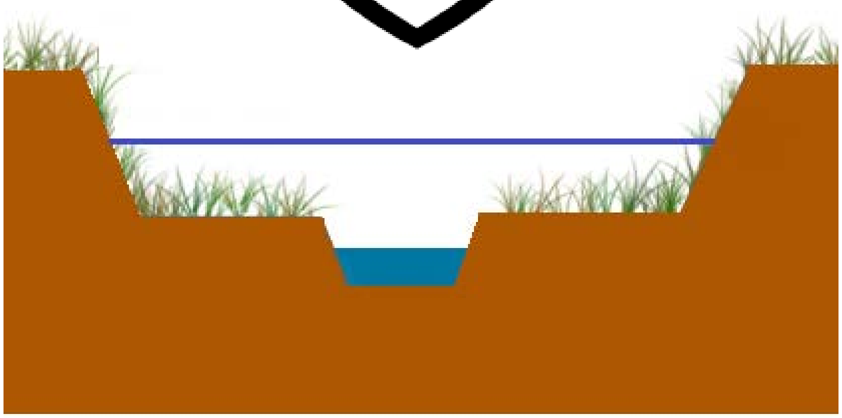
Benefits of Two-Stage Ditches



By: Prof. Hany El Naggar, Ph.D., P.Eng.

Department of Civil and Resource Engineering, Dalhousie University

Report Submitted to Ditch Doctor Inc. for the NRC – IRAP Project

Benefits of Two-Stage Ditches

Introduction

Agricultural ditches and channels have long been used to provide important drainage and flood control needs. These agricultural channels are often constructed as traditional trapezoidal ditches. Recently, a new approach has been developed to construct these channels to be two-stage channels incorporated with benches considered as flood plains and attempts to restore or create some natural alluvial channel processes (Part 654 Stream Restoration Design). Figure 1 shows the schematic drawings of the conventional trapezoidal and the two-stage channels, respectively.

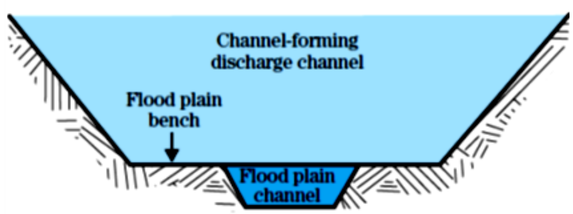


Figure 1: Schematic drawings of the one and two stage channels (Part 654 Stream Restoration Design)

The main goal of this report is to highlight briefly the benefits of two-stage ditching by studying the geotechnical aspects of the design of two-stage channels. The study involved a finite element (FE) analysis to investigate the stability of the channel slopes under different hydraulic conditions. The finite element analysis was conducted using the FE software package PAXIS 2D 2016 simulating in details the geometry, hydraulic conditions, and construction sequence.

Evaluation of Two-Stage Channels

The main concepts behind the design of two-stage channels are;

a- *Dissipating the energy of high flows by letting it spread on the benches.*

b- *Allowing the sediment to set on benches instead of being transported to downstream.*

c- *Increasing the interaction time of the water with the benches and the plants to grow in.*

Advantages of two stages channels

The main advantages of the two-stage channels over conventional trapezoidal channels are both the improved drainage function in addition to the ecological function. The two-stage design improves ditch stability by reducing water flow and the need of maintenance, saving both labor and money. It also has the potential to create and maintain better habitat conditions. In addition, two-stage channels are more effective in transporting the sediment over the conventional cross section.

Development of the Finite Element Models

In order to investigate the geotechnical aspects in the design of two-stage channels, the stability of the typical cross sections was evaluated. Two sets of numerical models were developed. The first set of models were utilized to compare the performance of a two-stage channel to that of a channel with a conventional cross section in silty soils as shown in Figure 2. The second set of models followed the same geometry and hydraulic conditions of the first set but conducted in a clay soil with medium stiffness. The considered cross sections were selected to satisfy the following criteria:

1- The minimum bench width should be according to Figure 3.
2- The slopes in the one-stage cross section or the upper part of the two-stage channel are 2HL: 1VL.
3- The slopes in the lower part of the two-stage channel are 1:1.

The stability of each model was evaluated for the two extreme water conditions, i.e., when the ditch is full and when it is dry. For each the minimum factor of safety was calculated and the critical slip surface was determined.

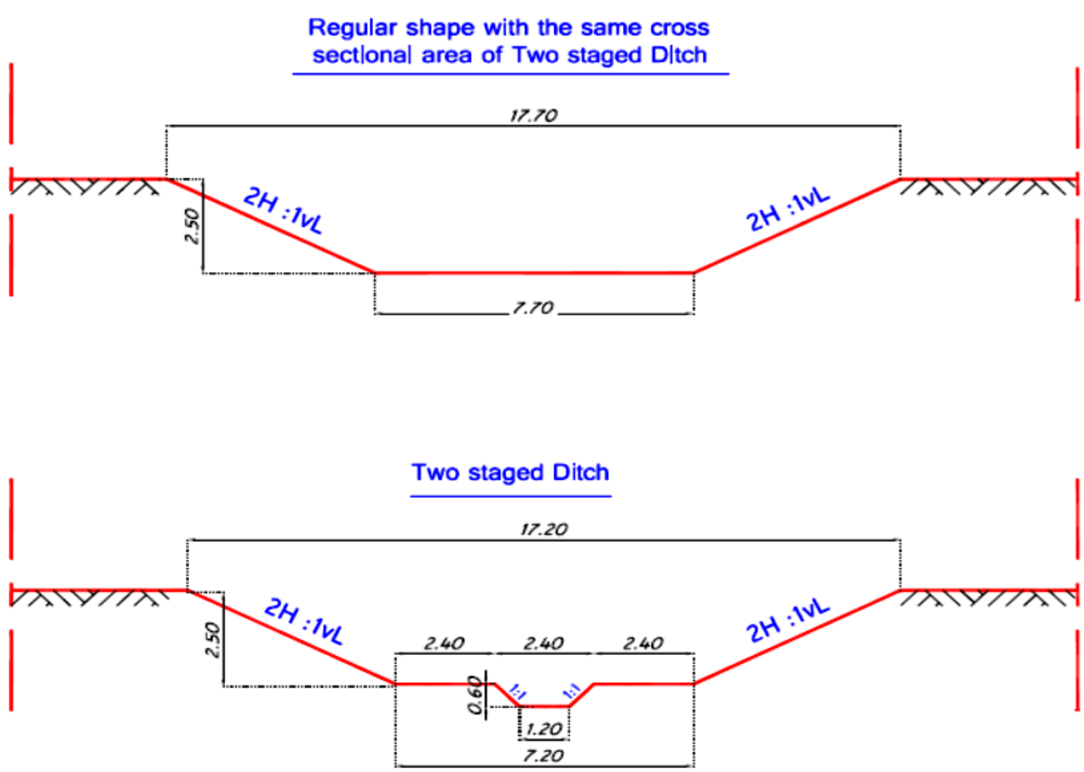


Figure 2: The considered cross sections in the finite element analysis.

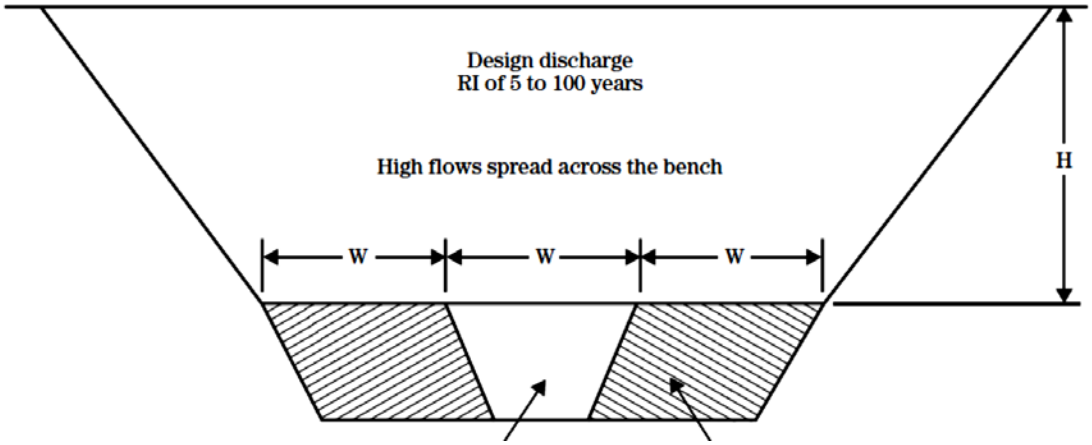


Figure 3: The minimum dimensions of the benches.

Material and Soil Properties

An elastic perfectly plastic soil constitutive model with Mohr- Coulomb failure criterion was used during the simulation the subsurface conditions in the finite element models. The properties of the subsurface conditions are selected to be silty soil in the first set of models and medium stiff clay in the second one as indicated in Table1.

Table 1: The soil parameters using Mohr Coulomb model

Material	φ	c (kPa)	E(MPa)	ɣ (KN/m^3)
silty soil (first set)	15	10	10	16
Medium stiff clay (Second set)	15	5	7	16

Construction Sequence

The staged construction technique was used to simulate the different FEMs. The following construction sequence is followed in all models, 1- The initial in-situ stress was installed using the K_o procedure in which the initial geostatic stresses were established assuming increasing vertical stress with depth ($\sigma_v = \gamma z$) and horizontal stresses based on $\sigma_h = K_o \sigma_v$. The groundwater table was assumed to be below the considered profile.

2- The excavation work for the channel was assumed to be under dry conditions (i.e., the channel is empty).

3- 10 kPa surcharge load was applied at the ground surface to simulate the loads from the equipment.

4- Raising the water level to investigate the stability in the flood condition.

Figures from 4 to 8 show details of the considered construction stages.

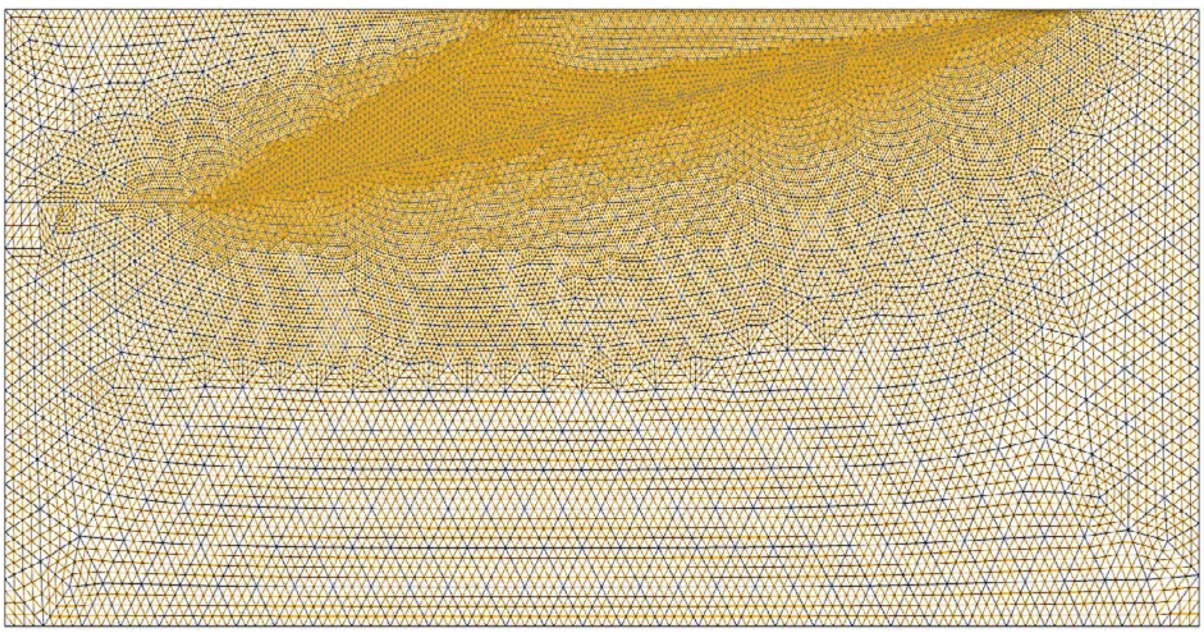


Figure 4: initial conditions

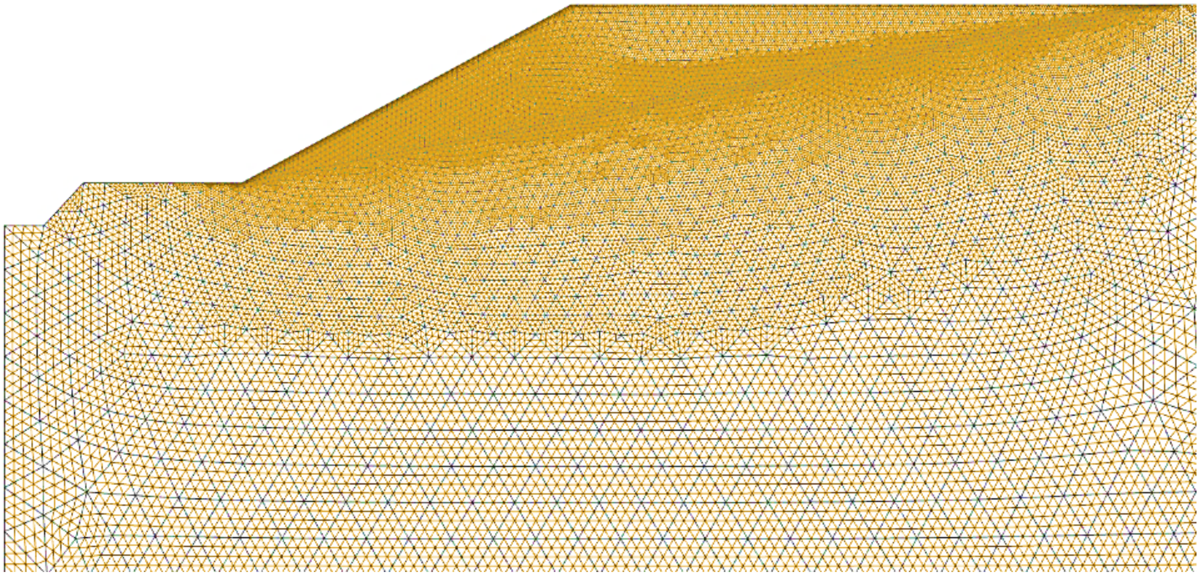


Figure 5: excavation of the proposed cross section

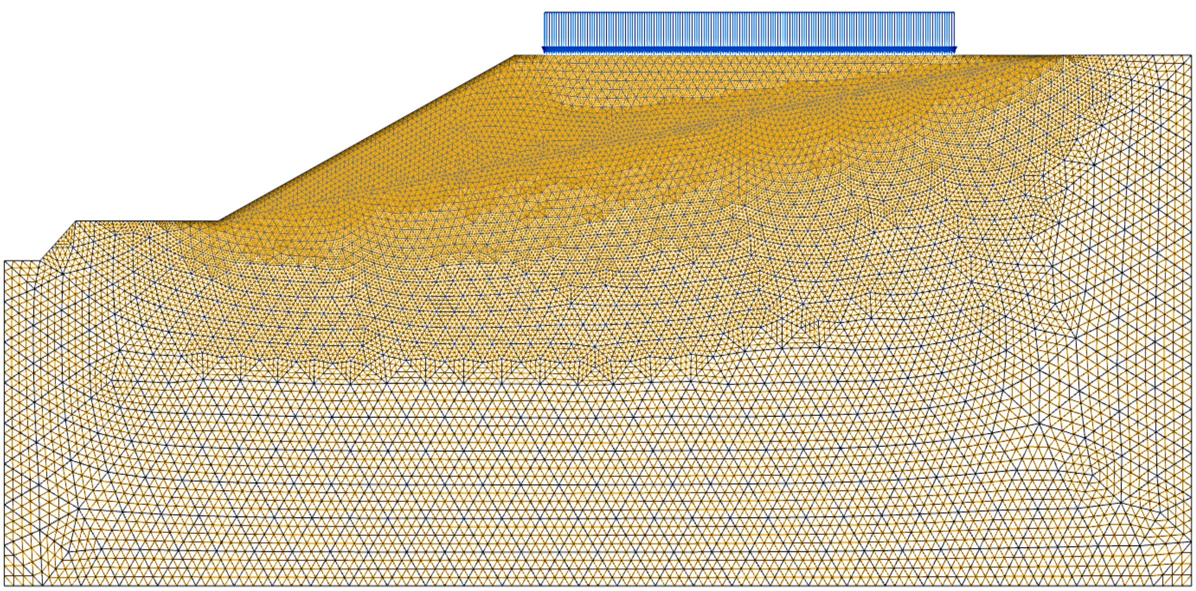


Figure 6: Applying surcharge of 10 KPa

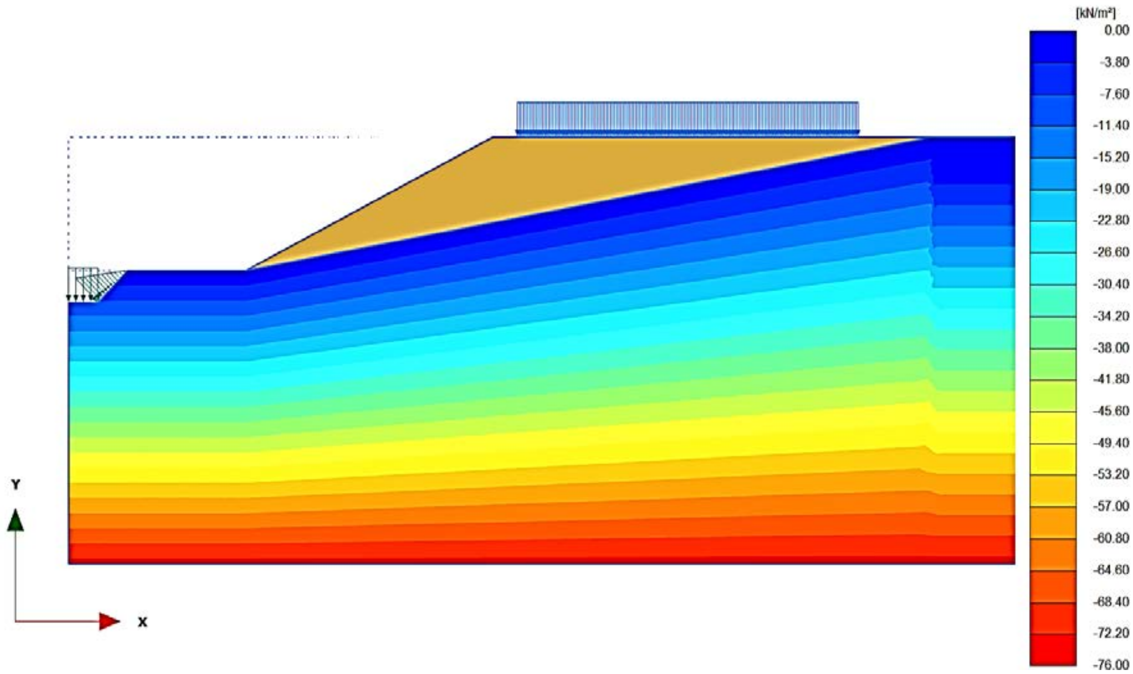


Figure 7: The hydraulic pressure at dry conditions.

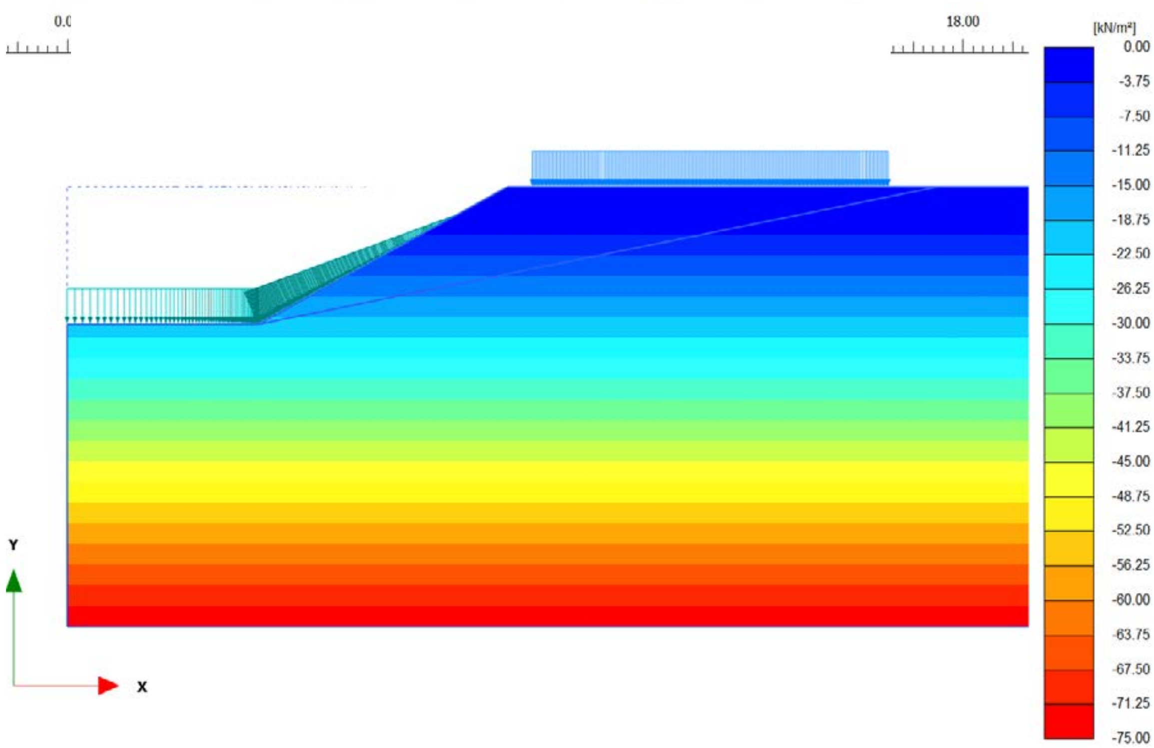


Figure 8: The hydrostatic pressure at flood conditions

Results and Discussions

This section presents the results of the extensive finite element study that was conducted to investigate the stability of two-stage channels under different hydraulic conditions. Table 3 shows the minimum factor of safety of each model in dry and flood conditions. The results indicated that there is no significant effect on the stability of the modified cross section after using steeper slopes in the lower part. Nevertheless, no vegetation considerations are simulated in the analyses which may increase the stability of the slopes especially in the lower part. Where the vegetation will reinforce the benches to be more stable and strengthen the soil properties of the lower slopes. Figures 9 to 12 explain examples of the failure and slip surfaces of the 1st set of models under dry conditions (Mode of failure).

Table 2: Minimum Factor of safety for different models.

Model index		Minimum F.o.S	
		Two-stage channel	Conventional cross section
1st set of models	dry condition	1.885	1.96
	Flood condition	2.95	2.96
2nd set of models	dry condition	1.1	1.15
	Flood condition	1.7	1.707

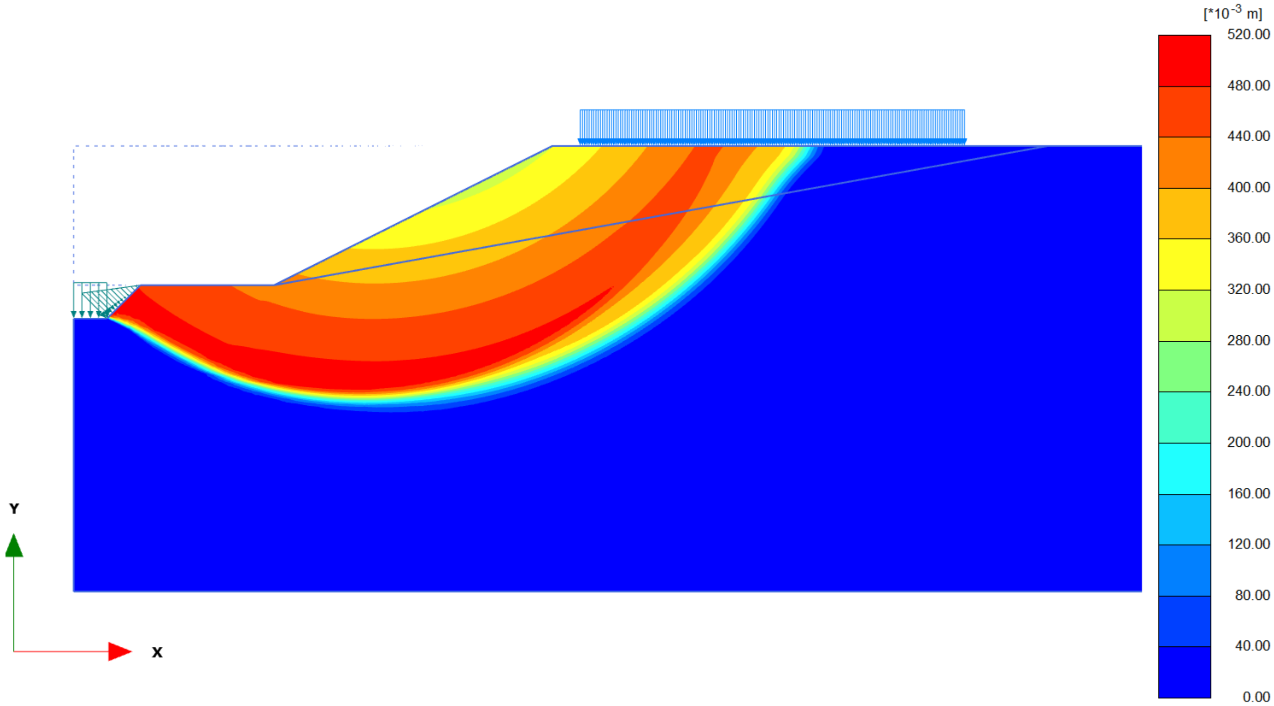


Figure 9: Failure mode of 2-stage channel in dry condition (1st set of models) with F.O.S=1.885

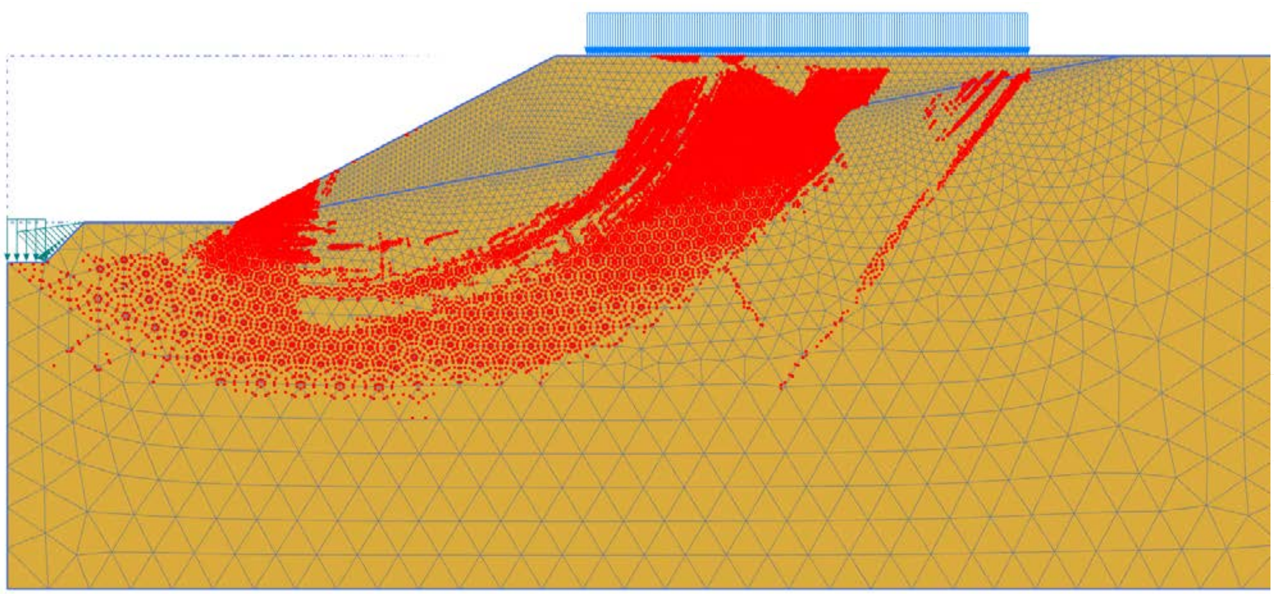


Figure 10: Failure/Plastic points of two-stage channel in dry condition (1st set of models) with F.O.S=1.885

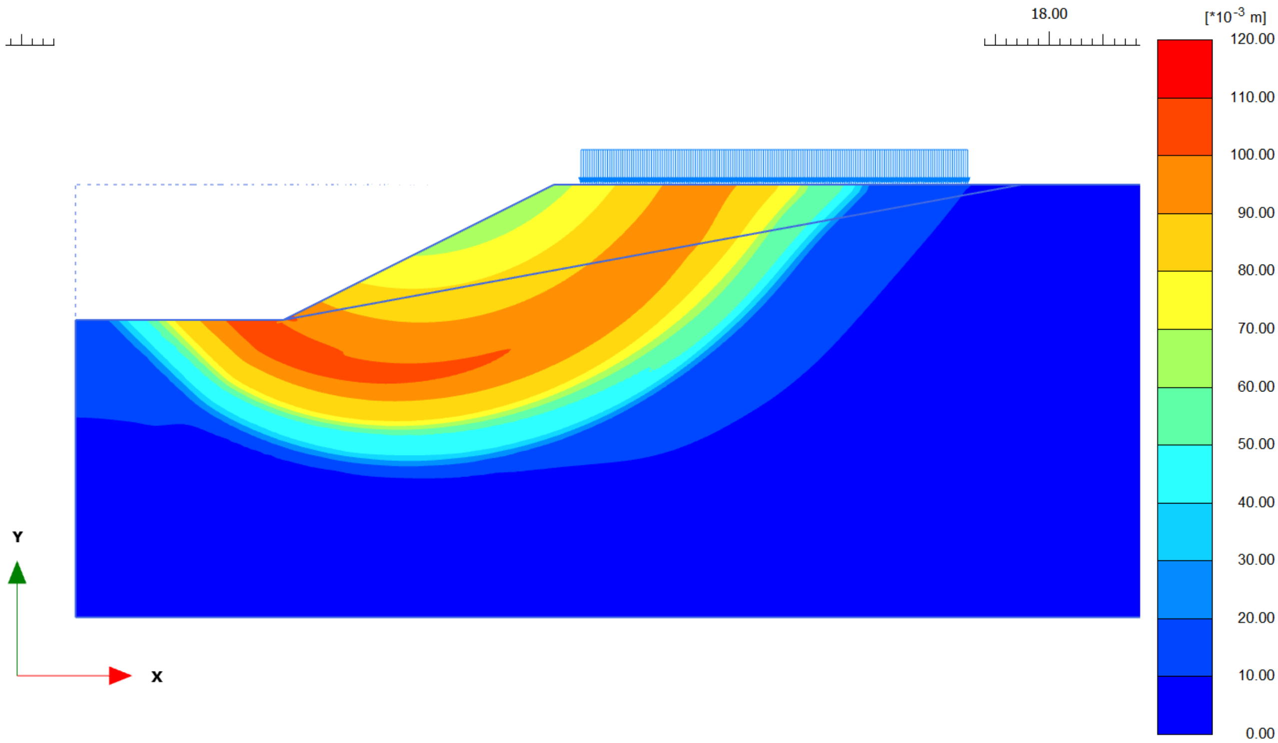


Figure 11: Failure mode of conventional channel in dry condition (1st set of models) with F.O. S=1.96

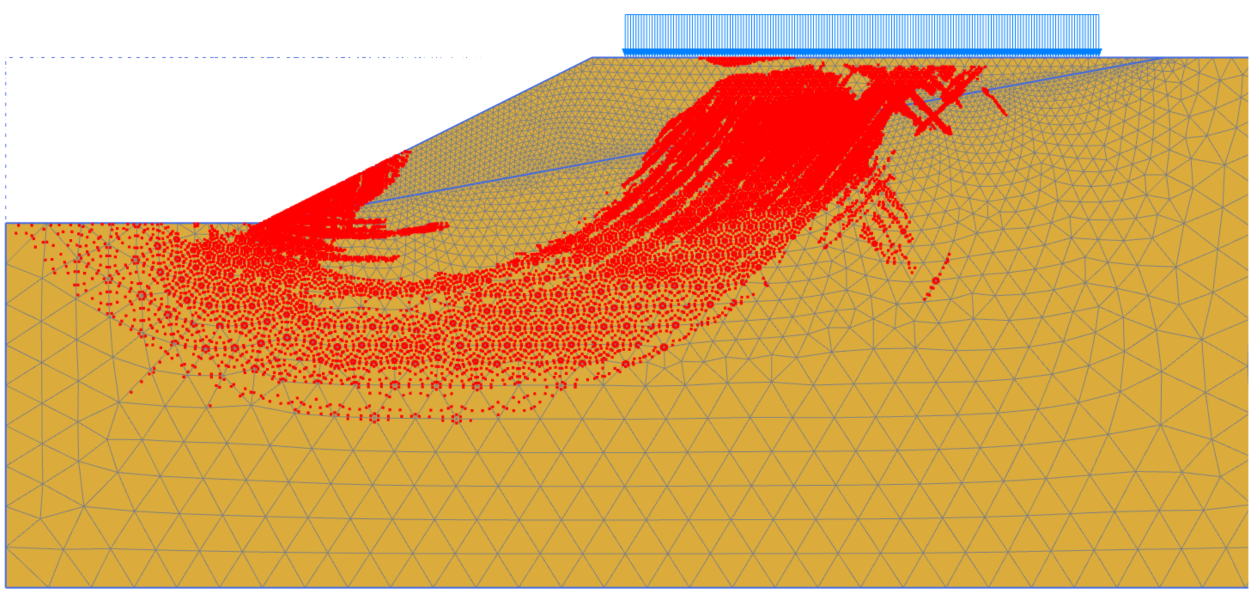


Figure 12: Failure/Plastic points of conventional channel in dry condition (1st set of models) with F.O.S=1.96

Summary and Conclusion

Two-dimensional finite element analyses were conducted to examine the stability of two-stage channels under different hydraulic conditions. Two sets of numerical models were developed. The first set of models were utilized to simulate the two-stage channel and the conventional cross section in silty soils. The second one considered the medium stiff clay.

The study showed that there is no significant effect on the stability of the modified cross section after using steeper slopes in the lower part. Nevertheless, no vegetation considerations are considered in the analyses which may increase the stability of the slopes especially in the lower part.

The results of this report showed that the two-stage ditching has great advantages over conventional ditching including the improved drainage in addition to the ecological benefits. Also, the geometry of the two-stage ditching cross-section did not alter the overall geotechnical stability of the considered sections.

References

Part 654, National Engineering Handbook, Chapter 10, “Two-Stage Channel Design”. United States Department of Agriculture, Natural Resources Conversation Services, 2007.