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CONSIDERATIONS FOR WINTER CONSTRUCTION OF MECHANICALLY STABILIZED EARTH (MSE) WALLS

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Abstract: For over 50 years, since the invention of the Mechanically Stabilized Earth (MSE) walls in France, this type of wall has been constructed to fulfill a variety of crossing and retaining solutions, including applications from simple retaining walls supporting roads, true bridge abutments, to very complex dam structures. As the demand for infrastructure increases, to meet with project schedules, there exists a greater need for the construction of MSE walls without interruptions over the installation period, which includes the winter season. Although this practice has been avoided, in part due to the multiple challenges presented by harsh Canadian winter conditions, MSE walls have proven their flexibility to meet any construction schedule and condition, in part due to the development, by the inventor company of MSE walls, of construction guidelines for winter specifications. The purpose of this paper is to identify the main challenges faced in the construction of MSE walls during Canadian winters, and to suggest solutions for mitigating the effects of those challenges. Among them, the following have been identified: (a) Considerations in Design through the Selection of Backfill, (b) Manufacture of Concrete Panels, and (c) Challenges in Installation, subcategorized into (i) Health and Safety, (ii) Backfill compaction, and (iii) Materials storage. The main conclusion is that with the proper construction methodology, MSE structures can be designed, produced, and installed all year round.

1 Introduction

The construction of Mechanically Stabilized Earth (MSE) walls most often is carried out during moderate weather conditions. In recent years, demanding project schedules, especially for large Public-Private Partnership projects, have proposed for the option of constructing MSE walls in winter conditions. Previous studies of MSE walls under winter conditions, as led by the inventor company of MSE walls, focused their efforts in the determination of the effects of ice sheet impact, for example, for MSE walls in coastal regions, and the prevention of frost heave in the reinforcement zone of the backfill. *Robinsky and Mora (1979)*[1]*, Mora being a founding member of the Reinforced Earth Company Ltd.,* identified that the tension forces experienced by the reinforcing strips due to differential expansion as the steel and soil particles cool were within the allowable tolerances and were accounted for in the design. The paper did not elaborate on the challenges encountered during installation, and in fact, few studies have reported on this topic, despite the increasing necessity to construct during winter conditions. Therefore, an opportunity has been identified, which this paper will embrace, to discuss the challenges and propose alternatives for the construction and installation of MSE walls under winter conditions and to present the argument that with the proper procedures it is possible to construct MSE walls all year round.

[1] E. I. Robinsky and P. H. Mora, *proceedings of International Conference on Soil Reinforcement: Reinforced Earth and other Techniques*, Ecole Nationale des Ponts et Chausses, Paris (1979), 581.

2 Challenges in Canadian Climate for MSE wall Installation

Installing MSE walls during the winter can present many challenges. There are several considerations that need to be addressed in order to plan for the potential difficulties and hazards that are encountered. The completion of an MSE wall can be separated in the following stages: (i) Design, (ii) Construction, and (iii) Installation. Each stage consists of challenges that become apparent while working in a cold environment. With respect to the design, consideration needs to be shown in the selection of the backfill and the percentage of fine particles allowed. For the construction of components, attention needs to be shown in the production of concrete in a cold environment. Finally, for the installation of the wall, caution needs to be shown regarding exposure of workers to cold temperatures, as well as consideration regarding the storage of materials and components, and development of a procedure for working with frozen backfills and difficult compaction. The following sections further illustrate these challenges.

2.1 Design Considerations

2.1.1 Selection of Backfill

The backfill is one of the most important elements within MSE structures. This is due to the fact that these structures retain loads based on the principle of friction between the backfill and the reinforcement. Therefore, the selection of the backfill for MSE walls is an important consideration in design, especially during winter construction.

During the winter season, recommendations for the selected backfill of MSE walls is to source specific aggregates which will not deteriorate when exposed to multiple freeze/thaw conditions and, in the process, create additional fines particles. The selected material must also provide adequate frictional resistance along reinforcing strips. In addition, when the ambient temperature is below 0°C, the placement and compaction of the material must be carried out before the moisture in the backfill freezes. If the moisture within the backfill freezes 95% SPMDD compaction (in accordance with MTO OPSS 501) cannot be achieved. Therefore, due to this restriction, material with a specific gradation shall be sourced, including such materials as: Clean Crushed Stone, where the gradation limits are 100% passing 150mm sieve, and <1% passing 5mm. Material that is commonly available is a 50mm-minus Clean Crushed Stone. Additionally, it is recommended to use only non-frost susceptible material and free-draining soil behind MSE structures.

2.2 Concrete Panels Manufacture

The manufacture of precast concrete panels requires that the material properties be guaranteed during production. This is achieved through a rigorous QC/QA program that includes continuous testing on the final product and the proper training of personnel that are involved with the manufacturing.

An additional advantage to precast concrete panels is that production takes place within a factory, a controlled environment where the quality of the panels can be ensured. Therefore, it is possible to continue production during the winter season, provided that the concrete panels are protected from the winter environment. Continuous production during the winter may be necessary in order to meet with scheduling criteria of the pouring and curing processes. The specifications for the concrete on the precast panels must be achieved during production, regardless of the time and location of manufacture. The following represent important considerations for production during the winter months, in order to achieve the highest quality of concrete.

The winter considerations for production of precast panels shall meet the special items specified below:

a) Poured moulds must be covered 100%, so that no part of the concrete is exposed.
b) Stacks of precast concrete panels must be covered and remain indoors until 28MPa strength is reached. Sufficient storage capacity in accordance with the panel production rates shall be stipulated.

c) Surface temperature of panels must be monitored to ensure that the maximum permissible temperature differential between the concrete and ambient temperature (as listed in Table 20 of CSA A23.1-14.), is not exceeded.

d) For ambient temperatures less than 10ºC, curing rate is slowed down, since chemical reactions are affected by temperature. Strength development resumes only when ambient temperatures are greater than 10ºC. At temperatures less than 5ºC, the curing process stops.. Therefore, it is important that the poured concrete panels be covered and stored in an environment with ambient temperature above 10ºC.

e) If concrete panels are to be transported under cold weather conditions, the products need to be protected from the winter environment and be stored indoors where the temperature is above 10ºC, until the design strength is attained. Actual concrete strength must be verified by a cylinder break.

If these considerations are followed during the manufacture of precast concrete panels, production can continue during the winter months, yielding excellent results for concrete testing.

2.3 Installation Challenges

2.3.1 Health and Safety

One major challenge in the installation of MSE walls during winter conditions is exposure to cold temperatures for the installers. Working in a cold environment is not only uncomfortable, but it can also lower work efficiency and increase the chance of hypothermia and frostbite, if precautions are not taken. Under cold temperatures the body loses heat, first in its extremities (nose, ear-lobes, fingers, toes), and if exposure to the cold is prolonged, in the core, at which point hypothermia develops. As hands become numb, the dexterity of fingers is reduced and work efficiency is lowered. As well, exposed hands can become susceptible to many cold-induced injuries such as chilblains, frostnip, and in extreme cases frostbite. As core temperature drops, muscles become stiffened and mental alertness is reduced, which is a health hazard and a factor for higher rates of accidents in the job-site.

To control these hazards, the Canadian Center for Occupational Health and Safety (CCOHS) provides education on the effects of cold environments on the body and training for first aid. Most importantly, it has developed recommendations to protect workers who are often exposed to cold temperatures. Based on the table below, the following are guidelines for limiting the exposure of workers to extreme conditions.

Table 1: Threshold Limit Values Work/Warm-Up Schedule for Four-Hour Shift[2]

Sunny Sky Air Temperature (ºC)		**-26 to -28**	**-29 to -31**	**-32 to -34**	**-35 to -37**	**-38 to -39**	**-40 to -42**	**-43 and below**
No Noticeable Wind	Max. work period	120 min	120 min	75 min	55 min	40 min	30 min	
	Number of work breaks[3]	1	1	2	3	4	5	
Wind 8 km/h	Max. work period	75 min	75 min	55 min	40 min	30 min		
	Number of work breaks	2	2	3	4	5		

[2] "Cold Environments - Working in the Cold," Canadian Center for Occupational Health and Safety, September 1, 2016, accessed February 10, 2017, http://www.ccohs.ca/oshanswers/phys_agents/cold_working.html.

[3] Warm-up breaks in warm environments for 10 minutes

Sunny Sky Air Temperature (°C)		**-26 to -28**	**-29 to -31**	**-32 to -34**	**-35 to -37**	**-38 to -39**	**-40 to -42**	**-43 and below**
Wind 16 km/h	Max. work period	55 min	55 min	40 min	30 min			
	Number of work breaks	3	3	4	5			
Wind 24 km/h	Max. work period	40 min	30 min	30 min				
	Number of work breaks	4	4	5				
Wind 32 km/h	Max. work period	40 min	30 min					
	Number of work breaks	4	5					
Little Danger if Dry Skin exposed for **less than one hour**		**DANGER** – Exposed flesh freezes within one minute		**GREAT DANGER** – Flesh may freeze within 30 seconds				

This table summarizes the maximum hours of exposure for workers under different cold temperature conditions. It also identifies the amount of warm-up breaks that must be provided to workers, and under what circumstances (mainly highly extreme weather conditions, often only encountered in remote parts of Canada) is the work completely ceased, with the exception of emergency work. Workers exposed to these conditions must wear proper protective equipment, including googles for eyes, since corneas can freeze when exposed to cold air, scarves, gloves, and insulating jackets.

Regarding the installation of MSE walls, from this table, it can be identified that under the worst environmental conditions, installers can work for a maximum of 30 minutes before being mandated to take a 10 minute warm-up break. In this 30 minute period, the workers could complete some work, albeit slowly, which may include installation of panels, or installation of strip reinforcement, which are tasks done while exposed to the environment. With respect to tasks like backfilling, excavation, or lifting and moving of panels, these tasks are accomplished while in enclosed environments, and therefore, the table for the limitation of exposure to cold environment does not apply. For an efficient installation, it is possible to utilize multiple workers who install in shifts, so that there is continuous work, even during frequent breaks. However, it is important that the work be planned effectively prior to commencement, since working time is very limited. The limiting factor for the installation of an MSE wall is often the backfill placement and compaction; therefore, depending on the geometry of the MSE wall, installation may be completed quickly, if the wall is a small abutment, or more slowly, if the wall is a long wing-wall, for example. Once again, it is important to emphasize that proper planning is required prior to the commencement of the work in a cold environment. Therefore, it is recommended that this procedure be implemented for multi-year projects only, with installation crews who have extensive experience in the construction of MSE walls, and who have already reached a level of efficiency in their installation process during standard working conditions. However, although there are many limitations to working under cold temperature conditions, primarily with respect to the maximum allowable exposure time for workers, and the reduction in work efficiency of installers, with the proper protective equipment, and with the right planning, it is possible to continue the installation of MSE walls even during the winter season.

2.3.2 Backfill Compaction

Construction in winter conditions presents difficulties with respect to the actual handling and installation of MSE wall components. However, with the proper planning and following some recommendations it is possible to continue working in the winter.

For the **Backfill**, the material must be placed and compacted in an unfrozen state. The embankment must be kept clear of snow and ice between backfill lifts, since backfill should not contain snow or ice, and frozen backfill cannot be used in the reinforced zone. The main reason for avoiding frozen backfill is to control the potential for void formation and reduction in compaction once the snow and ice melt during thawing season. Proper compaction of the backfill is important to activate the frictional forces between reinforcing strips and soil materials, which control the retaining capabilities of the MSE wall. Therefore, the temperature of the placed fill at the time of compaction should be above 1°C. Upon completion of placing, compacting, and testing, the backfill is allowed to freeze, however the ambient temperature must be monitored below freezing. Soil reinforcement can be placed on frozen backfill. For the non-critical (un-reinforced) backfill zone, frozen material greater than 150mm in depth must be removed and replaced with non-frozen fill. As well, to protect the backfill zone against snow and ice accumulation, the compacted backfill must be covered with tarp during heavy snow-fall conditions.

In the event of seasonal shutdown of construction, it is important that the top lift of backfill be compacted and its elevation noted. A thin lift of materials (100 to 140mm) should be spread, but not compacted, in order to absorb any snow and ice. This layer would then be removed once construction resumed in the spring season, and once the backfill is brought back to a suitable moisture level (2% below optimum), it can be re-compacted and tested before work continues. If work is continued in the winter months, winter backfill is utilized, avoiding the difficulties of regular backfill that must be protected from freezing.

2.3.3 Materials Storage

As material is delivered to the job-site, it is important that their quality be preserved as delivered. Furthermore, in cases when there is heavy snowfall, it is also possible that material be misplaced or lost in the snow. To overcome this challenge, designated storage places with elevated platforms are recommended to be used for the small accessories. Large containers which have been used with success in other countries can be utilized to protect and prevent misplacement of all MSE wall components, including precast concrete panels and reinforcing strips.

Figure 1: Storage Containers of MSE Wall Components

For the backfill, the fill material stockpiles should be covered with tarp at all times in order to prevent freezing. They can also be prepared with pipes at the base of the piles to allow for internal heating of the stockpile, depending on the ambient temperature. The temperature of the fill in the stockpile must be maintained above 2°C. If the temperature is below 2°C (as measured at 3 or more locations of the face of the mining face of the stockpiles), placement of fill material is discontinued and the already placed material in the backfill is insulated and protected from freezing. The stockpiles must be heated before work can resume.

Following these recommendations, the freezing of the backfill can be prevented and MSE wall components can be protected from the extreme environment.

3 Evaluation of MSE Wall Installation Rates

While in the experience of the author company, an experienced crew can install MSE walls on average at a rate of 50m^2 per day (250m^2 per week) this rate is applicable to standard conditions, under acceptable ambient temperatures of construction work. To determine the efficiency of working under winter conditions, the rate of MSE wall installation for a project in Saskatchewan was tracked[4]. The demanding project schedule required that construction continue through the winter months. The crew utilized winter backfill and followed the recommendations as outlined by the Canadian Center for Occupational Health and Safety regarding exposure to cold climates. In the following figure, the rates of MSE wall installation have been graphed for the weeks worked. The horizontal bars represent the average construction rates according to each season. From these values it can be inferred that the rate of installation decreases during the winter season, however it does not become insignificant. Although the crew averaged a rate of 273m^2 per week in the fall months, the installation rate in the winter months only dropped by 32% to 186m^2, which is expected considering the challenges that are faced in winter construction and have been outlined in this paper. Moreover, this low rate of installation increased to nearly equal values in the spring months as in the previous fall season, with a 37% increase to an average of 254m^2 of MSE wall installed per week. The discrepancy between the summer months and fall months (the average installation rate for the summer is 132m^2 per week) is indicative of the importance of having previous experience with installing MSE walls. Once the crew gained experience in the installation process of MSE walls, they increased their average rate of installation by 107% from 132m^2 to 274m^2 per week. It should also be noted that there were a total of 35 rainy days during the summer months, which further lowered the installation rate. Therefore, while variations exist between weeks of installation, and factors like weather conditions and the experience level of the crew affect the installation rate of MSE walls, it is shown through this example that construction can continue through the winter months, and while the installation rate is lower by about 25% than what is average for an experienced crew in the warm months, the rate does not drop to zero. If the schedule of a project demands it, it is possible to continue the installation of MSE walls in the winter, as has been illustrated with this project.

[4]The MSE walls installation rates were provided by Taj Gould, Superintendent Area 3, Regina Bypass Design Builders, and are published in this paper with permission

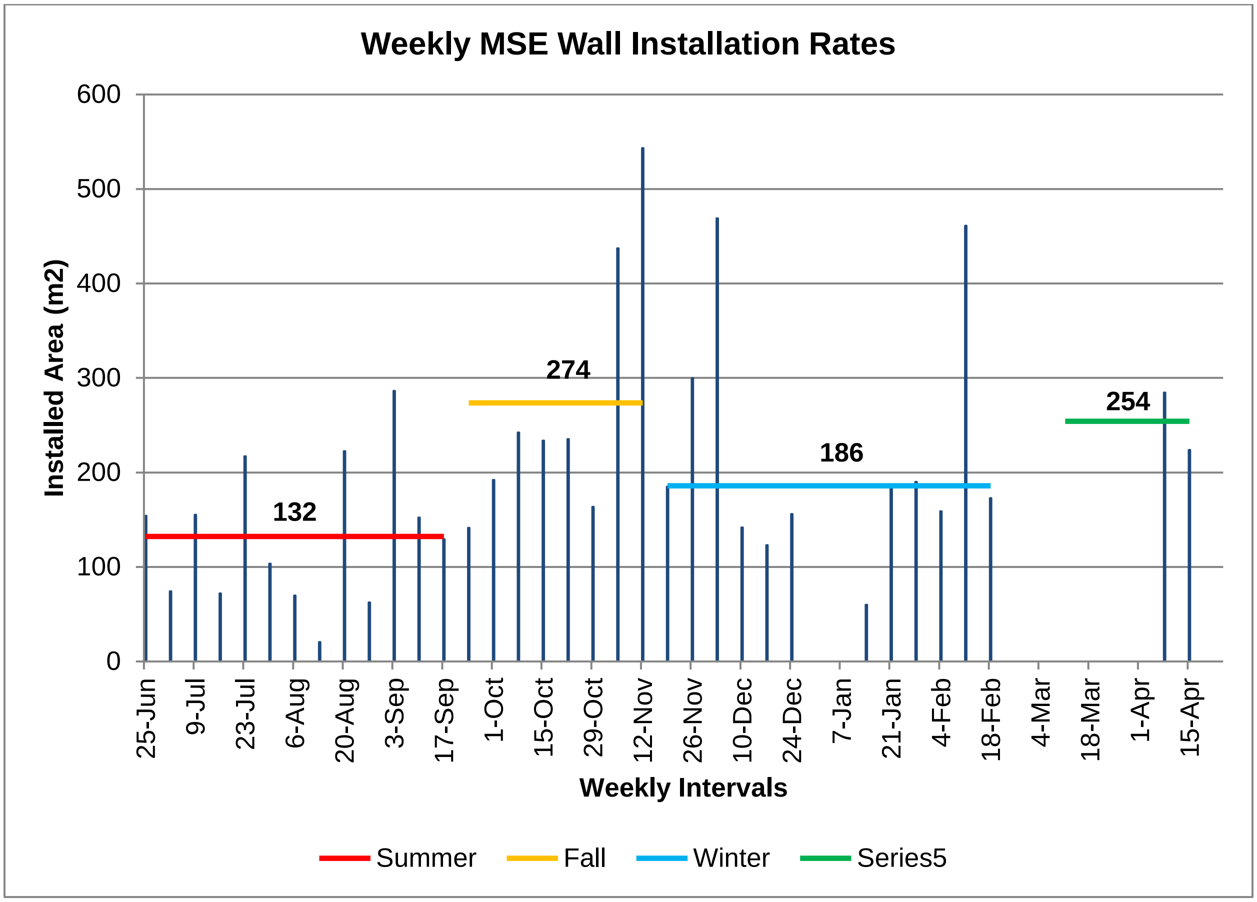

Figure 2: MSE Wall Installation Rates per Week in the Period 6-25-2016 to 4-15-2017

4 Conclusion

Although working in a cold environment presents multiple challenges for the construction and installation of MSE walls, including selection and compaction of proper backfill, constraint in winter environment exposure times for labor, and production of precast concrete panels, depending on the scheduling constraints of a construction project, and when following specified procedures, as illustrated in this paper, installation of MSE walls does not need to be paused for the winter season. While the efficiency and speed of installation is reduced during the winter, and the cost of construction is therefore increased, with proper planning, and when utilizing an experienced crew, it is possible to construct MSE structures all year round.

References

Robinsky, E. I., and P. H. Mora. *Proceedings of International Conference on Soil Reinforcement: Reinforced Earth and other Techniques*, Ecole Nationale des Ponts et Chausses, Paris. 1979. 579-84.

"Cold Environments - Working in the Cold." Canadian Center for Occupational Health and Safety. September 1, 2016. Accessed February 10, 2017. http://www.ccohs.ca/oshanswers/phys_agents/cold_working.html.