A STUDY ON THE EFFECT OF OVERFILL DESIGN ON THE STRUCTURAL BEHAVIOUR OF PRECAST CONCRETE CLOSED SPANDREL ARCH BRIDGE

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SCHOOL OF CIVIL ENGINEERING
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By

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I hereby declare that all corrections and comments made by the supervisor(s) and examiner have been taken into consideration and rectified accordingly.

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Date :

Approved by:

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(Signature of Examiner)

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Date :

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ABSTRACT

Arch bridges are gaining popularity since the introduction of precast concrete technology. Closed spandrel arch bridge is one type of precast arch bridge that consists of earth materials that is filled between the spandrel walls and the top of the precast arches. Among the backfilling materials, lean concrete is good in providing strength and rigidity for the arch, yet it comes with a higher cost. In order to achieve a more economical design, it is crucial to understand the structural behaviour of the precast concrete arch under different overfill design. Three types of models have been analysed including model with varying thickness of lean concrete overfill along the arch, model with varying thickness of lean concrete buttress support built adjacent to the end of the arch and model with interchange of soil and lean concrete layers backfill and different cut slope distance. The analysis was carried out using finite element analysis software, PLAXIS. The axial force, shear force, bending moment and deflection of the arch for different models were observed. It is found that models with lean concrete fill along the arch are effective in reducing the overall forces and bending moment while models with lean concrete buttress support are effective in reducing the maximum shear forces and hogging moment only. On the other hand, the models with interchange of lean concrete and soil layer backfill are inducing higher forces and bending moment to the arch. The cost reduction of steel reinforcement required and cost for replacement of soil fill with lean concrete was also calculated to estimate the effectiveness of the model. The model with lean concrete of 400mm thick at support and 100mm thick at crown lying along the arch panel and model with lean concrete buttress support of 1.0m width and 1.0m height show the highest reduction of cost required.

ABSTRAK

Jambatan gerbang telah menjadi semakin popular sejak pengenalan teknologi konkrit pratuang. Jambatan gerbang spandrel tertutup adalah salah satu jenis jambatan gerbang pratuang di mana dinding spandrel dan bahagian atas gerbang pratuang dipenuhi dengan kandungan bahan bumi. Antara bahan-bahan penimbunan, konkrit kurang simen adalah bahan yang dapat memberikan kekuatan dan ketegaran untuk gerbang, tetapi kos demikian adalah amat tinggi. Untuk mencapai reka bentuk yang lebih ekonomi, pemahaman terhadap struktur gerbang konkrit pratuang dengan reka bentuk *overfill* yang berlainan sangat kritical. Tiga jenis model telah dianalisis termasuk model yang menggunakan konkrit kurang simen di sepanjang lengkungan yang berlainan ketebalan, model dengan sokongan sagang konkrit kurang simen yang berlainan ketebalan dan model dengan pertukaran lapisan tanah dan konkrit kurang simen yang mempunyai jarak cerun yang berbeza. Analisis tersebut dikaji dengan penggunaan perisian analisis unsur terhingga, PLAXIS. Daya paksi, daya ricih, momen lentur dan pesongan untuk model yang berbeza telah diperhatikan. Hasilnya, model dengan konkrit kurang simen di sepanjang gerbang amat efektif dalam mengurangkan keseluruhan daya dan momen lentur manakala model dengan sokongan sagang konkrit kurang simen hanya berkesan dalam mengurangkan daya ricih maksimum dan momen meleding. Sebaliknya, model dengan pertukaran lapisan tanah dan konkrit kurang simen menyebabkan peningkatan daya dan momen lentur pada gerbang konkrit. Pengurangan kos untuk keluli tetulang dan kos untuk penggantian pengisian tanah dengan konkrit kurang simen juga telah dikira untuk menganggarkan keberkesanan model. Model dengan konkrit kurang simen yang mempunyai ketebalan 400mm pada sokongan dan 100mm pada puncak lengkungan dan model dengan sokongan sagang konkrit kurang simen yang mempunyai kelebaran 1.0m dan ketinggian 1.0m menunjukkan penurunan kos yang paling tinggi.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background

Arch structures are commonly built for bridges and various applications due to its outstanding durability and aesthetic value. Arch bridge is one of the most popular types of bridge came into use over 3000 years ago, even today arc bridges remain in use and with the help of modern materials, their arches can be built on much larger scales. (History of Bridges, 2018). Arch structures are effective in carrying loads by transmitting them along the curve of the arch to the supports on each end known as abutments. As a result, the arch structures generally use less materials compared to bridge structures such as beam bridges which results in a thinner section of the arch. Arch bridges were made from masonry blocks traditionally since Roman times, and in recent years precast concrete are gaining popularity since 1960's with the introduction of several proprietary system – Bebo arch, Matiere arch, Techspan arch, FlexiArch, Pearl Chain arch etc (Ong et al., 2015). Examples of precast concrete arch bridge are shown in Figure 1.1.

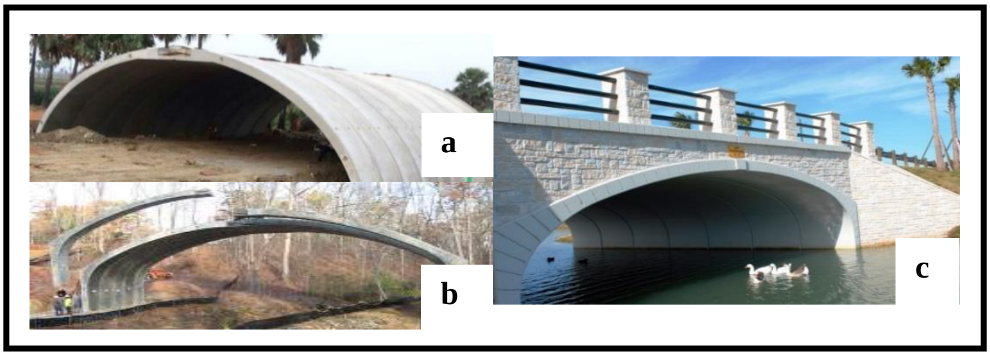


Figure 1.1: Example of Precast concrete arch bridge a) BEBO Precast Concrete Arch Bridge (http://www.strataindia.com) b) Eco-Span Arch Bridges (http://eco-span.comc) Tricon Precast Bridges (http://www.triconprecast.com)

The in-situ construction of arch structure was found to be more difficult and complicated than constructing a straight member due to the existence of curvature in arch structure. The introduction of precast concrete structure had eased the construction process of complicated arch segment and thus resulted in lower cost of construction and shorter construction period. Precast concrete units are often a preferable solution for small bridge replacement due to their low initial cost, rapid installation and low maintenance (Zoghi and Farhey, 2006).

There are typically two types of precast concrete arch bridges, known as (a) closed spandrel arch bridge and (b) open spandrel arch bridge, as shown in Figure 1.2. The spandrel of an arch bridge is the area between the arch ring and the roadway. Closed spandrel arches support the roadway on earth fill that is filled between the spandrel walls and the top of the arch. Open spandrel arches have vertical columns resting on the arch ring that support floor beams, which in turn carry the roadway. Both types of bridges have their own advantages and usage. This study focuses on precast concrete closed spandrel arch bridges. The advantages of precast closed spandrel arch bridge system include: efficient in use of materials, durable and aesthetic, able to form any desired shape, joint-less pavement in top, minimum disruption of streambeds during construction, smooth concrete surface, fast pace installation, erection without formwork and low maintenance (Ong et al., 2014).

(a) (b)

Figure 1.2: Type of Arch Bridge (a) Closed Spandrel Arch Bridge (Phalen Park Arch Bridge, Saint Paul) (Department of Transportation, 2018); (b) Open Spandrel Arch Bridge (Cetina River Bridge, Croatia) (Pouraminian and Ghaemian, 2016)

The major component of precast concrete closed spandrel arch bridge system consists of precast arch element, spandrel wall, wingwall, backfilling components and foundation as shown in Figure 1.3. The arch systems can be assembled from single-leaf, double leaf or triple-leaf precast segments with their respective proprietary jointing systems.

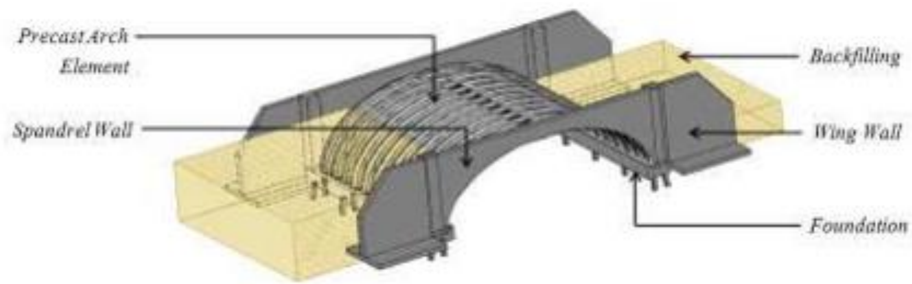


Figure 1.3: Main Component of Precast Concrete Closed Spandrel Arch Bridge (Ong et al., 2015)

The precast arch elements combine to form the base for supporting overfill until the deck of the bridge. It functions to transfer the live and dead load acting on top of the bridge to the support/foundation of the bridge. The precast arch segments are enclosed with two end spandrel units where the empty space enclosed by the arches and spandrel walls is then filled with suitable fill materials in layers. The stability of the arch structure is contributed by the soil-structure interaction between the arch elements and the backfilling components. The passive soil pressure on the arch structure will provide lateral supports by resisting the horizontal forces from the transverse load on top of the bridge. Precast concrete wing walls, placed at each end of the spandrel wall also function to retain the backfill due to abrupt change in loads. The wing walls assist in channeling the water through the arch and reduce entrance losses in waterway crossings. The arches are supported with pinned base support where the foundation could be simply footing or piling depends on condition. The foundation functions to support the vertical and horizontal forces from the arches and transfer to the ground. Figure 1.4 shows the soil-structure interaction in precast closed spandrel arch bridge system.

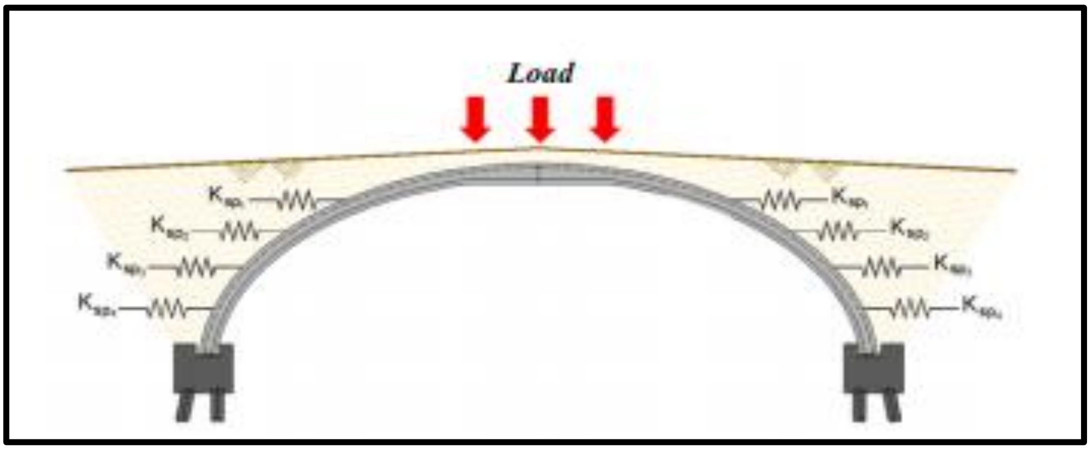


Figure 1.4: Soil-structure Interaction in Precast Concrete Closed Spandrel Arch Bridge (Ong et al., 2014)

Throughout history, various types of fill have been used worldwide depending on several factors, such as economic considerations and the static system of the arch bridge. Typical types of fill can be divided into the following two categories:

- Granular (unbound) materials including soil
- Cementitious (bound) materials (Lund et al., 2016).

The fill material itself is a susceptible part of the construction in which the fill made from poor quality material or with a lack of compaction is sensitive to deterioration and defects (Sihwa, 1987). Poor permeability and graded materials tend to trap water and thus, results in the lost in strength and durability of the bridge. Therefore, the fill material should be granular with angular grains, and should be well graded. Two different types of fill also have been tested on the FlexiArch bridges: a low-strength concrete backfill and a granular backfill and the strength of FlexiArch bridges was found to be much higher when using concrete backfill rather than granular backfill (Brouke et al., 2010). Several examples were shown in the paper by Sihwa (1987) on how old arch bridges have been strengthened by replacing old granular fill with concrete fill.

1.2 Problem Statement

Costs associated with varying mould profiles, logistics and weight of arch panels are major concerns for existing precast arch design. Different materials can be used for the backfilling of the arch. Among them, lean concrete is good in providing the strength and rigidity for the arch. However, cost for lean concrete is higher than soil materials. While FlexiArch (mimicking old masonry arch design with modern precasting technique) has resolved moulding issues, the thick layer of lean concrete overfills are equally costly. This investigation attempted to reduce the requirements of such expensive lean concrete overfills and steel reinforcement of precast arch panels. As the forces and bending moment acting on the arch bridge are expected to change with different condition of backfilling materials, it is crucial to determine the suitable amount of lean concrete used as an integrated part of the backfilling materials. In this way, the amount of steel reinforcement of the precast arch panels can be reduced and a more economical construction of precast concrete closed spandrel arch bridges can be achieved.

Figure 1.5 to Figure 1.7 show three examples of different backfilling condition with the use of lean concrete which are expected to affect the structures behaviour of the precast concrete arch:

(i) varying thickness for lean concrete overfills,

(ii) varying thickness of lean concrete buttress support built adjacent to the end of the arch and,

(iii) varying cut slope distance from the base of the backfills with interchange layers of soil and lean concrete.

The relative advantages of the three different backfilling condition with lean concrete should be studied in order to identify the most cost-effect option.

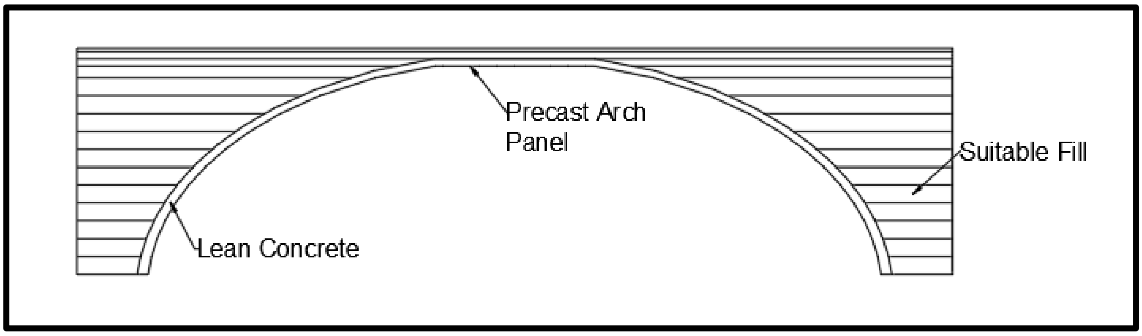


Figure 1.5: Varying Arch Thickness for Lean Concrete Overfills

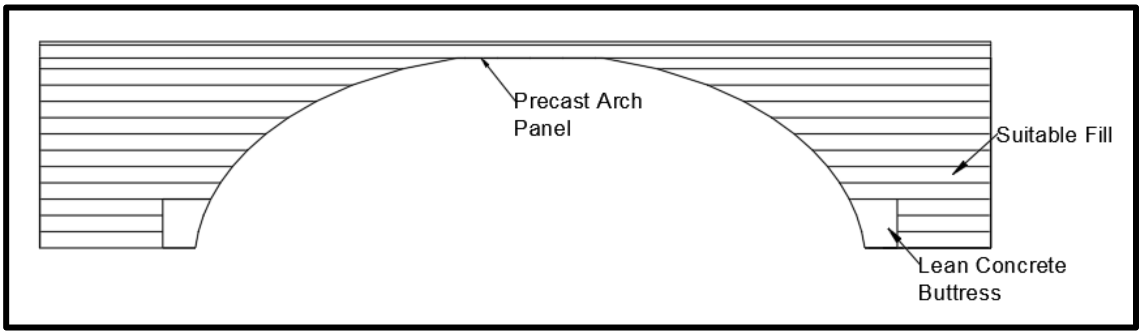


Figure 1.6: Varying Thickness for Buttress Support

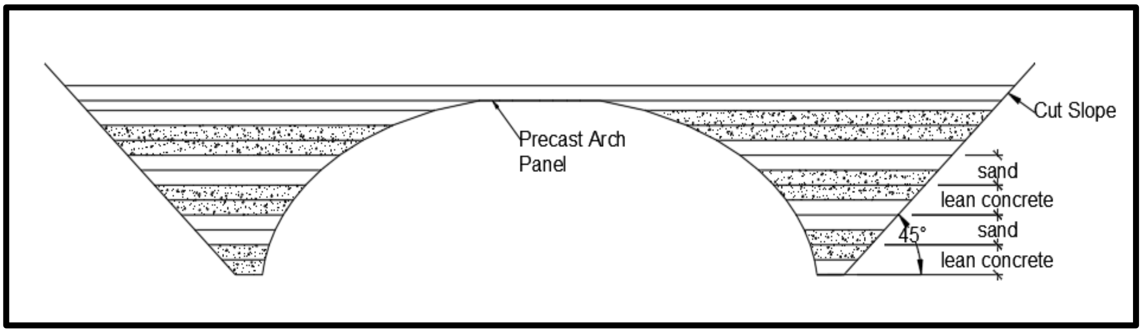


Figure 1.7: Varying Cut Slope Distance with Interchange of Soil and Lean Concrete Layers

1.3 Objectives

The objectives of this study are as follows:

(i) To assess the structural behaviour of precast concrete arch under soil-concrete interaction with varying thickness of lean concrete overfills.

(ii) To assess the structural behaviour of precast concrete arch in response to varying thickness of lean concrete buttress support built adjacent to the end of the arch.

(iii) To assess the structural behaviour of precast concrete arch in response to varying cut slope distance from the base of the backfills with interchange of soil and lean concrete layers.

(iv) To evaluate the cost-effectiveness of various option of using lean concrete as backfilling material for closed spandrel arch bridge.

1.4 Layout of Thesis

Chapter One introduces the background, problem statement and objectives of this research.

Chapter Two briefly describes the development of precast concrete closed spandrel arch bridge system. Besides that, the type of materials used for backfilling tested in past research are also presented.

Chapter Three describes the methodology from generation of models with various lean concrete overfill designs to the analysis to determine the structural behavior of precast concrete arch.

Chapter Four presents the results and discussion of the effect of overfill design on structural behaviour of precast concrete closed spandrel arch bridge.

Chapter Five presents the conclusion of this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The relevant research works that have been carried out in the past can be categorized into three categories as follows:

(i) Development of Precast Concrete Closed Spandrel Arch System

(ii) Analysis of Back Filling Materials

(iii) Properties of Lean Concrete

Various type of precast concrete closed spandrel arch system had been developed, each of them have different arch spans, type of arch segment, and techniques used. Some studies related to the back filling materials used in the closed spandrel arch also had been carried out. According to Lund (2016), the pervious concrete is found to be possessed better properties which improved the lifespan of the bridge. However, there are no studies related to the overfill design using lean concrete been done. Few findings on the related properties of lean concrete such as the unit weight and elastic modulus had also been done.

2.2 Development of Precast Concrete Closed Spandrel Arch System

With the advance of prefabrication technique, the use of precast concrete arches has become popular in bridge construction. It has brought much convenience and time-saving compared to the in-situ construction of arch structure. Currently, the available precast closed spandrel arch system includes BEBO Arch Bridge System, Matiere Arch

Bridge System, NUCON Arch Bridge System, Concrete-Filled FRP Tube Arch Bridge System, Flexi-Arch Bridge System, Rivo CS-P Series Arch Bridge System, Pearl Chain Arch Bridge System and CONSPAN Arch Bridge System (Tan et al., 2015). Table 2.1 shows the year and country of origin for the systems.

Table 2.1: Year and Country of Origin for Precast Closed Spandrel Arch Bridge System (Ong et al., 2015)

Precast Arch Bridge System	Year Originated	Originated Country
BEBO	1965	Switzerland
Matierre	1983	France
CON/SPAN B-Series	1983	United States
TechSpan	1983	Spain
NUCON	1995	United Kingdom
Concrete-Filled FRP Tube Arch	2001	United States
Flexi-Arch	2008	United Kingdom
Rivo CS-P Series	2008	Malaysia
Pearl Chain Arch	2010	Denmark
CON/SPAN O-Series	2012	United States

The precast arch segments are generally assembled from single-leaf, double-leaf or triple-leaf precast elements as shown in Figure 2.1. Each of the systems have their own limited designed spans and type of arch segment. The profile of arches can be in circular, elliptical or parabolic to suit the requirements of the specific project.

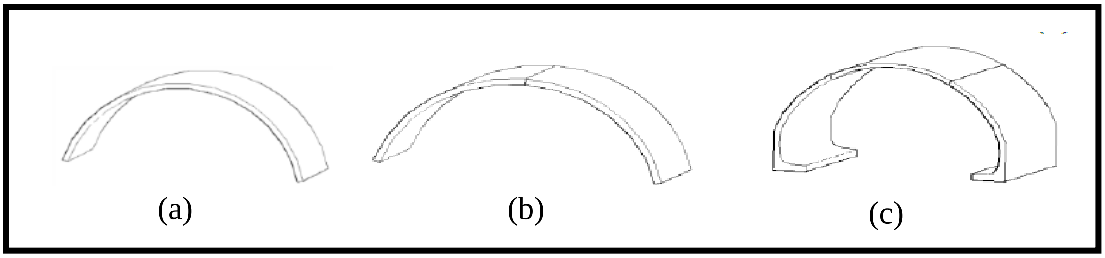
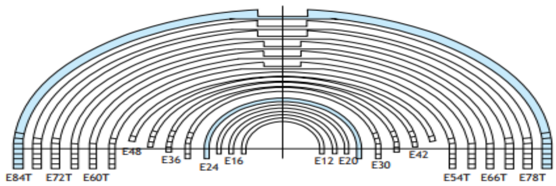
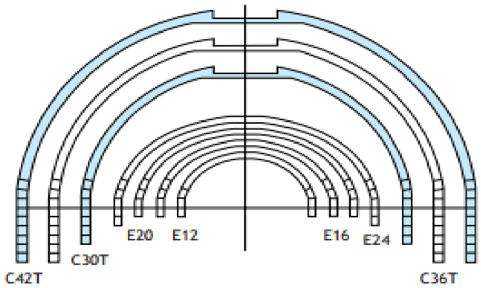
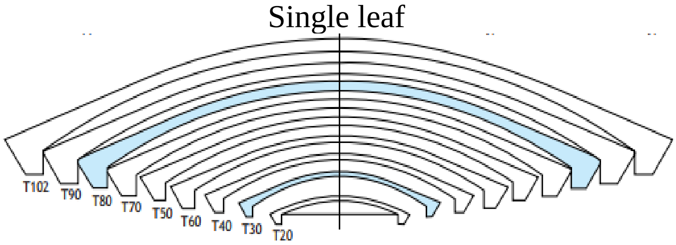


Figure 2.1: Precast arch segment types: (a) Single leaf; (b) Double leaf; (c) Triple leaf (Ong et al., 2015)

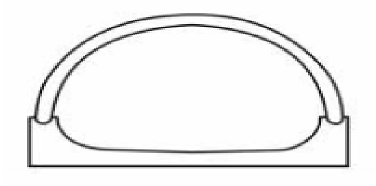
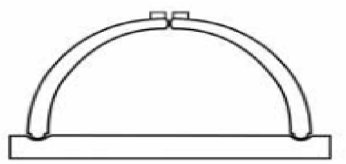
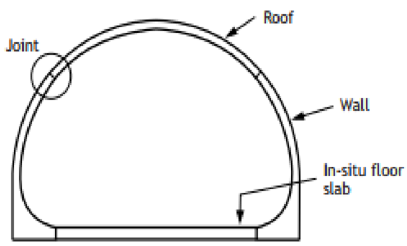
The BEBO system is developed by Swiss engineer Werner Heierli and first installs in 1967 in Switzerland. Spans range from 3.66m to 31m, and are uniquely capable of very low-profile geometries with span-to-rise ratios as low as 10:1 (Bernini, 2000). The versatility of the system makes it attractive for a multitude of applications. Table 2.2 shows span and arch segment for BEBO Arch System.

Table 2.2: Span and Arch Segment for BEBO Arch System (Precast Concrete Arch Structures-Technical Guide No.12, 2009)

Type	Span (m)	Type of Arch Segment
E-Series	3.6-25.6	Single and Twin leaf 
C-Series	9.1-12.8	Single and Twin leaf 
T-Series	7.0-31.0	Single leaf 

The most commonly used Matiere arch system is the CM4, which is formed using four precast reinforced concrete elements, two vaulted abutment walls, a flat invert and a vaulted roof element. The structure is developed from its predecessors, the CM2 and CM3. The improvement made has led to a larger-span structure with added standard features to simplify casting of the precast segment and site installation. The CM4 system provides a design which is more flexible than the three-pinned arch and better suited to clearance of profiles with low aspect ratios. Examples of Matiere Arch System are shown in Table 2.3.

Table 2.3: Span and Arch Segment for Matiere Arch System (Precast Concrete Arch Structures-Technical Guide No.12, 2009)

Type	Span (m)	Type of Arch Segment
Matiere CM 2	1.5-3.0	Single leaf 
Matiere CM 3	3.0-8.0	Twin leaf 
Matiere CM 4	2.5-20.0	Triple-leaf 

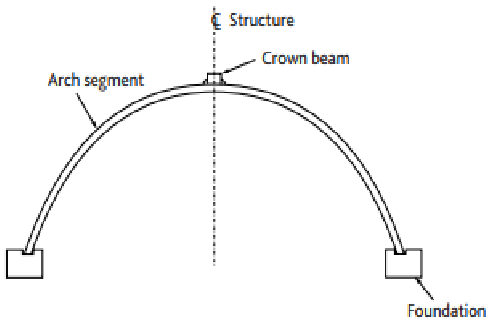
CON/SPAN system is widely used in Canada, the Caribbean, Central and South America, Korea and Japan. CON/SPAN precast arch units are two-hinged arches with vertical legs and variable thickness haunches. The spans range from 3.7m to 26.5m, and are efficiency in carries heavy loads at low stress levels. Besides, it consists of a curved surface sheds water and salts to increase life cycle length. Table 2.4 shows span and arch segment for CON/SPAN Bridge System.

Table 2.4: Span and Arch Segment for CON/SPAN Bridge System
(Crossing.Culverys.Bridges.Contech, 2015)

Type	Span (m)	Type of Arch Segment
B-Series	3.7-18.3	Single leaf
O-Series	4.0-19.8	Single leaf
	20.1-26.5	Double leaf

TechSpan system was developed in Spain by Groupe TAI in 1989 and it is currently used worldwide and supplied by the Reinforced Earth Company. It consists of segmental precast units forming a three-hinged arch structure. TechSpan utilizes the concept of a funicular curve. The span of the arches ranges from about 5 m to 20 m and the height of the arch ranges from about 30% to 70% of the span depending on the applications (Hutchinson, 2004). Table 2.5 shows span and arch segment for TechSpan Arch System.

Table 2.5: Span and Arch Segment for TechSpan Arch System (Precast Concrete Arch Structures-Technical Guide No.12, 2009)

Type	Span (m)	Type of Arch Segment
TechSpan	5.0-20.0	Twin leaf 

The NUCON ARCH was developed by Thorburn Colquhoun based on the use of purpose made plain concrete clocks. The blocks may be cast to any shape to allow interlocking whilst retaining the ability to absorb movement within the joints (Wakeman, 1995). The tropical arrangement is shown in Figure 2.2.

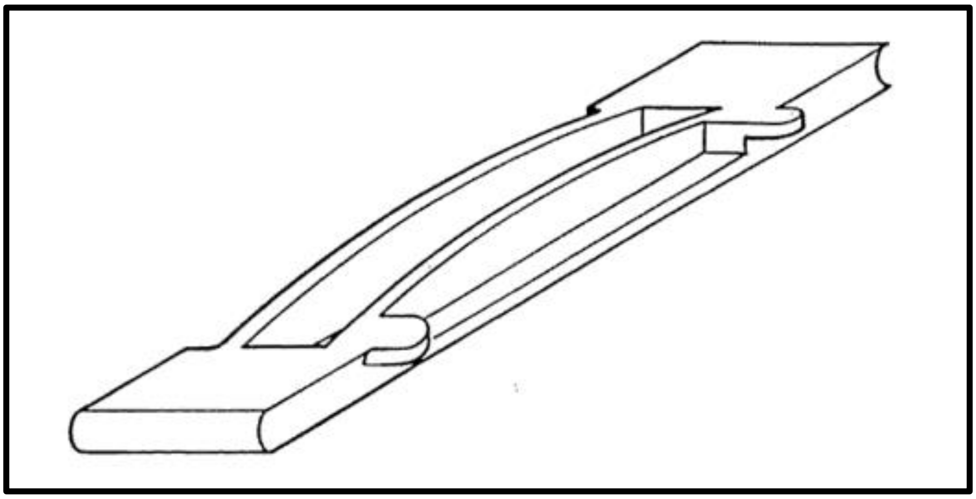


Figure 2.2: Typical NUCON Arch unit (Wakeman, 1995)

Concrete-Filled, Fiber Reinforced Polymer (FRP) Tube Arch applies the circular concrete section with FRP wrapped. The thin-walled hybrid composite tubes developed at the University of Maine are fabricated from a combination of E-glass and carbon fiber braid infused with vinyl ester resin. It functions as confinement, tension and shear reinforcing, eliminating the need for conventional steel rebar (Dagher et al, 2012). The "Bridge-in-a-Backpack" System which used the concrete-filled FRP tube arch was developed in 2001 by University of Maine. It consists of a single leaf arch segment and the spans of arch ranged from about 10.7 m to 19.8 m. The "Bridge-in-a-Backpack" System is shown in Figure 2.3.

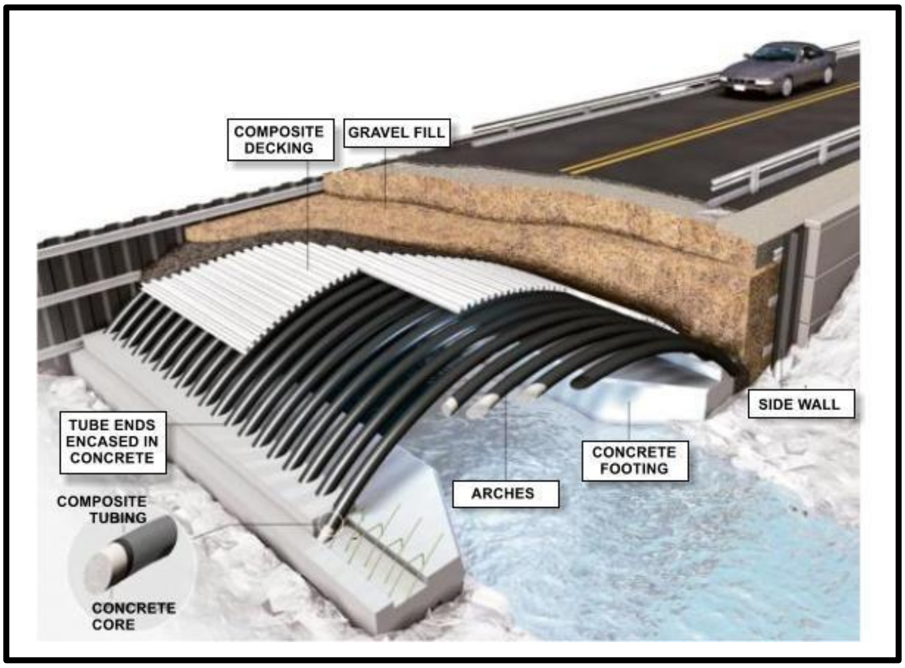
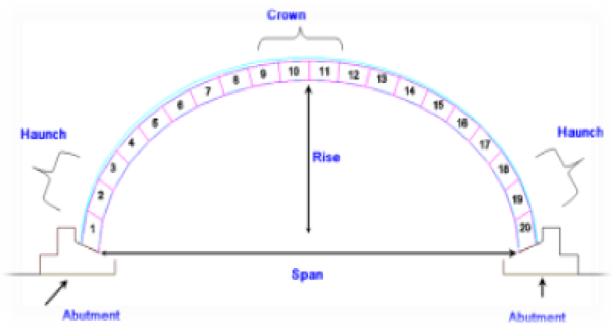


Figure 2.3: Concrete-Filled, Fiber Reinforced Polymer (FRP) Composite Tubes, "Bridge-in-a-Backpack" System (Advanced Infrastructure Technologies, 2013)

The FlexiArch system used masonry arch bridge principles but applied the modern precast concrete technology. The system was developed by Queen's University Belfast together with Macrete. FlexiArch contains no corrodible reinforcement, and not prone to concrete cracking (Macrete Brochure, 2012). The typical span and arch segment for FlexiArch system is shown in Table 2.6.

Table 2.6: Span and Arch Segment for FlexiArch System (Ong et al., 2014)

<table>
<tr><th>Type</th><th>Span (m)</th><th>Type of Arch Segment</th></tr>
<tr><td>FlexiArch</td><td>Up to 10</td><td rowspan="2">Single leaf

</td></tr>
<tr><td>Double Radius FlexiArch</td><td>8-15</td></tr>
</table>

The Rivo CS-P Series Arch system with a new corrugated arch section was developed and patented by Rivo Precast Sdn Bhd in 2008. The section has been proven to have higher stiffness and substantial material in which the self-weight is minimized by approximately 30 - 40% of equivalent solid rectangular section. Besides, the corrugated section also provides unique aesthetic value and ability to span beyond limit of 25.6m (Tan et al., 2013). Table 2.7 and Figure 2.4 shows span and arch segment for Rivo CS-P Series Arch System and its proposed arch geometry.

Table 2.7: Span and Arch Segment for Rivo CS-P Series Arch System (Product Brochure: Rivo Precast Concrete Closed Spandrel Panel Arch by Rivo Bina Sdn Bhd, 2013)

Type	Span (m)	Type of Arch Segment
Rivo CS-P Series	6.5-30.0	Twin leaf

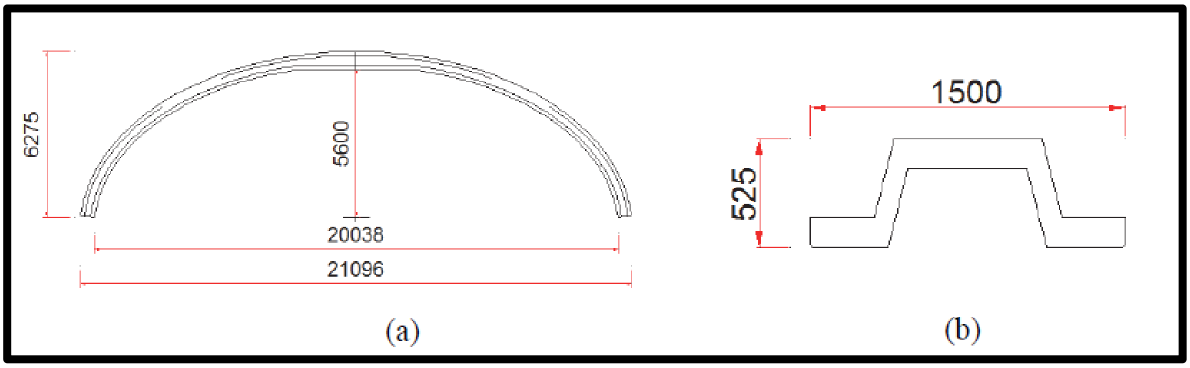


Figure 2.4: Proposed Arch Geometry (a) Parabolic Arch Profile (b) Corrugated Section (Tan et al, 2013)

The Pearl-Chain Bridge system was developed in Denmark in 2013. Pearl-Chain arches consist of a number of straight pre-fabricated concrete elements called Super-Light decks which are post-tensioned together into a desired shape by post-tensioning cables (Halding & Hertz, 2015). A new concept of "sandwich arch", where a prestressed concrete top plate above the fill allows for construction of long bridge spans up to more than 30m. The Pearl-Chain Bridge did not work on the soil structure interaction as the rise/span ratio of the bridges was relatively shallower. Figure 2.5 represents the Super-Light Deck section of Pearl Chain Bridge System.

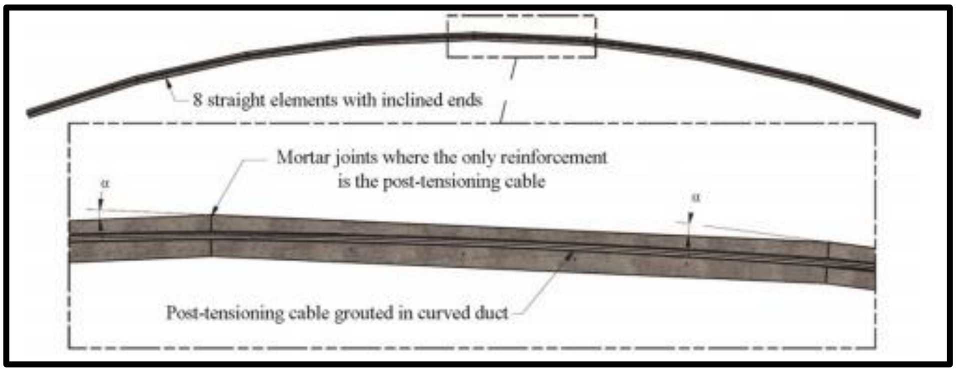


Figure 2.5: Side Elevation of a Pearl-Chain Arch (Halding & Hertz, 2015)

2.3 Analysis of Back Filling Materials

Callaway et al. (2012) studied the influence of backfill on masonry arch bridge and confirmed that passive restraint and live load distribution both contribute significantly to bridge-carrying capacity, and that, even comparatively simple limit analysis software can model the various effects remarkably well.

Gilbert et al. (2007) performed both small and full-scale model research on bridges filled with crushed limestone and/or soft clay and proved that the limestone filled arch bridge can carry significantly more load than its clay filled counterpart.

Brourke et al. (2014) stated that two different types of fill have been tested on the FlexiArch bridges: a low-strength concrete backfill and a granular backfill. The load capacity granular backfill found to be greatly influenced by the gradation of gravel while the strength of Flexi Arch bridges was much higher when using concrete backfill rather than granular backfill. Furthermore, concrete backfill also eliminate the needs of compaction, inhibits the ingress of flood water and allows the bridge to be used for traffic a few days after installation.

Hutchinson (2004) discussed the analysis, design and construction of TechSpan. The fill material around the arch is divided into three zones. Zone 1 is selected granular material placed 1.0 m around the back of the arch structure compacted through a light walk. The type of fill used in Zone 2 and 3 is not prescribed. Compaction of the material in Zone 2 may be achieved with heavy compaction equipment without any vibration while compaction is achieved with heavy compaction equipment with vibration in Zone 3. Figure 2.6 illustrates the zoning of backfill of TechSpan Arch.

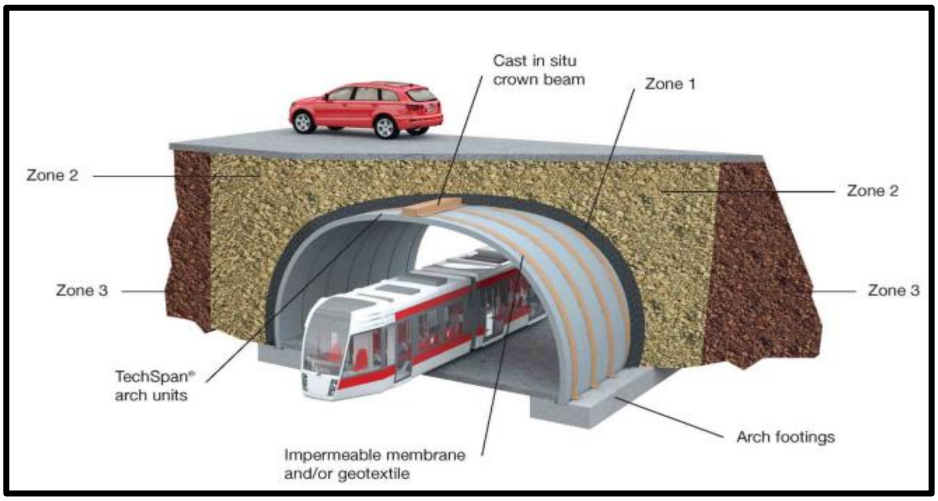


Figure 2.6: Zoning of Backfill for TechSpan Arch (Reinforced Earth Co. Ltd, Technical Information, 2014)

Lund et al. (2016) tested and compared the strength and durability properties of three different types of fill material: (i) sub-base gravel, (ii) cement-stabilized gravel, (iii) pervious concrete, to find the most optimal fill for a new idea of bridge system called Pearl-Chain Bridges. The pervious concrete possesses good strength properties, shear transferring, improved freeze–thaw durability and permeability which positively influence the lifespan of the bridge. Therefore, it is suitable for Pearl-Chain Bridges.

However, high material price was a concern compared to sub-base gravel and cement-stabilized gravel.

BEBO Arch Systems, BEBO System Technical Documentation: Installation Guide (2009) divided the fill material into 3 zones. Zone A requires natural ground or fill material with properties, filling procedures and compacting procedures, equal to that of normal road embankments. The material used in zone B should be granular and should not exceed 75 mm in diameter and the gradation should fall within the limits stated in the installation guide. Granular materials with a high content of silt and clay are unacceptable as backfill in zone B, unless they are stabilized with cement to improve their strength. Zone C describes the road section and consists of gravel, asphalt, or concrete. The critical zones for backfilling are as indicated in Figure 2.7.

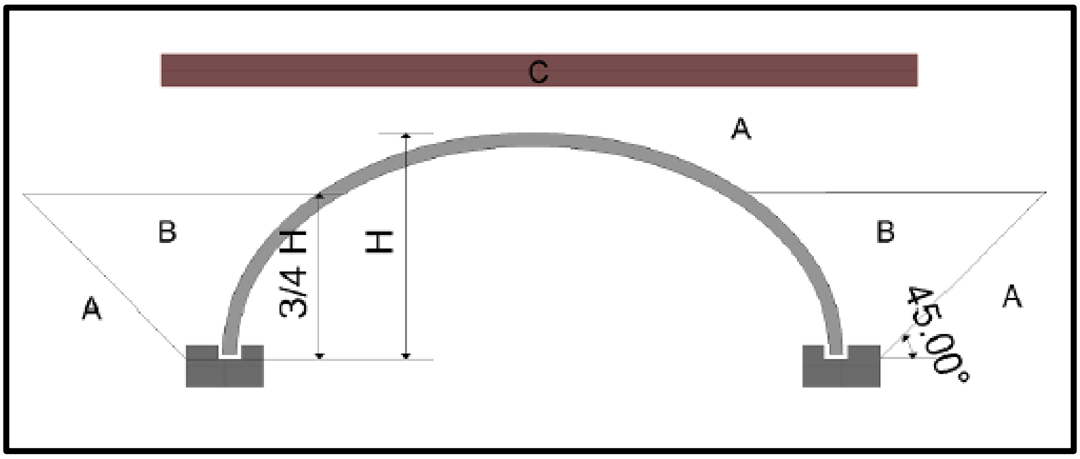


Figure 2.7: Critical Zones for Backfilling (BEBO Arch Systems Installation Guide, 2009)

2.4 Properties of Lean Concrete Fill

Density of Controlled Low Strength Material (CLSM): A highly flowable, lean concrete mix consisting of a mixture of cement, fly ask, densely graded mineral aggregates, water and admixture, when used as backfill of excavations is between 1600 – 2080 kg/m^3 in the as-placed condition as determined by ASTM D6023 (City of San Bruno, 2012).

BS 5400-2:2006 stated that the mean values for normal-weight concrete are derived from the Equation 2.1:

$$E_{c,28} = K_o + 0.2f_{cu,28} \qquad (2.1)$$

where, $E_{c,28}$ is the static modulus of elasticity at 28 days (in kN/mm^2);

K_o is a constant closely related to the modulus of elasticity of the aggregate (taken as 20 kN/mm^2 for normal-weight concrete);

$f_{cu,28}$ is the characteristic cube strength at 28 days (in N/mm^2).

For lean concrete of grade 15, the elastic modulus equal to 23 kN/mm^2 calculated from the equation above. Jones (1966) studied the elastic and strength properties of cemented materials in road bases. The results obtained on the tested specimen also showed that elastic modulus of lean concrete equal to approximately 24 GPa.

2.5 Summary

Based on the literature carried out, the research on the structural behaviour of precast concrete arch segment with different overfill design is found to be limited. Therefore, there is not much related information that related can be found from the literature review.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Finite element analysis using PLAXIS software is carried out to analyse and compare the precast concrete closed spandrel arch in response to different overfill design. A standard parabolic arch profile for the precast concrete closed spandrel arch bridge accordance to Rivo CS-P Series Arch System is used in the computational analysis. The dimension of the arch profile is shown in Figure 3.1. The arch section is designed as a single element with both ends pinned. A standard rectangular section with thickness of 350mm, unit length of 1800mm as shown in Figure 3.2 from the section provided by BEBO Arch of arch profile 21700T is adopted in this study (Precast Arch System, 2015).

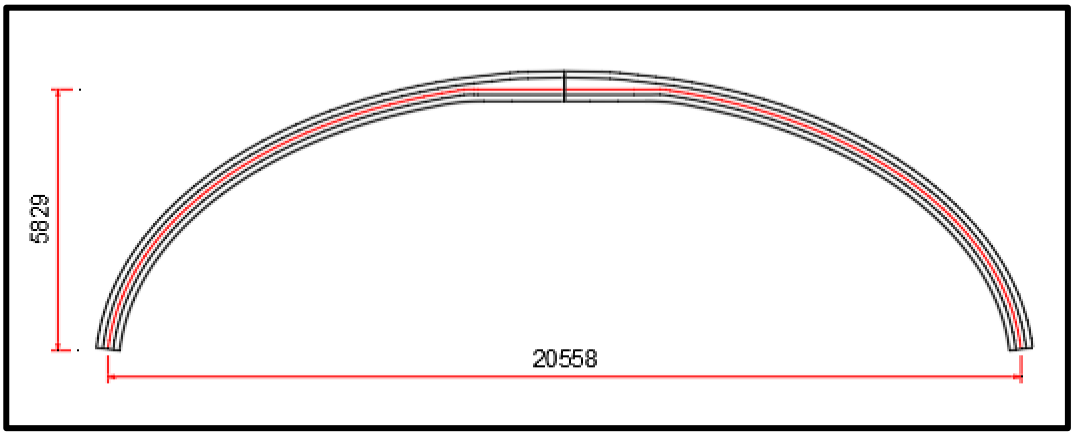


Figure 3.1: Dimension of Parabolic Arch Profile Used in Computational Analysis

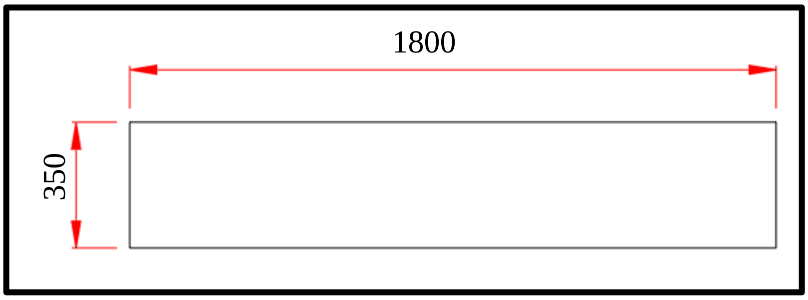


Figure 3.2: Cross Section of the Precast Concrete Arch Panel

3.2 Model of Overfill Design

The following considerations are taken into account in the modelling and analysis. The dumping of backfill is not permitted within 1m of the structure as shown in Figure 3.3. The backfill must be placed and compacted in layers not exceeding 0.5 m in their compacted state. The maximum difference in the surface levels of the fill on opposite sides of the arch must not exceed 1.0 m (BEBO Arch System Installation Guide, 2009).

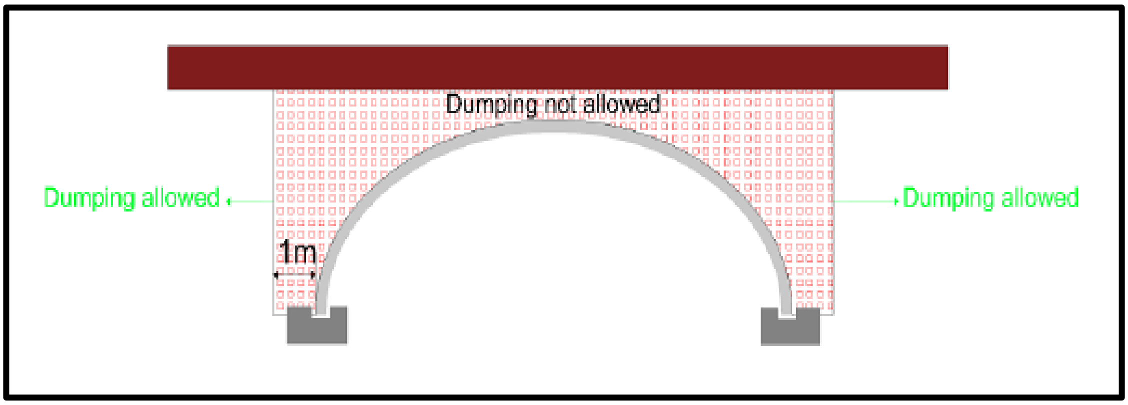


Figure 3.3: Restrictions on Dumping of Fill Material (BEBO Arch Systems Installation Guide, 2009)