensity and orientation.

### 4.1 Drone survey

The drone survey consists of a photogrammetric survey covering the whole quarry rock slope supporting the docks. The survey was carried with a point density close enough to be able to interpret the structural condition of the slope using a rock fracture software. The software SplitFx was use in this study and allowed the authors to carry a structural mapping and to produce stereonet for each dock foundations. This was done without having to go manually measure the joints on the faces, which have saved a lot of time and allow to obtain much more data. Cross sections were produced for each dock.

### 4.2 Rock slope stability

A structural study was carried in order to identify the typical type of instabilities presented in figure 5. The figure shows four instability types, toppling, buckling, plane sliding and circular slides. The circular slide does not control since it was established that the safety factor of this instability was in excess of 5, since the failure circle needs to pass through intact rock blocks. Thus, the first three instability types were examined in this study.

Figures 6a and 6b show a typical structural interpretation. Also, figure 7 presents a typical stereonet result. In that case, a stereonet was produced for the area of dock 8 and 9, which are close together and present similar structural features. In figure 7, only family no. 1 and no. 2 are shown. Since family no. 3 is the sub-horizontal one and is fairly obvious and well distributed across the rock mass, it was not presented into the model. Only potential sliding joints were modelled keeping in mind that the geometry of potential sliding block will be controlled by family 1, 2 and 3 altogether.

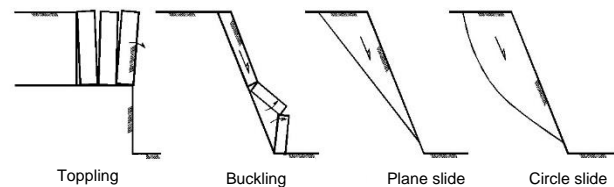


Figure 5. Type of instabilities[A6]

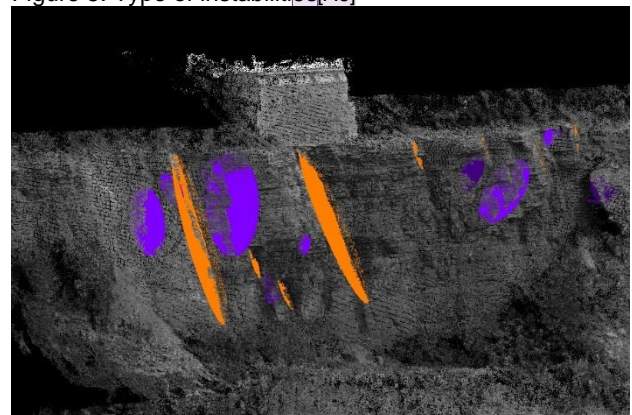


Figure 6a. Typical drone survey with fracture interpretation

Dock no.	Foundation state	Risk level	Possible instability type		
			Toppling	Buckling	Sliding
1	Very good	I	N	N	N
2	Good	I	N	N	N
3	Average to good	to II	Y	N	N
4	Good	I	N	N	N
5	Average to poor	III	N	Y	Y
6	Average to good	to II+	Y	N	N
7	Average	II	N	Y	Y
8	Good	I	N	N	N
9	Average to poor	III	N	Y	Y
10	Average to poor	III	N	Y	Y
11	Average to poor	III	N	Y	Y
12	Average	II	N	N	Y
13	Good to very good	I	N	N	N
14	Good but locally poor	I	N	N	N

(Dock no. 9)

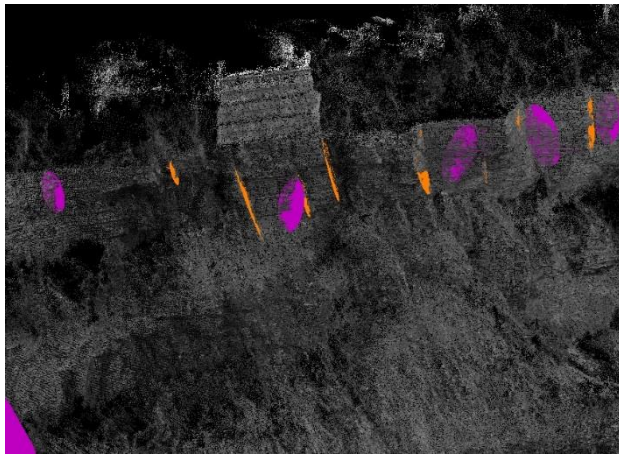


Figure 6b. Typical drone survey with fracture interpretation (Dock no. 7)[A7]

Figure 7 shows that family no. 1 is very well grouped and present slight variations, while family no. 2 is a little bit more spread. Also, a couple of random joints are visible on the figure.

The structural analysis and state of docks foundations assessment was carried out for each dock in a descriptive way, in order to be able to compare the docks together. So, the fracture density underneath the dock was described, their orientation and the possibility of a typical instability to be controlling is summarized on table 3.

Table 3. Summary of dock foundation

DOCK 8 - 9

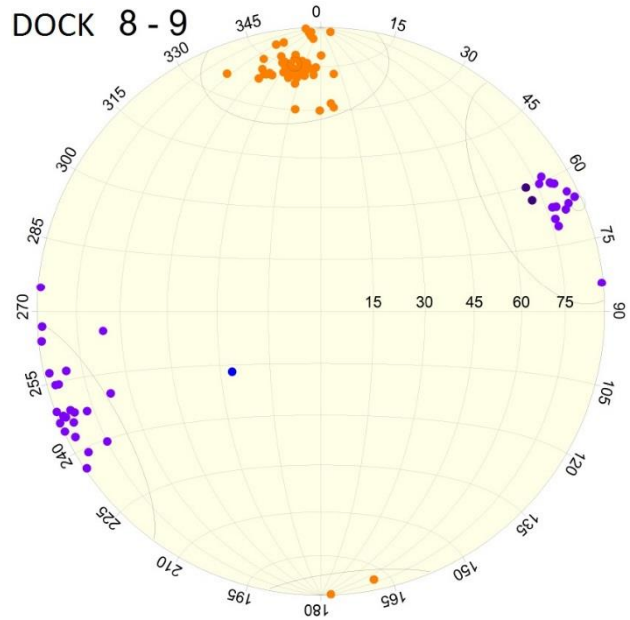


Figure 7. Typical stereonet results for area of dock 8 and 9

It can be seen on table 3 that a level of risk was assigned to each dock depending on the degree of fracturing, the likelihood of typical instabilities to occur. Risk level I is the lowest and level III is the highest. It was established that docks no. 5, no. 9, no. 10 and no. 11 are of risk level III and therefore present unacceptable conditions for long term safe operations.

## 5 DOCK REPAIRS VERSUS SNOW MANAGEMENT

Given the results of the analysis of section 4, the area between dock no. 8 and dock no. 11 was the object for an optimization study that compared dock construction costs to volume of snow that can be achieved depending on the type of docks.

### 5.1 Type of docks

Two types of docks were examined, punctual dock and continuous dock. Punctual docks are a single dock that can be used by one truck at a time and the truck dumps the snow down by gravity. The other type is the continuous dock that can be used by several trucks at a time, also dumping by gravity. The continuous dock allows for another method of snow disposal, the snow blower which does not use gravity but requires instead considerable energy to throw the snow further away from the rock slope thus providing more volume for snow disposal.

First in order to stabilize the rock slope on a long-term basis it was recommended to carry an excavation of the upper part of the slope. The objective of this excavation

was to remove any unstable sliding or toppling blocks and also to provide a better slope geometry for the snow to slide down to the quarry bottom. Figure 8 shows a typical cross section of the recommended excavation. In order to minimize overbreak, this excavation would be done using a tight line drilling [A8] that would not be loaded with explosives and would provide a weak plane break.

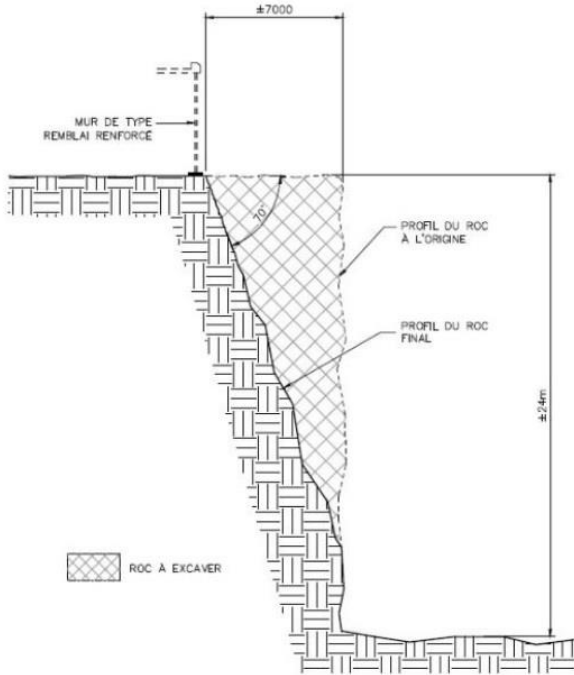


Figure 8. Recommended local excavation

Figure 9 shows a typical punctual dock structure which mainly overhangs above the slope and anchor to bedrock. Figure 10 presents a typical section of the continuous dock that would be composed of mechanically stabilized earth wall built along the slope excavated edge.

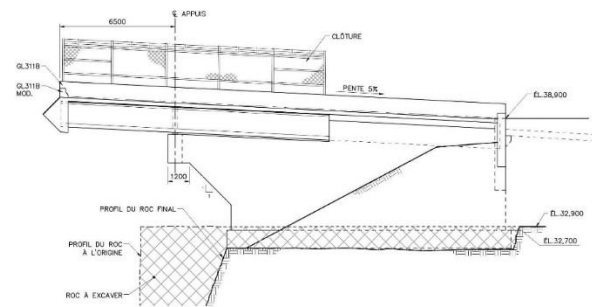


Figure 9. Typical punctual dock

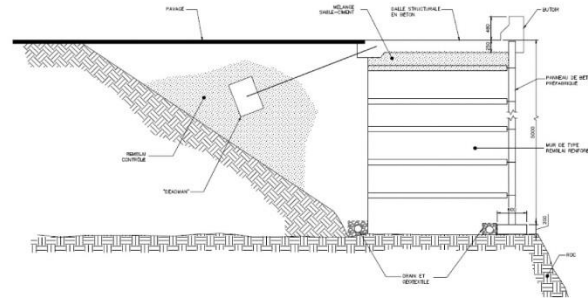


Figure 10. Typical continuous dock

## 5.2 Available volume

The volume of snow was calculated using the observed angle of repose of the snow which was set at  $36^\circ$  from horizontal. Based on that angle, two snow volumes were calculated, the first from punctual docks and the second with the continuous dock. Also, the blown volume was calculated assuming that first the gravity cone was filled and then the snow is blown above the gravity cones just like the section shown on figure 12. Figure 13 presents a plan view of the proposed continuous and punctual docks.

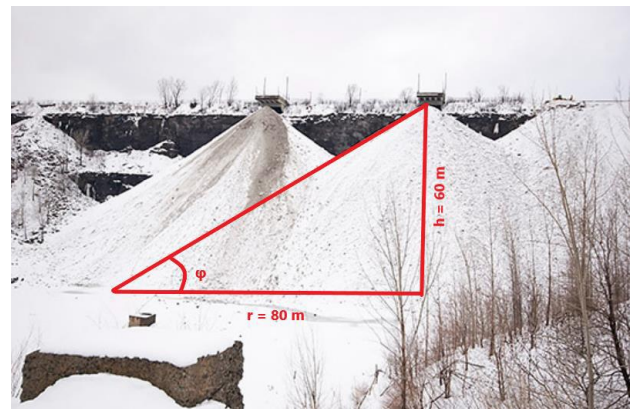


Figure 11. Angle of repose of snow

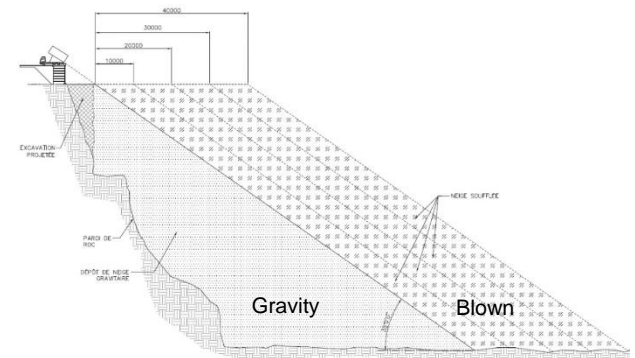


Figure 12. Typical section for snow volume calculation, gravity versus blown



Figure 13. Plan view of punctual docks versus continuous dock

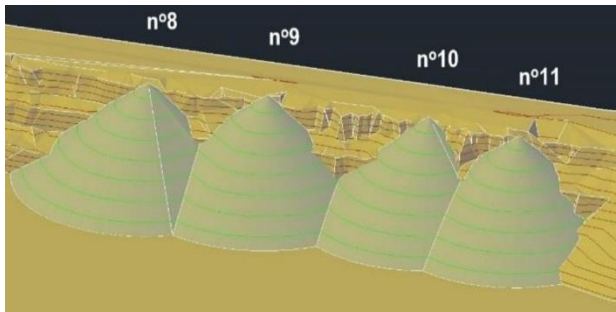


Figure 14. Geometry of gravity snow cones from punctual docks

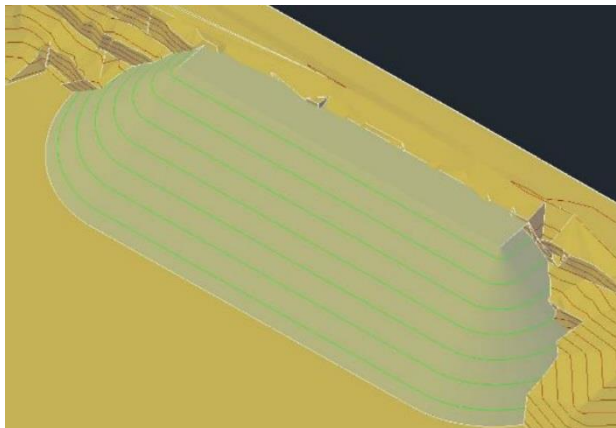


Figure 15. Geometry of gravity and blown snow stacks from continuous dock

From figure 14 it is possible to observe that four truncated cones are formed by gravity from the punctual docks. This also shows the available space in between the dock that is basically lost.

The continuous dock allows for continuous gravity loading, so there is no gap of space in between. Also, it allows for the snow blower to perform and throw the snow further away from the rock walls and thus allows for more volume of snow to be disposed of.

### 5.3 Optimization

Volume optimization was carried using total construction costs for new docks versus the available volume, compared with unit costs of snow disposal with both gravity and blown methods. Unit cost for gravity snow is 0.25\$/m<sup>3</sup>,

while unit cost for blown snow is 1\$/m<sup>3</sup>. The life No. 11 new docks was set at 75 years.

Based on these numbers, table 4 was prepared. Table 4 shows that the continuous docks offer twice the volume than the punctual docks. However, the continuous dock costs double of the price of the punctual dock to build. Therefore, the last column shows the unit costs No. 11 based on 75 years lifetime. Unit costs for the continuous dock is twice the unit cost of punctual dock, but continuous will provide twice the volume.

Table 4. Summary optimization results

Dock	Gravity Vol. (m <sup>3</sup> )	Blown Vol. (m <sup>3</sup> )	Total Vol. (Mm <sup>3</sup> )	Construction cost (M\$)	Unit cost (\$/m <sup>3</sup> /y)
Continuous	790 000	550 000	1.34	8.15	0.65
Punctual	649 000	0	0.65	3.3	0.33

These figures provide the City of Montreal with guidelines for decision takers, in order to make an enlighten choice of dock design.

## 5. AKNOWLEDGEMENTS

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### References

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SNC, 1983, *Site de déposition de la neige, Étude de stabilité de la paroi Est, Carrière Francon, Montréal, Québec. Pour Ville de Montréal, Novembre, 98 pages*