Challenges in the Design and Construction of MSE Walls on the Regina Bypass Project

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ABSTRACT
The Regina Bypass is the largest infrastructure project built in the City of Regina, Saskatchewan. The site for some of the structures of this project is characterized by soft clayey soils that exhibit high settlement rates. This project was constructed using Mechanically Stabilized Earth (MSE) walls with segmental panel facings. An advantage to segmental panels is their ability to accommodate high-anticipated total and differential settlements without major effects on the overall structure. The purpose of this paper is to discuss the challenges that were encountered during the design and construction phases of the project and the solutions that were followed to overcome them. Examples of challenges include high settlement rates and winter construction.

RÉSUMÉ
Le contournement de Regina (Regina Bypass) est le plus grand projet d'infrastructure dans la Ville de Regina, Saskatchewan, dont le site est caractérisé par la présence d'argile molle présentant des tassements anticipés importants. Le projet a été construit en utilisant des murs de Terre Stabilisée Mécaniquement (TSM) avec des panneaux de béton imbriqués. L'avantage de ces panneaux est leur capacité à s'adapter aux tassements totaux et différentiels sans impacts majeurs sur la structure complète. Le but de cet article est de discuter des défis qui ont été rencontrés pendant les phases de conception et la construction du projet et les solutions choisies afin de les surmonter. Des exemples de défis rencontrés sont les tassements anticipés élevés et la construction en hiver.

1 PROJECT SCOPE

The Regina Bypass project was proposed to improve the flow of traffic in the area, since most intersections on Victoria Avenue and Hwy 1 East were located at grade level. These 'at grade' intersections presented a major concern for both public safety and flow. The project goal was to minimize traffic passing through the City of Regina and to reduce traffic bottlenecks, which were a typical occurrence in the surrounding vicinity.

The project design consists of 60km of a new 4-lane highway, 55km of new service roads and 12 new interchanges (Figure 1 and Figure 2). MSE walls were a major component to the design of the new 4-lane highways, the new intersections, and the revitalization of older intersections. Twenty-four (24) structures which consisted of forty-six (46) separate walls, totaling approximately 23,000m^2 of MSE walls, were designed on this project, including individual MSE walls and False Bridge Abutments characterized by open-concept MSE walls, with soil reinforcing strips ranging from 3m to 41m in length.

Segmental MSE walls were considered and implemented in this project due to their ability to accommodate high anticipated settlements and their ability to absorb up to 1% differential settlement.

There were many challenges encountered during the project, including design complications and construction obstacles. More specifically, they included intricate wall designs, re-designs prompted by global stability concerns, winter construction, and general challenges consistent with poor foundation soils (Regina Clays) characterized by high settlement rates upon loading.

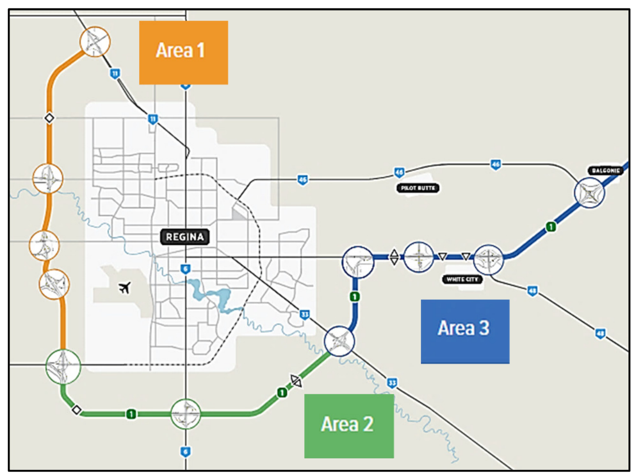


Figure 1. General Arrangement of Regina Bypass Project (Regina Bypass 2018-a)

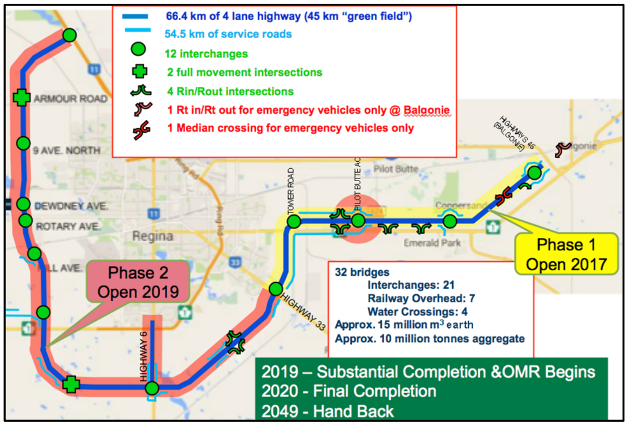


Figure 2. Overview of Completion Phases (Regina Bypass 2018-b)

2 DESIGN FOR HIGH SETTLEMENT SOILS

The soils found in the Regina Plains are categorized as 'Vertisolic' (soils that have shrink-swell characteristics). They were deposited during the last Ice Age (Wisconsinan Glaciation), when the retreating glaciers formed glacial lakes. Their main characteristic is a low soil bearing capacity and a high consistence of heavy clay (greater than 60%), which causes swelling under wet conditions and crack-formation under dry conditions (Pennock & Anderson). This process occurs due to the high content of smectite minerals (montmorillonite) in the clay, which can absorb water on the surface, as well as in between layers, causing the clay to expand when moistened.

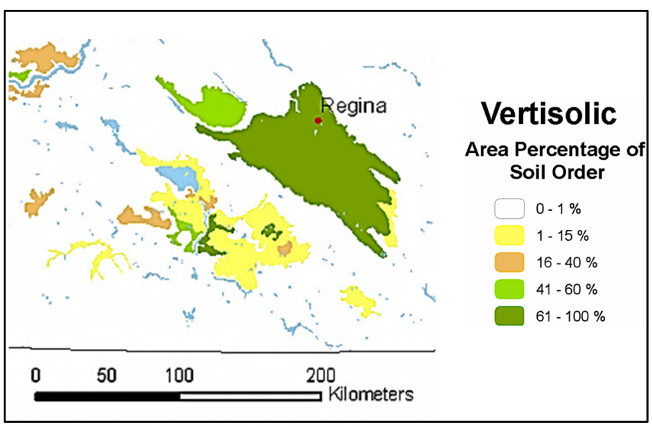


Figure 3. Vertisolic Soil Distribution Map of Regina, SK (Pennock & Anderson)

It was anticipated that high soil settlements would be observed in the area. The geotechnical consultant for this project provided the following settlement values for each structure, summarized in Table 1, Table 2 and Table 3.

Table 1. Area 1 Anticipated Total Settlements

Structures	MSE Walls	Anticipated Settlement (mm)
BRIDGE 23	N-RW-01	290
	N-RW-02	290
BRIDGE 24	N-RW-03	300
	N-RW-04	300
BRIDGE 25	N-RW-05	270
	N-RW-06	270
BRIDGE 26&27	N-RW-07	337
	N-RW-08	348
BRIDGE 30	N-RW-11	415
	N-RW-12	415
BRIDGE 31	N-RW-15	150
	N-RW-16	150
BRIDGE 33&34	N-RW-13	110
	N-RW-14	110
BRIDGE 35	N-RW-17	310
	N-RW-18	310

Table 2. Area 2 Anticipated Total Settlements

Structures	MSE Walls	Anticipated Settlement (mm)
BRIDGE 14&15	S-RW-07	300
	S-RW-08	300
BRIDGE 16	W-RW-01	335
	W-RW-02	335
BRIDGE 17	W-RW-03	305
	W-RW-04	340
BRIDGE 18	W-RW-05	650
	W-RW-06	695
BRIDGE 19	W-RW-08	565
	W-RW-09	490
BRIDGE 20	N-RW-10	200
	N-RW-11	200

Table 3. Area 3 Anticipated Total Settlements

Structures	MSE Walls	Anticipated Settlement (mm)
BRIDGE 01	E-RW-01	153
	E-RW-02	153
BRIDGE 02	E-RW-03	434
	E-RW-04	434
BRIDGE 03	E-RW-05	435
	E-RW-06	435
BRIDGE 04	E-RW-07	520
	E-RW-08	520
BRIDGE 06&07	E-RW-09	490
	E-RW-10	490
BRIDGE 08	S-RW-01	630
	S-RW-02	630
BRIDGE 09&10	S-RW-03	636
	S-RW-04	636

An advantage of MSE Walls with segmental panels is that they can tolerate substantial total settlement, which is only constrained by the superstructure being supported by the wall. When foundation soils with high clay content are not preloaded or improved, due to the heterogeneity of the native soil layers, settlement may occur at different rates for different locations. The construction of MSE Walls on top of these types of soils, presents challenges due to the potential for experiencing differential settlement. Usually MSE Walls constructed with segmental panels can tolerate up to 1% differential settlement (i.e. 15V: 1500H), before the structural integrity of the panels is affected.

To design for the anticipated settlements, two (2) options were proposed: (1) Design and construct MSE walls with no top panels until settlement is complete, (2) Design and construct MSE walls with top panels and raise the coping up to one meter to accommodate for settlement.

2.1 Design without Top MSE Wall Panels

When high settlements are anticipated, the most common solution is to design the MSE Wall without top panels. The main advantage of this solution is that the primary consolidation is completed before placement of the coping. Consequences of settlement that are likely to be prevented by this method include opening or closing of joints and cracking of concrete panels.

Due to variability in Contractor's construction schedules, this solution could not be implemented. Therefore, an alternative design was proposed and used for this project.

2.2 Design with Raised Cast-in-Place (CIP) Coping

This alternative consists of designing the MSE Wall for its final height, which includes the total anticipated settlement, and placing the coping after the settlement is complete. The top panels were designed as if no settlement is to occur; however, the total height for internal stability design included 100% of the total uniform anticipated settlement. Therefore, to account for the total settlement of the wall, the coping was to be adjusted and raised to the desired elevation up to 1m as required by the Owner.

2.3 Other Challenges in the Design

Besides the high amount of anticipated settlements, this design method presented other unusual design challenges:

- Additional lateral loads up to 190 kN/m from abutment piles acting towards the rear face of walls; as a result, high strip density and challenges due to conflict with the piles were encountered;
- Excessive reinforcing strip skew angle (greater than 20^{o} to horizontal as specified in the PA) to avoid any obstructions (i.e. HP steel piles, 700Ø CSP sleeve, or 900Ø ACIP Caisson, etc);
- Excessive reinforcing strip bending (to a slope greater than 3H:1V) due to the presence of a mud-slab that would serve as a footing for the abutment formwork;
- Vertical connection of wall panels utilizing galvanized steel angles to accommodate for the absence of the top row of reinforcing strips due to the conflict with underside of the abutment and/or mud-slab;
- Utilization of two (2) different types of reinforced backfill within the same structure (i.e. regular and winter backfill) due to the winter schedule. The challenges consisted in optimizing the design based on two different types of materials used within the same cross section of the wall, to design with different mechanical properties (i.e. design for $\varphi_1 = 34^{o}$, $\gamma 1 = 20$ kN/m³ and, $\varphi_1 = 40^{o}$, $\gamma_1 = 17$ kN/m³, respectively); and,
- The internal friction angles for the foundation $\varphi_3 = 25^{o}$ resulting in challenges with sliding at the base of the wall.

3 GLOBAL STABILITY

Another prevalent issue was the global stability of the MSE structures. Soil reinforcing strips lengths were provided to satisfy the Global Stability requirements. Due to the lengths recommended for design against Global Stability, which were great in value, the internal design strip length requirements were met and exceeded. The strip lengths recommended were extended beyond the failure-zone to satisfy the factors of safety for Global Stability.

One structure that required a redesign was the Bridge 8, S-RW-02 Wall. Upon initial excavation and subsequent placing of the CIP leveling pad, movement was detected in the foundation. This was due to unanticipated loading from a stockpile of material in the wall vicinity, resulting in a global stability failure. This stockpile was not considered during design. The location of the Global Stability failure is shown in Figure 4.

An investigation was carried out to determine the cause of failure, including the examination of the foundation, the excavation site, and the embankments. It was determined that to prevent this mode of failure, the length of soil reinforcing strips would need to be increased significantly. Whereas the initial design length was approximately 10m, the required length for preventing failure induced by stockpile loading was 41m. The wall cross-section consisted of three zones of reinforcement with lengths of 41m, 27m, and 8m, respectively in ascending order from the leveling pad. A visual representation of the MSE wall cross-section design is included in Figure 5.

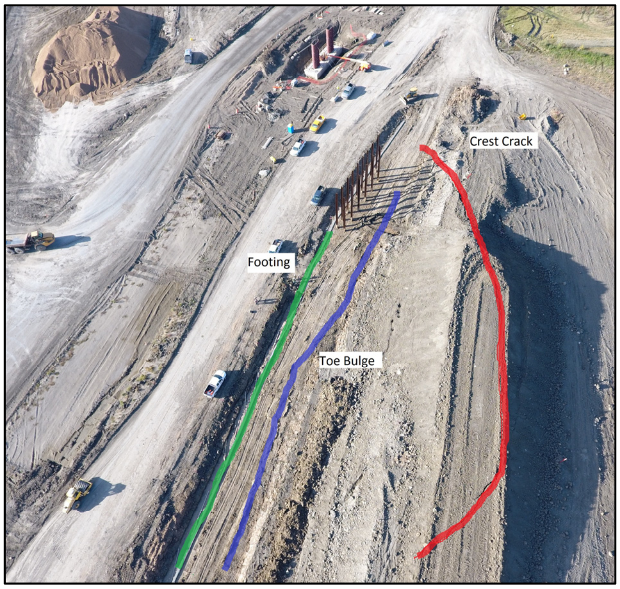
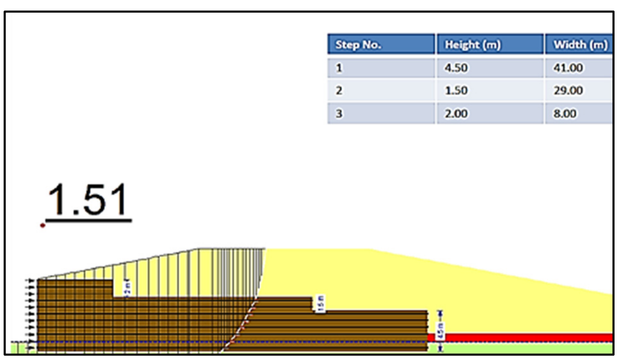


Figure 4. Location of Global Stability Failure



Step No.	Height (m)	Width (m)
1	4.50	41.00
2	1.50	29.00
3	2.00	8.00

Figure 5. Cross-section of Design with Standard Backfill (Yoshida, 2016)

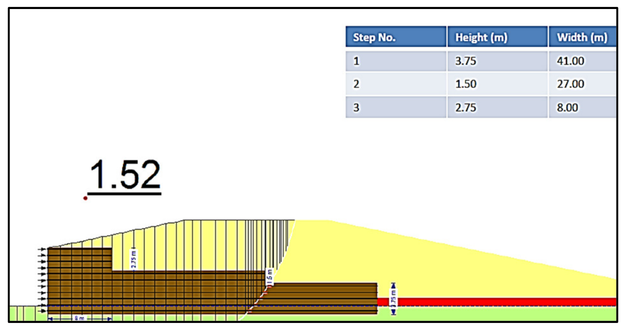
3.1 Design with Winter Backfill

Due to the MSE wall re-design that was brought on by the Global Stability failure, the construction schedule was also delayed. To meet construction milestones, as determined by the project agreement schedule, construction was continued during the winter months. To accommodate the conditions, winter backfill was utilized.

The term winter backfill refers to a material made of clean crushed stone with no sand which therefore holds very little water, which makes it not susceptible to freezing solid.

Challenges presented during winter construction mainly consisted of sourcing of the material and testing it to meet electrochemical and mechanical properties, as specified in the project agreement.

It should be noted that, MSE Walls are coherent gravity retaining systems where the interaction between the frictional soil and reinforcing strips is the mechanism of transferring the stresses within the soil mass. The unit weight and internal friction angle for the winter backfill utilized for the design of the MSE wall were $\gamma 1 = 18kN/m^3$ and $\varphi_1 = 34^o$, respectively. Therefore, it was determined that the utilization of winter backfill affected the design of the wall. As a result, the lengths of the reinforcing strips (Figure 6) were extended to fulfill the factors of safety.



Step No.	Height (m)	Width (m)
1	3.75	41.00
2	1.50	27.00
3	2.75	8.00

Figure 6. Cross-section of Design with Winter Backfill (Yoshida, 2016)

4 WINTER CONSTRUCTION

When constructing MSE walls during the winter months, with winter backfill, the following need to be considered. Backfill material that is used in the reinforced zone must be free of snow and ice during placing, as well as being placed in an unfrozen state. If frozen backfill is placed and compacted, the compaction test results may result in a false reading, presenting compaction percent (%) values that are higher than actual results. This occurs due to water freezing in the backfill voids and presenting a more compacted solid mass. This results in an un-compacted fill with a low relative. The main problem with frozen fill is that the soil particles are prevented from moving between each other during the compaction process. This loss of movement from the soil particles against each other reduces the frictional interactions between the soil reinforcing strips and the backfill. The result is that MSE wall panels can be displaced. The correct placement of steel soil reinforcing strips is shown in Figure 7.

Figure 7. Soil Reinforcing Strips in Winter Backfill

5 DESIGN-CONSTRUCTION CHALLENGES

Challenges during design and construction of the project required providing innovative solutions that met project specifications, while being easily implemented in the field.

5.1 Drain Chase

The project specifications required all drainage pipes used within the MSE structures to be exposed, while not being placed behind the MSE panels and within the reinforced zone. The primary reasoning for this specification was to be able to perform future maintenance on the drainage system without utilizing any invasive procedure that could damage the structure.

With the drainage system and wall layout completed, a new type of wall panel needed to be designed in order to accommodate the water run-off from the swales at the top of the MSE wall and meet existing specifications of the design.

The new wall panel, (Drain Chase), had to maintain the internal stability of the MSE wall, similarly to other standard panels. A precast box type panel was designed with the front face of the panel exposed, and with soil reinforcing strips implemented into the reinforced zone in the back. The Drain Chase had to resist lateral earth pressures from the backfill and resist the earth pressure applied from the adjacent sides. Therefore, with soil reinforcements installed only in the back, the panel used for drainage itself was designed as a reinforced concrete element to withstand the lateral earth pressures. The special panel designed for drainage is shown in Figures 8 and 9.

Figure 8. Drain Chase Element in Construction

Figure 9. Drain Chase Element Installed in Wall S-RW-09

5.2 Crash Walls

Some structures were designed near the CP rail tracks, which required the design of a crash wall in conjunction with the MSE wall. Typically, crash walls are designed as a cast-in-place (CIP) wall, with the MSE wall designed around it. The crash walls for this project were precast and designed to be non-typical, consisting of a 1m zone, located within the MSE reinforced fill behind the precast panels. A soil-cement mixture, containing 4% cement, was utilized for the crash wall zone design. A section drawing of the crash wall is provided in Figure 10.

The purpose of the zone is to protect the MSE wall backfill from erosion. In case of a crash, the panels may break. In the absence of the panels, the backfill, which in combination with the soil reinforcement, support the loads, will erode until the panels are again replaced. To mitigate this effect, the soil-cement mixture serves as a buffer zone for erosion, protecting the structural integrity of the MSE wall by preventing the erosion of the backfill. The 4%

cement in the mixture serves to reduce the rate of erosion in the zone, since cement in reaction with moisture will form a more cohesive material than if the zone consisted exclusively of soil.

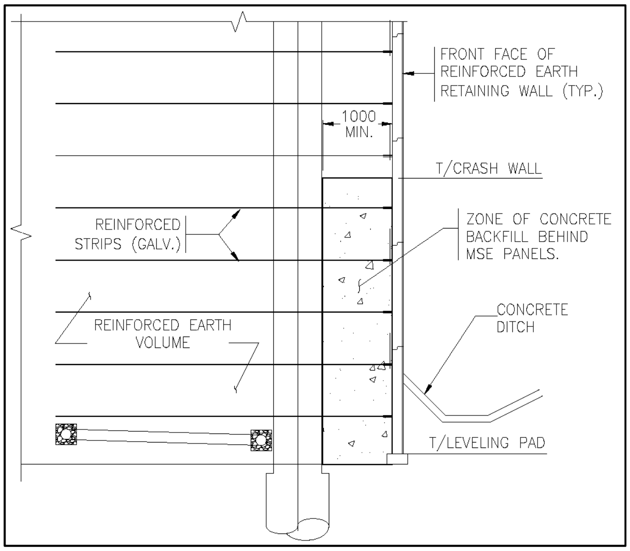


Figure 10. Crash Wall Detail

6 CONCLUSION

The Regina Bypass project is the largest 3P (Public Private Partnership) project in the province of Saskatchewan. Due to its scope and complexity, the project presented many challenges during design and construction. The major issue as outlined in this paper was the anticipated settlements, which were established in the beginning of the design phase, but were carefully mitigated by the implementation in the design of segmental MSE panels that allow for large settlements to occur. Other issues during construction were identified and resolved, such as using winter backfill in the MSE walls to reduce delays in the construction schedule, or incorporating a new panel type (drain chase) to resolve the drainage pipes issues.

As demonstrated by this paper, large multifaceted projects involving MSE walls are filled with many challenging situations that arise in the design and construction phases. However, in the presence of experienced engineers and by incorporating innovative design solutions, these challenges are overcome successfully and efficiently.

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