An Investigation on the Behaviours of Buried Structural Arch Culvert with Varying Rise/ Span Ratio

By

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ABSTRACT

Since the Romanian Empire until twentieth century, the arch structures are widely applied in all fields of engineering constructions, from bridge, subways, and underground structures to military shelters. The loadings are altered to fulfill the specific demand in transportation systems, materials quantity and the analysis methods. Therefore, we should improvise our understandings on structural behaviour.

The behaviour of buried structural arch for span 10m to 30m are analyzed with finite element method. The structural behaviours include the axial force, shear force and bending moment in both distributions diagram and magnitude. By applying three types of load cases, that is self-weight, fill weight and live load, the behaviours of arch for axial force, shear force, bending moment, horizontal and vertical reaction are observed. This research provides a better understanding about the behaviours on buried arch with various rises to span ratio.

From the analysis on the behaviours of buried arch by finite element method, the change in arch rise to span ratio for three types of load cases show the increment in maximum axial force, shear force, bending moment, horizontal and vertical reaction.

Investigation for buried arch structures with different rise to span ratio is importance for future designs of arch structures, with higher quality, durability and strength. Lastly, future design of arch structures will be able to achieve longer life cycle, cost effectiveness and environmental friendly.

ABSTRAK

Sejak Dynasti Rom hingga abad 20-an, struktur gerbang telah digunakan secara meluas dalam semua pembinaan bidang kejuruteraan seperti sistem pembetungan, struktur bawah tanah dan struktur pertahanan negara. Pembaharuan perlu ditambahbaik dalam bebanan untuk memenuhi keperluan yang semakin canggih dalam bidang pengangkutan, kuantiti bahan mentah and juga kaedah analisa. Oleh itu, kefahaman kami tentang kelakuan gerbang perlu diperdalam lagi.

Kelakuan struktur gerbang bagi jarak gerbang antara 10m hingga 30m dianalisa dengan penggunaan perisian FEM. Dengan mengambil kira pembebanan jisim gerbang, berat tanah and berat hidup, perubahan daya paksi, daya ricih, momen lentur dan daya tindakbalas diperhatikan. Kelakuan struktur termasuk daya paksi, daya ricih dan momen lentur dalam kedua-dua bidang bentuk gambarajah dan magnitud. Kajian ini memperdalam lagi kefahaman tentang kelakuan struktur gerbang apabila jarak dan tinggi struktur berubah.

Dari keputusan analisa, dengan pertambahan nisbah ketinggian terhadap jarak gerbang, perubahan untuk daya paksi maksimum, daya ricih, daya tindakbalas and momen juga semakin bertambah.

Kajian terhadap struktur gerbang yang terbenam di bawah tanah adalah sangat penting untuk rekabentuk masa hadapan. Pada masa yang akan datang, rekabentuk bagi gerbang akan menjadi lebih tahan lasak, mengurangkan kos dan juga menjaga alam sekitar.

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CHAPTER 1

INTRODUCTION

1.1 Problem Statement

Arch structures are the oldest form in engineering application since the Roman Empire until the Twentieth Century. The Romans are the first bridge builder. They applied arch structures and their structures are unsurpassed in excellence for nearly two thousand years. Nevertheless, the Roman built the semi-circular stone arch by crafted its own weight held together without mortar, therefore, such a bridge is narrow archway. However, Chinese builder has solved the problem by flattening out the arch. This technique made longer arch span possible.

For over two thousand years, the unique load carrying capability of the arch shape has been recognized. Arches were ideally suited for early builders whose principal materials, stone and masonry had little bending moment strength. With the unique arch shape, they were able to construct bridges, aqueducts, and cathedrals of astonishing size and beauty.

For the new developments, the arch structures should be able to meet all needs of humankind in various ways. New arch structures should be able to meet the future transportation needs, is a cost effective and time saving solution. Besides, it should be able to minimize the structures maintenance together with structurally sound and reliable yet environmental friendly.

Traditionally, bridges in Malaysia are constructed by beam/pier method. Overfilled Arch Bridges were introduced to Malaysia since 1990's (Bebo, 2005). These arch bridges were of proprietary systems and local designers do not commonly know the analysis / design method. More studies are needed on the arch bridges in order to develop some basic design information for future local usage.

Over the past 10 to 15 years, the application on the buried pre-cast concrete arch system has been increasing. Despite the durability, aesthetic value and economy, in the coming century, the development of high tensile strength materials will threaten the displacement of the arches in engineering constructions. Therefore, it is important to confidently optimise buried arches design for economy, durability and aesthetic appeal.

The buried arch system uses the feature of soil interaction and combines the advantages of the stabilizing influence of earth fill surrounding the arch. Besides, inherent the arch geometry property and application of precast materials, the stability and strength need to be further investigation and researches.

There are mainly two methods in designing the buried arch structure, that is the simple analysis methods and finite element analysis. However, the simple analysis method always overestimates the effect of surcharge loading and high fill. The moments and shear forces are usually much higher than those found by using finite element analysis. Therefore, the research on the behaviours of buried arch structures using finite element analysis should be carried out.

1.2 RESEARCH OBJECTIVES

The objectives of this research are

i) To establish the structural models with span varying from 10m to 30m with the aid of Finite Element Method.

ii) To investigate the effect of surcharge loading and high fills on the structural behaviours of arch culvert with varying rise to span ratio by using FEM software

iii) To obtain the trend line of the bending moment, shear force and axial force to rise/ span ratio.

1.4 IMPORTANCE OF THE RESEARCH

The durability of arch has been proven by history of over 2000 years. In the next century, the applications on soil-structural interaction arches will be increased due to the fine quality, durability and strength itself. Therefore, the research on the behaviours of the arch will benefit the future construction of longer span bridges and low cost culvert structures that may extend beyond 25m arch span. Right now, the maximum span length of precast arch culvert in worldwide market is around 25m only.

The research itself is important, as precast concrete is getting popular among the engineering construction, further research on the buried arch will bring a new development for precast concrete with higher compressive strength at lower cost, and without the elaborate formwork.

The possibility of buried arches for future developments are considered by looking into the advantages and disadvantages of buried arch construction in economy, durability and aesthetic appeal. For future developments, the arch structures should be able to meet the higher transportation needs of mankind by lowering the quantity the construction materials, structural reliability, shortening the construction time yet bring economical benefits and environmental friendly.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Since prehistoric times, arches have been built and well recognised by its unique engineering characteristics. It is durable, safe, economical and also aesthetically pleasing. The Egyptians, Babylonians and Greeks generally use the arch for secular structures such as storerooms and sewers. The Assyrians built palaces with arched ceilings. The Romans were the first to develop the arch on the massive scale. They used the semicircular arch in secular structures such as aqueducts and palaces. Many historical arched structures remain standing today as a testament to its durability and integrity. Today, with its unique load carrying capacity, it is widely used to construct bridges, tunnels and underground structures (HUME, 2005).

In 1995, the first installation of precast concrete arch bridge has been carried out at Water Bridge at Bukit Idaman, Selangor. It is a milestone for civil engineering industry in Malaysia. In the year of 1997 and 1998, over the Wetland of Putrajaya and the Garden Bridge of Prime Minister•s office, Putrajaya have also been set up the Multi • span BEBO Bridge (HUME, 2005). Traditionally, bridges in Malaysia are constructed by beam/pier method. However overfilled arch bridges were first introduced to Malaysia since 1990's by Matiere system (Kathy, 2003), Bebo system (Hume, 2005) and Techspan system (Davis, 1970). These arch bridges are proprietary systems and the analysis and design methods are not popular among local designers. Therefore, for future long-term benefit and usages, more studies and researches need to be carried out in this field.

2.2 Concept of Arch

Josef, (1981) gave the general design assumption about arches. The general design will be based on the following assumptions.

i) The centre line of the arches is a general curve, the arch cross • section is variable.

ii) The effect of bending, compressibility, shear and rotation of the bars is taken into account.

iii) The arch material is linearly elastic and has internal damping.

iv) The plane cross- sections before deformation remain plane after deformation.

According to Clive (1995) arches carry loads normal to its basic direction; however, it is most efficient when it redirects its vertical loads to compressive normal stresses directed along the arch•s axis and distributed uniformly over the arch•s thickness. Arch uses both transverse shear and normal bending stresses and compression stress to carry its vertical loads and to the reactions at the ends of the arch.

2.3 Types of Buried Arch System

Most of the buried arch structures are built with cast in place reinforced concrete. However, there is an alternative choice which is prefabricated concrete structure. Most of the buried arch structures built today are precast concrete structure. There are many reasons which make the products become popular among the users. Firstly, installation of precast component is rapid, simple and predictable. Secondly, it requires neither specialty formwork nor highly skilled labor.

In British Columbia, three segmental buried precast concrete arch culverts were constructed at the Coquihalla Freeway. Buried structures were used because the climatic condition and topographic constraints on road alignment. 20m span length and 6m in rise arch culverts were used for debris passages and to erect the culvert over creek without relocation (Hebden, 1986).

2.4 Buried Arch Structures

BEBO arch bridge system, TechSpan™ Arch System, Con • Arch system and Matiere system are proprietary systems use for soil • structure interaction and combines the stabilizing influence of the earth fill surrounding the arch (BEBO™ ,2005). These systems capitalize on soil-structure interaction phenomenon between the reinforced concrete arch foundation and the surrounding fill to support the live and dead loads on the structures.

The underground structures such as buried arch structures are frequently apply for the garages, wine and cheese cellars, vaults, food, water retention, protective structure and even museum. The advantages of the overfilled structures are it requires minimum land usage and the structure itself is able to maintain constant internal temperature. In additional, during natural catastrophes or wars, the underground structures will be able to provide shelter to human (HUME, 2005).

BEBO arch is first developed by a Swiss engineer, Dr.Werner Heierli in the early 1960•s. Soil • structure interaction phenomenon is used in his design concept, where the concrete arches are built with minimum thickness which is sufficient to support the loads yet slender enough for passive resistance of the backfill. Superior stability and strength plus the aesthetical is inherited in the property of percast arch geometry. The first Bebo arch bridge was built on Swiss Federal Highway in 1967 after the company succeeded in conducting a full-scale structure test. (BEBO^{TM} ,2005).

Another patented construction technique, Matiere precast concrete arch system is also well known around the world. In the 1980s, this technology was first developed in France to provide engineering solution for tunnels, underpasses and bridge application. Today, this kind of buried precast structure is definitely low in cost and technical advantages if compared with traditional reinforcement method. In additional, it resulted in very little environmental disruption. For example, installation time is reduced which can minimizes overall road downtimes and also the system flexible geometry allows for accommodation of multitude of clearance (Matiere, 2005).

On the other hand, the TechSpan^{TM} arch system is also well known for its buried precast concrete arch since 1986. TechSpan^{TM} arch system designs the unique structure based on finite element analysis. In order to verify the FEM design system, an investigation on non • linear analysis of buried arch structures has been carried out. In the test, it focuses on the effects on the analysis of the assumed construction sequence and the use of non • linear material properties. The essential features included in the analysis are

- An elasto- plastic soil model with soil stiffness, E (Young Modulus) and Poisson ratio, , and confining pressure, ƒ3.
- The soil loads are applied and compacted in each stage similarly to actual backfill sequence.
- Between the arch and soil, there is a skin friction element.

- Lastly, concrete is modelled as linear elastic.

Con Arch is another proprietary arch system, which is a cast in place buried arch construction methodology, applies on the construction of bridges, culvert, cut and cover tunnels, underpasses, underground vaults and reservoirs. It began its development in 1988 with the concept to build arches with inflatable banded reusable form by using the soil structure interaction finite element analysis and combine with the improved wet mix shortcrete concrete and placing methods. This trademark structures product is undergo extensive testing by using HITEC (Highway Innovative Technology Evaluation Center) .

The arch span range for the buried precast structures in the market today is around 2.5m to 25.6m.There are 3.6m to 25.6m span range for BEBO arch system, 5m to 20m span range for Techspan arch system and 2.5m to 20m span range for Matiere arch system. Hence, for future usage, the study and research for the longer span range should be carried out. There will be definitely a discovery on new trends of structural.

2.5 Soil-structure Interaction Phenomenon

Since the past few decades, soil structure interaction for buried structures has attracted much attention by researchers. Davis and Bacher, (1972) tested an arch culvert, under a 240 ft embankment. The objective of his investigation is to assess the influence of the buried structure behaviour with varying methods of backfilling including well-compacted structure backfill, straw surrounding the barrel and imperfect trenches with various inclusions. As a conclusion of the experiment, he concludes that good conditional of foundation can prevent large stresses which is resulted by differential displacement.

Kiger et. al, (1989) studied the effects of dynamic skin friction against the buried arches. They conducted a dynamic test on two identical arch structure to investigate the load, which is induced by the friction during the backfill soil, is compacted around the embedded structures. During the test, one of the models is covered with double layer Teflon to reduce the friction while the other covered with nothing. The result shows that, the Teflon • covered arch did not collapse while the other was totally damaged when the 1,700 psi dynamic pressure is applied. Hence, Kiger and his friends concluded that the skin friction loads could affect the maximum capacity and the failure mode of buried arches. Therefore, during the design of buried arch structures, engineers should be aware of the influence of skin friction loads against the designs.

Fairfield and Ponniah, (1994) performed an investigation to determine the effect of the fill on the buried arches. In their experiment, they used a small scale model to identify the behaviours of the backfilled arch bridges. Before the test, zones of the arch and fill displacement were identified. As a result from the test, the interactions observed between fill and arch significantly increased the collapse loads obtained.

Zoghi et.al, (1995) have carried out research to evaluate precast concrete arch culverts for soil• structure interaction. The objective of the research is to study the integrity of the „flexible structures• for the underground rigid structures which rely on the support from surrounding soil for its carry load bearing. An experimental research on the precast module and which was considered as rigid structures was carried out. In the test, earth pressure cells were installed at different locations at the interface of the buried unit and the backfill.

Besides, Hernandez-Montes et. al, (2005) recently proposed to use the buried arches to rather than conventional above-grade structural system to support gravity load. In their opinion, the soil pressure will equilibrate the horizontal thrust, as the horizontal soil pressure, which will increase with depth. Therefore the depth of arch will reduce while the depth below grade, will increase. In their study, they also address the influence of equilibrium, creep, and shrinkage as these behaviours will affect the design of the arch from a theoretical perspective.

Karinski et. al, (2003) have also conducted a test to evaluate the static soil pressure on a buried structure. They used a discrete- continuous model to analyze a buried structure under static loads as well as the soil gravitational load at service • state conditions. Soil-structure parameters that are included in the model are the soil and structure material properties, roof span and thickness, the structure•s height, the depth of the burial and external pressure.

Duncan et. al, (1980) has developed a model • Duncan Model which represent both the soil characteristics and the soil-structure interaction. The Duncan Model is powerful as it only requires limited number of soil parameters. The following are the features that Duncan model takes into account.

- Duncan model uses the soil initial tangent modulus, E_i and stress difference , $(f_1 \bullet f_3)_{ultimate}$ which can be obtained from Figure 2. 1,

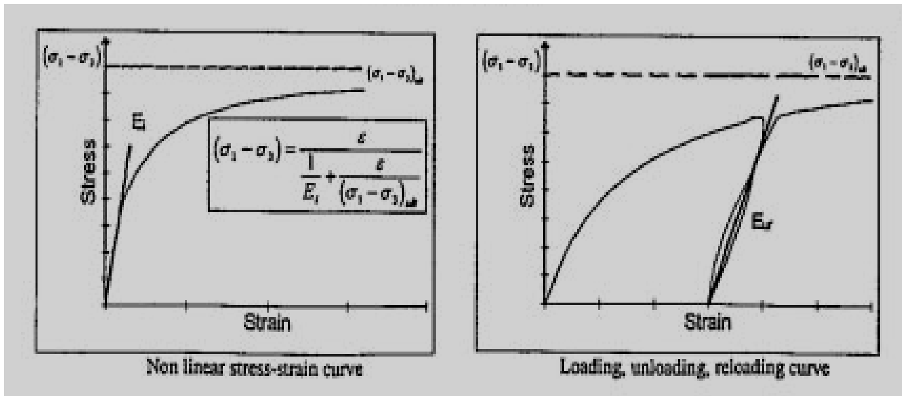


Figure 2.1 Duncan Model Graph

- Unloading / reloading behaviour during construction which differs from primary loading,
- Non-linear volume changes, and
- Ultimate shear strength, which is based on cohesion and friction angle.

Timothy, (1988) has written a load test report on the evaluation of a precast concrete arch culvert. This report evaluated a full-scale load test performed on a Con-Span culvert. This test is important, as the structure should be evaluated carefully for future usages. This load test procedure was devised to evaluate the structural integrity of this unit and to examine to what extent its field performance compared with its predicted behaviour.

Besides, Matson (RECo, 1986) also studied the soil structure interaction phenomenon. When a rigid or compressible structure is buried under soil, there will be an interaction between them. Fill compression on each side of the structure exceeds that occurring directly over it; hence induce a down drag force on the structures. Therefore, the structure is said to induce the load and increase the vertical stress on the structure beyond what would be generally considered. Marston developed the Marston coefficient, K_2=ƒ …†z (ratio of the vertical stress above the structure to the stress at the same location).The Marston•s coefficient depends on the backfill height, compressibility, the shape and rigidity of the structure. However, this coefficient is mainly designed for cast in place concrete structure.

Buried arch structures may be use as protective shelters for military purposes. Soil-structure interaction problems for underground protective structures under explosive threats have received much attention in the past three decades (Huang and Shen, 1996). Numerous static and dynamic test were conducted in the laboratory to study the behaviours of buried structures. From these tests, the importance of the interaction effects for burial depths with span and dynamic loadings was clearly demonstrated.

Stevens et. al, (1991) attempted to approach the behaviours of the dynamic soil structure interaction modelling. They combine the finite differences technique with the finite element method in order to analyze the behaviours of buried RC arches. The essential features of the objectives are

- Ÿ Understand the complex nonlinear response by carried out experiments.
- Ÿ Perform a parametric studies
- Ÿ Develop design guidelines

However, without an experiment, the study itself can also proves the truth. Therefore, by using two specimens of buried arch with different soil properties, depth of burial, surface blast pressures and geometry in a test, David and his friend managed to obtain a comparison with the prediction and test result.

Besides the researchers that have been mentioned, Kennedy, (1971) also carried out a dynamic tests on a flexible buried arch type protective shelter model. Through the test, he determined the dynamic response of a buried model flexible arch shelters, which was simulated to nuclear blast overpressures. This model was buried in dense and dry sand and overpressures of 37 to 177psi was applied on it. Strain, stress and deflection were measured throughout the experiment.

Flathau, (1965) also conducted research in soil structure interaction. The types of buried structure involved are semicircular and fixed-end concrete arches. In the laboratory tests, the air blast effects of the nuclear devices on the buried structures were studied.

To enhance the research on the buried arch structures, a report from McVay et al. , (1993) tried to figure out the long term behaviours of large • span buried culvert in cohesive soils after the end of the construction. The tests were conducted for three different culvert shapes with three different soils that are varied in degrees of plasticity. During the tests, effect of the vehicular live loads and the field conditions are taken into account. The result shows that the culvert•s original shape controls its deformed shape and possible failure mode. However, this test only is carried out in cohesive soils condition and there is no further study on horizontal thrust with the backfill equilibrates.

Additionally, Davis and Bacher (1968) tried to determine the structural behaviour of buried arch culvert by carrying out theoretical studies which include finite element analysis of embankment pressures. Observations of three arch culverts have been conducted. Strains, displacement, theoretical studies include finite element analysis of embankment pressures and neutral point analyses of arch culvert behaviours were developed.

When designing a buried arch structures, passive earth pressures should be taken into account. The magnitude of the passive earth pressure that resist the movement of a structure is controlled by the amount the structure moves and the direction of the movement, strength and stiffness of the soil that resists its movement, friction of the interface between the structure and soil and also the shape of the structure (Duncan and Mokwa ,2001)

2.6 Finite Element Analysis

In the design of buried arch structures, the Finite Element Method for beam element has been used and will consider only the linear elastic theory of structures. Thus, to further analyze the soil • structure interaction for buried arch structures, FEM design tools like ADINA, STAAD-III and BOPRE have been used to run the modelling of the structures.

Playdon and Simmonds, (1985) have evaluated the FEM program in ADINA software for analyzing the soil-structure interaction problems. They also discussed about the application of ADINA and general modelling considerations to soil-structure problems. In their evaluation, they consider the element types, material models, formulation etc. Besides, in the modelling, arch- beam culvert structure, which consists of soil, steel and concrete, is also under considerations.

During the Twenty-Eighth DoD explosive safety seminar presented by Kim (RECo,1986), P.E., senior engineer from The Reinforced Earth Company, Vienna, also recommend the advanced of FEM design tool is capable in determining the optimum profile of the arches. He highlighted the usages of prefabricated concrete arches, which are modelling with three- dimensional FEM software in designing the military projects like constructing blast protection shelters, vaults and etc. This program considers specific load requirements including live, static, handling loads and blast loads.

Finite element modelling of buried structure may sound easier by using the FEM programs, which is considered user friendly. Still, there are many considerations that need to be taken into account. In modelling a buried structure Karinski et.al,(2003) evaluate the static soil pressure on it. Other soil • structure parameters that are included are the soil and structure material properties, roof span and thickness, the structure•s height, the depth of burial and external pressure.

However, besides the few FEM programs that have been mentioned, another FEM program CANDE was used for detailed analysis of the structure. This program is specially designed for the evaluation of soil • structure interaction conditions and is especially suitable for the analysis of the field-testing (Timothy, 1988).

2.7 Summary

Overall, soil structure interaction phenomenon for buried arch structures has received much attention worldwide. However, some buried arch structures are under proprietary system, therefore, local designers are not familiar with it. Buried arch structure itself is durable and has superior stability. By using the soil interaction and the advantages of stabilizing influence of the earth fill surrounding the arch, the arch geometry is aesthetically pleasant.

Today, there are mainly two types of buried arch structures construction method, that is cast- in • situ arch construction and prefabricated concrete arch construction. Obviously, precast concrete buried arch structures are more popular among builders as it is safe and speedy, reduce the installation times, environmental friendly and economical. These kinds of buried precast arch structures are useful in the construction of crossing structures, underpasses structures and protective structures.

However, soil-structures interaction phenomenon for buried arch structures should be considered when modelling and analyzing this kind of structures. Finite element method programs like ADINA, LUSAS and STAAD have been developed to run modelling of buried arch structures by considering certain parameters such as lateral soil pressures, live and dead loads, structures self weight, transportation loading and etc.

CHAPTER 3

METHODOLOGY

3.1 Arch Model Idealization

A finite element analysis is carried out on each arch to investigate the behaviours of arch with various rise/span ratios. The following are the essential features included in the analysis.

3.1.1 Finite Element Model -Arch Model

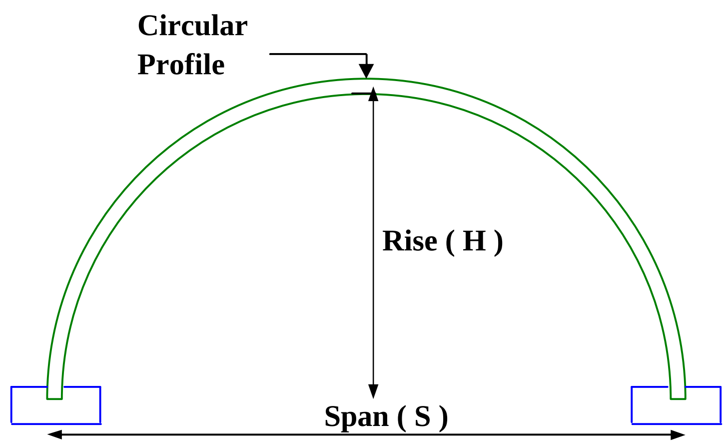


Figure 3.1 Arch Model

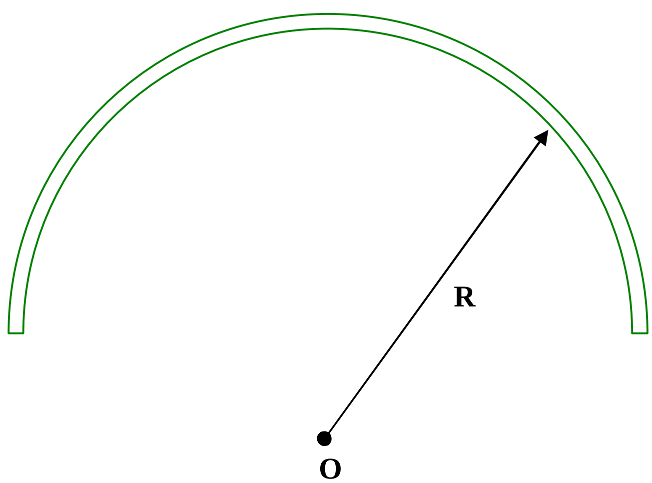


Figure 3.2: Arch with Fixed Radius

Arch is modelled as a circular arch with fixed radius, which means constant radius (Figure 3.2). Arch is typically designed as one piece, two pinned arch with uniform cross section.

The arch span is designed from 10m to 30m while the rise is from 1m to 26m. The arch is designed as buried precast concrete arch with reinforced concrete. Characteristic strength of concrete at 28 days, f_{cu} = 40MPa.The following table shows the arch profile which is being modelled.

Table 3.1 Arch Profile with Various Rise/Span

Span S (m)	Rise H (m)	Ratio H/S
10	1.0	0.10
10	1.5	0.15
10	2.0	0.20
10	4.0	0.40
10	6.0	0.60
10	8.0	0.80
10	9.0	0.90
12.5	1.5	0.12
12.5	2.0	0.16
12.5	4.0	0.32
12.5	6.0	0.48
12.5	8.0	0.64
12.5	10.0	0.80
12.5	11.0	0.88
15	1.5	0.10
15	2.0	0.13
15	4.0	0.27
15	6.0	0.40
15	8.0	0.53
15	10.0	0.67
15	12.0	0.80
15	13.5	0.90
17.5	2.0	0.11
17.5	4.0	0.23
17.5	6.0	0.34
17.5	8.0	0.46

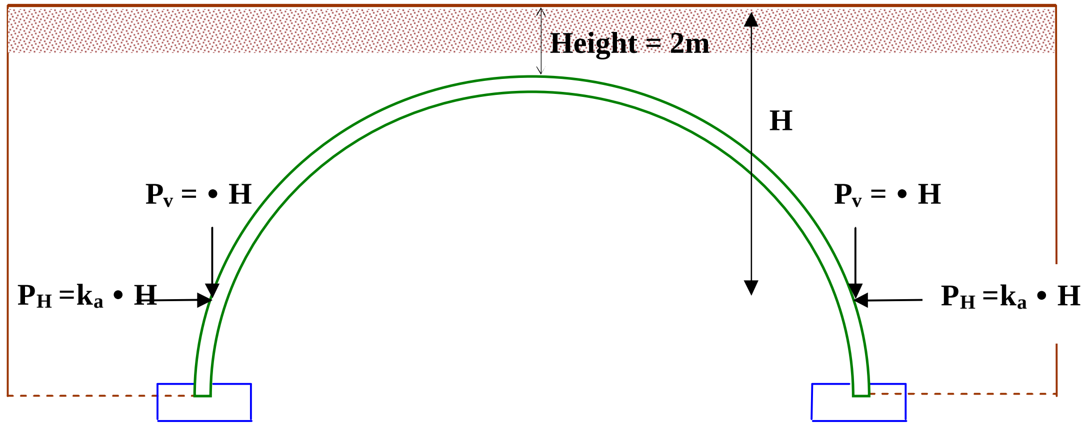
17.5	10.0	0.57
17.5	12.0	0.69
17.5	14.0	0.80
17.5	15.5	0.89
20	2.0	0.10
20	4.0	0.20
20	6.0	0.30
20	8.0	0.40
20	10.0	0.50
20	12.0	0.60
20	14.0	0.70
20	16.0	0.80
20	18.0	0.90
22.5	2.0	0.09
22.5	4.0	0.18
22.5	6.0	0.27
22.5	8.0	0.36
22.5	10.0	0.44
22.5	12.0	0.53
22.5	14.0	0.62
22.5	16.0	0.71
22.5	18.0	0.80
22.5	20.0	0.89
25	2.5	0.10
25	3.0	0.12
25	4.0	0.16
25	6.0	0.24
25	8.0	0.32
25	10.0	0.40
25	12.0	0.48
25	14.0	0.56
25	16.0	0.64
25	18.0	0.72
25	20.0	0.80
25	22.0	0.88
27.5	3.0	0.11
27.5	4.0	0.15
27.5	6.0	0.22
27.5	8.0	0.29
27.5	10.0	0.36
27.5	12.0	0.44
27.5	14.0	0.51

27.5	16.0	0.58
27.5	18.0	0.65
27.5	20.0	0.73
27.5	22.0	0.80
27.5	24.0	0.87
30	3.0	0.10
30	4.0	0.13
30	6.0	0.20
30	8.0	0.27
30	10.0	0.33
30	12.0	0.40
30	14.0	0.47
30	16.0	0.53
30	18.0	0.60
30	20.0	0.67
30	22.0	0.73
30	24.0	0.80
30	26.0	0.87

3.2 Estimation of Loads

The loads considered are

- Dead Load : Self weight of the arch
- Earth pressures from backfilling and overfill weight (Height = 2m) in various stages (Figure 3.3)
- Live Load as UDL = 20 kN/m^2 (Figure 3.4)



• = Soil Density ,20 kN/m^3
k_a= Soil Pressure Coefficient, 1/3 (constant)
H = Depth of Backfill, m

Figure 3.3: Earth Pressure on Buried Arch

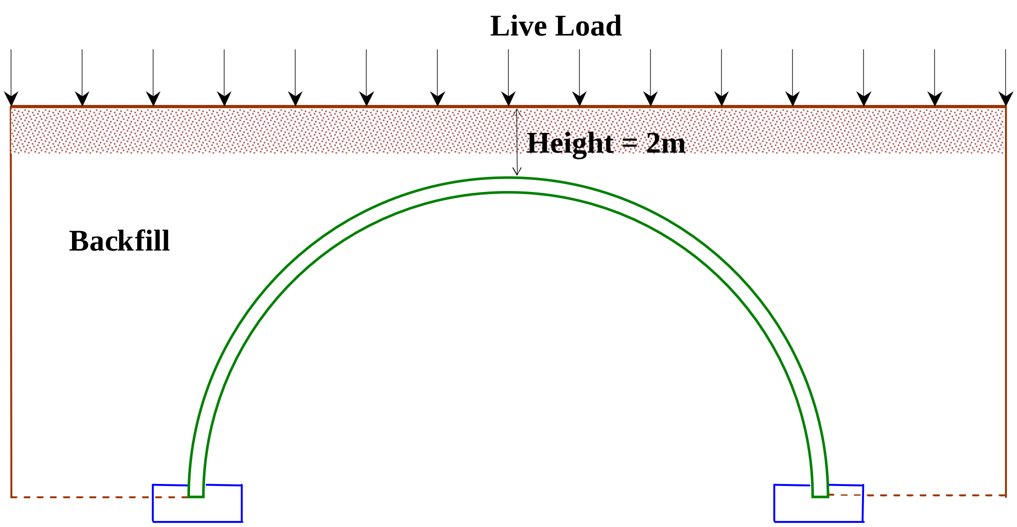


Figure 3.4: Buried Arch with Live Loads

A compaction load is applied to each backfill layer. Soil loads are applied as a series of horizontal and vertical point loads along the arch profile, depending on the depth (H) of backfill with a soil pressure coefficient, Ka (Figure 3.3). No soil structural interaction is considered in the structural analysis model while hydrostatic pressure is eliminated by providing drainage. The soil parameters used in analysis for typical select fill material are

$K_a = 1/3$

† = 20 kN/m^3

Backfill material is modelled as granular fill.

3.3 Finite Element Modelling

3.3.1 Beam Element

In beam element analysis, there are three types of forces need to consider. There are axial force, shear force and bending moment.

3.3.2 Modelling

The circular shape for arches culvert has been modelled by using AutoCAD. The span vary from 10m to 30m and also the rise of the arch profile vary from 1m to 26m depends on the ratio for rise to span (0.1 to 0.9).

The arch model is generated by specifying three points. For an example, if the arch span 10m: Rise 6m.

To draw an arc by specifying three points

1. From the Draw menu, choose Arc ➤ 3 Points.
2. Specify the start point (-5, 0).
3. Specify a point on the arc (0, 6).
4. Specify the endpoint (5, 0).

The next step is to divide the arch shape to smaller element that is around 0.5m for each element (Figure 3.5). The element length for node 1 to node 2 is equal to 0.5m.

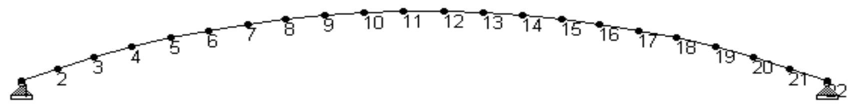


Figure 3.5 Beam Element with nodes

3.3.3 Model Properties

3.3.3.1 Section Properties

Design the arch as a rectangular shape beam as below

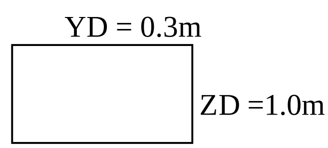


Figure 3.6: Cross Section for Rectangular Beam

Where, A = 0.3 m^2

Iz = 0.00225 m^4

3.3 .3.2 Material Properties

The concrete is modeled as a linear elastic material

Young•s Modulus (E) = 21718456kN/m^2

Poisson•s Ratio (nu) = 0.17

Density of concrete = 23.5616kN/m^3