FINITE ELEMENT ANALYSIS OF ARCH CONCRETE SLAB SYSTEM FOR UPPER FLOORS

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ABSTRACT

Industrialized Building System (IBS) products are very promising in Malaysia construction industry nowadays. Therefore, the Arch concrete slab system was innovatively designed to simplify the upper floors construction. This slab system has potential as an alternative method to design and build of the upper floors slabs in any multi storey buildings. The slab is constructed by using the precast concrete arch as permanent formwork and precast concrete beam made of lightweight concrete. The advantages of applying Arch concrete slab system are such as giving the extra strength to the structures, reduce the time of construction, environmental friendly, easy installation with minimum equipment and machineries needed, and unnecessary for using the scaffoldings during construction. This research is about the design and finite element analysis of precast arch concrete permanent formwork, precast concrete beam and Arch concrete slab system aided with an engineering software analysis such as ANSYS. The proposed model is designed so that it does not fail under deformation and shear stress. The results from the analysis shows that the proposed model of precast arch concrete as permanent formwork, precast concrete beam and Arch concrete slab system are safe and suitable for design and build for upper floors slabs in multi storey buildings.

ABSTRAK

Produk pembinaan sistem perindustrian (IBS) menjanjikan peluang yang amat cerah dalam industri pembinaan di Malaysia pada masa kini. Oleh yang demikian, satu sistem papak telah direka secara inovasi untuk mempermudahkan pembinaan papak di tingkat atas iaitu sistem papak konkrit berlengkung. Sistem papak ini dilihat mempunyai potensi sebagai salah satu kaedah alternatif untuk mereka bentuk dan membina papak untuk tingkat atas dalam mana-mana bangunan bertingkat. Papak ini dibina dengan menggunakan acuan kekal konkrit berlengkung pasangsiap dan rasuk konkrit pasangsiap yang diperbuat daripada konkrit ringan. Kelebihan dalam mengaplikasikan sistem papak konkrit berlengkung adalah seperti memberi kekuatan tambahan kepada struktur, mengurangkan masa pembinaan, Mesra alam sekitar, pemasangan yang mudah dengan penggunaan peralatan dan jentera yang minimum, dan tidak memerlukan perancah semasa pemasangan. Kajian ini adalah tentang reka bentuk dan analisis unsur terhingga acuan kekal konkrit berlengkung pasangsiap, rasuk konkrit pasangsiap dan sistem papak konkrit berlengkung yang dibantu dengan perisian analisis kejuruteraan seperti ANSYS. Model yang dicadangkan direka supaya tidak gagal di bawah ubah bentuk dan tegasan ricih. Hasil daripada analisis yang dilakukan, ia menunjukkan bahawa model yang dicadangkan untuk acuan kekal konkrit berlengkung pasangsiap, rasuk konkrit pasangsiap dan sistem papak konkrit berlengkung adalah selamat dan sesuai diaplikasikan untuk membina papak untuk tingkat atas dalam mana-mana bangunan bertingkat.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Slab is very important in building structure, which can be used for foundations, porches, decks, patios, and driveways. In the structures, slab is defined as a shallow, reinforced-concrete structural member that is very wide compared with depth. Also, there are many types of slab, such as flat slab, corrugated, ribbed slab, and wafer slab. In the conventional construction, the flat slab is always chosen because it is easy to design and construct. But nowadays, the innovative constructions are dominating the design and construction to minimize the construction cost and material used and much environmental friendly.

Therefore, the design for a new slab system is invented. The Arch Concrete Slab System for Upper Floors seems to have potential in Malaysia construction. Arch Concrete Slab System is the slab that constructed by using precast arch concrete as permanent formwork and precast concrete beam by interlocking system. It is an innovation design slab system which is applicable to the upper floors. Although the function of its formwork is same as ordinary, but there are advantages of this slab formwork in terms of its geometry such as predetermined contribution in strength of structures, beside from the reducing the time of construction, environmental friendly, easy installation with minimum equipment and machineries needed, and unnecessary for scaffoldings during construction.

Therefore, the structural analysis of Arch Concrete Slab System is carried out by using the manual calculation and by aided with the engineering software analysis. Recently, the application of the engineering software design seems necessary to reduce the time and errors in design calculation. The complicated formulas and the precise analysis are easily solved by using the right software. ANSYS Software is an example of software that can be used to analyse the structural design.

In order to verify the feasibility on the implementation of Arch Concrete Slab System, the design of proposed model for this system is analysed in term of its shear and deformation. In this study, the design of proposed model of Arch Concrete Formwork and Arch Concrete Slab System is analysed structurally by using ANSYS Software. The analysis is carried out on deformation, shearing stress, and maximum principal stress on model designed. As the results, the variation of deformation, shearing stress, and maximum principal stress of the proposed model is obtained and compared with its limit state.

1.2 PROBLEM STATEMENT

Nowadays, construction of building gained high demand. The clients not only demands for low cost construction, but also demand for the quality such as artistically design and very secure. Therefore, there is an idea by implement the Arch Concrete Slab System in constructions. This system using Arch Concrete as precast permanent formwork, which is can reduce the waste from formworks and increase the strength of the slab structures.

Therefore, continuity from the previous study on Arch Pan Slab design, this study will be focus on design analysis of the Arch Concrete Slab System and its formwork by using ANSYS software. It is to determine either the Arch Concrete Slab System is adequate and safe for construction or not. This study will design and analyse about the deformation, shearing stress, and maximum principal stress on the proposed model.

Since the proposed model of the Arch Concrete Slab System is very difficult to analyse by manual calculations, the engineering software like ANSYS is used to obtain the results. Hence, to understand more about this innovation, the finite element analysis by using ANSYS Software is conducted to verify the feasibility of the Arch Concrete Slab System implementation as an alternative for constructing the slabs for upper floors.

The capacity limit for the Arch Concrete Slab System also must be defined. Therefore, the application of code of practice is adapted to calculate the capacity limit. Malaysia has using British Standard, Euro code and its own code of practise in designing the building structures.

1.3 OBJECTIVES OF THE STUDY

The objectives of this study are:

i. To design and analyse the Arch Concrete Slab System.

ii. To design and analyse the arch concrete permanent formwork.

iii. To verify the feasibility of Arch Concrete Slab System using Finite Element Analysis.

1.4 SCOPE OF THE STUDY

Scope of study in this analysis will be specifying only by covering the topics on:

i. Design and analyse the Arch Concrete Slab System using manual and ANSYS Software.

ii. Design and analyse the Arch Concrete formwork.

1.5 SIGNIFICANT OF THE STUDY

Slab is very important in building structure, which is can be used for foundations, porches, decks, patios, and driveways. In the structures, slab is a shallow, reinforced-concrete structural member that is very wide compared with depth. In the conventional construction method, the flat slab is always chosen because it is easy to design and construct. But nowadays, the innovative constructions are dominating the design and construction to minimize the construction cost and material used.

Arch Concrete Slab System is an innovative construction was proposed to become alternative choice for constructing the upper floor slabs. This system have the advantages such as giving the extra strength to the structures, reduce the time of construction, environmental friendly, easy installation with minimum equipment and machineries needed, and unnecessary for using the scaffoldings during construction.

This study also encourages the usage of software in analysing the designed products. Therefore, it can be used as reference in the future on how to use the ANSYS Software in slab design analysis.

CHAPTER 2

LITERATURE REVIEW

2.1 CONCRETE SLAB

This topic will introduce literally on concrete slab definition and the types of concrete slab system.

2.1.1 Introduction of Concrete Slab

Concrete slabs are floor systems of concrete and steel reinforcing. A Reinforced Concrete Slab is the one of the most important component in a building. It is a structural element of modern buildings. Slabs are supported on Columns and Beams. (Benzujk , 2010). According to McGraw-Hill Concise Encyclopaedia of Engineering, slab can be defined as 'a shallow, reinforced-concrete structural member that is very wide compared with depth'.

Construction of slab can be pre-cast or cast in-situ. Pre-cast slab is made in factory and then transferred to site when it's done. Meanwhile, cast in-situ slab need formwork to be casted. The concrete is pour after the reinforced bars and formwork are done. Practically, most of contractors are preferred to the cast in-situ slab. (Benzujk , 2010).

2.1.2 Type of Concrete Slab

The design of suspended slabs can be classified into three types. Suspended slabs are slabs that are not in direct contact with the ground. They form roofs or floors above ground level. For a suspended slab, there are a number of designs to improve the strength-to-weight ratio. In all cases the top surface remains flat, and the underside is modulated (Randall Bullard, 2010). There are Corrugated Slab, Ribbed Slab and Waffle Slab. These types of slab are as shown in Figure 2.1, Figure 2.2, and Figure 2.3.

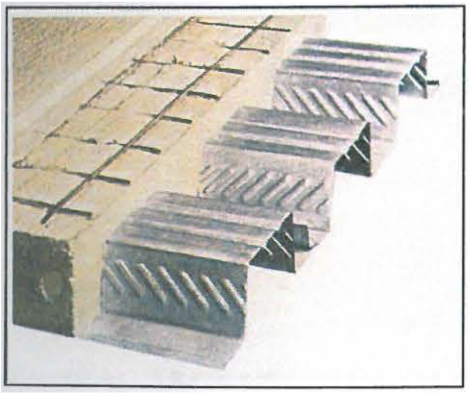

Figure 2.1: Corrugated Slab

Source: http://www.metecno.es

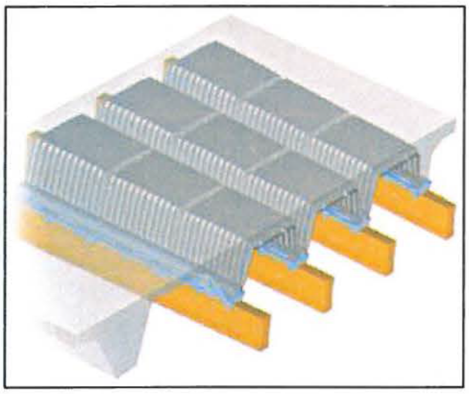

Figure 2.2: Ribbed slab

Source: http://www.geoplast.it

Figure 2.1 shows the corrugated slab type. It is usually where the concrete is poured into a corrugated steel tray. This improves strength and prevents the slab bending under its own weight. The corrugations run across the short dimension, from side to side. (Benzujk , 2010).

Figure 2.2 shows the sample of ribbed slab, which is giving considerable extra strength on one way direction. The space between the ribbings can be used for the passage of cables, wires, sanitary fittings, and the installation of lights and air conditioning system. (Benzujk , 2010). Ribbed slabs are made up of wide band beams running between columns with equal depth narrow ribs spanning the orthogonal direction. A thick top slab completes the system (McGraw-Hill, 2002).

Figure 2.3: Waffle slab

Source: http://www.archiproducts.com

Waffle slab is as shown in Figure 2.3. This type is increasing strength in both directions. The waffle slab formed is suitable for buildings open to the public and subject to crowding. (Benzujk , 2010).

"The reinforcement design for the slab can be divided into two conditions, such as one way slab and two-way slab". (Mac Gregor, J. G., 1992).

"A one-way slab needs moment resisting reinforcement only in its short-direction. Because, the moment along long axes is so small that it can be neglected. When the ratio of the length of long direction to short direction of a slab is greater than

2 it can be considered as a one way slab. These slabs are considered to be supported along the two long sides only even if there is small amount of support on the narrow end" (Randall Bullard, 2010). It is as shown in Figure 2.4.

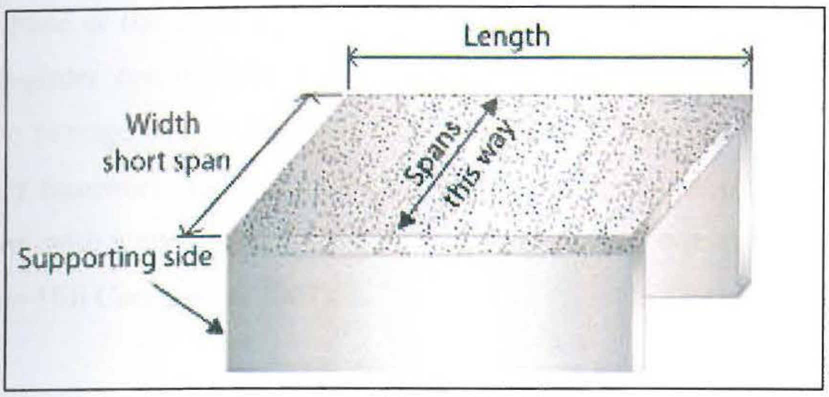

Figure 2.4: One-way slab

Source: http://toolboxes.flexiblelearning.net.au

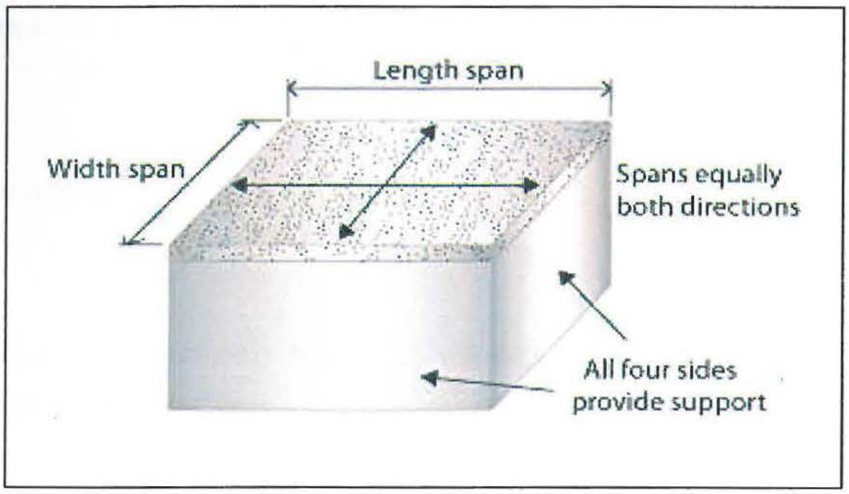

Figure 2.5: Two-way slab

Source: http://toolboxes.flexiblelearning.net.au

A two way slab needs moment resisting reinforcement in both directions. If the ratio of the lengths of long and short side is less than one then moment in both directions should be considered in design and the slab is supported equally on all four sides. This type is shown in Figure 2.5.

When a slab is supported directly on columns, without beams and girders, it is called a flat plate or flat slab. Although thicker and more heavily reinforced than slabs in beam-and-girder construction, flat slabs are advantageous because they offer no obstruction to passage of light (as beam construction does); savings in story height and in the simpler formwork involved; less danger of collapse due to overload; and better fire protection with a sprink-ler system because the spray is not obstructed by beams (The McGraw-Hill Companies, 2002).

2.2 FORMWORK OF SLAB

The scope of literature discussion on formwork of slab is only to introduce what are the slab formwork, and the type of formwork systems often used in construction.

2.2.1 Introduction to slab's formwork

The formwork is commonly built from wooden planks and boards, plastic, or steel. On commercial building sites today, plastic and steel are more common as they save labour. For low-budget sites, when laying a concrete garden path, wooden planks are very common. Formwork is the term given to either temporary or permanent moulds into which fresh concrete materials are poured (Chad Godwin, 2011)

The temporary formwork is the type of formwork that supports a fresh concrete before it's gained the strength. After the concrete is hardened in several days, the formwork is removed.

The structure called permanent formwork is just a support to control the shape of the fluid concrete until it gains strength. After the concrete has set the formwork may be left there permanently.

2.2.2 Type of slab formwork system

There are many different types of formwork which are used in building, for many different purposes. There are three main materials for creating formwork – traditional timber formwork, engineered formwork (usually a metal frame) and stay-in-place formwork systems (usually pre-made concrete systems). Using these types of formwork, there are a variety of different ways to create slabs and structures from formwork.

Traditional slab formwork as shown in Figure 2.6 is uses timber, masonry and carpentry to complete construction. The method works through tree trunks or other lumber supporting rows of stringers which are placed three to six feet or one to two meters apart with joints placed between the stringers. Between these stringers, joists are positioned apart upon which boards or plywood is placed. The stringers and joists are usually from lumber.

Metal beam slab formwork is much the same as the traditional slab formwork method, the only difference being that steel is used instead of timber and metal props are used instead of supports. This system is reusable and more methodical than the traditional method. The finish of the concrete is smoother and the formwork is easier to remove after the cement has cured. The installation is shown in Figure 2.7 below:

Figure 2.6: Traditional slab formwork

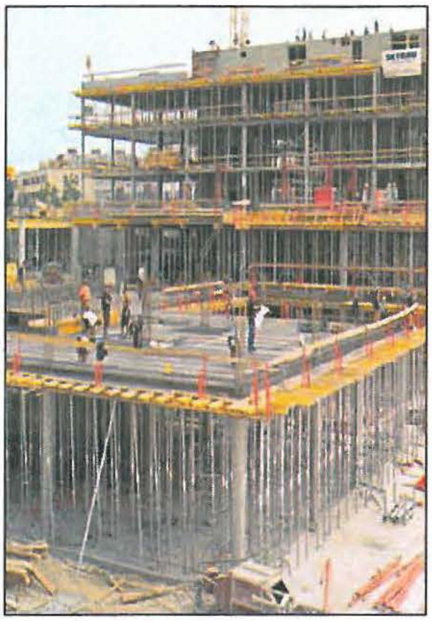

Figure 2.7: Metal beam slab formwork

Source: http://www.builderbill-diy-help.com

Figure 2.8: Modular slab formwork

Source: http://www.formwork1systems.com

Figure 2.8 shows the modular slab formwork, which is created from pre-made timber modules or modules made from steel or aluminium. These are usually produced in a factory offsite and added to construction once completed. Formwork modules can be removed after concrete sets leaving only beams in place prior to achieving design strength.

Another type of formwork is table or flying form systems, as shown in Figure 2.9. These consist of slab formwork tables which are reusable. These tables do not have to be dismantled and can be used in high buildings where cranes or elevators are used to lift the tables. Once the table is positioned, the space between the wall and table is filled. This type of formwork is a huge saver of both labour and time and is a favourite of construction engineers and architects. However, table formwork is best used in the construction of large, but simple structures.

Figure 2.9: Flying form systems

Source: http://www.mesaimalat.com

2.3 ARCH CONCRETE SLAB SYSTEM

This topic will discuss on the previous study and laboratory test made by Mohamad Fathi Kamil and Brendan Anak Richard Tegang. The experimental results and design of the model is used as references.

2.3.1 Introduction to arch concrete slab system

Arch Concrete Slab System is an innovative slab system whereby the slab is constructed by using permanent arch formwork. Figure 2.10 shows the examples of Arch Concrete Slab System model which is constructed by using the pan arch permanent formwork. The design dimensions of the model as shown in Figure 2.11.

Figure 2.10: Arch concrete slab system model

Source: Mohamad Fathi, 2010

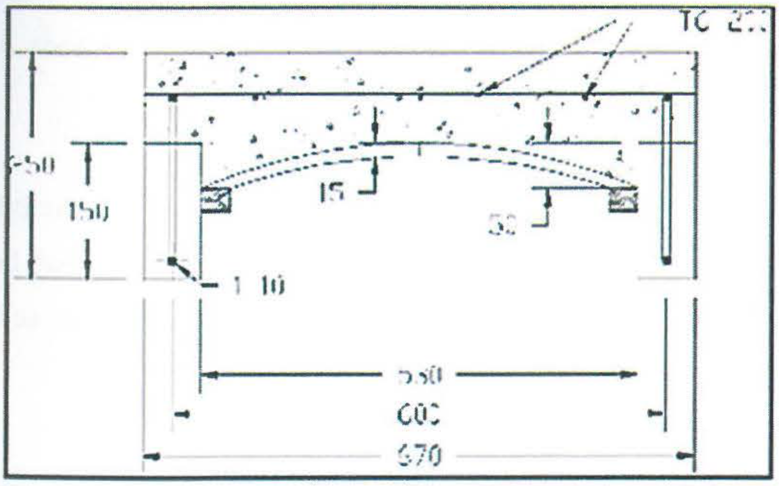

Figure 2.11: Arch concrete slab system model dimension

Source: Mohamad Fathi, 2010

Mohamad Fathi, 2010, state that the dimension of the pan arc slab constructed for laboratory testing is with 150mm height of beam, 100mm height of slab, 600mm x 600mm width and length of pan formwork and 1.8m x 1.8m sample of slab system.

2.3.2 Theories of arch in structure

"The development of the arch was one of the most significant events in the history of structural design. The arch was well known to the ancient, proved by many stone arches constructed by Romans and even older races, and arch remains to the present day as one of the most useful in structures construction. Its employment being frequently dictated both by aesthetic and utilitarian consideration". D. Matthew S. 2007.

According to M.R Maheri, 2005, arches can be polygonal, circular, parabolic, elliptical and other curved shapes. Its advantages are such as the ability of the arch to transfer vertical loading into manageable compressive stresses, thus significantly eliminates the tensile stresses in spanning an open space. This is very useful in building material such as stone and concrete, which is can firmly resist compression, but weak against tension, shear or torsion stress that applied to them.

In addition, arch also carries most of the load axially with bending moment greatly reduced due to the curvature of the arch. This geometry allows significant spans to be achieved as all compressive forces are held together in a state of equilibrium.

One of the important of understanding arch behaviour concepts is moment, which is the tendency of a force to produce movement or rotation, around a point. A moment is calculated by multiplying the magnitude of the applied force with its distance from a fulcrum point, which rotation occurs. This is called as moment arm. A simple example of these concepts applied to the human body as shown in Figure 2.12

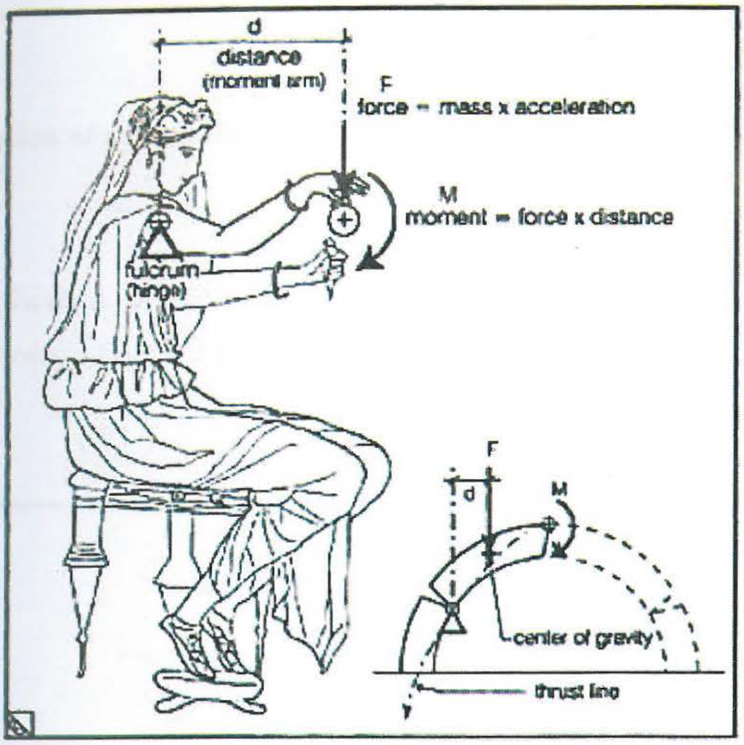

Figure 2.12: Concept of moment

Source: Brendan, 2010

A woman holds a bottle in her right hand with her arm partially extended in front of her. The weight of bottle applied a force (through gravitational pull) to the end of her arm. The fact that her arm is extended creates a moment arm extending from her hand to her shoulder joint, which acts as the fulcrum of rotation. If the woman in Figure 2.12 were extend her arm straight, the distance (d) become greater causing the moment increase even though the force remain same. She feels the stress in her arm muscles and become tired quicker (Brendan, 2010).

Correspondingly, in an inert material like stone and brick, the stress is resisted by the ways in which rotation the atoms are bond to each other within the material. The concept of moment relates to the behaviour of arches because an arch will tend to fail when a section of its moves around a fulcrum point

2.3.3 Application of arch theory in arch concrete slab system

The application of the theories of arch in Arch Concrete Slab System is illustrated as shown in Figure 2.13 below:

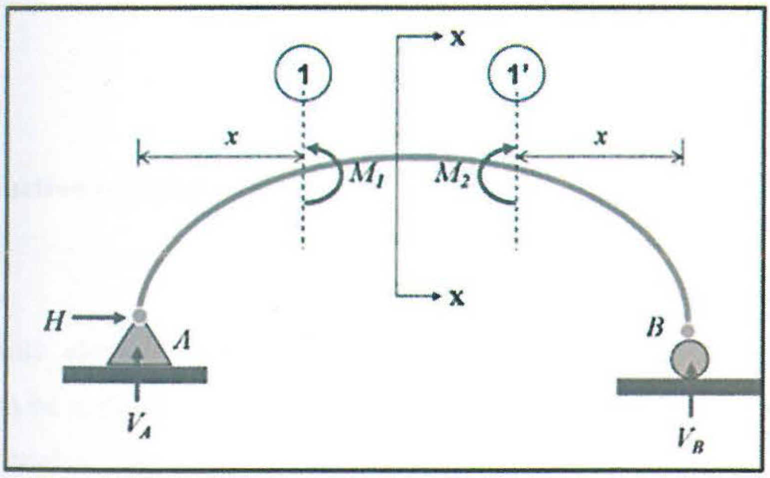

Figure 2.13: Arch theory in structure

Source: M. A. Bradford, 2002

Figure 2.13 show the concept of the arch theory in structure, which is when the structure applied with the loading, the moment and reaction that occur at the arch is as describe in figure. M_1 and M_2 are representing Moment, V_A and V_B represent the vertical reactions.