CERTIFICATION OF APPROVAL

Optimum Floor Framing System Supporting Largely Spaced Columns

by

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NG SOK MOOI

ABSTRACT

The development of technology and design procedures of modern tall building that started in 1880s, now reached to an advanced level, particularly with the use of software available for design and construction of tall buildings. The sophisticated structural systems high accuracy is possible to obtain. Besides the main structural system, selection of an appropriate floor framing system is essential to determine the overall economy of the building. The efficiency of buildings using same material with the same height is measured by the weight per unit floor area of it.

The focus of this project is to analyze the most optimum two-way concrete floor framing system, supporting largely spaced columns for tall buildings, especially public gathering buildings. Four types of floor framing systems were analyzed. Optimum in this context refers to the optimum deflection satisfying the permissible deflection range. Besides, cost effectiveness with minimum floor thickness fulfilling the head room specified is also taken into consideration.

The grids of the slabs analyzed are 12m x 12m, 15m x 15m and 18m x 18m, while the types of floor framing systems analyzed are conventional beam-slab system, flat plate, waffle slabs and the post-tensioned flat slabs. The conventional beam-slab system acts as the bench mark for comparison. Computer modeling using STAAD.Pro 2002 was carried out. Two life load conditions, which are the normal floor and mechanical floor, with two life load patterns were modeled. The results were analyzed and the most optimum floor framing system was determined. The controlling parameters in determining the optimization of the floor framing system are the maximum deflection, the slab thickness, the floor headroom, the cost and the construct ability of the structure. With this analysis, the most optimum floor framing system can thus be applied for design of tall buildings with slabs supported by largely space columns in the future. Recommendations were given at the end of the report for further study of this project.

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CHAPTER 1: INTRODUCTION

1.1 Background

In conjunction with the growth of modern tall buildings which was started in the 1880s, more advanced technologies and software are now available for design and construction of buildings with complex structural system. Besides the main structural system, selection of an appropriate floor framing system is necessary to determine the overall economy of the building. The efficiency of buildings constructed of same material having same height is measured by the weight per unit floor area. The main factor that affects the selection of the floor system is the architecture input. Besides, the structural performance of the floor system, such as whether it is to participate in the lateral load-resisting system is also an important parameter to be considered in selection of floor framing system. Construct ability and requirement for construction speed play an equally important role in determining the selection of the buildings' floor system.

Scarcity of land, especially in rapidly growing cities such as Singapore and Kuala Lumpur, urges the construction of tall buildings for variety of uses. Currently major public gathering buildings are in high demand, as compared to few decades ago. Modern office buildings call for large open floor spaces that offer high flexibility in column layout and can be subdivided with lightweight partitioning to suit the individual tenant's needs. Public gathering buildings, such as the lobby for hotels, airports, gathering halls, car parks, library and concourse also requires large open floor to accommodate its intended use. In order to achieve this, the columns supporting the beams and floors are required to be largely spaced.

Formally, the reinforced concrete slabs supported by beams, the optimum columns are thus spaced at 6m to 8m grid. Providing beams between columns in certain cases does give advantageous of stiffening the slab. Such beams will decrease slab deflections and so permit longer spans with thinner slab sections [1]. The use of beams greatly reduces the problems of shear and moment transfer between columns and slabs. However, the large span of slabs with columns layout arranged at 12m, 15m or 18m grid, the beams require great height, which kills most of the head room and eventually increase the cost of the structure due to the self-weight imposed by the large sized beams. Thus, feasibility of other beamless floor systems is extensively studied in order to achieve overall cost effectiveness for the buildings.

1.2 Problem Statement

- Building floors supported by largely spaced columns, such as, airport concourse halls, hotel lobbies, etc consist of conventional beam-slab system is not very cost effective.
- An economically efficient and cost effective floor framing system supported by largely spaced columns is required to be investigated.

1.3 Objectives and Scope of Study

1.3.1 Objectives

The main objectives of this analytical study are:

- To determine the optimum floor framing system for widely spaced columns
- To determine the optimum column spacing
- To determine the effect of live load on the slab thickness and effectiveness of floor framing systems
- To determine the effect of live load patterning towards the slab thickness

1.3.2 Scope of Study

A great variety of floor framing systems with the construction technology are available in the market. However, the scope of study of this project is narrowed to four common floor framing systems, which are the two-way beam-slab system, two-way flat plate system, waffle slabs and post tensioning slabs system. The column spacing to be studied is 12m x 12m, 15m x 15m and 18m x 18m.

CHAPTER 2: LITERATURE REVIEW AND THEORY

2.1 Floor Framing System

In general, slabs are classified by the way they are supported. One-way slabs are those slabs supported such that they can bend essentially in one direction only. This means that the loads are carried effectively in one direction only. Two-way slabs are those deflect in two directions, and are usually supported by columns arranged more or less in regular rows. Slabs that carry load by two-way action but without the use of beams are one of the most efficient structural systems [1].

While floor systems are categorized by the material, which are the reinforced concrete, steel and hybrid floor framing systems. For reinforced concrete floor systems, there are one-way slabs on beams or walls, one-way pan joists and beams, one-way slabs on beams and girders, two-way flat plate, two-way flat slab, waffle flat slabs, two-way slab and beam, etc., whilst steel floor system inclusive of one-way beam system, two-way beam system and three-way beam system. However, concrete is arguably the most important building material. Its virtue is its versatility, durability, as well as high fire resistant [4].

2.1.1 Two-way Reinforced Slabs Supported by Beams

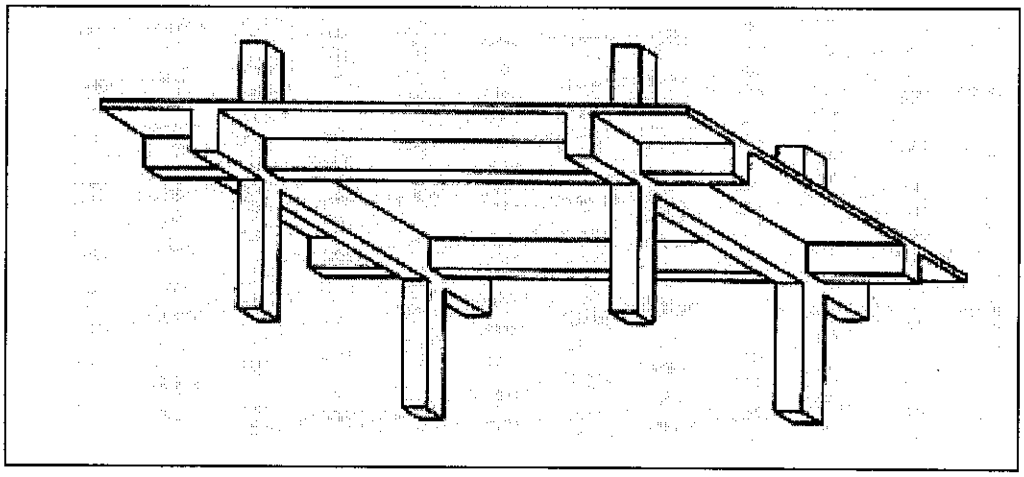

Figure 2.1: Two-way Slabs Supported by Beams.

Figure 2 Shows a two-way slab supported on beams on all sides of the slab. This system is a development from beam-and-girder systems. In a beam and girder system, it was quite easy to visualize the path from load point to column as being from slab to beam to girder to column, and from this visualization then to compute realistic moments and shears for the design of all members [6]. This system is still used with heavy timber and steel frame construction, especially when the column spacing becomes large. Removal of the beams, except those on the columns lines, results in the two-way slab structure [6].

The slab spans two ways between orthogonal sets of beams that transfer the load to the columns or walls. The two-way system allows a thinner slab and is economical in concrete and reinforcement. It is also compatible with a lateral load-resisting rigid-frame structure. The maximum length-to-width ratio for a slab to be effective in two directions is approximately 2.

2.1.2 Two-way Flat Plate Floor System

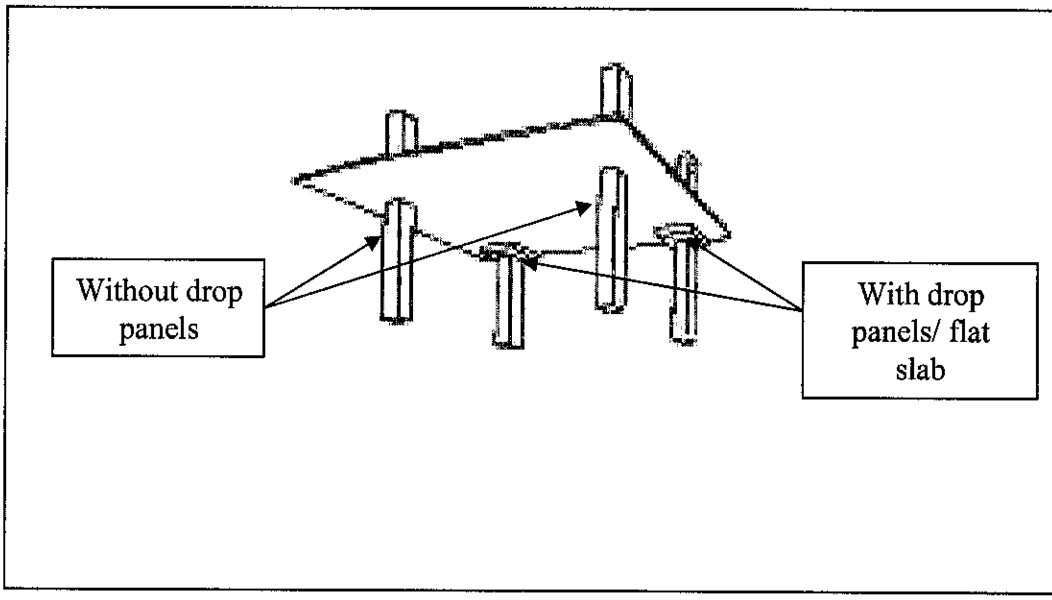

Figure 2.2: Flat Plate.

It is a uniformly thick, two-way reinforced slab. The load of this slab is transferred directly to the supporting columns or individual short walls without the aid of beams or capitals or drop panels. In the ordinary reinforced form, it can span up to 8m. With drop panel, the slab span can extend to 8.5m to 10m [1]. For post tensioned flat plate, its span can extend up to 11m [2].

Its simplicity makes it the most economical floor system in terms of formwork and reinforcement, as well as time of construction. Its uniform thickness provides great flexibility in the arrangement of the supporting columns and partitions or walls and, with the possibility of using the clear soffit as a ceiling eliminates the costly hung ceiling [2]. This is especially beneficial for high-rise apartment and hotel. All of these results in minimum story height for specified clear head room [1]. This type of floor system also gives little obstruction to light and have high fire resistance because there are few sharp corners where spalling of the concrete might occur. However, flat plates has problem in transferring the shear at the perimeter of the columns, which means punching at the columns might happen. This is usually overcome by increasing the column sizes or slab thickness or use shearheads. The choice between the use of flat slabs (with drop panels) and flat plates is largely a matter of the magnitude of the design loading and of the span [6].

2.1.3 Waffle (Two way) Floor System

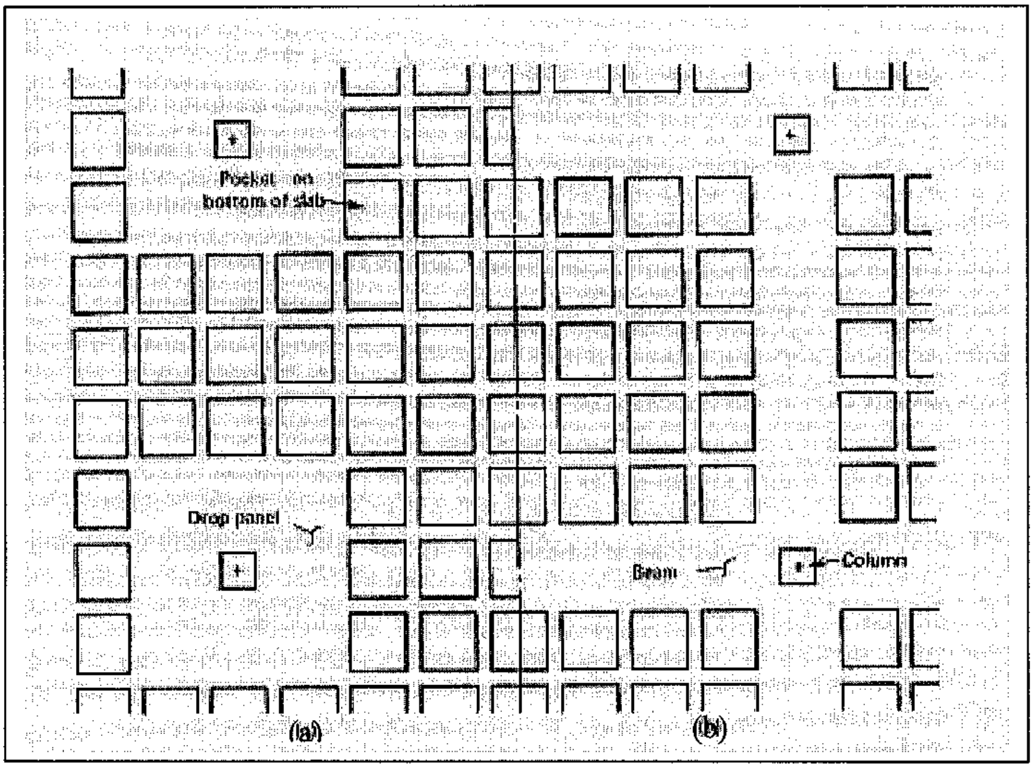

Figure 2.3: Arrangement of Waffle Slabs: (a) as a flat slab; (b) as a two-way slab.

The waffle slabs may be visualized as a set of crossing joists set at small spacings relative to the span, which support a thin top slab [6]. This type of floor system is constructed with ribs in both directions of span. It is formed using temporary or permanent shuttering systems while the hollow block floor is generally constructed with blocks made of fiberglass, metal, clay tile or with concrete containing light-weight aggregate, tapered at all sides.

The forms, which are of sizes up to 76cm square and up to 50cm deep, provide a geometrically interesting soffit, which is often left without further finish as the ceiling. The intervals between the pans form the beam webs, which provide large moment arms for the reinforcing bars. Removing part of the concrete below the neutral axis of waffle floor system gives the advantage of reduction in weight without significantly changing the moment resistance of the floor system [4]. Waffle slabs are generally used in situations demanding spans larger than perhaps about 10m [6].

2.1.4 Post Tensioning Floor System

Post-Tensioning is a method of reinforcing concrete, masonry, and other structural elements. The main different of post tensioning with prestressed slabs is that, instead of stressing the reinforcing inside of large steel buttresses at a manufacturing plant, the reinforcing is simply installed on the job site after the contractor forms up the structural member. The reinforcing steel is housed in sheathing or duct that prevents the steel from bonding to the concrete so that it can be stressed after the concrete cures.

Post-tensioning method of prestressing has the following benefits over the others:

- Allows for a much larger single monolithic pour, eliminates the need for expansion joints
- Allows longer clear spans between supports, thinner slabs, fewer beams and more slender, dramatic elements
- Slabs are of crack-free, or nearly so, at full service load
- Reduces reflective and surface cracking that can allow the passage of moisture and termites
- Construction of the member on the job site is possible
- The formwork is simple
- Labor and time saving
- Beneficial for watertight structure as it is crack-free

An example of completed project employing the post tensioning concrete slab is the Penang Airport in Malaysia, which was designed for three jumbo jets

2.2 Design Criteria

Today the structural design profession is concerned with a limit states philosophy. The term limit state is used to describe a condition at which a structure or some part of a structure ceases to perform its intended function. There are two categories of limit states, strength and serviceability [4].

Strength limit states are based on the safety or load-carrying capacity of structures and include buckling, fracture, fatigue, overturning, and so on. While serviceability limit states refer to the performance of structures under normal service loads and are concerned with the uses and/ or occupancy of structures. Serviceability is measured by considering the magnitudes of deflections, cracks, and vibrations of structures as well as by considering the amounts of surface deterioration of the concrete and corrosion of the reinforcing [4].

2.2.1 Deflection

The check for deflection is a very important consideration in slab design and usually controls the slab depth. Excessive deflections of slabs may cause sagging floors, ponding on flat roofs, excessive vibrations, ill-fitting doors and windows, and even interference with the proper operation of supported machinery. Such deflections may damage partitions and cause poor fitting of doors and windows. The most common type of deflection damage in reinforced concrete structures is the damage to light masonry partitions. They are particularly subject to injury due to concrete's long term creep. When the floors above and below deflect, the relatively rigid masonry partitions do not bend easily and are often severely damaged. In addition, deflection may create discomfort to occupants [4].

The deflection of slabs is discussed in BS 8110: Part 1, section 3.5.7. In normal cases a strip of slab 1 m wide is checked against span-to-effective depth ratios including the modification for tension reinforcement set out in section 3.4.6, Table 3.10 and modified by Table 3.11 of the code. Only the conditions at the center of the span in the width of slab under consideration should be considered to influence deflection. The ratio for a two-way spanning slab should be based on the shorter span.

CHAPTER 3: METHODOLOGY/ PROJECT WORK

3.1 Project Management

The final year project was carried out in two phases, each phase last for one semester. In phase 1, literature review is the main emphasis. Thorough understanding of the floor framing systems enables the author to appreciate the project work done. Study of the software was carried out in the first phase as well, by going though the tutorial exercises provided in the software.

The planning of the project work is done using Gantt chart. This aids the author to carry out the project in a more systematic manner. Moreover, the time frame set in the planning will guide the author in time management while carry out the project.

3.2 Design Standards and Code of Practice

In the design of structure, the following Codes of Practice provide the guide:

BS 8110: Part 1: 1997 – Structural Use of Concrete (Code of Practice for Design and Construction)

3.3 Project Work

This study was mainly based on computer analysis to determine the efficiency of 4 different floor framing systems using STAAD.Pro 2002 and RAM Conce*pt*™. The above mentioned floor framing systems are the conventional beam-slab system, flat plate, waffle slab and post tensioned floor framing system. The main loading applied in the analysis is the gravity load. Uniformly distributed dead load, which is the self-weight of the structural members and imposed loads of 3.0 kN/ m^2 (normal floors) and 7.5 kN/ m^2 (mechanical floors), were applied. The normal floor with imposed load of 3.0 kN/ m^2 and mechanical floor with imposed load of 7.5 kN/m^2 is referred as Case 1 and Case 2 respectively herein after. The floor systems with fixed supports, regular square grids of

12m, 15m and 18m spans were developed using the structural software application. The models were developed by defining the finite elements and dimensions of it. The material properties and type of supports are defined as well. These models were then analyzed by finite element analysis. Besides, two live load patterns were also modeled and analyzed for beam-slab and flat plate systems in order to determine the effect of live load patterning in the floor framing systems.

The controlling parameters are the maximum deflection, thickness, cost, and story height of the slab. The controlling head room for each storey is 2.6m. Cost effective in this context refers to saving in material as well as saving in construction, which includes the formwork. The design criteria can be summarized as followed:

- The long term deflection of the floor should be controlled at L/ 500 or 25mm.
- The optimum floor framing system should be cost effective.
- The controlling height of each floor is 2.6m.
- The floor framing system must be functional for its intended purposes and build able.
- The floor framing system should fulfill the aesthetic requirement of the architectural input.

Figure 4 shows the typical column arrangement for a 9 square grid floor. The slabs are basically categorized into 3 types, which is the Type 1, the corner slabs with 2 edges restrained, Type 2 with 3 edges restrained and Type 3, restrained in all four edges. The analysis will be carried out for slabs of 12m, 15m and 18m spans (L). For live load patterning, first pattern was by loading slabs Type 1 and 3 with full live load and leave slabs Type 2 unloaded; second pattern is by loading slabs Type 2 with full live load and the rest leave unloaded (refer to **Figure 5** and **Figure 6**).

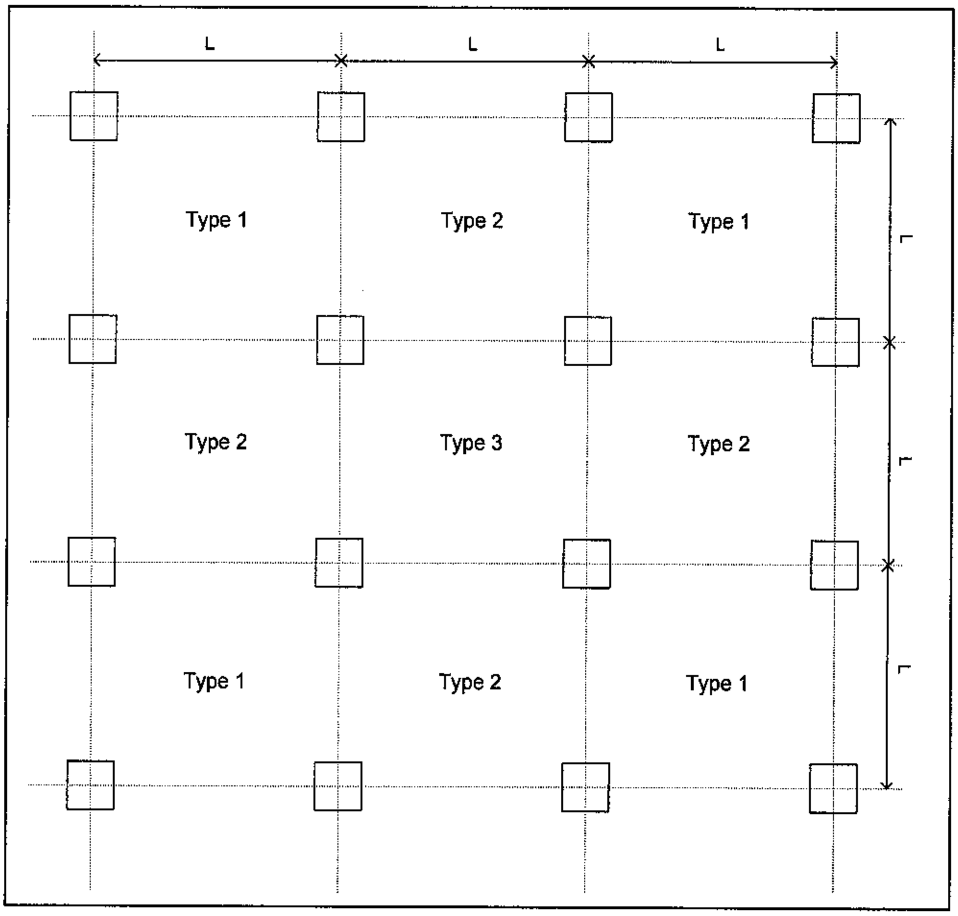

Figure 3.1: Typical Arrangement of Columns in Two-way Spanning Slabs.

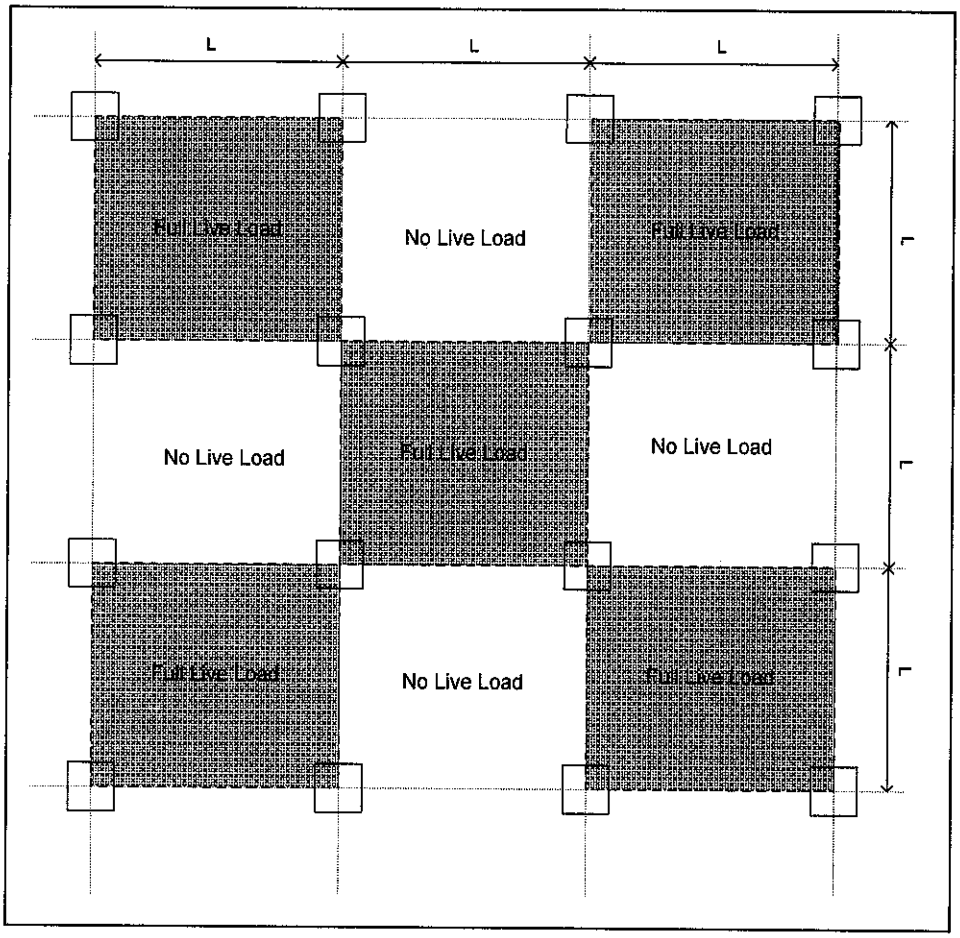

Figure 3.2: Live Load Pattern 1.

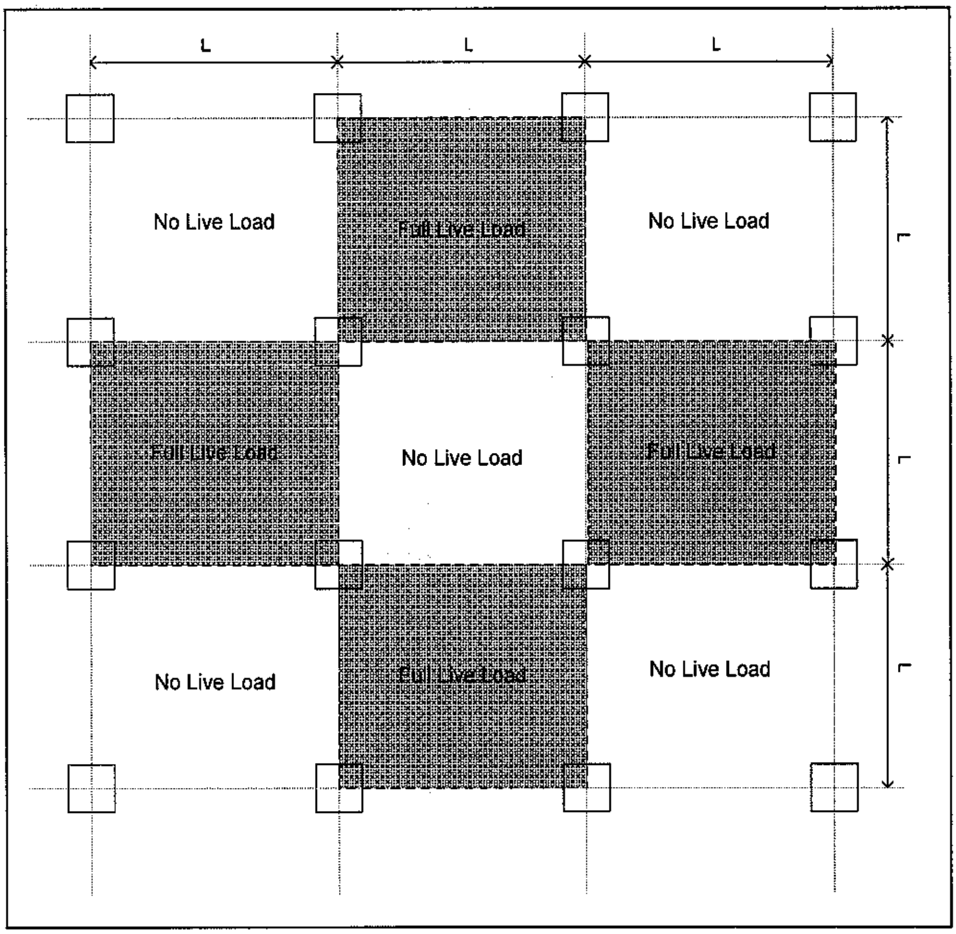

Figure 3.3: Live Load Pattern 2.

Before carrying out the analysis and design work, instruction manual were gone through thoroughly and tutorial exercises were carried out. The information and knowledge regarding the existing floor framing system as well as the research papers was found from Internet and information resource center. This enables the analysis work carried out with great appreciation.

3.4 Structural Loading

The main structural loading taken into consideration in this project is the gravity load, which are the dead load and imposed load. The main source of dead load is mainly the self-weight of the structural members. Imposed load mainly comes from the mechanical equipment and the buildings' occupants.

The load combination applied in analyzing the models are:

- Load Combination 1: 1.0 Dead Load + 1.0 Live Load
- Load Combination 2: 1.4 Dead Load + 1.6 Live Load

(Referring to BS 8110: Part 1, Table 2.1 Load Combinations and values of γ_f for the ultimate limit state)

3.5 Material Properties

Concrete

Young's Modulus	27.33 kN/ mm^2 (Grade 35)
Poisson ratio	0.17
Density	23.5616 kN/ m^3
Alpha	5.5 x 10^{-6}
Damping ration	0.05

Reinforcement

High Tensile Deformed Type 2   460N/mm^2

3.6 Tools

The above analysis will be done using the available structural software application in the CBT lab, which is the STAAD.Pro 2002. Finite element analysis is applied in the modeling and analysis of the floor systems.

CHAPTER 4: RESULTS AND DISCUSSION

The controlling short term and long term deflection of the slabs given by BS 8110 is expressed in the following equations and summarized in **Table 4.1**.

$\Delta_{short\ term} \quad = L/250$

$\Delta_{long\ term} \quad = L/500$

Table 4.1: Short Term and Long Term Deflection of Slabs (to BS 8110).

Span (m)	$\Delta_{short\ term}$ (mm)	$\Delta_{long\ term}$ (mm)
12	48	24
15	60	30
18	72	36

The data shown below are based on the results of computational models analyzed from STAAD.Pro 2002 and RAM Conce*pt*™. The following are the discussions of the results based on the main parameters of the analysis, which includes the slab thickness and deflection, efficiency, cost, and effects of live load patterning (on the slab thickness and deflection as well as the efficiency of the floor framing systems) on the floor framing systems.

4.1 Slab Thickness and Deflection

Table 4.2: Thickness and Deflection of Floor Framing Systems for Case 1.

Span (m)	Beam-Slab		Flat Plate	
	Thickness (mm)	Deflection (mm)	Thickness (mm)	Deflection (mm)
12	325	28	325	28
15	500	27	500	27
18	725	27	725	27
Span (m)	**Waffle Slab**		**Post-tensioned Flat Slab**	
	Thickness (mm)	**Deflection (mm)**	**Thickness (mm)**	**Deflection (mm)**
12	175	30	240	47
15	225	40	300	81
18			360	105

Table 4.3: Thickness and Deflection of Floor Framing System for Case 2.

Span (m)	Beam-Slab		Flat Plate		Waffle Slab	
	Thickness (mm)	Deflection (mm)	Thickness (mm)	Deflection (mm)	Thickness (mm)	Deflection (mm)
12	400	25	400	25	225	28
15	575	26	575	26	400	41
18	800	27	800	27	-	-

For slab span of normal range (6m to 8m), checking of deflection usually deem not necessary. This is because deflection is a function of moment. As long as the maximum moment is designed for deflection, the deflection will normally falls within the permissible range. However, as the designed floor span increases, control and checking of deflection is essential.

Excessive deflections of slabs may cause sagging floors, ponding on flat roofs, and even damage the partitions as well as cause poor fitting of the doors and windows. In addition, deflections may damage the structure appearance and frighten the occupants of the building. Clause 3.4.6 in BS 8110: Part 1: 1997 gives the guideline for checking of deflections.

Table 4.2 shows the thickness and deflection of 4 different types of floor framing systems, which are the conventional beam-slab system, flat plate, waffle slab and post-tensioned flat slab system with imposed load at Case 1. While **Table 4.3** shows the thickness and deflection of 3 different types of floor framing systems, which are the conventional beam-slab system, flat plate and waffle slab system with imposed load at Case 2. The guideline for long term deflection is controlled at span/ 500. However, due to the large span, the deflections of conventional beam-slab system and flat plate are controlled at 25mm (± 3mm).

It is shown that both conventional beam-slab and flat plate systems having same magnitude of deflection with the same thickness for both cases. As the span of the slabs increases, the thickness acquired to control the deflection within the prescribed range increases as well. The above results are expressed in **Figure 4.1** and **Figure 2** below. The polynomial lines for conventional beam-slab system and flat plate coincide for both cases. The relationship of the slab thickness and span is then expressed by the following equation:

Case 1:

$$y = 2.7778x^2 - 16.667x + 125$$

Case 2:

$$y = 2.7778x^2 - 16.667x + 200$$

Extrapolation can be done to determine the thickness of floor with larger span using this relationship. The relationship of thickness and slab span for post-tensioned flat slab system for Case 1 is expressed by a linear relationship of **y = 20x**. In another word, the thickness of the slab increases linearly with the slab span. Same goes for waffle slab system. The relationship of slab thickness and slab span is related linearly. Extrapolation was done to obtain the thickness for 18m span slab and it is estimated to be 275mm for case 1 and 575mm for case 2.

The controlling head room of each floor is set to be at 2.6m with 3.0m height for each floor. This in another word means that the optimum floor span should not exceed 12m for conventional beam-slab and flat plate system in both cases. While for both post-tensioned flat slab and waffle slab system, slab thickness does not impose any setback for span up to 18m for Case 1. The optimum slab span of waffle slab system for Case 2 (mechanical floor) is limited to 15m. Considering the thickness of the slab as the only parameter, the performance of waffle slab in Case 1 is way more excellent than other three systems. However, the depth of the pans required to control the deflection within the permissible range take up most of the head room and impose great self-weight to the structure. This leads to non optimum of this floor framing system. Thus, post-tensioned flat slab system is recommended for slab span up to 18m.

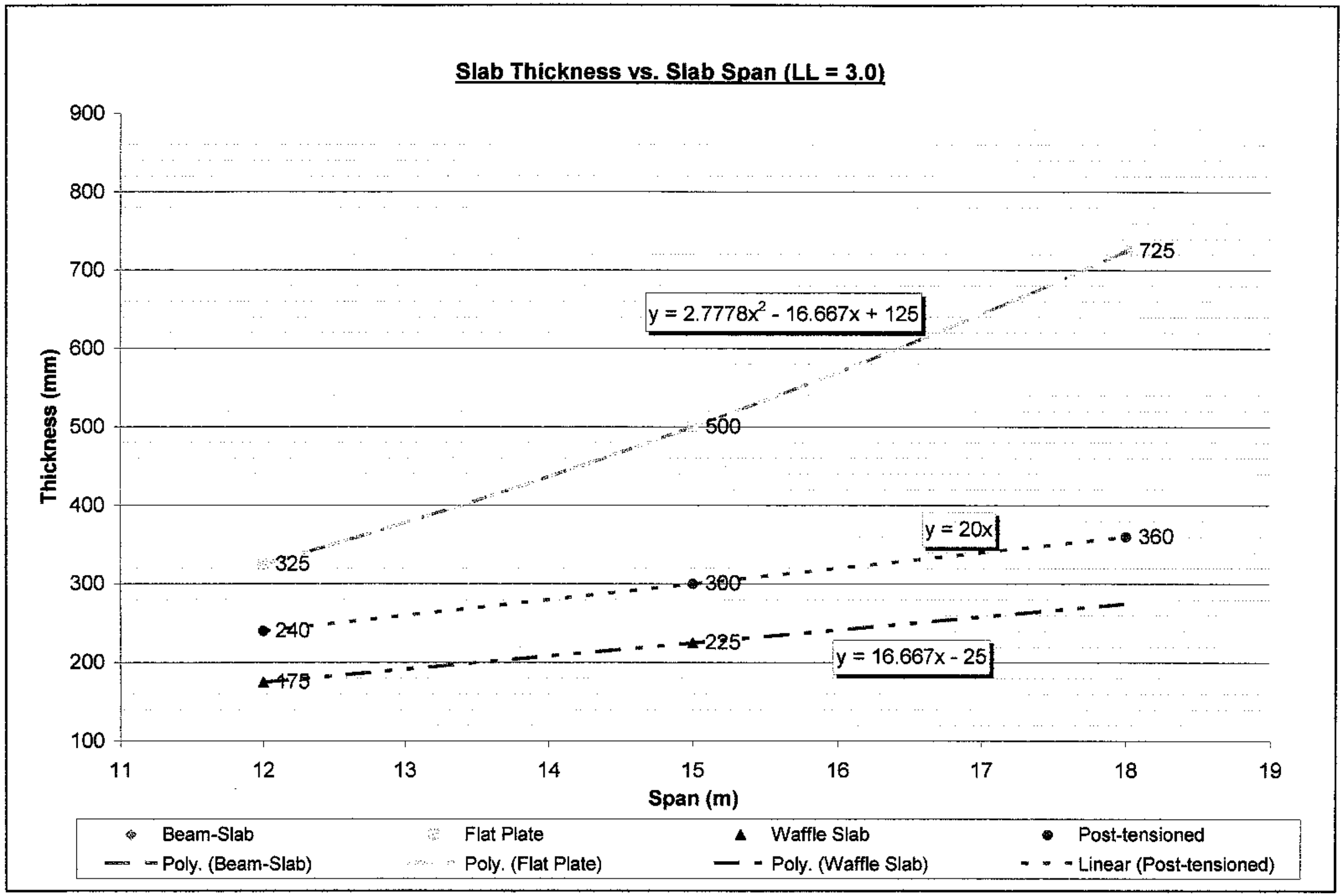

Figure 4.1: Slab Thickness vs. Slab Span for Case 1.

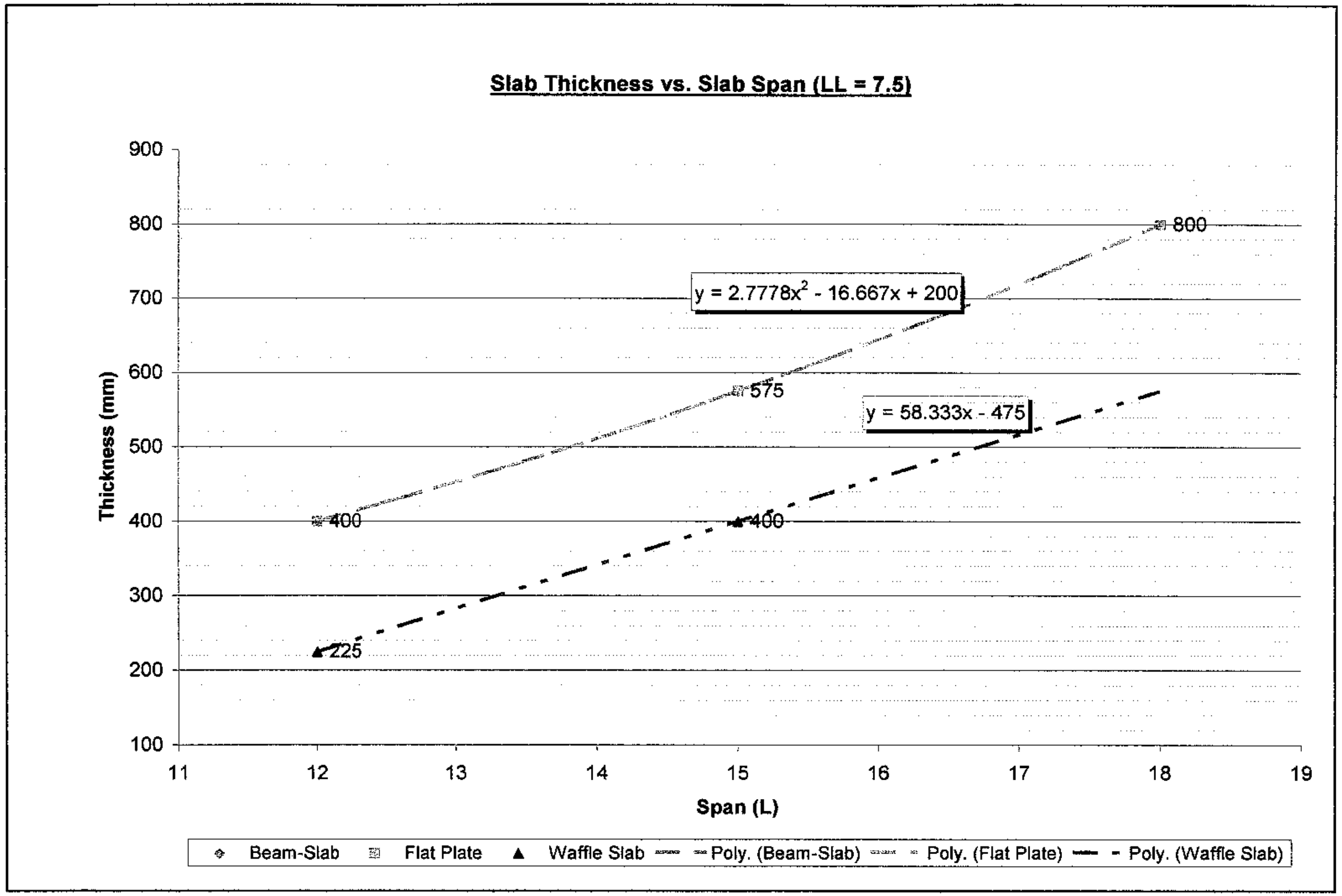

Figure 4.2: Slab Thickness vs. Slab Span for Case 2.

4.2 Slab Thickness and Actual Weight of the Structure

Table 4.4: Thickness and Weight of Floor Framing System for Case 1.

Span (m)	Beam-Slab		Flat Plate	
	Thickness (mm)	Weight (kN)	Thickness (mm)	Weight (kN)
12	325	11,145.58	325	9,924.14
15	500	25,764.64	500	23,856.15
18	725	53,475.80	725	49,811.52
Span (m)	**Waffle Slab**		**Post-tensioned Flat Slab**	
	Thickness (mm)	**Weight (kN)**	**Thickness (mm)**	**Weight (kN)**
12	175	22,664.81	240	8,422.39
15	225	44,093.16	300	16,498.53
18	-	-	360	28,503.84

Table 4.5: Thickness and Weight of Floor Framing System for Case 2.

Span, m	Beam-Slab		Flat Plate		Waffle Slab	
	Thickness, mm	Weight, kN	Thickness, mm	Weight, kN	Thickness, mm	Weight, kN
12	400	13,435.76	400	12,214.33	225	24,267.12
15	575	29,215.85	575	27,434.59	400	59,926.43
18	800	59,036.07	800	54,964.60	-	-

Table 4.4 and **Table 4.5** show the data of slab thickness and actual weight for the floor framing systems. The span and thickness are linearly related with the weight of the structure. As the slab span increases, the thickness and thus the weight of the structure increases linearly.

In the previous section, it is shown that the performance of waffle slab is excellent in thickness wise. However, data above prove that the great depth of the pans in waffle slabs impose great self-weight to the structure, which eventually lead to non optimum of the system. From **Table 4.4**, it can be summarized that the weight of the post-tensioned flat slab outperforms the other three systems in Case 1. From the previous section, the performance of conventional beam-slab system and flat plate system is undetermined. A clearer picture can be seen from the above data that the performance of flat plate is more excellent than conventional beam-slab system owing to lighter self-weight of flat plate.

4.3 Area and Efficiency of the Floor Framing System

Table 4.6: Area and Efficiency of Floor Framing System for Case 1.

Span, m	Area, m^2	Efficiency (Weight/ unit floor area), kN/ m^2			
		Beam-Slab	Flat Plate	Waffle Slab	Post-tensioned Flat Slab
12	1296	8.60	7.66	17.49	6.50
15	2025	12.72	11.78	21.77	8.15
18	2916	18.34	17.08	-	9.77

Table 4.7: Area and Efficiency of Floor Framing System for Case 2.

Span, m	Area, m^2	Efficiency (Weight/ unit floor area), kN/ m^2		
		Beam-Slab	Flat Plate	Waffle Slab
12	1296	10.37	9.42	18.72
15	2025	14.43	13.55	29.59
18	2916	20.25	18.85	-

As mentioned in the **Introduction**, the efficiency of a floor framing system is measured by the weight per unit floor area of it. The lower the weight per unit floor area, the more efficient the floor framing system is. **Table 4.6** and **Table 4.7** show the area and efficiency of the floor framing systems. The graphs of weight per unit floor area versus slab span for Case 1 and Case 2 are plotted and shown in **Figure 4.3** and **Figure 4.4** respectively.

This parameter concern, post-tensioned flat slab is the most efficient floor framing system for Case 1. The weight per unit floor area is directly related to the slab span by the linear equation **$y = 0.546x - 0.0502$**. It is noticed that the trend of the linear line shown in **Figure 4.3** is very flat. That means the efficiency of this floor framing system does not drop tremendously with increase of slab span.

As the slab span increases, the weight per unit floor area increases as well. Whereas the relationship of weight per unit floor area versus slab span for flat plate system, which ranked second among the four framing systems, is shown by the following equations:

Case 1: $$y = 0.0654x^2 - 0.3926x + 2.9447$$

Case 2: $$y = 0.0654x^2 - 0.3928x + 2.9447$$

It is noticed that the first and third constant of both equations are the same. The beam-slab system posses the same trend of graph with flat plate system. The efficiency of beam-slab system is slightly less than the flat plate system. This is because of the beams which add load to the self-weight of the structure does not function to reduce the deflection. The beams behave like spring as the floor span increases. The stiffness that the beams offer is compensated by the self-weight that it imposed.

Waffle slab posses a linear relationship for weight per unit floor area with slab span. Even though it should give benefits by saving concrete, the large pan dimension forfeited this benefit of waffle slab. Furthermore, the head room is killed as the dimensions of the pans increase. This causes the waffle slab to be the least efficient floor framing system.

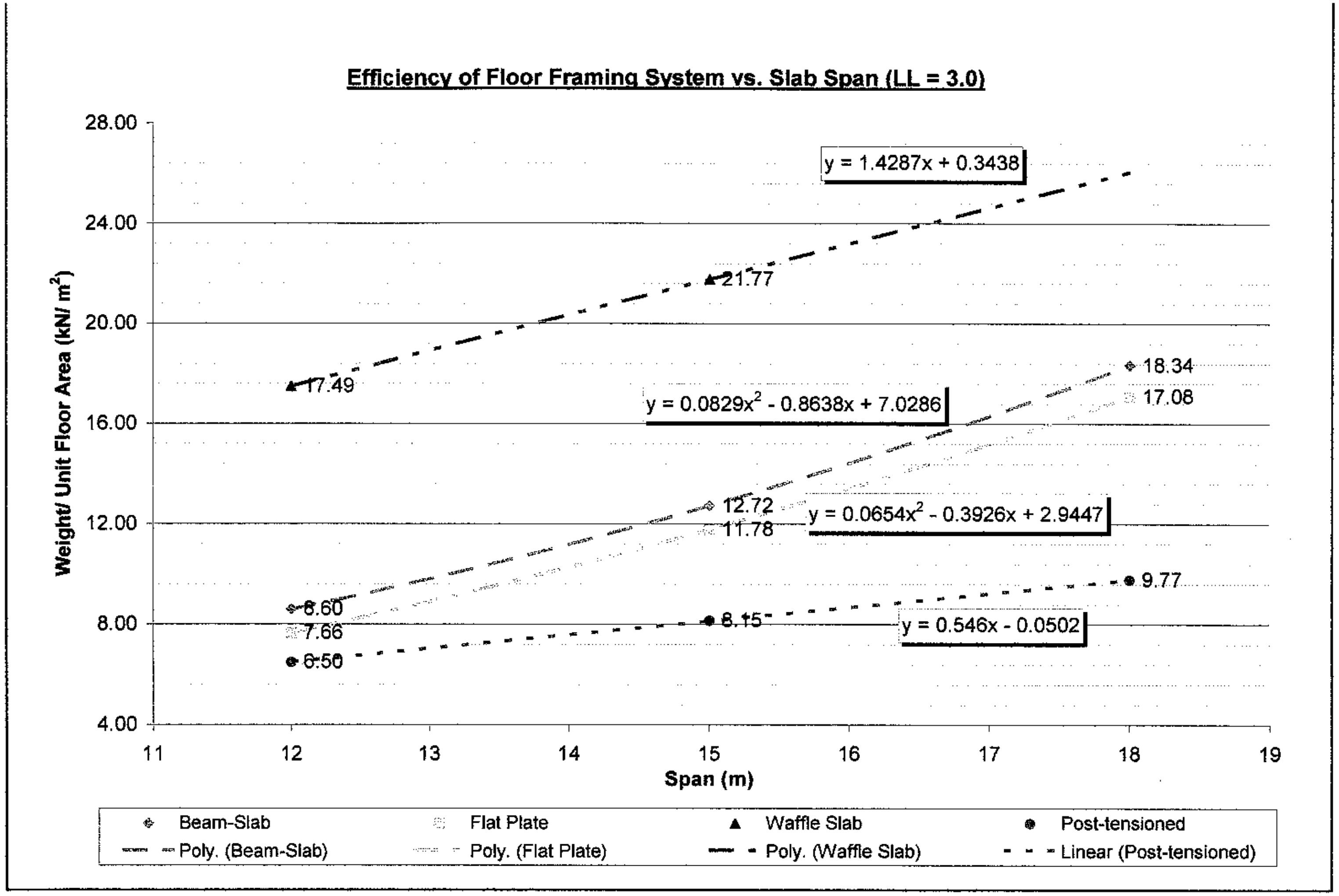

Figure 4.3: Efficiency of Floor Framing System vs. Slab Span for Case 1.

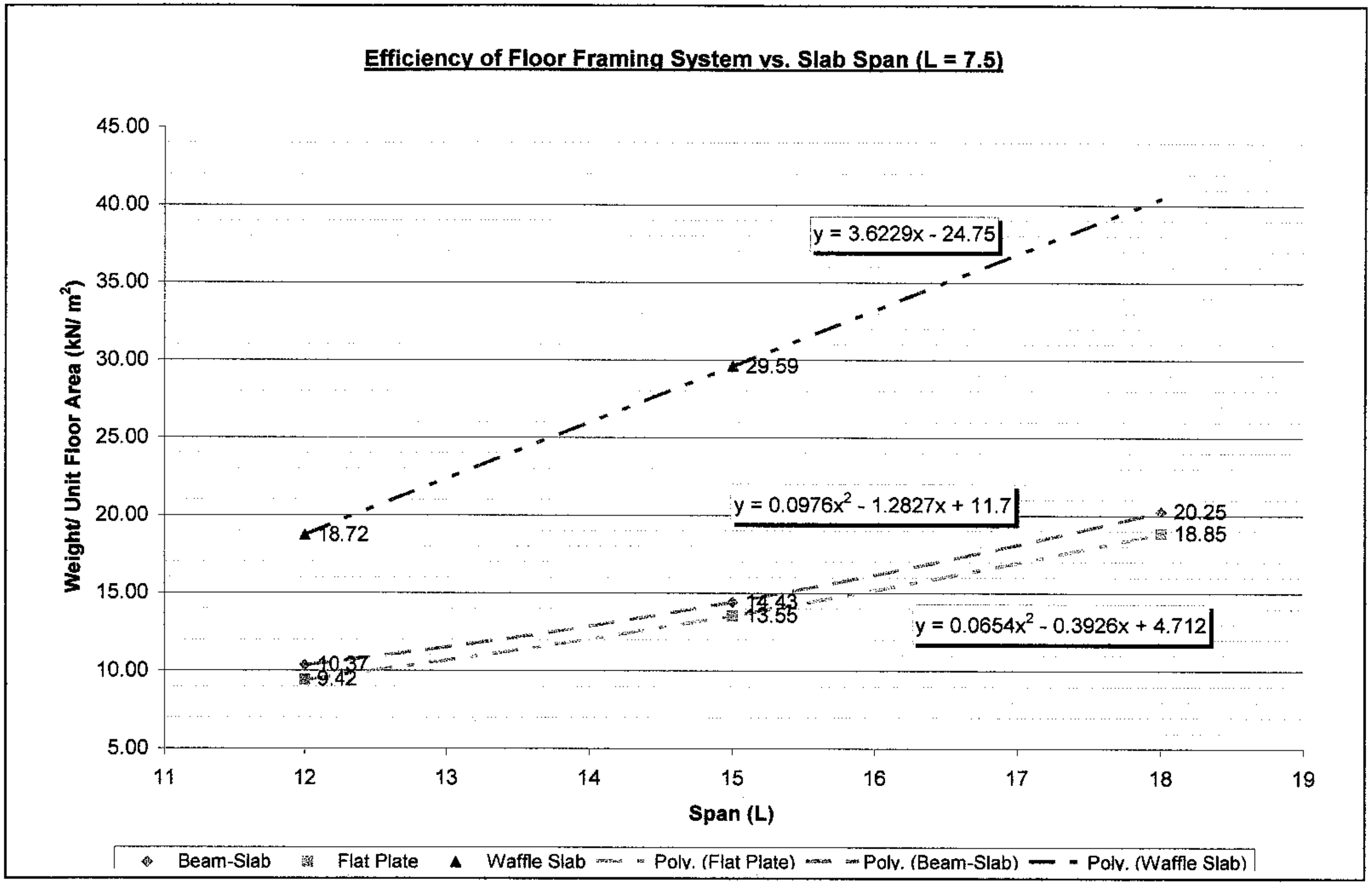

Figure 4.4: Efficiency of Floor Framing System vs. Slab Span for Case 2.

4.4 Cost

Table 4.8: Cost of Floor Framing System for Case 1.

Span (m)	Cost (RM/ m^2)			
	Beam-Slab	Flat Plate	Waffle Slab	Post-tensioned flat slab
12	215.00	191.44	437.21	217.44
15	318.08	294.52	544.36	268.84
18	458.47	427.05	-	320.54

Table 4.9: Cost of Floor Framing System for Case 2.

Span (m)	Cost (RM/ m^2)		
	Beam-Slab	Flat Plate	Waffle Slab
12	259.18	235.62	468.12
15	360.69	338.70	739.83
18	506.14	471.23	-

Table 4.8 and **Table 4.9** show the cost of the floor framing systems for Case 1 and Case 2 respectively. The trend of the cost per unit floor area versus the slab span is expressed graphically in **Figure 4.5** and **Figure 4.6**. The cost calculated based on the cost of material (concrete, reinforcement bars, and formwork) as well as the labor cost.

From **Figure 4.5**, it is noticed that the waffle slab system has the greatest cost for each square meter of floor. The cost increases linearly as the span increases. This is mainly due to the great amount of material and great labor cost of this floor framing system. Whereas conventional beam-slab system and flat plate system, the cost increases as a function of second degree polynomial. However, the cost of flat plate system is lower than the conventional beam-slab system due to lower cost of material. This shows consistency with the two parameters discussed previously.

For slab span of 13m and below, flat plate has the lowest cost for Case 1. This in another word means that flat plate is the most optimum floor framing system for slab span 13m and below. With span increases above 13m, post-tensioned flat slab system is economically more efficient. The intersection point of the post-tensioned flat slab and flat plate system occurs at 13.8m. At 12m span, the cost of conventional beam-slab system and flat plate is less than post-tensioned flat slab system. This is because handling of post-tensioned slab system requires skilled personnel as well as consultation from professionals. Besides, cost of post-tensioning and construction is higher as well. This leads to uneconomical of the slab when the span is low.

For Case 2, the data for post-tensioned flat slab is not available. According to the available data, flat plate outperform the other two systems and is proven to be more efficient as compared to the conventional beam-slab system and waffle slab system in economic sense.

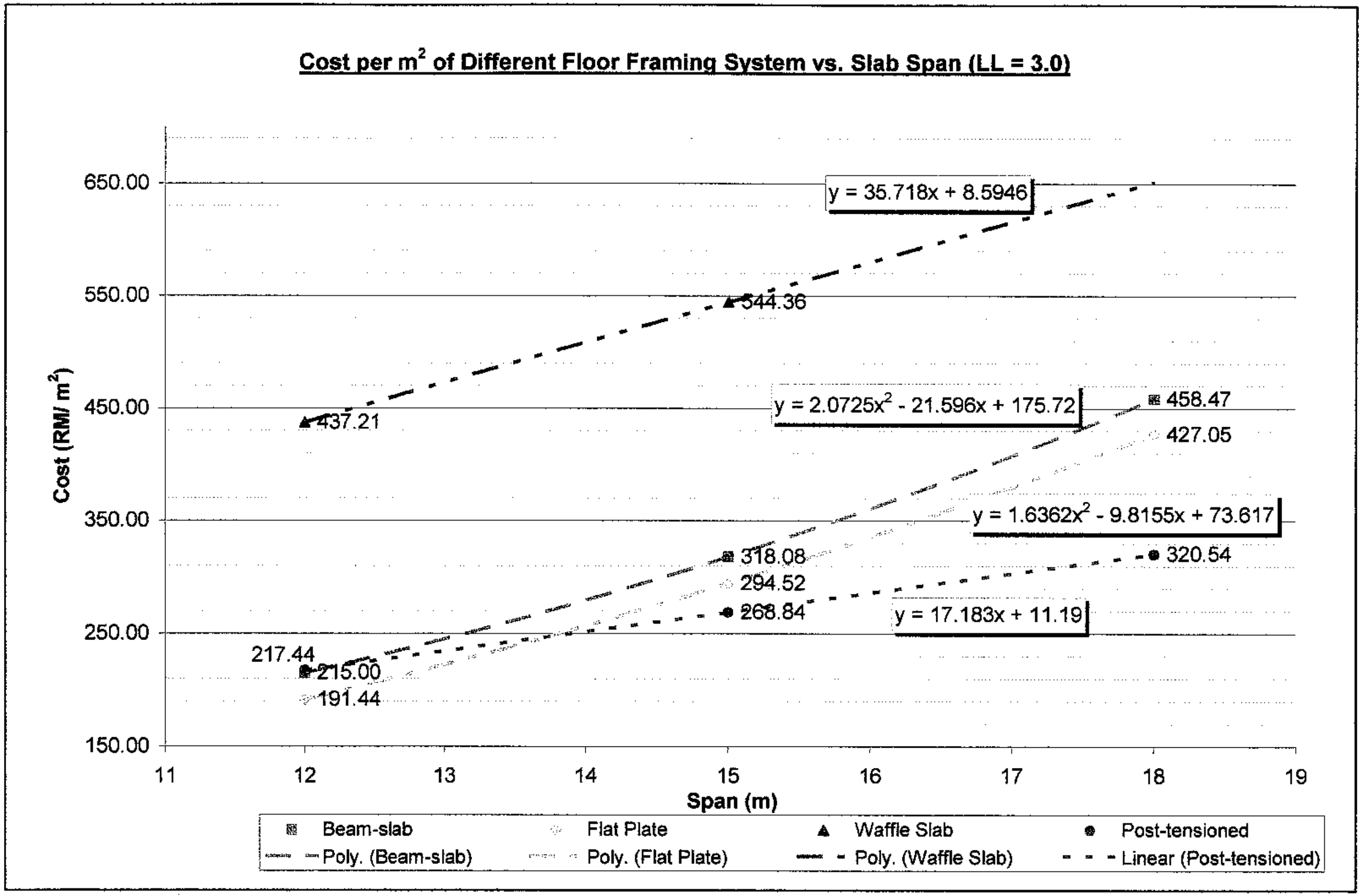

Figure 4.5: Cost per Square Meter of Floor Framing System vs. Slab Span for Case 1.

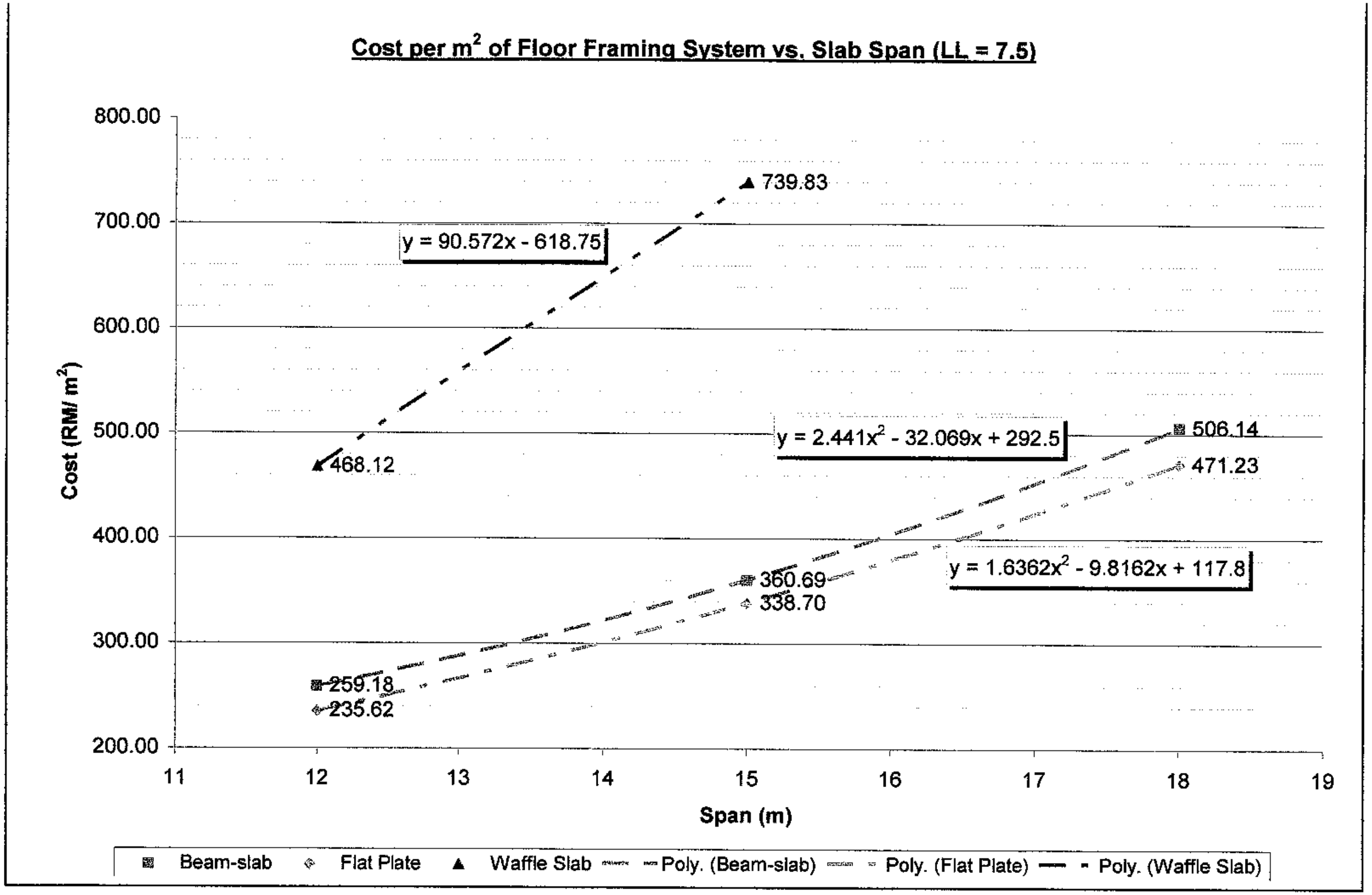

Figure 4.6: Cost per Square Meter of Floor Framing System vs. Slab Span for Case 2.

4.5 Effect of Live Load Patterning

For most instances, the floor will not be fully loaded by the imposed load. In order to ensure that the structure is not over designed, the effects of live load patterning were studied. Two live load patterns (refer to **Figure 3.2** and **Figure 3.3**) were randomly selected and analyzed for conventional beam-slab system and flat plate system.

4.4.1 Thickness and Deflection

Case 1: Imposed Load = 3.0 kN/ m²

Table 4.10: Effect of Live Load Patterning on Thickness and Deflection of Slab (Pattern 1).

Span, m	Beam-Slab		Flat Plate	
	Thickness, mm	Deflection, mm	Thickness, mm	Deflection, mm
12	325	27	325	28
15	500	26	500	27
18	725	27	725	27

Table 4.11: Effect of Live Load Patterning on Thickness and Deflection of Slab (Pattern 2).

Span, m	Beam-Slab		Flat Plate	
	Thickness, mm	Deflection, mm	Thickness, mm	Deflection, mm
12	325	24	325	24
15	475	25	475	25
18	675	27	675	27

Case 2: Imposed Load = 7.5 kN/ m²

Table 4.12: Effect of Live Load Patterning on Thickness and Deflection of Slab (Pattern 1).

Span, m	Beam-Slab		Flat Plate	
	Thickness, mm	Deflection, mm	Thickness, mm	Deflection, mm
12	375	28	375	28
15	550	27	575	26
18	800	27	800	27

Table 4.13: Effect of Live Load Patterning on Thickness and Deflection of Slab (Pattern 2).

Span, m	Beam-Slab		Flat Plate	
	Thickness, mm	Deflection, mm	Thickness, mm	Deflection, mm
12	375	24	375	24
15	525	27	525	27
18	725	28	725	28

From **Table 4.10** and **Table 4.11**, it is noticed that in order to control the slab deflection within prescribed range, the live load Pattern 1 does not gives any effect to the slab thickness, except that the magnitude of deflection is reduce by 1 or 2mm. **Table 4.12** and **Table 4.13** show the slab thickness and deflection of floor framing system under live load Pattern 2 for Case 1 and Case 2 respectively. The slab thickness required to control the deflection within the prescribed range varies from those with fully loaded and those with live load Pattern 1. **Figure 4.5** and **Figure 4.6** show the trend and effect of live load patterning on the thickness of the slabs for Case 1 and Case 2 respectively.

For Case 1, the polynomial lines for conventional beam-slab system and flat plate with full live load, as well as live load Pattern 1 coincide. This means that the live load Pattern 1 impose the same effect as when the slab is fully loaded. While the polynomial lines for conventional beam-slab system and flat plate floor system with live load Pattern 2 coincide. Therefore, it is shown that the live load patterning has an effect on the thickness, thus overall economic of the slab system. From **Figure 4.5** as well, it is shown that the live load patterns do not affect the thickness of the slabs at 12m span. However, as the span increases, the gap between the polynomial lines increases. This means that the live load patterning is important at span greater than 12m. The maximum variation occurs at span 18m, which is 50mm between live load Pattern 1 and live load Pattern 2. Proper study of the live load pattern with real life data input for simulation is necessary in order to determine the actual pattern of imposed load for design.

For imposed load Case 2, the polynomial lines of conventional beam-slab system and flat plate system with full live load coincide. The polynomial lines of conventional beam-slab system and flat plate system with live load Pattern 2 coincide as well. Both of the systems having the same magnitude of slab thickness and the trend shows an increase of thickness with slab span for both live load patterns. This shows consistency of the analysis with the parameters discussed previously. However, the polynomial lines of both floor framing systems loaded with live load Pattern 1 is deviated and show a different trend as those of Case 1. At slab with 12m span, the thickness required to control the deflection within the prescribed range for both live load patterns are the same. However, as the span increases, the polynomial lines of both systems for live load Pattern 1 deviated. The flat plate requires greater thickness at span 15m as compared to conventional beam-slab system. However, the thickness required to control the deflection within the prescribed range at 18m span is the same for both floor framing system, and meet the polynomial lines of the floor with full live load.

The trend of the slab thickness versus slab span shows differences for different live load patterns. This indicates that the live load patterns impose an effect on the slab thickness and eventually may affect the selection of the floor framing system.

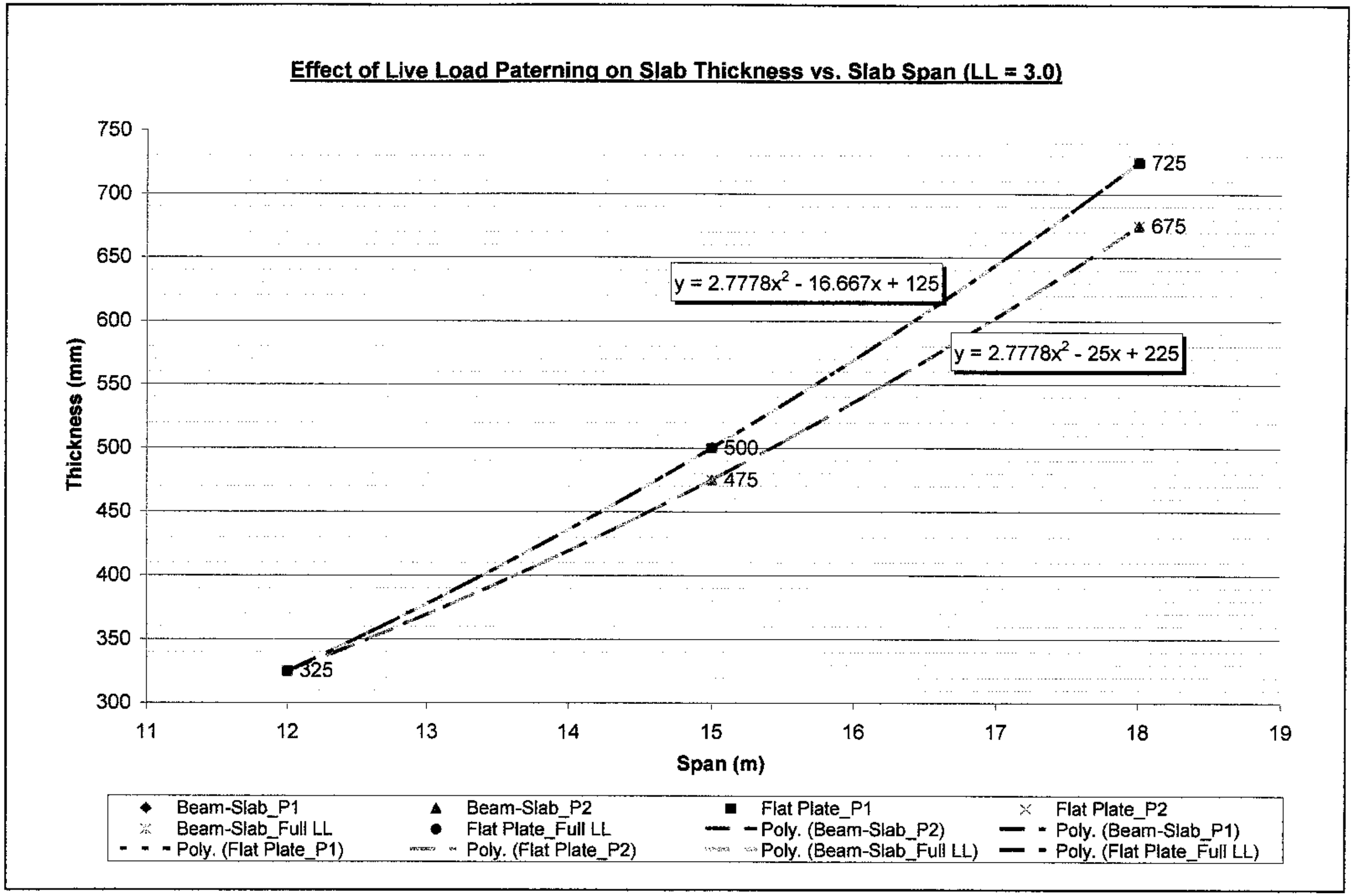

Figure 4.7: Effect of Live Load Patterning on Slab Thickness for Case 1.

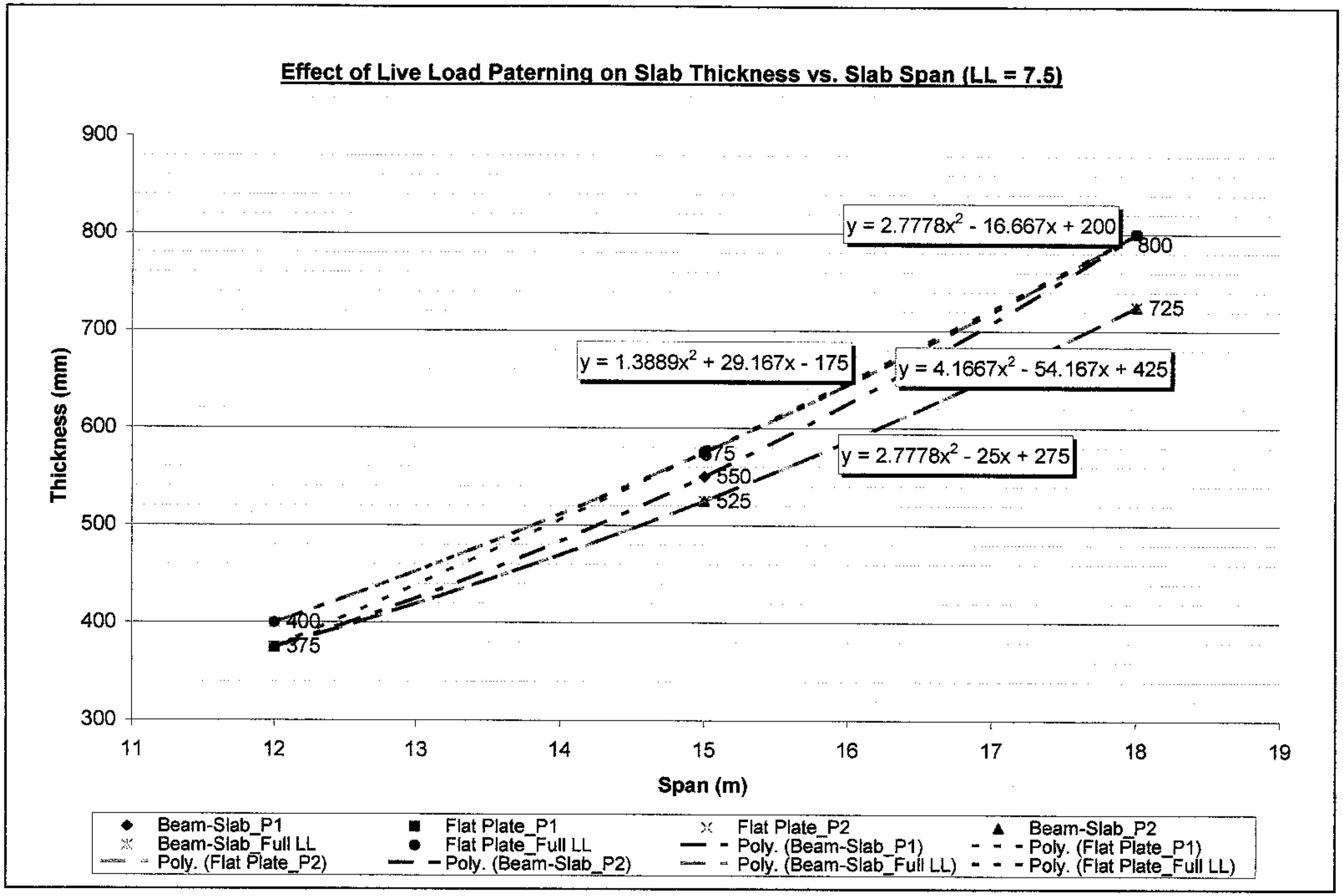

Figure 4.8: Effect of Live Load Patterning on Slab Thickness for Case 2.

4.4.2 Weight and Efficiency

Case 1: Imposed load = 3.0 kN/ m²

Table 4.14: Effect of Live Load Patterning on Weight and Efficiency of Slab (Pattern 1).

Span, m	Area, m²	Beam-Slab		Flat Plate	
		Weight, kN	Efficiency, kN/ m²	Weight, kN	Efficiency, kN/ m²
12	1296	11,145.58	8.60	9,924.14	7.66
15	2025	25,637.40	12.66	23,856.15	11.78
18	2916	53,475.80	18.34	49,811.52	17.08

Table 4.15: Effect of Live Load Patterning on Weight and Efficiency of Slab (Pattern 2).

Span, m	Area, m²	Beam-Slab		Flat Plate	
		Weight, kN	Efficiency, kN/ m²	Weight, kN	Efficiency, kN/ m²
12	1296	11,145.58	8.60	9,924.14	7.66
15	2025	24,571.84	12.13	22,663.34	11.19
18	2916	51,465.60	17.65	46,376.30	15.90

Case 2: Imposed load = 7.5 kN/ m²

Table 4.16: Effect of Live Load Patterning on Weight and Efficiency of Slab (Pattern 1).

Span, m	Area, m²	Beam-Slab		Flat Plate	
		Weight, kN	Efficiency, kN/ m²	Weight, kN	Efficiency, kN/ m²
12	1296	12,672.39	9.78	11,450.95	8.84
15	2025	28,023.08	13.84	27,434.59	13.55
18	2916	58,628.92	20.11	54,964.60	18.85

Table 4.17: Effect of Live Load Patterning on Weight and Efficiency of Slab (Pattern 2).

Span, m	Area, m^2	Beam-Slab		Flat Plate	
		Weight, kN	Efficiency, kN/ m^2	Weight, kN	Efficiency, kN/ m^2
12	1296	12,672.39	9.78	11,450.95	8.84
15	2025	27,084.58	13.38	25,048.87	12.37
18	2916	53,475.80	18.34	49,811.52	17.08

Weight and efficiency of the floor framing system is inversely proportional. The higher the weight, the less efficient the floor framing system is. **Table 4.14** and **Table 4.15** show the actual weight of the structure and the weight per unit floor area (efficiency) of the conventional beam-slab system and the flat plate system with live load Pattern 1 and live load Pattern 2, for Case 1 while **Table 4.16** and **Table 4.17** show the data for Case 2. **Figure 4.9** and **Figure 4.10** show the trend of weight per unit floor area of the floor framing system versus the slab span for the fully loaded slabs as well as the slabs with live load Pattern 1 and live load Pattern 2 of Case 1 and Case 2 respectively.

For imposed load Case 1 (normal floors), the polynomial lines for fully loaded slabs coincide with the polynomial lines of slabs loaded with live load Pattern 1 for both floor framing systems. Whereas for slabs loaded with live load Pattern 2, the polynomial lines deviated from the initial one with weight per unit floor area of it reduce from the initial value of 18.34 to 17.65 for conventional beam-slab system and 17.08 to 15.90 for flat plate system at 18m span. The efficiency of flat plate is higher than the conventional beam-slab system for all three loading condition. This result is consistent with the results discussed earlier.

For imposed load Case 2 (mechanical floors), the trend of the polynomial lines are almost similar for both floor framing systems. Which means for all three loading conditions, the trend of the weight per unit floor area versus slab span graph are similar. However, the graph for fully loaded slabs does not coincide with the polynomial lines of slabs with live load Pattern 1. This shows a different result as compared to those with imposed load Case 1. This is simply because when the imposed load to be carried by the slab increases, live load patterning tends to have greater influence to the slab thickness as well as the overall performance of the slab system.

From the results gained, analysis suggests that the patterning of the imposed load implies great effect on performance of the floor framing systems. The effects become more apparent as the imposed load to be undertaken increases. Proper study and simulation of the live load patterning can increase the efficiency of the floor framing system by a great percentage.

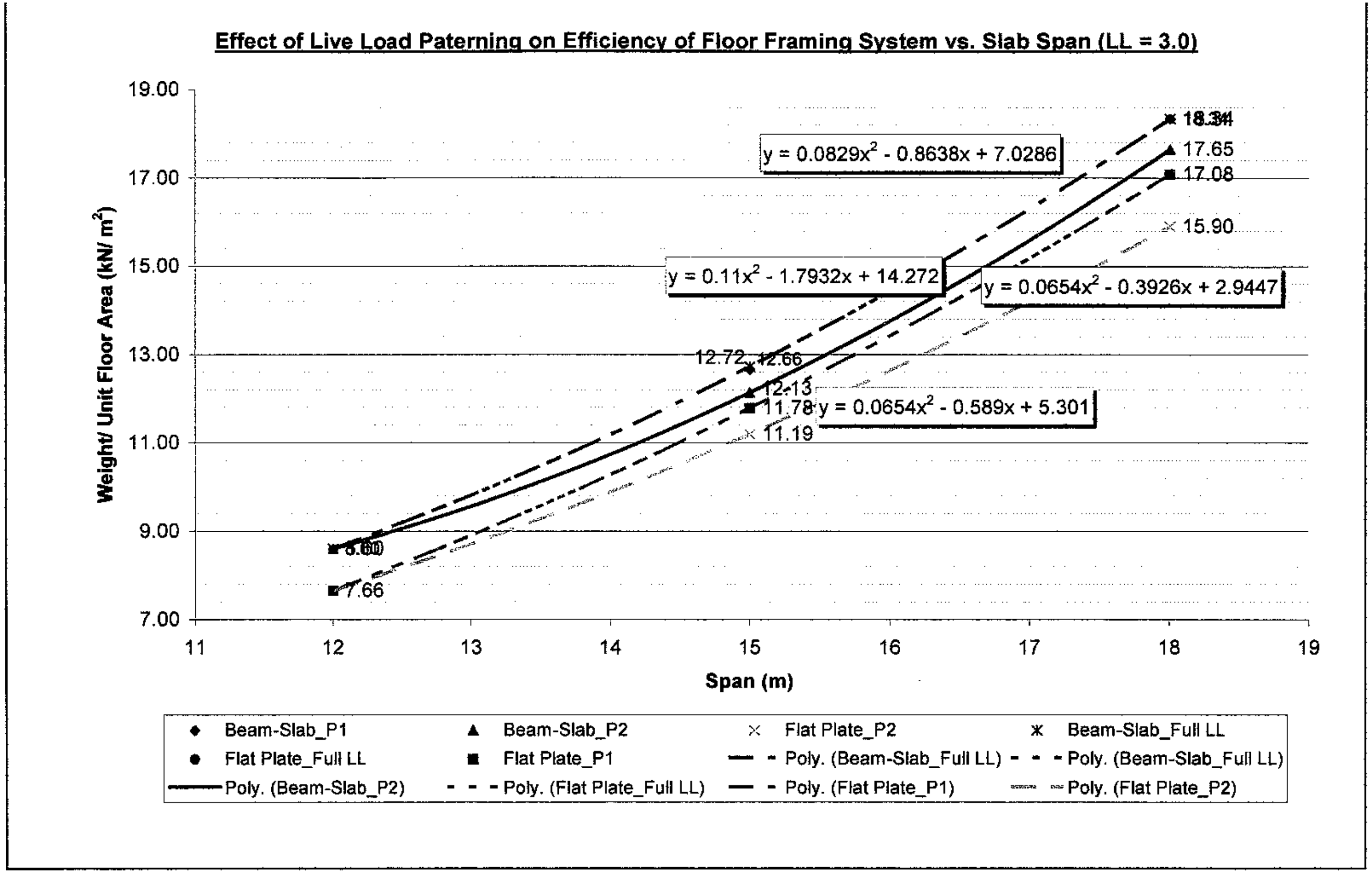

Figure 4.9: Effect of Live Load Patterning on Efficiency of Floor Framing System for Case 1.

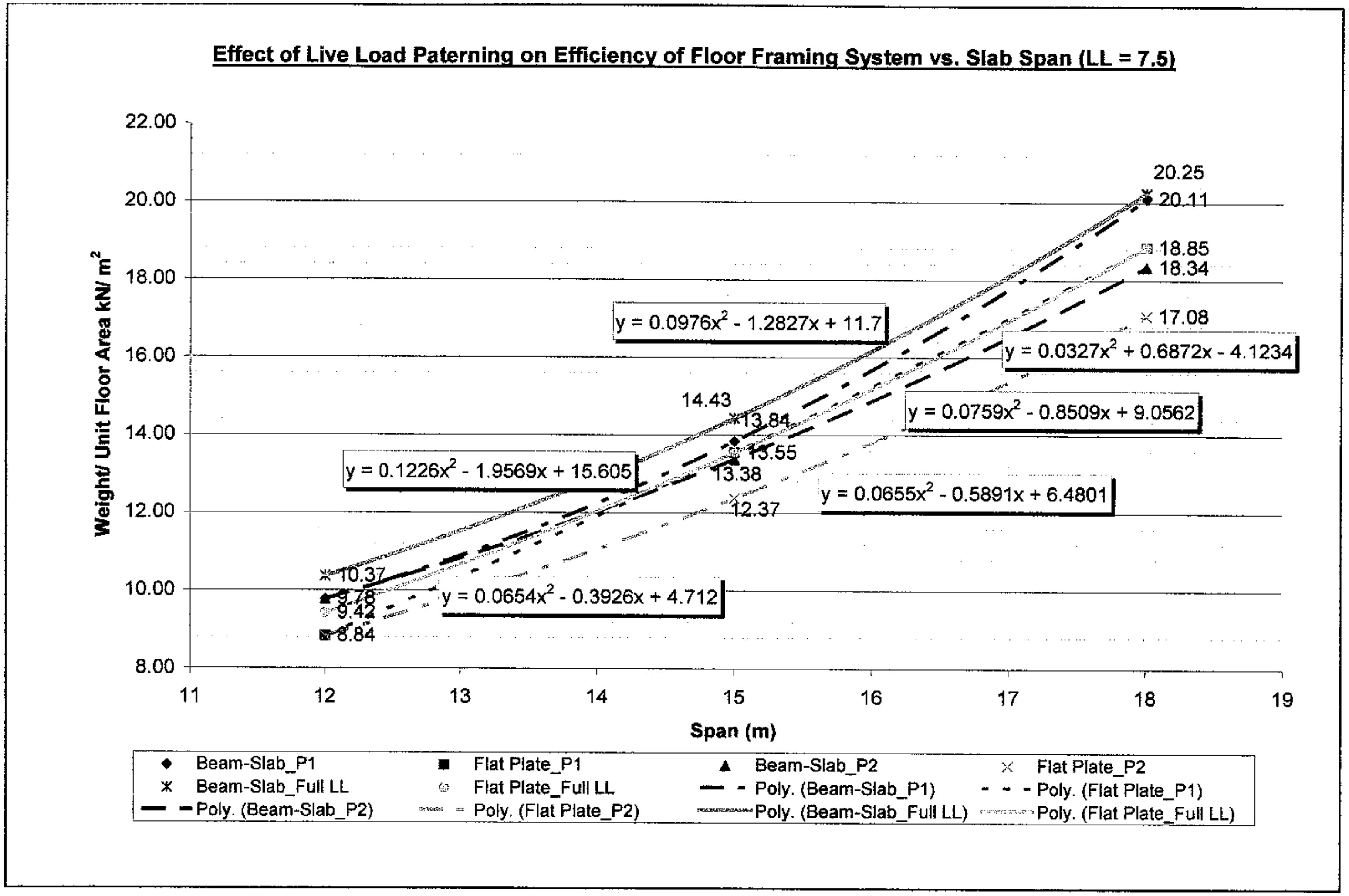

Figure 4.10: Effect of Live Load Patterning on Efficiency of Floor Framing System for Case 2.

4.6 Others

Besides the above-mentioned parameters, the build ability, the speed of construction and the aesthetic value, as well as the non-structural benefits of the floor system shall be taken into consideration as well.

For conventional beam-slab system, the performance in all these parameters is of moderate. The simplicity of flat plate makes it highly build able. The uniform thickness and the elimination of the beams enable this floor system to be cost effective in formwork as well as the reinforcement. Besides, this floor system gives great flexibility for the arrangement of the columns.

The benefit of post-tensioned flat slab is that the slab thickness is greatly reduced while maintaining the load carrying capacity of it. However, the handling and construction of this system requires skilled personnel, which might impose additional problem in construction industry. Besides, professional consultation is required for the design and supply of material, especially the prestressing strands and the stressing anchorage. The drop panels at the column head reduce the flexibility of the partitioning arrangement.

Whereas the waffle slab system imposes great problem in construct ability. The casting of ribs and pans requires skilled worker and it also requires great amount of formwork. Due to these reasons, the time of construction might require double the time for construction of the flat plate system. However, waffle slab gives other non-structural benefits such as concentrating the lighting. This is especially useful for buildings where lighting plays a very important role, such as the library. Besides, the waffle of the floor system acts as the absorber of the echo. The trouble and cost might be compensated by these benefits, especially when the echo is an issue to be countered. The example of buildings that could utilize this add on point of waffle slab is the gathering hall and the musical arena.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

1. The R^2 value for all graphs is 1. This shows a great accuracy of the equation derived from the graphs.
2. The most optimum floor framing system is the post-tensioned flat slab system based on the analysis of the four main floor framing systems analyzed.
3. Post-tensioned flat slab outperform the other three floor framing systems in:
   - Thickness
   - Weight
   - efficiency
   - cost per unit floor area
   - The thickness as well as the efficiency of this floor framing system shows a linear relationship with the slab span
4. For slabs span 12m and below, flat plate system is highly recommended as
   - Shows better cost efficiency compared to post-tensioned flat slab system.
   - Handling and simplicity of construction add to the plus to this floor framing system.
5. Waffle slabs give other non-structural benefits such as concentrating the lighting and acts as the absorber of the echo.
6. As imposed load increases, the thickness increases linearly while the efficiency drops correspondingly.
7. Live load patterning affects the designed output of the floor framing systems
   - This effect becomes more apparent when the structure designed is to carry heavy imposed load
8. Live load pattern is to be analyzed for real life condition for more optimum design.

5.2 Recommendation

This project can be extended by further the study on the performance of the other floor framing systems. This includes the hybrid systems and the steel floor framing system. Besides, the efficiency of the overall building can be studied to assure that the floor framing system analyzed is the most optimum one.

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[11] Article referred to http://www.post-tensioning.org/info_whatispt.asp *What is Post-Tensioning?*

[12] Article referred to http://www.vsl.net/construction_systems/post_tensioning.html *Post-tensioned in Buildings*

APPENDICES

Appendix A: Sample Input of 12m x 12m Flat Plate System (STAAD.Pro2002)

```
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END JOB INFORMATION
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E 2.733e+007
POISSON 0.17
DENSITY 23.5616
ALPHA 5.5e-006
DAMP 0.05
END DEFINE MATERIAL
CONSTANTS
MATERIAL CONCRETE MEMB 1 TO 144
ELEMENT PROPERTY
1 TO 144 THICKNESS 0.325
SUPPORTS
1 2 6 10 14 54 58 62 66 106 110 114 118 158 162 166 FIXED
LOAD 1 DEAD LOAD
SELFWEIGHT Y -1
LOAD 2 LIVE LOAD
ELEMENT LOAD
1 TO 144 PR GY -3
LOAD COMB 3 1.0DL + 1.0LL
1 1.0 2 1.0
LOAD COMB 4 1.4DL + 1.6LL
1 1.4 2 1.6
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START CONCRETE DESIGN
CODE BS8110
DESIGN ELEMENT 1 TO 144
FYMAIN 460000 MEMB 1 TO 144
FC 35000 MEMB 1 TO 144
END CONCRETE DESIGN
PDELTA ANALYSIS PRINT LOAD DATA
FINISH
```

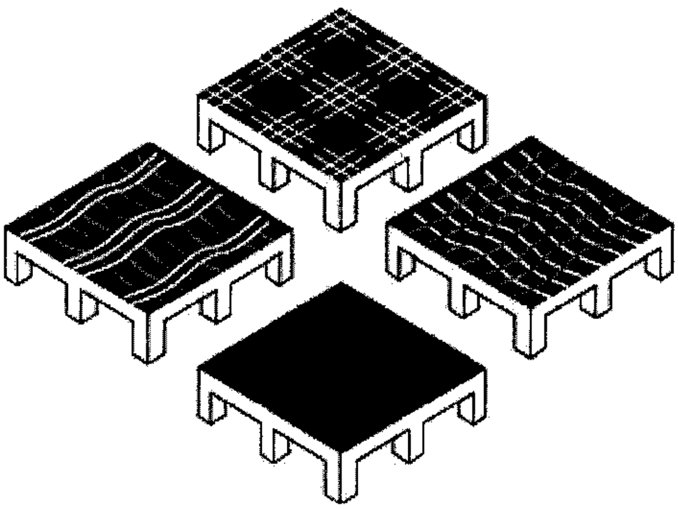
Appendix B: Sample Design of 12m x 12m Post-tensioned Flat Slab

(by James Ng of RAM International)

RAM Structural Engineering Solutions

Prestressed Drop Panel Flat Slab - 12m x 12m

LL = 3.0



Untitled
3/31/2005
for NG SOK MOOI

1.2.1

nits

ɔmetry Units

ı Dimensions: meters
les: degrees

Slab Thickness: mm
Elevations: mm

Support Dimensions: mm
Support Height: meters

ıding and Reaction Units

ıt Force: kN
Report As Zero: 0 kN
ıt Moment: kN-m
Report As Zero: 0 kN

Line Force: kN/m
- Report As Zero: 0 kN/m

Line Moment: kN
- Report As Zero: 0 kN-m

Area Force: kN/m²
- Report As Zero: 0 kN/m²

Area Moment: kN/m
- Report As Zero: 0 kN/m

ing and Stiffness Units

ıt Force Spring: kN/mm
ıt Moment Spring: kN-m/rad

Line Force Spring: kN/mm²
Line Moment Spring: kN/rad

Area Force Spring: N/mm³
Area Moment Spring: kN/m-rad

b Analysis Units

e: kN
Report As Zero: 0 kN
e Per Width: kN/m
Report As Zero: 0 kN/m

Moment: kN-m
- Report As Zero: 0 kN-m

Moment Per Width: kN
- Report As Zero: 0 kN

Concrete Stress: N/mm²
- Report As Zero: 0 N/mm²

Deflection: mm
- Report As Zero: 0 mm

:erials Units

ɔrete Volume: cu. m
ər Weight: tonnes
Veight: kg

Reinforcing Area: sq. mm
Tendon Profile: mm
Cover: mm

PT Force: kN
Reinforcing Stress: N/mm²

cellaneous Units

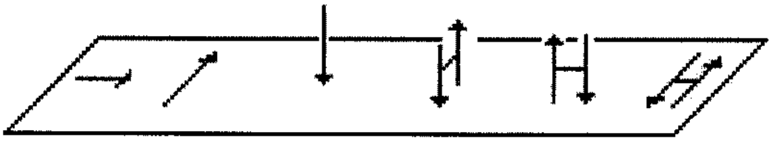
r Area: sq. m
lon Angles (for friction): radians

Density: kg/m³

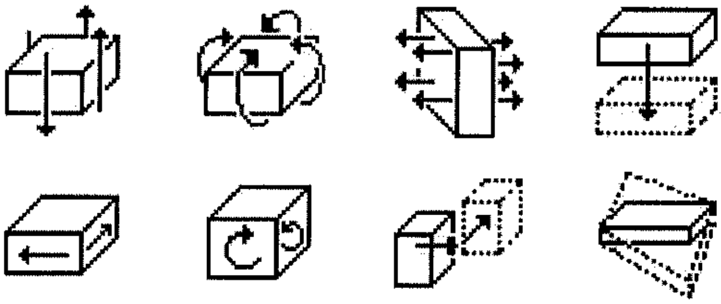
Elongations: mm

gns

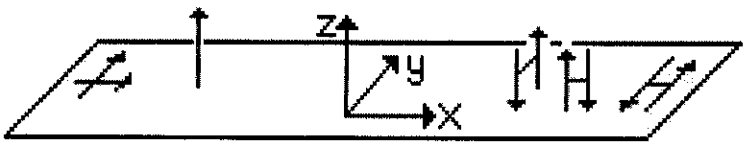
Positive Loads



Positive Analysis



Positive Reactions



aterials

ıcrete Mix

ıe	Density (kg/m³)	fci (N/mm²)	fc (N/mm²)	fcul (N/mm²)	fcu (N/mm²)	Poissons Ratio	Ec Calc	User Eci (N/mm²)	User Ec (N/mm²)
'25	2400	16	20	20	25	0.2	BS fig. 2.1	20000	22500
'30	2400	20	25	25	30	0.2	BS fig. 2.1	22500	25000
'35	2400	20	28	25	35	0.2	BS fig. 2.1	22500	26500
'37	2400	20	30	25	37	0.2	BS fig. 2.1	22500	27500
'40	2400	20	32	25	40	0.2	BS fig. 2.1	22500	28500
'45	2400	20	35	25	45	0.2	BS fig. 2.1	22500	30000
'50	2400	20	40	25	50	0.2	BS fig. 2.1	22500	32000
'55	2400	20	45	25	55	0.2	BS fig. 2.1	22500	33500
'60	2400	20	50	25	60	0.2	BS fig. 2.1	22500	35000
'67	2400	20	55	25	67	0.2	BS fig. 2.1	22500	37000
'75	2400	20	60	25	75	0.2	BS fig. 2.1	22500	39000
'85	2400	20	70	25	85	0.2	BS fig. 2.1	22500	41500

Systems

'em ıe	Type	Aps (sq. mm)	Eps (N/mm²)	fse (N/mm²)	fpy (N/mm²)	fpu (N/mm²)	Duct Width (mm)	Strands Per Duct	Min Radius (meters)
mm Unbonded	unbonded	100	195000	1200	1580	1860	13	1	2
mm Bonded	bonded	100	195000	1100	1580	1860	100	4	2
ım Unbonded	unbonded	150	195000	1200	1500	1770	16	1	2.5
ım Bonded	bonded	150	195000	1100	1500	1770	100	4	2.5

Stressing Parameters

em 'e	Jacking Stress (N/mm²)	Seating Loss (mm)	Anchor Friction	Wobble Friction (1/meters)	Angular Friction (1/radians)	Long-Term Losses (N/mm²)
ım Unbonded	1395	6	0	0.003	0.06	100
ım Bonded	1395	6	0.02	0.0017	0.2	100
ım Unbonded	1328	6	0	0.003	0.06	100
ım Bonded	1328	6	0.02	0.0017	0.2	100

ıforcing Bars

e	As (N/mm²)	ES (N/mm²)	Fy (N/mm²)
	50.3	200000	460
	78.5	200000	460
	113	200000	460
	201	200000	460
	314	200000	460
	491	200000	460
	804	200000	460
	1260	200000	460

›adings

ding Name	*Type*	*On-Pattern Factor*	*Off-Pattern Factor*
·Dead Loading	Self-Weight	1	0.7143
ınce Loading	Balance	1	1
erstatic Loading	Hyperstatic	1	1
ıporary Construction (At Stressing) Loading	Standard	1	0
›r Dead Loading	Standard	1	0.7143
Loading	Standard	1	0

ɔad Combinations

Dead LC

/e Design Criteria: <none>

ding	*Standard Factor*	*Alt. Envelope Factor*
·Dead Loading	1	1
nce Loading	0	0
ərstatic Loading	0	0
porary Construction (At Stressing) Loading	0	0
ər Dead Loading	1	1
Loading	0	0

ɪd + Balance LC

/e Design Criteria: <none>

ding	*Standard Factor*	*Alt. Envelope Factor*
·Dead Loading	1	1
nce Loading	1	1
ərstatic Loading	0	0
porary Construction (At Stressing) Loading	0	0
ər Dead Loading	1	1
Loading	0	0

al Service LC

'e Design Criteria: Initial Service Design

ding	*Standard Factor*	*Alt. Envelope Factor*
Dead Loading	1	1
nce Loading	1.15	1.15
ərstatic Loading	0	0
porary Construction (At Stressing) Loading	1	1
r Dead Loading	0	0
Loading	0	0

vice LC

'e Design Criteria: Service Design

ding	*Standard Factor*	*Alt. Envelope Factor*
Dead Loading	1	1
nce Loading	1	1
ərstatic Loading	0	0
porary Construction (At Stressing) Loading	0	0
r Dead Loading	1	1
Loading	1	1

›ad Combinations (2)

·nate LC

·e Design Criteria: Strength Design, Ductility Design

ding	*Standard Factor*	*Alt. Envelope Factor*
Dead Loading	1.4	1
nce Loading	0	0
›rstatic Loading	1	1
porary Construction (At Stressing) Loading	0	0
·r Dead Loading	1.4	1
Loading	1.6	0

g-Term Deflection LC

·e Design Criteria: <none>

ding	*Standard Factor*	*Alt. Envelope Factor*
Dead Loading	3.35	3.35
nce Loading	3.35	3.35
›rstatic Loading	0	0
porary Construction (At Stressing) Loading	0	0
·r Dead Loading	3.35	3.35
Loading	1.59	1.59

ɜsign Rules

al Service Design

ı.l Service Design

vice Design

ice Design

de detailed section analysis

ɪngth Design

ıgth Design

:hing Shear Design

:tility Design

ility Design

stimate

crete Costs

rials:	131.2	per cu. m	x	354.5	cu. m	=	46510
r:	524.7	per cu. m	x	354.5	cu. m	=	186000
l:	655.9	per cu. m	x	354.5	cu. m	=	232500

t-Tensioning Costs

rials:	2.205	per kg	x	4362	kg	=	9617
r:	1.102	per kg	x	4362	kg	=	4808
l:	3.307	per kg	x	4362	kg	=	14430

nwork Costs

rials:	10.79	per sq. m	x	1354	sq. m	=	14610
r:	10.79	per sq. m	x	1354	sq. m	=	14610
l:	21.57	per sq. m	x	1354	sq. m	=	29210

Steel Reinforcing Costs

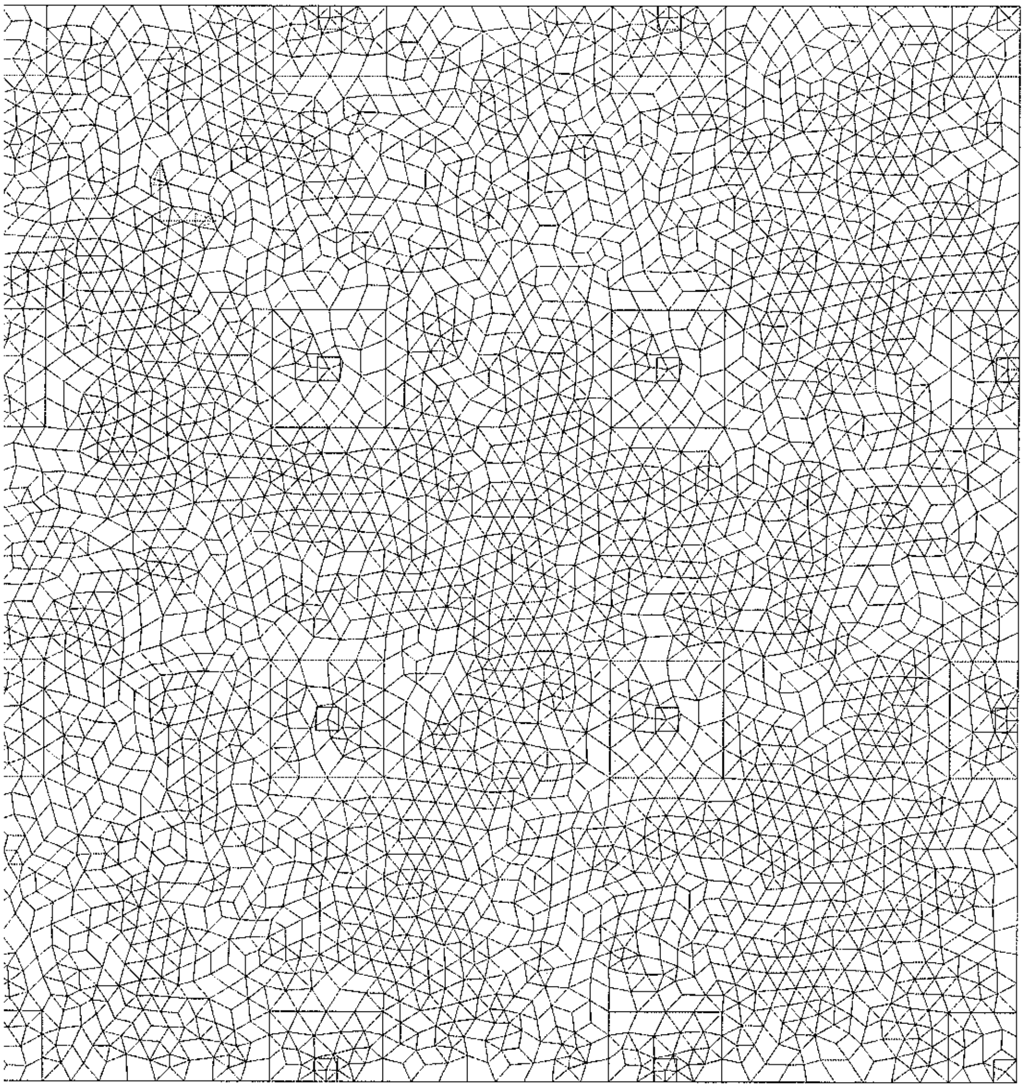
rials:	1102	per tonnes	x	3.389	tonnes	=	3736
r:	551.2	per tonnes	x	3.389	tonnes	=	1868
:	1653	per tonnes	x	3.389	tonnes	=	5604

l Costs

rials:	54.99	per sq. m	x	1354	sq. m	=	74460
r:	153.1	per sq. m	x	1354	sq. m	=	207300
:	208.1	per sq. m	x	1354	sq. m	=	281800

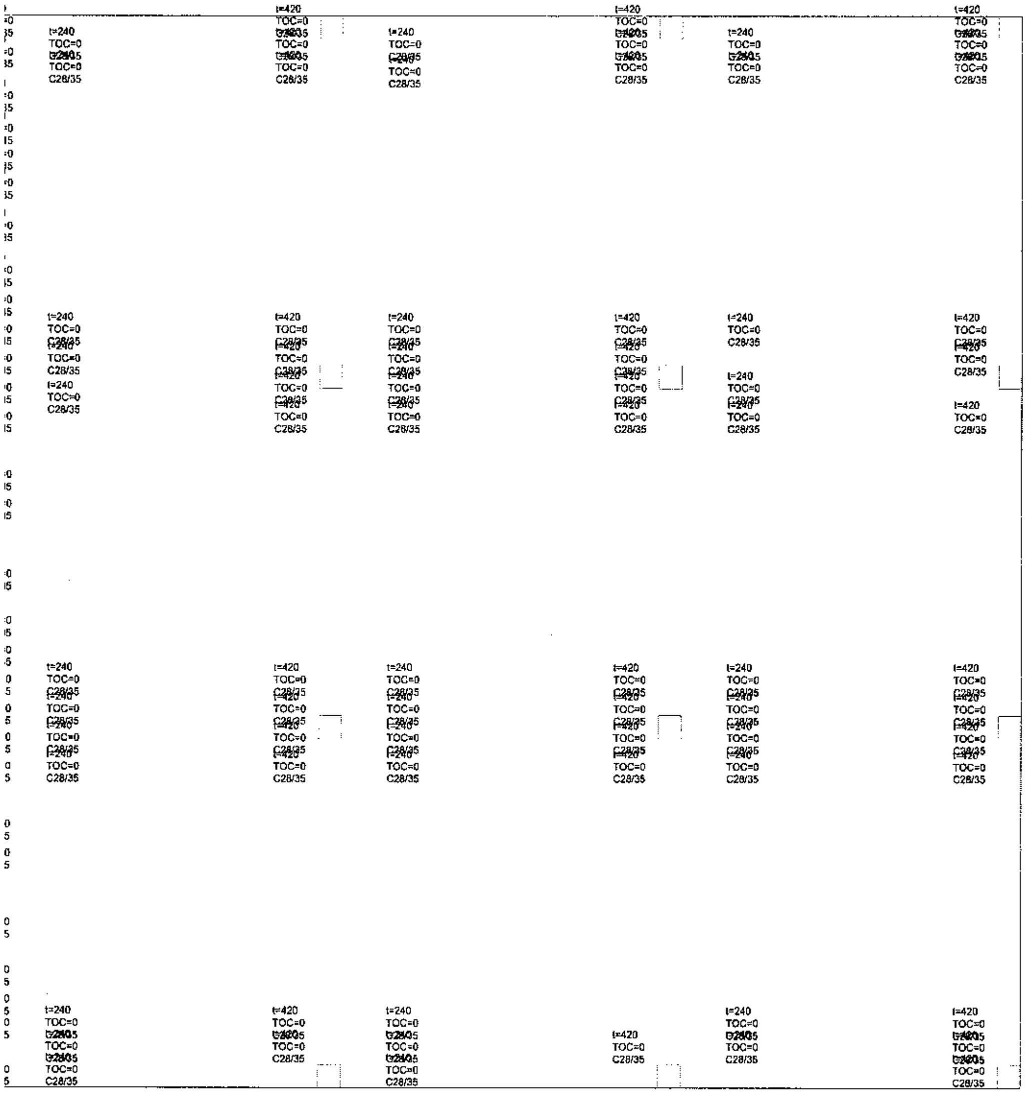
ement: Standard Plan

User Lines; User Notes; User Dimensions; Wall Elements Below; Wall Elements Above; Column Elements Below; Column Elements Above; Slab Elements; Point Springs; Point Spring Icons; Line Springs; Line Spring Icons; Area Springs; Area Spring Icons; Point Supports; Point Sup
mport: User Lines; User Notes; User Dimensions;
:250



ement: Slab Summary Plan

Wall Elements Below; Wall Elements Above; Column Elements Below; Column Elements Above; Point Springs; Point Spring Icons; Line Springs; Line Spring Icons; Slab Elements; Slab Element Edges; Slab Element Thicknesses; Slab Element Elevations; Slab Element Concrete Mo
Import: User Lines; User Notes; User Dimensions;
:250



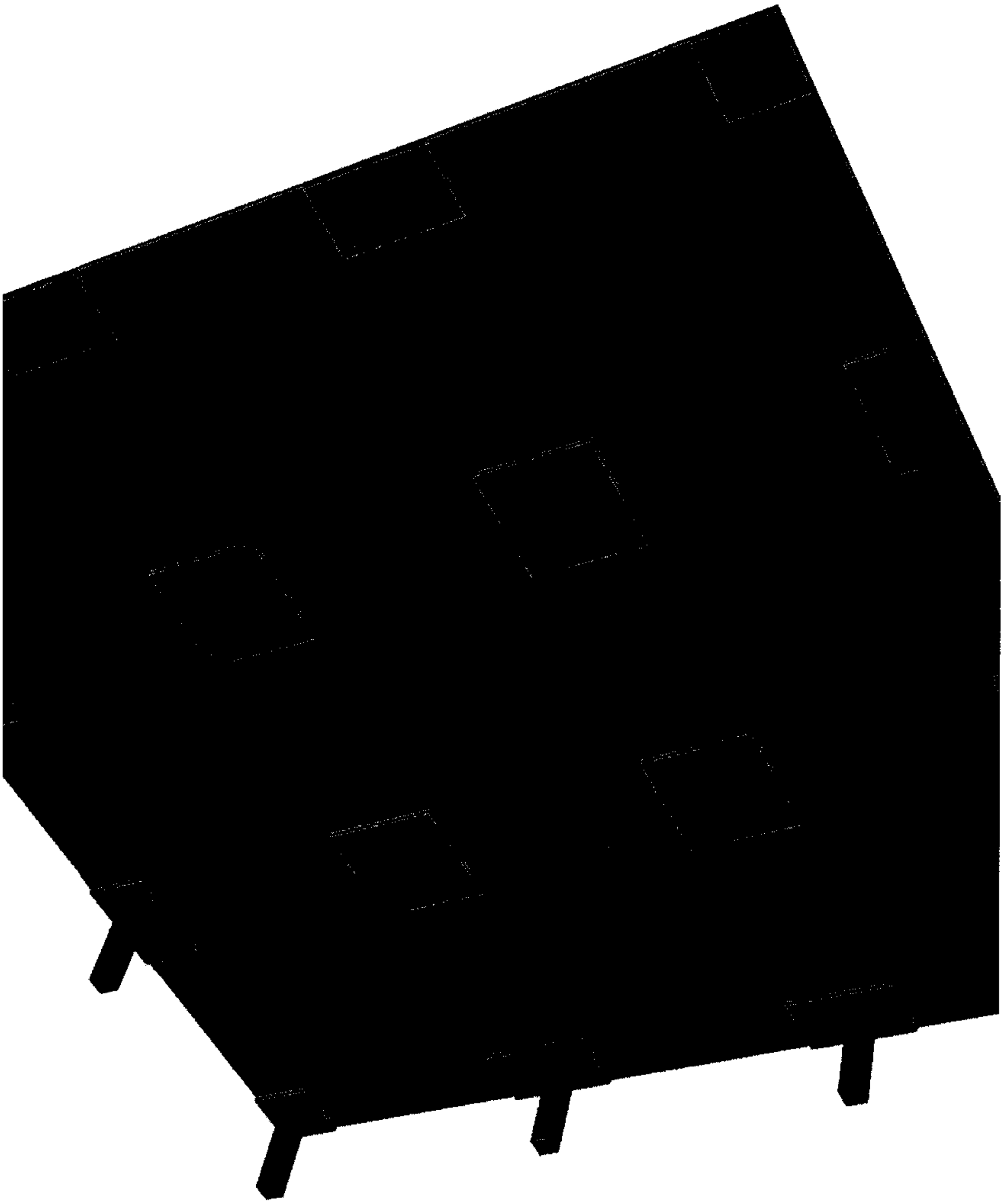
ement: Supports Below Slab Summary Plan

Wall Elements Below; Wall Element Thicknesses; Wall Element Heights; Wall Element Fixity; Wall Element Shear Fixity; Wall Element Concrete Models; Column Elements Below; Column Element Dimensions; Column Element Heights; Column Element Fixity; Column Element Conc
mport: User Lines; User Notes; User Dimensions;
:250

gid	b=800 d=800 h=3 Fix,Fix,Rigid C28/35	b=800 d=800 h=3 Fix,Fix,Rigid C28/35	b=800 d=800 h=3 Fix,Fix,Rigid C28/35
gid	b=800 d=800 h=3 Fix,Fix,Rigid C28/35	b=800 d=800 h=3 Fix,Fix,Rigid C28/35	b=800 d=800 h=3 Fix,Fix,Rigid C28/35
gid	b=800 d=800 h=3 Fix,Fix,Rigid C28/35	b=800 d=800 h=3 Fix,Fix,Rigid C28/35	b=800 d=800 h=3 Fix,Fix,Rigid C28/35
gid	b=800 d=800 h=3 Fix,Fix,Rigid C28/35	b=800 d=800 h=3 Fix,Fix,Rigid C28/35	b=800 d=800 h=3 Fix,Fix,Rigid C28/35

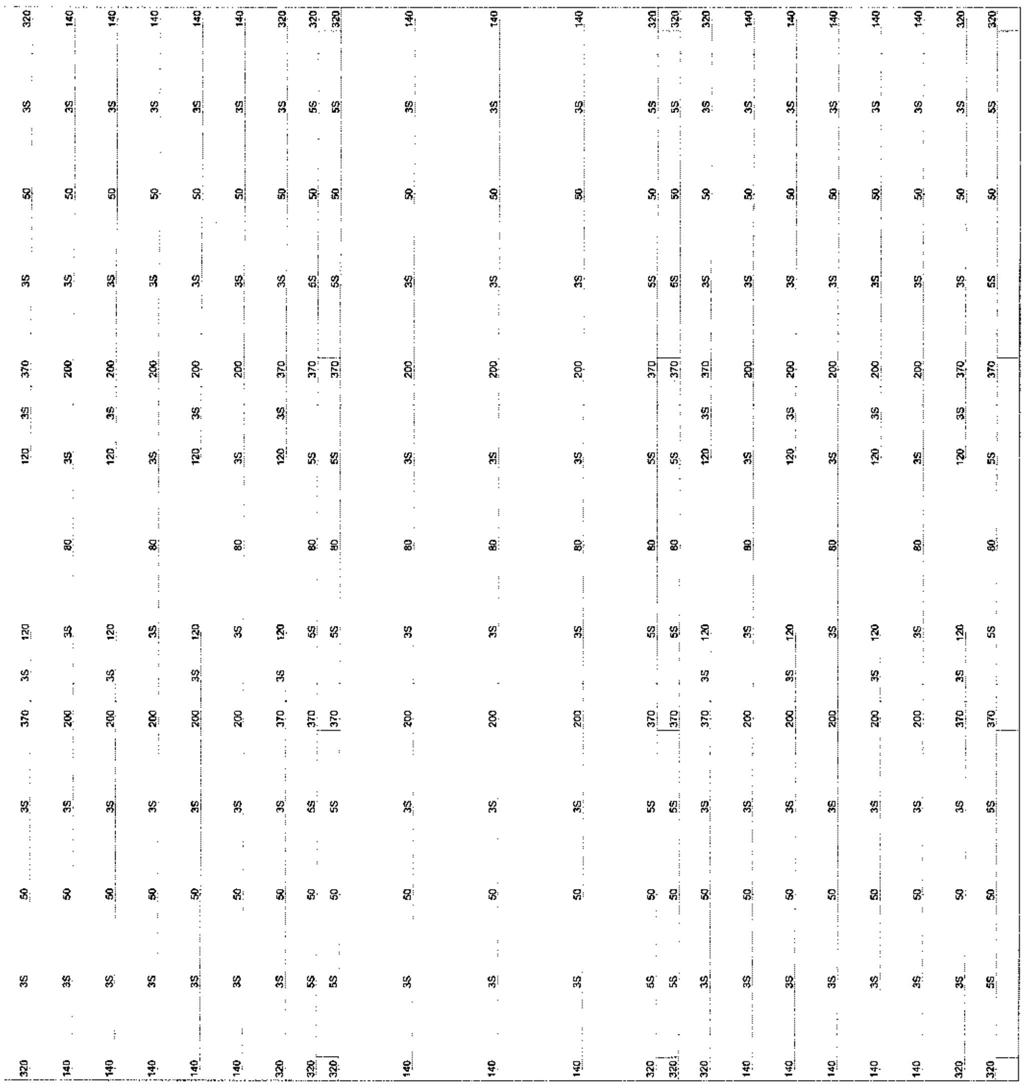
ement: Structure Summary Perspective

ll Elements Below; Wall Elements Above; Column Elements Below; Column Elements Above
er Lines; User Notes; User Dimensions;



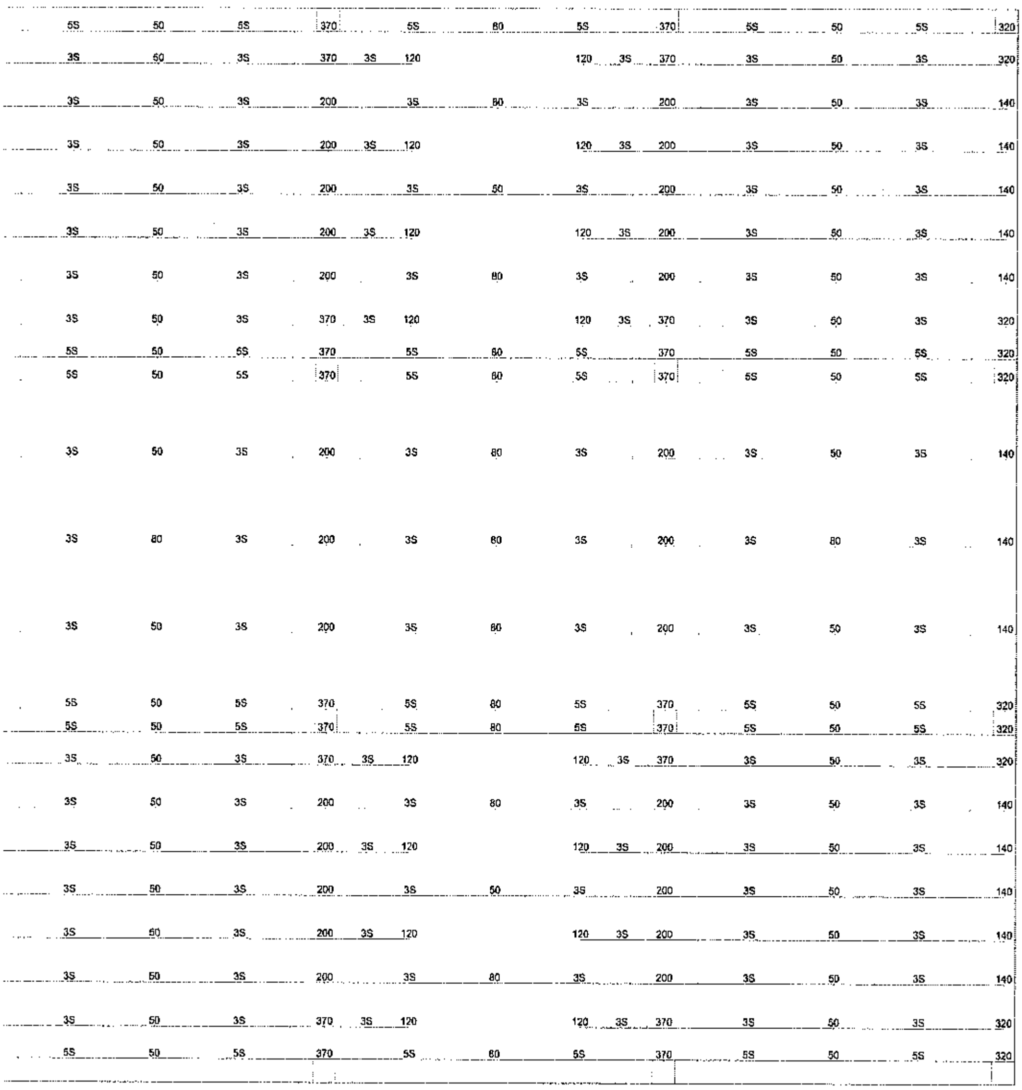
ɜnded Tendon: Standard Plan

'endon: User Lines; User Notes; User Dimensions; Tendons; Num Strands; Profile Points; Profile Values; Jacks;
mport: User Lines; User Notes; User Dimensions;
Wall Elements Below; Wall Elements Above; Column Elements Below; Column Elements Above; Slab Elements; Slab Element Edges;
:250



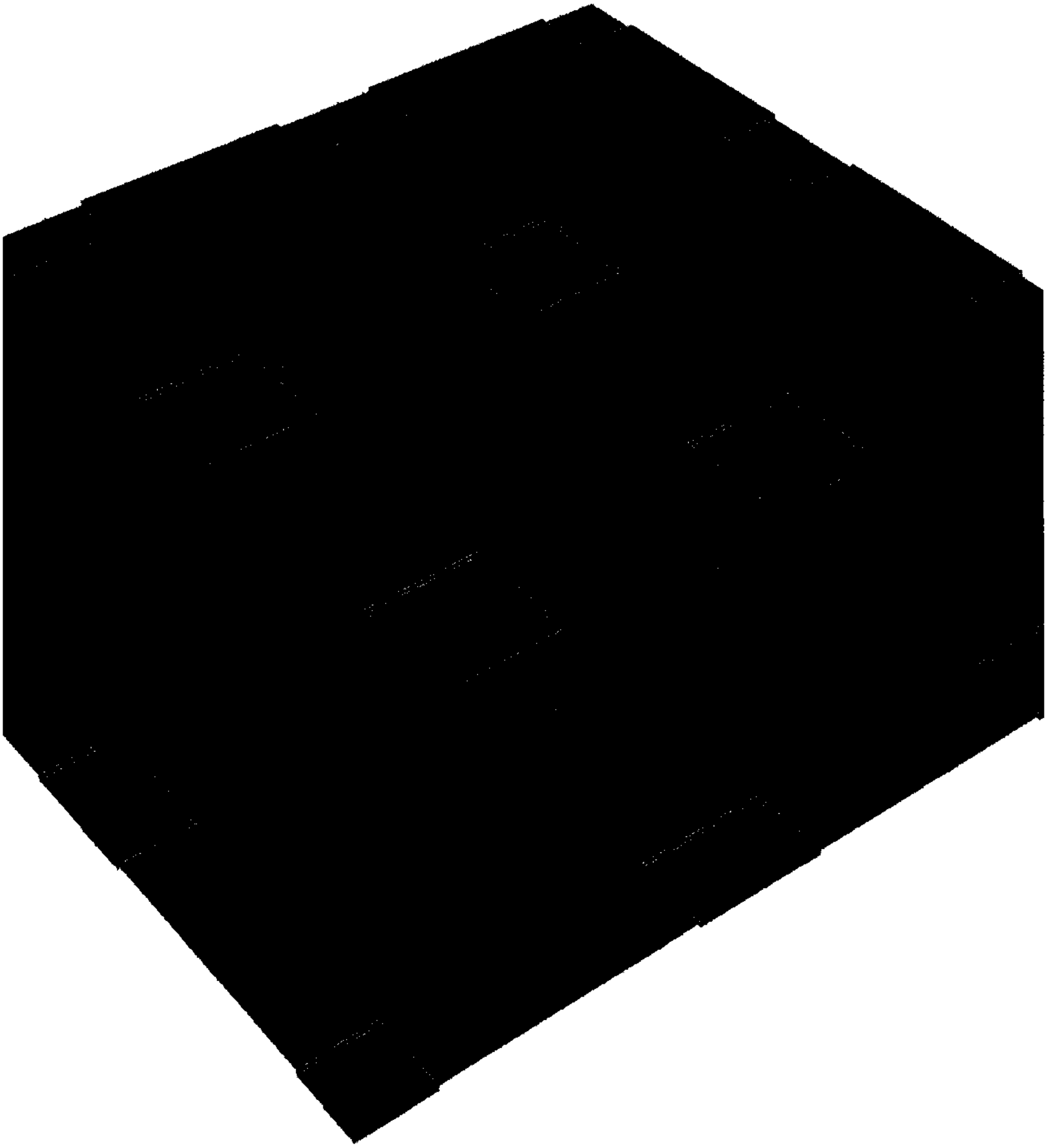
stributed Tendon: Standard Plan

d Tendon: User Lines; User Notes; User Dimensions; Tendons; Num Strands; Profile Points; Profile Values; Jacks;
mport: User Lines; User Notes; User Dimensions;
Wall Elements Below; Wall Elements Above; Column Elements Below; Column Elements Above; Slab Elements; Slab Element Edges;
:250



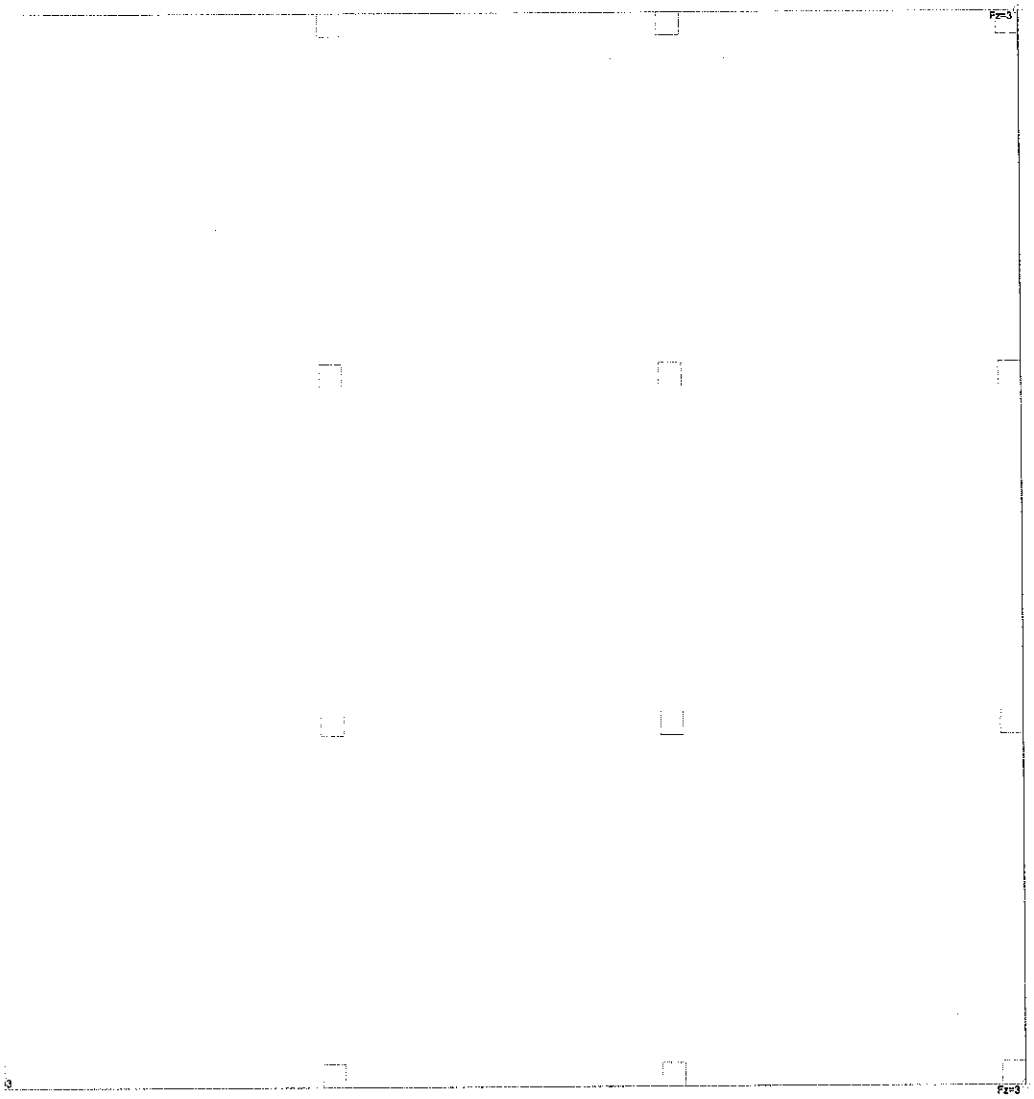
stributed Tendon: Standard Perspective

dons; Jacks;
ɔ Elements; Slab Elements Soffit Only;
dons;



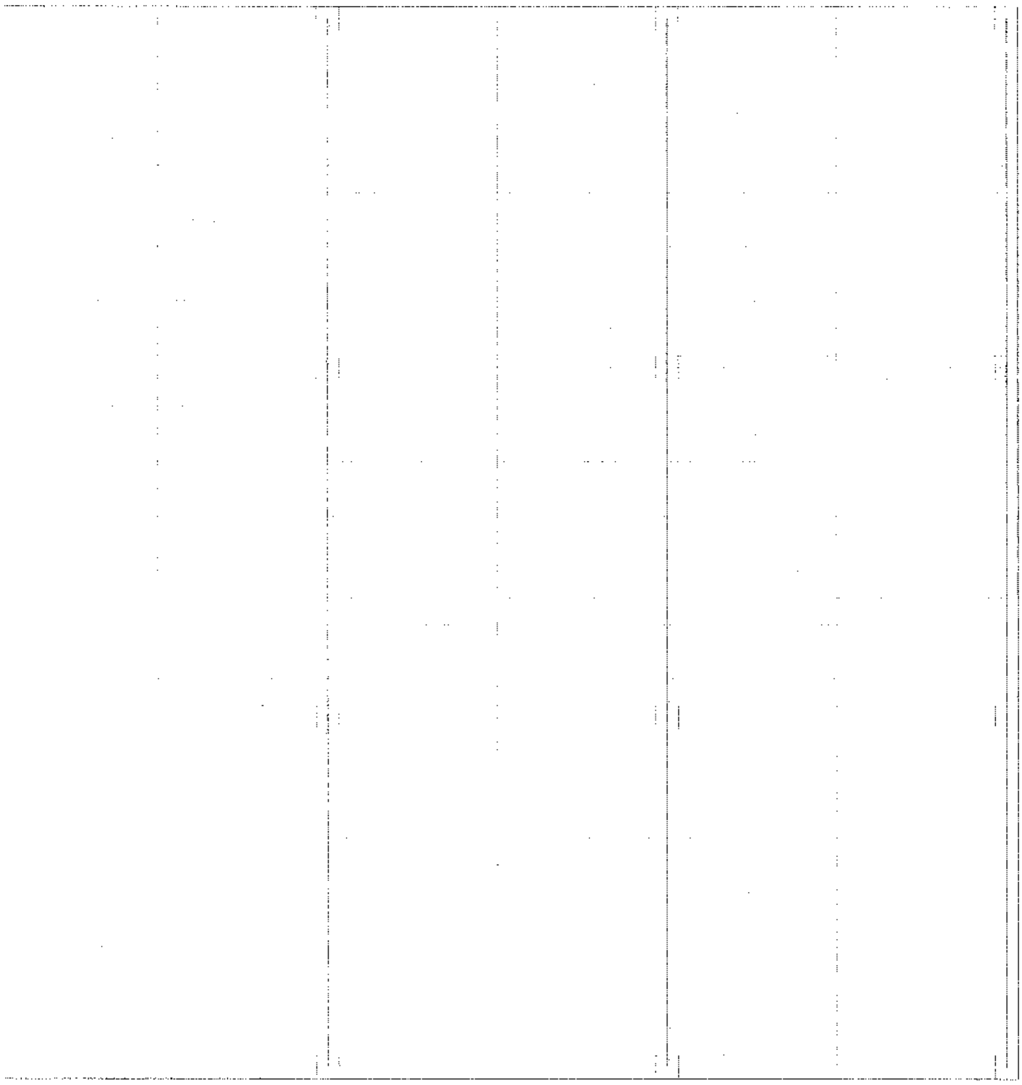
/e Loading: All Loads Plan

ng: User Lines; User Notes; User Dimensions; Point Loads; Point Load Icons; Point Load Values; Line Loads; Line Load Icons; Line Load Values; Area Loads; Area Load Icons; Area Load Values;
nport: User Lines; User Notes; User Dimensions;
Vall Elements Below; Wall Elements Above; Column Elements Below; Column Elements Above; Slab Elements; Slab Element Edges;
250



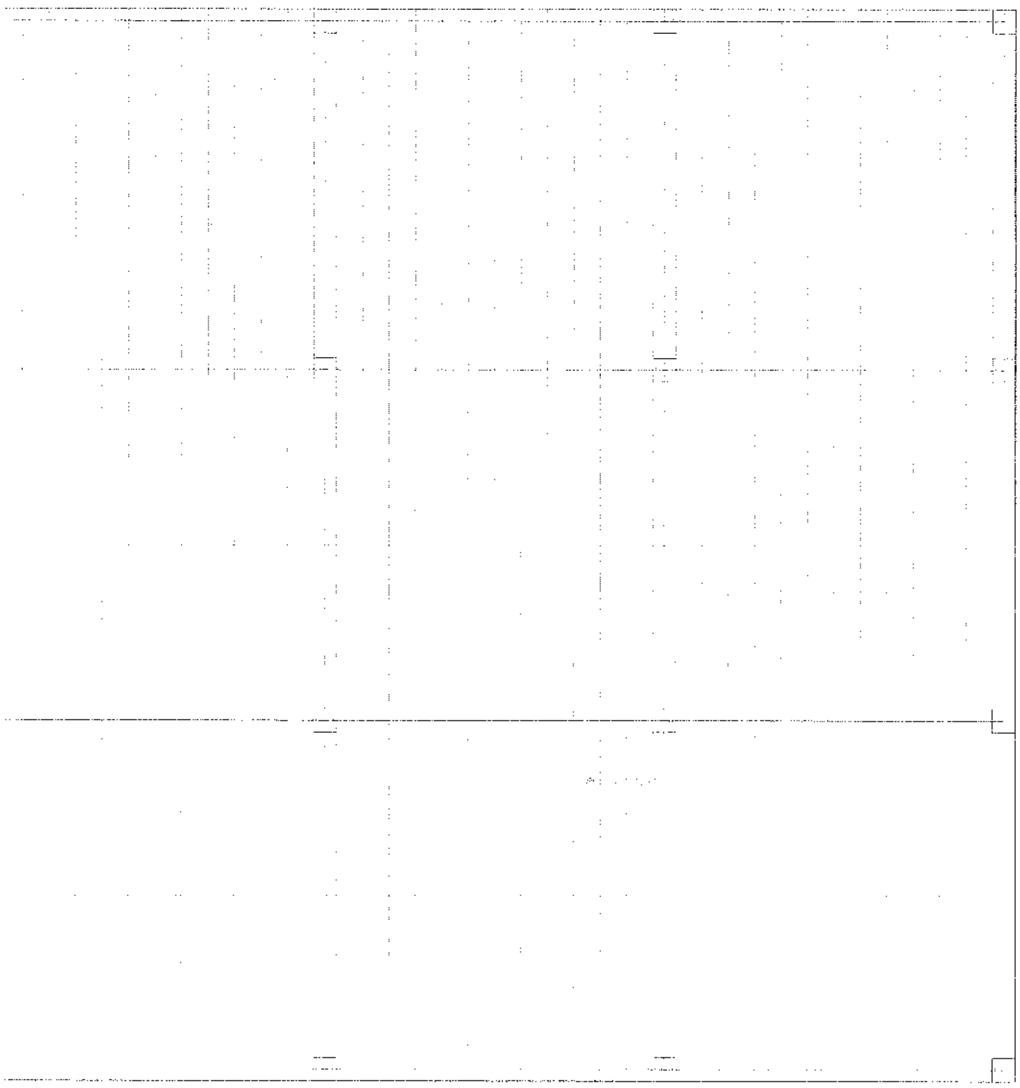
esign Strip: Banded Design Strips Plan

ip: User Notes; User Lines; User Dimensions; Banded DSSs; DSS Internal Sections; Banded DSs;
nport: User Notes; User Lines; User Dimensions;
Vall Elements Above; Wall Elements Below; Column Elements Above; Column Elements Below; Slab Elements; Slab Element Edges;
250



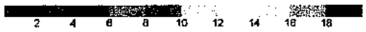
ɘsign Strip: Distributed Design Strips Plan

lp: User Notes; User Lines; User Dimensions; Distributed DSSs; DSS Internal Sections; Distributed DSs;
ıport: User Notes; User Lines; User Dimensions;
Vall Elements Above; Wall Elements Below; Column Elements Above; Column Elements Below; Slab Elements; Slab Element Edges;
250

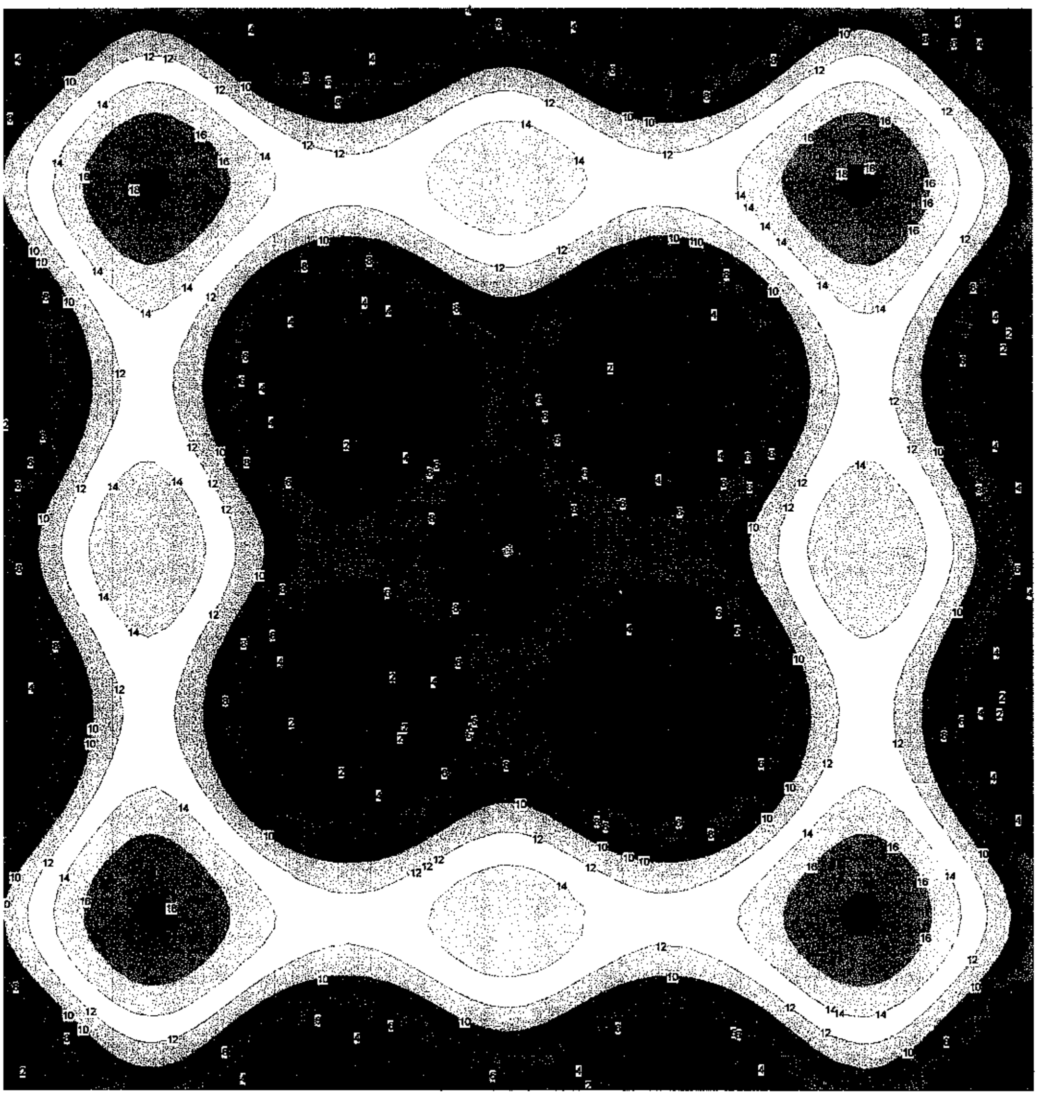


ervice LC: Deflection Plan

.C: User Lines; User Notes; User Dimensions;
Import: User Lines; User Notes; User Dimensions;
Wall Elements Below; Wall Elements Above; Column Elements Below; Column Elements Above; Slab Elements; Slab Element Edges;
:250
Deflection Plot

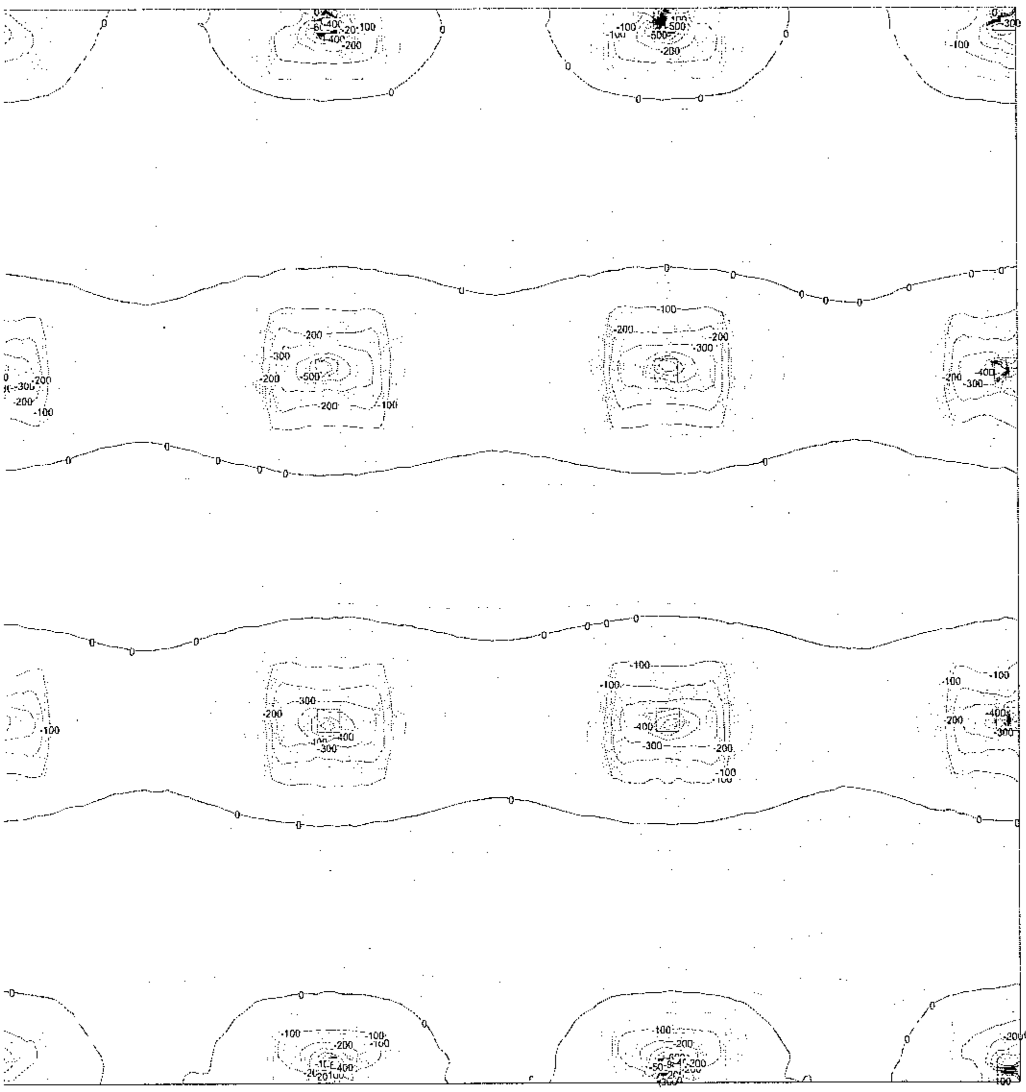


Min Value = -0.707 mm @ (-6.4,-16) Max Value = 18.2 mm @ (24.4,-23.2)



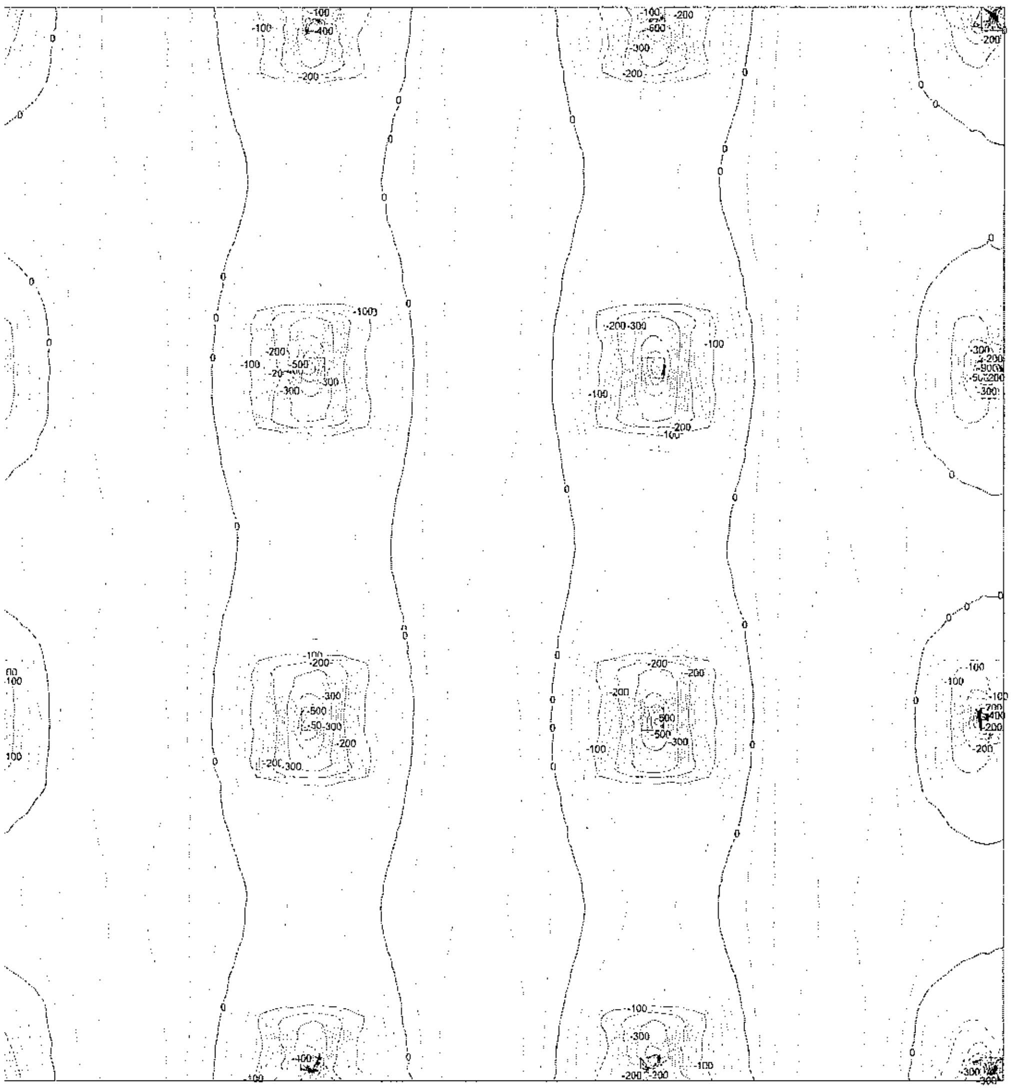
timate LC: Mx Plan

C: User Lines; User Notes; User Dimensions;
nport: User Lines; User Notes; User Dimensions;
Vall Elements Below; Wall Elements Above; Column Elements Below; Column Elements Above; Slab Elements; Slab Element Edges;
250
oment Plot (X-Axis direction)
e Contour = 20 kN
n Value = -969 kN @ (16.1,-28.7)   Max Value = 461 kN @ (18,7.2)



imate LC: My Plan

User Lines; User Notes; User Dimensions;
ort: User Lines; User Notes; User Dimensions;
ll Elements Below; Wall Elements Above; Column Elements Below; Column Elements Above; Slab Elements; Slab Element Edges;
)
nent Plot (Y-Axis direction)
Contour = 20 kN
Value = -970 kN @ (-5.72,-17.1)   Max Value = 461 kN @ (30.2,-17)

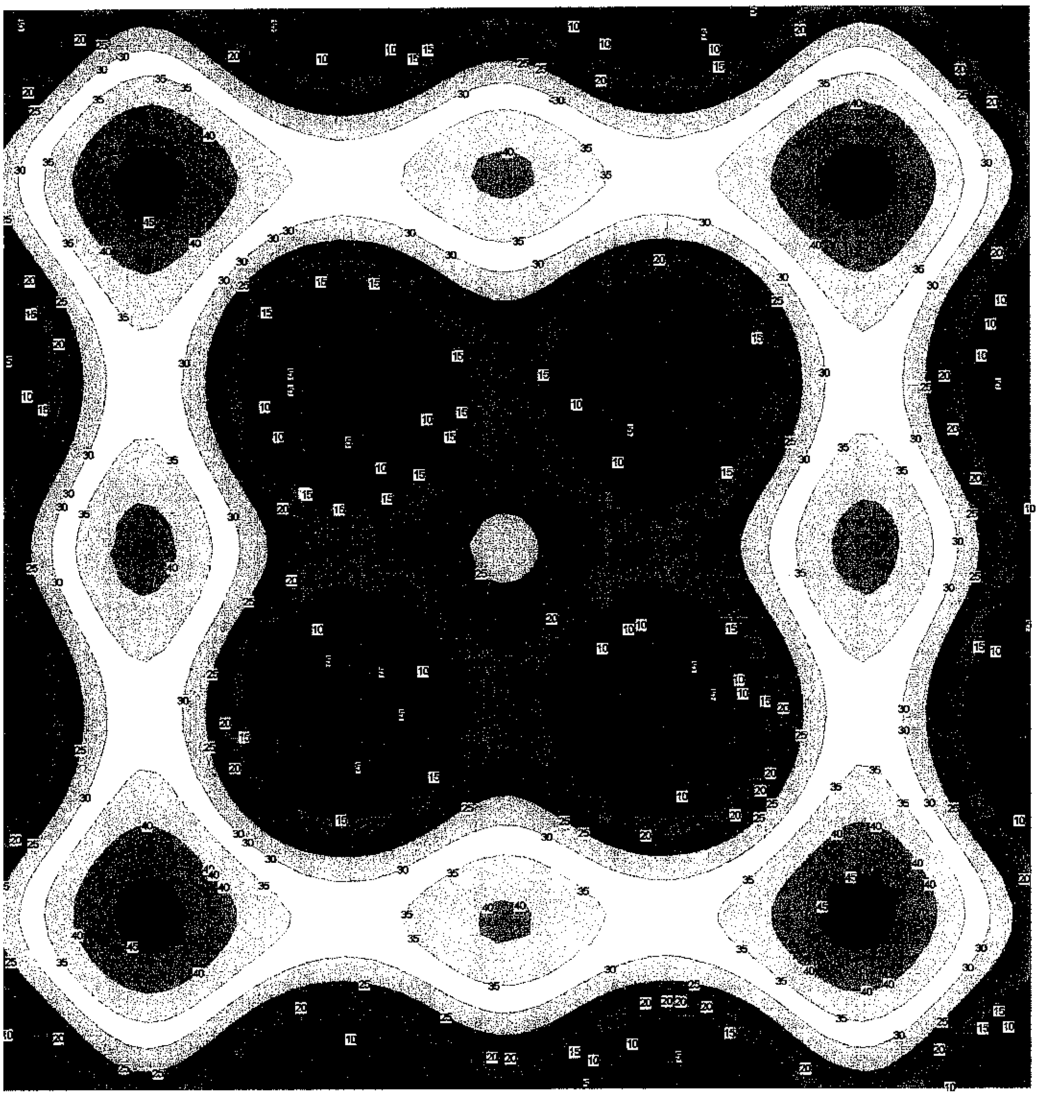


›ng-Term Deflection LC: Deflection Plan

n Deflection LC: User Lines; User Notes; User Dimensions;
mport: User Lines; User Notes; User Dimensions;
Wall Elements Below; Wall Elements Above; Column Elements Below; Column Elements Above; Slab Elements; Slab Element Edges;
:250
eflection Plot

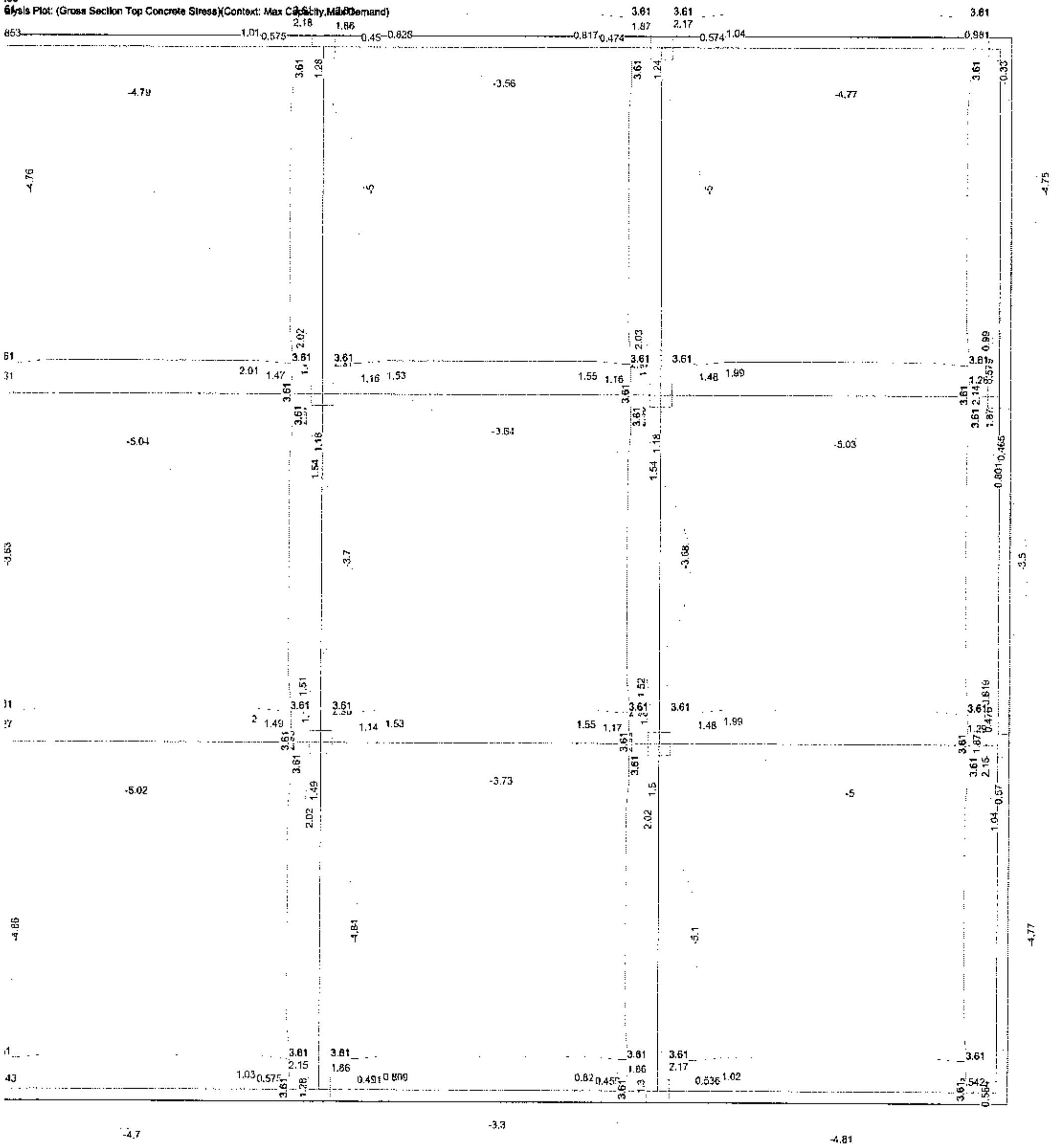
5 10 15 20 25 30 35 40 45

in Value = -1.92 mm @ (-6.4,-16)   Max Value = 46.6 mm @ (24.5,1.2)



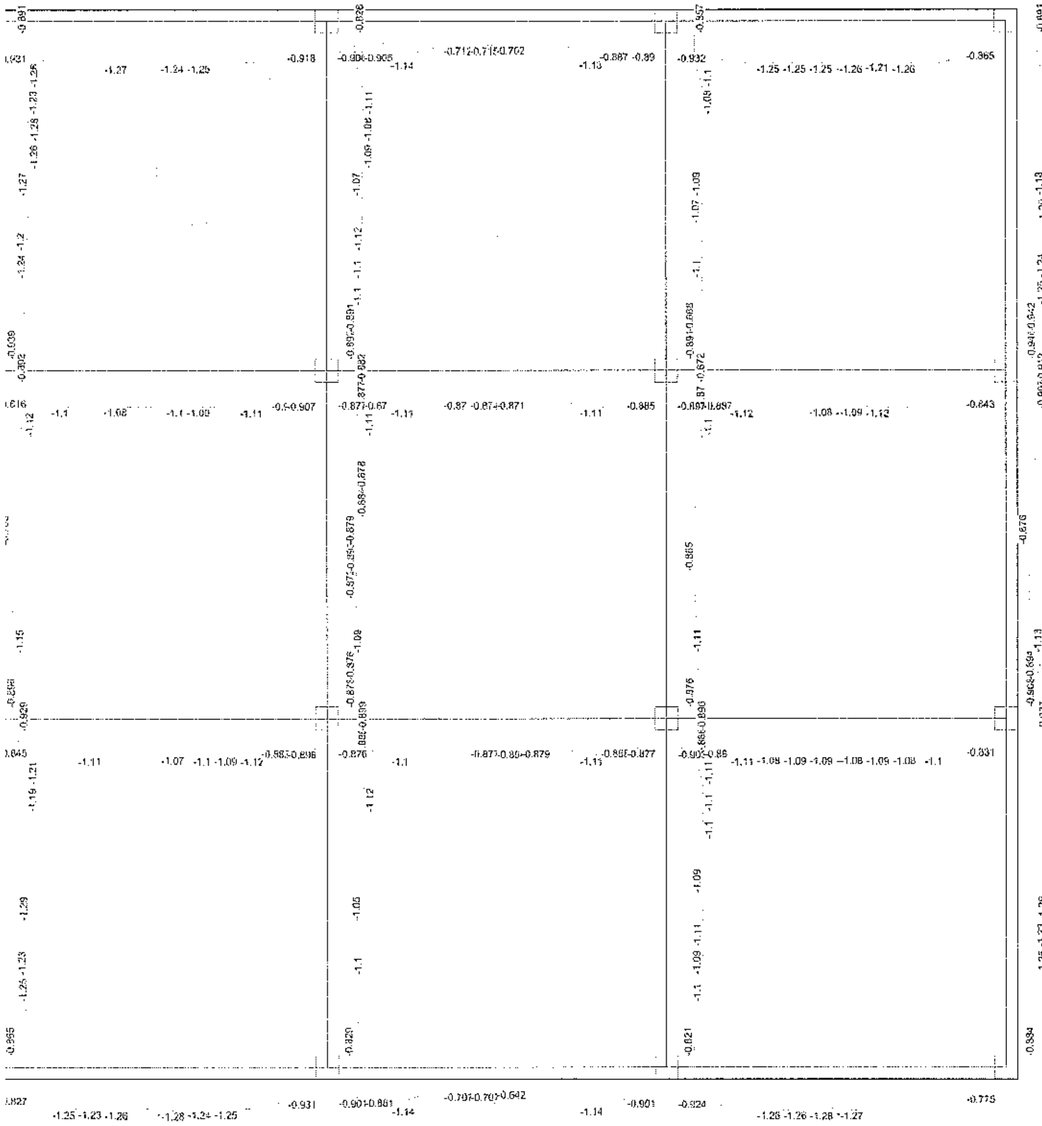
ervice Design: Top Stress Plan

sign: User Lines; User Notes; User Dimensions; Banded DSS Designs; Distributed DSS Designs; Banded DS Designs; Distributed DS Designs;
port: User Lines; User Notes; User Dimensions;
Vall Elements Below; Wall Elements Above; Column Elements Below; Column Elements Above; Slab Elements; Slab Element Edges;
250
alysis Plot: (Gross Section Top Concrete Stress)(Context: Max Capacity,Max Demand)



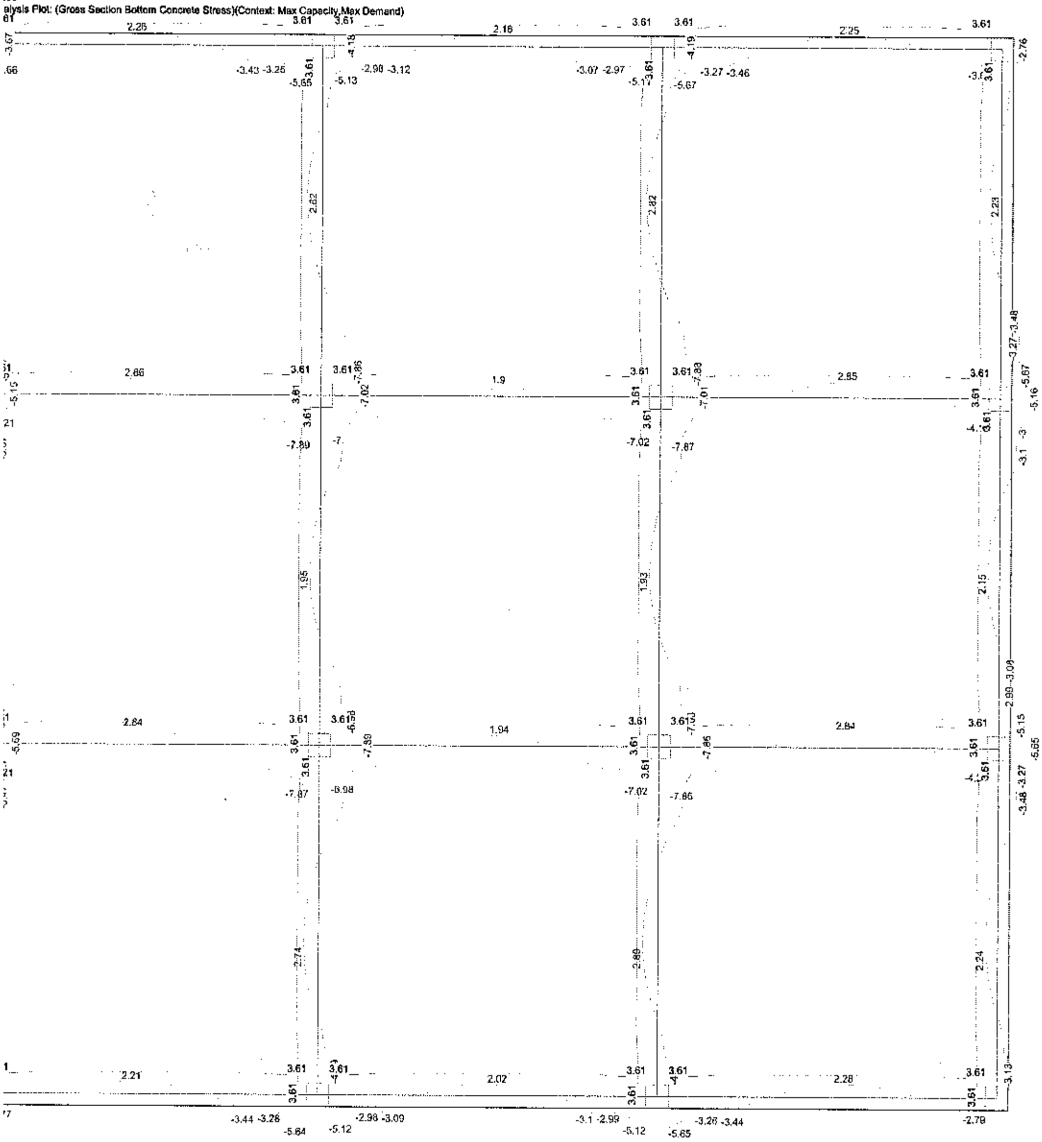
ervice Design: Centroid Stress Plan

sign: User Lines; User Notes; User Dimensions; Banded DSS Designs; Distributed DSS Designs; Banded DS Designs; Distributed DS Designs;
port: User Lines; User Notes; User Dimensions;
Vall Elements Below; Wall Elements Above; Column Elements Below; Column Elements Above; Slab Elements; Slab Element Edges;
250
alysis Plot: (Gross Section Centroid Concrete Stress)(Context: Max Demand,Min Demand)



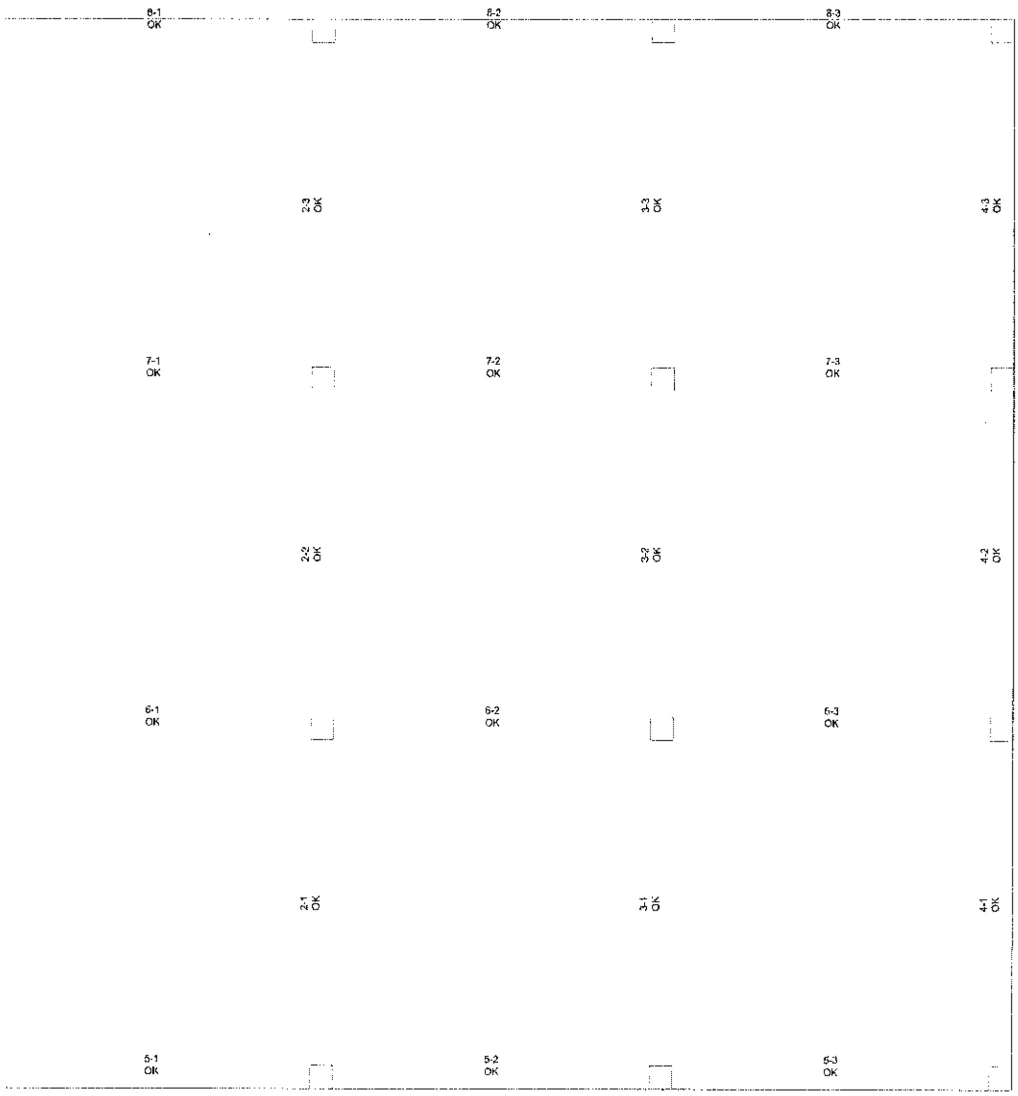
ervice Design: Bottom Stress Plan

esign: User Lines; User Notes; User Dimensions; Banded DSS Designs; Distributed DSS Designs; Banded DS Designs; Distributed DS Designs;
apport: User Lines; User Notes; User Dimensions;
Wall Elements Below; Wall Elements Above; Column Elements Below; Column Elements Above; Slab Elements; Slab Element Edges;
250
alysis Plot: (Gross Section Bottom Concrete Stress)(Context: Max Capacity,Max Demand)



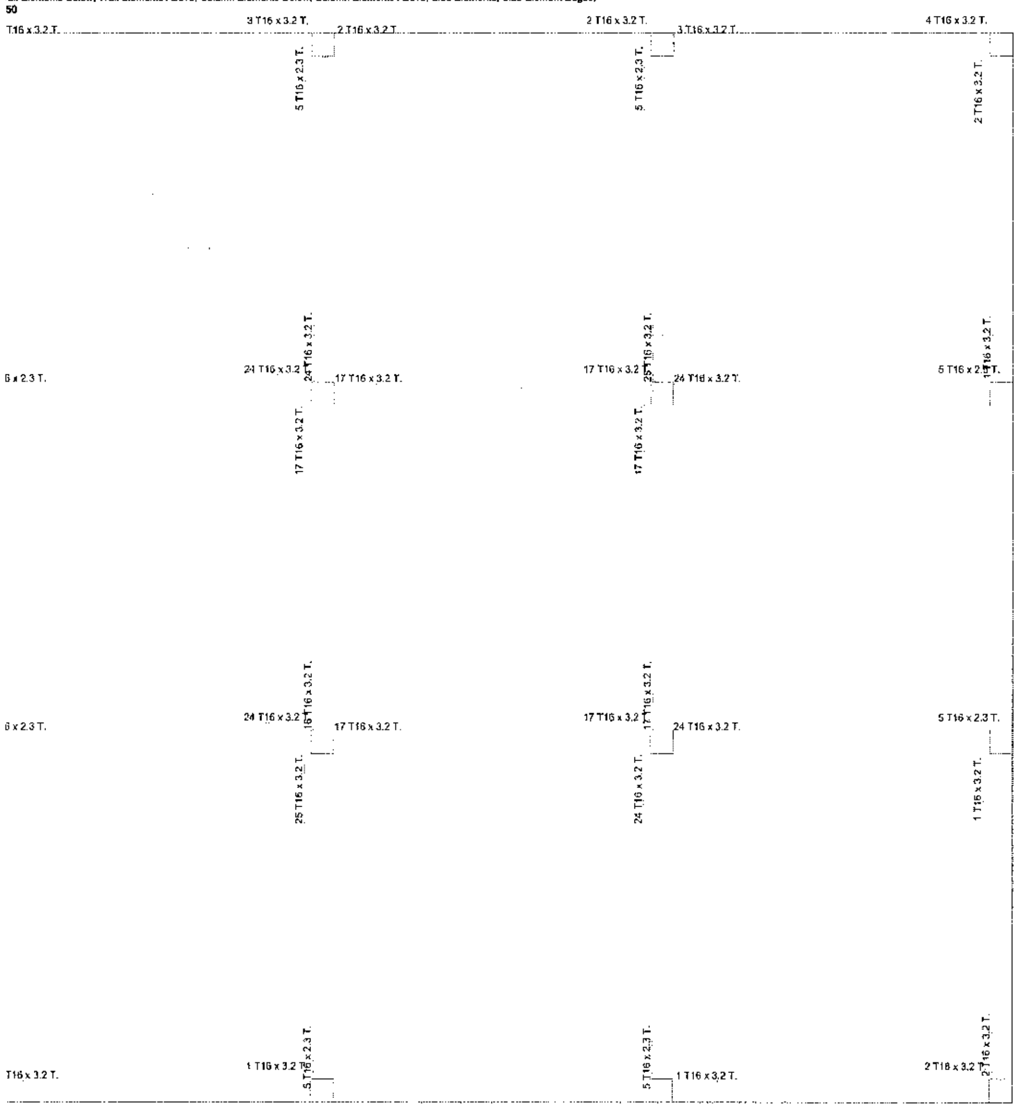
›sign Summary: Status Plan

ımmary: User Lines; User Notes; User Dimensions; Banded DSS Designs; Distributed DSS Designs; DSS Design Numbers; DSS Design Status; Banded DS Designs; Distributed DS Designs; DS Design Numbers; DS Design Status; PC Designs; PC Design Numbers; PC Design Stat
ıport: User Lines; User Notes; User Dimensions;
/all Elements Below; Wall Elements Above; Column Elements Below; Column Elements Above; Slab Elements; Slab Element Edges;
:50



:sign Summary: Top Reinforcement Plan

nmary: User Lines; User Notes; User Dimensions; Banded DSS Designs; Distributed DSS Designs; DSS Design Top Bars; DSS Design Bar Descriptions; Banded DS Designs; Distributed DS Designs; DS Design AsTop; DS Design AsBottom; DS Design AsShear;
port: User Lines; User Notes; User Dimensions;
'all Elements Below; Wall Elements Above; Column Elements Below; Column Elements Above; Slab Elements; Slab Element Edges;
50



ɘsign Summary: Bottom Reinforcement Plan

nmary: User Lines; User Notes; User Dimensions; Banded DSS Designs; Distributed DSS Designs; DSS Design Bottom Bars; DSS Design Bar Descriptions; Banded DS Designs; Distributed DS Designs; DS Design AsTop; DS Design AsBottom; DS Design AsShear;
port: User Lines; User Notes; User Dimensions;
'all Elements Below; Wall Elements Above; Column Elements Below; Column Elements Above; Slab Elements; Slab Element Edges;
50