STABILITY ANALYSES OF THE DUMP SITE CULVERT IN TINAZ SURFACE MINE

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Approval of the Graduate School of Natural and Applied Sciences.

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ABSTRACT

STABILITY ANALYSES OF THE DUMP SITE CULVERT
IN TINAZ SURFACE MINE

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In this thesis, studies associated with the stability analyses of the box-shaped dump-site culvert constructed in Tınaz Surface Mine of Turkish Coal Enterprises (TKİ) are presented. In addition, stability conditions of other culvert alternatives are evaluated.

Existence of creeks in a surface mining area is a significant factor to be considered in selection of dump-site location. Since, the dumped overburden material on the valley acts as a barrier and behaves like a dam causing flood problem behind the dump-site. TKİ engineers prevented the flood potential that might have occurred behind the dump-site by constructing a 480-meter long reinforced-concrete culvert on the downstream of Gevenez Creek Valley. However, considerable amount of deformations occurred in the first 100 meters of the culvert, as a result of overburden material being replaced on this structure.

In order to determine the failure mechanism associated with the culvert, a series of numerical modeling analyses were carried out utilizing back analysis technique. The validity of the numerical model was justified by convergence measurements and observations carried out inside the culvert as overburden material being replaced on the stable part of this structure. Finally, based on the numerical model developed, the stability of other culvert alternatives that could be used in future projects were evaluated considering different embankment conditions (positive projecting and negative projecting), bedding conditions (impermissible, ordinary, first-class and concrete cradle), culvert shapes (box and circular) and dumping conditions.

Key words: Dump-site culvert, numerical modeling, convergence measurements, back analysis.

ÖZ

TINAZ AÇIK İŞLETMESİNDE İNŞA EDİLEN DÖKÜM SAHASI MENFEZİNİN DURAYLILIK ANALİZLERİ

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Bu tezde, Türkiye Kömür İşletmeleri'nin (TKİ) Tınaz Açık İşletmesi'nde inşa edilen kutu tipi döküm sahası menfezinin duraylılık analizleriyle ilgili olan çalışmalar sunulmuştur. Ayrıca, diğer menfez seçeneklerinin duraylılık koşulları değerlendirilmiştir.

Açık işletme alanında derelerin bulunması döküm sahası yeri seçiminde dikkate alınması gereken önemli bir etkendir. Çünkü, vadiye dökülen örtü malzemesi bir set gibi çalışarak baraj gibi davranabilir ve döküm sahasının arkasında kalan alanda taşkın sorunlarına yol açabilir. TKİ mühendisleri döküm sahası arkasında oluşabilecek taşkın tehlikesini ortadan kaldırmak için Gevenez Deresi vadisi üzerine 480 metre uzunluğunda donatılı betondan bir menfez inşa etmişlerdir. Ancak, örtü malzemesinin bu yapı üzerine dökülmesi sonucunda menfezin ilk 100 metrelik kısmında dikkate değer deformasyonlar oluşmuştur.

Menfezin yenilme mekanizmasını belirlemek için sayısal modelleme çözümlemeleri yapılmış ve geriye dönük analiz tekniği kullanılarak sayısal model geliştirilmiştir. Sayısal modelin geçerliliği, menfezin duraylı kısmı üzerine örtü malzemesi dökülürken menfez içerisinde gerçekleştirilen konverjans ölçümleri ve gözlemlerle kanıtlanmıştır. Son olarak, geliştirilen sayısal modele dayanılarak, gelecekte kullanılabilecek diğer menfez seçenekleri değişik dolgu koşulları (yüzeyden yukarı ve hendekten yukarı), yataklama koşulları (izin verilemez, normal, birinci sınıf, ve beton beşikte), menfez şekilleri (kutu ve dairesel) ve döküm koşulları göz önünde bulundurularak değerlendirilmiştir.

Anahtar kelimeler: Döküm sahası menfezi, sayısal modelleme, konverjans ölçümleri, geriye dönük analiz

To My Family

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CHAPTER 1

INTRODUCTION

1.1 General Remarks

In a surface mine, considerable amount of overburden material has to be removed to produce coal or ore. To decrease the cost of production, dump sites should be chosen as close to the production panels as possible. On the other hand, a dump site should have enough space to accommodate the required amount of overburden material. Consequently, volume of the overburden material to be dumped and distance, that it should be carried, are the two important factors in selection criteria of dump sites. Existence of a creek valley on the selected dump site, on the other hand, is another significant issue to be considered. Since, the dumped overburden material on the valley acts as a barrier and behaves like a dam, it disturbs the natural flow pattern of the surface waters and cause flood problem behind the dump site.

1.2 Statement of the Problem

A similar problem was observed in Tınaz Surface Mine of Turkish Coal Enterprises (TKİ). TKİ tried to solve this problem by constructing a cast-in-place concrete box-shape-culvert on the existing valley and decided to convey water through this culvert without disturbing the natural flow pattern of the creek. After construction of the culvert, TKİ started to dump the overburden material on the valley including the culvert. However, when the height of the overburden material, dumped on the culvert, reached to 33 meters, which is much lower than the designed height of 80 meters, TKİ engineers observed a considerable amount of deformation inside part of the culvert.

1.3 Objectives of the Thesis

This study has three main objectives. The first one is to investigate the stability problem of the Tınaz Mine culvert by field studies including determination of the nature of deformations occurring in the culvert as a result of overburden load. The second objective consists of three stages, namely: i) determination of failure mechanism of the culvert by numerical analyses, ii) development of a numerical model by making use of back analysis technique, and iii) justification of validity of the numerical model by convergence measurements and field observations carried out inside the culvert as overburden material is being replaced on this structure. The third objective is to present other alternatives that could be used in future culvert projects of surface mines.

1.4 Methodology of the Thesis

In design of underground-structures, many uncertainties are involved especially characterization of the geological and geomechanical properties of soils and rocks, as well as determination of initial state of stresses. In other words, structures like tunnels are designed under conditions where mechanical properties and other input parameters may not be properly determined, and stresses developing cannot be soundly identified. According to Sakurai (1997); the mechanical behavior of underground structures can be predicted by using Finite Element Method or Boundary Element Method and also by considering material properties, such as Young's modulus, Poisson's ratio, and internal friction angle as input data for the computation. However, the actual behavior of these structures quite often differs from that predicted by numerical methods. Therefore, observational methods are adopted to improve agreement between the actual and predicted behaviors of underground structures, by modifying the input data that have been used in the computations.

The methodology followed in this study is as follows: In order to obtain acceptable agreement between the actual in-situ behavior of the culvert (failed locations), observed during preliminary field studies (Chapter 3) and the results (safety factors) obtained from numerical modeling studies, the technique known as "back analysis" will be used (Chapter 4).

To justify the validity of the numerical model developed, the results (predicted behavior of the culvert) obtained from the numerical studies (Chapter 4), will be compared with the results (actual behavior of the culvert) obtained from field measurements and observations (Chapter 5). Consequently, it will be shown that the actual and predicted behaviors of the culvert are in acceptable agreement.

As mentioned above, in order to justify the validity of the determined properties of the four different materials identified in the field, and to utilize them in numerical modeling, convergence measurements will be taken inside the culvert while overburden material is being dumped on this structure. By evaluating the relations between "Convergence" vs. "Time" and "Convergence" vs. "Height of the Overburden Material" and observing the deformations in the culvert, the maximum height of the overburden material that could be dumped on the culvert will be determined. Comparing the results obtained from numerical modeling with the results obtained from field measurements, the validity of the numerical model will be justified (Chapter 5).

In view of the fact that the existing dump site culvert of Tınaz Mine could not be able to stay stable under the required height (80 meters) of overburden material, alternative culvert models, for future projects, will be evaluated based on justified numerical model (Chapter 6).

1.5 Thesis Outline

Following the introduction, Chapter 1, basic concepts associated with culverts, including classification of culverts from different perspectives and their applications in mining are reviewed in Chapter 2 as a part of the literature survey carried out in this study.

Chapter 3 includes information about the study area located in Tınaz Surface Mine. Material pertinent to the study area as well as data and maps used in stability analysis of the culvert, are given in this chapter.

Studies associated with the development of a numerical model, back analysis technique used, and the results of numerical analyses including the maximum height of the overburden material that can be dumped on the culvert are presented in Chapter 4.

Chapter 5 includes justification of the validity of the numerical model by field measurements and observations. The studies associated with determination of the maximum height of the overburden material by field measurements are presented in this chapter in addition to the results of convergence measurements and their interpretation.

Analyses on alternative culvert models, which are evaluated based on the justified numerical model, are given in Chapter 6.

Finally, conclusions and recommendations pertinent to this study are presented in Chapter 7. Additional information associated with the stability analyses and interpretation of field measurement data are given in the Appendices included at the end of this thesis.

CHAPTER 2

LITERATURE SURVEY

2.1 General

A culvert, which is a kind of conduit, is simply an enclosed channel that is open at both ends and used to convey the water through an embankment (O'Flaherty, 2002). Typical application of a culvert is given in Figure 2.1.

History records the use of underground culverts for the past 3000 years. Some have lasted for centuries. Evidently these culverts were built as a result of experience, observation or by guess, rather than on the bases of rational design. No doubt that there were many failures due to poor construction or to the disregard of simple engineering principles. On the other hand, many were built wastefully strong for similar reasons.

Even the simple culvert becomes important when considered in the overall picture. Significantly high amount of money is spent annually for small drainage structures. Furthermore, these are for the purpose of protecting much more worthier engineering constructions. Hence the need for engineers to determine when and where drainage structures are required, and to select or design them adequately but not wastefully.

An engineer is defined as "one who understands the forces and materials of nature and applies them for the benefit of mankind with greater economy than a layman" (Spindler, 1958).

The type of culvert selected for use in a given location is dependent on the hydraulic requirements and the strength required to sustain the weight of a fill. After these items have been established, the selection is then largely a matter of economics. Consideration must be given to durability and to the cost of the completed structure, including such items as first cost of manufactured units and cost of transportation and installation. Maintenance costs should also be considered in any overall comparison of the cost of different culvert types (Wright et al., 1996).

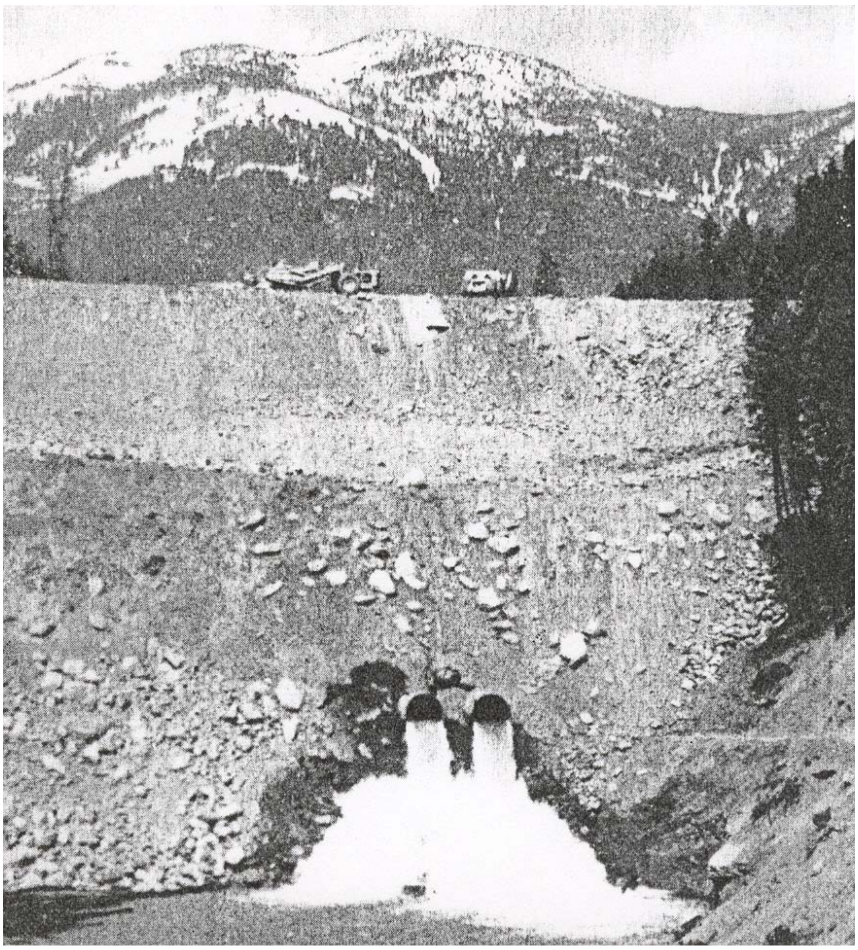


Figure 2.1: Culverts are used to convey the water through an embankment (Spindler, 1958)

2.2 Characteristics of Culverts

All culverts have three characteristics in common, such as alignment of the culvert with respect to natural streambed and embankment, grade of the culvert and type of flow in the culvert. These characteristics must be taken into consideration during design process.

2.2.1 Alignment

The first principle of culvert location is to give the stream a direct entrance and a direct exit. Any abrupt change in direction at either end will retard the flow and make a larger structure necessary (Spindler, 1958).

The selection of the natural direction of the stream is somewhat difficult in some areas, where the stream bed is not in a fixed position but shifts with the passage of time. In such a case, judgment must be exercised in selecting the most desirable location for the culvert, and some channel improvements may be necessary to ensure the proper functioning of the culvert after it is built (Wright et al., 1996).

A direct inlet and outlet, if not already existent, can be obtained in one of three ways, by means of channel change, a skewed alignment or both. The cost of a channel change may be partly offset by a saving in culvert length or decrease in size. A skewed alignment requires a greater length of culvert but is usually justified by improving the hydraulic design and the safety of the roadbed (Spindler, 1958). The purpose of hydraulic design is to provide a drainage facility or system that will adequately and economically provide for the estimated flow throughout the design life without unreasonable risks to the roadway structure or nearby property (Wright et al., 1996). Methods of selecting proper alignment are illustrated in Figure 2.2 (Spindler, 1958).

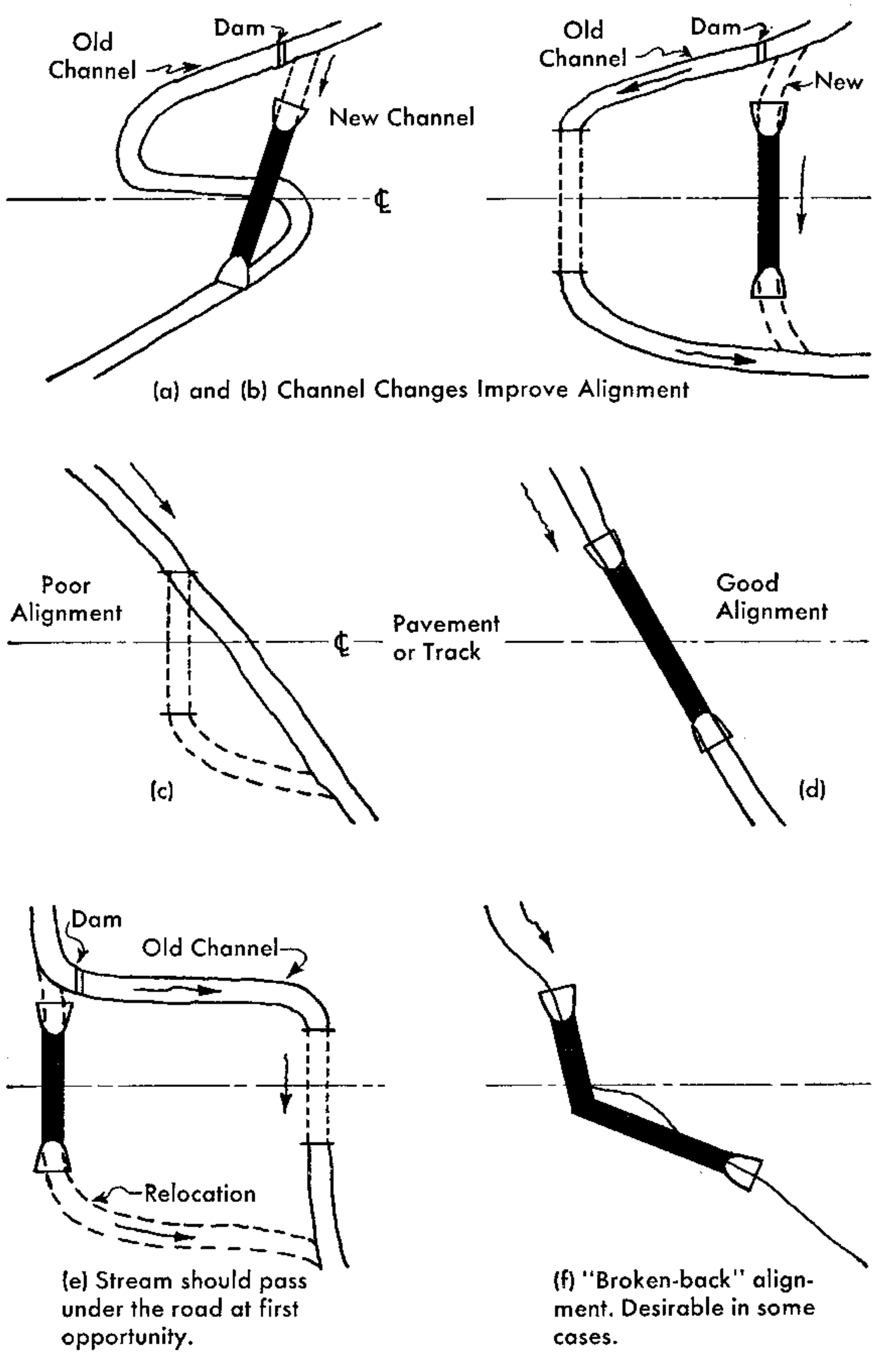


Figure 2.2: Various methods of securing correct culvert alignment (Spindler, 1958)

2.2.2 Grade

The ideal grade line for a culvert is one that produces neither silting nor excessive velocities and scour, one that gives the shortest length and one that makes replacement simple (Spindler, 1958).

The grade of the culvert should generally conform to the existing grade of the stream. If the grade is reduced through culvert, the velocity may be reduced, sediment carried in the water will be deposited at the mouth or in the length of the culvert, and the capacity of the structure will thus be further reduced. Culvert grades that are greater than those existing in the natural channel may result in higher velocities through the culvert and at the outlet end. Undesirably high velocities at the outlet will result in scour or erosion of the channel beyond the culvert and may make it necessary to install elaborate and costly protective devices. Changes in grade within the length of the culvert should also be avoided (Wright et al., 1996).

2.2.3 The Type of Culvert Flow

The type of the flow occurring in a culvert depends on the total energy available between the inlet and outlet. The available energy consists primarily of the potential energy or the difference in the headwater and tailwater elevations (the velocity in the entrance pool is usually small under ponded conditions, and the velocity head or kinetic energy can be assumed to be zero). The flow that occurs naturally is that which will completely expend all of the available energy. Energy is thus expended at entrances, in friction, in velocity head, and in depth.

The flow characteristics and capacity of a culvert are determined by the location of the control section. A control section of a culvert is similar to a control valve in a pipeline. The control section may be envisioned as the section of the culvert that operates at maximum flow; the other parts of the system have a greater capacity than is actually used.

Laboratory tests and field studies have shown that highway culverts operate with two major types of control: inlet control and outlet control. Figures 2.3 and 2.4 show examples of flow with inlet control and outlet control, respectively (Wright et al., 1996).

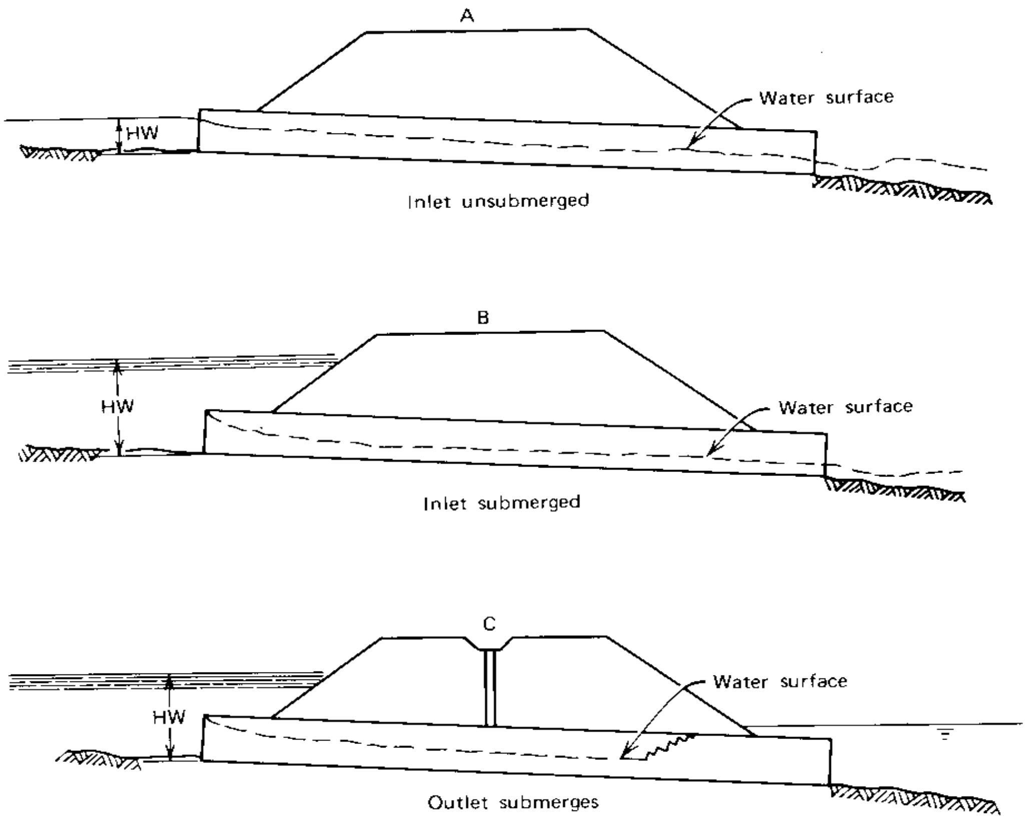


Figure 2.3: Inlet controls for culverts (Wright et al., 1996)

Culverts Flowing with Inlet Control

If the culvert is operating subject to inlet control, the control section is the entrance of the culvert; that is the flow that can pass from the inlet is less than the one that can pass from outlet. The hydraulic performance of the inlet controlled culvert is affected by the depth of headwater, entrance geometry, culvert barrel shape, cross-sectional area and inlet shape. The other properties of the culvert (roughness, length) and outlet conditions have no effect on the hydraulic performance. According to Tosun (2002), the improvement of entrance shape and inlet geometry can increase the performance of the culvert.

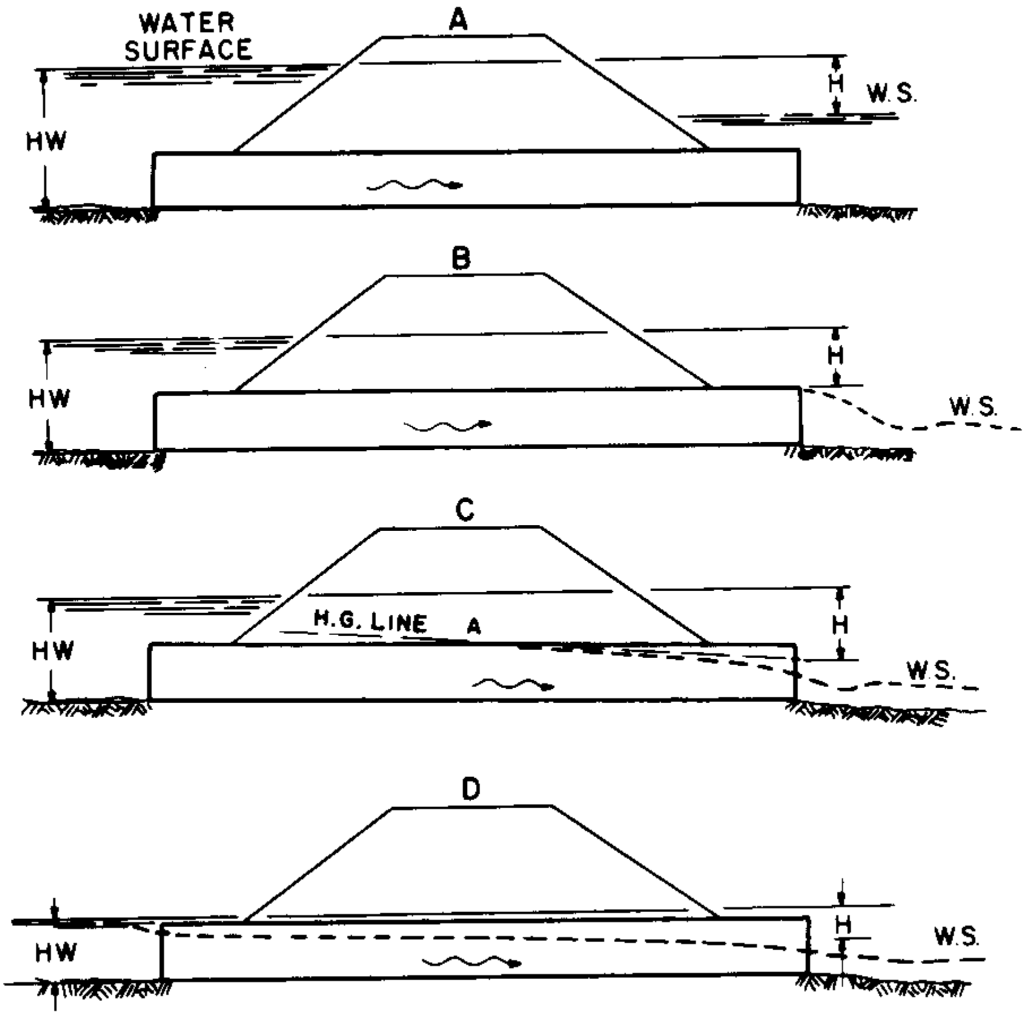


Figure 2.4: Outlet controls for culverts (Wright et al., 1996)

Culverts Flowing with Outlet Control

Outlet control occurs when the culvert flow is limited by the downstream conditions or by the flow capacity of the culvert barrel. The hydraulic performance of the outlet control is affected by the inlet control factors plus outlet control flow conditions, which are slope, length and roughness of the culvert barrel. The culvert with outlet control may flow full or partially full according to above conditions. Although culvert entrance has an influence on the performance, minor improvement can be reached by the entrance modifications (Tosun, 2002).

2.3 Classification of Culverts

Culverts could be classified according to many of its properties such as shape of the culvert, type of material used, construction conditions, area of application and also alignment, grade and type of the culvert flow, which are discussed above under culvert characteristics.

Design of culverts has two main bases: (i) hydrological design, and (ii) structural design. It is, however, more convenient to classify them according to load-related properties for structural design, which is corresponding with the scope of this thesis. Although many of those properties have influence on structural design of culverts, type of material used and construction conditions are leading ones. Other properties, quoted above, could be used to derive subclasses.

According to type of material used, culverts can be classified as flexible culverts and rigid culverts. Based on construction conditions, culverts could be classified in two main groups, such as embankment culverts and trench culverts. Furthermore embankment culverts can be subdivided into positive projecting culverts (embedded) and negative projecting culverts (unembedded) (Yang, 2000). A summary of the classification of culverts, from a load standpoint, is shown in Figure 2.5.

2.3.1 Classification of Culverts According to Material Types

Culverts are of many shapes and materials, but one major distinction, degree of flexibility, is important in classifying from a load standpoint:

1. Flexible culverts, such as corrugated metal culverts, aluminum culverts and plastic pipes fail by deflection. Flexible pipe relies only partly on its inherent strength to resists external loads. In deflecting under load, the horizontal diameter increases, compresses the soil at the sides and thereby build up "passive resistance" which in turn helps support the vertically-applied load (Spindler, 1958).

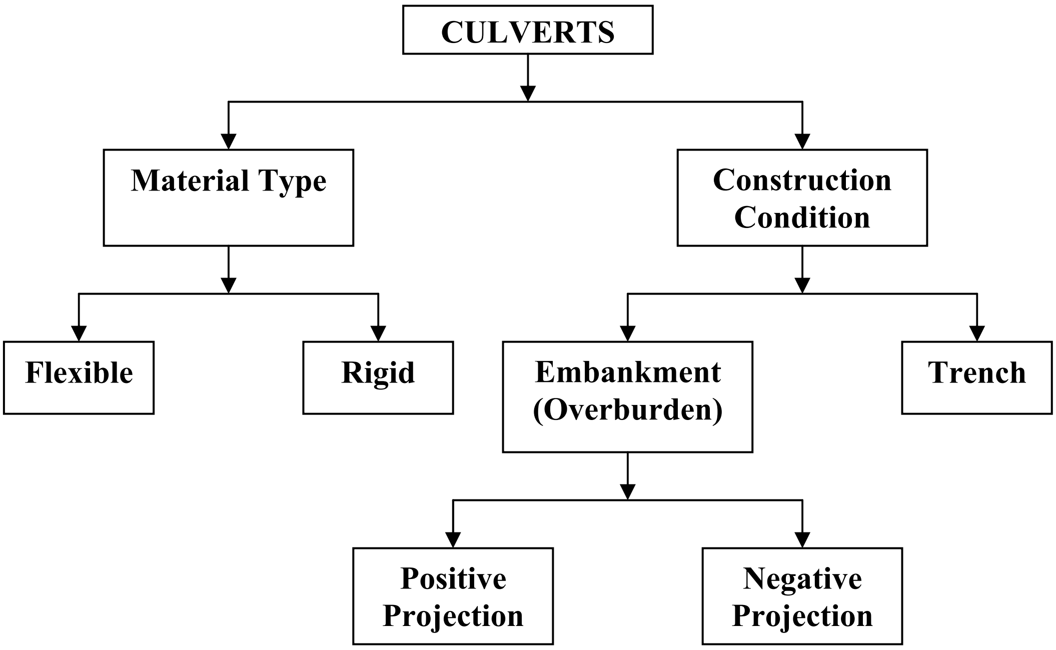


Figure 2.5: Classifications of culverts (Yang, 2000)

2. Rigid culverts are composed of reinforced concrete, cast iron or vitrified clay and their load-carrying ability is primarily a function of the stiffness of the culvert walls (O'Flaherty, 2002).

2.3.1.1 Flexible Culverts

Corrugated metal, aluminum and plastic are the most widely used materials in flexible type culverts.

2.3.1.1.1 Corrugated Metal Culverts (Steel)

Corrugated metal pipe was first developed and used as culverts in 1896 (Spindler, 1958). As confidence was gained in the use of this light-weight, thin-walled pipe, the diameters were increased to 183 (72 in.) and 213 (84 in.) cm. Fill heights were increased to 33 m. (100 ft) or more. Users include highway departments, railroads, sewer departments, levee engineers and many others. In Figure 2.6, corrugated metal culvert is seen in construction stage.

Figure 2.6: Corrugated metal culvert in construction stage
(Asset International, 2003)

Because of their ability to resist impact, vibration and unforeseen loads, and because of positive joint strength, corrugated metal structures have been found dependable for difficult as well as normal service conditions (Spindler, 1958).

Corrugated metal culverts may be used in rural levee systems when risk of substantial property damage and loss of life is low. Corrugated metal culvert is subject to chemical and galvanic corrosion, is not easily tapped, has a high hydraulic coefficient of friction, and is vulnerable to joint leakage and associated piping to live load distortion.

Corrugated steel pipe usually fails due to corrosion of the invert or the exterior of the pipe. Properly applied coatings can extent the product life to at least 50 years for most environments (U.S. Army Corps of Engineers, 1997).

2.3.1.1.2 Aluminum Culverts

Aluminum box culverts are a practical and cost efficient solution for a small bridge replacement. Lower installation costs result from aluminum box culverts being faster to install than cast-in-place concrete structures, as illustrated in Figure 2.7. Moreover, it is easier to install them because no heavy cranes are required, as with precast concrete structures (Contech, 2003).

Figure 2.7: Aluminum culverts are faster to install than cast-in-place concrete culverts (Contech, 2003)

Aluminum culvert is usually affected more by soil-side corrosion than by corrosion of the invert. Long-term performance is difficult to predict because of relatively short history of use, but the designer should not expect a product service life of more than 50 years (U.S. Army Corps of Engineers, 1997).

2.3.1.1.3 Plastic Culverts

Plastic pipes are available in both solid wall and profile wall thermoplastic acrylonitrilebutadiene-styrene (ABS), high-density polyethylene (HDPE), and polyvinyl chloride (PVC) pipes, as well as thermoset reinforced plastic mortar (RPM) pipes. Different wall profiles are illustared in Figure 2.8, which are produced by Fırat-Krah Sanitary Sewer Systems (FKS). Materials all possess the general attributes normally associated with plastics including light weight, long lengths, as seen in Figure 2.9, tight joints, and resistance to normal atmospheric corrosion. All these pipes are flexible, and in general the design considerations are similar to metal pipes. However, due to the viscoelastic nature of these materials, the time under load condition may require that long-term material properties be used in the design. Additionally, each specific grade of material, as well as the type of pipe (i.e., solid or profile) dictates the design properties.

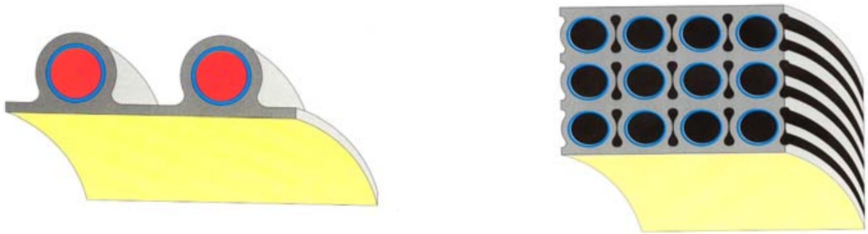


Figure 2.8: According to design characteristics different wall profiles are used (FKS, 2002)

Plastic pipes vary significantly in strength, stiffness, and performance. Differences depend more on their design and intended use than on the specific pipe wall material. A thorough evaluation of the intended use and detailed material, jointing, and backfill specifications is necessary to ensure performance. Use of plastic pipes in drainage and subdrainage applications is increasing. However, their use in low cover with heavy wheel loads or high cover applications is limited. Plastic pipes will typically be used for drainage piping behind structures.

Figure 2.9: Light weight, long length plastic pipes are easy-to-install (FKS,2002)

For culvert applications, the exposed ends of some types of plastics pipes need protection from exposure to ultraviolet, thermal cycling, etc. Concrete or metal end sections, headwalls, or other end protection is recommended.

As quoted above, many different materials fall under the general category of plastic. Each of these materials may have some unique applications where it is suitable or unsuitable. Performance history of plastic pipe, which are served as culvert, is limited so, a designer should not expect a product service life of greater than 50 years (U.S. Army Corps of Engineers, 1997).

2.3.1.2 Rigid Culverts

In general, concrete culverts are designed as rigid culverts, and the other materials are designed as flexible culverts (U.S. Army Corps of Engineers, 1997). Furthermore, cast iron and vitrified clay could be used as rigid culvert materials (O'Flaherty, 2002). Concrete culverts can be classified into two types, such as cast-in-place reinforced concrete culverts (Figure 2.10-a) and precast concrete culverts (Figure 2.10-b).

Cast-in-place reinforced concrete culverts are used for medium to large dams, and precast culverts are used for small dams, urban levees, and other levees where public safety is at risk or substantial property damage could occur. Intake structures, intake towers, gate wells, and outlet structures should be constructed of cast-in-place reinforced concrete. However, precast concrete structures may be used in agricultural and rural levees.

For fills of moderate height, cast-in-place reinforced concrete culverts in circular or rectangular openings will frequently be the most practicable because of the speed and economy obtainable in design and construction. For openings of less than 5.6 m^2 (60 ft^2), a single rectangular box probably most economical for moderate fills up to about 18.3 m. (60 ft). However, a rectangular culvert entrenched in rock to the top of the culvert may be economical for higher fills since the applied vertical load need be only the weight of the earth directly above with no increase for differential fill settlement. The ratio of height to width should be about 1.50 to accommodate the range of loading conditions economically (U.S. Army Corps of Engineers, 1997).

(a)

(b)

Figure 2.10: (a) Cast-in-place reinforced concrete culverts and (b) Precast concrete culverts (Tarmac, 2003)

Precast reinforced concrete pipe intended for use in culverts is made in diameters of 300 to 3600 mm (12-108 in.) and in various lengths, the usual length being 1.2 to 2.4 m (2-4 ft). Precast reinforced concrete box culverts are constructed with square or rectangular cross-sections; single box culverts vary in size from 0.6 m to 3.6 m (2-12 ft.) square, depending on the required waterway opening. Rectangular cross-sections are used where it is desired to reduce the height of the culvert and the roadway surface. The use of box culverts has declined in recent years, largely because of the time required for their construction (Wright et al., 1996). Typical precast culvert shapes are given in Figure 2.11 (U.S. Army Corps of Engineers, 1997).

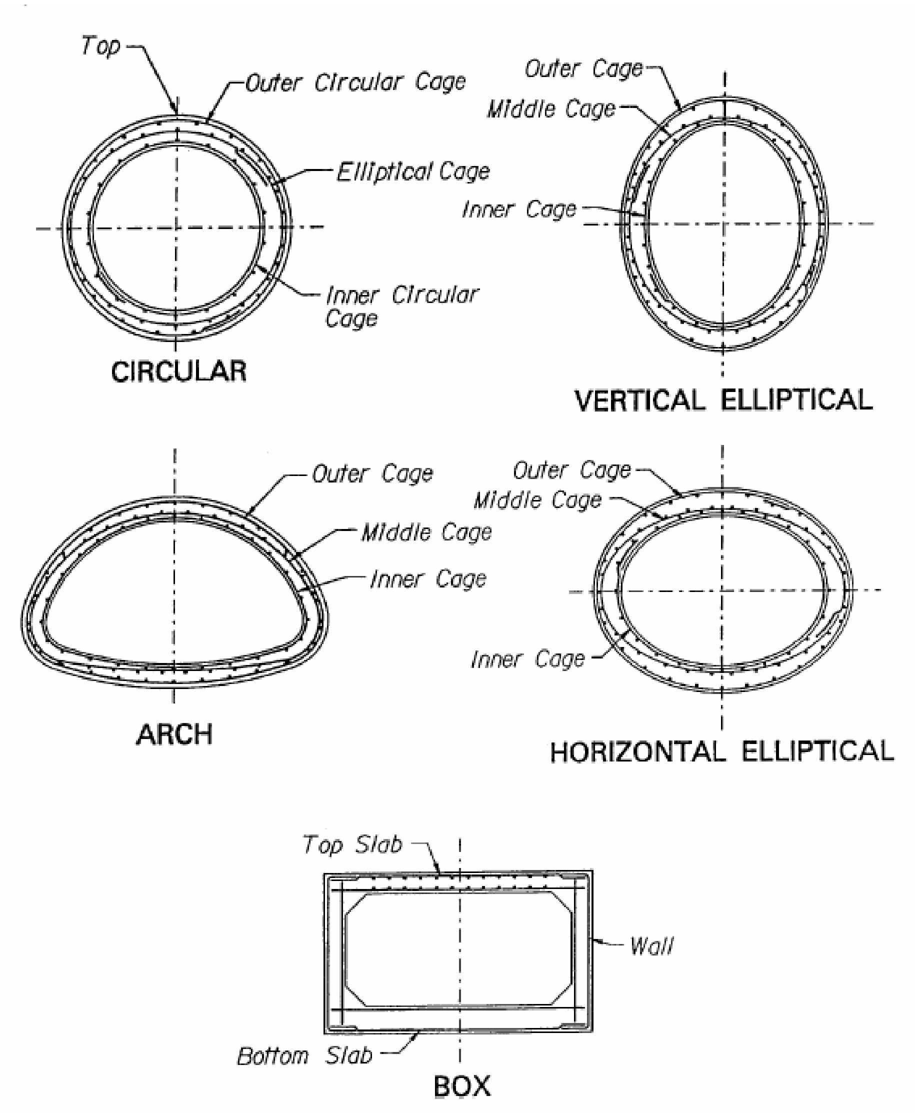


Figure 2.11: Precast culvert sections (US Army Corps of Engineers, 1997)

2.3.2 Classification of Culverts According to Construction Conditions

On the basis of construction conditions under which they are installed, culverts are divided into three main classes: (1) trench culverts, (2) positive projecting culverts, and (3) negative projection culverts, (Figure 2.12).

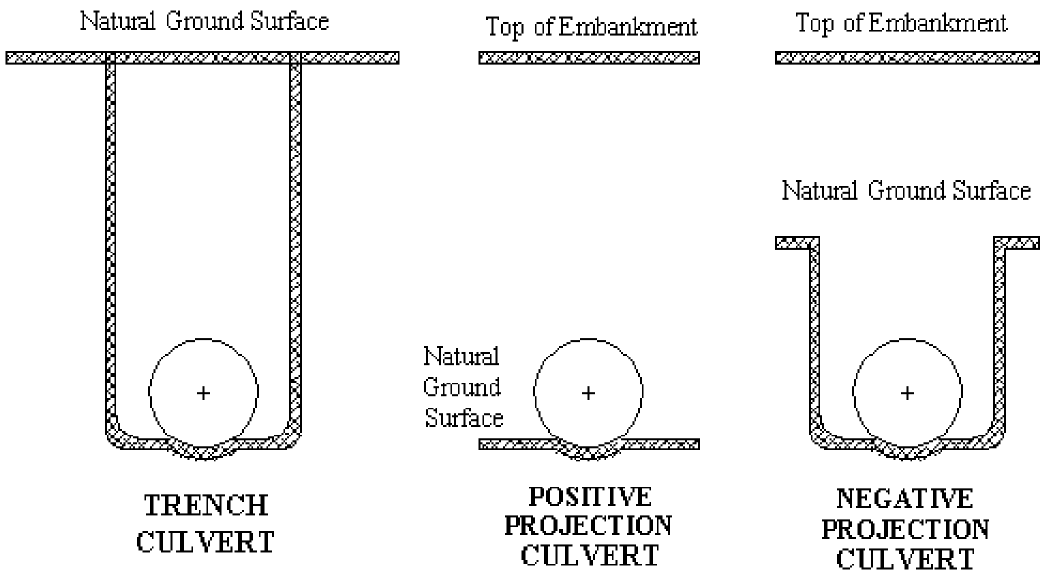


Figure 2.12: Classification of culverts according to construction conditions (Spindler, 1958)

1. Trench culverts are structures installed and completely buried in narrow trenches in relatively passive or undisturbed soil. Examples are sewers, drains and water mains.
2. Projecting culverts are structures installed in shallow bedding with the top of the culvert projecting above the surface of the natural ground, and then covered with an embankment. Railway and highway culverts are good examples. Culverts installed in ditches wider than two or three times their maximum horizontal breadth may also be treated as projecting culverts.
3. Negative projecting culverts: Highway or railway culverts are sometimes placed in a shallow ditch at one side of the existing

watercourse, with the top of the culvert below the natural ground surface and then covered with an embankment above this ground level.

Bedding conditions affect settlement and thereby affect the supporting strength of culverts. These bedding conditions, illustrated for trench culverts in Figure 2.13, and for embankment culverts in Figure 2.14, are: (a) impermissible, (b) ordinary, (c) first class and (d) concrete cradle, used only for rigid culverts.

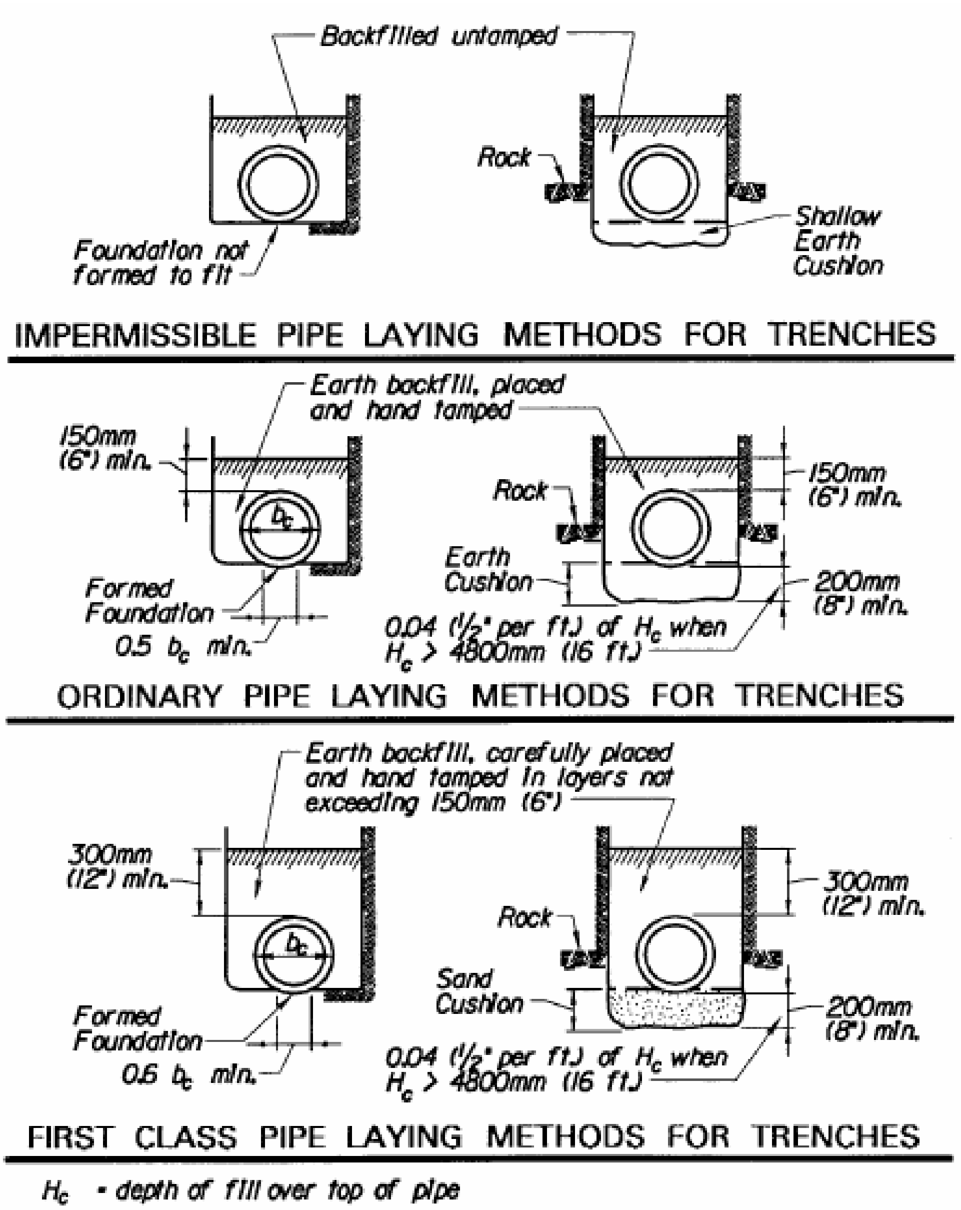


Figure 2.13: Trench bedding conditions (U.S. Army Corps of Engineers, 1997)

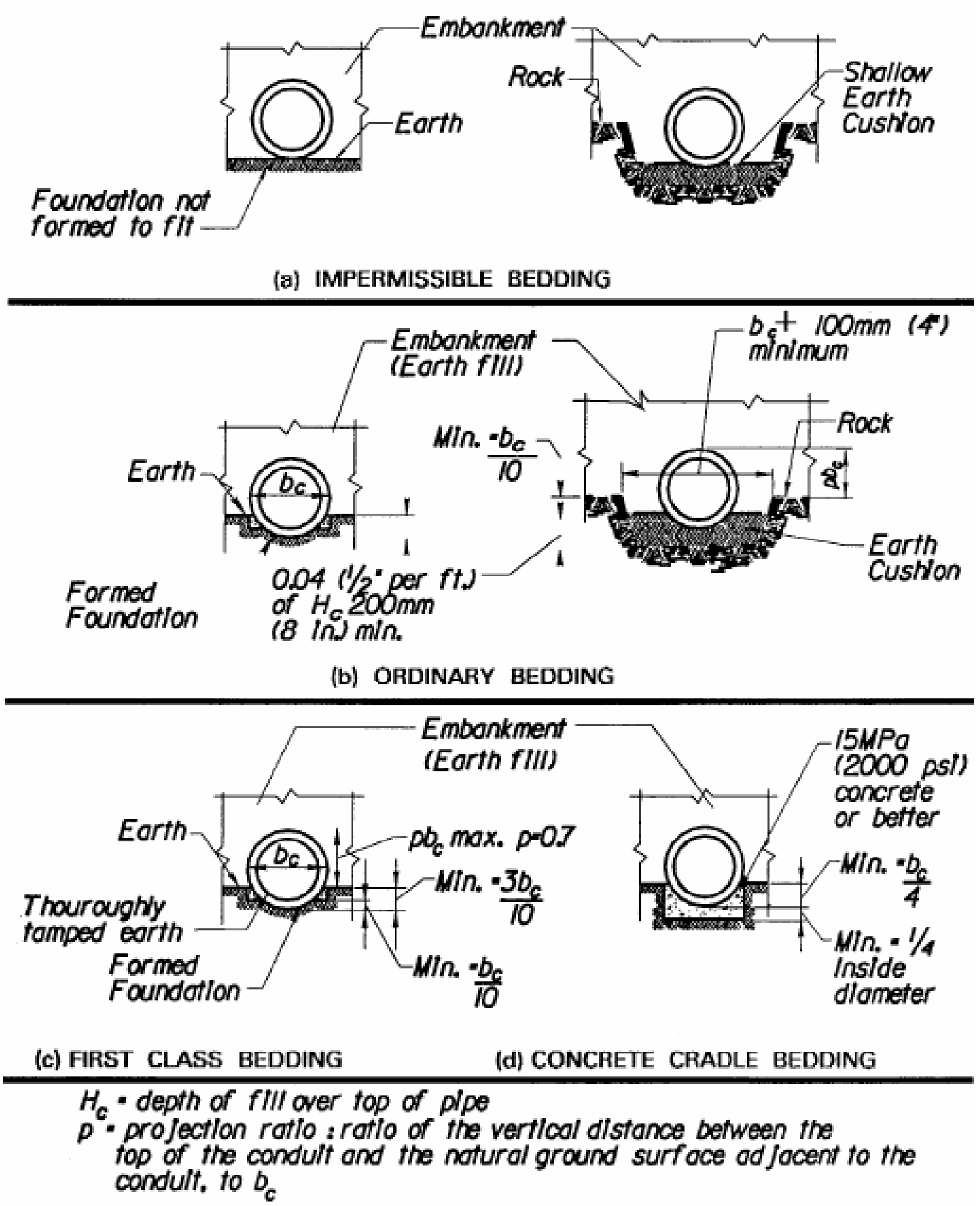


Figure 2.14: Embankment bedding conditions (U.S. Army Corps of Engineers, 1997)

2.4 Applications of Culverts in Mining

In a surface mine, considerable amount of overburden material has to be removed to produce ore. Volume of the overburden material to be dumped and distance that it should be carried are the two important factors in selection criteria of dump sites when cost of production is taken into consideration. Existence of a creek valley on the selected dump site, on the other hand, is another significant factor to be considered. Since, the dumped overburden material on the valley acts as a barrier and behaves like a dam disturbing the natural flow pattern of the surface waters causing flood problem behind the dump site (Özcan and Ünal, 2002).

Diversion of a creek, where geographic conditions are favorable, and construction of a culvert in the proposed dump site are the two alternative solutions to that flood problem. Turkish Coal Enterprises (TKİ) is preferred to construct a culvert to convey the creek through dumped overburden material in two of its surface mines namely Tınaz and Eynez.

In Tınaz Surface Mine of TKİ, cast-in-place reinforced concrete culvert is composed of two parts. First part is 350 m long and has a cross-section of 3 x 3 m. Second part is 480 m in length and has a cross-section of 3 x 3.7 m. Second part of the culvert is seen in construction stage in Figure 2.15.

Figure 2.15: Second part of the culvert in Tınaz Mine in construction stage

Karanlıkdere Culvert of Eynez-8 Panel, was constructed in Karanlıkdere Valley where 17,000,000 m^3 of overburden material will be dumped (Çatal et al., 2001). It is planned to construct precast reinforced concrete culvert of 1100 m. in length and 2 x 2 m. in cross-section. Installation of 600 m. was completed in June 2001. Installed culvert in Karanlıkdere can be seen in Figure 2.16.

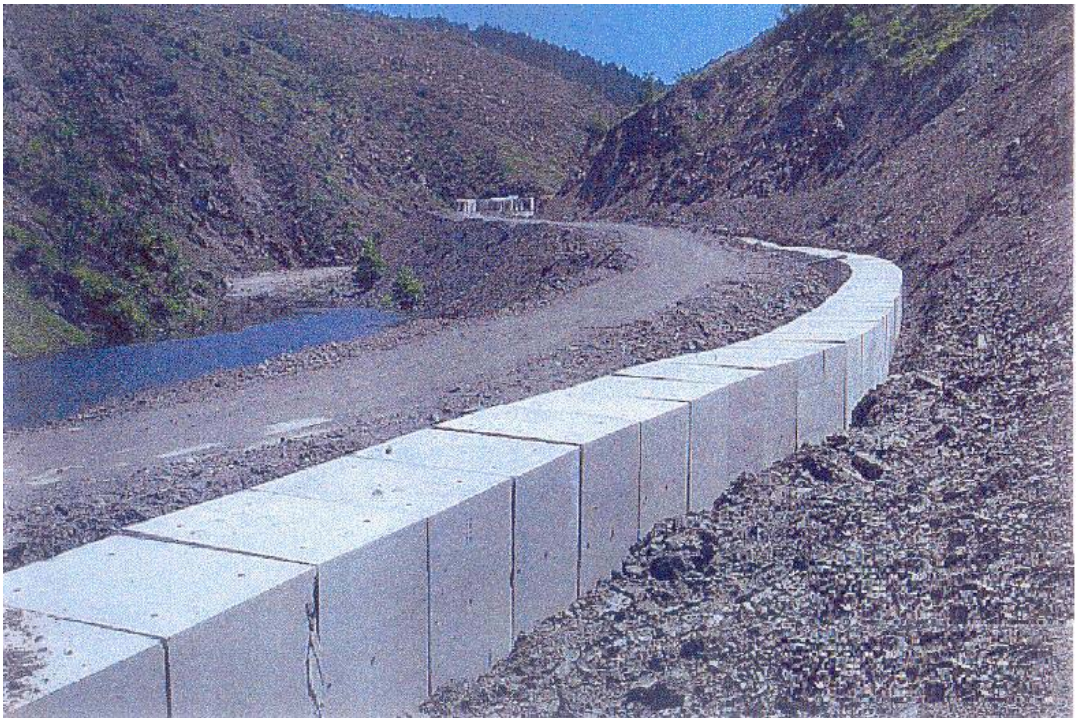


Figure 2.16: Precast, reinforced concrete culvert of Eynez-8 Panel in Karanlıkdere (Sağlamer et al., 2001)

Dewatering culverts are another essential applications of culverts in mining. Figure 2.17 is a plan view of typical cross-valley deposit with coarse tailings retaining dams at both upstream and downstream ends of the production. The river was diverted through a tunnel in the right abutment. Both retaining dams were constructed of hydraulically placed coarse tails. As the height of the tailing dam was increased, a rockfill anchor dike was constructed at the toe of the downstream retaining dam.

The original design included a reinforced concrete dewatering culvert placed in the valley bottom, which was to be extended upstream as the tailing deposit was enlarged. Chimneys were used to control the location, size and depth of the decant pond. New chimneys were added as the culvert was extended upstream. As the slimes inundated the lower chimneys and the decant pond moved upstream the chimney opening were plugged at the top of the culvert. A cross-section of the reinforced concrete culvert is provided in Figure 2.18. Dewatering culverts are designed using the expected maximum loading from superimposed tailings. The estimated life of the mine and the size of the ore body provide the input data for determination of the final height of the tailing deposit (Smith and Connell, 1979).

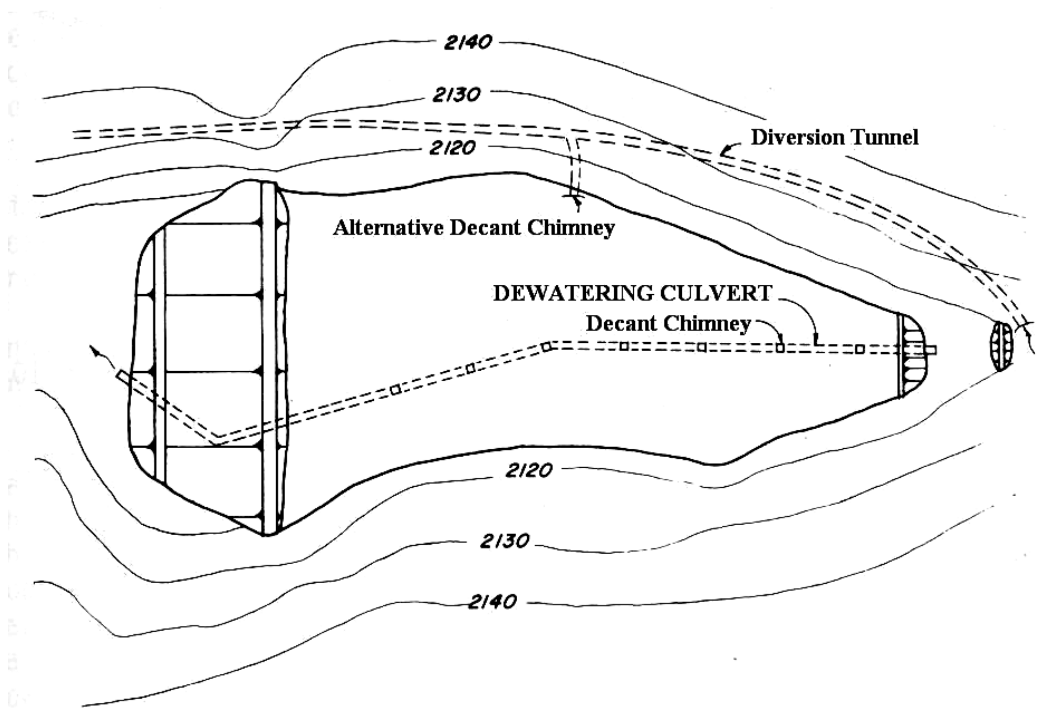


Figure 2.17: Plan view of tailing deposit (Smith and Connell, 1979)

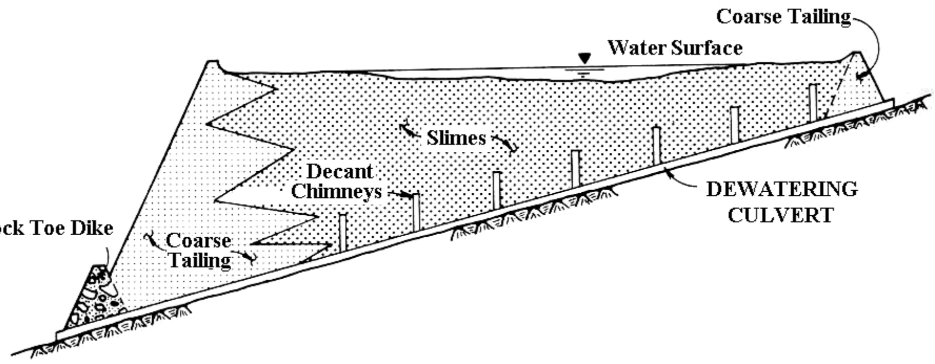


Figure 2.18: Cross-section of the reinforced concrete culvert in tailings dam (Smith and Connell, 1979)

As it is discussed above, although the application areas of culverts in mining industry seem to be limited, their existence is essential in continuation of cost effective production.

CHAPTER 3

PRELIMINARY FIELD STUDIES AT TINAZ MINE

3.1 Introduction

Existence of a creek in a surface mining area is a significant factor to be considered in selection of dump-site location. Because, the dumped overburden material on the valley acts as a barrier and behaves like a dam, disturbing the natural flow pattern of the surface waters, causing flood problem behind the dump site.

A similar problem was observed in Tınaz Mine of Turkish Coal Enterprises (TKİ). They tried to solve this problem by constructing a cast-in-place concrete box-shape culvert on the existing valley and they decided to convey water through this culvert without disturbing the natural flow pattern of the creek. However, when the height of the overburden material, dumped on the culvert, reached to 33 meters, TKİ engineers observed considerable amount of deformation inside one part of the culvert. This 33 meter height was much lower than the design height of 80 meters. The stability and design studies associated with the dump-site culvert of Tınaz Mine are selected as research subject of this M.Sc. Thesis.

In this chapter, general information about Tınaz Mine, geological and hydrological conditions around the culvert, and initial state and stability of the culvert with respect to dump sites will be presented.

3.2 General Information About Tınaz Mine

City of Muğla, which is rich in lignite coal reserves, is located in the southwestern part of Turkey. Southern Aegean Lignite Enterprises (GELİ) of Turkish Coal Enterprises (TKİ) is operating these three lignite mines, called as Eskihisar, Bağkaya and Tınaz, located in Yatağan-Muğla region. Tınaz-Bağkaya lignite mines are located near to Tınas and Bağkaya towns of Muğla. Tınas town is 16 km away from Muğla. Location maps of Tınaz Mine, Yatağan and Muğla are shown in Figure 3.1. The roads that connect Tınaz Mine to the surrounding population centers, namely to Yatağan and Muğla are open to transportation in all seasons. Tınaz Regional Management of GELİ operates Tınaz Mine.

The study area is located along northwest-southeast direction and surrounded by high hills from both sides in that, the area almost forms a corridor. Kapuz Creek is located in northwestern part of Tınaz. Altitude of the Tınaz ranges between 450 and 550 meters from sea level. Lowest flat surface (450 m) is formed between Gevenez and Karakuyu, and altitude increases towards the northwest direction reaching up to 630 meters in Bağkaya.

In rainy seasons, small creeks flowing from surrounding hills are collected in graben forming the Tınaz region. Collected surface waters are than drained by Kapuz Creek located in the north of Karakuyu town.

Typical Aegean climate prevails in the area. Summers are hot and dry, and winters are warm. In winters rain falls are seen instead of snow. Heavy rains are observed usually between November and April.

The hills surrounding the region are covered with pine trees. Since most of the Tınaz area is covered with colluviums, the region is not suitable for agriculture. Tobacco, olive and pine peanut are the products of agricultural activities in the region (Ünal et al., 2002).

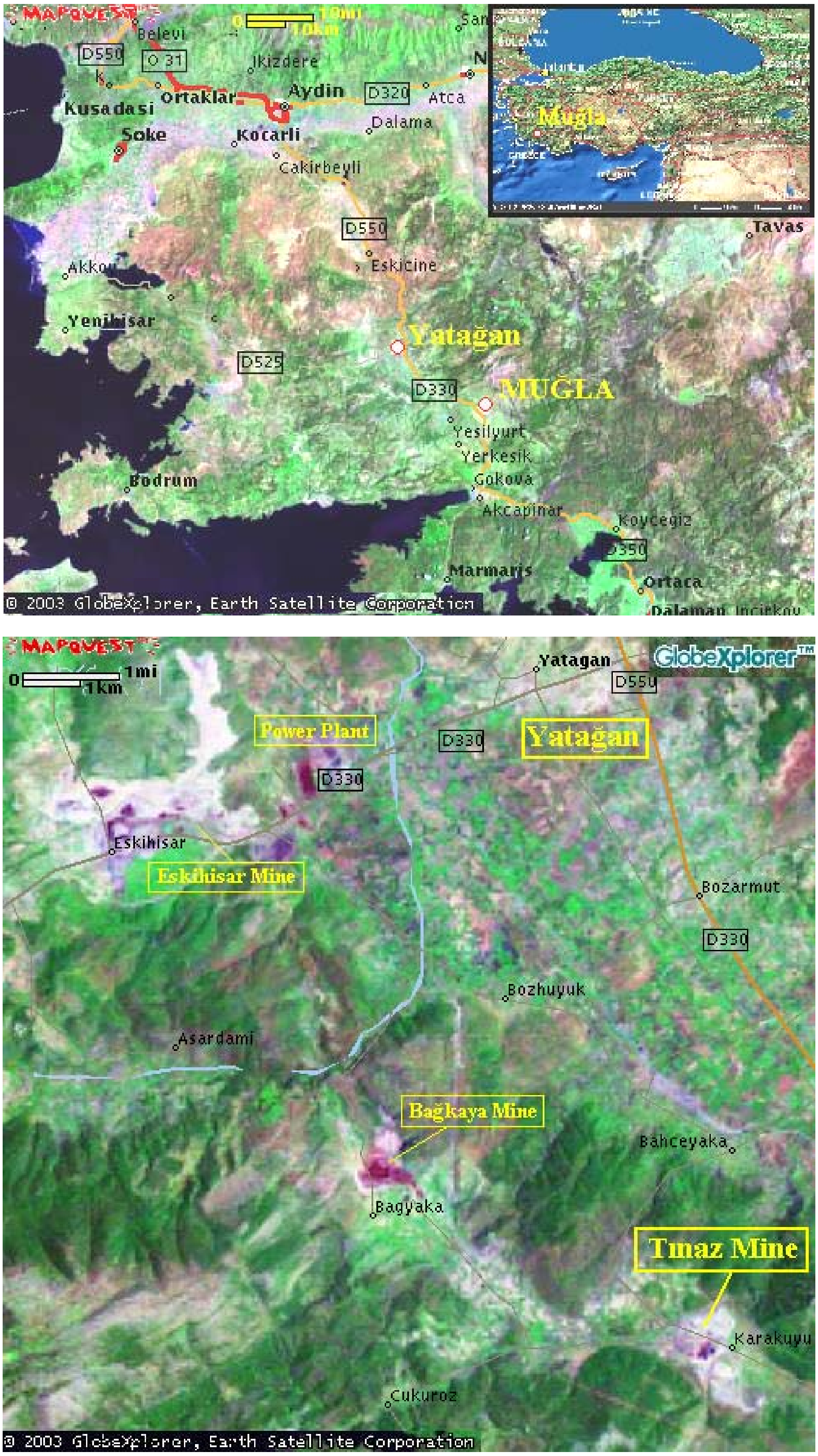


Figure 3.1: Location map of Tınaz Mine, Yatağan, Muğla (Mapquest, 2003)

3.3 Geological and Hydrological Conditions Around the Culvert

In general, lignite was formed in a subsided basin. Paleozoic schists and Mesozoic marbles, composing the upper layers of the subsided basin, border the lignite zone. Middle-upper Miocene aged Neogene deposit, including lignite horizon, fills the subsided basin (Ünal et al., 2002).

As shown in Figure 3.2, the dump-site culvert in Tınaz Mine Region consists of two parts, namely “old culvert” and “new culvert”. The total length of the old culvert, and the first 85 meters of the new culvert were constructed on Middle-Miocene aged Turgut Formation. This formation is intercalated with foliated clays and silts, well-cemented silt, clay and fine-grained gravel. During investigations it was observed that a discontinuity plane is passing through the 85^{th} - 100^{th} meters of the new culvert. A simplified geological map of the region is given in Figure 3.2.

The exit of the old culvert, excavation carried out in foundation of the new culvert, different lithological units in Turgut Formation, existing groundwater in the foundation, and steel drainage pipe intersecting culvert at 67^{th} meter are shown in Figure 3.3. After excavating the Turgut Formation units, to form a competent foundation, first 100 meters of the new culvert was constructed on boulder-sized limestone having a particle size greater than 300 mm, as illustrated in Figure 3.4. Rest of the new culvert is constructed on the existing marble foundation.

It is interesting to note that two different creek valleys intersect each other within the first 100 meters of the new culvert route. The completed cast-in-place new culvert is shown in Figure 3.5 (Ünal et al., 2002).

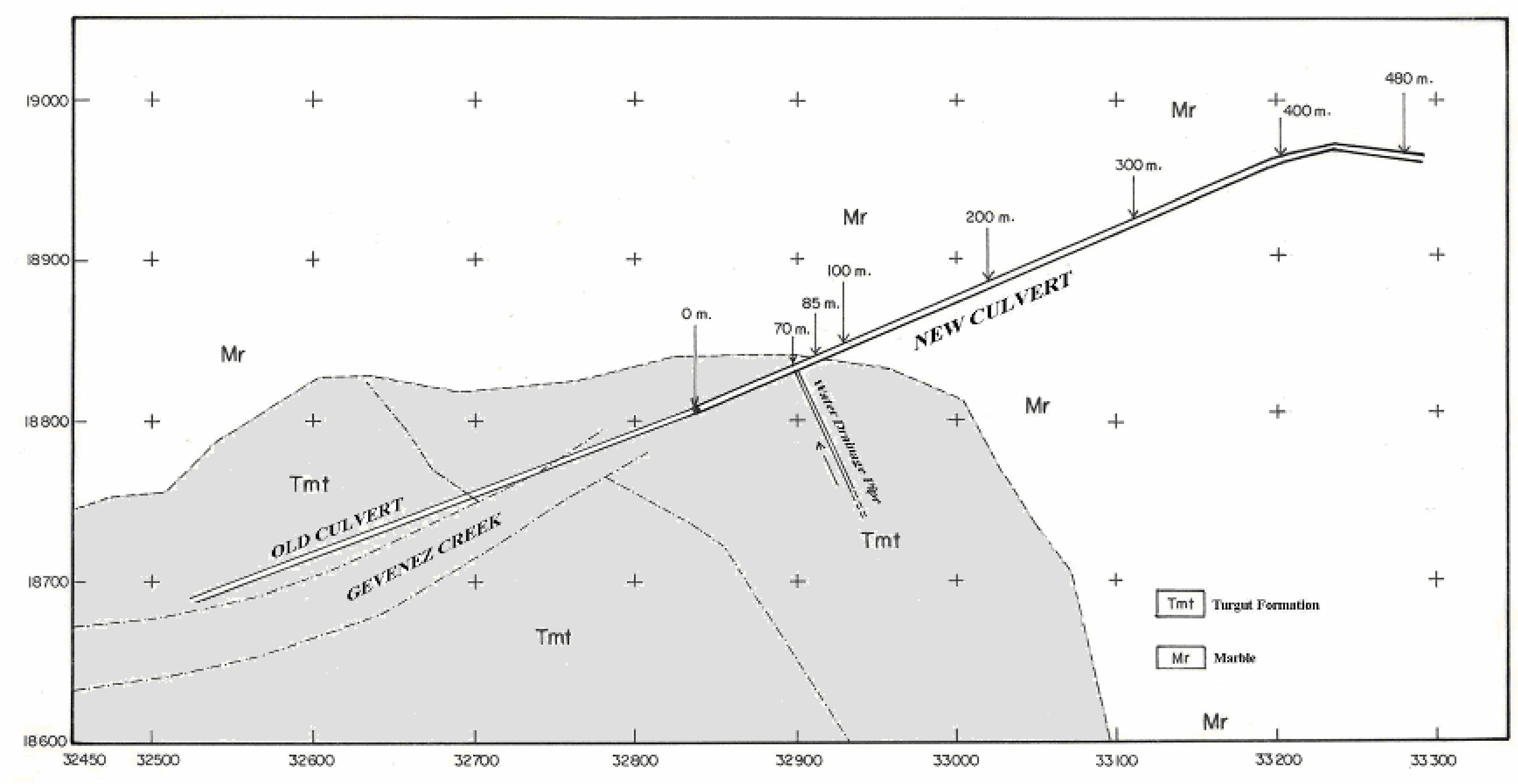


Figure 3.2: Simplified geological map of the region (Ünal et al., 2002)

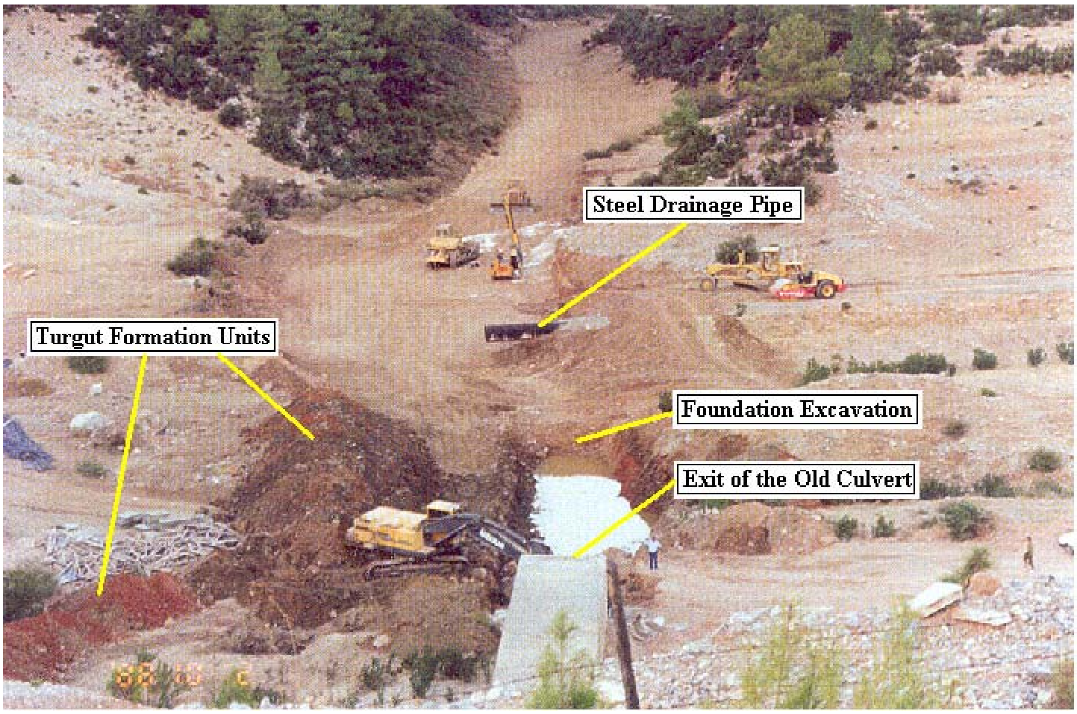


Figure 3.3: Exit of the old culvert, Turgut Formation units and steel drainage pipe

Figure 3.4: Boulders are layered to form competent foundation for the culvert

Figure 3.5: Completed, cast-in-place, culvert of Tınaz Mine

3.4 Condition of the Culvert Prior to Thesis Studies

Two culverts were constructed to convey the collected water in the Gevenez Valley. The old culvert is 350 m long having a cross-section of 3 x 3 m. The new culvert is 480 m in length from a joint connection to the old culvert. The new culvert has a cross-section of 3 x 3.7 m and a wall thickness of 60 cm. In rainy seasons the culverts are filled with water. Only second part of the culvert (new culvert) is taken under consideration in this thesis study.

Initially, collected water in the Gevenez Valley was planned to convey with a 350-meter long old culvert. However, as parallel to the continuing production in Tınaz Mine an additional dump site was required. Consequently the new culvert was constructed on the new dump site. New culvert is positive projecting, cast-in-place (Figure 3.6), reinforced concrete (Figure 3.7) box-shape culvert.

Figure 3.6: Positive projecting, cast-in-place dump site culvert of Tınaz Mine

Figure 3.7: Reinforcement of dump site culvert

According to the tests carried out by Bilgin İnşaat (2001), the concrete is used in the first 192 meters of the culvert is BS18 type, having a uniaxial compressive strength changing between 24 and 29 MPa. On the other hand the concrete used between the 288th and 384th meters of the culvert is BS25 type having a uniaxial compressive strength ranging between 30 and 32 MPa.

During initial stages of the overburden dumped on the new culvert deformations were observed between the 4th and 96th meters of the culvert when the overburden height reached to 33 meters. The maximum deformation estimated was about 30 cm. The region that this maximum deformation occurred is shown in Figure 3.8. There were also considerable deformations taking place in the upper left and lower right corners, when looking from the entrance towards to the exit of the culvert. Moreover, within the same interval, deformations, originated from the joint of concrete frame were observed (Figure 3.9). These deformations were occurring on the surfaces of the culvert walls due to the effect of water. Furthermore, minor cracks were also observed in the roof of the culvert as a result of asymmetric loading of overburden material. On the other hand, the cracks occurring on the floor of the culvert were much larger and visible than the roof cracks, as shown in Figure 3.10. There were no roof and floor cracks at the 375th meter of the culvert.

As illustrated in Figure 3.11, a steel drainage pipe having a diameter of 120 cm is coupled to the culvert wall at a point 67 meters from the entrance of the new culvert shown earlier in Figures 3.2 and 3.3.

Figure 3.8: The region where maximum deformation was observed as 30 cm.

Figure 3.9: Deformations occurring along the connection surfaces of concrete frames

Figure 3.10: Existing cracks in the culvert floor

Figure 3.11: Steel drainage pipe coupled to culvert's 67th meter

On the floor of the culvert, water ponds were observed especially between the 65th and 69th meter, 81st and 91st meter, around 140th meter, 286th and 289th meter, and 467th and 475th meter. The typical wet zones observed repeatedly on roof and floor of the culvert are shown in Figures 3.12 and 3.13.

Figure 3.12: Wet zones on the roof of the culvert

Figure 3.13: Wet zones on the floor of the culvert

3.5 Condition of the Dump Sites Prior to Thesis Studies

The location of dump sites around the culvert, just before the M.Sc. Thesis studies have started in August 2001, are shown in Figure 3.14. As can be seen from this figure, the height of overburden material on different parts of the culvert was changing significantly. This non-homogenize dumping was one of the reasons why deformations occurred inside the culvert.

In the first 125 meters of the new culvert, thickness of the overburden material was changing between 14 and 35 meters because, this part of the culvert was under the slope of a waste dump, as shown in Figure 3.15. Between 125th and 310th meters of the culvert the thickness of the overburden material, was uniform, changing between 14 and 17 meters. Since the region between 310th and 350th meter of the culvert was under the slope of +454 waste dump, thickness of the overburden material was changing between 4 and 17 meters. A uniform thickness of about 4 meters was observed in rest of the culvert. The overburden material dumped on the culvert end having different elevations or thicknesses as shown in Figure 3.16. The slope angles of the waste dumps were about 25º-35º due to characteristics of the overburden material (Ünal et al., 2002).

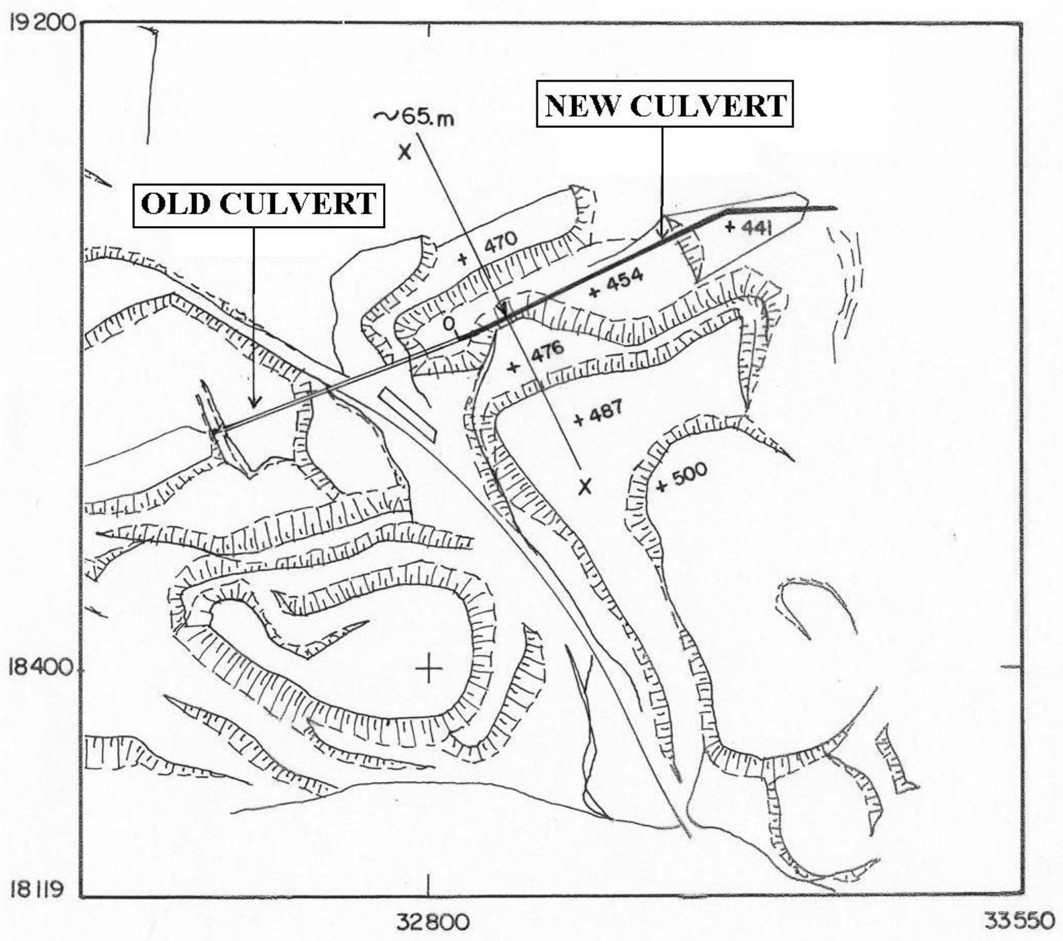


Figure 3.14: Location of dump sites around the culverts (Ünal et al., 2002)

Figure 3.15: Elevations of the overburden material on the first 125 meters of the culvert

Figure 3.16: Elevations of waste dumps on the “new culvert” in initial condition

CHAPTER 4

NUMERICAL STUDIES ON DUMP SITE CULVERT IN TINAZ MINE

4.1 Introduction

In this chapter, firstly a brief information about the importance of numerical modeling and back analyses in rock engineering will be given, secondly, the Phase2 software used in numerical studies will be briefly explained. Thirdly, the numerical analyses carried out on the existing dump-site culvert in Tınaz Mine will be given in detail, including the model properties, input parameters, output parameters and interpretation of results. Special attention will be given to the analyses of the deformed and non-deformed (stable) parts of the existing dump-site culvert in Tınaz Mine. As a result of numerical analyses, maximum height of the overburden material that could be dumped on non-deformed part of the culvert will be predicted.

4.2 Numerical Modeling

Some form of predictive capability is necessary in order to coherently design an engineered structure, whether it will be constructed on a rock-mass surface or within subsurface, and whether it will be constructed for civil, mining, petroleum or environmental engineering purposes. The predictive capability can be achieved through a variety of modeling methods. Even if one simple adopts the same design as previously constructed structure, the rock-mass condition is generally site-specific, therefore, one should use a computer model adopted for the specific site-conditions to ensure that the rock mass is likely to behave in similar fashion. As rock mechanics modeling has developed for the design of rock engineering structures with widely different purposes, and because different modeling methods have been developed, researchers and engineers now have a wide range spectrum of modeling approaches (Jing, 2003).

A number of numerical methods of analysis, such as the Finite Element Method, the Boundary Element Method, the Distinct Element method, etc., have rapidly developed in rock mechanics during the last decade. They have been used extensively in engineering practices in designing tunnels, large caverns, dams, and so on. However, even if these advanced methods are used, it is not an easy task to predict the mechanical behavior of the structures with sufficient accuracy. This is simply due to the fact that there are many uncertainties involved in the input data for the numerical analysis, such as geological and geomechanical characteristics of rocks, rock joint system, underground water table, initial state of stress, permeability, etc. Thus, it is not surprising that the actual behavior of the structures offer differ from those predicted (Sakurai, 1997). “In rock mechanics and engineering design, having insufficient data is a way of life, rather than a simple local difficulty, which is why the empirical approaches, i.e. classification systems, have been developed and are still required” (Jing and Hudson, 2002).

The Finite Element Method (FEM) is perhaps the most widely applied numerical method across the engineering field. Since its origin in early 1960s, much FEM development work has been specifically oriented towards rock engineering. This has been because it was the first numerical method with enough flexibility for the treatment of material heterogeneity, non-linear deformability, complex boundary conditions, gravity and in situ stresses (Jing and Hudson, 2002).

The FEM may be defined as “a general discretization procedure posed by mathematically defined statements” (Mathab and Grasso, 1992). The basis of the finite element method is the explanation of a problem domain surrounding an excavation, and a division of the domain, into an assembly of discrete, interacting elements. Figure 4.1-a illustrates the cross section of an underground opening generated in an infinite body subject to initial stresses p_{xx}, p_{yy}, p_{xy}. In Figure 4.1-b, the selected boundary of the problem domain is indicated, and appropriate supports and conditions are prescribed at the arbitrary outer boundary to render the problem statically determinate. The domain has been divided into a set of triangular elements. A representative element of the set is given in Figure 4.1-c, with the points *i, j, k* defining the nodes of the element. The problem is to determine the state of total stress, and the excavation induced displacements, throughout the assembly of finite elements (Brady and Brown, 1985).

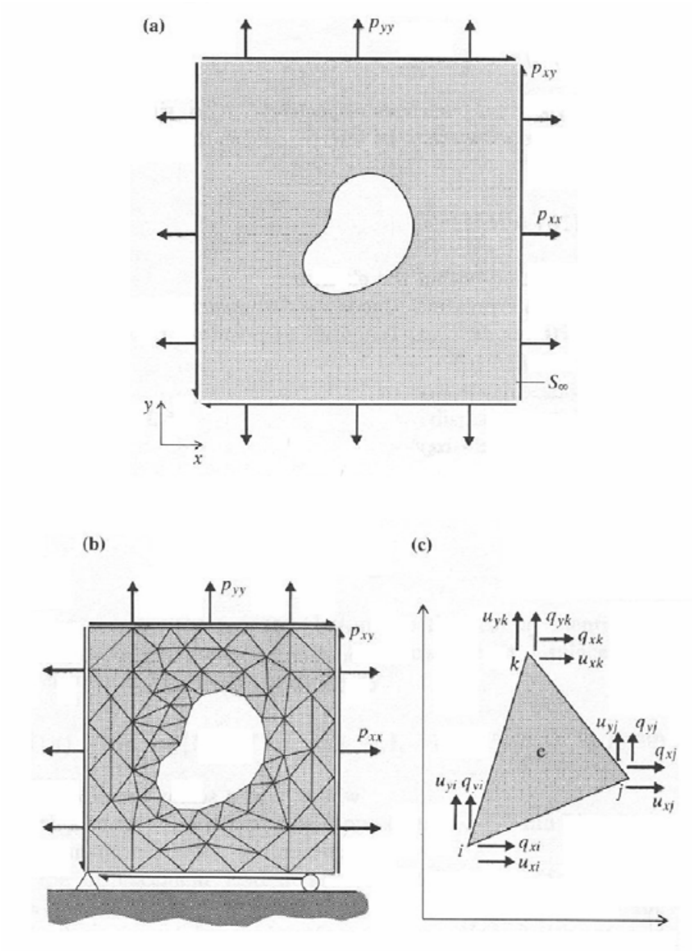


Figure 4.1: Development of a finite element model of continuum problem, specification of element geometry and loading for a constant strain, triangular finite element (Brady and Brown, 1985)

In view of the fact that application of finite element method in numerical modeling techniques are widely used in rock engineering field with confidence, studies in order to determine the stability conditions of the dump site culvert in Tınaz Mine will be based on this method.

4.3 Back Analysis

A large and important class of numerical methods in rock mechanics and civil engineering practice is the inverse solution techniques. The essence of the inverse solution approach is to derive the unknown material properties, system geometry, and boundary or initial conditions based on a limited number of laboratory or usually in-situ measured values of some key variables, using either least square or mathematical programming techniques of error minimization. In the case of rock engineering, the most widely applied inverse solution technique is back analysis (Jing and Hudson, 2002). It can bridge the gap between prediction and reality (Sakurai, 1997).

In order to model dump site culvert of Tınaz Mine, back analyses method is used in combination with numerical modeling. Observed deformations during preliminary field studies are used to predict unknown data about the culvert and dump site.

4.4 "Phase2" Software

Phase2, which was introduced by Rocscience (19..), is a 2-dimensional plastic finite element program for calculating stresses and displacements around underground openings, and can be used to solve a wide range of mining and civil engineering problems, involving: plane strain or axisymmetry, elastic or plastic materials, staged excavations, multiple materials, support, constant or gravity field stress, and groundwater.

The Phase2 program consists of three program modules: model, compute and interpret. Model is the pre-processing module used for entering and editing the model boundaries, support, in-situ stresses, boundary conditions, material properties, and creating the finite element mesh. Compute is the data processing module of the program. Finally, interpret is the post-processing module used for data visualization and interpretation of the Phase2 analyses result (Phase2, 2001). In this study Phase2 V5.0 software was used during analyses.

4.5 Modeling of Existing Culvert for Tınaz Mine Project

The main purposes of the numerical analyses carried out on the existing culvert are the following: i) to determine the failure mechanism in the deformed part of the culvert (0-100 m), ii) to determine the maximum height of the overburden material that could be dumped on the non-deformed part of the culvert (100-480 m), and iii) to determine the relation between the safety factor (calculated by dividing the rock strength by the induced stresses at every point in the mesh) and height of the overburden material. In order to determine the above quoted purposes, the dump-site culvert of Tınaz Mine is modeled and analyzed in two parts, namely the deformed and non-deformed (stable) parts.

4.5.1 Analyses on Deformed Part of the Culvert

To determine the failure mechanism in the deformed part of the culvert, characteristics of the model and the associated input parameters should be determined. The necessary analyses could be carried out only after constructing the model properly.

4.5.1.1 Characteristics of the Model

As mentioned earlier in Chapter 3, significant deformations were observed in the first 100 meters of the new culvert due to the affect of overburden material dumped on this structure. To determine the failure mechanism in this existing condition of the culvert, numerical studies were initially carried out based on the information gathered from the dump-site maps. During preliminary field investigations, on the other hand, it was observed that the maximum deformation has taken place in the 65th meter of the culvert. Consequently 65th meter of the culvert is taken into consideration in modeling. The culvert and dump site model, created by using Phase2, is presented in Figure 4.2. Considering the real dimensions in the field, upper-left level of waste dump is taken as +470 m., minimum level of waste dump is taken as +454 m., floor level of culvert is taken as +435 m. and upper-right level of waste dump is taken as +476 m. in this model geometry. Map and the photograph of the region are shown in Figures 3.14 and 3.15 in Chapter 3.

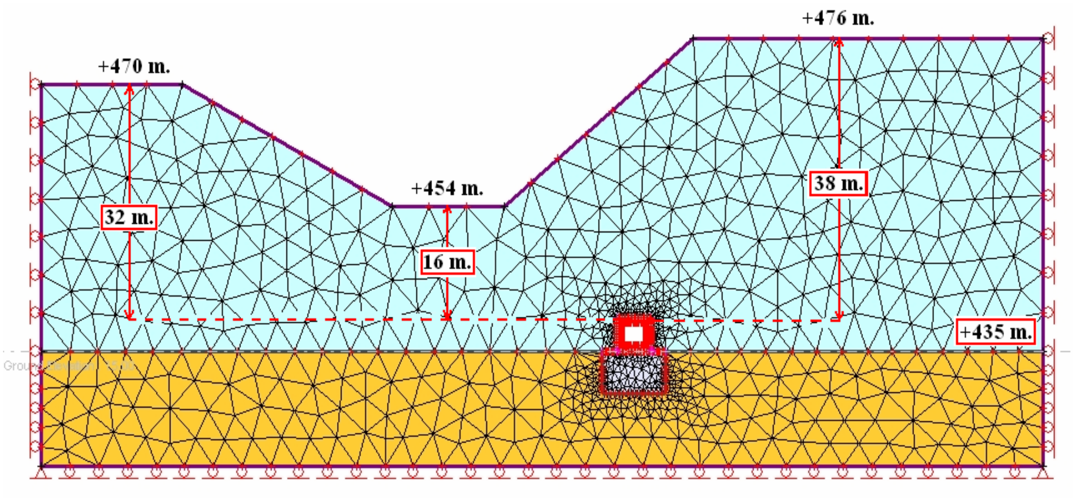


Figure 4.2: Culvert and dump site model in existing situation

In the model, illustrated in Figure 4.2, a total of 2391 triangular elements and 1282 nodes were used. In order to minimize the effect of boundaries on the main study zone, including the culvert, the model boundaries was taken 10 culvert-width away from the opening. Left and right sides of the model were restrained in horizontal dimension while the bottom of the model was restrained in vertical dimension.

In order to characterize the applied construction method in the model, five different stages are identified. Stage 1 represents the initial condition of the selected dump site before construction of the culvert. In Stage 2, foundation excavation is completed, as illustrated in Figure 3.3. In Stage 3, boulders are put on the foundation of excavation, as shown in Figure 3.4. In Stage 4, construction of the cast-in-place reinforced concrete culvert is completed (Figure 3.5). Finally, in Stage 5, overburden material is dumped on dump site including culvert, as shown in Figures 3.14 and 3.15. All of these five stages are shown in Figure 4.3, as they appear in the model.

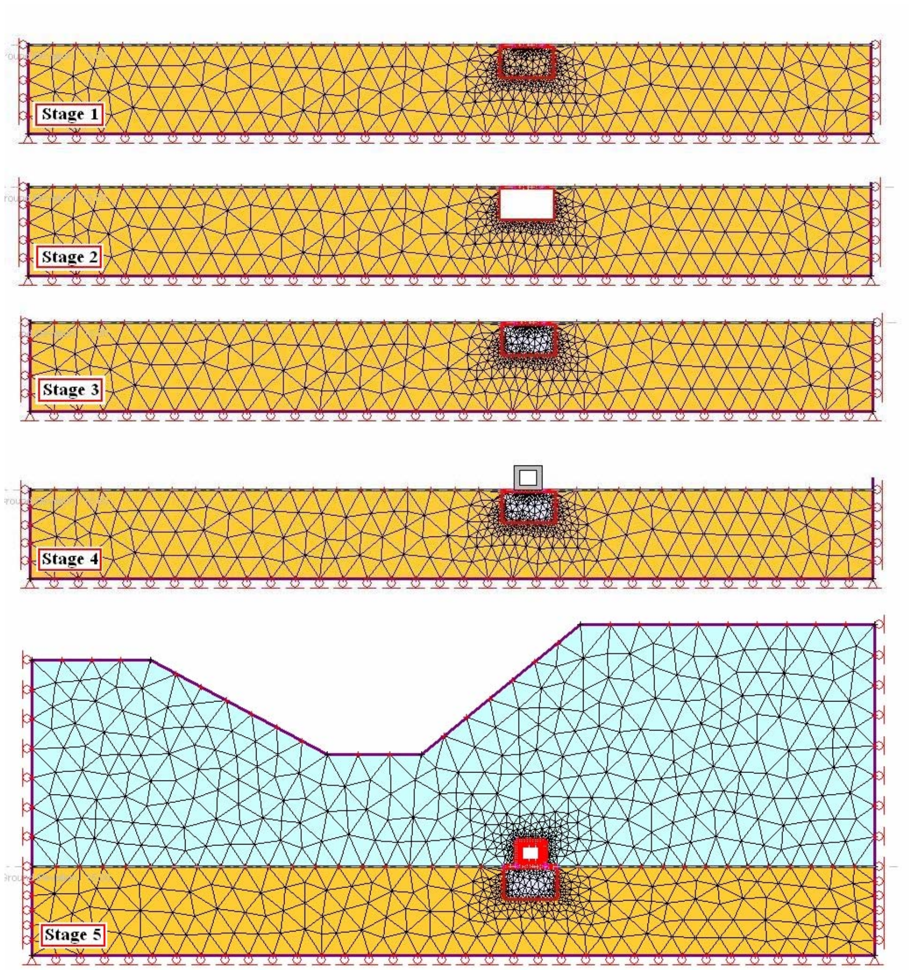


Figure 4.3: Five different stages of the model

4.5.1.2 Input Parameters

During preliminary field studies carried out in Tınaz Mine, four different material types were identified, namely undisturbed ground, foundation, reinforced concrete and overburden. The input parameters used for each material type are given in Table 4.1.

Table 4.1: Input parameters for each material type in existing situation

INPUT PARAMETERS	Undisturbed Ground	Foundation	Reinforced Concrete	Overburden
Loading Condition	Field Stress & Body Force	Body Force	Body Force	Body Force
Unit Weight (MN/m^3), γ	0.027	0.027	0.027	0.0255* 0.0188**
Young's Modulus (MPa), E	5000	20000	30000	20
Poisson's Ratio, ν	0.2	0.2	0.3	0.2
Material Type	Elastic	Elastic	Elastic	Elastic
Failure Criteria	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Tensile Strength (MPa), σ_t	0	0	5	0
Internal Friction Angle (°), φ	30	35	30	30
Cohesion (MPa), c	3	10.5	8	0

* Unit weight of the overburden material decided based on back analyses
** Unit weight of the overburden material used in culvert project

The unit weight, Poisson's ratio, internal friction angle, and cohesion parameters associated with the overburden material (composed of marl and conglomerate) have been provided by TKİ. As shown in Table 4.1, two different overburden unit-weights are taken into consideration during analyses, namely 18.8 kN/m^3 and 25.5 kN/m^3. Because TKİ engineers in their culvert project have taken the unit weight of the overburden material as 18.8 kN/m3, whereas it has been decided as 25.5 kN/m^3 based on back analyses. In numerical analyses both unit-weights have been taken into consideration, for the sake of completeness. The data related to the properties of the reinforced concrete (modeled as a composite material) have been obtained from Bilgin İnşaat (2001). Initially, properties of the two other materials, namely undisturbed ground (composed of foliated clays and silts, well-cemented silt, clay and fine-grained gravel) and foundation (composed of boulder-sized limestone), have been estimated according to the suggestions given by Bell (1983) and Farmer (1983). However, in later steps, they have been modified slightly based on engineering judgment and the observations carried out in field studies.

During numerical analyses it has been assumed that the culvert is under the effect of gravitational forces. In other words, the principal stresses in the culvert are assumed to be developing due to interaction of the weight of the overburden material and the reinforced-concrete support. It has also been assumed that before excavation hydrostatic stress conditions are acting on undisturbed ground. However, as a result of applied stages, non-hydrostatic stress conditions yield same results as shown in Appendix D.

Throughout the preliminary field studies, the existence of water was clearly seen in the roof, the side walls (Figure 3.12) and the floor (Figure 3.13) of the culvert. Consequently, it is believed that groundwater around the culvert has an obvious effect on the observed deformations. Accordingly, the effect of groundwater should be taken into consideration during modeling. From the hydrogeological data and topographic maps, the maximum groundwater level was determined as 17 meters above natural ground surface. In order to include the effect of groundwater into the developed model piezometric line option of Phase2 program was utilized, as illustrated in Figure 4.4. However, after a series of analyses, and comparing results (safety factors) with the actual culvert case (deformations observed in the culvert) it was realized that groundwater option of Phase2 (V5.0) couldn't adequately include the effect of groundwater into the model. In other words, the decrease in safety factors inside the culvert, (side walls, roof and floor) as a result of groundwater was negligible, consequently it is not realistic.

In order to reflect the physical observations made (failed locations) inside the culvert to the output obtained from the software (safety factors) and thus to be able to obtain comparable results, the "back analyses" technique was used. In order to obtain safety factor less then one at the locations where failure was observed the tensile strength and cohesion of the reinforced concrete was reduced. In that, the tensile strength and cohesion of the reinforced concrete was taken as 3.25 MPa and 5.2 MPa, respectively, reducing the original values about 35%.

4.5.1.3 Evaluations on Deformed Part of the Culvert

Numerical analyses, associated with the deformed part of the culvert are carried out by utilizing the culvert and dump site model given in Figure 4.2 and using the input parameters shown in Table 4.1. The output of the Phase2 program is given in Figure 4.5. During this analysis the unit weight of the overburden was taken as 25.5 kN/m^3, and effect of groundwater was taken into account. Distribution of safety factors in the inner walls of the culvert are also shown in Figure 4.5. The results significantly reflect the existing conditions observed inside the culvert.

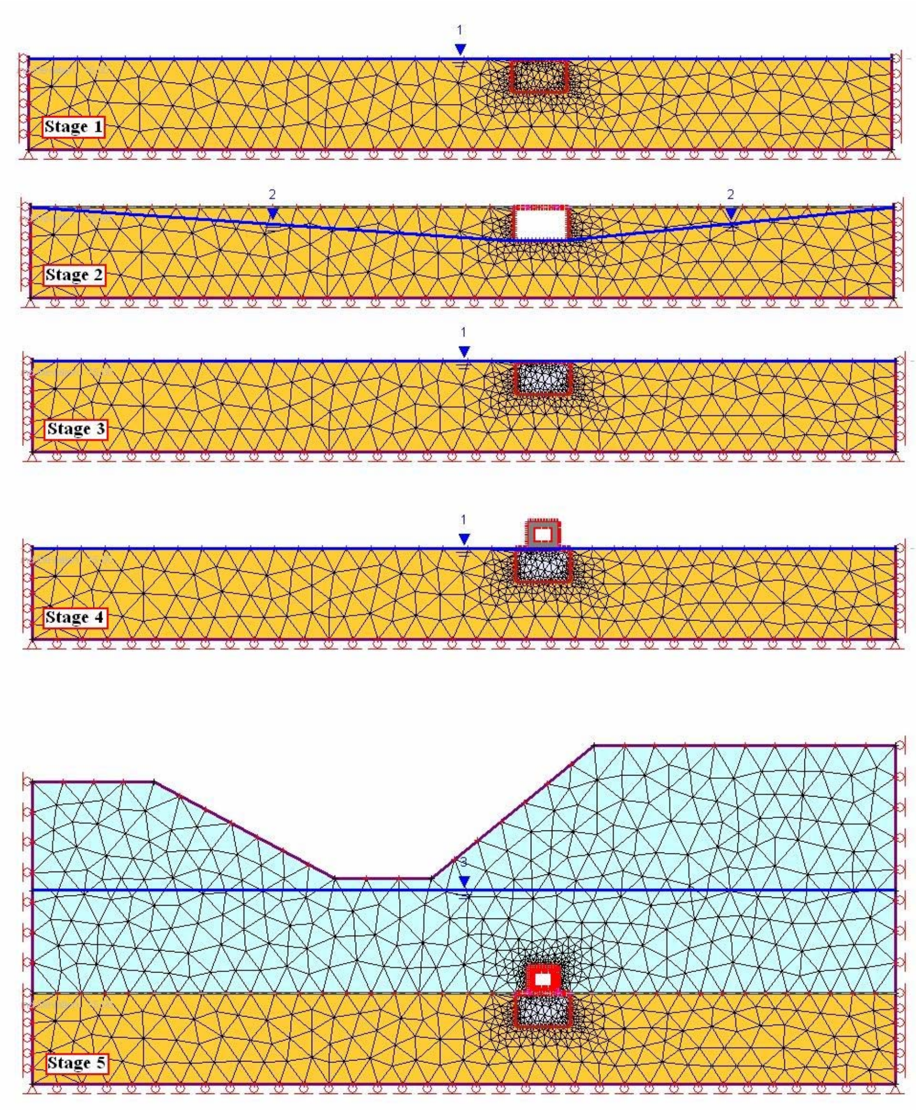


Figure 4.4: Stage by stage representation of groundwater by piezometric lines

In Figure 4.5, it is seen that safety factors in the upper-left and lower-right corners are below 1.00, meaning that compression failures occur in this two regions. Additionally, negative safety factors are observed in the roof and lower-left corner of the culvert, meaning that tensile failures are expected to occur.

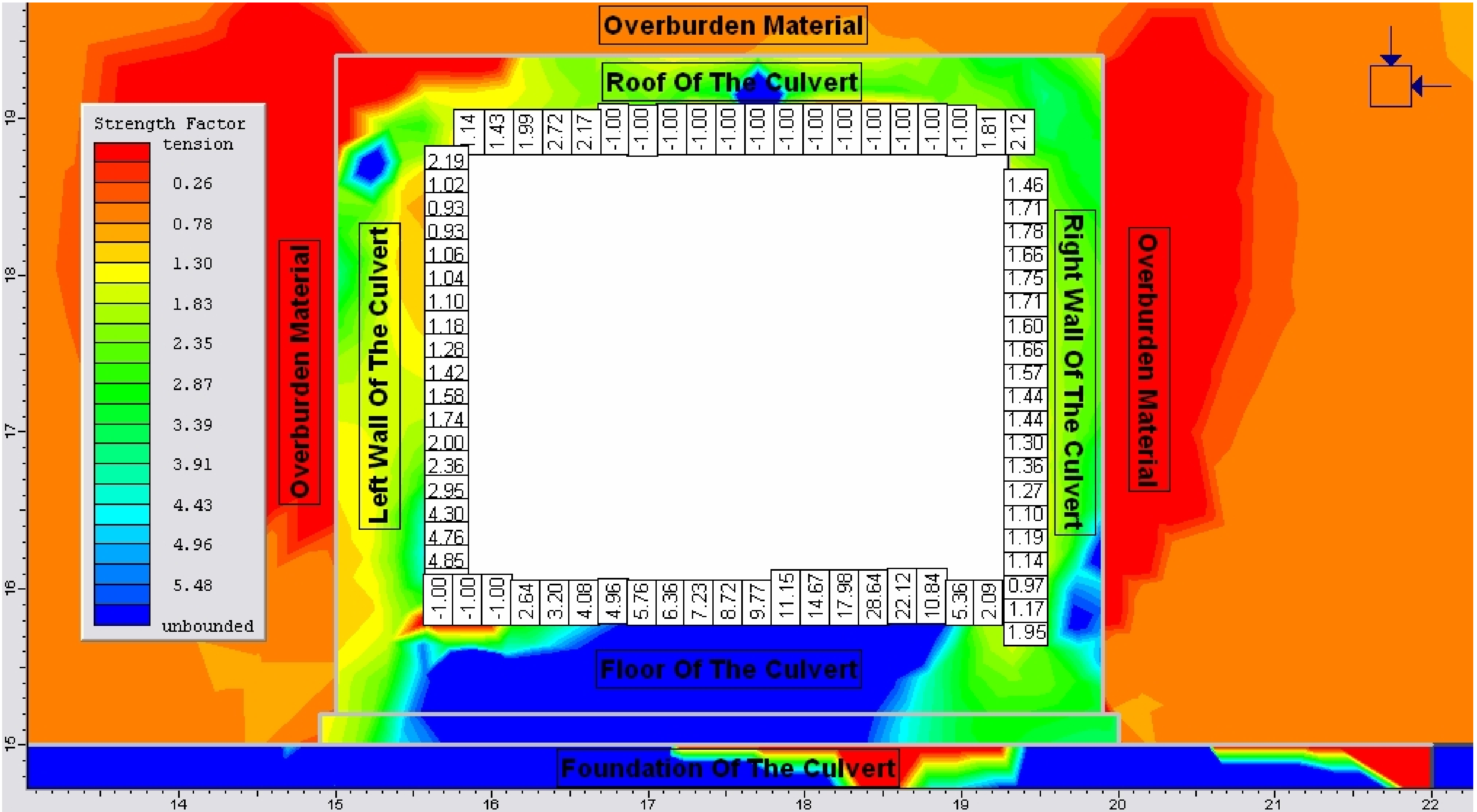


Figure 4.5: Safety factor distributions in the inner walls of the culvert in existing situation considering the affect of groundwater (γ =25.5 kN/m^3)

In Figure 4.6, distribution of safety factors in the inner walls of the culvert is given for dry condition and unit weight of the overburden material dumped on the culvert was taken as 25.5 kN/m^3. In this analysis tensile strength and cohesion of reinforced concrete are taken as 5 MPa and 8 MPa respectively, as given in Table 4.1.

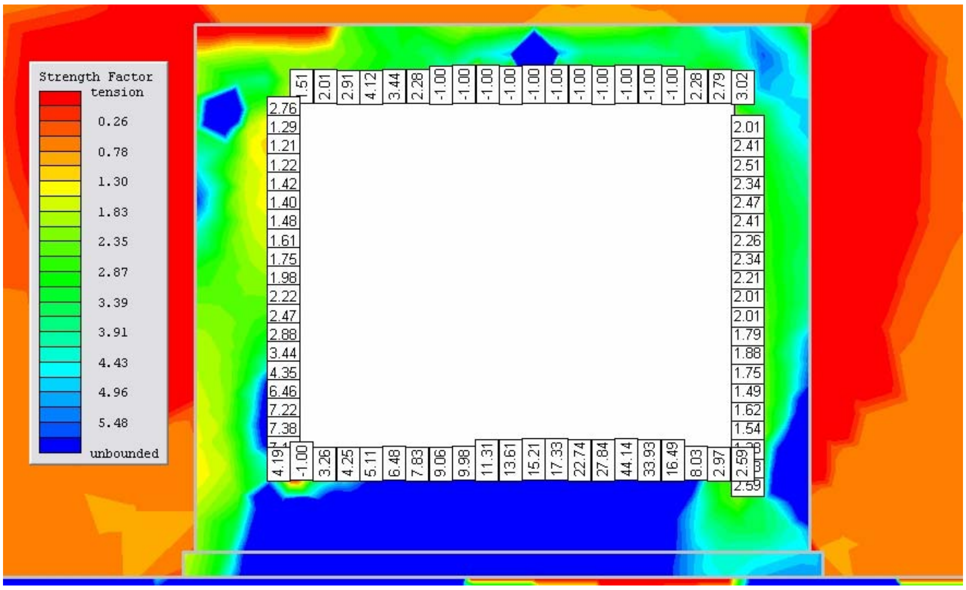


Figure 4.6: Safety factor distributions in the inner walls of the culvert in existing situation disregarding the affect of groundwater (γ = 25.5 kN/m^3)

As it can be seen from Figure 4.6 failure regions occurring due to tensile stresses become smaller compared to Figure 4.5. Furthermore, the lowest positive safety factor increases to 1.21 from 0.93 in the upper-left corner of the culvert. Consequently, it can be concluded that culvert is stable in dry conditions but becomes unstable due to the effect of groundwater.

Numerical analyses, similar to the ones explained above were also performed for overburden unit-weight of 18.8 kN/m^3. As explained earlier, this unit-weight value had been used by TKİ engineers in their culvert project as opposed to 25.5 kN/m^3 calculated by back analyses. In these analyses minimum safety factors, for the inner walls of the culvert, were found as 1.11 and 1.48 both considering and disregarding the effect of groundwater, respectively. These results indicate no failure inside the culvert. Consequently the results are not realistic.

Distribution of major and minor principle stresses in the inner walls of the new culvert are illustrated in Figures 4.7 and 4.8. These analyses were carried out for the same cross section at the 65th meter of the culvert, considering unit weight of the overburden as 25.5 kN/m^3.

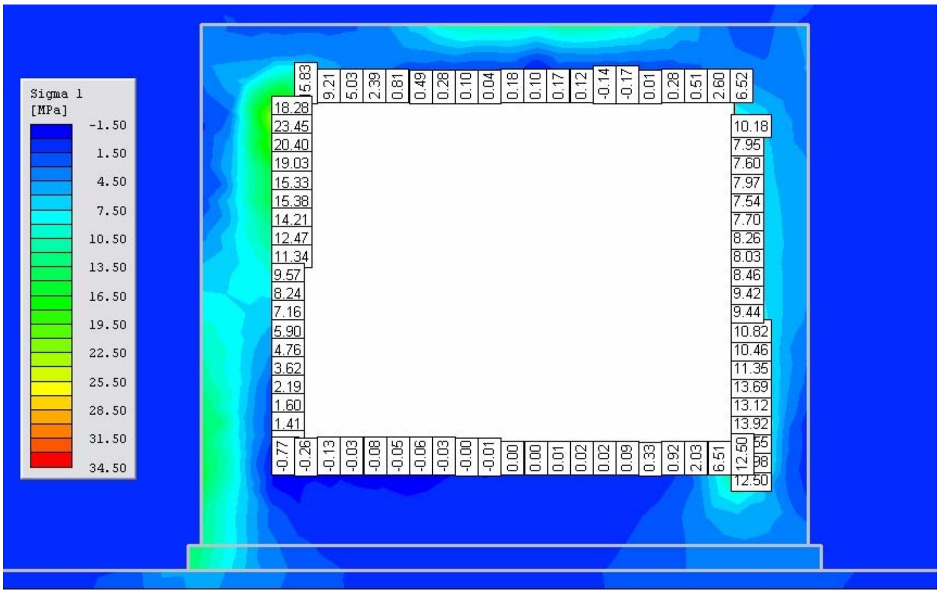


Figure 4.7: Distribution of major principle stresses in the inner walls of the culvert in existing situation (γ = 25.5 kN/m^3)

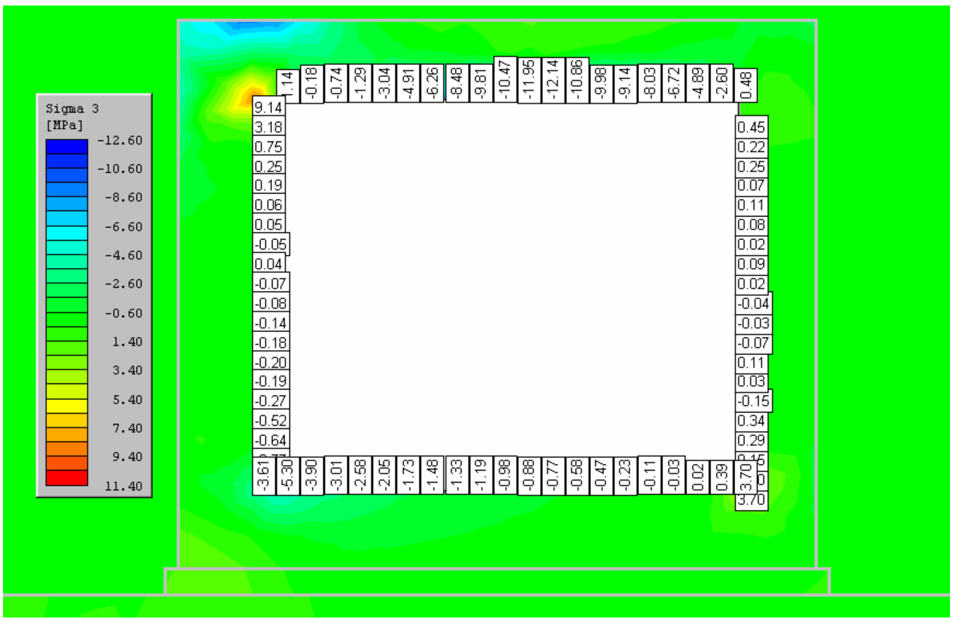


Figure 4.8: Distribution of minor principle stresses in the inner walls of the culvert in existing situation (γ = 25.5 kN/m^3)

As it can be seen from Figure 4.7 the compressive stresses reach to higher values in the upper-left and lower-right corners of the culvert, causing lower safety factors in the same locations as shown before. Deformation vectors, for the same cross-section, in the dump site are given in Figure 4.9. Rotational movements starting from both sides and advancing towards the center are results of non-uniform dumping.

As a result of numerical studies carried out on the deformed part of the culvert in Tınaz Mine, an acceptable agreement between the behavior of actual deformations in the culvert (Figure 4.10) and in the model is evident. As mentioned before, tension cracks are observed in the roof and floor; compressive failures are occurred in the upper-left and lower-right corners of the culvert. Consequently, it is concluded that numerical model, including model characteristics and input parameters for four identified materials, represents the existing failure mechanism in the dump site culvert of Tınaz Mine.

4.5.2 Analyses on Non-Deformed Part of the Culvert

To determine the maximum height of the overburden material that could be dumped on the non-deformed part of the culvert (100-480 m), a new numerical model was considered. As an outcome of these numerical analyses, a relationship between the minimum safety factor in the inner walls of the culvert and height of the overburden material that could be dumped on the culvert was determined.

4.5.2.1 Characteristics of the Model

The model geometry, used in analyses of the non-deformed part of the culvert, is given in Figure 4.11. In this model, 2708 elements, 1448 nodes and 17 stages are used. The first four stages of the analyses are similar to the ones presented in Figure 4.3. After Stage 4, which represents the completion of construction of culvert, overburden material is replaced, on both the dump site as well as on the culvert, homogeneously and with predetermined heights. In each stage, following Stage 4, a new layer of overburden material is replaced on the

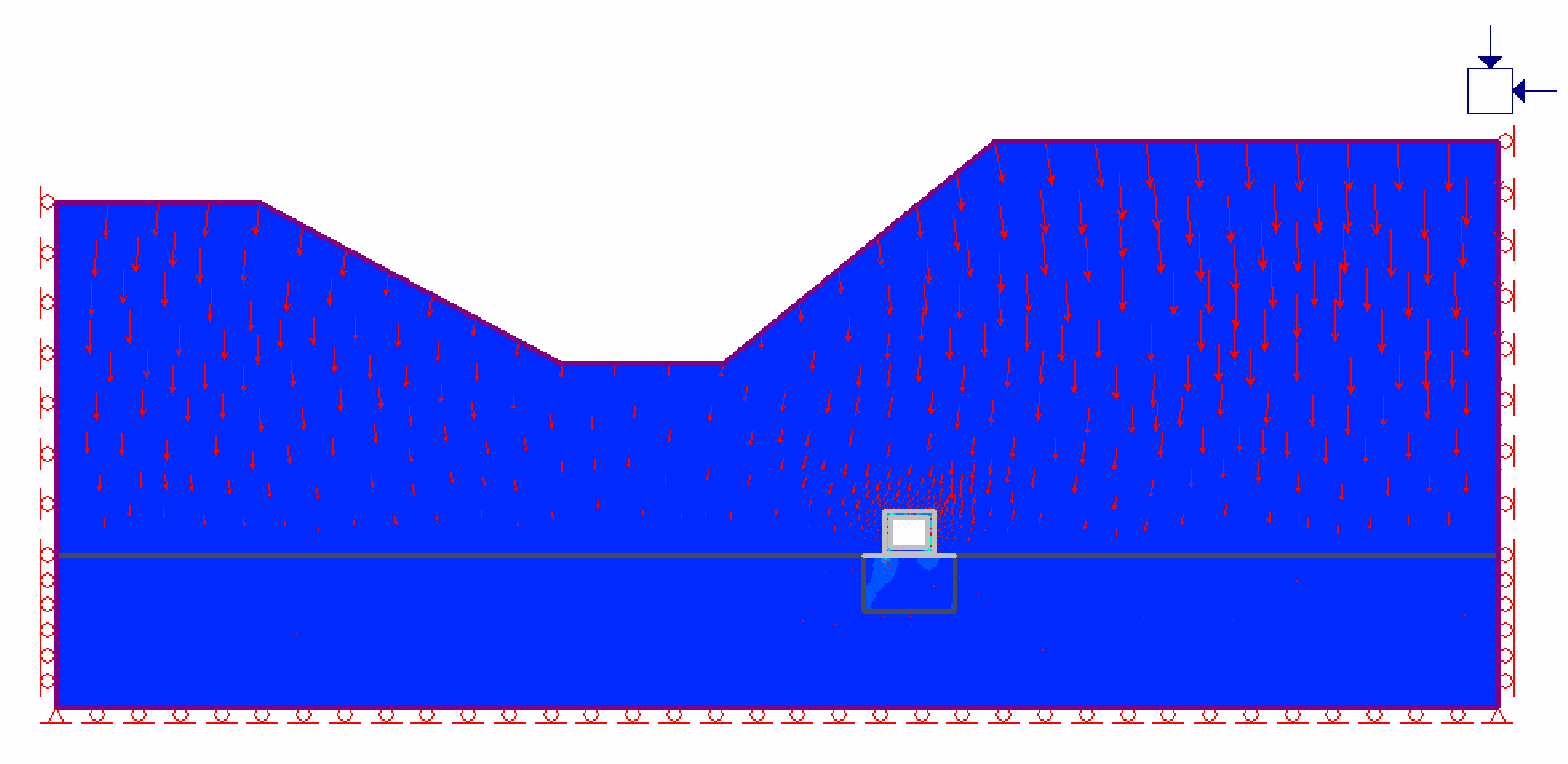
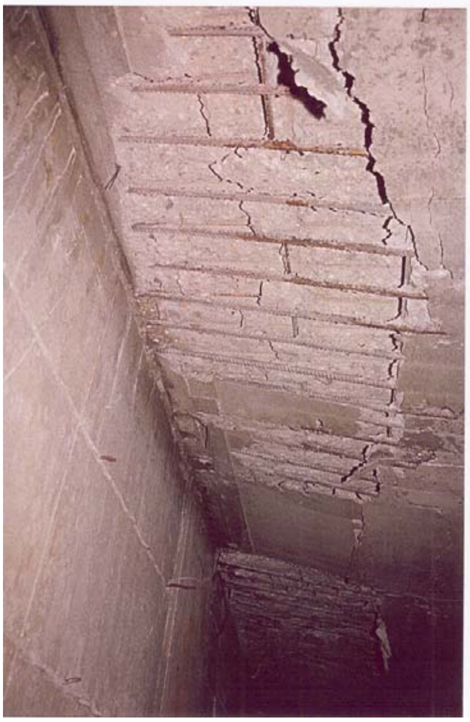


Figure 4.9: Deformation vectors in the dump site and around the culvert in existing situation

(a)

(b)



(c)

(d)

Figure 4.10: Locations of deformations occurred in the culvert (a) upper-left roof, (b) upper-left wall, (c) upper-left wall, (d) lower-right wall

dump site. Heights of the overburden material on the culvert are selected as 17, 26, 35, 42, 50, 57, 65, 72, 80, 100, 120, 155 and 200 meters, respectively, in stages 5 to 17, as shown in Figure 4.10. To clarify and illustrate the sequence of dumping Stages 4, 5 and 17 are illustrated in Figure 4.12.

4.5.2.2 Input Parameters

In view of the fact that, the results obtained from numerical and back analyses of the deformed part of the culvert represent the behavior of the actual culvert of Tınaz Mine, the same input parameters, presented in Table 4.1, could be used for the non-deformed part with confidence.

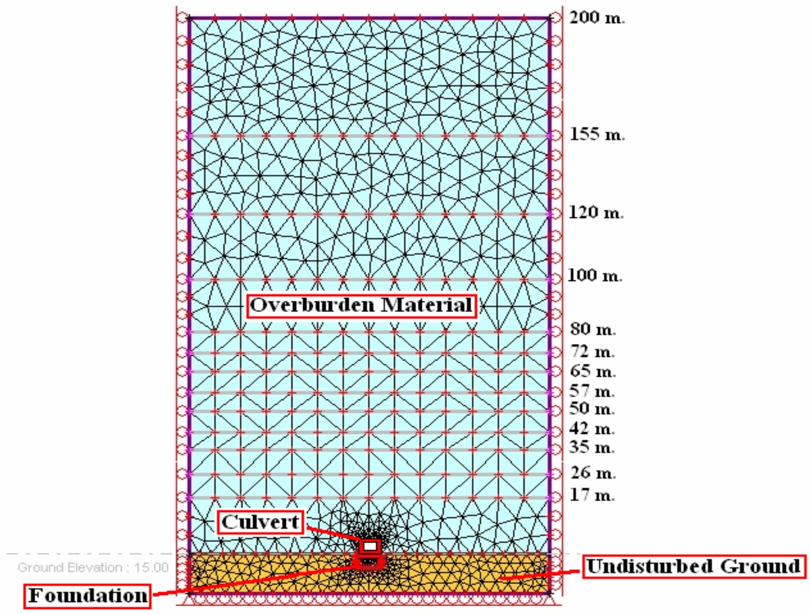


Figure 4.11: Model geometry used in analyses on non-deformed part of the culvert

4.5.2.3 Evaluation on Non-Deformed Part of the Culvert

For the non-deformed part of the dump-site culvert, numerical studies were carried out by using the dump site model given in Figure 4.11 and the input parameters given in Table 4.1. During first phase of these studies, an overburden height of 80-meters, unit weight of 25.5 kN/m^3, and existence of groundwater were considered. The results (distribution of safety factors in the walls of the culvert) shown in Figure 4.13 were obtained.

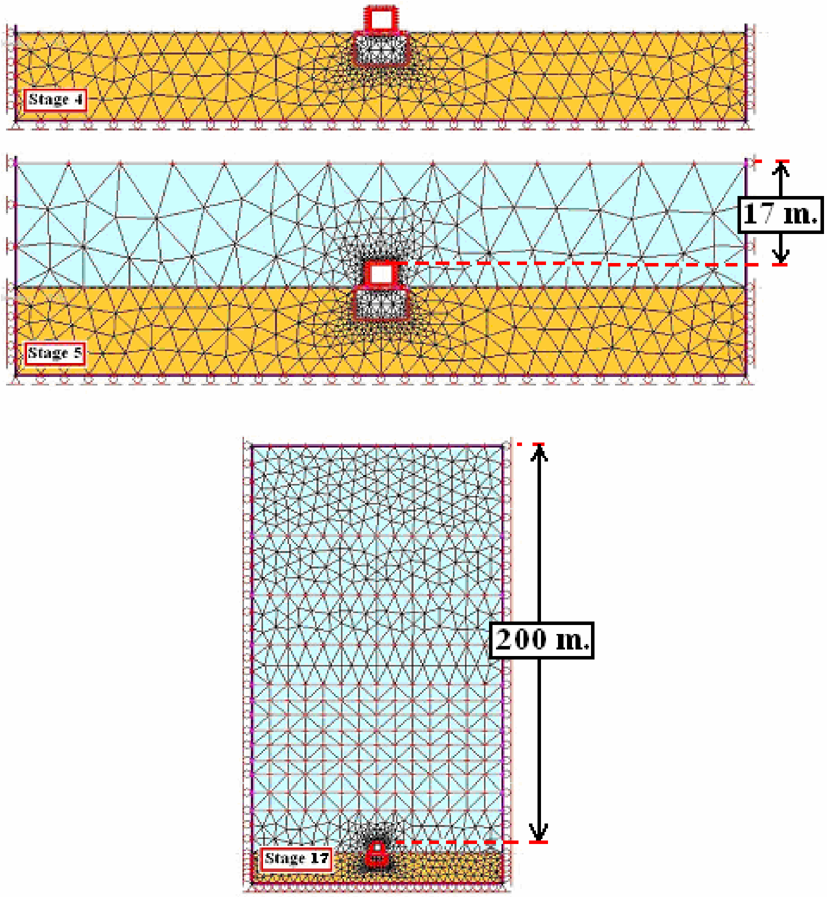


Figure 4.12: Sequence of dumping of overburden material

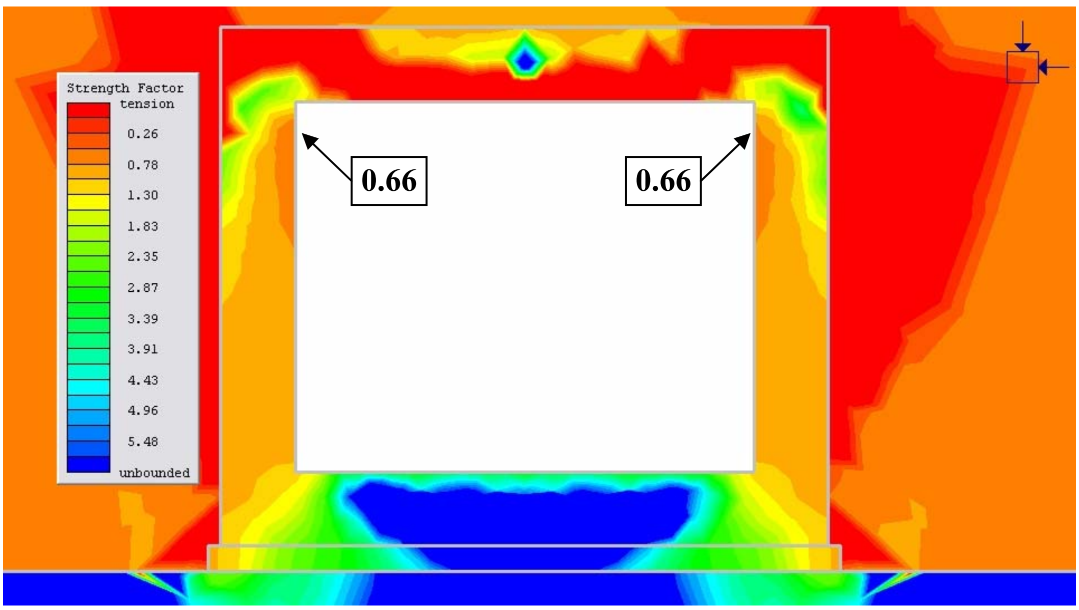


Figure 4.13: Distribution of safety factors in the walls of the culvert for overburden height of 80 meters (min. safety factor = 0.66)

As can be seen in Figure 4.13, minimum safety factor was found as 0.66 in both upper corners of the culvert. Compressive and tensile failures are observed, respectively, in the sidewalls and the roof. These results indicate that the culvert cannot be stable under an overburden height of 80 meters under given conditions.

During second phase of numerical studies an overburden unit weight of 25.5 kN/m^3 was taken for dry conditions, disregarding the affect of groundwater. The results obtained from the first and second phase of the studies are shown in Figure 4.14.

Although it was shown that an overburden unit weight of 18.8 kN/m^3 does not model the actual behavior of deformations, for the sake of completeness, analyses associated with this case were also carried out. Consequently, during the third and fourth stage of the modeling studies the runs were made respectively for wet and dry conditions while taking the unit weight of the overburden as 18.8 kN/m^3. The results obtained from these analyses are shown in Figure 4.15.

Considering the fact that safety factors (SF) for İstanbul metro excavations are taken as 1.20 (Dalgıç, 2002), a safety factor of 1.10 for the dump-site culvert was accepted to be realistic. This was due to the importance of metro excavations with respect to culverts.

As it can be seen from Figure 4.14, under the effect of groundwater, the culvert could be regarded as stable up to 30-meters height of overburden material for a safety factor of 1.10. For dry (no groundwater) condition however, the culvert could be considered as stable up to 46 meters of overburden material. Increasing safety factor to 1.20 decreases maximum height of the overburden material that could be dumped on the culvert to 26 and 40 meters for groundwater exists and does not exists cases, respectively.

Height of the overburden material that could be dumped on culvert was found as 40 meters, considering an overburden unit-weight of 18.8 kN/m^3, a safety

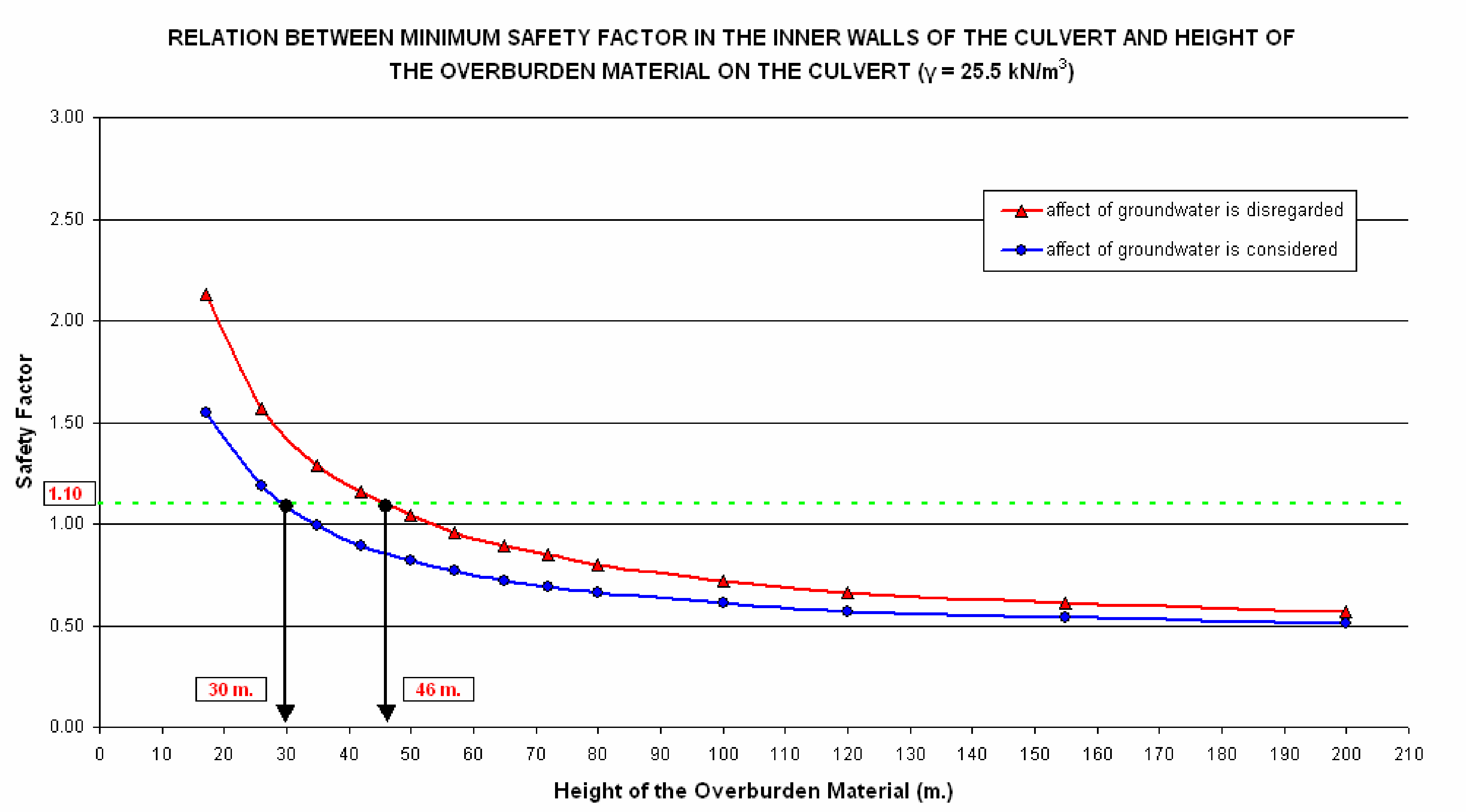


Figure 4.14: “Safety Factor” vs. “Height of the Overburden Material” (γ = 25.5 kN/m^3)

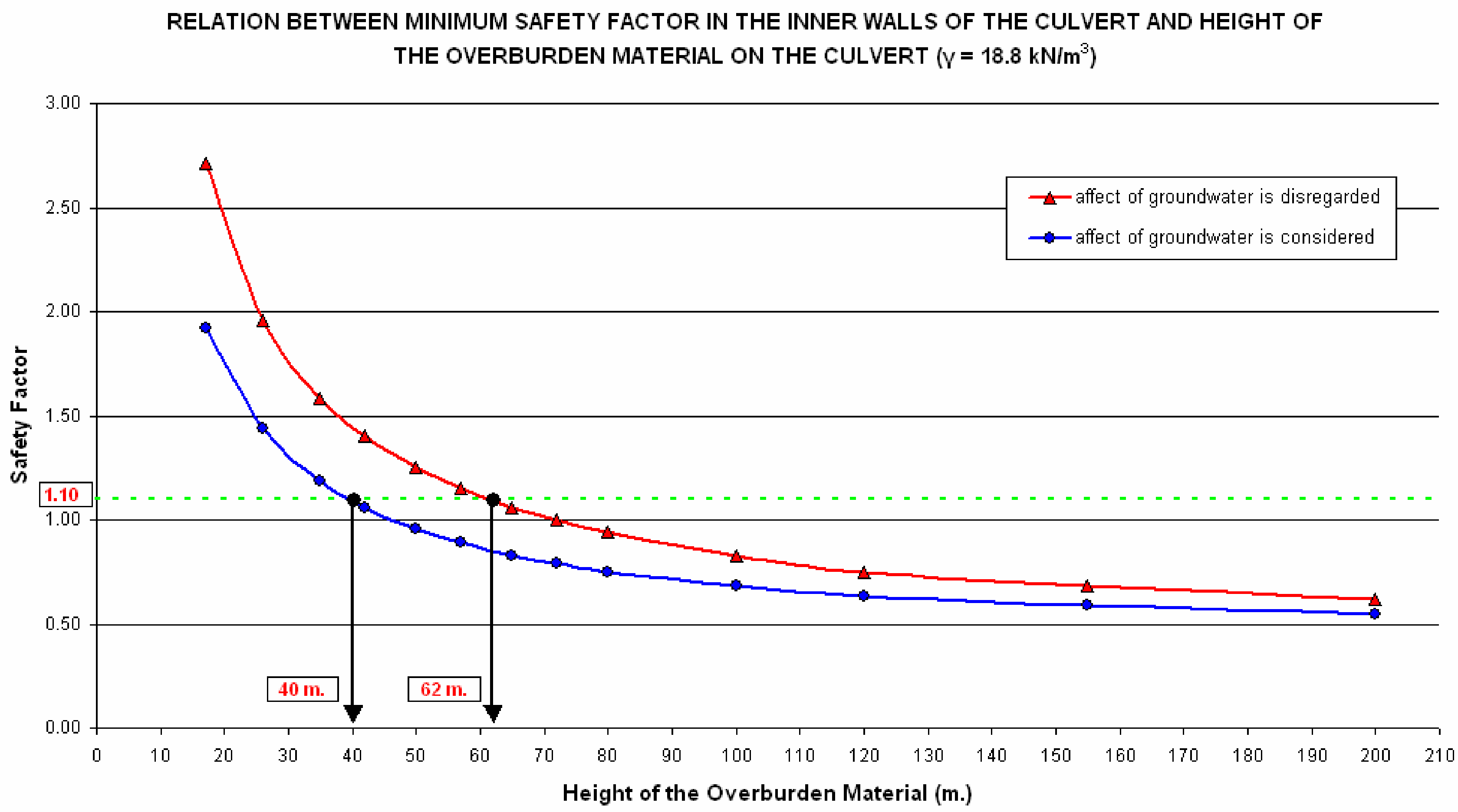


Figure 4.15: “Safety Factor” vs. “Height of the Overburden Material” ($\gamma = 18.8\ kN/m^3$)

factor of 1.10, and existence of groundwater effect (Figure 4.15). Disregarding the effect of groundwater, under same conditions, the height of the overburden material increases up to 62 meters.

As a result of the analyses carried out for the non-deformed part of the culvert, it can be concluded that under existing conditions the dump site culvert in Tınaz Mine could not be stable under an overburden load of 80 meters as opposed to the results obtained by TKİ engineers based on Terzaghi's equations.

4.6 Analyses on Alternative Culvert Models

Since the existing dump site culvert of Tınaz Mine could not stay stable for an overburden height of 80 meters, which is the desired height of overburden material, alternative culvert models were taken into consideration to determine the maximum overburden-height for subsequent culvert projects. Alternative culvert models for positive and negative projecting embankment conditions will be analyzed in Chapter 6. Analyses carried out on positive projecting embankment condition include circular-shape culverts having impermissible, ordinary, first-class and concrete cradle beddings. The analyses that will be carried out on negative projecting embankment condition will include both a box-shape and circular-shape culverts having impermissible, ordinary and first-class bedding.

CHAPTER 5

FIELD MEASUREMENTS IN DUMP SITE CULVERT OF TINAZ MINE

5.1 Introduction

In this chapter, firstly, details associated with convergence measurements, including information on convergence recorder, locations of convergence stations and installation of stations, are presented. Secondly, description of the dump sites before initiation of filed studies will be explained followed by information given on suggested dumping pattern, stages of applied dumping and condition of culvert after completion of dumping. Thirdly, the results of convergence measurement will be presented in detail considering the relation between “convergence” vs. “time” and “convergence” vs. “height of the overburden material”. Finally, the results of convergence measurements will be compared with those derived from the numerical studies, from stability point of view.

5.2 Convergence Measurements

In order to justify the validity of numerical modeling studies on the non-deformed part of the existing dump site culvert and to determine the maximum height of the overburden material a series of convergence measurements were carried out during overburden material being dumped on the non-deformed part of the culvert. The details of these convergence measurements are presented in the following sections.

5.2.1 Convergence Recorder

Generally, a convergence recorder consists of a tape, wire, rod, or tube in series with a deformation indicator. The gage is usually portable and is fixed at time of reading to permanent anchors installed at each end of the measuring span. Rod and tube type convergence recorders generally consist of telescoping rods or rigid tubes, a dial gauge or micrometer, and contact places that mate with anchors. Some gauges have invar rods or tubes, other have aluminum or galvanized stainless steel. Range of span depending on the model, is usually between 150 mm and 8 m. The telescoping mechanism is usually spring loaded (Dunnicliff, 1993).

In order to measure the deformations in the dump-site culvert, a home-made telescopic convergence recorder, made-up of three galvanized stainless-steel, has been used. Resolution of the dial gauge, mounted on convergence recorder, is 0.01 mm. A general view of the dial gauge and convergence recorder used during measurements is shown in Figure 5.1.

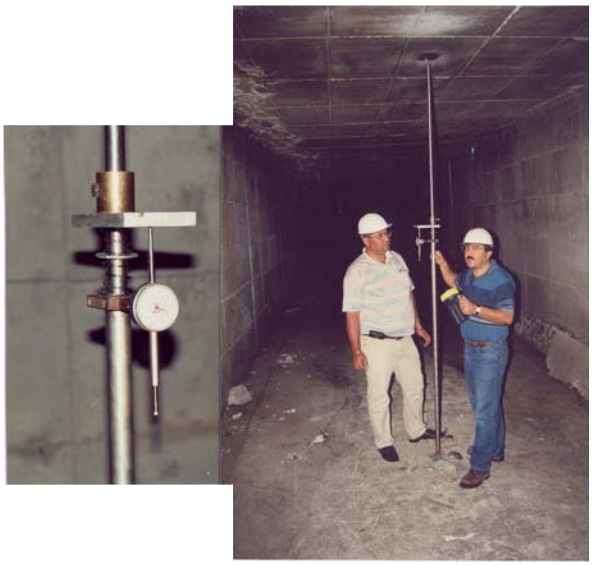


Figure 5.1: A general view of the dial gauge and convergence recorder used during convergence measurements carried out in the culvert of Tınaz Mine

5.2.2 Locations of Convergence Stations

During field studies 14 convergence stations were installed in the culvert. Three of them (E2, E4 and E5) were located in the deformed part (0-100 m) and 11 of them (Y1, Y2, …, Y10 and E1) were located in the non-deformed part (100-480 m) of the culvert. Distances between stations Y1 to Y8 are taken as 25 meters. However, distances between stations Y8 to E1 were taken as 50 meters. On the other hand, since some parts of the first 100-meters of the culvert were highly deformed and unstable, the convergence stations were installed at locations appeared to be safe. For example, Station E3 could not be installed at the location originally planned because of safety reasons (Figure 5.2). The location of the convergence stations are given in Table 5.1 and illustrated in Figure 5.3.

Figure 5.2: Deformations inside the culvert around Station E3

5.2.3 Installation of Convergence Stations

In each convergence stations two rebars were installed one in roof and the other one in floor of the culvert. To install steel rebars, firstly, vertical holes were drilled (32 mm in diameter and 450 mm in depth) both in the roof and floor of the predetermined locations. Following that, the rebars (22 mm in diameter and 400 mm in length) were installed into these holes with a fast-curing type of concrete. In order to align the roof and floor rebars, a plump was used.

Table 5.1: Locations of the convergence stations in the culvert

Station ID	Location (m)		Station ID	Location (m)
Y1	450		Y8	275
Y2	425		Y9	225
Y3	400		Y10	175
Y4	375		E1	125
Y5	350		E2	100*
Y6	325		E4	50*
Y7	300		E5	15*

* Installed in the deformed part of the culvert

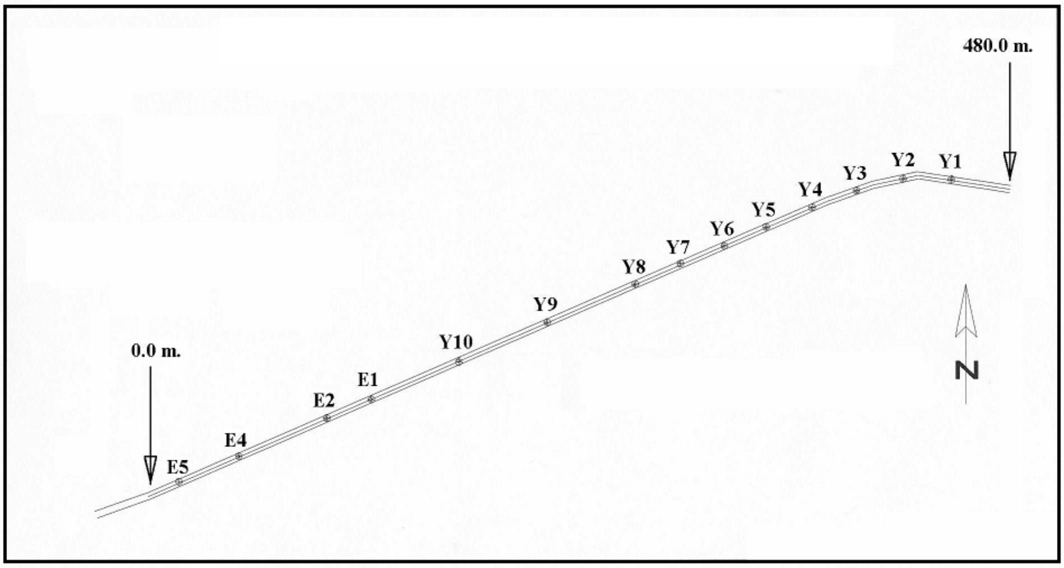


Figure 5.3: Locations of convergence stations in the “new culvert”

The convergence stations were installed by the help of the members of The Middle East Technical University (METU), Turkish Coal Enterprises (TKİ) and contractor firm, Özdoğu İnşaat. Different stages of installation of convergence stations are shown in Figures 5.4 and 5.5.

(a) (b) (c)

Figure 5.4: (a) Injection of special concrete, (b) installation of roof rebar (c) installed floor rebar

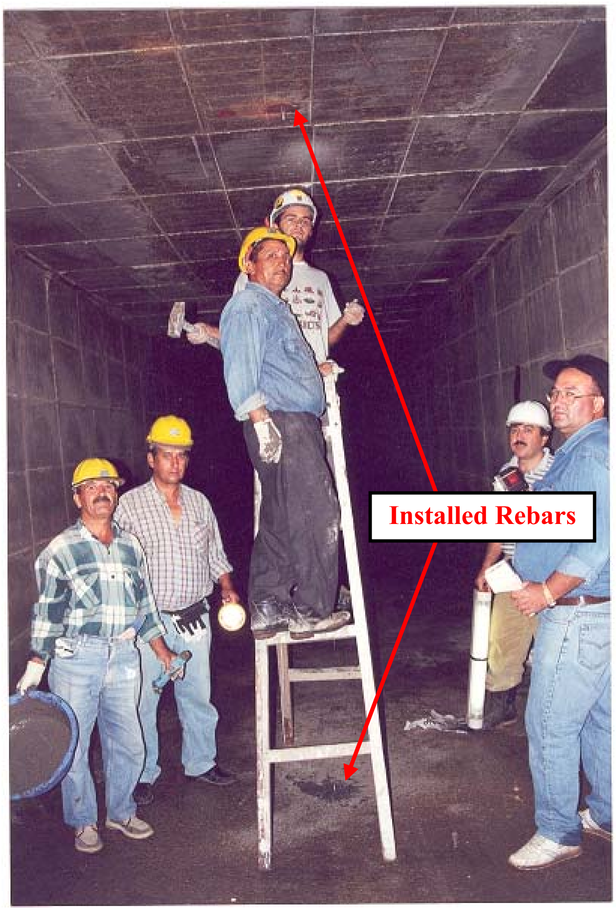


Figure 5.5: Completed convergence station

5.2.4 Frequency of Convergence Measurements and Analysis of the Results

Dumping process has started following completion of installation of the convergence stations in the culvert. Convergence measurements were taken daily, between September 5 and December 13, 2001, except holidays, as the overburden material being dumped. As a result of these measurements, the deformations occurring due to dumping of overburden material were identified. Figure 5.6 presents the convergence measurement in a station.

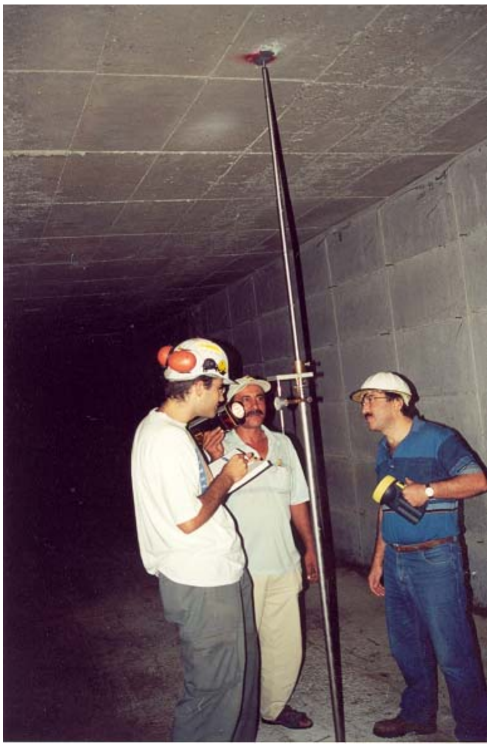


Figure 5.6: Convergence measurement in a station

"Convergence" vs. "Time" and "Convergence" vs. "Height of the Overburden Material" relations were examined for each station by using the data obtained from convergence measurements. Considering the changes in convergence rate and total convergence, and observing the deformations in the culvert, the maximum height of the overburden material that could be dumped on the existing culvert was determined. The results of convergence measurements are given in Section 5.4.

5.3 The Dump Sites and Dumping of Overburden Material

In this section, information on dump sites before the initiation of thesis study, suggested dumping method and pattern on the non-deformed part of the culvert, stages of actual dumping, and measured convergences in the culvert, during dumping of overburden material, will be given in detail.

5.3.1 Dump Sites Prior to Initiation of This Thesis Study

Situation of the dump sites before the initiation of this thesis study is explained in Section 3.5 on Chapter 3. In brief, the maximum height of the overburden material dumped on the culvert reached to a height of 33 meters in the first 100 meters of the culvert. Significant deformations were observed especially in the upper left and lower right corners in this part. Consequently the first 100 meters of the culvert was unstable, however it did not totally caved probably due to the reinforced concrete.

After initiation of a project as a result of the contract signed between METU and TKİ the unstable part of the culvert was supported by steel sets, as illustrated in Figure 5.7. Additional dumping of the overburden material, on this part of the culvert, was not suggested for safety reasons (Ünal et al., 2002).

Figure 5.7: Applied steel sets in the first 100 meters of the culvert (Ünal et al., 2002)

5.3.2 Suggested Dumping Pattern

In order to determine the maximum height of the overburden material that could be dumped on the culvert, the overburden material was layered on the non-deformed part of the culvert (100 m-480 m) in several stages. In order to maintain an overall slope angle of 25º-30º, in each stage, a bench is created having a height of 6 m and width of 12 m. The thickness of the overburden material dumped at a time was decreased from 6 m to 3 m less when the convergence-rate was higher than the expected value. It should be emphasized here that the applied dumping pattern was quite different than the suggested pattern, the actual slope angle was much less than the suggested (25º-30º).

In its original situation, the overburden material was dumped perpendicular to culvert axis, as shown in Figure 5.8. In this dumping method, since the culvert was not loaded uniformly along its axis, deformations were likely to occur as a result of non-uniform loading. As a result of modifications in the dumping method, overburden material was dumped along the culvert axis with a uniform thickness, as presented in Figure 5.9.

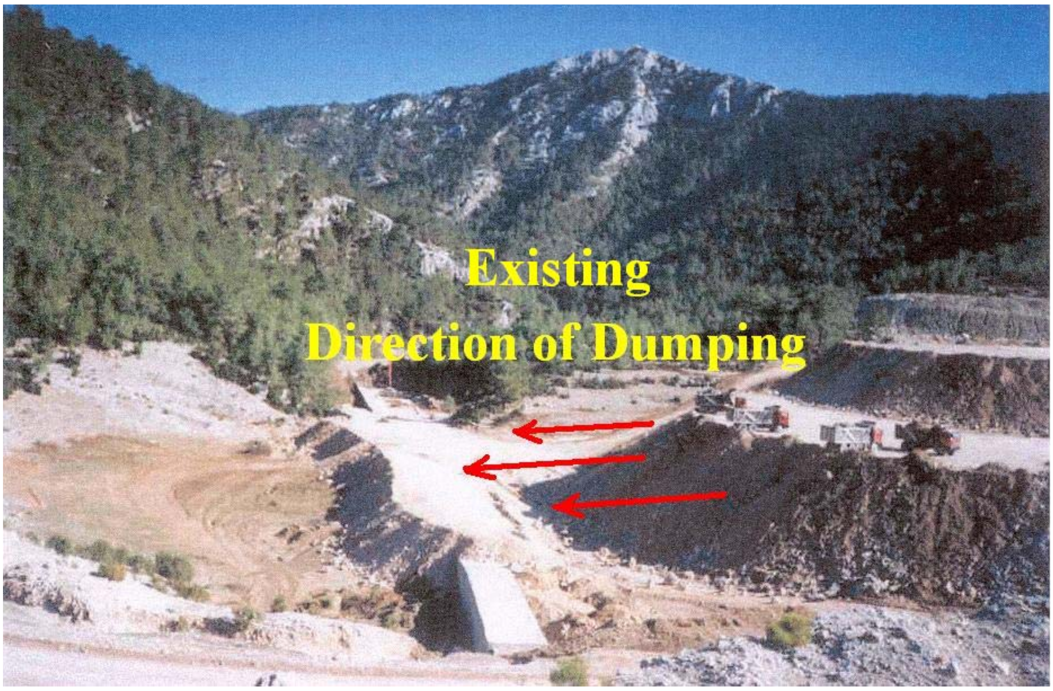


Figure 5.8: Direction of dumping in existing situation

Figure 5.9: Suggested direction of dumping

General view of the suggested dumping method is illustrated in Figure 5.10. Details of the southwestern and northeastern slopes of the suggested dumping are given in Figures 5.11 and 5.12 respectively (Ünal et al., 2002).

5.3.3 Stages of Applied Dumping

In this section, information on stages of applied dumping is given. As it is mentioned previously in Section 3.5, height of the overburden material on different parts of the culvert was changing significantly. This non-uniform dumping (Figures 3.14, 3.15 and 3.16) was one of the reasons why asymmetric deformations occurred inside the culvert.

The aim of Stage-1 was to obtain a flat region for the subsequent dumping stages. In order obtain that flat region, overburden material was dumped on the area between stations Y5 and Y1. The elevation of this region was approximately 9-10 meters below the region remaining between the stations Y6

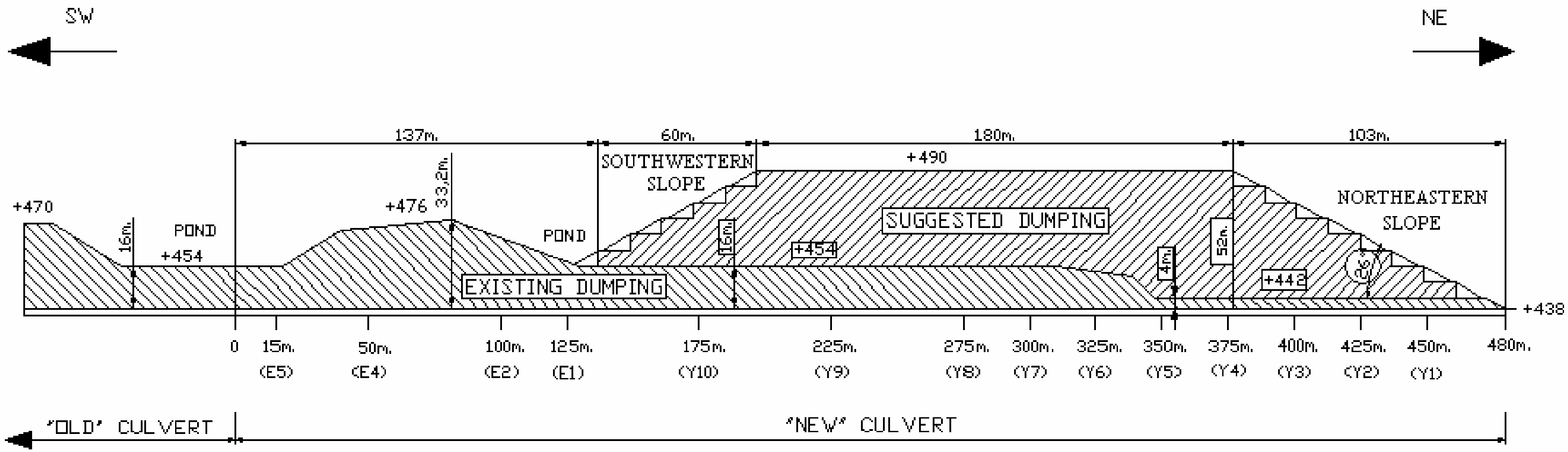


Figure 5.10: Suggested dumping pattern for the new culvert (Ünal et al., 2002)

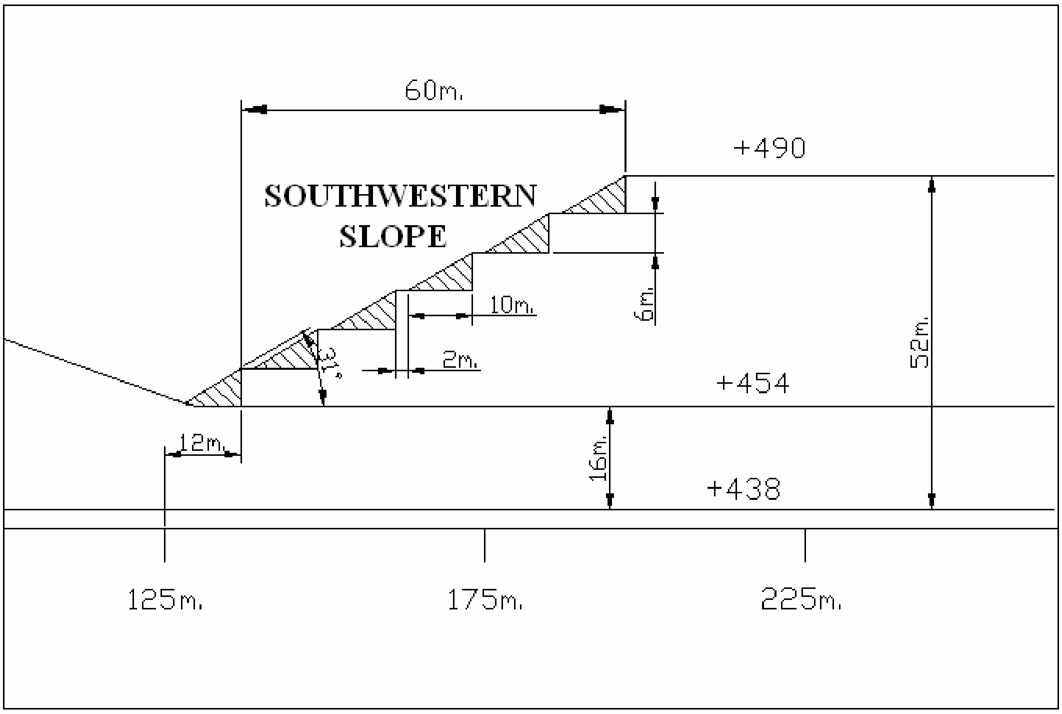


Figure 5.11: Details of southwestern slope of suggested dumping
(Ünal et al., 2002)

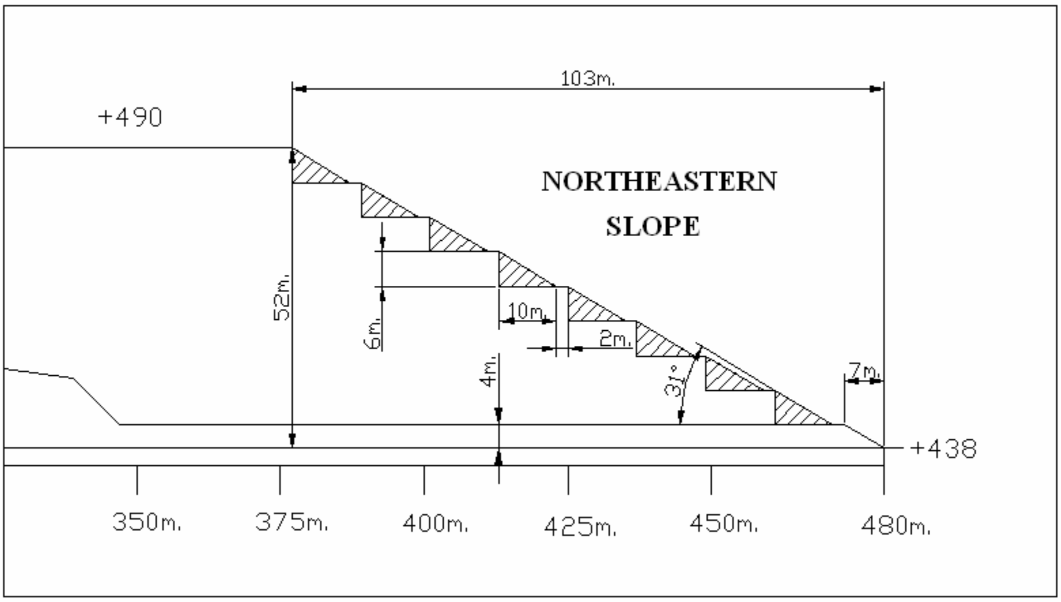


Figure 5.12: Details of northeastern slope of suggested dumping
(Ünal et al., 2002)

and Y10. In this stage, overburden material was dumped at a location between Station Y5 and Station Y1. The direction of dumping was from Y5 toward Y1 as shown in Figure 5.13. At the end of the first stage, the height of the overburden material on the culvert was reached to a height of 12.5-14 m between stations Y10 and Y2. The region between Station Y1 and the exit of the culvert was kept as a bench to maintain the overall slope angle.

Figure 5.13: First stage of dumping

The aim of the subsequent dumping stages was to reach to the maximum height by controlled and homogeneous dumping process.

After completion of Stage 2, lasted 14 days, height of the overburden material on the culvert reached to 18-18.5 m between stations Y10 and Y3. In Stage 3, lasted 11 days, the total thickness of the overburden material reached to 5 meters between stations Y10 and Y4 and the region above Station Y3 was kept as a bench to maintain a low slope angle.

After the completion of third dumping stage, a bowl-shaped region, as shown in Figure 5.14, was formed on the deformed part of the culvert. In order to prevent possible pond formation on this region, adding extra load on deformed part, TKİ has developed a drainage project. Firstly, controlled and homogeneous dumping of 6-7 meters thick of overburden material, on the region between stations E1 and E2, was completed (Figure 5.15). Following that, a water drainage channel, as shown in Figure 5.16, was formed between the hill and recent dump sites.

Figure 5.14: Bowl-shaped region formed on the deformed part of the culvert

Figure 5.15: Completed controlled and homogeneous dumping on the deformed part of the culvert

Figure 5.16: Water drainage channel formed in the North-direction of culvert

In the fourth stage of dumping, thickness of the overburden material dumped on the culvert at a time could not be kept constant at 3 meters but forced by the contractor to reach up to 8.5 meters above the Station Y6. As a result of this, the total convergence measured in Station Y6 exceeded 45 mm. At this stage, lasted 12 days, region above Station Y4 and Station Y10 were kept as a bench to maintain low slope angle.

After the completion of the first four stages of controlled and homogeneous dumping (Figure 5.17), the subsequent stage was modified as a result of evaluating the convergence values measured in stations Y6 and Y9. The objective at the fifth stage was to reach to the level of +474 m (33.58 meters of overburden height) above Station Y8.

In the last stage, Stage 5, the height of the overburden material above convergence stations Y6, Y7 and Y8 reached 31.08 (+471.5 m), 29.22 and 28.80 meters, respectively. As a result of heavy rain falling between November 15 and December 20, 2001, it was not possible to operate the trucks. Although, the originally planned overburden height could not be reached, considering the latest situation of the dump sites, the observed deformations in the culvert (Section 5.4.4)

Figure 5.17: Panoramic view of the controlled and homogeneous dumping

and evaluating the measured convergence values (Section 5.5), the field studies were terminated. The latest situation of the dump sites on the culvert are shown in Figures 5.18, 5.19 and 5.20.

Figure 5.18: Panoramic view of levels after the completion of the dumping process

Figure 5.19: Situation of dump sites on the culvert

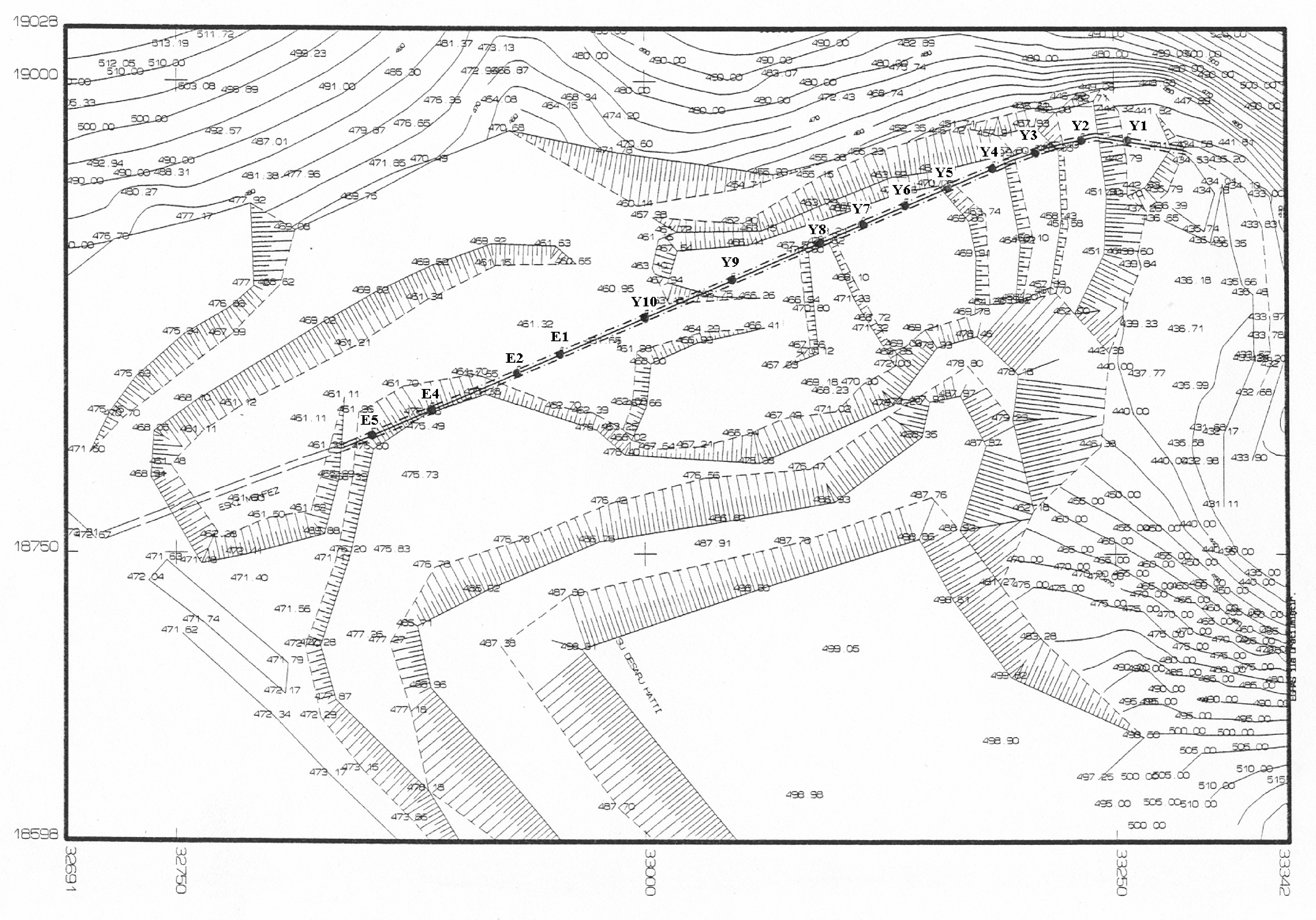


Figure 5.20: Situation of dump sites after the completion of dumping (December 7, 2001)

5.4 Condition of the Culvert After Completion of Dumping

As a result of controlled and homogeneous dumping, deformations as well as roof and floor cracks observed in the culvert. The roof cracks, originally within the first 375 meters of the culvert extended up to the exit of the culvert. Moreover a total of 1-1.5 cm of floor heave was observed between the Stations Y5 and Y6, as shown in Figure 5.21. A number of floor cracks, with apertures reaching up to 1-2 mm, were formed parallel to culvert axis (Figure 5.22).

Figure 5.21: Observed floor heave between stations Y5 and Y6

Figure 5.22: Floor cracks formed between stations Y5 and Y6

After completion of the last stage of the dumping process a considerable number of cracks were observed in the roof with apertures reaching up to 1-2 mm, as presented in Figure 5.23. Moreover, several roof cracks were formed perpendicular to culvert axis (Figure 5.24).

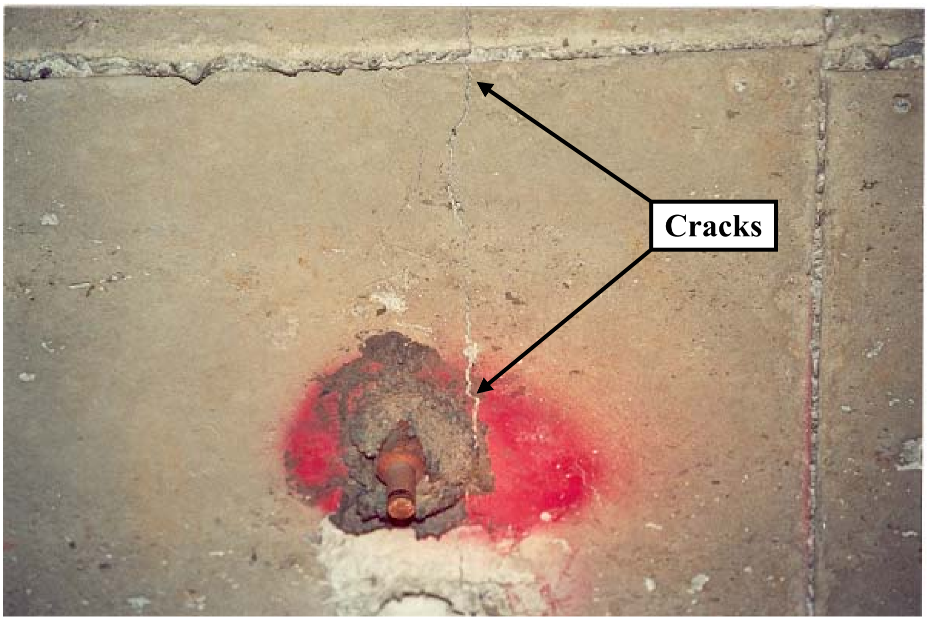


Figure 5.23: Roof cracks, parallel to culvert axis, between stations Y6 and Y10

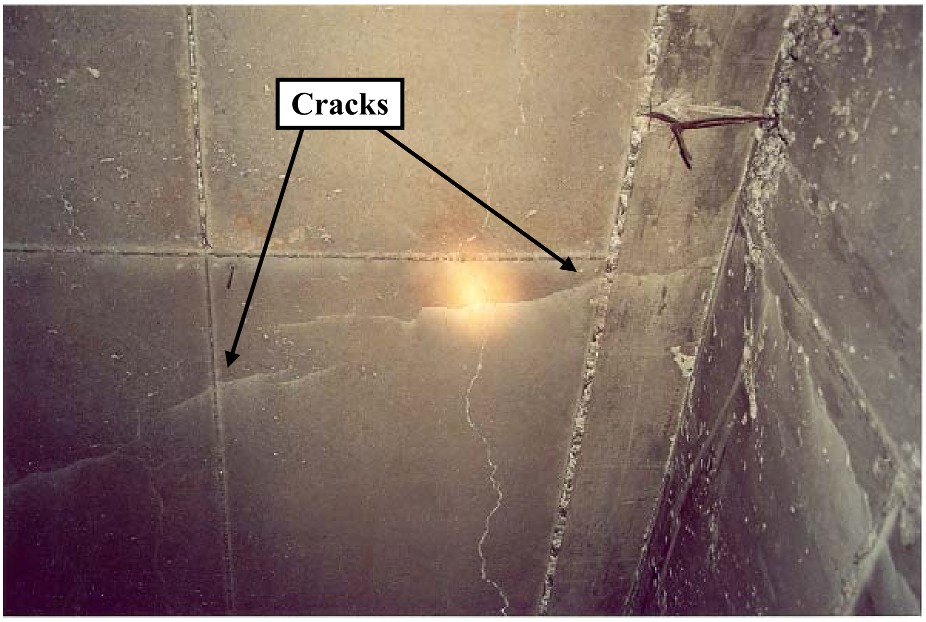


Figure 5.24: Roof cracks, perpendicular to culvert axis, between stations Y6 and Y10

Between stations Y6 and Y9, on the other hand a floor heave reaching to a magnitude of 7-8 mm was observed. In addition, floor cracks, with apertures of 1-2 mm, were formed parallel to culvert axis near Station Y10. In the same region, as illustrated in Figure 5.25, roof drop offs were taken place in three different locations (203rd, 205th and 227th m).

Figure 5.25: Roof drop offs in the 203rd and 205th meters

Deformations could not be observed in E stations because of the steel set supports installed in this area. However, floor and roof cracks, with apertures reaching up to 1-2 mm, were observed in Station E1, located out of the supported region.

As a result of heavy rainfalls in the region, a considerable amount of groundwater income, from the floor and sidewall cracks, was observed in the supported region as shown in Figure 5.26. On the other hand, groundwater leakages, from roof, floor and sidewalls, were observed in the entire culvert, as shown in Figure 5.27.

Figure 5.26: Groundwater income, from the floor cracks, in the supported region

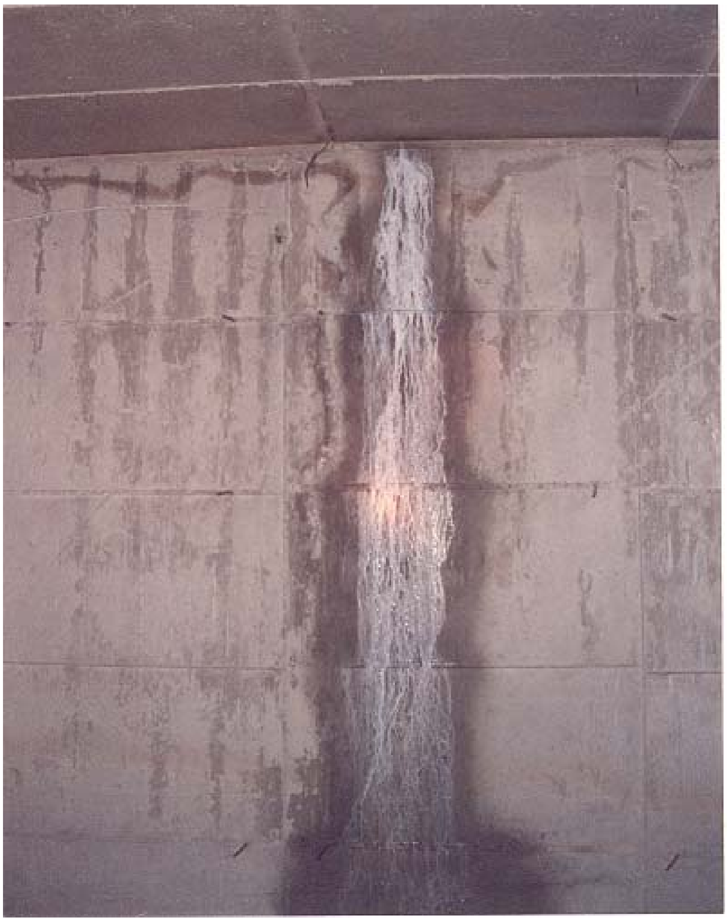


Figure 5.27: Groundwater leakage from the sidewall

5.5 Convergences Occurring Due to Dumping

In this section results and evaluations on convergence measurements will be given. In addition, deformations occurring due to controlled and homogeneous dumping of the overburden material will be evaluated based on i) “Convergence” vs. “Time” and ii) “Convergence” vs “Height of the Overburden Material” plots (Özcan and Ünal, 2002). Finally, the results obtained from field measurement results will be compared with the results obtained from numerical modeling giving special attention to the stability of culvert in terms of safety factor.

5.5.1 Results of Convergence Measurements

The convergences occurring due to the overburden material being dumped on the culvert were measured almost once a day in 14 stations. As mentioned in Section 3.5 of Chapter 3, the heights of the overburden material on the culvert, prior to initiation of this thesis study showed great differences. Therefore, the area on the culvert is divided into three regions, based on the height of the overburden material and the convergences occurring due to controlled and homogeneous dumping of overburden material, were evaluated in these three regions separately.

The region between stations Y1 and Y5 is considered as Region 1, since, the height of the overburden material on culvert was originally in the range of 3-4 meters. Region 2 includes the area between stations Y6 and Y10, where height of the overburden material on culvert was changing between 12-17 meters. In Region 3, covering the area between stations E1 and E5, the height of the overburden material showed great differences due to dumping prior to culvert studies. Moreover, significant deformations had been observed in the first 100 meters of the culvert.

The location of the convergence stations, height of the overburden material on each station, and measured total-convergence values, after the completion of controlled and homogenous dumping, are given in Table 5.2.

Table 5.2: Measured convergence values for stations after completion of dumping (December 7, 2001)

Station		Height of the Overburden (m)	Total Convergence (mm)
ID	Location (m)		
E-5	15	29.77	1.69
E-4	50	32.81	1.20
E-2	100	20.46	-4.21
E-1	125	21.48	-7.91
Y-10	175	20.75	-12.48
Y-9	225	25.72	-31.73
Y-8	275	28.80	-16.12
Y-7	300	29.22	-31.45
Y-6	325	31.08	-55.34
Y-5	350	28.45	-46.21
Y-4	375	24.43	-21.32
Y-3	400	18.73	(-7.58)* -5.98
Y-2	425	13.13	(-2.62)* -0.86
Y-1	450	4.04	(-0.61)* 2.65

*Measured convergence value in October 21, 2001

In view of the fact that Region 1 is under the northeastern slope of controlled and homogeneous dumping, the height of the overburden material, after the completion of dumping was ranging between approximately 4 to 18.7 meters on Stations Y1 to Y3. The convergence measured in this region was changing between –0.61 to –7.58 mm. The regions above stations Y1, Y2, Y3 and Y4 were kept as benches in order to maintain overall slope angle. The total convergence measured in Station Y4 increased to –21.33 mm when the height of the overburden material reached to 24.43 meters. The height of the overburden material on Station 5 was

28.45 meters causing 46.21 mm of total convergence. It should be noted that although the height of the overburden material on Station Y5 is only 4 meters more than Station Y4, the total convergence value measured in Station 5 (46.21 mm.) was more than twice measured in Station Y4 (21.32 mm.). As a result of heavy rainfall after October 2001, and settlement observed in foundation, the convergence values of first three stations were increased in opposite way. In other words, height of the culvert was relatively increased.

In Region 2, the height of the overburden material was more or less uniform except the area above Station Y10, since this area was kept as bench of southeastern slope of dump site. In Region 2, as a result of applied dumping practice, a difference of 5.4 meters occurred between the heights of the overburden material on stations Y6 (31.08 m) and Y9 (25.72 m). It is important to note that height of the overburden material above Region-2 stations increases in southeastern direction (from Y10 towards Y6). The measured convergence values on the other hand, show the same trend. The maximum value of the total convergence measured in Station Y6 is –55.34 mm as also indicated in Table 5.2.

At the beginning of M.Sc. studies, dumping of any additional overburden material on Region 3 was not suggested. However, in order to prevent the possible pond formation in this region, 6-7.5 meters of overburden material was dumped by the decision of TKİ. The rate of convergence at stations E1 and E2 was much more than the others. Since the stations E4 and E5 are located below the slope of +476 waste-dump and they are relatively far away from the dumping area, the effect of dumping on them was much less. The total height of the overburden material on Station E1 was 21.48 m where the measured convergence was -7.91 mm. Since Station E2 is just located on the border of supported and unsupported parts of the culvert, the measured convergence value (-4.21 mm) at this station was relatively less than Station E1, although it is located approximately under the same overburden height (20.46 m).

5.5.2 Relation Between “Convergence” and “Time”

In this section the relation between convergence and time is evaluated. A total of 41 convergence measurements were taken in the culvert in 94 days. A typical plot from Station Y5 showing the relation between convergence and time is given in Figure 5.28. In this plot, the total convergence occurring in 94 days was -46.21 mm. The convergence rates in parts of the plot marked as I, II, III and IV, marked on graph, are 1.83, 2.22, 2.15 and 1.68 mm/day, respectively.

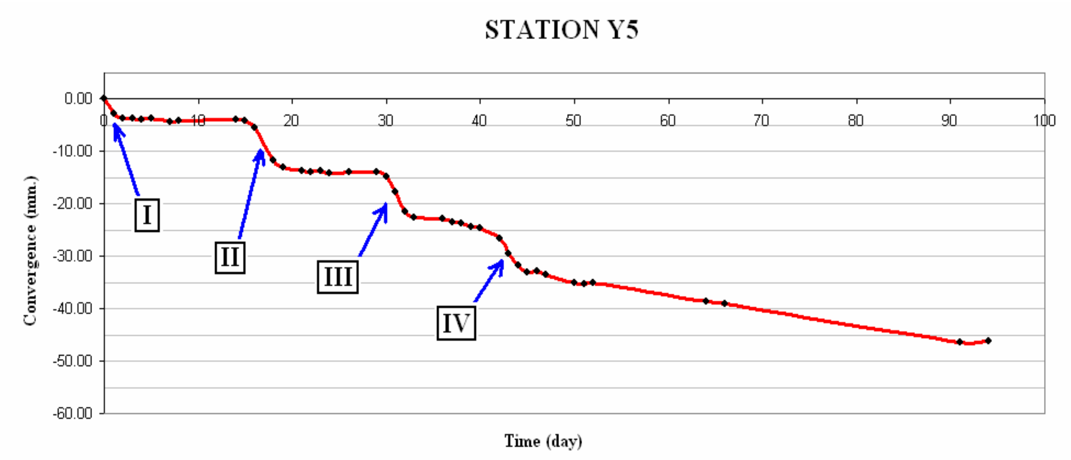


Figure 5.28: “Convergence” vs. “Time” relation for Station Y5

As mentioned in Section 5.5.1, relation between convergence and time is evaluated separately in three different regions. The “Convergence” vs. “Time” plots representing Region-1 and including the stations, Y1-Y5, are given in Figure 5.29. As can be seen from this figure, the convergence values measured in Region 1 Stations show considerable difference. Since Region 1 Stations are under the slope of dump site, the heights of the overburden material placed on these stations increases from Station Y1 towards Station Y5. An increase in convergence rate (slope of lines) indicates that the dumping activity is becoming closer to the locations above that station. On the other hand, decreasing convergence rate indicates that the dumping activity is going away from the region located on that station. The convergence rate becomes zero when dumping is far away form the station considered. Parallel trend of the plot, to time axis, represents the situation where the culvert becomes stable after the completion of dumping.

The “Convergence” vs. “Time” plots representing Region 2 and including stations Y6-Y10, are shown in Figure 5.30. As it is seen from this figure, convergence values measured at stations Y8 and Y10 are significantly lower than the others. On the other hand, convergence values measured at station Y7 and Y9 are close to each other. The Station Y10 could be considered as stable after 24 days. Although small increases in convergence rates are observed in Stations Y7, Y8 and Y9 after 66 days, the culvert could be considered as stable in an area limited with these stations. As a result of controlled and homogeneous dumping, the total convergence value was measured as -55.34 mm in Station Y6. This considerably high convergence value is a result of higher dumping height on Station Y6 with respect to the other stations. High convergence rate (6.15 mm/day) observed between the 40^{th} and 45^{th} day is a typical instability behavior. As a result of this behavior, dumping pattern was modified, as explained in Section 5.3.3, consequently the region around Station Y6 became more stable after the 45^{th} day. In Region 2, the effect of dumping was observed in different days (Figure 5.30) because the distances between the stations were longer and the dumping area perpendicular to the culvert axis was wider. For example, while overburden was dumped on Station Y9 in 21^{st}-22^{nd} day, same layer was dumped on Station Y6 in 29^{th}-31^{st} day.

Relations between “convergence” and “time” for Region 3 Stations (E1-E5) are given in Figure 5.31. As it is seen from this figure, the overburden material wasn’t dumped on the area between Stations E4 and E5, consequently there were no convergence developing in this area. In Stations E1 and E2, however, convergence having small magnitude (-7.91, -4.21) were measured due to the dumping of overburden material on the bowl-shaped area shown in Figure 5.14. Because of the steel supports installed, starting from the entrance of the new culvert up to the Station E2, different total convergence values were measured although the overburden height was the same in this region.

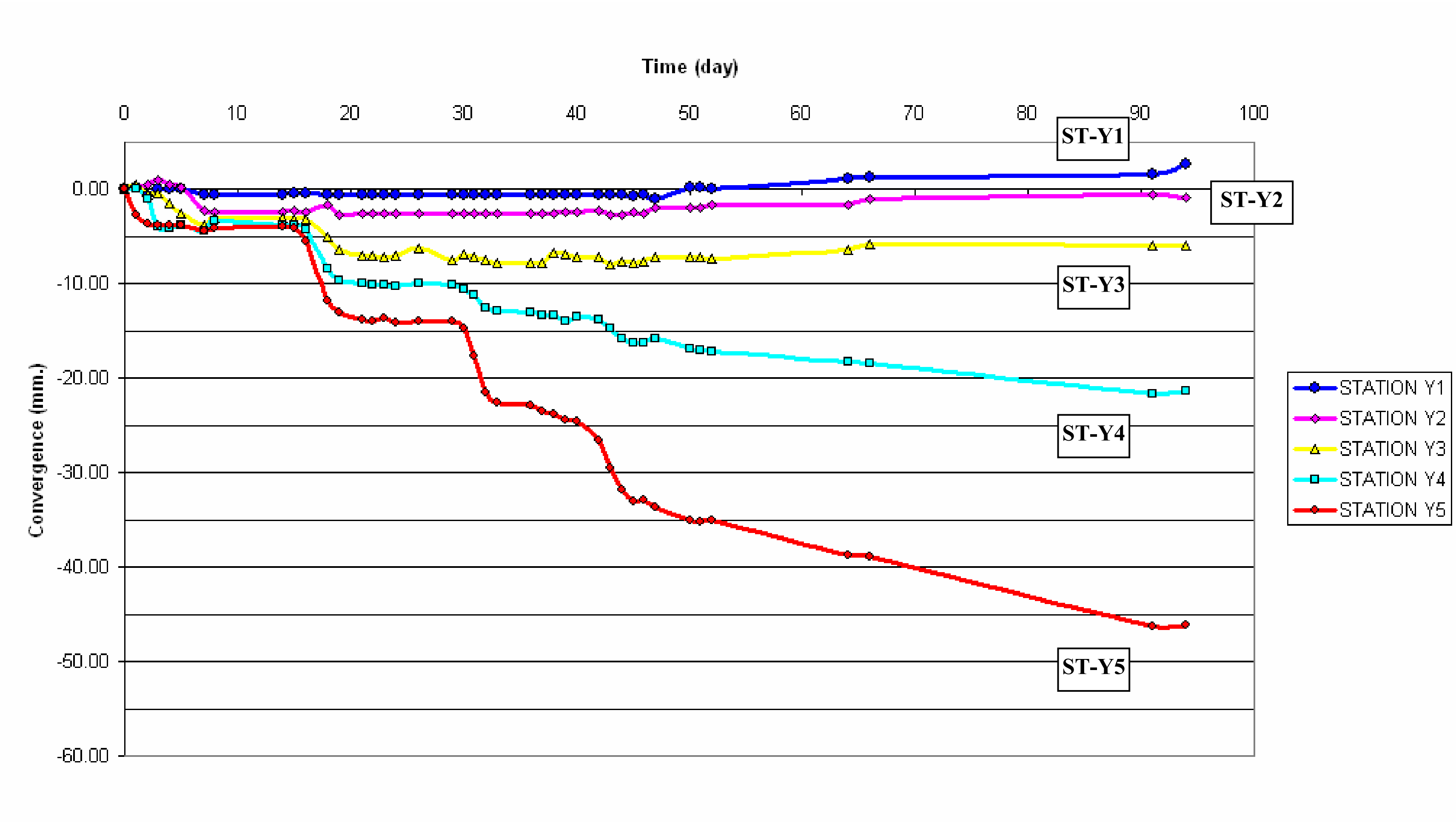


Figure 5.29: Relationship between convergence and time for Region 1 Stations

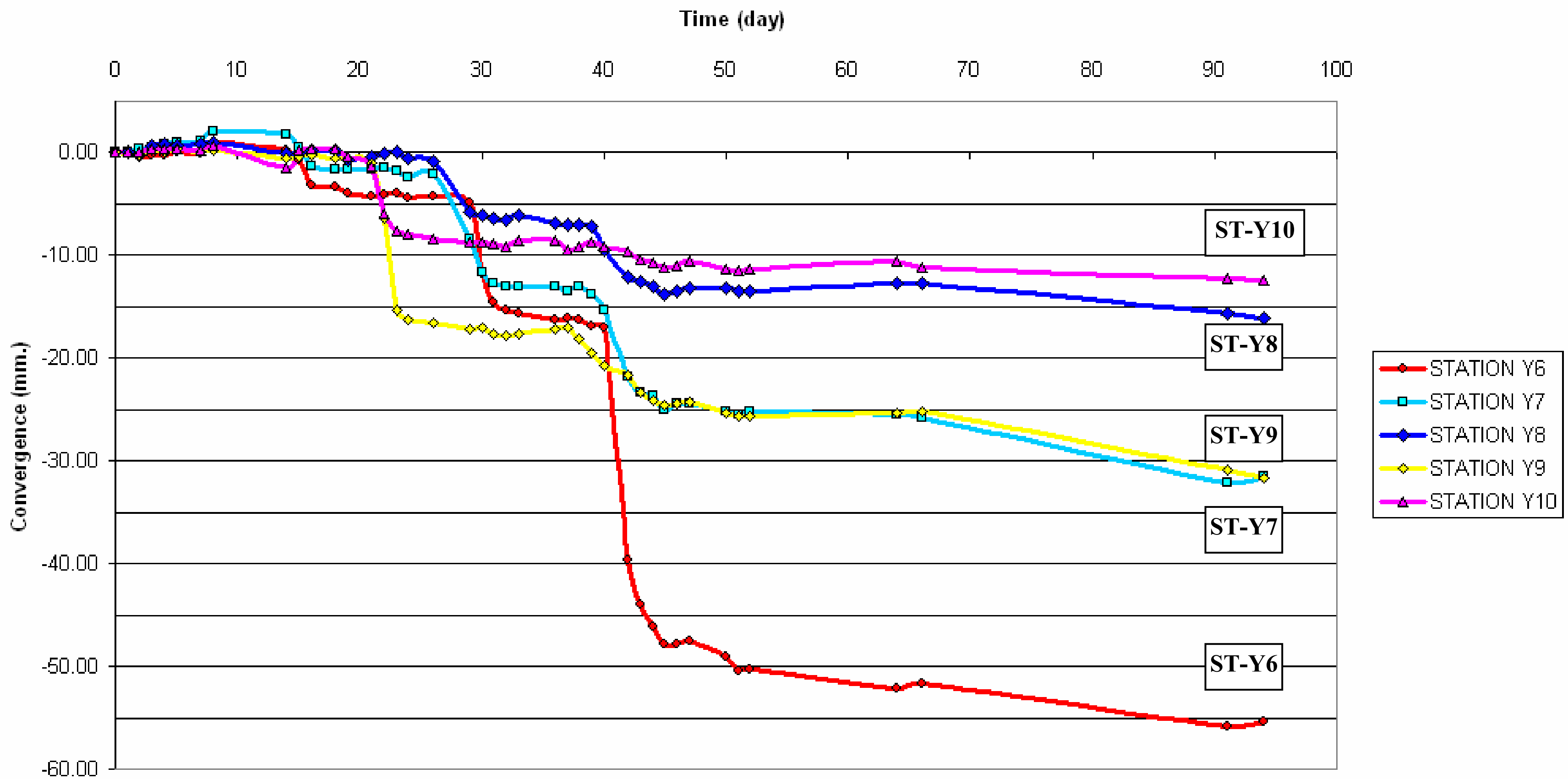


Figure 5.30: Relationship between convergence and time for Region 2 Stations

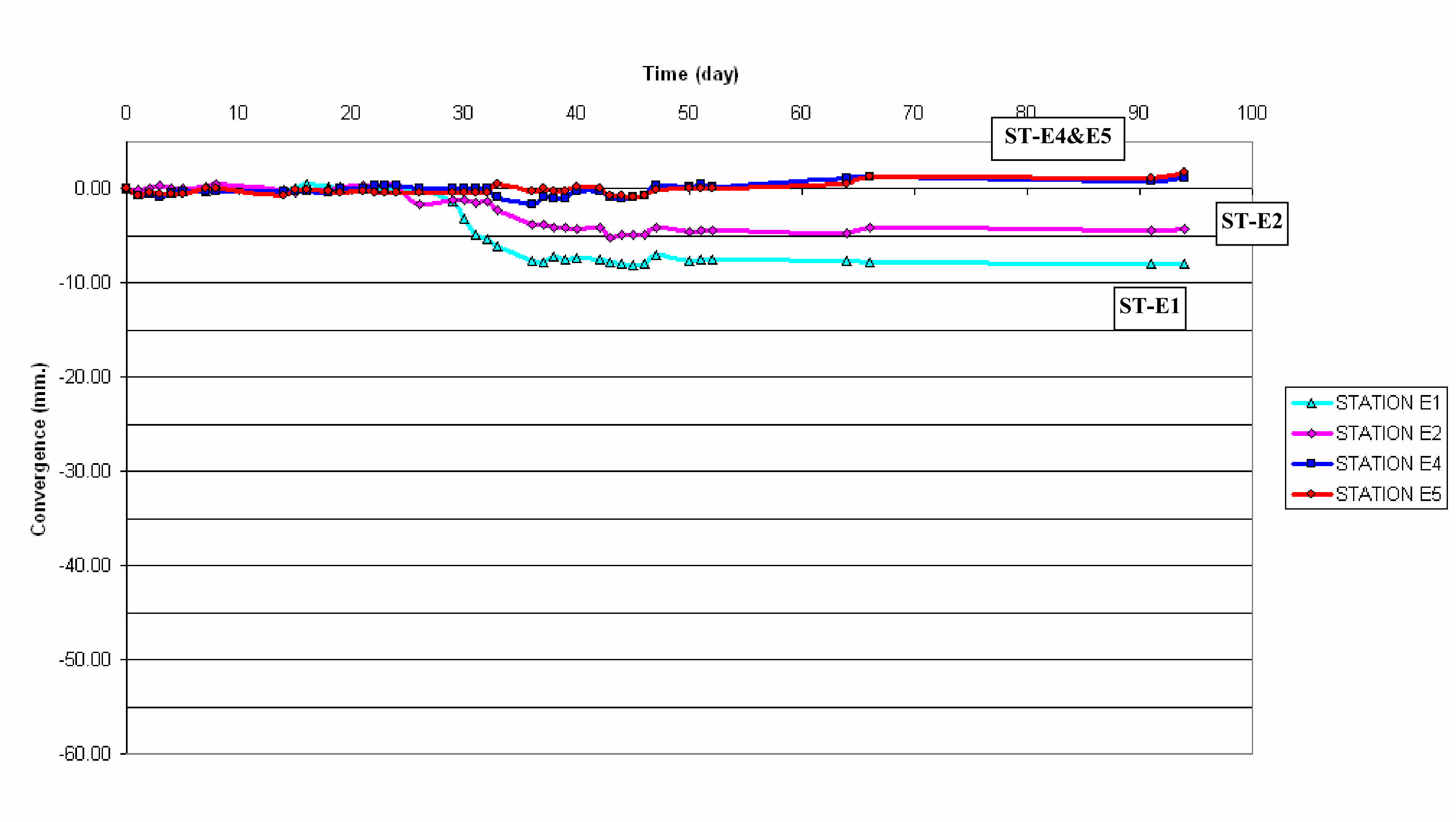


Figure 5.31: Relationship between convergence and time for Region 3 Stations

5.5.3 Relation Between "Convergence" and "Height of the Overburden"

In order to decide on stability relationship between the measured total convergence and the height of overburden material dumped on the culvert has also been evaluated. As an example, the above mentioned relationship for Station Y5, is shown in Figure 5.32. As can be seen in this graph, the total convergence measured is 46.21 mm and it occurs as a result of 28.45 meters of overburden gradually dumped on the culvert. Convergences occurring as a result of unit dumping height (slope of the line) marked as I, II, III and IV, on the plot given in Figure 5.32, are 0.51, 1.98, 1.69 and 4.98 mm/m respectively.

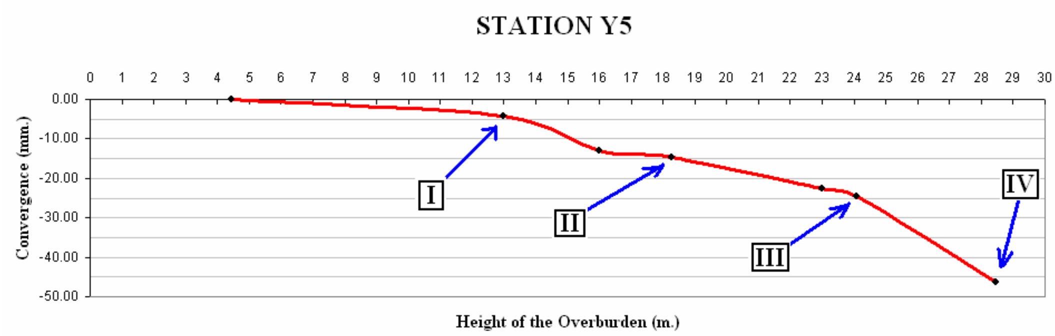


Figure 5.32: "Convergence" vs. "Height of the Overburden" relation for Station Y5

During evaluation of the stability of the culvert, relationship between the convergence and the overburden height the three region described earlier in Section 5.5.1 were considered. The slopes of the plots obtained from the relation between convergence and height of the overburden material was also taken into account, hoping to detect the ground arching effect if it had developed.

The details explaining the relationship between the "total-convergence" and "overburden-height" in Regions 1, 2 and 3 are presented in Appendix A included at the end of this thesis.

The heights of the overburden material and associated convergences occurring in 14 stations for different stages of controlled and homogeneous dumping are given in Table 5.3 and Figure 5.33.

In Figure 5.33, the part above the convergence station (Y1, Y2, …, E5) axis represents the heights of the overburden material dumped on culvert in different stages while the part below represents the measured convergences during the associated dumping stages. Convergence stations are located to scale in horizontal axis.

In Figure 5.33, the blue lines represent the situation of the dump site before the initiation of the thesis studies (September 05, 2001). As can be seen from the figure, heights of the overburden material on the culvert show considerable variations. For example the heights of the overburden material on Stations E4 and Y1 were 32.81 and 4.07 meters, respectively. Since convergence measurements were not taken, prior to thesis studies they were assumed as zero at the originally existing stage (blue horizontal line in Figure 5.33).

The two "purple" lines in Figure 5.33 represent the overburden height and the associated total convergences measured in October 2, 2001. It should be noted that the total convergence value of Station Y8 is significantly lower than the ones measured at Stations Y6 and Y7 although the height of the overburden material on them is more or less the same.

The convergence measured at Station Y9 in October 18, 2001 is significantly higher than the ones measured at Stations Y10, Y8 and Y7 although the height of overburden material is the same. A low level of convergence value at Station Y8 is still valid for this stage of dumping. The effect of 6-7 meters of overburden dumping on Stations E1 and E2 can clearly be seen in Figure 5.33. The levels formed in northeastern slope of dumping cannot be seen in southwestern slope, because this slope was used as a ramp for trucks to dump overburden material. It should be noted that the height of the overburden material replaced in Southwestern slope of the dump site has decreased between October 18 and December 7, 2001.

Table 5.3: Heights of the overburden material and associated convergence values for the entire culvert

Convergence Stations		Height of the Overburden Material (m)					Convergence (mm)				
Location (m)	ID	Sep 5, 2001	Oct 2, 2001	Oct 18, 2001	Oct 26, 2001	Dec 7, 2001	Sep 5, 2001	Oct 2, 2001	Oct 18, 2001	Oct 26, 2001	Dec 7, 2001
15	E5	29.77	29.77	29.77	29.77	29.77	0	-0.32	-0.19	-0.74	1,69
50	E4	32.81	32.81	32.81	32.81	32.81	0	0.35	-1.00	-0.75	1.20
100	E2	14.65	14.65	20.46	20.46	20.46	0	0.41	-4.05	- 4.84	- 4.21
125	E1	14.06	14.06	21.48	21.48	21.48	0	0.09	-7.11	-7.98	-7.91
175	Y10	12.88	20.68	23.51	20.75	20.75	0	-5.97	-9.21	-11.05	-12.48
225	Y9	13.73	22.24	25.54	25.72	25.72	0	-6.41	-18.13	-24.38	-31.73
275	Y8	14.15	17.79	23.50	26.94	28.80	0	-0.08	-7.02	-13.45	-16.12
300	Y7	13.89	17.95	23.70	29.22	29.22	0	-1.40	-12.99	-24.45	-31.45
325	Y6	12.01	18.11	23.90	31.08	31.08	0	-4.08	-16.32	-47.81	-55.34
350	Y5	4.45	18.28	24.10	28.45	28.45	0	-13.89	-23.75	-32.82	-46.21
375	Y4	3.00	18.45	24.31	24.43	24.43	0	-10.04	-13.31	-16.28	-21.32
400	Y3	3.35	18.61	18.61	18.73	18.73	0	-6.96	-6.64	-7.58	-5.98
425	Y2	3.72	13.07	13.07	13.13	13.13	0	-2.60	-2.62	-2.62	-0.86
450	Y1	4.07	4.07	4.07	4.07	4.07	0	-0.55	-0.55	-0.61	2.65

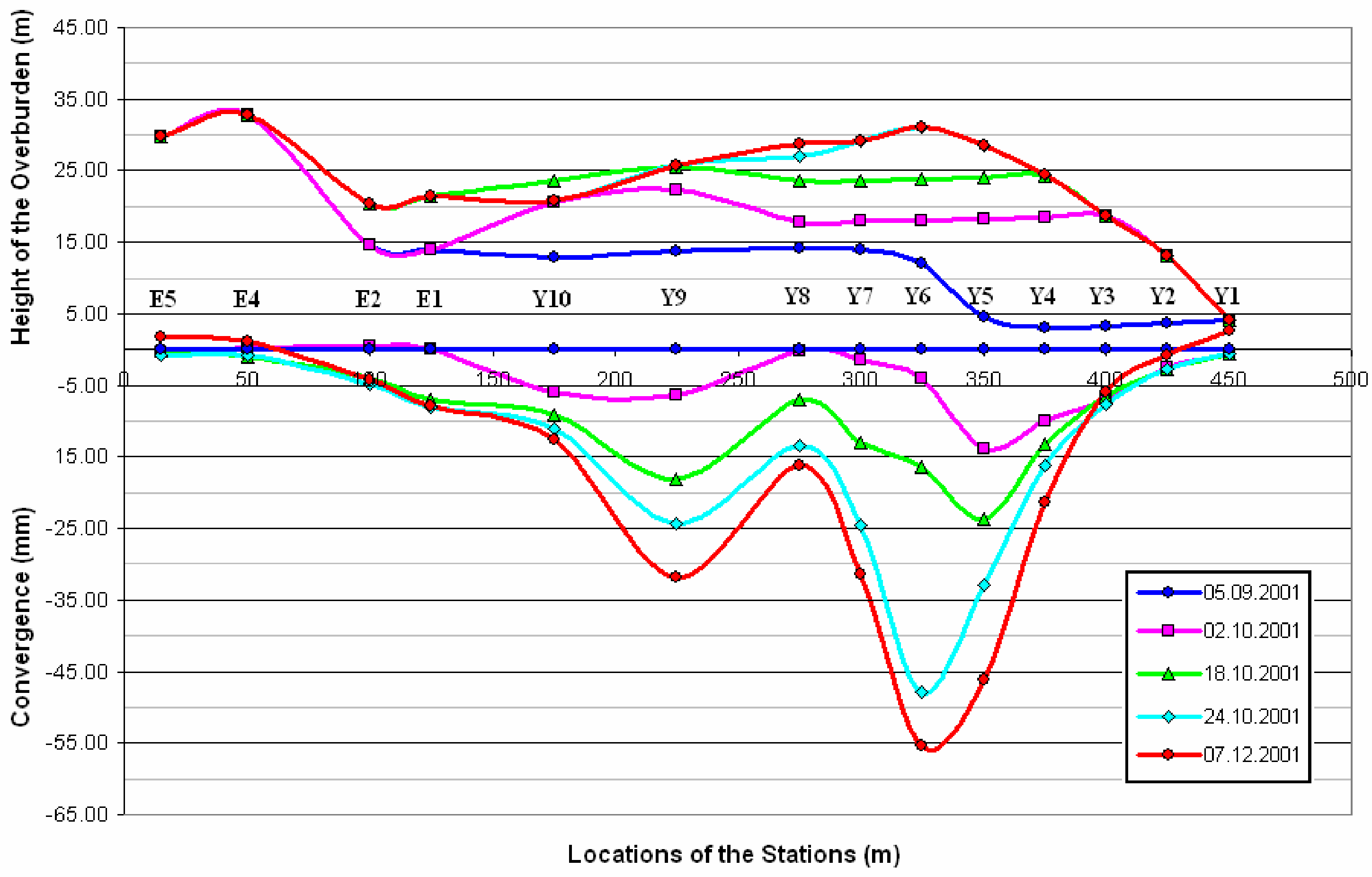


Figure 5.33: Height of the overburden material and measured convergences along the culvert

As a result of excessive dumping, the total convergence reach to -47.81 mm in Station Y6 in October 26, 2001. At this stage the height of the overburden material on Station Y6 was 31.08 meters while it was 25.72 meters for Station Y9. In view of the fact that the convergence value in Station Y8 was lower than the other stations having the same height of overburden material, the final dumping was concentrated on this region.

The two "red" lines shown in Figure 5.33 represent the final heights of the overburden material and the associated total convergences. In Station Y8, the measured total convergence was -16.12 mm. for an overburden height of 28.80 meter. Height of the overburden material on Station Y10 has decreased, because the material dumped on this station has transferred on Station Y8. At this stage, although overburden was dumped only on Station Y8, there was an increase in convergence values measured at other stations. This is probably due to heavy rainfalls affecting the overburden material and the applied loads on the culvert as well.

5.5.4 Comparison of Convergence Measurement's Results with Numerical Studies from Stability Point of View

In order to justify the validity of the numerical model developed, convergence measurements were taken inside the culvert while overburden material was being dumped on this structure.

By evaluating the relationships between "Convergence" vs. "Time" and "Convergence" vs. "Height of the Overburden Material" and observing the deformations inside the culvert, the maximum height of the overburden material reached on the culvert was about 31 meters.

Based on the results obtained from the numerical modeling studies, carried out on the deformed part of the culvert, the maximum height of the overburden material that could be replaced on the culvert was determined as 30 meters (see Figure 4.13). During this studies, the following parameters were taken into account; an overburden unit-weight of 25.5 kN/m^3, a safety factor of 1.10 and the existence of groundwater.

Consequently, by comparing the results (maximum height of the overburden material that could be dumped on culvert) obtained both from numerical analyses and field studies it is concluded that there is an acceptable agreement between the predicted and actual behavior of the culvert. Thus, the numerical model developed can be used to predict the actual behavior of dump site culvert in Tınaz Mine. In view of the fact that existing culvert model could not be able to stay stable under 80 meters of overburden height, alternative culvert models should be derived for future culvert projects based on the justified numerical model.

CHAPTER 6

ANALYSES ON ALTERNATIVE CULVERT MODELS

6.1 Introduction

In view of the fact that different culvert models could be designed and constructed in surface mines, it was decided to show how effective these culvert models would be, by using Tınaz Mine data as an example.

In this chapter, firstly alternative culvert models will be explained including input parameters and model characteristics. Secondly, analyses and evaluations on alternative culverts having positive projecting embankment condition will be given. Thirdly, culverts having negative projecting embankment condition will be analyzed and evaluated. Fourthly, alternative culverts will be compared with the existing culvert. Fifthly, a culvert having larger dimensions will be taken into consideration. Finally a short evaluation of the results will be presented at the end of this chapter.

6.2 Analyses on Alternative Culvert Models

In order to determine the maximum height of the overburden material that could be replaced on other culvert types, Tınaz Mine conditions will be taken into account and the input parameters shown in Table 4.1 will be used. In addition, the data obtained from back analyses technique will be used in order to include the effect of groundwater and other parameters into analyses.

During analyses, cross sectional area of the culverts in alternative models, will be taken as equal to the cross sectional area of the existing dump-site culvert of Tınaz Mine. Consequently, the hydrological conditions of the region will be assumed to be valid for the subsequent culvert models.

In practice, both the positive and negative projecting embankment conditions are applied for dump-site culverts as explained in Chapter 2. Consequently, in this study both of the alternatives will be taken into account. In addition, box-shape as well as circular-shape culverts will be modeled in analyzing possible alternatives. Moreover, different bedding conditions will be applied for circular-shape culvert models.

6.3 Positive Projecting Embankment Condition

A positive projecting embankment culvert is one which is installed in shallow bedding with its top projecting above the surface of natural ground and which is covered with an embankment (Spangler and Handy, 1973).

The positive projecting culvert models for four different bedding conditions namely, impermissible, ordinary, first class, and concrete cradle are illustrated in Figures 6.1, 6.2, 6.3 and 6.4, respectively.

Since the existing box-shape culvert of Tınaz Mine, analyzed previously, is in this category, modeling of box-shape culvert, as an alternative in positive projecting embankment condition, is not necessary. Consequently, only circular-shape culverts will be evaluated under positive projecting embankment condition.

A typical output obtained from Phase 2 program, showing the distribution of safety factors in inside walls of the circular-shape culvert having first class bedding is given in Figure 6.5 presented in Section 6.3.3

The results obtained from analyses of the circular-shape culvert models having different bedding condition are shown and compared in Figure 6.6 presented in Section 6.3.5.

In carrying out analyses associated with positive projecting embankment the following conditions are considered: i) taking the overburden unit weight as 25.5 kN/m^3 and considering groundwater effect, ii) taking the overburden unit weight as 25.5 kN/m^3 and disregarding the effect of groundwater, iii) taking the overburden unit weight as 18.8 kN/m^3 and considering the groundwater effect, iv) taking the overburden unit weight as 18.8 kN/m^3 and disregarding the effect of groundwater.

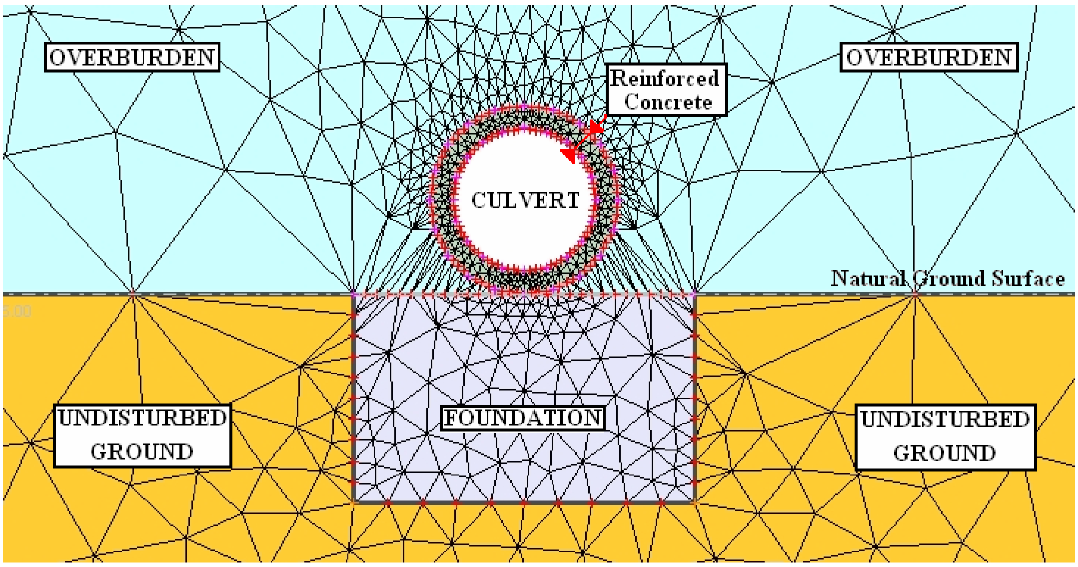


Figure 6.1: Positive projecting circular-shape culvert model having impermissible bedding condition

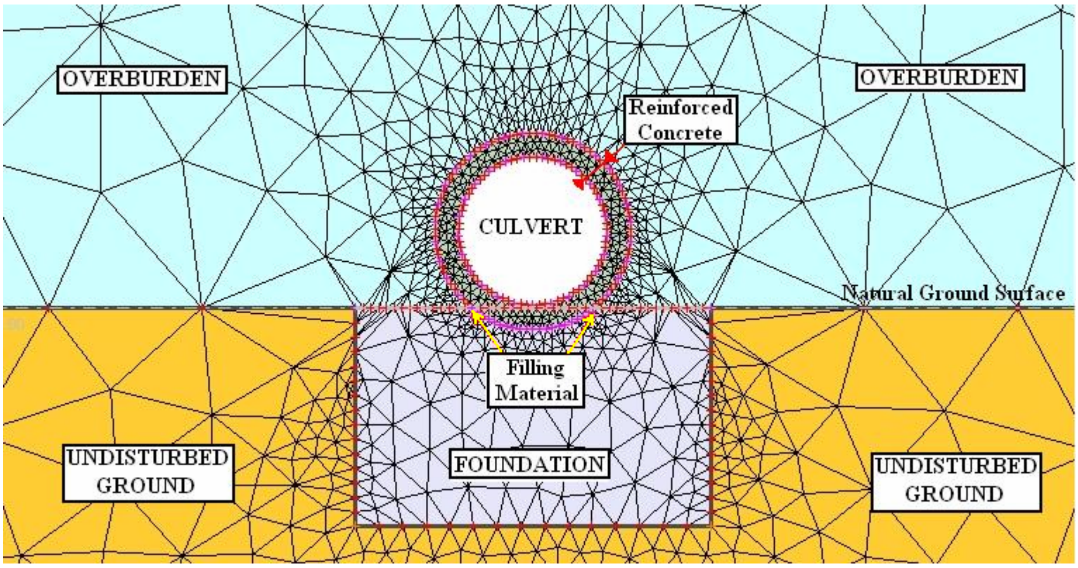


Figure 6.2: Positive projecting circular-shape culvert model having ordinary bedding condition

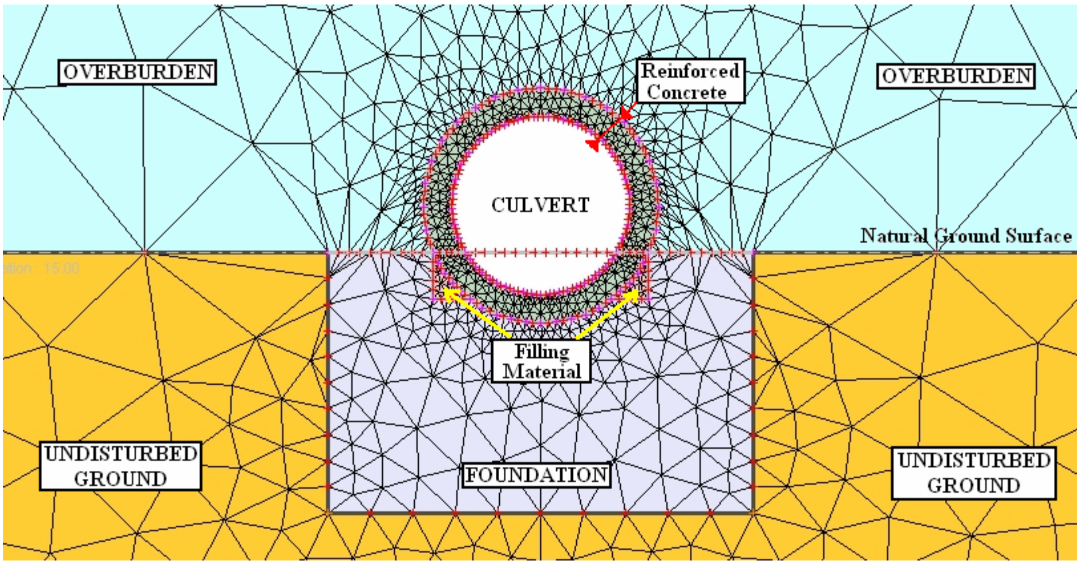


Figure 6.3: Positive projecting circular-shape culvert model having first-class bedding condition

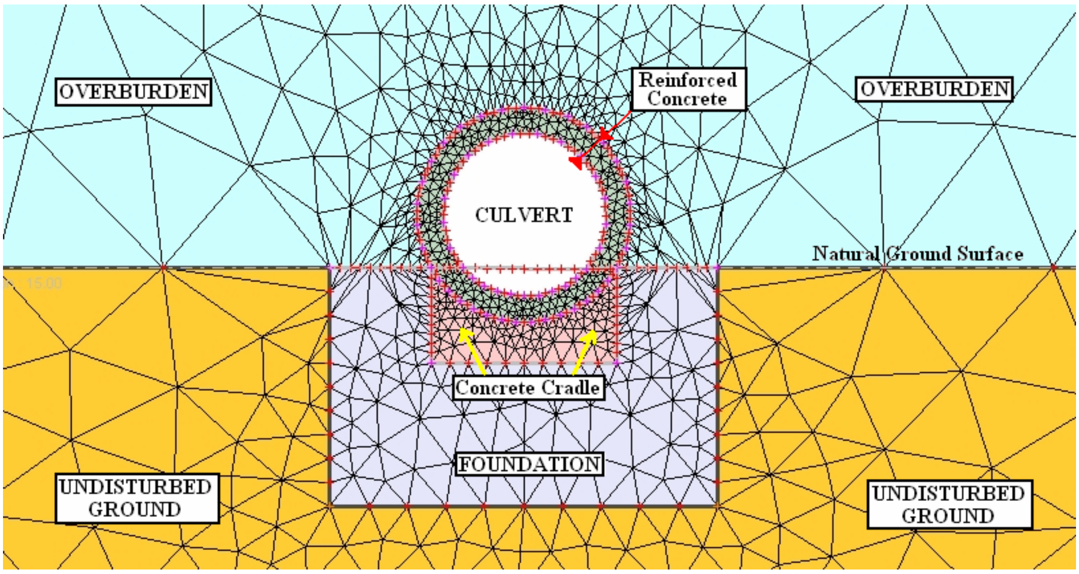


Figure 6.4: Positive projecting circular-shape culvert model having concrete cradle bedding condition

6.3.1 Circular-Shape Culvert Model Having Impermissible Bedding Condition

The circular-shape culvert model having impermissible bedding condition shown in Figure 6.1 is used in analyses. In this model, 2429 elements, 1309 nodes and 17 stages are used. The first 4 stages represent the construction of the culvert and the remaining 13 stages represent the replacement of the overburden material on the dump site including the alternative culvert model. As mentioned before, input parameters provided in Table 4.1 are used in this alternative culvert model.

The results obtained from analyses of the circular-shape culvert model having impermissible bedding are shown in Figure 6.6 presented in Section 6.3.5. The output obtained from Phase 2 program for an overburden height of 80 meters, an overburden unit weight of 25.5 kN/m^3, and considering the effect of groundwater is given in Figure B1 included in Appendix B. In this figure, distribution of safety factors in the walls of the culvert is illustrated. The results indicate that the lowest safety factor is 0.49 occurring in the sidewalls of the culvert model. Comparison of the results obtained from numerical analyses associated with other alternative bedding conditions is presented in Section 6.3.5 in detail.

6.3.2 Circular-Shape Culvert Model Having Ordinary Bedding Condition

The circular-shape culvert model having ordinary bedding condition shown in Figure 6.2 is used in analyses. In this model, 3073 elements, 1633 nodes and 18 stages are used. The first 5 stages represent the construction of the culvert and the remaining 13 stages represent the replacement of the overburden material on the dump site including the alternative culvert model. As mentioned before, input parameters provided in Table 4.1 are used in this alternative culvert model. Input parameters of filling material, shown in Figure 6.2, are same as the input parameters of foundation material given in Table 4.1.

The results obtained from analyses of the circular-shape culvert model having ordinary bedding are shown in Figure 6.6 presented in Section 6.3.5. The output obtained from Phase2 program, for an overburden height of 80 meters, an overburden unit weight of 25.5 kN/m^3, and considering the effect of groundwater is given in Figure B2 included in Appendix B. In this figure, distribution of safety factors in the walls of the culvert is illustrated. The results indicate that the lowest safety factor is 0.58 occurring in the sidewalls of the culvert model. Comparison of the results obtained from numerical analyses associated with other alternative bedding conditions is presented in Section 6.3.5 in detail.

6.3.3 Circular-Shape Culvert Model Having First Class Bedding Condition

The circular-shape culvert model having first class bedding condition shown in Figure 6.3 is used in analyses. In this model, 2956 elements, 1524 nodes and 18 stages are used. The first 5 stages represent the construction of the culvert and the remaining 13 stages represent the replacement of the overburden material on the dump site including the alternative culvert model. As mentioned before, input parameters provided in Table 4.1 are used in this alternative culvert model. Input parameters of filling material, shown in Figure 6.3, are same as the input parameters of foundation material given in Table 4.1.

The results obtained from analyses of the circular-shape culvert model having first class bedding are shown in Figure 6.6 presented in Section 6.3.5. The output obtained from Phase 2 program for an overburden height of 80 meters, an overburden unit weight of 25.5 kN/m^3, and considering the effect of groundwater is given in Figure 6.5. In this figure, distribution of safety factors in the walls of the culvert is illustrated. The results indicate that the lowest safety factor is 0.64 occurring in the sidewalls of the culvert model. Comparison of the results obtained from numerical analyses associated with other alternative bedding conditions is presented in Section 6.3.5 in detail.

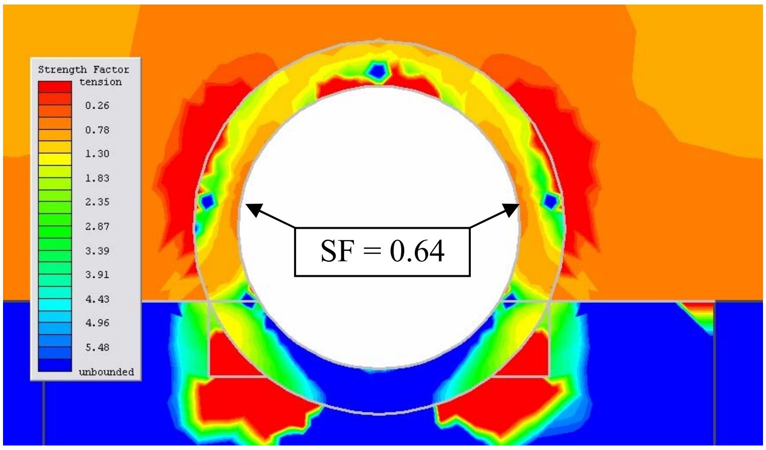


Figure 6.5: Distribution of safety factors in the walls of the culvert having first-class bedding (min. safety factor = 0.64)

6.3.4 Circular-Shape Culvert Model Having Concrete Cradle Bedding Condition

The circular-shape culvert model having concrete cradle bedding condition shown in Figure 6.4 is used in analyses. In this model, 2871 elements, 1527 nodes and 18 stages are used. The first 5 stages represent the construction of the culvert and the remaining 13 stages represent the replacement of the overburden material on the dump site including the alternative culvert model. As mentioned before, input parameters provided in Table 4.1 are used in this alternative culvert model. Input parameters of concrete cradle, shown in Figure 6.4, are similar to the input parameters of reinforced concrete material given in Table 4.1. Only tensile strength and cohesion values are different. These values of the concrete are determined in proportion to the reinforced concrete of culvert. Since the ratio of concrete cradle's strength (15 MPa) to reinforced concrete's strength (25 MPa) is 0.6, tensile strength and cohesion values are determined by using the same proportion and found as 3 MPa and 4.8 MPa, respectively.

The results obtained from analyses of the circular-shape culvert model having concrete cradle bedding are shown in Figure 6.6 presented in Section 6.3.5. The output obtained from Phase 2 program for an overburden height of 80 meters, an overburden unit weight of 25.5 kN/m^3, and considering the effect of groundwater is given in Figure B3 included in Appendix B. In this figure, distribution of safety factors in the walls of the culvert is illustrated. The results indicate that the lowest safety factor is 0.60 occurring in the sidewalls of the culvert model. Comparison of the results obtained from numerical analyses associated with other alternative bedding conditions is presented in Section 6.3.5 in detail.

6.3.5 Comparison of Positive Projecting Culverts

In view of the fact that the existing dump site culvert of Tınaz Mine could not stay stable when the overburden height exceeds 30 meters, the alternative positive-projecting culvert models have been taken into consideration in order to investigate the possibility of replacing higher overburden material.

A comparison of results, obtained from numerical analyses of positive-projecting culvert models, is illustrated in plots shown in Figure 6.6. Numerical analyses have been carried out for the following conditions: i) taking unit weight of the overburden material as 25.5 kN/m^3, which is the measured unit-weight value in field, and considering the groundwater effect ii) taking the unit-weight as 25.5 kN/m^3, but disregarding the effect of groundwater iii) taking the unit-weight of overburden as 18.8 kN/m^3, and taking the effect of groundwater into account, and finally iv) taking the unit-weight of overburden as 18.8 kN/m^3 but assuming a dry overburden condition, in other words disregarding the effect of groundwater. A comparison of the results obtained from these analyses ii, iii and iv are presented in Figures B4, B5 and B6 given in Appendix B.

In Figure 6.6, presented on the next page, the relationship between "the lowest safety factor observed in the inner walls of the culvert" and "height of the overburden material on alternative culverts" for positive-projecting embankment cases is given.

From Figure 6.6, it is seen that the alternative circular-shape culvert model, having an "impermissible bedding" condition, is considered as unstable (safety factor <1.10) under any predetermined height of overburden material having a unit weight of 25.5 kN/m^3, and under the effect of groundwater.

Under the same overburden unit-weight and under the effect of groundwater, the alternative culvert models having ordinary bedding, concrete-cradle bedding and first-class bedding stay stable up to overburden height of 19, 24 and 27 meters, respectively.

When there is no effect of groundwater the height of the overburden material that could be dumped on alternative culverts increases at most 16 meter, as shown in Figure B4.

Although it is not realistic to take the unit weight of the overburden material as 18.8 kN/m^3 and to assume there is no groundwater effect, analyses for these cases, (iii) and (iv) mentioned in the above paragraphs, were carried out for the sake of completeness. In these cases, decreasing the unit weight of the overburden material to 18.8 kN/m^3 increases the heights of the overburden material that could be dumped on culvert significantly. Alternative culverts having ordinary, concrete cradle and first class bedding are considered as stable up to 25, 33, and 37 meters of overburden material respectively considering the affect of groundwater (Figure B5). Significant increases, up to 21 meters, are observed in heights of the overburden material that could be dump on the culvert by disregarding the affect of groundwater (Figure B6).

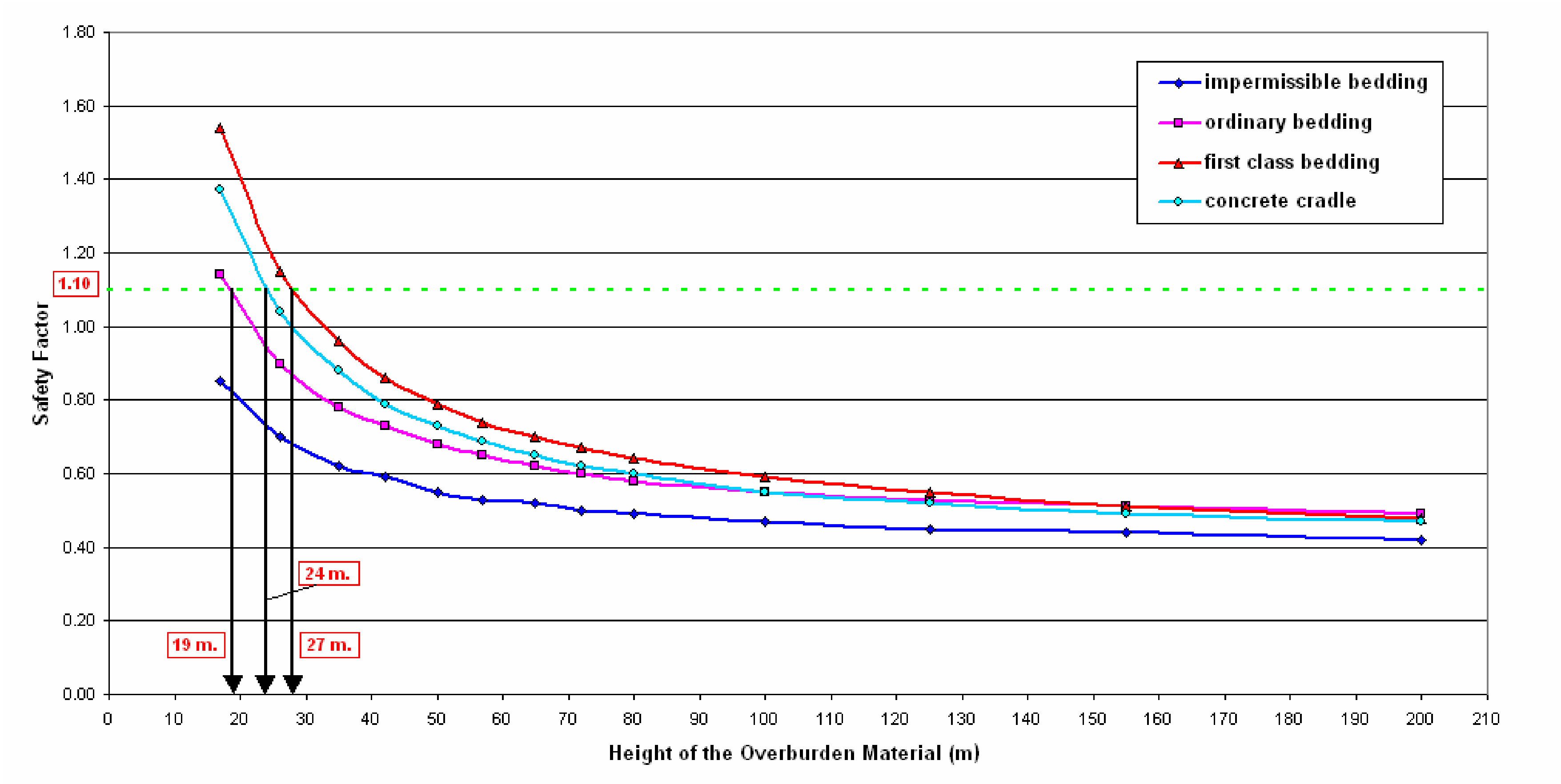


Figure 6.6: Relationship between the lowest safety factor in the inner walls of the culvert and height of the overburden material (γ = 25.5 kN/m^3, considering the effect of groundwater) for positive projecting embankment condition

As a result of numerical analyses carried out on alternative positive projecting culvert models, none of the alternative culverts stay stable under an overburden height of 80 meters under any of the considered overburden unit-weight or groundwater condition.

6.4 Negative Projecting Embankment Condition

A negative projecting culvert is the one, installed in a relatively narrow and shallow trench with its top at an elevation below the natural ground surface and which is then covered with an embankment. This is a very favorable method of installing a culvert since the load produced by a given height of fill is generally less than it would be in the case of positive projecting culvert (Spangler and Handy, 1973).

Since the existing dump-site culvert of Tınaz Mine, analyzed previously, could not be included in this category, not only circular-shape culvert models but also a box-shape culvert model will be analyzed as an alternative in negative projecting embankment condition.

A negative projecting box-shape culvert model is illustrated in Figure 6.7. Additionally negative projecting circular-shape culvert models for three different bedding conditions namely, impermissible, ordinary and first class are given in Figures 6.8, 6.9 and 6.10 respectively.

A typical output obtained from Phase 2 program, showing the distribution of safety factors in inside walls of the culvert having first class bedding is given in Figure 6.11 presented in Section 6.4.4

The results obtained from analyses of the box-shape culvert model and circular-shape culvert models having different bedding condition are shown and compared in Figure 6.12 presented in Section 6.4.5.

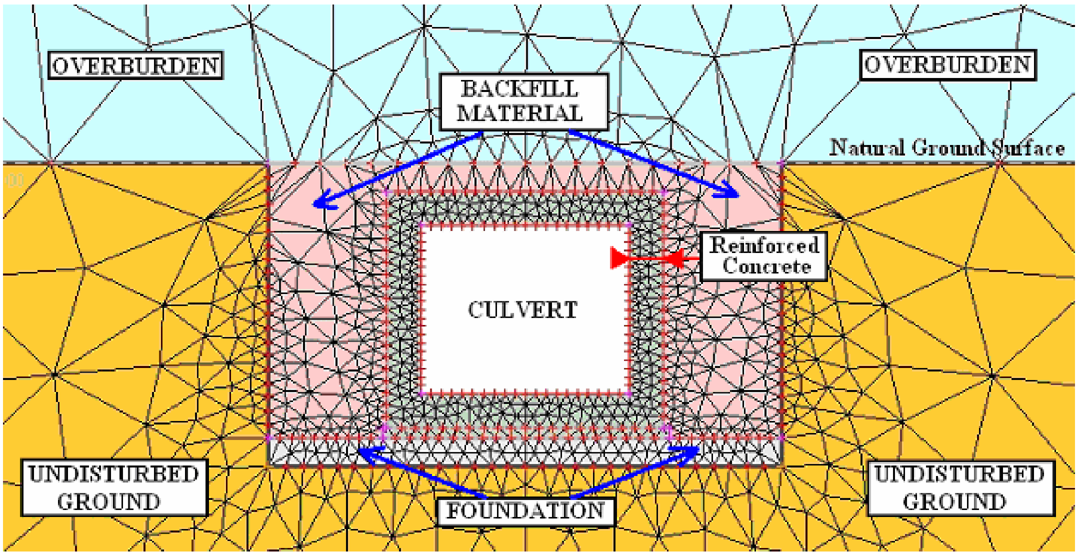


Figure 6.7: Negative projecting box-shape culvert model

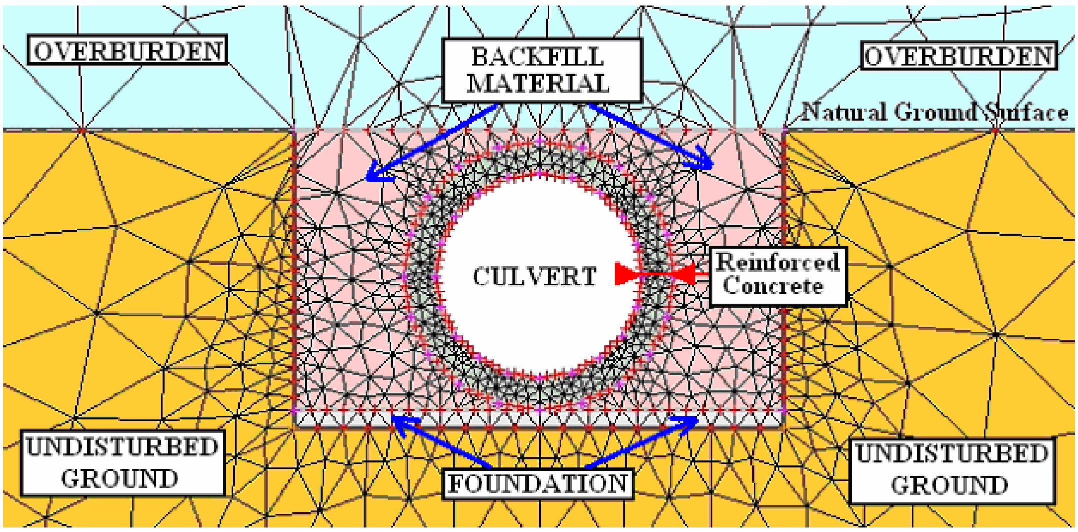


Figure 6.8: Negative projecting circular-shape culvert model
having impermissible bedding condition

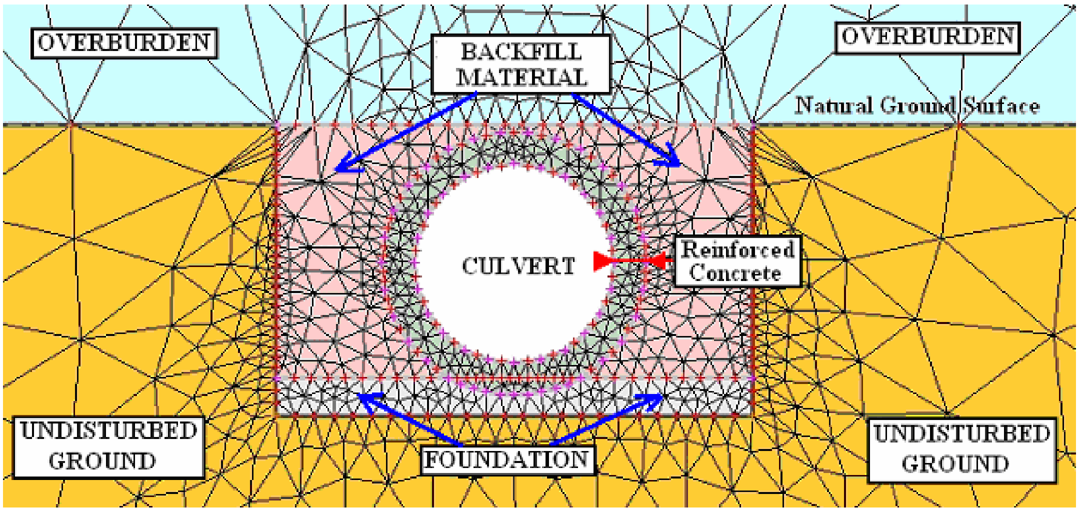


Figure 6.9: Negative projecting circular-shape culvert model having ordinary bedding condition

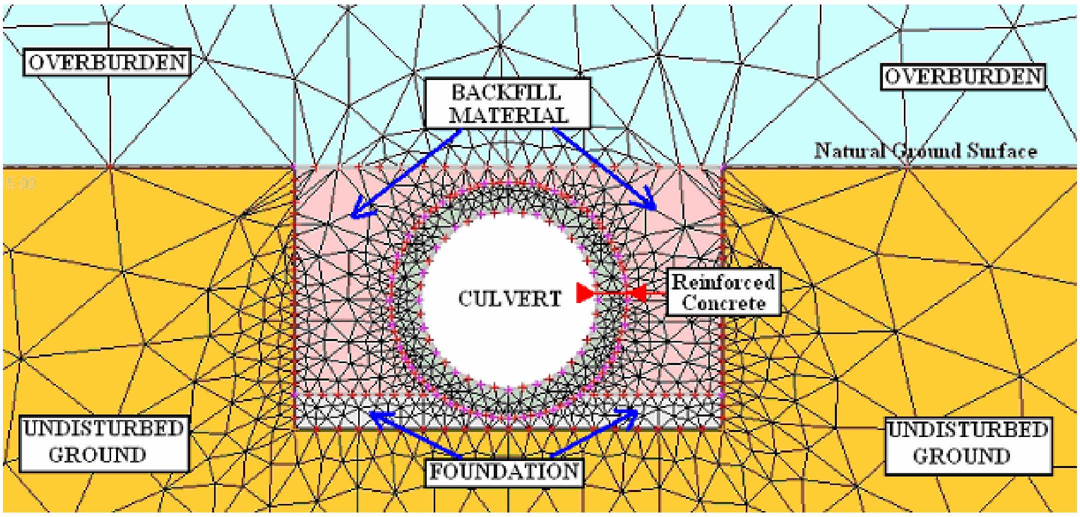


Figure 6.10: Negative projecting circular-shape culvert model having first-class bedding condition

In carrying out analyses associated with negative projecting embankment the following conditions are considered: i) taking the overburden unit weight as 25.5 kN/m^3 and considering groundwater effect, ii) taking the overburden unit weight as 25.5 kN/m^3 and disregarding the effect of groundwater, iii) taking the overburden unit weight as 18.8 kN/m^3 and considering the groundwater effect, iv) taking the overburden unit weight as 18.8 kN/m^3 and disregarding the effect of groundwater.

6.4.1 Box-Shape Culvert Model Having Negative Projecting Embankment Condition

The box-shape culvert model having negative projecting embankment condition shown in Figure 6.7 is used in analyses. In this model, 2926 elements, 1558 nodes and 18 stages are used. The first 5 stages represent the construction of the culvert and the remaining 13 stages represent the replacement of the overburden material on the dump site including the alternative culvert model. As mentioned before, input parameters provided in Table 4.1 are used in this alternative culvert model. Input parameters of backfill material, shown in Figure 6.7, are same as the input parameters of foundation material given in Table 4.1.

The results obtained from analyses of the box-shape culvert model having negative projecting embankment are shown in Figure 6.12 presented in Section 6.4.5. The output obtained from Phase2 program, for an overburden height of 80 meters, an overburden unit weight of 25.5 kN/m^3, and considering the effect of groundwater is given in Figure C1 included in Appendix C. In this figure, distribution of safety factors in the walls of the culvert is illustrated. The results indicate that the lowest safety factor is 1.17 occurring in the sidewalls of the culvert model. Comparison of the results obtained from numerical analyses associated with other alternative culvert models is presented in Section 6.4.5 in detail.

6.4.2 Circular-Shape Culvert Model Having Impermissible Bedding Condition

The circular-shape culvert model having impermissible bedding condition shown in Figure 6.8 is used in analyses. In this model, 2876 elements, 1537 nodes and 18 stages are used. The first 5 stages represent the construction of the culvert and the remaining 13 stages represent the replacement of the overburden material on the dump site including the alternative culvert model. As mentioned before, input parameters provided in Table 4.1 are used in this alternative culvert model. Input parameters of backfill material, shown in Figure 6.8, are same as the input parameters of foundation material given in Table 4.1.

The results obtained from analyses of the circular-shape culvert model having impermissible bedding are shown in Figure 6.12 presented in Section 6.4.5. The output obtained from Phase2 program, for an overburden height of 80 meters, an overburden unit weight of 25.5 kN/m^3, and considering the effect of groundwater is given in Figure C2 included in Appendix C. In this figure, distribution of safety factors in the walls of the culvert is illustrated. The results indicate that the lowest safety factor is 1.31 occurring in the sidewalls of the culvert model. Comparison of the results obtained from numerical analyses associated with other alternative culvert models is presented in Section 6.4.5 in detail.

6.4.3 Circular-Shape Culvert Model Having Ordinary Bedding Condition

The circular-shape culvert model having ordinary bedding condition shown in Figure 6.9 is used in analyses. In this model, 2828 elements, 1497 nodes and 18 stages are used. The first 5 stages represent the construction of the culvert and the remaining 13 stages represent the replacement of the overburden material on the dump site including the alternative culvert model. As mentioned before, input parameters provided in Table 4.1 are used in this alternative culvert model.

Input parameters of backfill material, shown in Figure 6.9, are same as the input parameters of foundation material given in Table 4.1.

The results obtained from analyses of the circular-shape culvert model having ordinary bedding are shown in Figure 6.12 presented in Section 6.4.5. The output obtained from Phase2 program, for an overburden height of 80 meters, an overburden unit weight of 25.5 kN/m^3, and considering the effect of groundwater is given in Figure C3 included in Appendix C. In this figure, distribution of safety factors in the walls of the culvert is illustrated. The results indicate that the lowest safety factor is 1.39 occurring in the sidewalls of the culvert model. Comparison of the results obtained from numerical analyses associated with other alternative culvert models is presented in Section 6.4.5 in detail.

6.4.4 Circular-Shape Culvert Model Having First Class Bedding Condition

The circular-shape culvert model having first class bedding condition shown in Figure 6.10 is used in analyses. In this model, 2928 elements, 1543 nodes and 18 stages are used. The first 5 stages represent the construction of the culvert and the remaining 13 stages represent the replacement of the overburden material on the dump site including the alternative culvert model. As mentioned before, input parameters provided in Table 4.1 are used in this alternative culvert model. Input parameters of backfill material, shown in Figure 6.10, are same as the input parameters of foundation material given in Table 4.1.

The results obtained from analyses of the circular-shape culvert model having first class bedding are shown in Figure 6.12 presented in Section 6.4.5. The output obtained from Phase2 program, for an overburden height of 80 meters, an overburden unit weight of 25.5 kN/m^3, and considering the effect of groundwater is given in Figure 6.11. In this figure, distribution of safety factors in the walls of the culvert is illustrated. The results indicate that the lowest safety factor is 1.50 occurring in the sidewalls of the culvert model. Comparison of the results obtained from numerical analyses associated with other alternative culvert models is presented in Section 6.4.5 in detail.

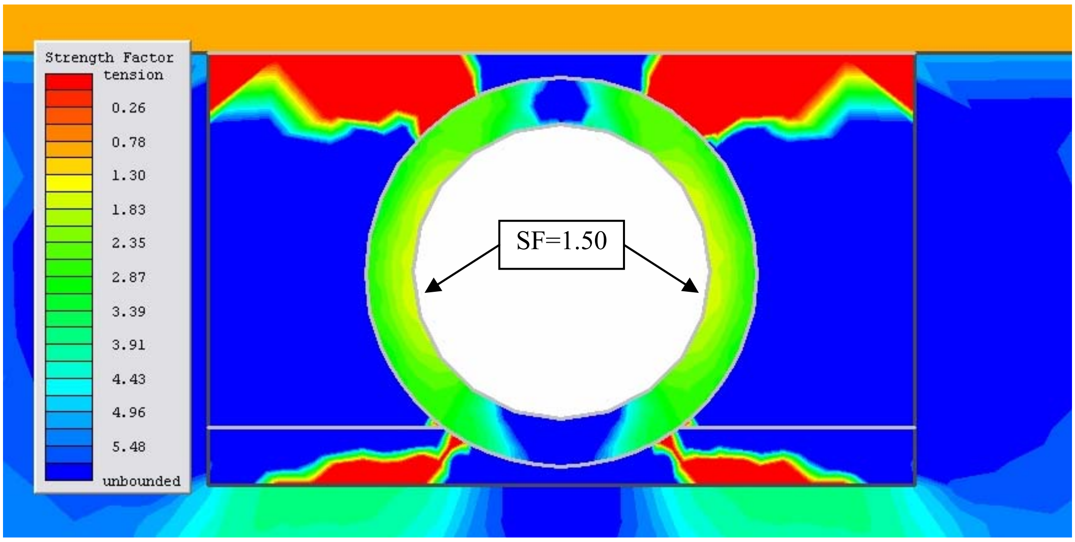


Figure 6.11: Distribution of safety factors in the walls of the culvert having first class bedding (min. safety factor = 1.50)

6.4.5 Comparison of Negative Projecting Culverts

In view of the fact that the existing dump site culvert of Tınaz Mine could not stay stable when the overburden height exceeds 30 meters, the alternative negative-projecting culvert models have been taken into consideration in order to investigate the possibility of replacing higher overburden material.

A comparison of results, obtained from numerical analyses of negative-projecting culvert models, is illustrated in plots shown in Figure 6.12. Numerical analyses have been carried out for the following conditions: i) taking unit weight of the overburden material as 25.5 kN/m^3, which is the measured unit-weight value in field, and considering the groundwater effect ii) taking the unit-weight as 25.5 kN/m^3, but disregarding the effect of groundwater iii) taking the unit-weight of overburden as 18.8 kN/m^3, and taking the effect of groundwater into account, and finally iv) taking the unit-weight of overburden as 18.8 kN/m^3 but assuming a dry overburden condition, in other words disregarding the effect of groundwater. A comparison of the results obtained from these analyses ii, iii and iv are presented in Figures C4, C5 and C6 given in Appendix C.

In Figure 6.12, presented on the next page, the relationship between "the lowest safety factor observed in the inner walls of the culvert" and "height of the overburden material on alternative culverts" for negative-projecting embankment cases is given.

From Figure 6.12, it is seen that the alternative box-shape culvert model is considered as unstable (safety factor <1.10) under 87 meters of overburden material having a unit weight of 25.5 kN/m^3, and under the effect of groundwater.

Under the same overburden unit-weight and under the effect of groundwater, the alternative culvert models having impermissible, ordinary and first-class bedding stay stable up to overburden height of 105, 115 and 130 meters, respectively.

When there is no effect of groundwater the height of the overburden material that could be dumped on alternative culverts increases at most 70 meter, as shown in Figure C4.

Although it is not realistic to take the unit weight of the overburden material as 18.8 kN/m^3 and to assume there is no groundwater effect, analyses for these cases, (iii) and (iv) mentioned in the above paragraphs, were carried out for the sake of completeness. In these cases, decreasing the unit weight of the overburden material to 18.8 kN/m^3 increases the heights of the overburden material that could be dumped on culvert significantly. Alternative culverts having impermissible, ordinary and first class bedding are considered as stable up to 139 meters, 157 meters, and 176 meters of overburden material respectively considering the affect of groundwater while box-shape culvert is considered as stable up to 118 meters under same conditions (Figure C5). Significant increases, more than 70 meters, are observed in heights of the overburden material that could be dump on the culvert with disregarding the affect of groundwater (Figure C6).

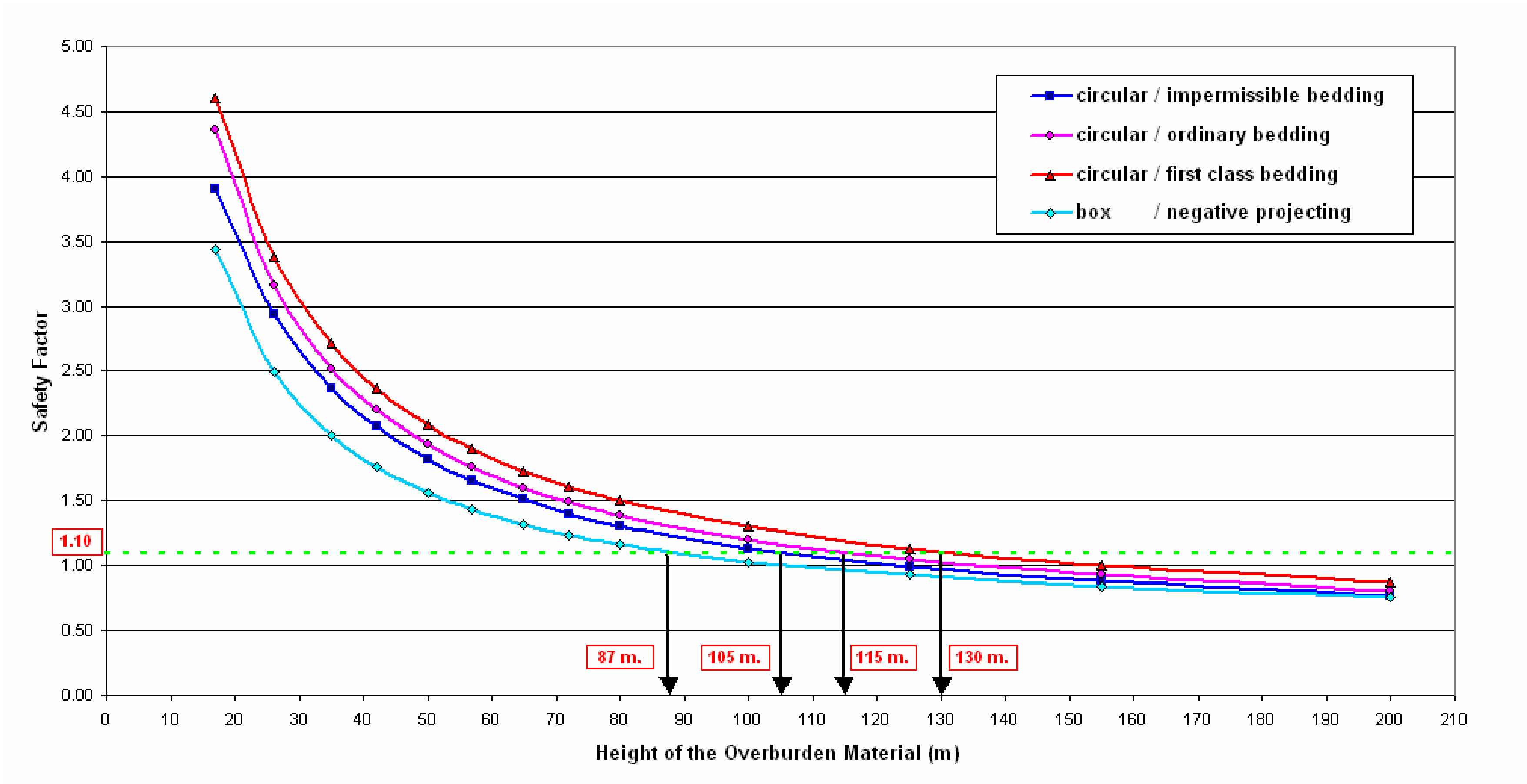


Figure 6.12: Relationship between the lowest safety factor in the inner walls of the culvert and height of the overburden material ($\gamma = 25.5$ kN/m^3, considering the effect of groundwater) for negative projecting embankment condition

As a result of numerical analyses carried out on alternative negative projecting culvert models, all of the alternative culverts stay stable under an overburden height of 80 meters under any considered overburden unit weight or groundwater condition.

6.5 Comparison of Existing and Alternative Culvert Models

During this M.Sc. thesis study stability of different dump-site culvert alternatives that could be constructed in Tınaz Mine were analyzed using FEM and utilizing Phase2 V5.0 software.

During numerical analyses, two different embankment conditions namely: positive projecting and negative projecting culvert models were taken into account. A total of eight culvert models having two different shapes (box and circular), and having four different bedding conditions (impermissible bedding, ordinary bedding, first class bedding and concrete cradle) were examined. Each model was examined for two different overburden unit weights (18.8 kN/m^3 and 25.5 kN/m^3) and two different groundwater conditions (wet and dry).

In order to compare the existing dump-site culvert of Tınaz Mine with alternative culverts, the most stable culverts (culverts having higher safety factor under same overburden height and groundwater condition) are selected from each embankment condition.

In positive projecting embankment condition, the culvert having first class bedding was determined as the most stable alternative among the other culverts models having impermissible bedding, ordinary bedding and concrete cradle bedding. Alternative positive projecting circular-shape culvert having first class bedding stays stable under 27 meters of overburden load with considering an overburden unit-weight of 25.5 kN/m^3, an existence of groundwater (wet condition), and a design safety factor of 1.10. The existing box-shape culvert on the other hand, stays stable under 30 meters of overburden load.

In negative projecting embankment condition, again the culvert having first-class bedding was determined as the most stable alternative among the other culvert models having impermissible bedding and ordinary bedding. It is also more stable then the negative projecting box-shape culvert. Alternative negative projecting circular-shape dump site culvert having first class bedding stays stable under 130 meters of overburden load with considering an overburden unit-weight of 25.5 kN/m^3, an existence of groundwater and a design safety-factor of 1.10. In order to compare the influence of embankment condition on the existing culvert, which could be classified as positive projecting, alternative box-shape culvert with negative projecting embankment condition is also taken into consideration in comparison of alternatives.

In view of the fact that the condition where overburden material has a unit weight of 25.5 kN/m^3 and the culvert is under the affect of groundwater is more realistic, comparison of the existing box-shape culvert with the other best alternatives are based on these conditions.

The plots, showing the relation between the "lowest safety factor" in the inner walls of the existing and alternative culverts and the "height of the overburden material" on the culverts, is illustrated in Figure 6.13.

From Figure 6.13, it is seen that the existing box-shape culvert in Tınaz Mine having positive projecting embankment condition, could be considered as stable up to 30 meters of overburden height, where all other alternative culverts having negative projecting embankment condition indicates better safety factors under same conditions.

Since the purpose of analyzing the alternatives is to investigate the possibility of culvert models that could be stable under 80 or more meters of overburden material, examination should base on this point of view. As can be seen from the Figure 6.13 that all "positive projecting" culvert models whether existing

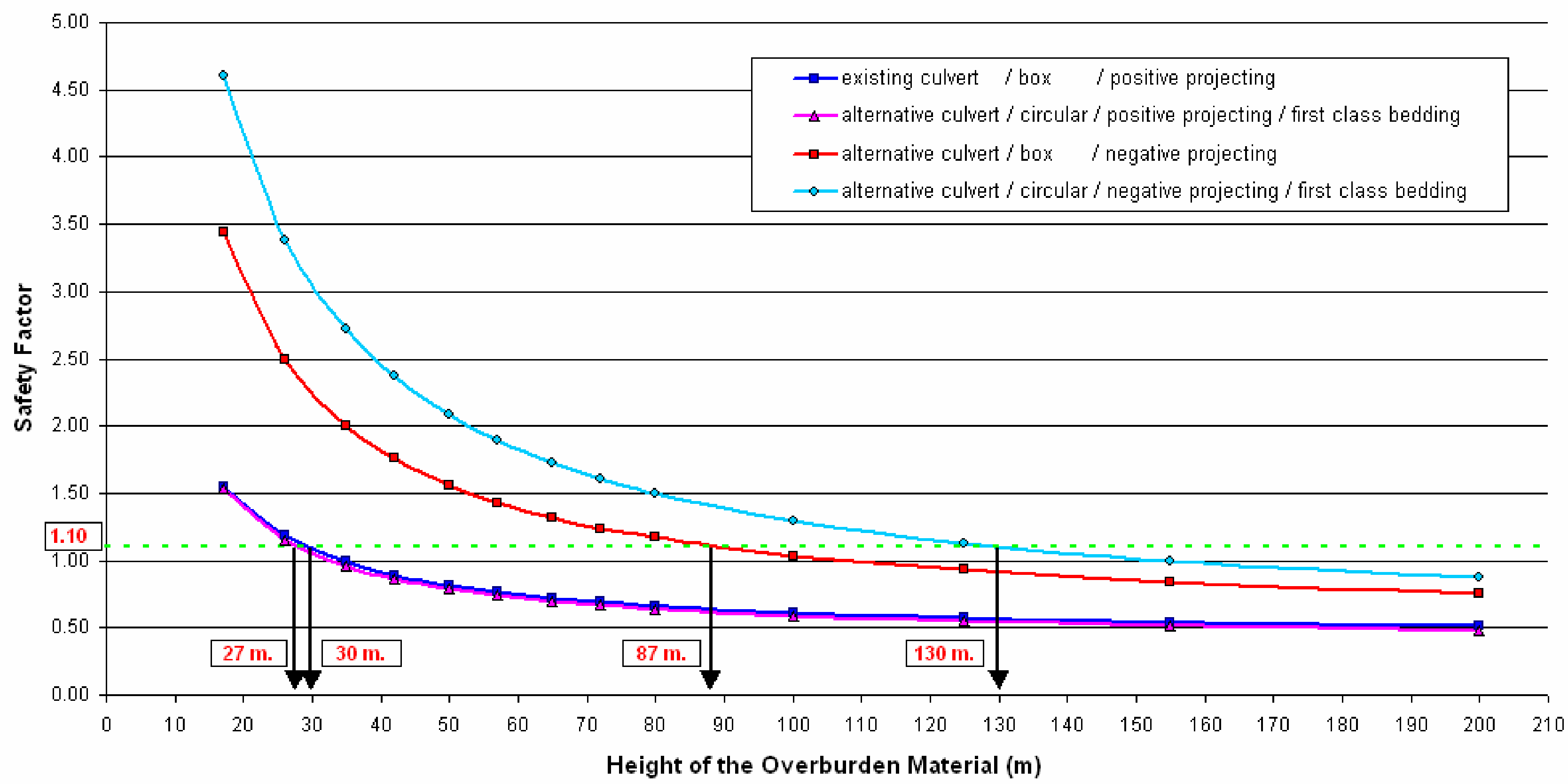


Figure 6.13: Relationship between the lowest safety factor in the inner walls of the culvert and height of the overburden material on the culvert ($\gamma = 25.5$ kN/m^3, considering the effect of groundwater)

box-shape culvert or circular-shape, having first class bedding, should be considered as unstable under 80 meters of overburden material since the safety factors for that overburden height are much less than 1.00. On the other hand, it is clearly seen from the same figure that all “negative projecting” culvert models, whether box-shape or circular-shape having first class bedding, could be considered as stable under 80 meters of overburden material since safety factors are more than 1.00.

6.6 Large Cross-Section (High Capacity) Culverts

During the analyses carried out in this study, it is assumed that the amount of water to be conveyed is constant for the entire-length of culvert. However, as it was mentioned in preliminary field studies and illustrated in Figures 3.2, 3.3 and 3.11 in Chapter 3, a water drainage pipe had been coupled to culvert at it’s 67^{th} meter, in order to convey the water flowing throughout the valley and intersecting the existing culvert. In view of the fact that the increase of water quantity coming through may call culverts having larger cross-section, two different alternatives were taken into consideration. In order to analyze the effect of increasing dimensions to the stability of culvert, two models were created namely high-capacity negative-projecting circular-shape culvert (radius=2.31 m.) having first class bedding and high-capacity negative-projecting box-shape culvert (height=3.75m, width=4.45 m). Cross sectional areas of these culverts were taken as approximately 50% more than the alternative culverts analyzed in Sections 6.3 and 6.4. In these models, the most stable culvert alternative from each culvert shape was selected based on the results of the analyses on alternative culverts, carried out earlier.

Larger size (high-capacity) negative-projecting culvert models having box-shape and circular-shape with first class bedding condition are illustrated in Figure 6.14 and 6.15, respectively. Numerical studies were carried out by using these culvert models and the input parameters presented earlier in Table 4.1. The outputs of the Phase2 program, for 80 meters of overburden height having a unit weight of 25.5 kN/m^3 and considering the effect of groundwater are given for box-shape and circular-shape culverts in Figures 6.16 and 6.17, respectively. In these figures, distribution of safety factors in the walls of the culverts are illustrated.

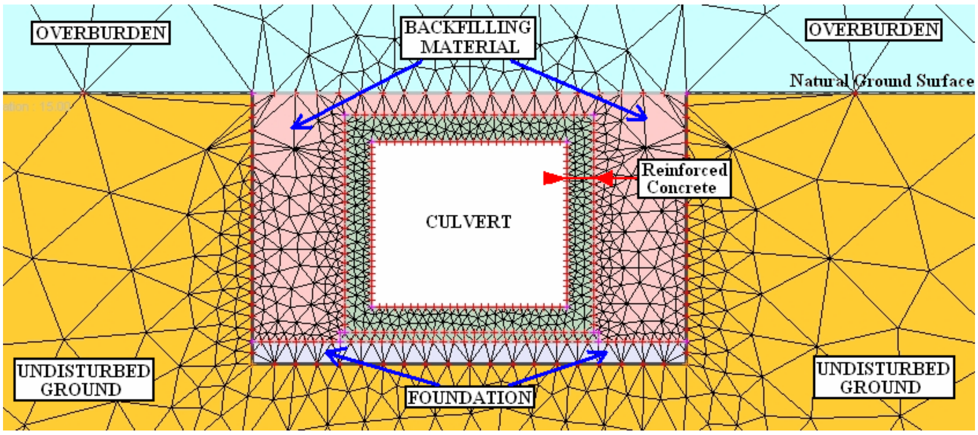


Figure 6.14: Large cross-section box-shape culvert model for negative projecting embankment condition

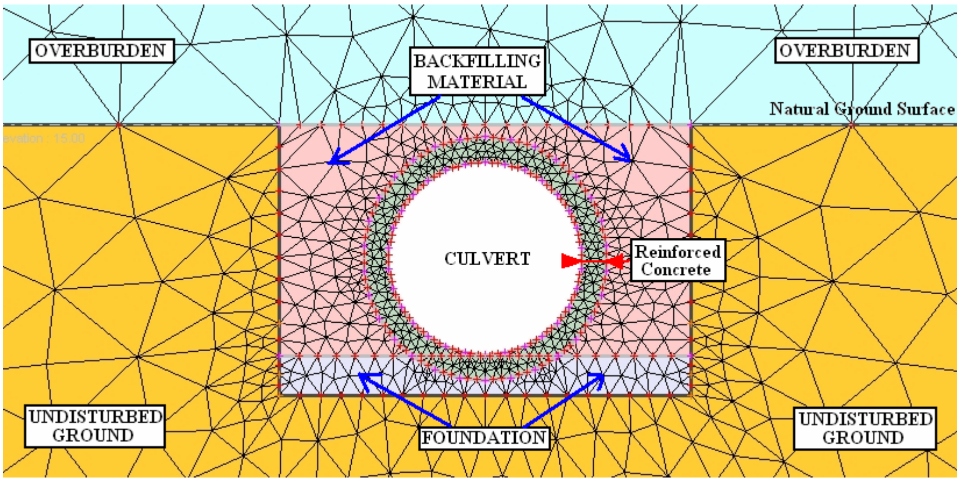


Figure 6.15: Large cross-section circular-shape culvert model having first class bedding for negative projecting embankment condition

During analyses of the model shown in Figure 6.14, the lowest safety factor was found as 1.03 in the inner walls of the culvert. As can be seen from the figure that alternative high capacity box-shape culvert is stable to compressive stresses. However, tensile failures are observed in the roof of the culvert. In view of the fact that the safety factor for culverts are taken as 1.10 during analyses, high-capacity negative-projecting box-shape culvert should be considered as unstable.

During analyses of the model shown in Figure 6.15, the lowest safety factor is found as 1.19 in the inner walls of the culvert. As can be seen from the figure that alternative high-capacity circular-shape culvert having first class bedding is stable to both compressive and tensile stresses.

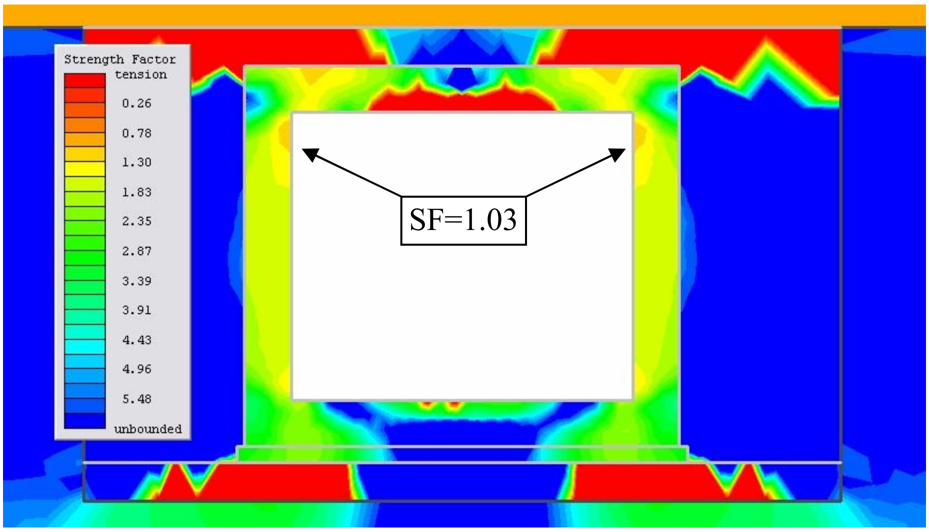


Figure 6.16: Distribution of safety factors in the walls of the large cross-section box-shape culvert (min. safety factor = 1.03)

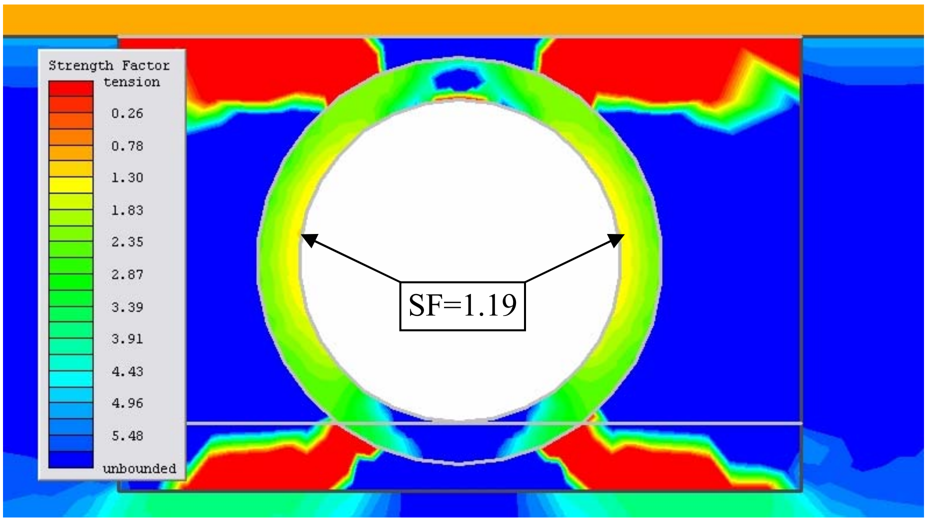


Figure 6.17: Distribution of safety factors in the walls of the large cross-section circular-shape culvert (min. safety factor = 1.19)

A comparison graph showing the relation between "lowest safety factor" in the inner walls of the culvert and "height of the overburden material" on the culvert is given in Figure 6.18. In this figure, these relations are plotted for both normal-capacity culverts and high-capacity culverts. As it can be seen from the figure, both of the circular shape culverts (normal capacity and high capacity) having negative projecting embankment condition could be considered as stable under 80 meters of overburden height with a unit weight of 25.5 kN/m^3, considering the affect of groundwater. On the other hand negative-projecting high-capacity box-shape culvert could not be able to stay stable under same conditions as opposed to negative-projecting normal-capacity box-shape culvert.

6.7 Discussion

Detailed information about the numerical studies on future dump site culverts has been presented in this chapter. However, one part of the numerical analyses requires further discussion.

According to the numerical studies, mentioned in Section 6.3, it is found that the existing box-shape positive projecting culvert of Tınaz Mine is more stable than any of the alternative circular-shape positive-projecting culvert models under same conditions. A comparison graph showing the relation between "lowest safety factor" in the inner walls of the positive projecting culverts and "height of the overburden material" on the culverts is given in Figure 6.19.

In order to investigate the result of these analyses, which is interesting enough since lower safety factors are expected in the box-shape culvert as a result of higher stress concentrations in the edges, distribution of principle stresses were examined in the inner walls and in the basement of the culverts. Examined locations of principle stresses, marked with red lines, are illustrated in Figure 6.20. Results of these examinations are given in Table 6.1 including lowest safety factors in the inner walls of the culverts.

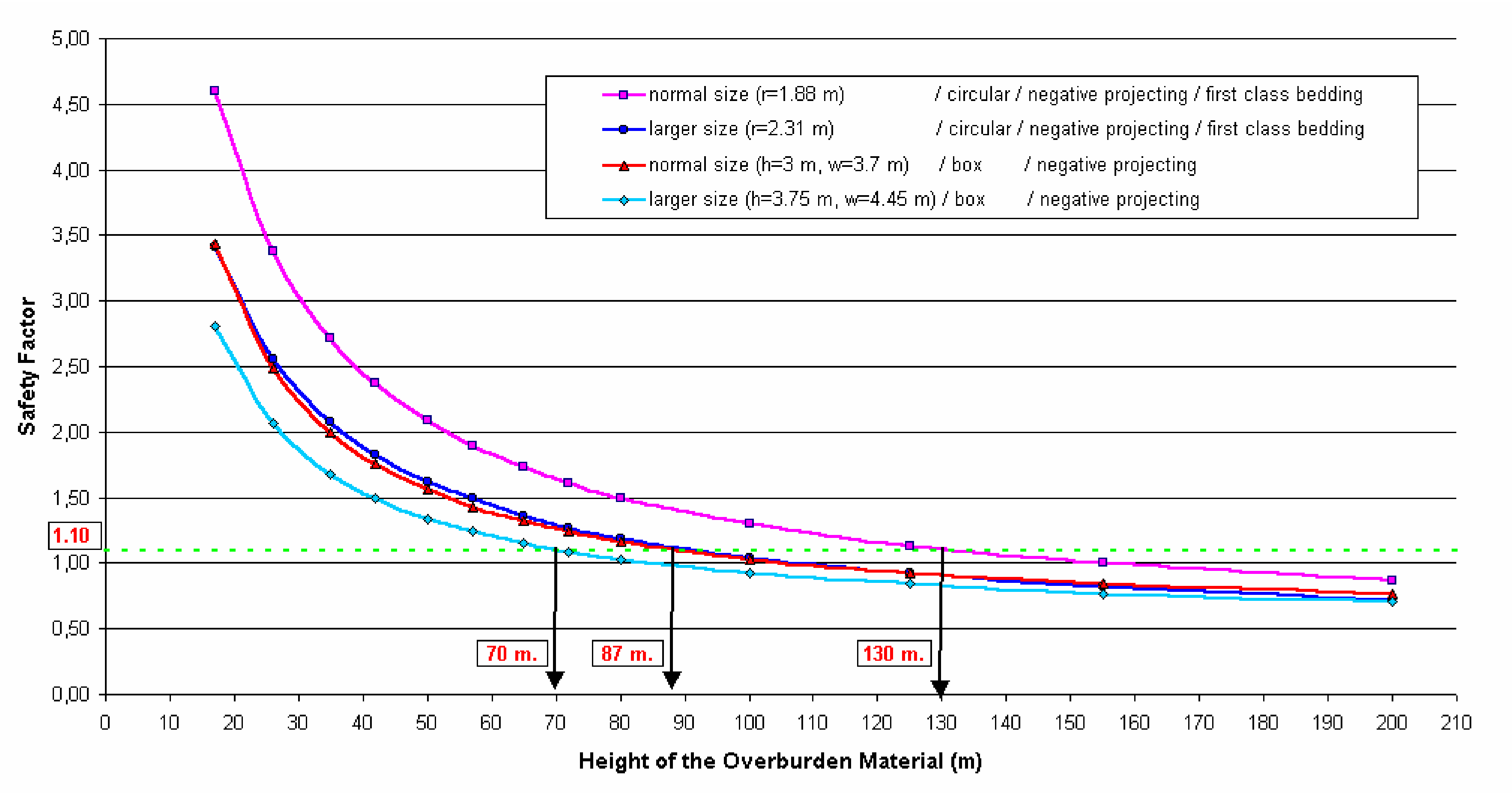


Figure 6.18: Relationship between the lowest safety factor in the inner walls of the culvert and height of the overburden material on the culvert for normal and larger size culverts ($\gamma = 25.5$ kN/m^3, considering the effect of groundwater)

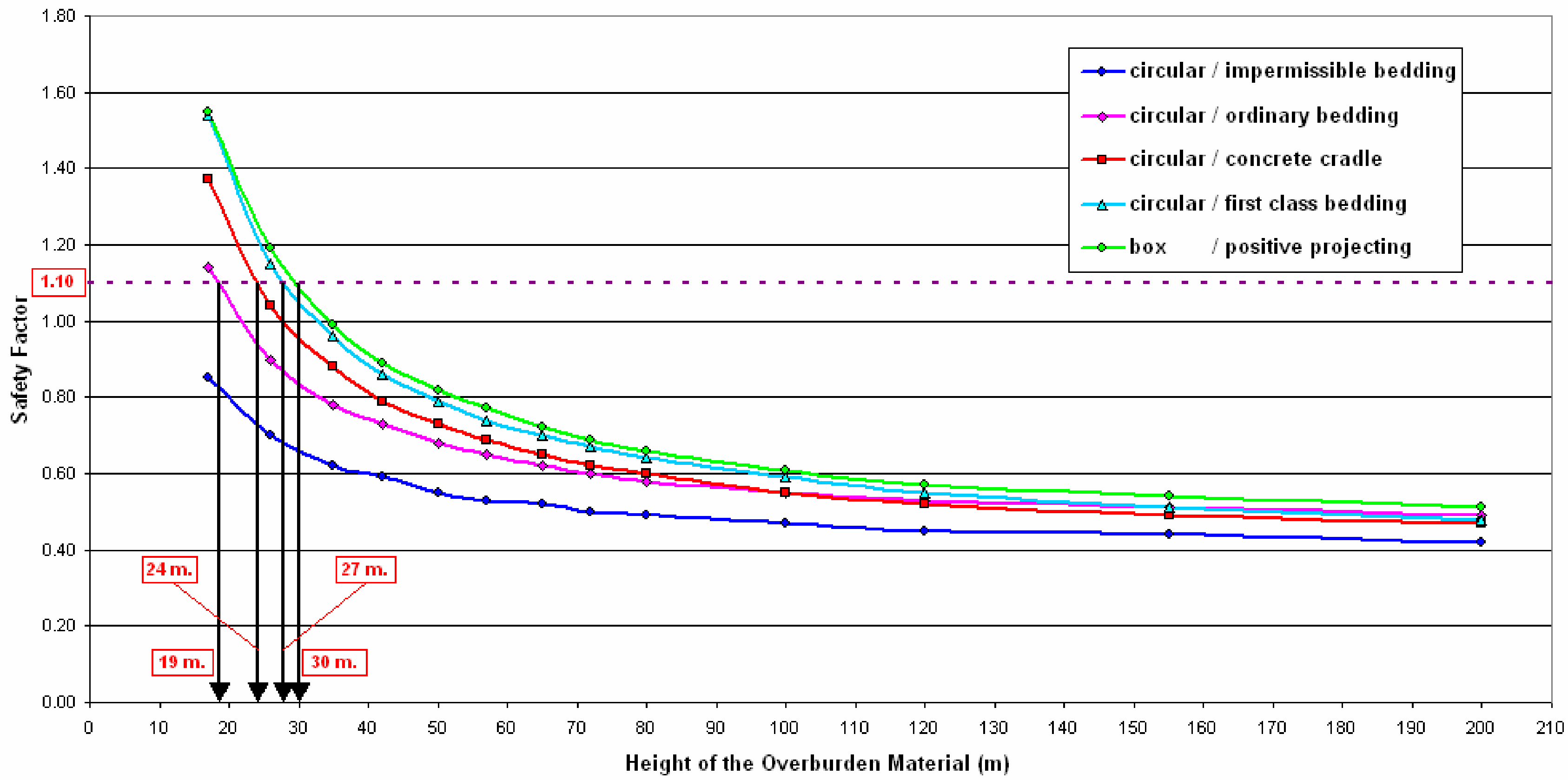


Figure 6.19: Relationship between the lowest safety factor in the inner walls of the culvert and height of the overburden material for positive-projecting culverts ($\gamma = 25.5$ kN/m^3, considering the effect of groundwater)

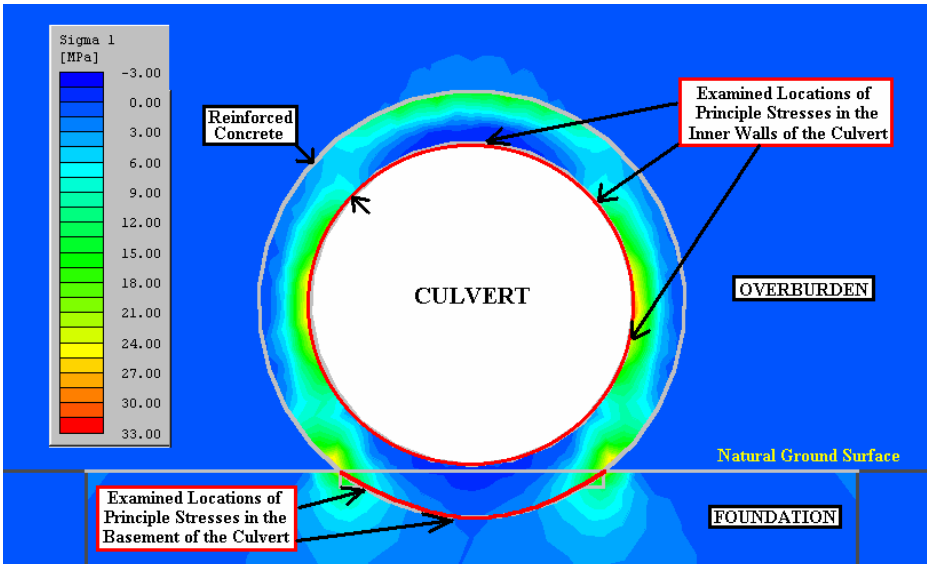


Figure 6.20: Examined locations of principle stresses

Table 6.1: Examination results of principle stresses including lowest safety factors in the inner walls of the culverts

Culvert Shape	**Bedding Condition**	**Max. σ_1 (MPa)**		**Min. σ_3 (MPa)**		**Min. Safety Factor (inner walls)**
		Inner Walls	**Basement**	**Inner Walls**	**Basement**	
Circular	Impermissible	45.70	50.46	-59.12	20.83	0.62
Circular	Ordinary	29.12	22.00	-15.90	-1.34	0.78
Circular	Concrete	19.66	18.34	-8.35	-0.35	0.88
Circular	First-Class	17.18	14.32	-7.87	-0.51	0.96
Box	-	20.48	10.01	-12.68	0.09	0.99

As can be seen from Table 6.1, the highest value of major principle stress occurred in circular-shape culvert having impermissible bedding. As the contact area between the culvert and foundation increases (from circular-shape culvert having impermissible bedding towards box-shape culvert), value of major principle stress decreases on basement, since the load on culvert is better transferred to the ground. Although principle stress in the inner walls of the box-shape culvert is higher than principle stress in the inner walls of the circular-shape culvert having first-class bedding as a result of stress concentration in the edges, box-shape culvert transfers that stress better because of having larger contact surface consequently it has the highest safety factor.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Based on the studies carried out in the M.Sc. Thesis, the following conclusions can be drawn:

1. The behavior of the existing Tınaz Mine culvert namely, the initiation of tension cracks in the roof and floor; and compressive failures occurring on culvert walls have been acceptably modeled by Phase2 software.

2. In all numerical analyses it is assumed that hydrostatic stress conditions are acting on undisturbed ground. However, after analyses of the result of non-hydrostatic cases (different horizontal to vertical stress ratios), as a result of applied construction stages, similar results were obtained, in other words the lowest safety factors in the inner walls of the culverts were more or less the same.

3. Groundwater option of Phase2 (V5.0) software was utilized in order to consider the effect of groundwater on behavior of the existing culvert model. However, after a series of analyses, and by comparing the results (safety factors) obtained from the two cases, namely groundwater "exists" and "does not exist" it was realized that the difference in results

were negligible. In addition, comparing the results obtained from the numerical analyses and the actual deformations observed inside the culvert, it was concluded that groundwater option of Phase2 (V5.0) couldn't adequately model the effect of groundwater when the piezometric lines was used.

4. To include the effect of groundwater and some other uncontrolled parameters on the stability of the existing culvert, tensile strength and cohesion of the reinforced concrete was reduced by 35%. As a result, safety factors became less than one, at the locations where excessive deformations in the culvert were observed. In other words "back analyses" technique was utilized by modifying the two input parameters. Consequently a numerical model representing the Tınaz Mine culvert was developed.

5. Based on the results obtained from the numerical modeling studies carried out on deformed part of the culvert, the maximum height of the overburden material that could be replaced on the culvert was determined as 30 meters, as opposed to the results obtained by TKİ engineers based on Terzaghi's equations calculating 80 meters, considering an overburden unit-weight of 25.5 kN/m^3, a safety factor of 1.10 and assuming the existence of groundwater effect.

6. Considering the results of convergence measurements, evaluating the plots of "Convergence vs. Time" and "Convergence vs. Height of the Overburden Material", and observing the deformations inside the culvert, the maximum height of the overburden material attained in the field, was about 31 meters justifying the validity of numerical modeling, computing 30 meters.

7. The maximum total convergence measured in the culvert was -55.78 mm in Station Y6 when the overburden replaced on the non-deformed part of the culvert reached to a height of 31.08 meters.

8. The maximum convergence-rate was found as 6.15 mm/day in Station Y6, while the maximum convergence occurring as a result of unit dumping-height was found as 6.18 mm/m in Station Y4. These were developed due to controlled and homogeneous replacement of the overburden material on non-deformed part of the culvert. These are quite high and significant values possibly indicating an initiation of instability.

9. After the completion of the dumping process it has been justified that the methods of dumping possess significant effect on the stability of a culvert. In that, when the overburden reaches to a height of 31.08 meters as a result of controlled and homogeneous replacement along the culvert axis, the maximum total convergence occurring inside the culvert reaches to a value of –55.78 mm. This value is considerably small when compared to the deformations occurred (about 30 cm) in failed part of the culvert as a result of non-homogeneous and uncontrolled replacement (about 33-meters in height), carried out perpendicular to the culvert axis, for approximately the same overburden heights.

10. Based on the results of numerical analyses carried out on the alternative culvert-models it was found out that:

    i. Although positive projecting circular-shape culvert model having first class bedding condition is more stable than positive projecting circular-shape culvert models having impermissible, ordinary and concrete cradle beddings, none of the these alternative culvert models stay stable under an overburden height of 80 meters. This is true for any of the considered overburden unit-weight (18.8 kN/m^3 or 25.5 kN/m^3) and groundwater condition (dry or wet).

ii. Interestingly enough, the existing box-shape positive projecting culvert of Tınaz Mine is more stable than any of the alternative circular-shape positive-projecting culvert models for any of the considered overburden unit-weight (18.8 kN/m^3 or 25.5 kN/m^3) and groundwater condition (dry or wet).

iii. For the considered overburden unit weights and groundwater conditions all of the negative-projecting culvert models, stay stable under an overburden height of 80 meters. In addition, the circular-shape culvert model with first class bedding condition is more stable than the box-shape culvert and the circular-shape culverts having impermissible and ordinary bedding conditions.

iv. All of the negative-projecting circular-shape culvert models provide better safety factors than the negative-projecting box-shape culvert model under the same overburden height.

v. A negative projecting box-shape culvert model having larger dimension such as a span of 4.45 meters and a height of 3.75 meters stay unstable under an overburden height of 80 meters, considering an overburden unit-weight of 25.5 kN/m^3, a safety factor of 1.10 and the existence of groundwater effect. On the other hand, a negative projecting circular-shape culvert model with first class bedding condition having a larger radius such as 2.31 meters, could be able to stay stable under the same conditions.

vi. Bedding conditions of circular-shape culvert models, having positive or negative projecting embankment conditions, have significant affect on the stability of culvert. In the developed models first-class bedding condition provides better safety factors than concrete cradle, ordinary and impermissible beddings, under the same loading conditions.

vii. From stability point of view, any culvert in negative projecting embankment condition is significantly better than any culvert in positive projecting embankment condition, since the stresses developing around the culvert for a given height of fill are significantly less in case of negative projecting condition than in the case of positive projecting culvert.

viii. For the existing conditions and culvert dimensions in Tınaz Mine the maximum height of the overburden that can be replaced on the negative projecting circular-shape culvert having first-class bedding is 130 meters, under worst conditions (unit weight of the overburden material is 25.5 kN/m^3 and under the effect of groundwater).

11. For optimum design, the ease of construction of the culvert should also be considered. Although the most stable alternative culvert is determined as circular-shape culvert with first-class bedding in negative-projecting embankment condition, the box-shape culvert in negative projecting embankment condition could also be chosen for ease of construction in practice. Construction of circular-shape culvert may not only be time consuming, because of its frame structure, but also difficult to cast the concrete and install the reinforcement, as opposed to construction of box-shape culvert is much more easier.

12. In order to derive more alternatives, a preliminary study was carried out on plastic culverts of Fırat-Krah Sanitary Sewer Systems (FKS) with Dr. Fathalla Qasem, technical coordinator of FKS. Unfortunately, as a result of this study it was concluded that plastic pipes having 3.6 meters diameter could stay stable only under an overburden height of 5-6 meters.

7.2 Recommendations for Future Studies

1. During numerical modeling studies carried out on the deformed part of the culvert, it was assumed that the asymmetrical overburden material was replaced on the culvert in a single stage. However, different stages of asymmetrical loading should also be investigated and be modeled in future studies.

2. It is believed that the reduction of 35% in strength parameters of the reinforced concrete reflects not only the effect of groundwater but also other effects such as characteristics of reinforced concrete-structure and material properties of the rock mass around the culvert consisting of the undisturbed ground, foundation, and overburden material. Consequently, the reduction of 35% in cohesion and tensile strength values of reinforced concrete may reflect a combined effect. As emphasized earlier, this percentage value was determined from back analyses in order to fit the results of numerical analyses to the actual field observations.

   In order to determine the actual effect of water, on the other hand, it is strongly suggested that the groundwater option of the Phase2 V5.0 should be re-evaluated significantly and be modified adequately. Moreover groundwater monitoring and percolation assessments should be carried out in the field.

3. In numerical modeling analyses, it was assumed that the failure of the reinforced concrete was significant compared to the surrounding materials namely, undisturbed ground, foundation and overburden material. Therefore, linear mohr-coulomb failure criterion was used for the surrounding material as well as for the reinforced concrete. However, non-linear mohr-coulomb failure criterion, which is more suitable for weak materials, should be used in order to model and analyze the actual behavior of the surrounding material.

4. During numerical analyses carried out on the existing culvert in Tınaz Mine, input parameters of the foundation material were estimated based on the suggestions given by Bell (1983) and Farmer (1983). However, for the future studies, properties of the boulder size limestone at Yatağan strip coal mine, suggested by Yoleri et. al. (1994), should be taken into consideration.

5. Phase2 software, used in numerical modeling studies, calculates proper values of safety factors only for compressive zones, but takes "-1" for tensile zones. In order to determine the actual values of negative safety factors, tensile strength of the material should be divided to the tensile stresses acting on it.

6. During analyses carried out on alternative circular-shape culvert models, properties of filling material for positive projecting embankment and backfill material for negative projecting embankment conditions were taken as the same with the foundation material. However, for the future studies their own material properties should be taken into consideration for more precise results.

7. During derivation of alternatives for future culvert projects, only box-shape and circular-shape culvert models with different embankment and bedding conditions were taken into consideration. In order to derive more alternatives, other possible culvert shapes, including horseshoe and trapezoidal shapes, should be taken into consideration.

8. In order to increase the confining stress around the culvert and to reduce the pore pressure of the surrounding material, and thus to get better safety factors in the inner walls of the culvert, first few layers of the replaced overburden material should be compacted.

9. A mining tunnel should be compared with a culvert both on economical and technical bases.

REFERENCES

Asset International, 2003. "Multiplate, Corrugated Steel Structures Design Manual", Asset International, http://www.multiplate.co.uk/mpdesignman/section/m200/index.htm.

Bell, F. G., 1983. "Engineering Properties of Soils and Rocks", Butterworths, 149 pages.

Brady B.H.G. and Brown, E.T., 1985. "Rock Mechanics for Underground Mining", George Allen & Unwin, 527 pages.

Bilgin İnşaat, 2001. "Internal Report" submitted to Özdoğu İnşaat.

Çatal, H. H., Koca, Y., Onargan, T., Özden, G., Türkel, S., Köse, H. and Alku, Ö. Z., 2001. "Ege Linyit İşletmeleri Eynez-Karanlıkdere Vadisi Menfez Projesi İçin Teknik Rapor", Mühendislik Fakültesi, Dokuz Eylül Üniversitesi, 117 pages.

Contech, 2003. "Aluminum Box Culvert", Contech Construction Products Inc., 16 pages.

Dalgıç, S., 2002. "A Comparison of Predicted and Actual Tunnel Behaviour in the İstanbul Metro, Turkey", Engineering Geology, Vol. 63, Issue 1-2, pp. 69-82.

Dunncliff, J., 1993. “Geotechnical Instrumentation for Monitoring Field Performance”, John Wiley and Sons. Inc., 577 pages.

Farmer, I., 1983. “Engineering Behaviour of Rocks”, Chapman and Hall, 208 pages.

FKS, 2002. “Fırat Sanitary Sewer System User Manual”, Fırat-Krah Sewer Systems, 72 pages.

Jing, L., 2003. “A Review of Techniques, Advances and Outstanding Issues in Numerical Modeling for Rock Mechanics and Rock Engineering”, International Journal of Rock Mechanics & Mining Sciences, Vol. 40, Issue 3, pp. 283-353.

Jing, L. and Hudson, J. A., 2002.”Numerical Methods in Rock Mechanics”, International Journal of Rock Mechanics & Mining Sciences, Vol. 39, Issue 4, pp. 409-427.

Mathab, M. A. and Grasso, P., 1992. “Geomechanics Principles in the Design of Tunnels and Caverns in Rock”, Elsevier Science Publishers B. V., 250 pages.

Mapquest, 2003. “Maps: map”, http://www.mapquest.com/maps/map.adp?add to history=&country=TR&city=&historyid=&submit.x=41&submit.y=6

O’Flaherty, C. A., 2002. “Highways”, Butterworth-Heinemann, 553 pages.

Özcan, Ö. C. and Ünal, E., 2002. “Tınaz Ocağı’nda İnşa Edilen Kutu Menfezin Duraylılık Koşullarının Belirlenmesi”, 6. Bölgesel Kaya Mekaniği Sempozyumu, Konya, Turkey, pp. 317-324

Mapquest, 2003. " Maps: map", http://www.mapquest.com/maps/map.adp? add to history =&country =TR&city=&historyid=&submit.x=41&submit.y=6

Sağlamer, A., Ergüven, M. E., Gedikli, A. and Hatipoğlu, B., 2001. "Ege Linyitleri İşletmesi Eynez-8 Panosu Karanlıkdere Menfezinde Meydana Gelen Hasarlar Hakkında Teknik Rapor", Yapı ve Deprem Uygulama Araştırma Merkezi, İTU, 67 pages.

Sakurai, S., 1997. "Lessons Learned From Field Measurements in Tunneling", Tunneling and Underground Space Technology, Vol. 12, No. 4, pp. 453-460.

Spangler, M. G. and Handy, R. L., 1973. "Soil Engineering", Intext Educational Publishers, 748 pages.

Smith, E. S. and Connell, D. H., 1979. "The Role of Water in the Failure of Tailings Dams", Proceeding of the First International Mine Drainage Symposium, Denver, Colorado, USA, pp. 627-650.

Spindler, W. H., 1958. "Handbook of Drainage and Construction Products", The Armco International Corporation, 529 pages.

Tarmac, 2003. "Box Culverts", Tarmac Precast Concrete Limited, Lincolnshire, England, http://www.tarmacprecastconcrete.co.uk/home.htm

Tosun, E., 2002. "Numerical Implementation of Culvert Design Methods", M.Sc. Thesis, Department of Civil Engineering, METU, 94 pages.

U.S. Army Corps of Engineers, 1997. "Engineering and Design: Conduits, Culverts and Pipes", US. Army Corps of Engineers, Department of the Army, Washington DC., USA, 87 pages.

Ünal, E., Öztürk, H. and Özcan Ö. C., 2002. "GELİ Tınaz Açıkocağında İnşa Edilen Kutu Menfezin Duraylılık Koşullarının İncelenmesi", Project No: 01-03-05-01-2-00-05, METU, 117 pages.

Wright, P. H., Lai, J. S., Parsonson, P. S. and Meyer, M., 1996. "Highway Engineering", John Wiley and Sons, Inc., 680 pages.

Yang, M. Z., 2000. "Evaluation of Factors Affecting Earth Pressures on Buried Box Culverts", PhD Thesis, The University of Tennessee, Knoxville, USA, 565 pages.

Yoleri, M. F., Çağlan, D., Arıkan, F. and Ulusay, R., 1994. "TKİ-GELİ Eskihisar (Yatağan-Muğla) Linyit Açık İşletmesi Pasa Yığınlarının Şev Stabilitesi ve Tasarımı", Kaya ve Zemin Etüdleri Birimi, Fizibilite Etüdleri Dairesi, Maden Tetkik ve Arama Genel Müdürlüğü, Ankara, 194 pages.

APPENDIX A

In this appendix, the relation between "Convergence" and "Height of the Overburden" is evaluated for Regions 1, 2 and 3 in detail.

The "Convergence" vs. "Height of the Overburden" plots representing Region-1 and including the stations Y1-Y5, are given in Figure A.1. As can be seen from this figure, height of the overburden material on Region 1 Stations were similar to each other before the controlled and homogeneous dumping has started. For an overburden height of 13 meters, convergence as a result of unit dumping height, in other words slope of the graphs, are similar to each other for all Region 1 Stations except Station Y1 kept as a bench to maintain low slope angle. In view of the fact that regions on stations were kept as a bench in each subsequent stage of dumping, heights of the overburden material on stations are increasing towards Station Y5. As it is seen from Figure A.1 that measured convergence values are increasing as the height of the overburden material on the stations increases. In other words, arching effect is not observed. In the last stage of dumping, failure behaviors were seen in Stations Y4 and Y5 however, since these stations were kept as a bench, continuation of behavior cannot be seen.

The "Convergence" vs. "Height of the Overburden" plots representing Region-2 and including the stations Y6-Y10, are given in Figure A.2. As it can be seen from this figure, height of the overburden material on Region 2 Stations were changing between 12-14 meters before the initiation of controlled and homogeneous dumping. In general, measured convergences in stations increases with the height of the overburden material dumped on them consequently, arching effect is not seen. Dumping of overburden material on Stations Y9 and Y10 were terminated after reaching 25 meters of overburden height. Moreover, some amount of dumped overburden material on Station Y10 was hauled to other regions, causing decrease in overburden height on this station, as seen in Figure A.2. Convergence as a result of unit dumping height in Station Y6 is significantly high (5.4 mm./m.) with respect to other stations. As a result of this instability signal, dumping of overburden on Station Y6 was terminated in this height (31.08 m.) so instability behavior was controlled. In the same way, Stations Y7 and Y9 were kept out of the last dumping stage to prevent the continuation of instability behaviors seen in Figure A.2. In the last stage, overburden was dumped on only Station Y8, seemed stable up to this stage. After the completion of last stage convergence as a result of unit dumping height was measured as 2.73 mm./m. As mentioned before, dumping of additional overburden material on Station Y8 was terminated due to the heavy rains in Tınaz Region.

The “Convergence” vs. “Height of the Overburden” plots representing Region-3 and including the stations E1-E5, are given in Figure A.3. As can be seen from the figure height of the overburden materials on the stations show great variety prior to M.Sc. Thesis studies. Affect of controlled and homogenous dumping on Stations E1 and E2 are seen from this figure. In view of the fact that overburden material was not dumped on the region above Station E4 and E5, any significant convergence values cannot be observed in these stations. Although more or less same amount of overburden material was dumped on Stations E1 and E2, convergence as a result of unit dumping height (slope of the lines) of Station E1 is lower than Station E2. This is why the applied steel supports between the 0^{th} and 100^{th} meter of the culvert.

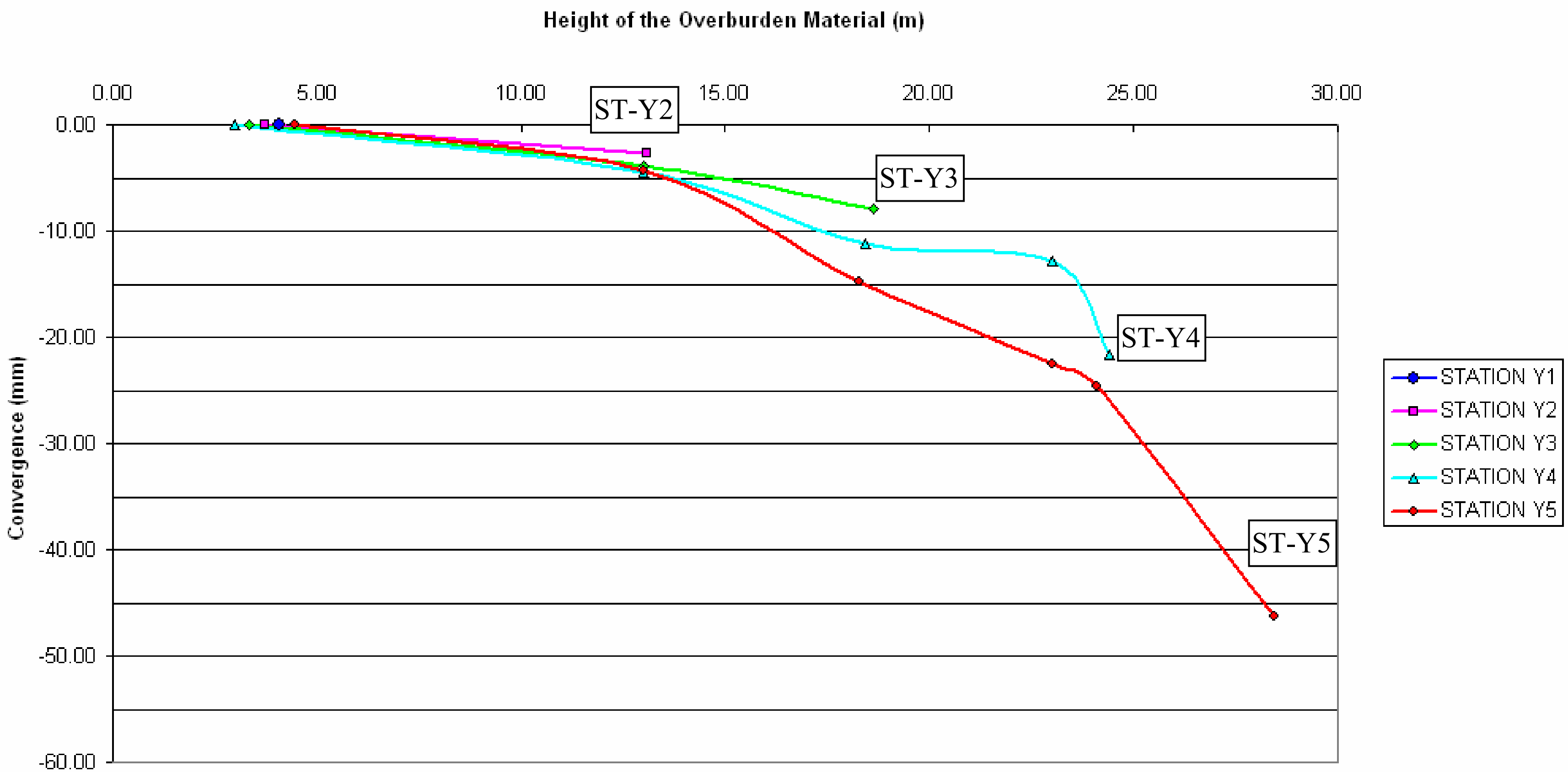


Figure A.1: Relationship between convergence and height of the overburden material for Region 1 Stations

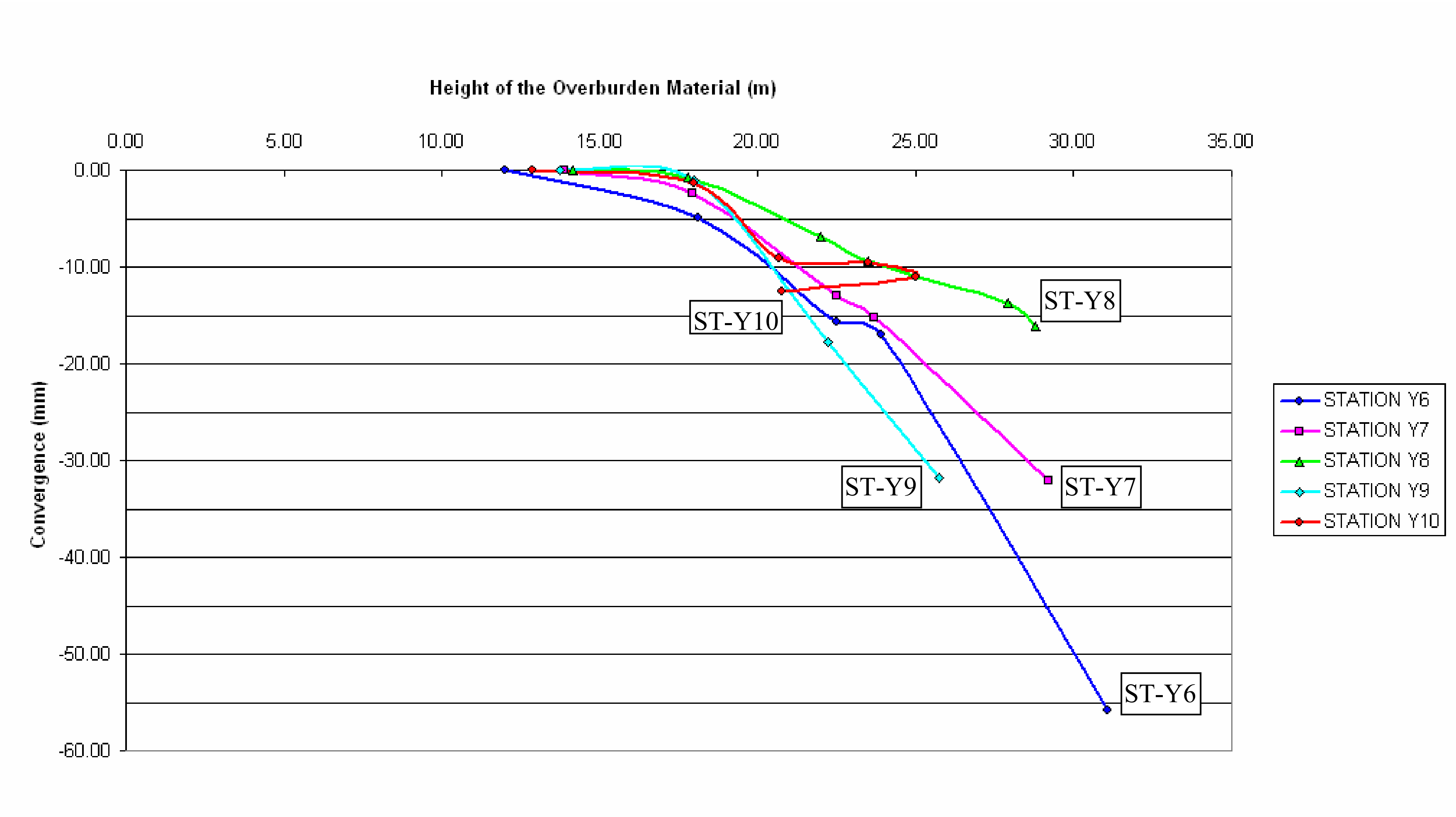


Figure A.2: Relationship between convergence and height of the overburden material for Region 2 Stations

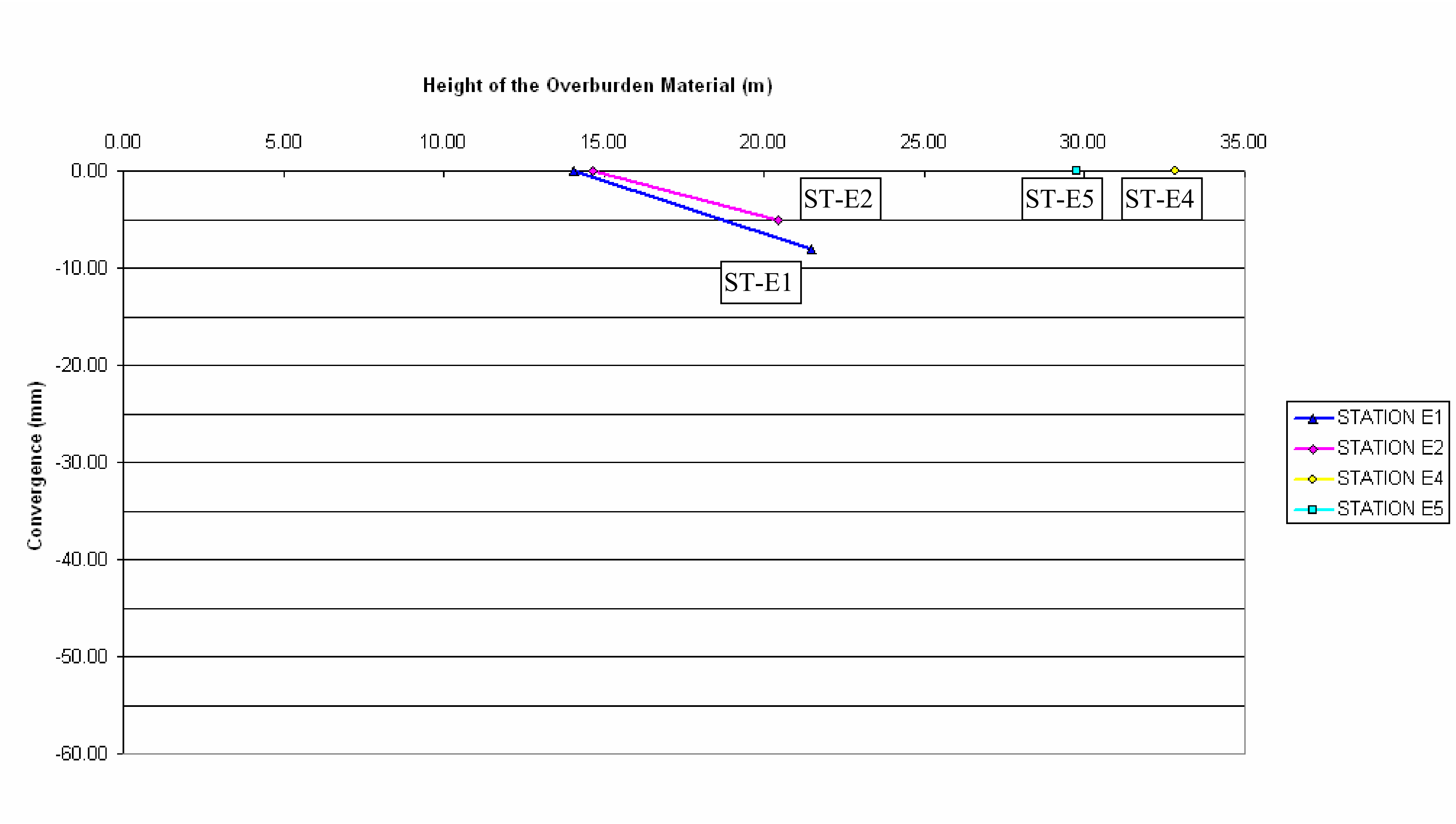


Figure A.3: Relationship between convergence and height of the overburden material for Region 3 Stations

APPENDIX B

In this appendix distribution of safety factors in the walls of the alternative positive projecting culverts are presented for an overburden height of 80 meters. In addition, relationships between “Safety Factor” and “Height of the Overburden Material” for alternative positive projecting culverts are given for different overburden unit weights and groundwater conditions.

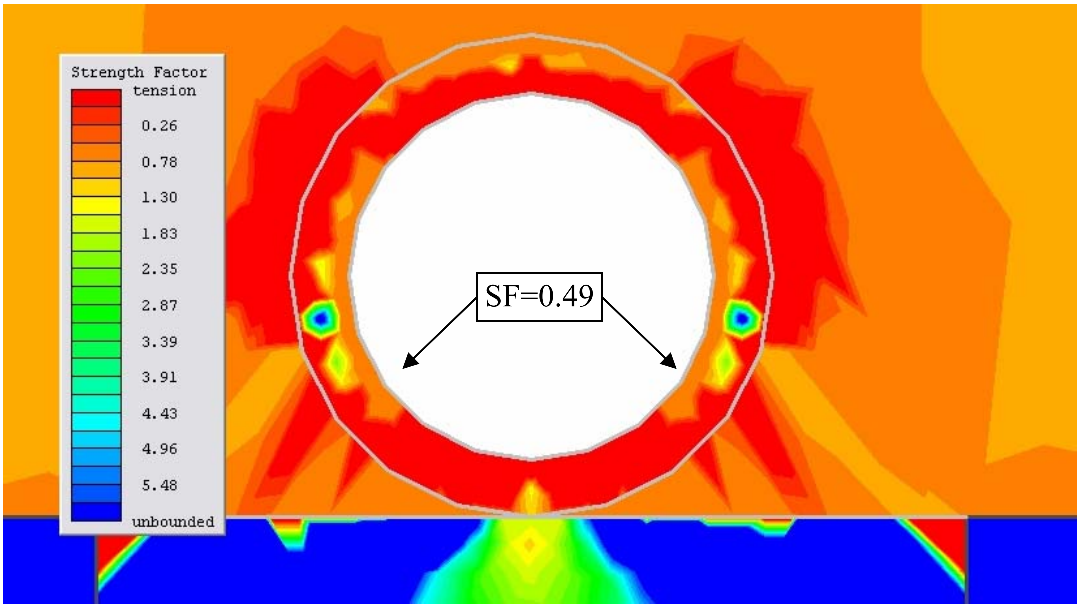


Figure B1: Distribution of safety factors in the walls of the culvert having impermissible bedding condition (min. safety factor =0.49)

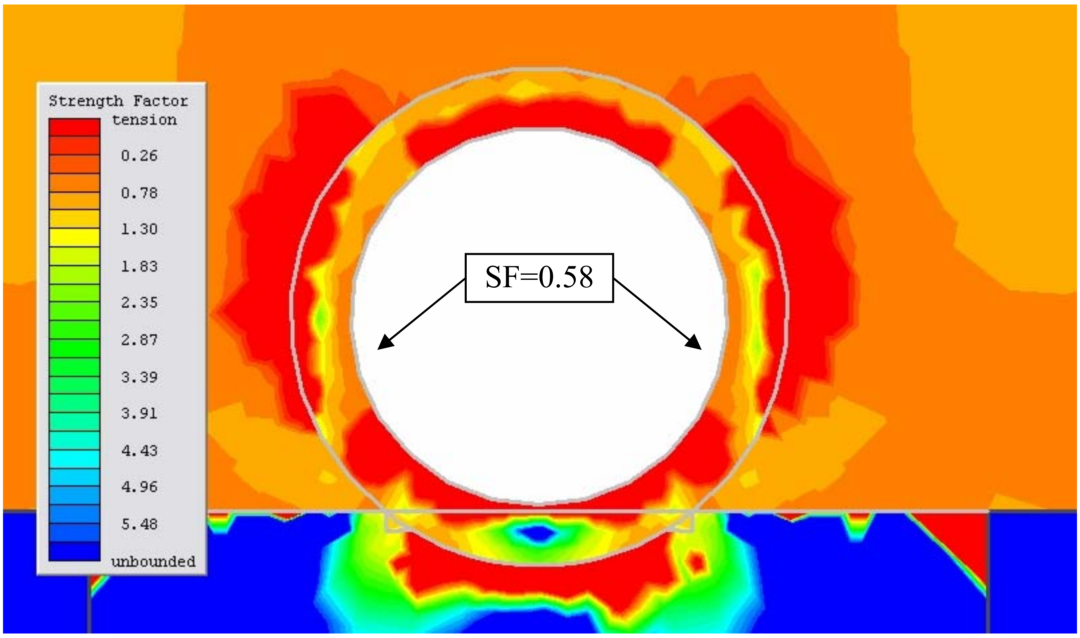


Figure B2: Distribution of safety factors in the walls of the culvert having ordinary bedding condition (min. safety factor =0.58)

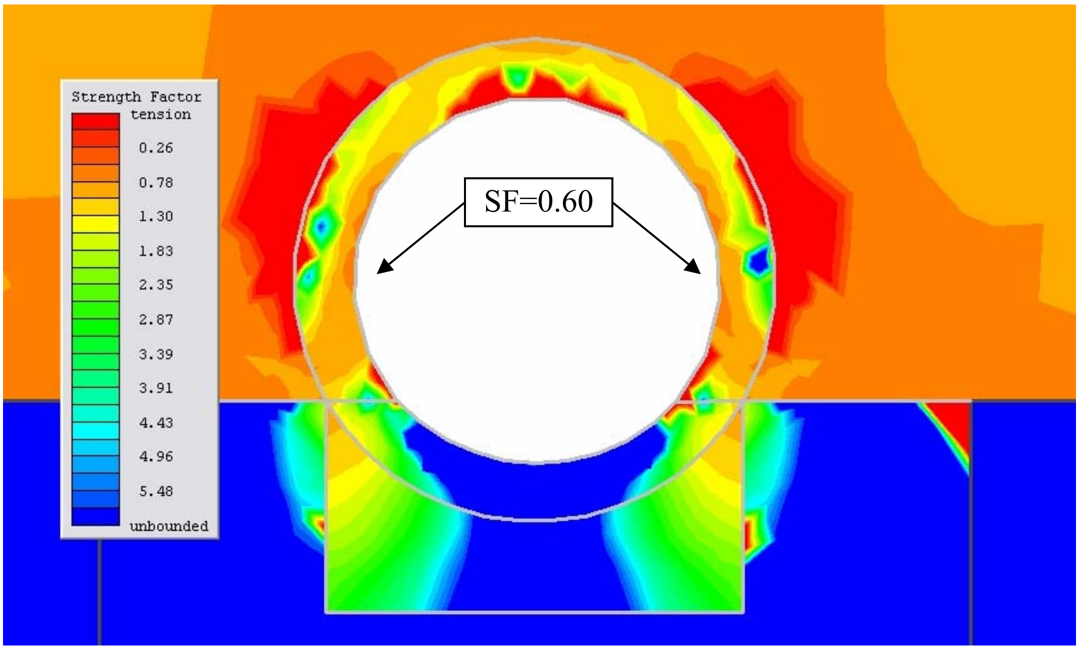


Figure B3: Distribution of safety factors in the walls of the culvert having concrete cradle bedding condition (min. safety factor =0.60)

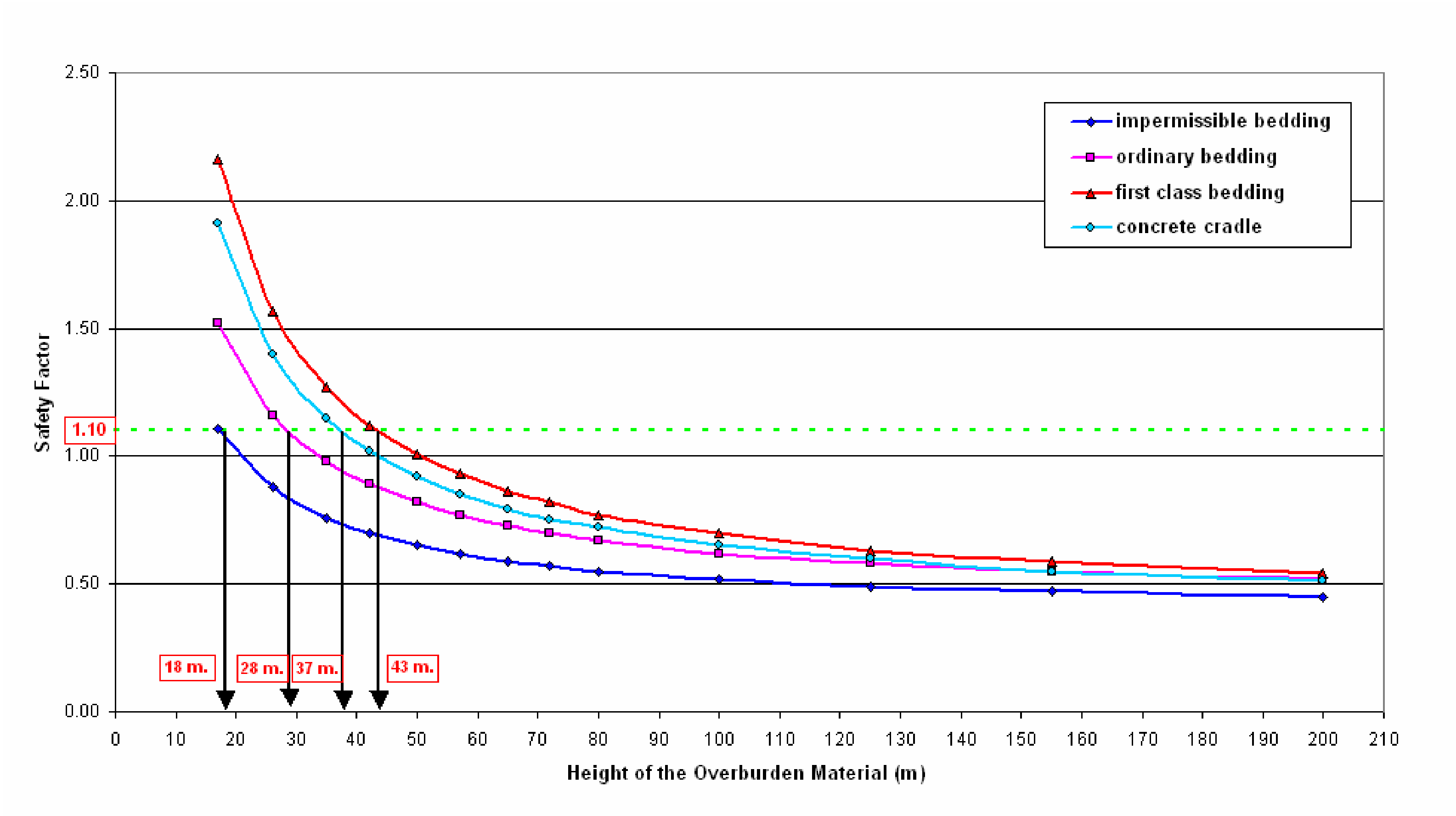


Figure B4: Relationship between the lowest safety factor in the inner walls of the culvert and height of the overburden material ($\gamma = 25.5$ kN/m^3, disregarding the effect of groundwater) for positive projecting embankment condition

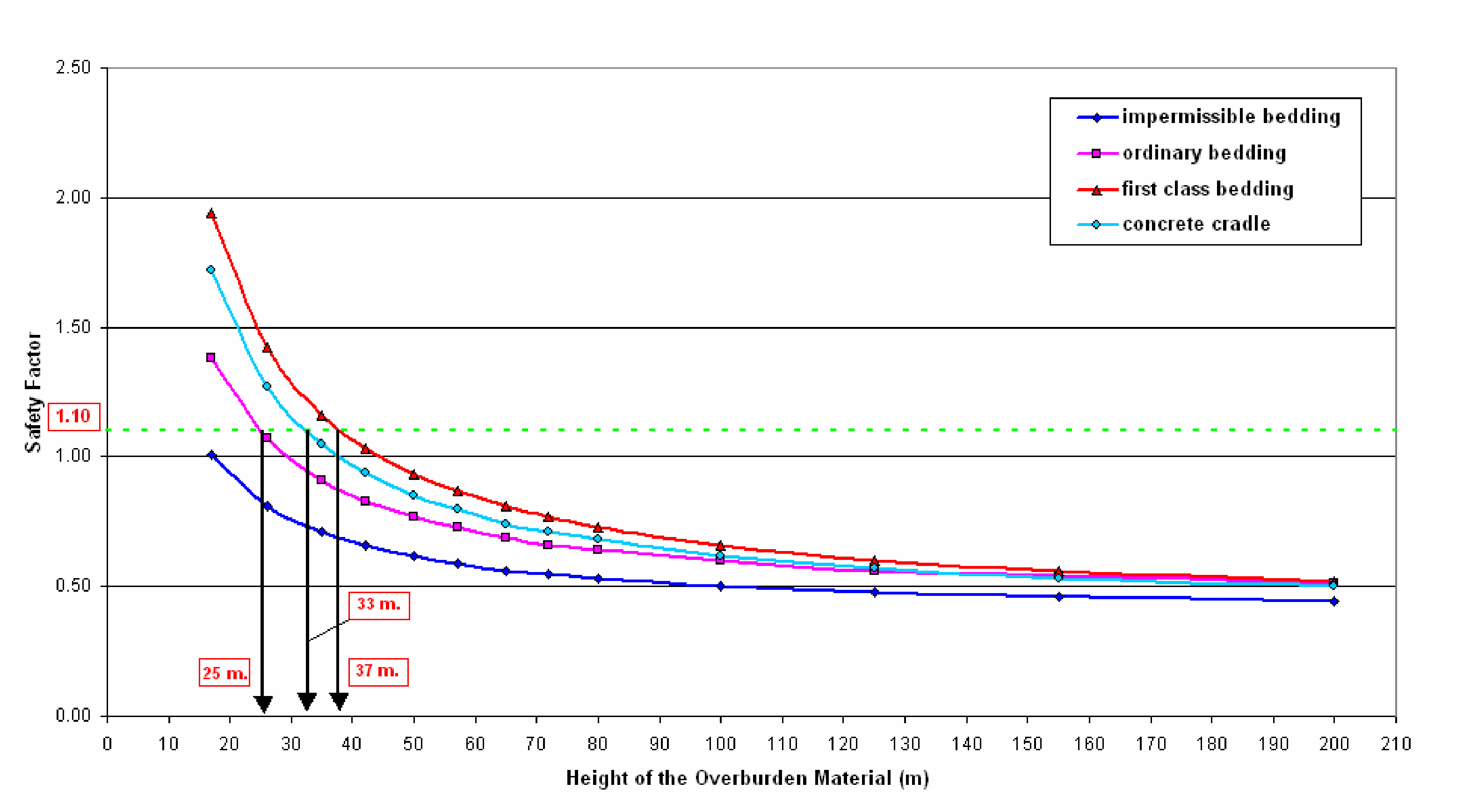


Figure B5: Relationship between the lowest safety factor in the inner walls of the culvert and height of the overburden material ($\gamma = 18.8\ kN/m^3$, considering the effect of groundwater) for positive projecting embankment condition

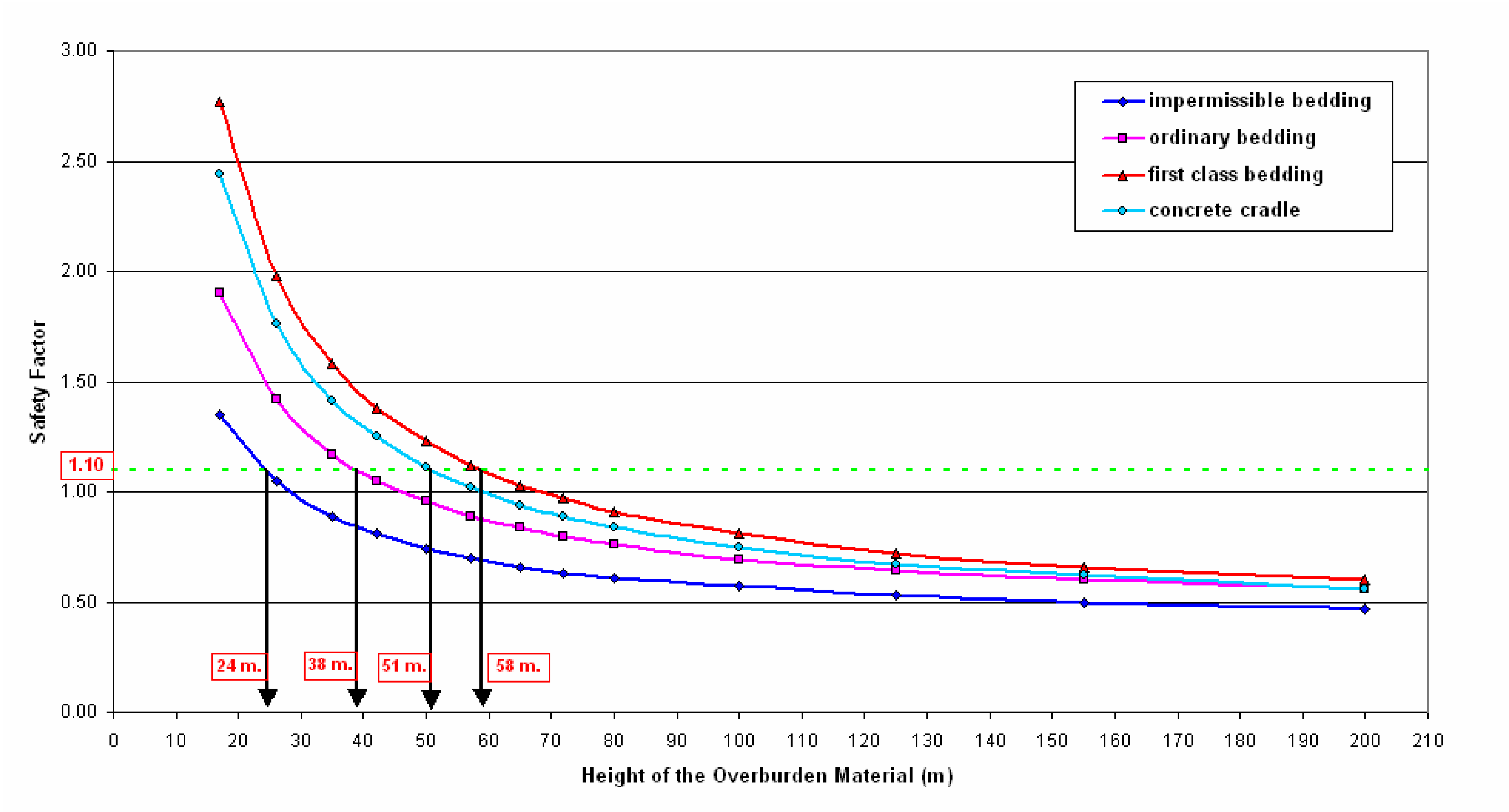


Figure B6: Relationship between the lowest safety factor in the inner walls of the culvert and height of the overburden material (γ = 18.8 kN/m^3, disregarding the effect of groundwater) for positive projecting embankment condition

APPENDIX C

In this appendix distribution of safety factors in the walls of the alternative negative projecting culverts are presented for an overburden height of 80 meters. In addition, relationships between “Safety Factor” and “Height of the Overburden Material” for alternative negative projecting culverts are given for different overburden unit weights and groundwater conditions.

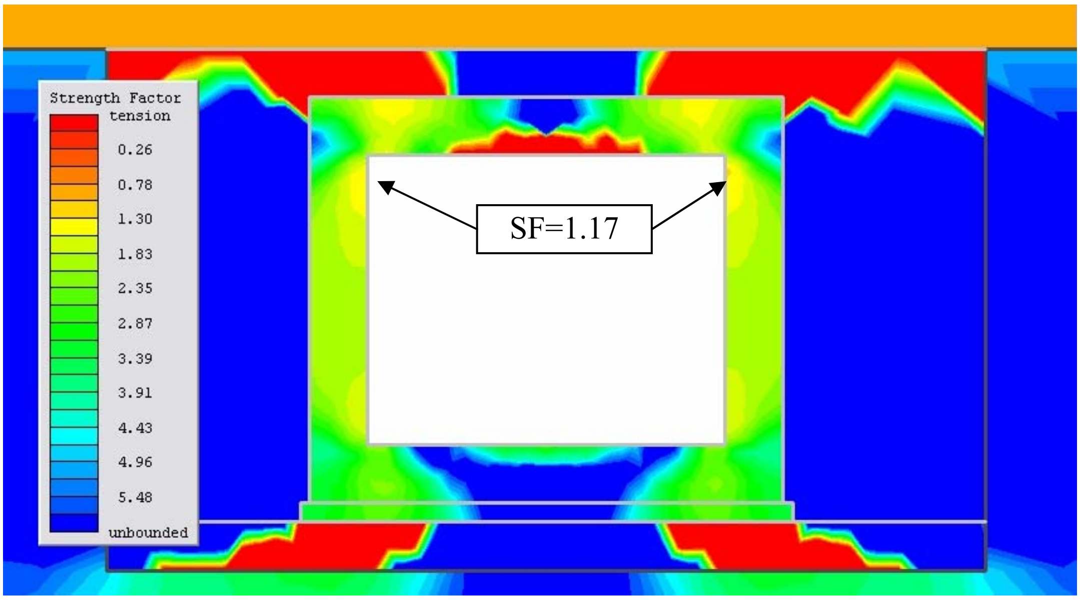


Figure C1: Distribution of safety factors in the walls of the box-shape culvert (min. safety factor =1.17)

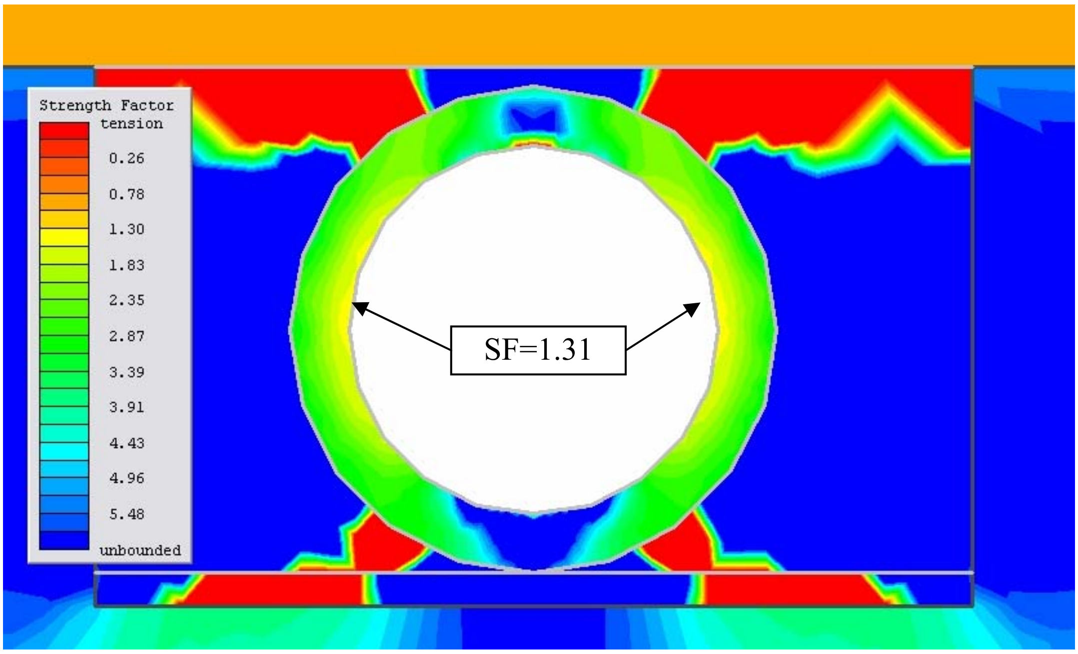


Figure C2: Distribution of safety factors in the walls of the culvert having impermissible bedding condition (min. safety factor =1.31)

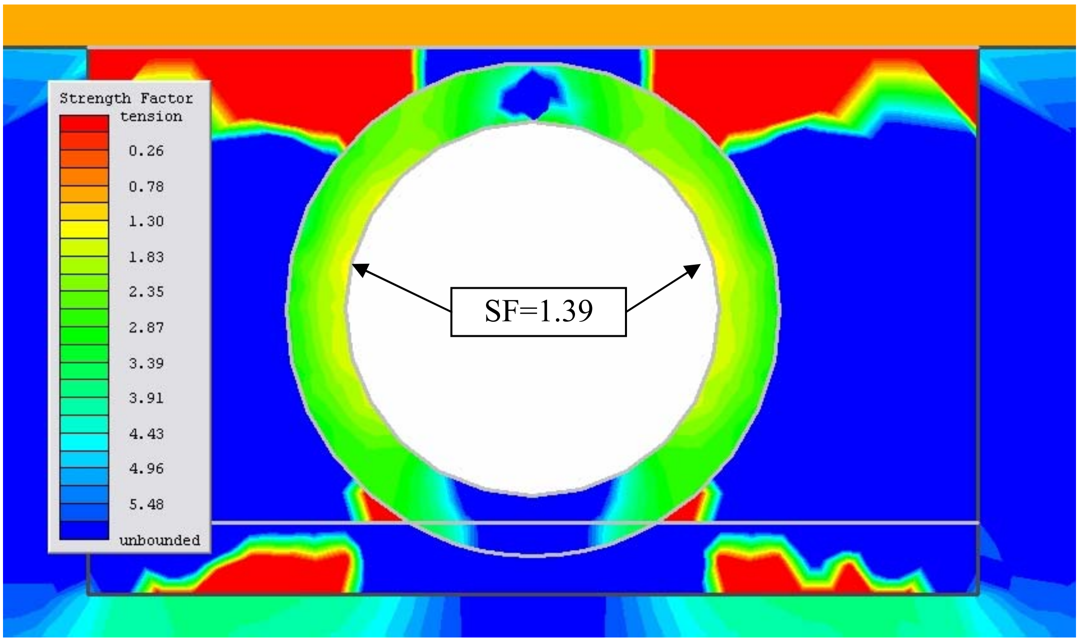


Figure C3: Distribution of safety factors in the walls of the culvert having ordinary bedding condition (min. safety factor =1.39)

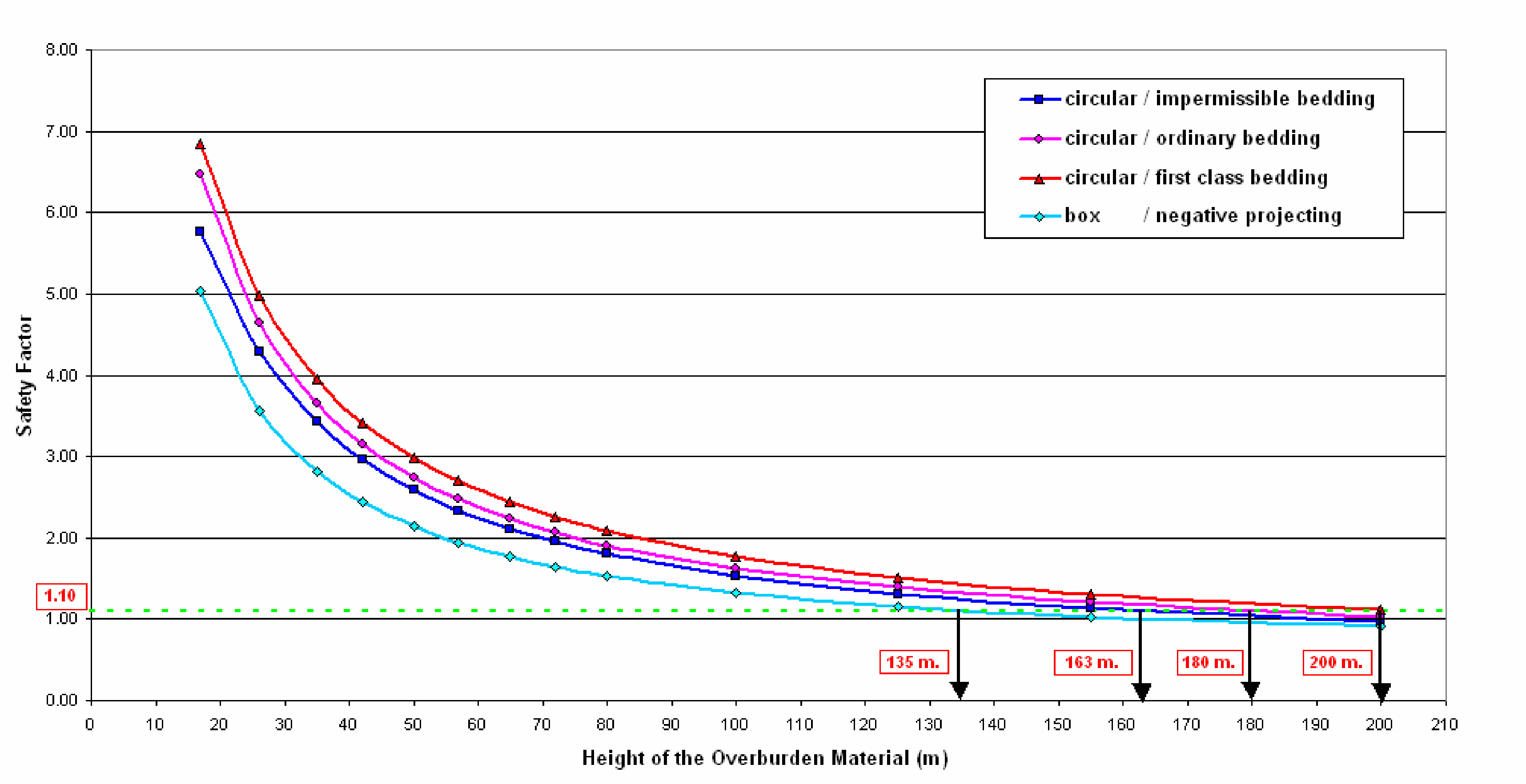


Figure C4: Relationship between the lowest safety factor in the inner walls of the culvert and height of the overburden material (γ = 25.5 kN/m^3, disregarding the effect of groundwater) for negative projecting embankment condition

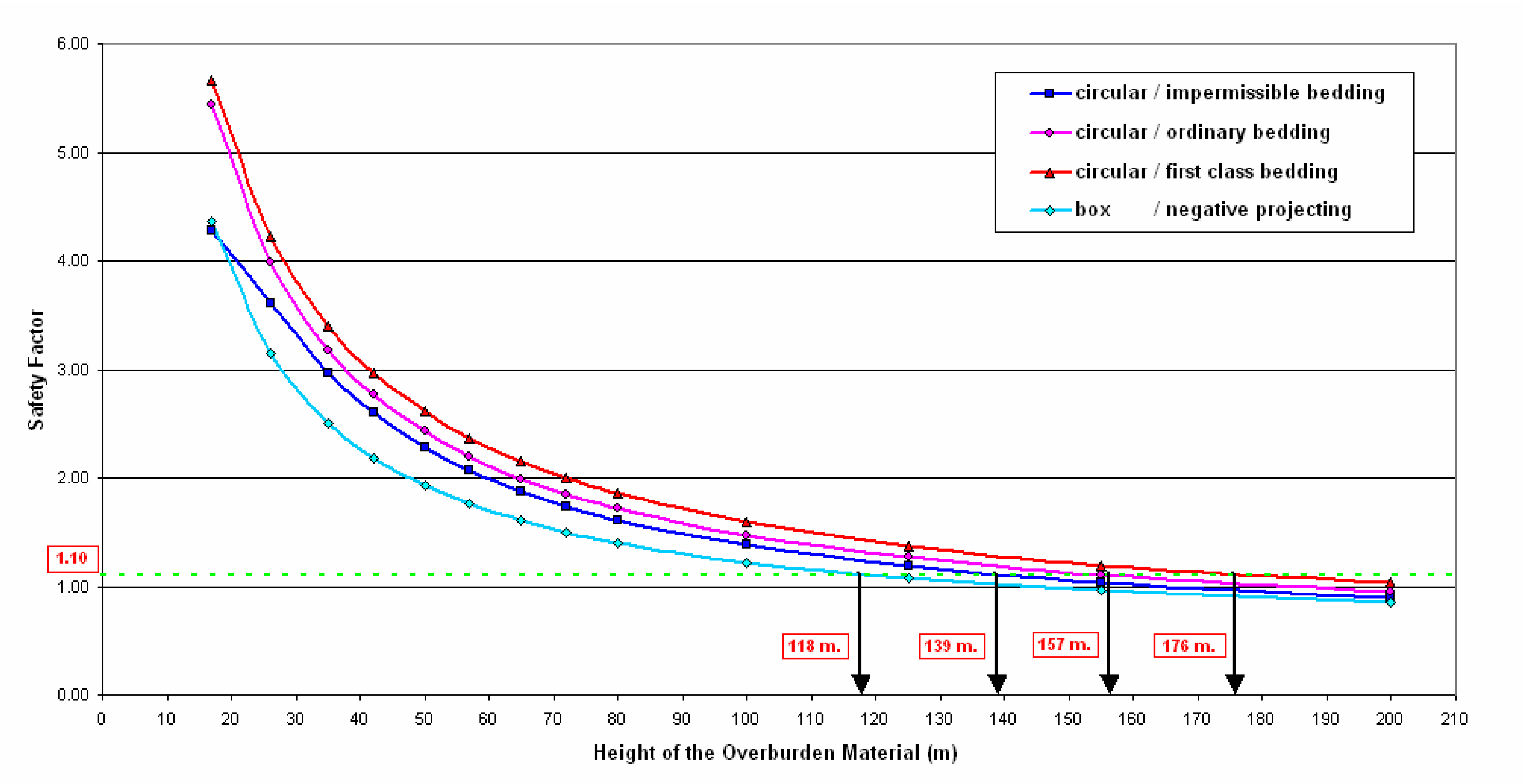


Figure C5: Relationship between the lowest safety factor in the inner walls of the culvert and height of the overburden material ($\gamma = 18.8$ kN/m^3, considering the effect of groundwater) for negative projecting embankment condition

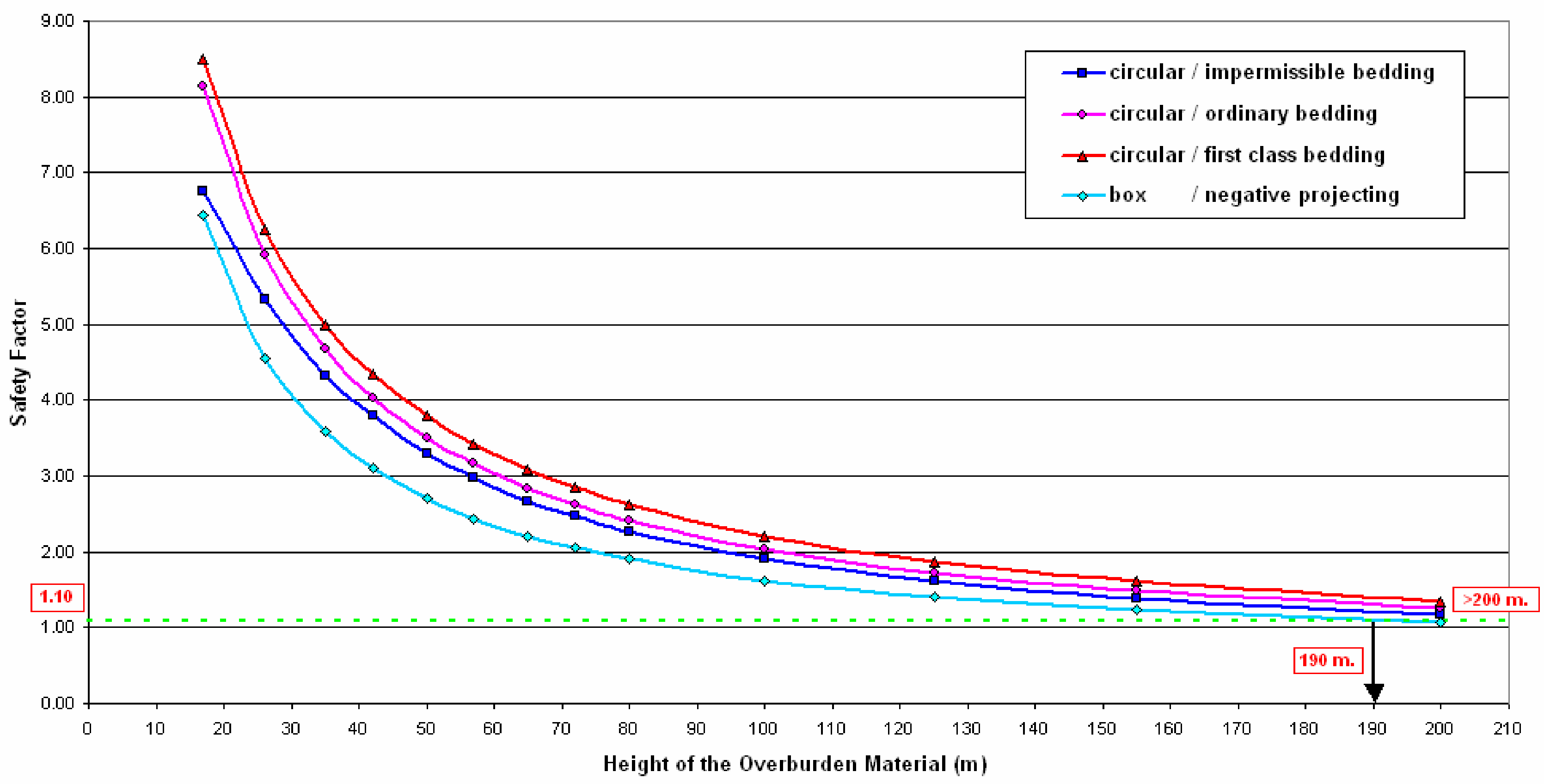


Figure C6: Relationship between the lowest safety factor in the inner walls of the culvert and height of the overburden material ($\gamma = 18.8$ kN/m^3, disregarding the effect of groundwater) for negative projecting embankment condition

APPENDIX D

In this appendix distribution of safety factors in the walls of the existing positive projecting box-shape culvert are presented for different horizontal to vertical stress ratios (k) namely k=0.3 (Figure D1), k=1 (Figure D2) and k=3 (Figure D3).

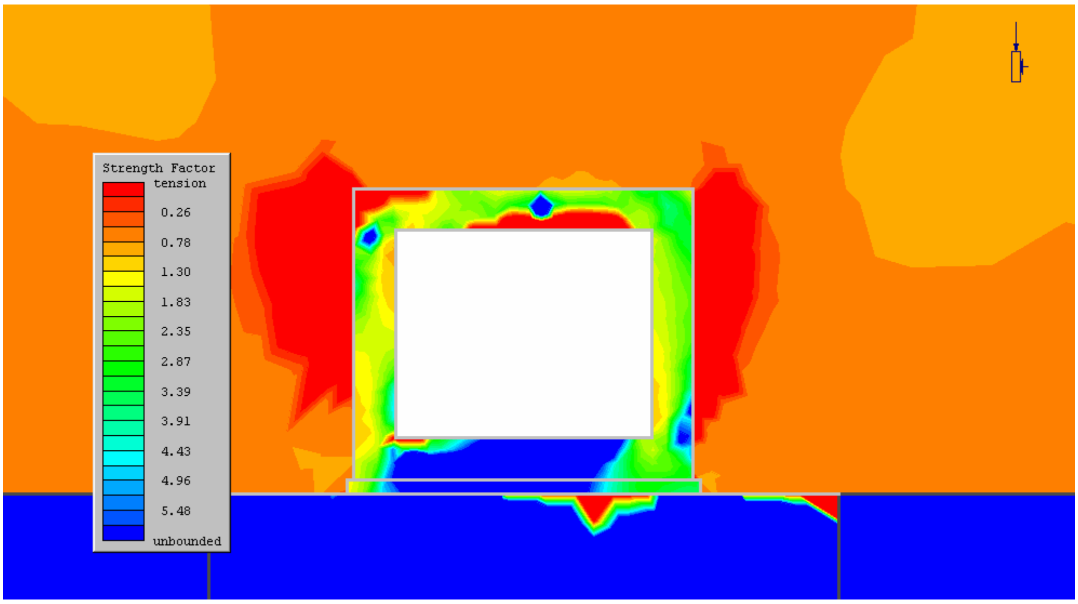


Figure D1: Distribution of safety factors in the walls of the existing culvert where horizontal to vertical stress ratio is "0.3" (γ=25.5 kN/m^3, considering the effect of groundwater)

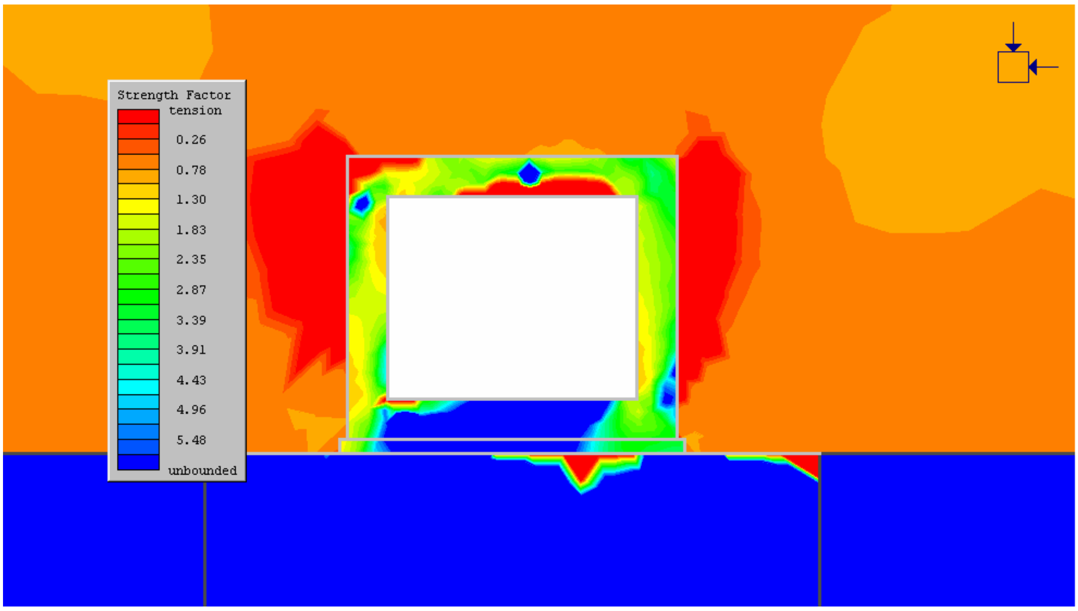


Figure D2: Distribution of safety factors in the walls of the existing culvert where horizontal to vertical stress ratio is “1.0” (γ=25.5 kN/m^3, considering the effect of groundwater)

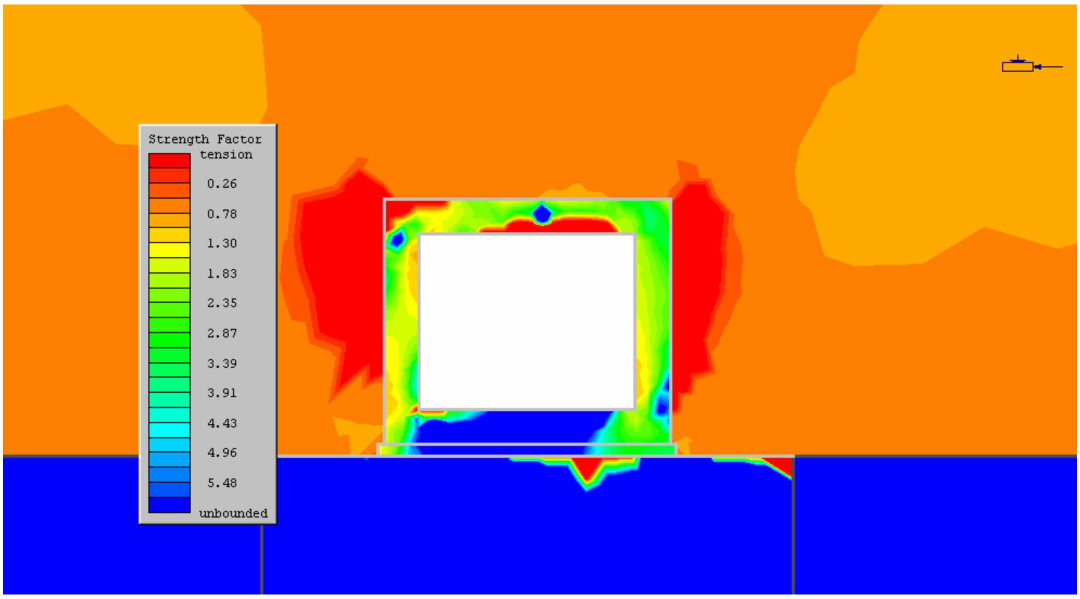


Figure D3: Distribution of safety factors in the walls of the existing culvert where horizontal to vertical stress ratio is “3.0” (γ=25.5 kN/m^3, considering the effect of groundwater)