Rows of vertical steel-silos filled with debris – an effective and space-saving avalanche defence structure

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Abstract: Multiplate steel configurations, primarily used for road tunnels and culverts, are introduced as effective, flexible and space-saving avalanche defence structures. Silos of specified height and profile are filled with debris and located in rows or any actual defence pattern. The self-bearing vertical structures have fixed spacing for any given snowdepth and slope-angel. The layout, foundation, height, cross-section and quality of steel are adjusted to the internal and external dimensioning loads. Steel-silos are space-saving and more flexible than alternative defence structures of comparable efficiency, especially on sloping ground. They are also much faster and normally cheaper to construct than defence structures erected by concrete, stonewall, geo-textiles or steel fabrics. A variety of layouts and uses of multiplate corrugated steel profiles in avalanche mitigation are suggested.

Keywords: Avalanche mitigation, defence structure, multiplate steel-silos, breaking mounds, dams, ploughs

1. Introduction

Conventional deflecting and catching dams and mounds are space consuming, especially on sloping ground and snow and avalanche deposits along their inclined slopes drastically reduce their effect. To improve the effect of these structures, the front and sides are often erected of stonewall, geo-textile, steel fabric etc. Time-consuming procedures for construction and compaction of backfill add costs to the expenses of the selected material in these cases (Fig. 1).

Planning mitigative measures above the avalanche endangered residential area of Bolungarvík, Iceland, compelled considerable innovative work because houses are located on the lower part of the steep slope (Jónsson and Hestnes 2001, Jónsson et al. 1999, 2001). An important finding was that rows of vertically erected corrugated steel-silos showed to be an effective and space-saving alternative to conventional dams and mounds.

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Fig.1 Ten metre high mounds erected by steel fabric in Neskaupstaður, Iceland (Photo E. Hestnes)
In avalanche protection works, corrugated steel profiles have primarily been used for road and railway tunnels through loose deposits. The idea of using prefabricated silos filled with debris was invented in seeking new solutions for optimising the efficiency and costs of breaking mounds on steep slopes (Jónsson et al. 2001). After the breakthrough it was also understood that vertically erected steel tubes or silos might be arranged in any convenient pattern for retarding, deflecting and stopping avalanches. It was further realised that appropriate cross-profiles and sizes already were merchandise and additional designs could easily be tailored.

Any available material can be used as fill in such silos and they are easily dimensioned for the internal forces exerted by compacted fill. The cost of the silos can be optimised by reducing the wall thickness with increasing height above ground. Cross-profiles with almost flat section facing the avalanche is preferable in most cases. The size and form of the cross-profiles can be optimised based on the actual height and design of the protection work and the expected dynamic loads (Fig. 3).

The silos have to be located on stable horizontal platforms. An excavated periphery with about 30 cm of compacted gravel under the steel work may normally offer a satisfactory foundation. Special foundation or anchoring may be necessary or preferable when the constructions or dynamic loads are high.

3. Advantages of vertical steel-silos

The unequalled advantage of steel-silos is the self-bearing vertical wall with fixed spacing for any given snowdepth. Secondly, they occupy less ground than alternative mitigative measures of equal efficiency, especially on sloping ground. Consequently, they are also environmentally favourable. And thirdly, silos are flexible merchandise, easily transported and very fast mounted. In addition, cost estimates indicate that steel-silos are cheaper than comparative structures made of stonewall, concrete, geo-textile or steel fabrics supported by compacted backfill.

4. Principle design of mounds and dams

Steel-silos may be erected both on horizontal and sloping ground. Mass balance between excavation and in fill is normally sought on inclined terrain. Compacted platforms might sometimes be preferable or necessary (Fig. 4a).
Silos may also lead to a new era of breaking and catching dams on steep slopes and where space is limited. The silos may be put up side by side or with certain spacing, depending on the intended effect (Fig. 4c). Distance to endangered objects will be of importance in this context.

Deflecting dams and ploughs are also easily constructed by steel-silos. In fact, using silos puts an end to the eternal problem of splitting avalanches on slopes, as the vertical top wedge will be especially effective on steep terrain. Silos may be used for splitting avalanches even when the wings are made of debris. Layout, size of cross-section and orientation of the long axis of the silos, should be adjusted to solve the specific problems at each location (Fig. 4d).

The distal side of the top part of silos may preferably be constructed 1:1.5 to reduce the height and environmental impact of such constructions. Neutral colours may also be used.

Both dams and mounds made by steel-silos have been recommended for avalanche protection during the 2001. However, none have yet been built. The lack of practical experience and theoretical studies of the interactions between silos and avalanches evidently invites the scientific community into numerical research and model studies for optimising the dimensioning and use of silos.

5. Volumetric comparison of alternative designs

Although the effect of mounds and dams of different design may be questioned, a volumetric comparison of selected layouts of supposedly similar efficiency, is presented. In this context, the following assumptions are made: Proximal gradients of 1:1.5 and 3:1, requires additional heights of 20% and 10%, respectively, compared to vertical sides. These approximations are primarily based on recent work by Jónsson et al. (1999), Jóhannesson and Tómasson (2000) and Hákonardóttir et al. (2001).

When space or gradient are the main limiting factors, silos are an alternative to earth dams. Primarily, they are flexible, space-saving and cost-efficient alternatives to mounds and dams erected by stonewall, concrete, geo-textile, steel fabrics etc. Examples of transverse and longitudinal cross-sections are illustrated. The design part above the snow-covered ground is supposed to have the same efficiency for these mounds (Fig. 5a-b). The differences in size and layout on a 20° slope are visualised in figure 6.

The surface area of erected sides and volume of fill of comparative constructions having basic height 11.5 metres and effective length 140 metres, are estimated and summarised in Table 1.

![Table 1: Estimated surface area and volume of fill for comparative constructions](image)

![Fig. 5 Cross-sections of mounds of assumed same efficiency on slope of 20°](image)
6. Preliminary cost estimates

Comparing the cost of mounds and dams partly built at different locations and partly based on defined assumptions, does not give a fully correct picture. However, the cost of the defence structures shown in figure 5a-b has been estimated based on available unit cost of merchandise, concrete constructions, transportation, excavation, loading, layout and compaction of fill, as well as estimation of man hours.

It is assumed that in-situ fill material is available on sloping ground, i.e. mass balance is achieved. Local transportation of fill is included for building defence structures on horizontal ground. Choosing the cost of steel-silos as a unit, the estimated relative costs of comparative structures are shown in Table 1.

Lack of mass balance will increase the cost of huge earth fills unfavourably compared to vertical silos, especially on sloping ground.

7. Future uses in avalanche protection

Multiplate corrugated steel structures may also be competitive to other steel fabrics, geo-textile, concrete etc. for lining the proximal side of earth dams (Jönsson et al. 1999). Such walls may be given any desired cross-profile. The upper part of walls may even be

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Table 1: Surface area, volume and relative cost of comparative constructions

<table>
<thead>
<tr>
<th>Construction</th>
<th>Mound 0°</th>
<th>Mound 20°</th>
<th>Dam 0°</th>
<th>Dam 20°</th>
</tr>
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<tr>
<td></td>
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<td>m³</td>
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<td>m²</td>
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<td>-</td>
<td>-</td>
<td>-</td>
</tr>
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<td>9500</td>
<td>1.00</td>
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<td>15000</td>
<td>1.83</td>
<td>3000</td>
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<tr>
<td>stonewall</td>
<td>2700</td>
<td>15000</td>
<td>1.18</td>
<td>3000</td>
</tr>
</tbody>
</table>
given a concave design like a snowplough to improve the efficiency of the dam (Fig. 7a). The corrugated steel walls can be anchored in the backfill. The effect of such designs in avalanche protection has not yet been evaluated.

Steel-silos linked together with cylindrical or elliptical half-shells of corrugated steel without backfill, is a cost saving alternative when dynamic loads do not exceed the strength of the corrugated steel-archs (Fig. 7b). As a matter of fact, this solution should be an optimal design for many dams. Corrugated steel-shells may also successfully be used at the top of ploughs for splitting the avalanches (Fig. 7c).

The multiplate corrugated steel profiles are foretold to have an interesting future in avalanche mitigation work. They are flexible to use, their employment being limited only by the lack of new innovative designs.

8. Conclusions

Corrugated multiplate steel-silos are space-saving and cost-efficient alternatives to mounds and dams erected by stonewalls, geo-textile, steel fabrics etc. Their flexibility and efficiency in breaking, splitting and stopping avalanches are unequalled. Steel-silos linked with half-archs without backfill are even more favourable when load does not exceed the strength of the shells. The proximal side of dams may also be given a concave profile by such plates.

Due to the lack of practical experiences and theoretical studies on these promising defence structures, the scientific community is invited to contribute to numerical research and model studies for optimising the dimensioning and layout of bolted multiplate steel configurations in avalanche mitigation.

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10. References


Tubosider. Corrugated steel load bearing structures and pipes. Tubosider Italiana s.p.A, Corso Torino 236, 14100 Asti, Italy.

ViaCon. ViaCon MP200. ViaCon as, 2215 Matrand, Norway.