COMPARISON OF THE STRUCTURAL BEHAVIOR BETWEEN CONVENTIONAL BEAM AND BAND BEAM

by

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ABSTRACT

Beams are the significant structural elements that transmit the tributary loads from floor slabs to vertical supporting columns. Conventional beams are normally deep in order to sustain the bending moment which is resultant of the dead load and live load imposed by the slab. Consequently, the understanding of behavior of beams is very important to a designer before making any assumptions and decision. The objective of this study is to obtain the minimum construction cost for various deflection ratios. After that comparison between the structural behavior between critical conventional beams and critical band beams in terms of bending moment and shear force from the deflection ratio which will give the optimum cost is made. This study operated two types of analysis with EsteemPlus software, namely to analyze a car park building which is constructed with conventional beams and to analyze a car park building which is constructed with band beams. The result shows that the optimum building cost will be obtained when the deference deflection ratio is 30% for conventional beam system and 10% for the band beam system. Optimum building cost of band beam is higher than conventional beam by 16.09%. Difference between conventional beams and band beams in terms of bending moment is an average 21.12% for continuous beams in x-direction and an average 10.34% for continuous beam in y-direction. However, the difference in terms of shear force is not conspicuous comparatively, with an average of 16.17% and 15.83%, respectively. The building height can be reduced 0.825m if band beam is applied.

ABSTRAK

Rasuk merupakan elemen struktur yang penting untuk memindah beban dari papak ke tiang. Kedalaman rasuk biasanya direkabentuk dengan dalam untuk menanggung momen lenturan yang dihasilkan oleh daya mati dan daya hidup yang bertindak di atas papak. Jadi memahami kelakuan rasuk adalah penting untuk perekabentuk supaya dapat memastikan langkah-langkah yang diambilkira adalah bersesuaian dan berkesan. Objektif kajian ini adalah untuk mendapatkan jumlah kos pembinaan yang minimum dengan mengawal pesongan rasuk. Selepas itu membuat perbandingan tingkah laku struktur di antara rasuk biasa dan rasuk cetek dari segi momen lentur dan daya ricih bagi pesongan tersebut. Kajian ini akan membuat dua jenis analisis dengan menggunakan perisian EsteemPlus, iaitu menganalisis bangunan tempat letak kereta bertingkat yang dibuat dengan rasuk biasa dan satu lagi yang dibuat dangan rasuk cetek. Keputusan yang didapati menunjukkan bahawa perbezaan nisbah pesongan sebanyak 30% untuk sistem rasuk biasa dan 10% untuk sistem rasuk cetek akan memberi kos yang minimum. Kos bagi rasuk cetek adalah lebih tinggi daripada kos rasuk biasa dengan perbezaan sebanyak 16.09%. Perbezaan antara kedua-dua rasuk dari segi momen lentur sebanyak 21.12% bagi rasuk selanjar dalam arah x dan 10.34% bagi rasuk selanjar dalam arah y. Manakala perbezaan dari segi daya ricih bagi kedua-dua rasuk adalah tidak ketara iaitu 16.17% dan 15.83%. Ketinggian bangunan dapat dikurangkan sebanyak 0.825m jika rasuk cetek digunakan.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Band beams are wide shallow beams and it is normally applied in the car park building. The shape of band beam is illustrated in Figure 1.1 and Figure 1.2. Conventional beams are normally deep to sustain the bending moment and to minimize the deflection so that it does not exceed the limit as required in the design code.

1.2 Problem statement

One of the problems faced by developed countries nowadays is the availability of land for development. Therefore, the demand for high-rise building is increasing. It is expected that more high-rise buildings will be built to accommodate the needs of an increase in population. Density of these high-rise buildings will become higher due to a higher occupancy rate for each unit land area. Inevitably, the height of high-rise buildings will be continually increased to meet this demand.

One of the factors to be considered when designing high-rise buildings is the lateral force caused by wind load. Increas of the height of buildings will automatically increase the lateral force. To solve this problem, the alternative way can be adopted is to reduce the inter-storey height of the building while maintaining the clearance of the building. This can be done by using a special beam which is known as band beam. The used of deep conventional beam with the required clearance of the building will increase the total height of that building. Consequently, the lateral forces exerted on the building which is dependant to the building height will be increased.

For unattractive function facilities such as car park they should be hiding from the sensitive location as shown in Figure 1.3. This will enhance the urban environment of the surrounding area where dense residential apartments may be located. The environment issue such as wind circulation of surrounding high-rise building should be taking into consideration.

One of the advantages of the application of band beam is to produce less storey height with the same effective clearance compare to conventional beam as shown in Figure 1.4. The M&E works will be easier to proceed for this less storey height and it will save a lot of cost. The other application of band beam is related to the usage of certain part of a building where the existence of deep conventional beam is not favorable or the floor-to-floor height is critical especially for multi-storey car park.

Construction cost is a common issue in the construction industry. There is a need to estimate the cost to obtain the optimum construction cost by considering all the important variables such as material used, design feature and size of beams. A comprehensive design will be provided an economical building.

This project will analyze the cost of the building with different deflection ratios for the conventional beam and band beam and obtained the optimum cost. And this study will compare two types of beam behavior in term of bending moment and shear force depend on the deflection ratio which will obtain optimum cost. With the understanding of the different behavior between band beam and conventional beam, special consideration in design could be taken by the designers when they deal with these beams.

1.3 Objectives

The objectives of this project are to:

a. investigate and evaluate the structural behavior between conventional beam and band beam in term of bending moment, shear force with the optimum construction cost

b. compare the application of conventional beam and band beam in term of total building cost, material used and total building height for the multi-storey car park

1.4 The importance and the benefits of the project

This project wills enhance the serviceability of band beam especially for car park building. The result of this study can be used to assess the practicability of the application for band beam and as the baseline design data for the structural designer.

1.5 Report outline/Layout

The general introduction of this chapter is about the problems statement and the objective of the study. Chapter 2 is a literature review related to the beam properties and band beam system. The method of implementation of this project from beginning until the generation of the result by using the software EsteemPlus 6.2 is present in chapter 3.

The results from analysis will be discussed in Chapter 4. Chapter 5 is the conclusion of the project.

Figure 1.1: Band beam

Figure 1.2: Band beam used in car park

Figure 1.3: Multi-storey car park building

Figure 1.4: Less storey height car park building

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Reinforced concrete is a composite material of steel bars embedded in a hardened concrete. It is widely used material in Malaysia construction industry. Hence, the basic understanding of the fundamentals of reinforced concrete is essential for every civil engineer.

2.2 History of the concrete structures

Concrete is the most important material used in building construction, consisting of a hard, chemically inert particulate substance, known as an aggregate (usually combination from different types of sand and gravel), that is mixed together by cement and water. Concrete is used because of its high compressive strength.

In 1756, British engineer, John Smeaton made the first modern concrete by adding pebbles as a coarse aggregate into the cement. In 1824, English inventor, Joseph Aspdin created the first true artificial cement by burning ground limestone and clay together known as Portland cement. The burning process changed the chemical properties of the materials and Joseph Aspdin created stronger cement than what using plain crushed limestone would produce.

The first reinforced concrete was invented by Joseph Monier in 1849, who received a patent in 1867. Joseph Monier was a Parisian gardener who made garden pots and tubs of concrete reinforced with an iron mesh (Nawy, 2000). Reinforced concrete combines the tensile or bendable strength of metal and the compression strength of concrete to withstand heavy loads. Joseph Monier exhibited his invention at the Paris Exposition of 1867. Besides his pots and tubs, Joseph Monier promoted reinforced concrete for use in railway ties, pipes, floors, arches, and bridges. In 1906, C. A. P. Turner developed the first flat slab without beams (Nawy, 2000).

2.3 History of the concrete beams

Beams have been used since darkish antiquity to support vertical loads. For example, as a roof beams supported by massive columns, or as a bridges thrown across river. The Egyptians invented the colonnaded building that was the inspiration for the classic Greek temple. Even with the scarcity of timber in Egypt, a wooden beam was used as a structural element to support the load. Stone beams also used as structural element and it could be used only for very short spans and light loads like door lintels. It’s because of the brittleness of stone.

At 15th century, Galileo studied beams. He developed a hypothesis concerning bending stress that was sensible but not correct. A better theory was not widely understood until more than 60 years later. The theory of beams was only perfected in the late 17th century with the rise of the science of elasticity.

2.4 Properties of reinforced concrete

Concrete is arguably the most important building material, playing a part in all building structures. Reinforced concrete is a strong durable building material that can be formed into many varied shapes and size ranging from a simple rectangular column, to a slender curved dome or shell. Its utility and versatility is achieved by combining the best characteristics of concrete and steel. Some of the widely differing properties of these of two materials that are list in Table 2.1:

Table 2.1: Properties of concrete and steel

(W. H. Mosly et al., 1999)

	Concrete	Steel
Strength in tension	Poor	Good
Strength in compression	Good	Good but slender bars will buckle
Strength in shear	Fair	Good
Durability	Good	Corrodes if unprotected
Fire resistance	Good	Poor – suffers rapid loss of strength at high temperature

2.5 Properties of reinforced concrete beam

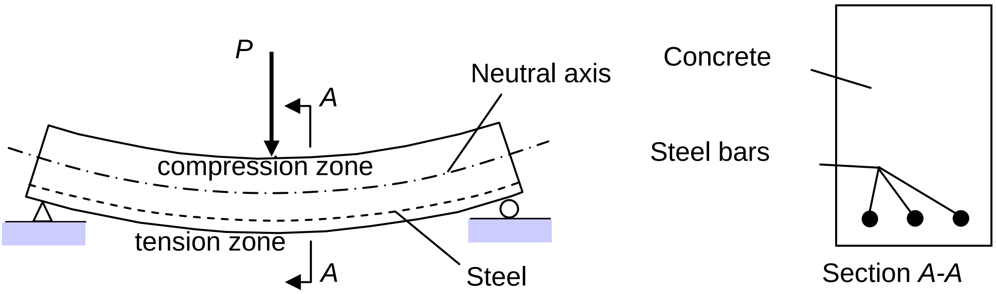


Figure 2.1: Composite action of reinforced beam

A beam is a structural carries load primarily in bending (flexure). Beams are generally design to carry vertical gravitation forces but it can also be used to carry horizontal loads (i.e. loads due to a gust of wind or an earthquake). The loads carried by a beam are transferred to columns, walls or girders, which in turn transfer the force to adjacent structural members.

When load is acting on the beam, the reinforcement concrete beam will be deflected. The top side of beam will be in compression state whereas bottom side of the beam will be in tension state as shown in Figure 2.1. As reinforced concrete beams deflect, the tension side of the beam cracks wherever the low tensile strength of the concrete is exceeded. So the steel bars are needed to provide at the tension zone to increase the tensile strength of concrete. Thus, when these two materials are combined, the steel is able to provide the tensile strength and probably some of the shear strength while the concrete is in compression. Concrete will protects the steel to give durability and fire resistance.

2.6 Behavior of reinforced beam

The behavior of reinforced concrete beams such as bending moment, shear force and deflection are depending on:

a. the material from which the beam is made
b. the nature of the force acting on the beam
c. the size of the beam
d. the shape of the beam

2.6.1 Bending moment

Bending moment and internal shear force within the beam will be created when external forces are applied to a beam. The magnitude of bending moment of these varies from one end of the beam to the other depending on the location and direction of the applied forces. The equation of maximum bending moment at middle span of the simply supported beam is given as below,

$$M = \frac{wl^2}{8} \qquad \text{--------------------(2.1)}$$

where $w =$ uniform load, kN/m

$l =$ length of span, m

The ability of beam to resist the applied bending moment is fully depended to the size of the beam. An extremely thin beam has little ability to resist the applied moment. To resist the higher applied moment, it is suggested to increase the size of beam. The uniform load will be increased with the increase of the size of the beam. According to the equation 2.1, the maximum bending moment is proportional to the uniform load. Finally, the bending moment will be increased with the increase of the beam size.

Theory of moment distribution for sub-frame (Aslam Kassimali, 1999) was defined that the bending moment at the support is depend to the moment of inertia. Therefore, sizes of beam play an important role which will influenced the bending moment at the support. Increase the moment inertia of the beam will be increased the bending moment acting near the support and at the middle span. Similarly, increasing of the moment inertia will increase the ability of beam to carry more bending moment cause by the vertical loading.

2.6.2 Shear force

Reinforced concrete beams must be designed for shear as well as bending. The maximum shear forces are generally occurred near the supports. Figure 2.2 shows the shear force diagram of the simply supported beam.

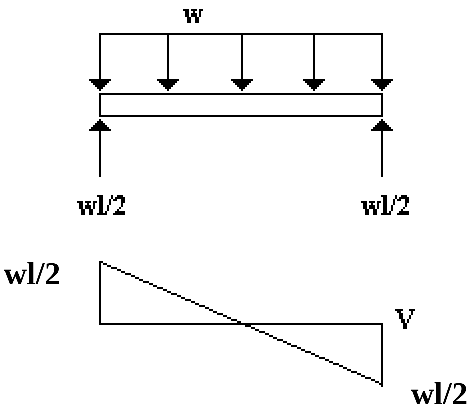
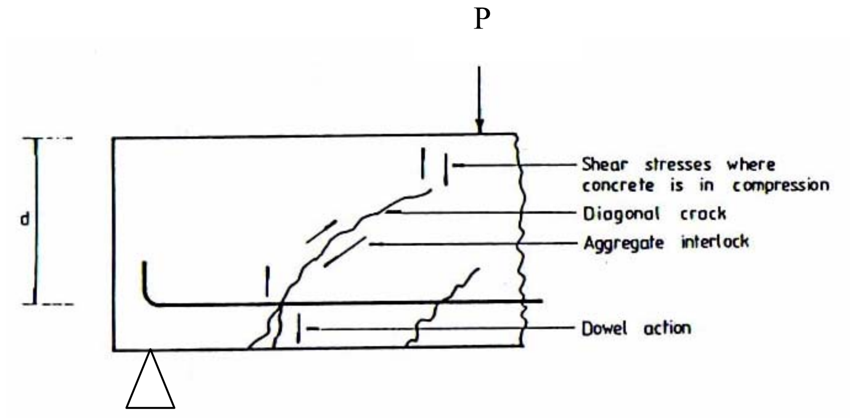


Figure 2.2: Shear force diagram

Shear failure is actually a diagonal tension failure that is related to the brittleness of the concrete and should be avoided. To better understand diagonal tensions, the basic mechanics of a beam with no shear web reinforcing and the diagonal shear stress acting on the stress element is considered as shown in Figure 2.3. When the load is increased on the beam, a flexure shear crack will be formed. If the shear stresses are larger than the shear strength of the beam, it will immediately cause the beam to fail. However, the situation is quite different when the shear web is provided. Even though the shear crack will be formed in the concrete beam, the required shear strength is furnished by the steel as shown in Figure 2.4 and much higher loads can be carried by the beam. Shear stresses increase proportionally to the load. The shear failures normally occur close to support because the maximum shear stress is acting at the support.



where P = point load, kN

d = effective depth, m

Figure 2.3: Beam without shear web and the diagonal shear stress acting on the stress element (T.J. Macginley et al., 1990)

where fv = shear tress

ft = diagonal tension

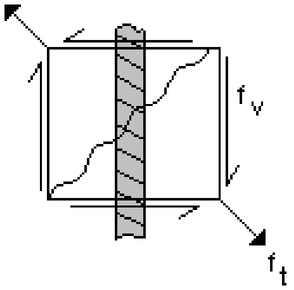


Figure 2.4: The shear steel is provided crosses the diagonal cracks

The detail of web reinforcement design procedure for shear is given in BS 8110: Part 1: 1997 Cl 3.4.5.

2.6.3 Deflection

A beam that is initially straight will deflect if it is subjected to loading. Figure 2.5 shows a simply supported beam with the point load P at the center.

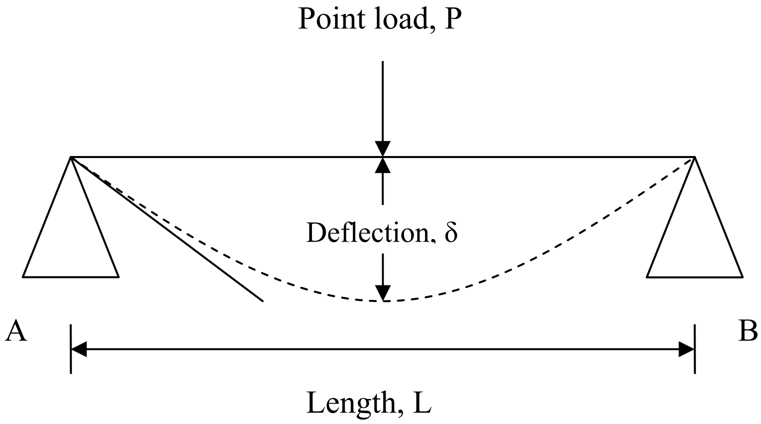


Figure 2.5: Deflection of simply supported beam with a load P acting at the center

The maximum deflection for simply supported beam is given as:

$$\delta = \frac{PL^3}{48EI} \qquad \text{--------------------(2.2)}$$

Where δ = deflection, m

P = point load, N

L = Length of the beam, m

E = modulus of concrete, N/m^2

I = moment of inertial, m^4

Equation 2.2 shows that the deflection is proportional to the load P, to the length of the span, and inversely proportional to the rigidity EI. When the size of beam is increased, the value of moment of inertia will be increased. The expected value of deflection is obviously become small.

2.6.3.1 Checking the deflection based on the BS 8110

When checking for the beam deflection, the actual deflection should be calculated and then compared to allowable deflection. According to the code of practice for design, deflection is acceptable when the ratio of allowed span/effective depth of beam is greater then actual span/effective depth of beam. Refer to BS 8110: Part 1: 1997 Cl 3.4.6.3, the span/effective depth ratio for a rectangular or flanged beam is given in Table 2.2.

Table 2.2: Basic span/effective depth ratio for rectangular beam or flanged beams (BS 8110)

Support conditions	Rectangular section	Flanged beams with $\frac{b_w}{b} \leq 0.3$
Cantilever	7	5.6
Simply supported	20	16.0
Continuous	26	20.8

2.6.3.2 Modification of span /depth ratio for tension reinforcement

The quantity of the tension reinforcement used in beam will influence the deflection of the beam. Therefore, the span/effective depth ratio in Table 2.2 should be modified with multiplied by the appropriate tension factor as given in Table 2.3.

Table 2.3: Modification factor for tension reinforcement (BS 8110)

Service stress	M/bd^2								
	0.50	0.75	1.00	1.50	2.00	3.00	4.00	5.00	6.00
100	2.00	2.00	2.00	1.86	1.63	1.36	1.19	1.08	1.01
150	2.00	2.00	1.98	1.69	1.49	1.25	1.11	1.01	0.94
(fy = 250) 167	2.00	2.00	1.91	1.63	1.44	1.21	1.08	0.99	0.92
200	2.00	1.95	1.76	1.51	1.35	1.14	1.02	0.94	0.88
250	1.90	1.70	1.55	1.34	1.20	1.04	0.94	0.87	0.82
300	1.60	1.44	1.33	1.16	1.06	0.93	0.85	0.80	0.76
(fy = 460) 307	1.56	1.41	1.30	1.14	1.04	0.91	0.84	0.79	0.76

2.6.3.3 Modification of span /depth ratio for compression reinforcement

The quantity of the compression reinforcement used will also influence the deflection of the beam. The span/effective depth ratio value in Table 2.2 should be modified by the tension factor as given in Table 2.3 therefore may be multiply by a compression factor as given in Table 2.4.

Table 2.4: Modification factor for compression reinforcement (BS 8110)

$100\frac{A'_{s\,prov}}{bd}$	Factor
0.00	1.00
0.15	1.05
0.25	1.08
0.35	1.10
0.50	1.14
0.75	1.20
1.0	1.25
1.5	1.33
2.0	1.40
2.5	1.45
≥3.0	1.50

2.6.4 Relationship between depth of beam and required steel area

According to the British Standard (BS 8110: Part 1: 1997, Cl 3.4.4.4), the design formulas for rectangular beam are given as:

$$K = \frac{M}{f_{cu}bd^2} \qquad \text{--------------------(2.3)}$$

$$z = d\left\{0.5 + \sqrt{0.25 - \frac{K}{0.9}}\right\} \leq 0.95d \qquad \text{--------------------(2.4)}$$

$$\text{x} = \frac{d - z}{0.45} \qquad \text{-------------------(2.5)}$$

And the required compression reinforcement area, A_s is

$$A_s = \frac{M}{0.95 f_y z} \qquad \text{--------------------(2.6)}$$

From the equation 2.4,

$$z \propto d \qquad \text{--------------------(2.7)}$$

From the equation 2.6,

$$A_s \propto \frac{1}{z} \qquad \text{--------------------(2.8)}$$

By substitute equation 2.7 to equation 2.8, it will obtain

$$A_s \propto \frac{1}{d} \qquad \text{--------------------(2.9)}$$

Equation 2.9 shows that the required steel area is inversely proportional to the depth of the beam. When the depth of the beam is increased, the value of required steel area will be reduced.

2.7 Band beam

Band beams are the width and shallow beams and has been introduced as a part of the building structure. The illustrate of the band beam is shown in Figure 2.6 and Figure 2.7 shows the system of combination of band beam, one-way slab and skip joists. Figure 2.8 represent the application of band beam in car park. The slab in between the band beam is usually designed as a bending-member with varying moment of inertia to take into account the increased thickness at the beam. These wide shallow beams should be investigated in which the floor-to-floor height is critical. Band beam is suitable apply in unattractive structures such as multi-storey car park.

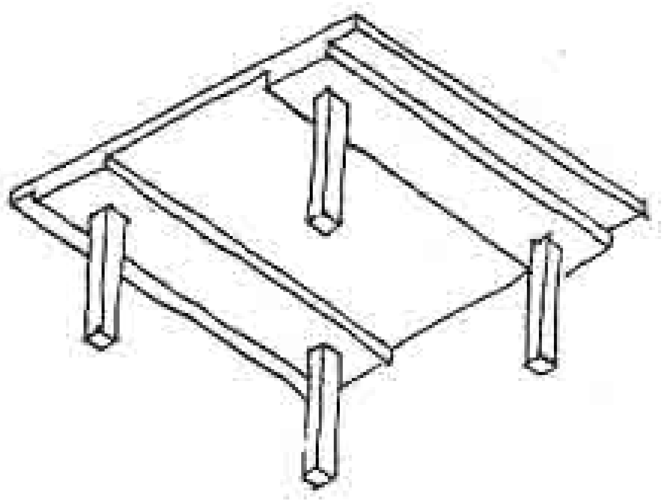


Figure 2.6: Band beam and one way slab system

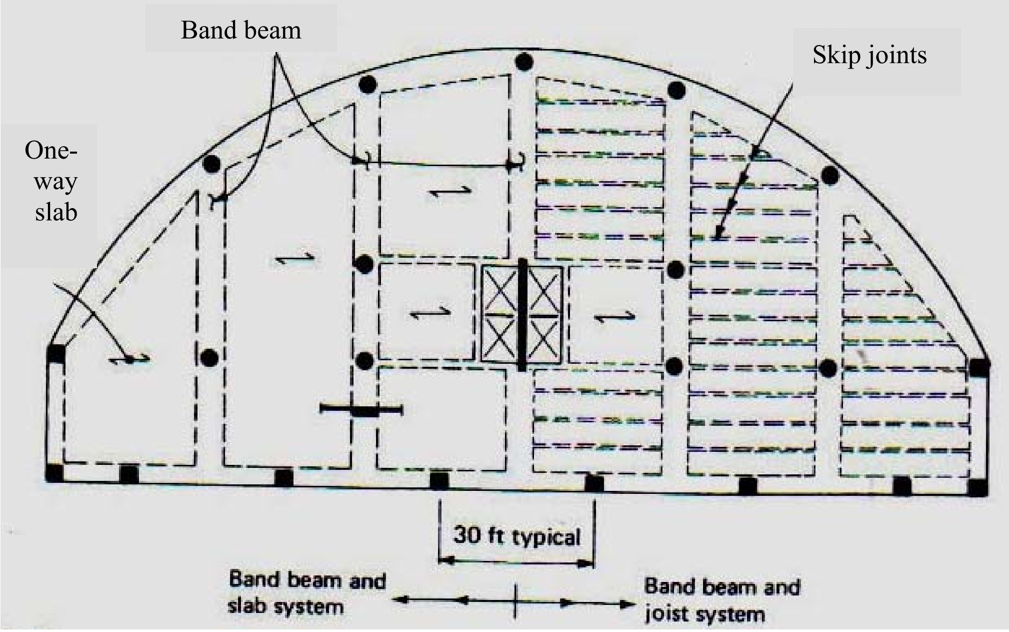


Figure 2.7: Band beam system (Taranath, 1998)

Figure 2.8: Combination of band beams and skip joists for car park

Multi-storey car park is a building which is designed specifically to automobile parking. Many car parks are independent buildings that are dedicated exclusively to that use. In recent time, car park built to serve residential and some business properties are built as part of larger building and often are built underground as part of basement.

2.7.1 Advantage of band beam

The main advantage of the band beam is it can produce a less storey floor height of the building compare to conventional beam with the same effective clearance. It is cause by the depth of the band beams are less than conventional beam. The multi-storey car park consists of numerous floors levels. By applying the band beam system to this multi-storey car park, it will produce less total building height.

Car park can be built as an independent building or built underground as part of the basement to the building. When the car park is built at the bottom of the high-rise building, by reducing the car park floor height will decrease the total height of the high-rise building. As a result, this will reduce the lateral force which acts horizontally to the building. Lateral force plays an important part in the structural design especially for high-rise building. When the high-rise building is too high, it will be subjected to large lateral force. Therefore, an oscillation movement resulted from this situation can induce a wide range of response. The alterative way to solve this problem is to reduce the building height with introducing the band beam system.

If the car park is an independent building, it should be located in a suitable location. Figure 2.9 presents the plan view of the car park located at the surrounding high-rise building. The car park is normally located at the center of few high-rise residential building. In this condition, the consideration of the height for car park building will affect the wind flow to the surrounding building as illustrated in Figure 2.9. Hence, the height of the car park should be kept as minimum as possible to enhance the surrounding built environment.

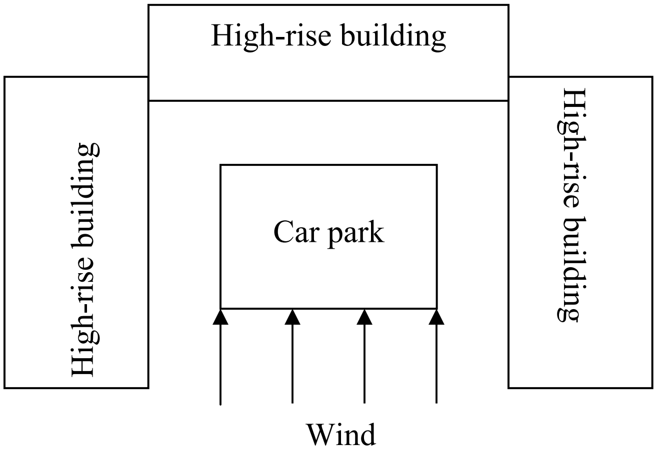


Figure 2.9: Location of car park at surrounding high-rise building

CHAPTER 3

METHODOLOGY

3.1 Introduction

The flowchart of the methodology is shown in Figure 3.1.

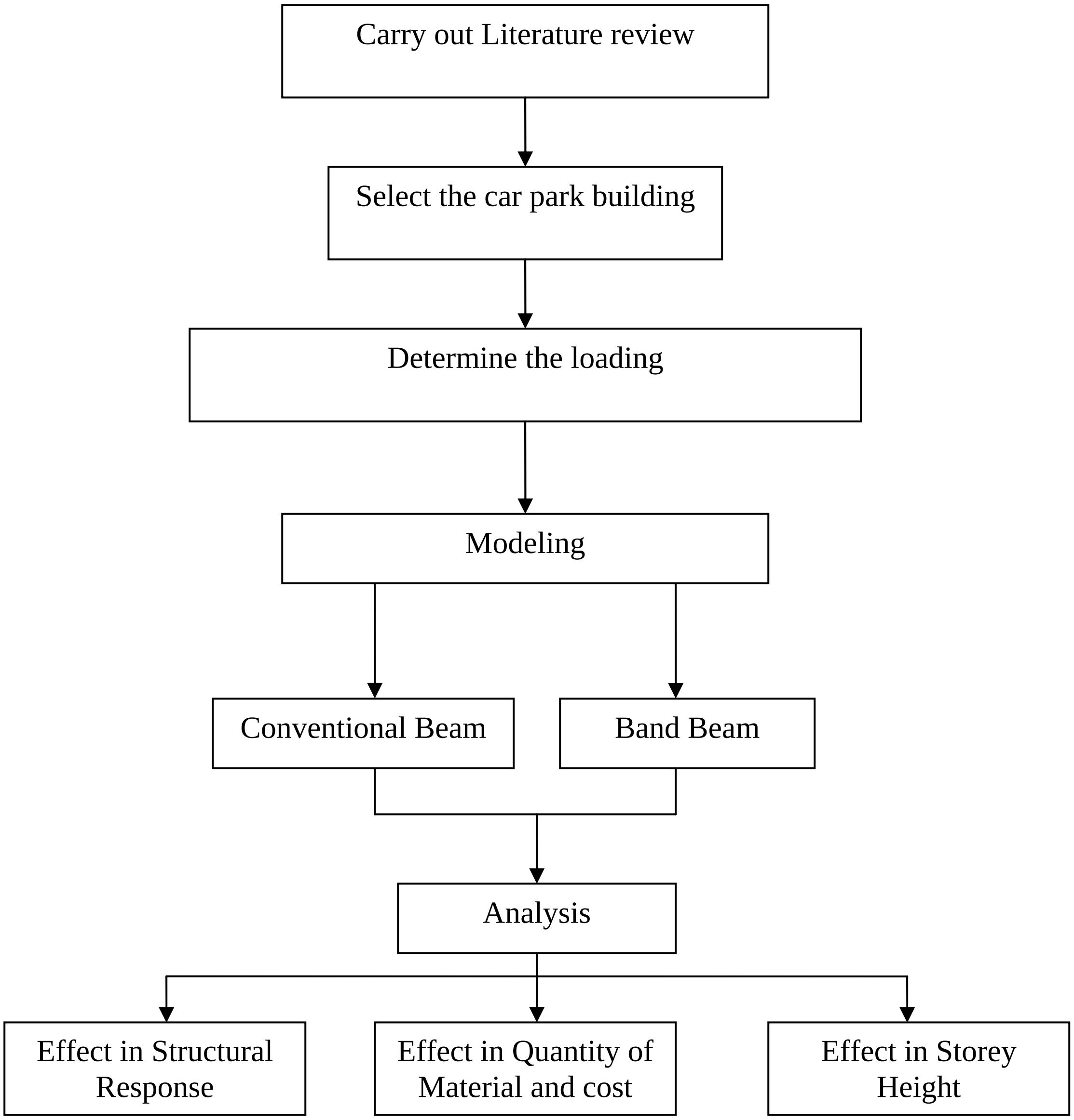


Figure 3.1: The flowchart of the methodology

3.2 Literature review

The project in started by reviewing the Literature on the beam behavior as the flexural element of structure. The application of band beam system is studied.

3.3 Model Used

The multi-storey car park was selected to be modeled and analyzed. The area of the building is 100m x 34.8m in plan. This building contains 7 floors of multi-storey car park as shown in Figure 3.2 and every floor effective clearance of car park is 2.1m. The Figure 3.3 and Figure 3.4 show the plan views of the car park building.

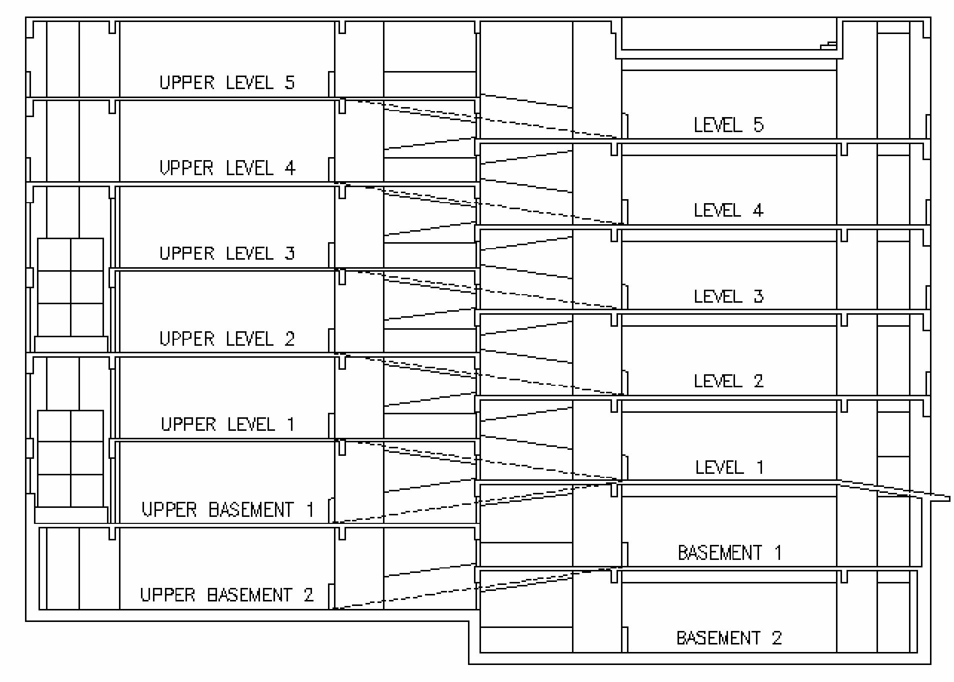


Figure 3.2: Side elevation of car park