The Effects of Using Coarse and Fine Meshing For Analysis of Flat Plate Using Finite Element Software (EsteemPlus 6.2)

by

Nadwah Binti Ab. Aziz

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

JANUARY 2007

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CERTIFICATION OF APPROVAL

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Approved by,

(Assoc. Prof. Dr. Nasir Shafiq)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
JANUARY 2007

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.

NADWAH BINTI AB. AZIZ

ABSTRACT

The author has selected a project, title – The Effects of Using Coarse and Fine Meshing for Analysis of Flat Plate using Finite Element Software. The author has chosen EsteemPlus Version 6.2.5.8 software as it has so far been the most user friendly structure design software. The objective of this project is to compare and contrast the design analysis of using coarse meshing and fine meshing of a regular grid slab and irregular column grid slab. This topic was chosen because both method of analyzing has its benefits and disadvantages, but which method will be most likely practical to be used in a consultant firm will be determined. The existing conventional R.C design method as done by consulting engineers is fond to careless mistakes. With the aid of EsteemPlus software, the author will hopefully reach the main objective of this project accurately. Since quality of design has such a profound influence, it is best to find out the best method that can be use to produce a reliable yet efficient design. In this report, the author presented the literature review done to achieve the understanding of this project. Then the methodology of the process that has been gone through in this project was shown. The result and discussion of the analysis is then thoroughly explained further in this report. This report seals with a brief conclusion on which method will be best to used and in the appendix attached are all the figures of the analysis done.

ACKNOWLEDGEMENT

Firstly, the author would like to express the author's sincere gratitude to her supervisor, Dr. Nasir Shafiq, for his constant supervision, guidance and support until the final day of completing this project. Besides sharing his knowledge and experience throughout the project, he also thought the author a lot on how to manage a thesis project for use in the future further studies.

The author would also like to thank Dr. Victor Macam for his previous teachings and all the technicians, Mr. Ahmad Yusri, Mr. Johan, and Mr. Zaini, who had been kind and helpful throughout the years.

Throughout the project, the author had been exposed to a lot of different challenges and since had learned a lot from all of it. Thanks again for the patience of those all around the author and their encouragement have been really helpful.

Last but not least, the author would also like to thank the coordinators of Final Year Project for Civil Engineering Department, Miss Koh Moi Ing and Puan Hamiza and all other lecturers who have thought the author a lot throughout the years. Not to forget, the author's parents, which without their support, none of this could have been done the way it suppose to be.

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CHAPTER 1: INTRODUCTION

1.1 *Background of Study*

EsteemPlus version 6.2.5.8 software offers a complete package in reinforced concrete structural analysis, design and detailing software aid, which simplifies and speed up tedious calculations and detailing process. It incorporates a graphic driven interface with the option of using manual entry in recording key plan grids, slabs, columns, and RC wall data into the program. This research is a creative process that seeks the proper blend of essential ingredients-specifically function, aesthetics, economy and minimum time consumption. To compare whether coarse meshing or fine meshing is the better choice in designing a flat plate, considering other main factors such as cost and time is compulsory to adequate with the needs of a design consultant. There exists no single formula for creating a good design, for the design process involves making a set of decisions on issues for which no absolutely right answer exists. Thus the author as well as designers is continually seeking a comfortable rationally based solution, and two identical solutions are not likely to be produced even successively by the same constructive designers.

1.2 *Problem Statement*

Reinforced Concrete structure design and analysis involves a very tedious work calculation. As we know, the larger the structure means more structure members are involved. This means that more calculations will be needed to complete the design. Nowadays, Finite Element based softwares are commonly used in consultancy practices to ease the structure design process. However, adequate modeling of structure members is a major issue for the level of accuracy of design and analysis. So for this project, using a finite element software (EsteemPlus), the author will study the effects of using coarse and fine meshing for analysis of a flat plate. The subjected flat plate will be used for this project is a slab (Refer to *Figure 1* in appendix).

The slab can be modeled in different ways and sizes of element to run the structural software. These different ways of meshing affects the behaviour of the analysis to a great extent. For example, in EsteemPlus, the default mesh size value is 1000mm, meaning each square, which are called the mesh, are 1000mm x 1000mm. The mesh can be done as coarse or fine mesh, but the smaller mesh size will take a longer analysis process as this will provide more accurate result. But is it really practical to get the most accurate result when other design factor needs is also a criteria? Because cost and time factor has always been a main concern of every structural engineers other than design reliability. So in this project the author will compare and analyze the difference and effects of the coarse and fine meshing (Refer to *Figure 3* in appendix).

1.3 Objectives and Scope of Study:

i. To evaluate various slab meshing design techniques.

ii. To give guidance on topics where no generally exactly right method is currently available.

iii. To indicate the more important specialist literature.

The objectives of the Project:

Based on the problem statement, the following objectives are set for this project:

i. To determine the closer and further node location on a finite element mesh for a slab on **regular** column gridlines and subjected to **various live load patterns.** Using Triangular-meshing, for each mesh size, the author will study **three types of loading patterns** to analyze the **loading action effects on the slab** (Refer to *Figure 1, 2 and 3* in appendix).

ii. To study the effects of **different meshing patterns (Triangular-Mesh, Mixed-Mesh, and Quadrilateral-Mesh)** when used in analysis in resulting the values. *(Refer to Figure 3, 6 and 7 in Appendix).*

iii. To determine the closer and further node locations on a finite element mesh for a slab on ***irregular*** **column grids. Using Triangular-meshing, for each mesh size, the author will study and analyze the loading distribution effects the the irregular positioning of columns on the slab.**

iv. Determine the maximum displacement values on Nodal Deflection and Moment for X and Y direction.

v. To study and compare the effect of mesh size and mesh pattern on larger and smaller scale of irregular column grids.

vi. To compare and contrast the effectiveness of using finite element software with the existing conventional R.C. design method as done by consulting engineers.

1.5 Feasibility of the Project within the Scope and Time Frame

The feasibility of the project can be measured with respect to the time frame, scope of the work, and source availability. The overall scope of the project will be based on a software, literature review and discussion of 28 weeks (2 semesters). The project scope covers the literature study, experimental and data analysis within the time frame. The feasibility of the project is also depending on the availability of the laboratory equipments such software required for the project.

CHAPTER 2: LITERATURE REVIEW AND THEORY

2.i Finite Element Method Types of Model

For flat plates, these methods include the direct design, equivalent frame, yield line, and strip design techniques, all of which approximate the results of classical plate theory. These methods have gained wide acceptance among engineers because of their simplicity. However, these approximate techniques have significant limitations. Direct design and equivalent frame methods are both limited to structures with very regular geometry. The application of yield lines or strip design may lead to overly conservative designs as well as to poor serviceability.

As such, the finite element method has been an obvious choice for the modeling and analysis of reinforced concrete systems for many years. Finite elements have the unique capability to conform to virtually any geometry that could be physically implemented. Thus, the finite element method has gained acceptance as an appropriate tool for the analysis of flat plates, especially those with highly irregular or unusual geometries where the direct design and equivalent frame techniques are not valid. In irregular slabs such as these, the finite element method can be shown to accurately solve for the distribution of stress where numerous approximations and assumptions would be invoked if the yield line or strip design technique were applied.

An additional benefit of a finite element approach to slab design is that engineers no longer need to develop multiple models to design a structure for various types of behavior. By integrating the slab model with the three-dimensional frame, the combined effects of gravity and lateral loading conditions can be assessed together. The interaction of the slab and columns is accurately simulated, providing favorable results to approximations of connection stiffness. An integrated approach to analysis and design thus emerges. Significant research efforts have been devoted to the application of finite elements in the analysis of reinforced concrete since the emergence of the finite element method in the 1950s. While the approaches used by the pioneers are dramatically different, they share one essential characteristic: mesh discretization of a continuous domain into a set of discrete sub-domains. Hrennikoff's work discretizes the domain by using lattice analogy while Richard Courant's approach divides the domain into finite triangular subregions for solution of second order elliptic partial differential equations (PDEs), which arise from the problem of torsion of a cylinder. Courant's contribution was evolutionary, drawing on a large body of earlier results for PDEs developed by Rayleigh, Ritz, and Galerkin.[6]

In its application, the object or system is represented by a geometrically similar model consisting of multiple, linked, simplified representations of discrete regions—i.e., finite elements on an unstructured grid. Equations of equilibrium, in conjunction with applicable physical considerations such as compatibility and constitutive relations, are applied to each element, and a system of simultaneous equations is constructed. The system of equations is solved for unknown values using the techniques of linear algebra or nonlinear numerical schemes, as appropriate. While being an approximate method, the accuracy of the FEA method can be improved by refining the mesh in the model using more elements and nodes. [5]

2.ii ESTEEMPLUS version 6.2

EsteemPlus version 6.2.5.8 software offers a complete package in reinforced concrete structural analysis, design and detailing software aid, which simplifies and speed up tedious calculations and detailing process. It incorporates a graphic driven interface with the option of using manual entry in recording key plan grids, slabs, columns, and RC wall data into the program. This research is a creative process that seeks the proper blend of essential ingredients-specifically function, aesthetics, economy and minimum time consumption.

More interestingly about the EsteemPlus software, it was designed and produced locally by Malaysian software designers with cooperation of Civil Structure engineers. The company is based in Puchong, Selangor. That makes the usage of this software much more practical to utilize compare to other softwares since to contact the designers for help and additional information on the software is easier. They also provide free updates and conference on the software.

There are various code of practices available in the EsteemPlus software which are BS 8110:1985, BS8110:1997, CP65:1999, ACI-318-99, and the latest one, AS3600:2001.The detailing parameter covers a whole wide range of options to choose. For the beam details, for example, user can choose to use either two rebar sizes auto combination for multi-layer longitudinal rebar or automatic continuous rebar at top left and right end for the beam detailing. For the slab, user can choose either non-suspended slab, BRC slab, top bar BRCB slab or Full FEM slab design. For column braced or unbraced column can be used. User can also design wall by choosing BRC wall or BRCB wall.

For footing design, there are different types of footing design to be chosen from accordingly. There is pad footing, pile footing, or raft foundation. There is also the function of designing stairs available. These entire components, the user can set their own preference for the detailing layer parameters. For the 3d analysis option, user can apply wind load analysis, pin foundation, slab diaphragm effect and use double precision in the analysis. The software also offers the function of estimating the summation of the cost for the structure designed which act as the primary quantity surveyor for the project.

To compare whether coarse meshing or fine meshing is the better choice in designing a flat plate considering other main factors such as cost and time is compulsory to adequate with the needs of a design consultant. There exists no single formula for creating a good design, for the design process involves making a set of decisions on issues for which no absolutely right answer exists. Thus the author as well as designers is continually seeking a comfortable rationally based solution, and two identical solutions are not likely to be produced even successively by the same constructive designers.

2.iii STAADPro 2002

STAADPro is a widely used structural analysis and design software. The versatility of STAADPro makes it the best choice of most leading engineering consultancies whilst the entry level version means it is also the choice for smaller consultants as well. STAADPro features a user friendly interface, visualization tools, powerful analysis and design engines with advances finite element and dynamic analysis capabilities. From model generation, analysis and design to visualization and result verification, STAADPro is the choice for steel, timber, aluminum and cold-formed steel structures.

STAAD Pro has building codes for most countries including U.S., Brotaon, Canada, Australia, Frances, Germany, Spain, Norway, Finland, Sweden, India, China, Euro Zone, Japan, Denmark, and Holland. More building codes are constantly being added. STAAD Pro is fully COM (Component Object Model) compliant and is designed using an open architecture. Any third party or in-house application can be seamlessly integrated with STAAD Pro. STAAD Pro's User interfaces the industry standard features too.

Complex models can be quickly and easily generated through powerful graphics, text and spreadsheet interfaces that provide true interactive model generation, editing, and analysis, STAAD Pro generates comprehensive custom reports for management, architects, owners, etc. STAAD Pro's reports contain only the information required by users, and the users can add their own logo as well as graphical input and output results. All data can be exported to Word, Excel or WordPerfect.

2.iv PROKON W1.1.02

Prokon is also one of the most prominent structural software in the engineering consultancies industry. Similiarly to STAAD Pro and ESTEEMPLUS, PROKON features a user friendly interface, visualization tools, powerful analysis and design engines with advanced finite element and dynamic analysis capabilities. Basically it is able to provide reliable solution to a wide range of structural and geotechnical engineering problems which include frame and finite element analysis, steel member and connection design, reinforced and pre-stressed concrete design, reinforced concrete detailing, timber member design and geotechnical analysis. But this version does not incorporate with modeling solution.

Calculation reports prepared in the PROKON system are totally customizable by the user. They include tables, diagrams and maps of results, plus any view of the structure. The report always keeps track of any changes made to the structural model, thereby ensuring that the calculations and results are always associated with the current structural model.

CHAPTER 3: METHODOLOGY

3.1 Tools and Equipments required

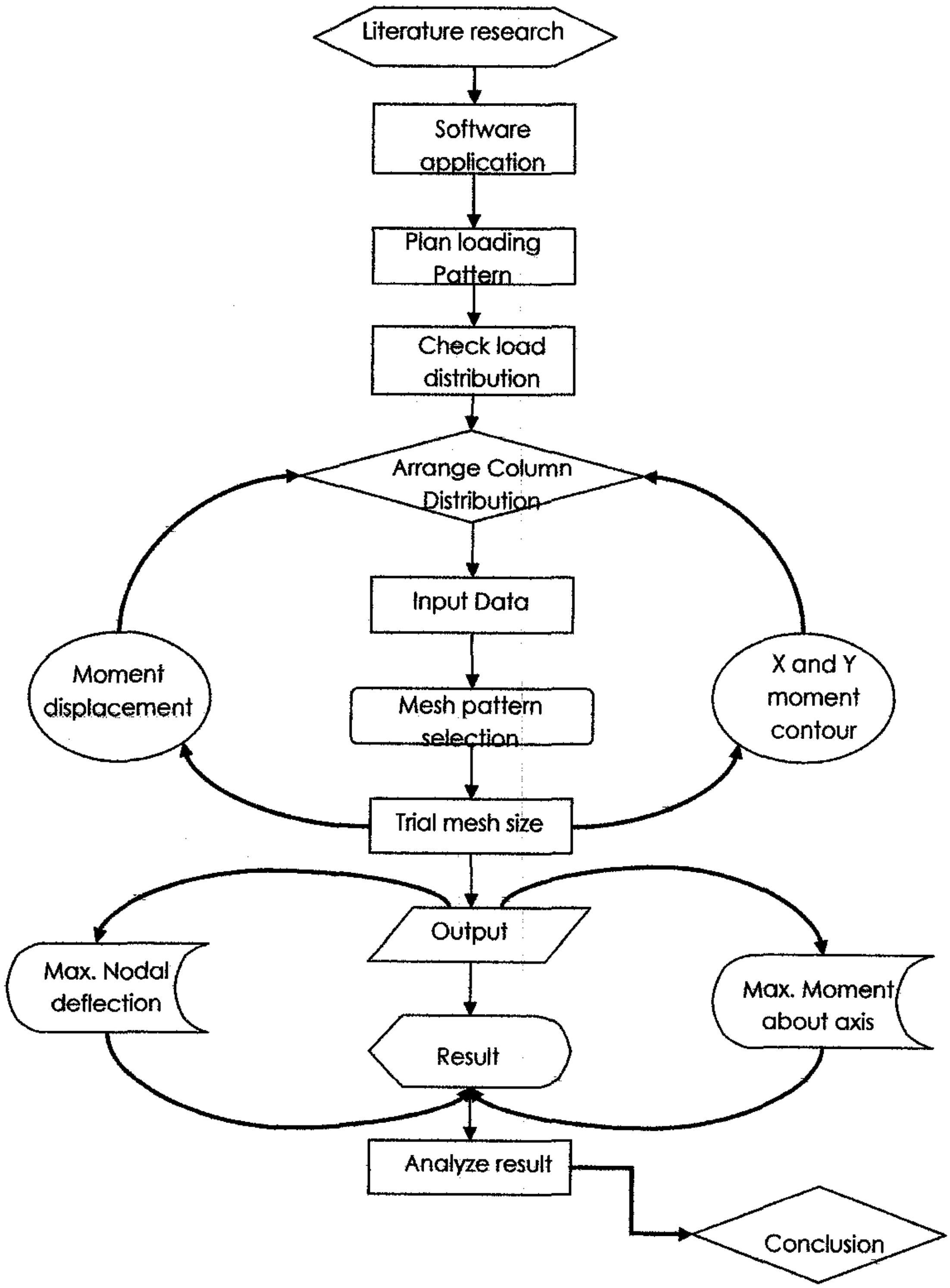
The following are the tools and equipments that will be used in the project

- ESTEEM structural software.
- Relevant structural software.

Basically, when the loading pattern on slab has been selected, then column distribution is decided on how it should be arranged. Once both loading pattern and column arrangement has been fixed, meshing size and meshing pattern was decided. Then, plan mesh data was then generated and slab analysis option was selected to be done as a plate and thus the data was analyzed. From the analysis, maximum displacement values on Nodal Deflection and Moment for X and Y direction were obtained.

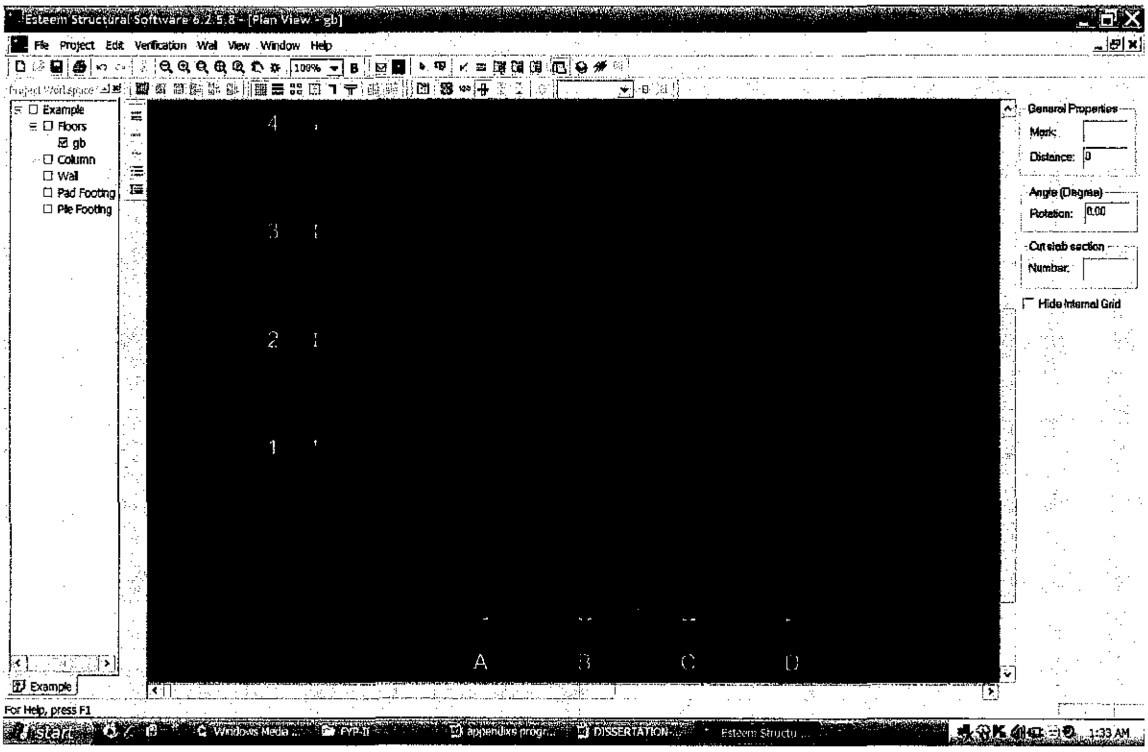
For this project, the selection of beam dimension, column dimension and slab thickness is based on common size generally used for standard structure size. For slab size 3m x 3m, the dimension used for beams are 150mm for width and 375mm for depth of the beam. For slabs' dimension, 100mm thickness was used. As for slab size 10m x 10m, the dimension for beams are 150mm for width and 400mm for beams' depth. For the slabs' dimension, 350mm thickness was applied. All columns' size are 150mm x 150mm. And for design load of the slabs, Dead Load of 0.50 kN/m^2 and Live Load of 1.50 kN/m^2 was where needed. Those design load values are used based on the slab design function as referred to BS6399 : Part 1 : 1984, Table 5, where it is stated that for self-contained dwelling units, the intensity of distributed load or known as live load, is 1.5 kN/m^2. Dead load refers to the finishing loads that are commonly used in the design industry.

3.2 Project Process Flow

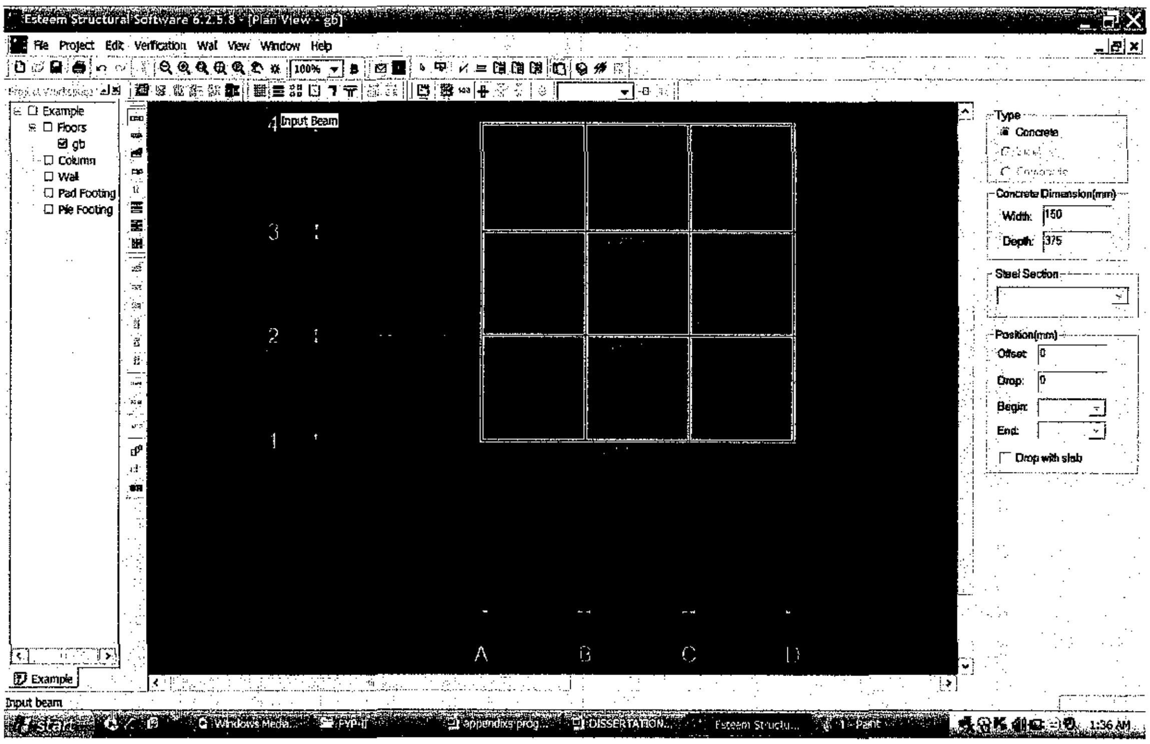


3.3 Steps of Slab Design on EsteemPlus 6.2

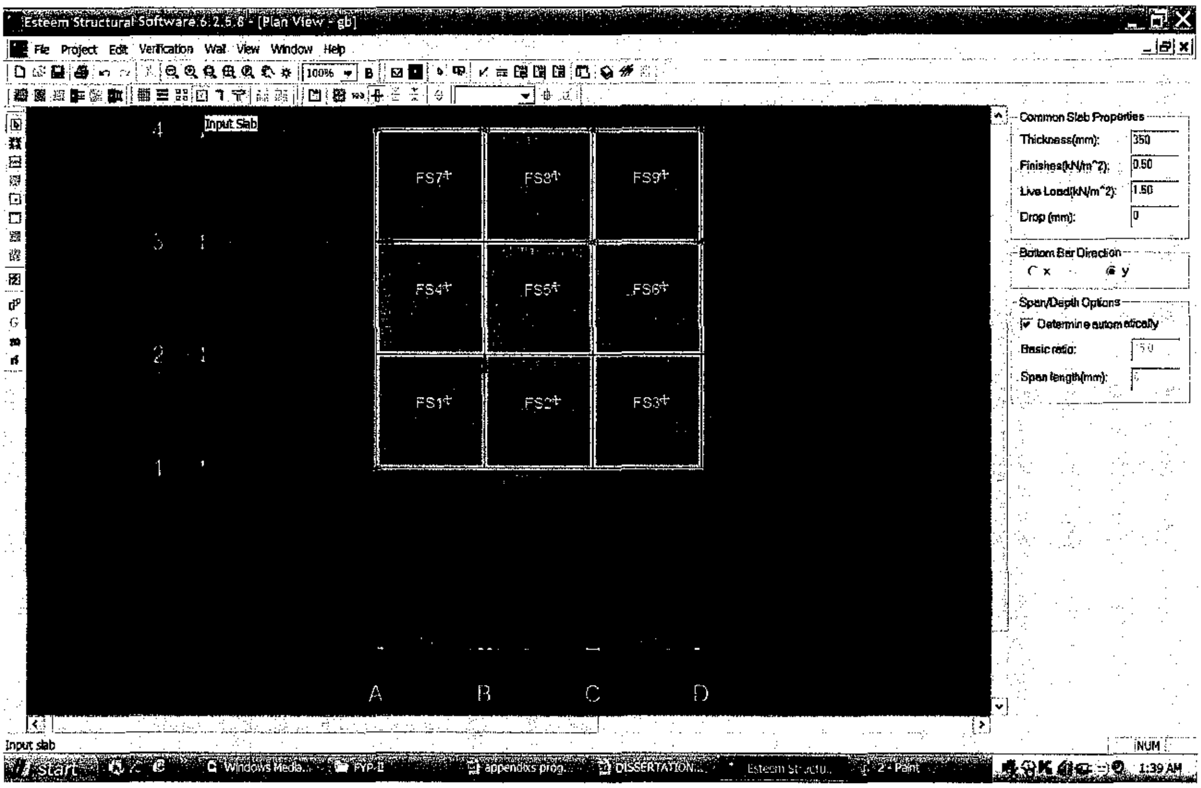
3.3.i Plan Input of Grid



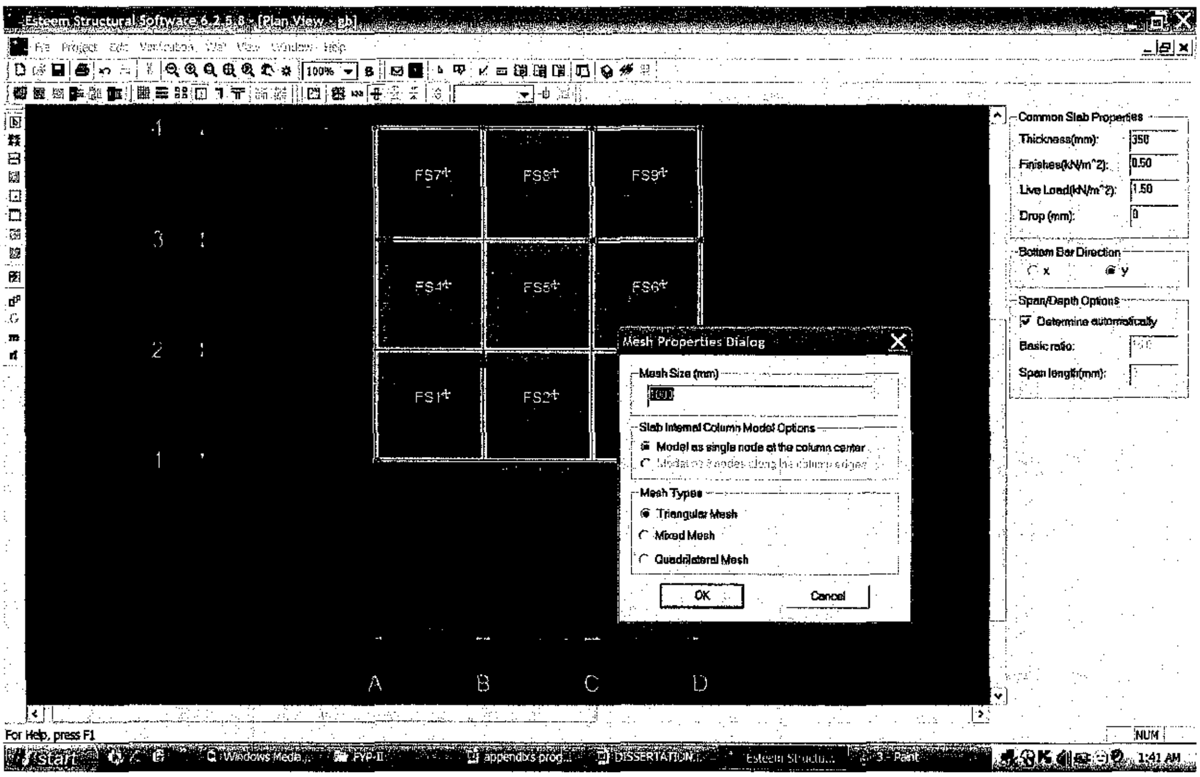
3.3.ii Beam Positioning and Dimension Input



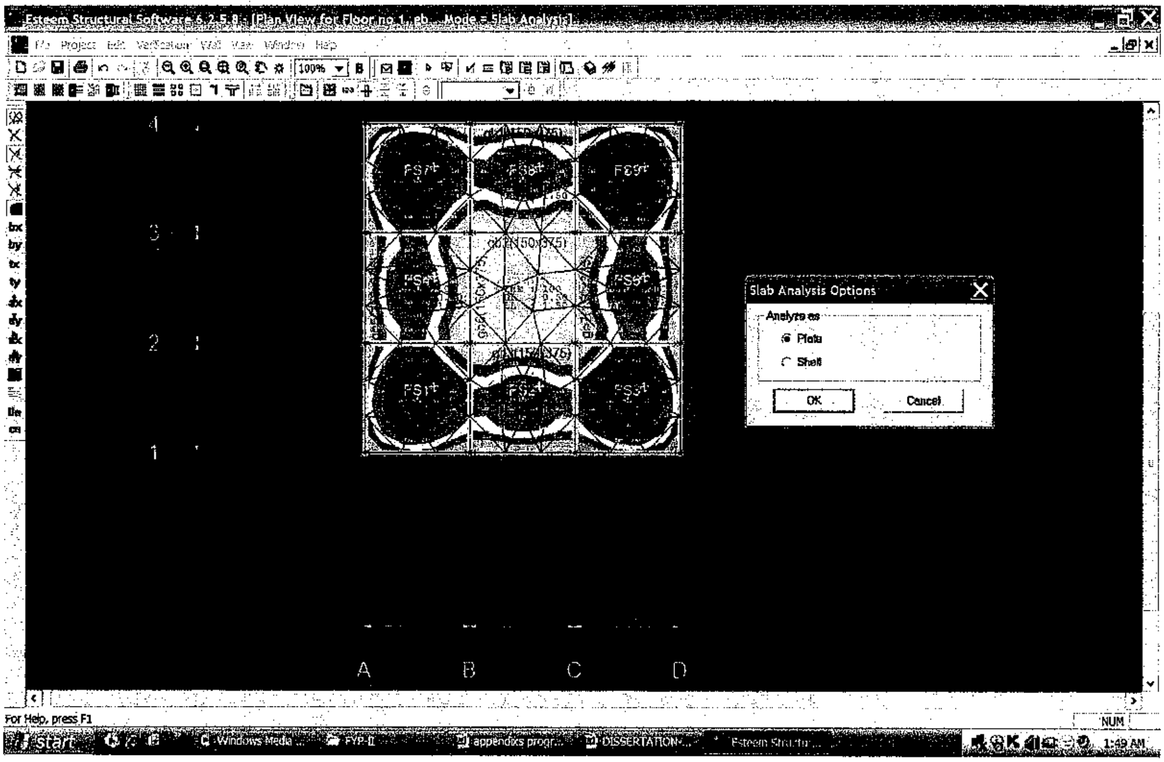
3.3.iii Slab and Column Positioning, Dimension and Load Input



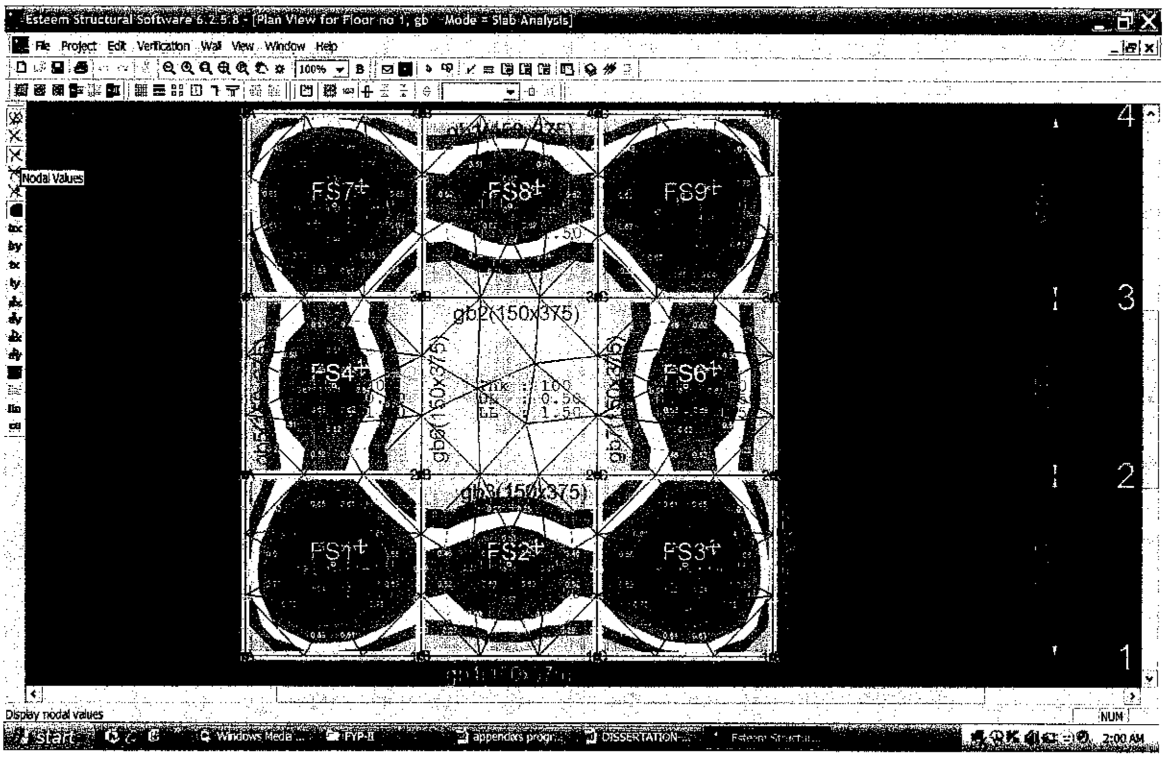
3.3.iv Mesh Input



3.3.v Slab Analysis Option



3.3.vi Run Analysis



CHAPTER 4: RESULTS

4.i Regular Columns Distribution on Small Scale Slab of 3m x3m Size.

4.i.1 Maximum Positive Nodal Deflection Values in Millimeter (mm) Using Triangular Mesh Pattern.

As shown in Appendix – Figure 1, Figure 3 and Figure 4.

Loading Pattern 1

Slab No.	Mesh Size (mm)		
	500	1000	1500
FS 1	1.12	1.13	1.00
FS 2	0.38	0.36	0.30
FS 5	0.34	0.32	0.19

Loading Pattern 2

Slab No.	Mesh Size (mm)		
	500	1000	1500
FS 1	0.66	0.66	0.57
FS 2	0.79	0.79	0.69
FS 5	-0.09	-0.10	-0.15

Loading Pattern 3

Slab No.	Mesh Size (mm)		
	500	1000	1500
FS 1	1.08	1.08	0.95
FS 2	0.71	0.70	0.60
FS 5	0.18	0.16	0.04

4.i.2 Maximum Positive Displacement Values of Moment for X-direction in kNm/m Using Triangular Mesh Pattern.

As shown in Appendix – Figure 5

Loading Pattern 1

Slab No.	Mesh Size (mm)		
	500	1000	1500
FS 1	2.29	2.31	1.59
FS 2	0.52	0.55	0.75
FS 5	1.22	1.26	0.50

Loading Pattern 2

Slab No.	Mesh Size (mm)		
	500	1000	1500
FS 1	1.43	1.28	0.78
FS 2	1.69	1.50	1.48
FS 5	0.34	0.24	-0.27

Loading Pattern 3

Slab No.	Mesh Size (mm)		
	500	1000	1500
FS 1	1.37	1.22	1.28
FS 2	2.27	2.08	1.47
FS 5	0.31	0.42	0.44

4.i.3 Maximum Positive Displacement Values of Moment for Y-direction in kNm/m Using Triangular Mesh Pattern.

As shown in Appendix – Figure 6

Loading Pattern 1

Slab No.	Mesh Size (mm)		
	500	1000	1500
FS 1	2.22	2.13	2.01
FS 2	1.16	1.13	0.74
FS 5	1.29	1.39	1.02

Loading Pattern 2

Slab No.	Mesh Size (mm)		
	500	1000	1500
FS 1	1.37	1.22	1.28
FS 2	2.27	2.08	1.47
FS 5	0.31	0.42	0.44

Loading Pattern 3

Slab No.	Mesh Size (mm)		
	500	1000	1500
FS 1	0.99	2.04	1.99
FS 2	1.98	1.96	1.35
FS 5	2.11	1.12	0.89

4.i.4 Maximum Positive Nodal Deflection Values in Millimeter (mm) Using Triangular Mesh, Mixed-Mesh, and Quadrilateral Mesh Pattern with Different Mesh Sizes.

Analysis done based on Slab with load Pattern 3 as shown in Appendix-Figure 7

Mesh Size 500mm

Slab No.	Mesh Pattern		
	Triangular	Mix-Meshed	Quadrilateral
FS 1	1.08	1.07	1.06
FS 2	0.71	0.70	0.69
FS 5	0.18	0.17	0.17

Mesh Size 1000mm

Slab No.	Mesh Pattern		
	Triangular	Mix-Meshed	Quadrilateral
FS 1	1.08	1.07	1.02
FS 2	0.70	0.71	0.68
FS 5	0.16	0.17	0.16

Mesh Size 1500mm

Slab No.	Mesh Pattern		
	Triangular	Mix-Meshed	Quadrilateral
FS 1	0.95	0.96	1.09
FS 2	0.60	0.59	0.73
FS 5	0.02	0.04	0.20

4.ii Slab 10m x 10m Size.

4.ii.a *Regular Grid Column Distribution*

4.ii.a.1 Maximum Positive Nodal Deflection Values in Millimeter (mm) Using Triangular Mesh Pattern.

Refer Appendix Figure 8: (a), (b), and (c)

Results on Center of **Slab**

Mesh Size (mm)	Slab Name								
	FS1	**FS2**	**FS3**	**FS4**	**FS5**	**FS6**	**FS7**	**FS8**	**FS9**
500	22.18	13.82	22.18	13.81	3.44	13.81	22.34	13.82	22.34
1000	22.32	13.83	22.31	13.98	3.66	13.97	22.47	13.97	22.47
1500	22.33	13.95	22.38	13.97	3.73	14.11	22.50	14.13	22.59

Results on Center of **Beam** Span

Beam Name	Span-A			Span-B			Span-C		
	Mesh Size (mm)			Mesh Size (mm)			Mesh Size (mm)		
	500	**1000**	**1500**	**500**	**1000**	**1500**	**500**	**1000**	**1500**
GB1	14.71	14.80	14.82	5.05	5.15	5.16	14.70	14.79	14.81
GB2	14.70	14.80	14.83	5.06	5.14	5.14	14.70	14.80	14.82
GB3	14.70	14.80	14.85	5.06	5.15	5.15	14.71	14.80	14.81
GB4	14.70	14.80	14.82	5.05	5.16	5.15	14.70	14.80	14.84
GB5	14.93	15.08	15.15	4.55	4.74	4.80	14.93	15.07	15.12
GB6	14.93	15.07	15.16	4.55	4.73	4.79	14.93	15.07	15.11
GB7	14.93	15.07	15.16	4.55	4.74	4.83	5.06	15.08	15.18
GB8	14.93	15.07	15.13	4.55	4.74	4.76	14.93	15.08	15.11

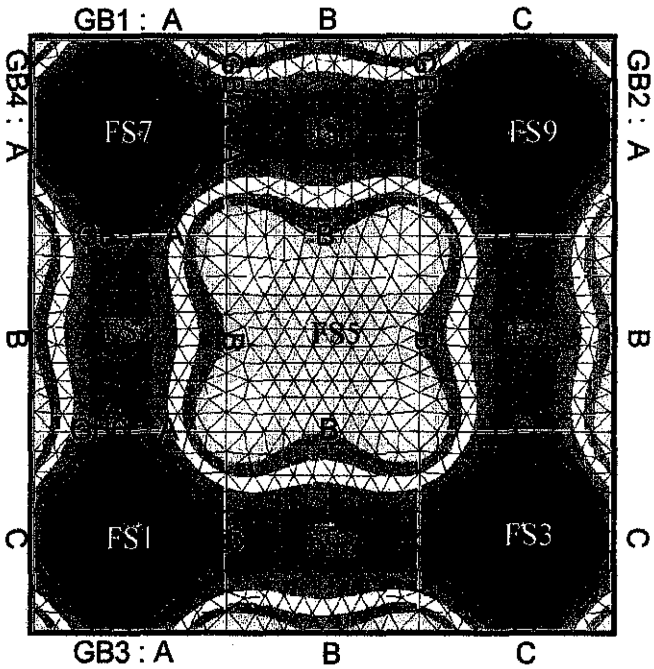


Fig. 8: Slab 10m x 10m with Regular Column Grid. Maximum Nodal Deflection

4.ii.a.2 Maximum Positive Displacement Values of Moment for **X-direction** in kNm/m :

Refer Appendix Figure 9: (a), (b), and (c)

Results on Center of **Slab**

Mesh Size (mm)	Slab Name								
	FS1	**FS2**	**FS3**	**FS4**	**FS5**	**FS6**	**FS7**	**FS8**	**FS9**
500	98.27	30.80	98.27	99.69	20.33	99.69	99.64	30.62	97.64
1000	98.68	31.38	98.69	100.06	21.16	100.05	100.34	31.10	98.06
1500	98.14	31.54	100.88	98.72	21.49	103.12	97.22	31.72	99.99

Results on Center of **Beam** Span

Beam Name	Span-A			Span-B			Span-C		
	Mesh Size (mm)			Mesh Size (mm)			Mesh Size (mm)		
	500	**1000**	**1500**	**500**	**1000**	**1500**	**500**	**1000**	**1500**
GB1	138.18	137.65	137.92	74.38	73.70	73.57	138.29	137.88	138.08
GB2	0.88	1.19	1.72	0.89	1.44	0.13	0.89	1.63	1.96
GB3	138.17	137.25	137.74	74.39	73.29	75.63	138.17	137.24	137.69
GB4	0.96	1.28	4.31	0.89	1.44	4.18	0.85	1.63	3.84
GB5	129.18	130.14	130.58	56.64	57.23	59.08	129.25	129.83	130.79
GB6	129.18	129.88	130.70	56.63	57.16	57.47	129.28	129.84	130.88
GB7	-24.03	-23.63	-23.43	-52.73	-52.23	-50.76	-23.90	-23.04	-22.77
GB8	-24.01	-23.60	-22.21	-52.73	-52.24	-52.24	-23.98	-23.03	-22.82

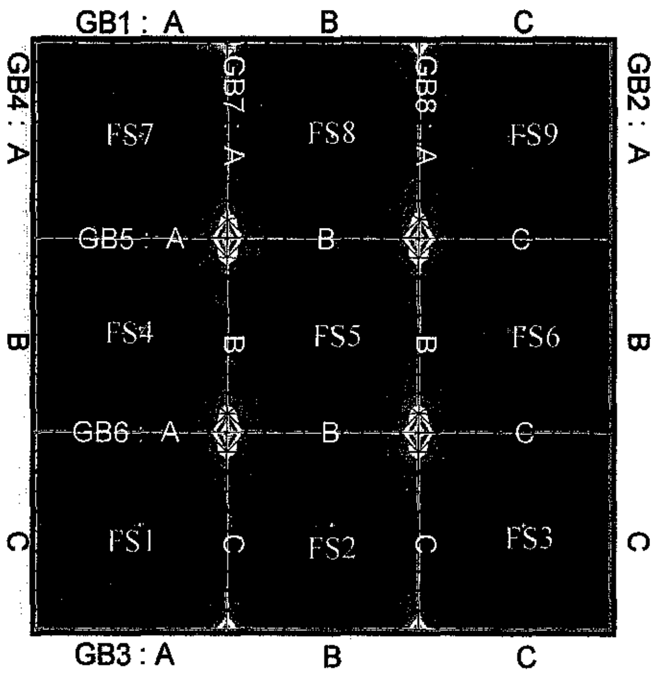


Fig. 9: Slab 10m x 10m with Regular Column Grid. X-contour Displacement

4.ii.a.3 Maximum Positive Displacement Values of <u>Moment for **Y-direction**</u> in kNm/m :

Refer Appendix Figure 10: (a), (b), and (c)

Results on Center of **Slab**

Mesh Size (mm)	Slab Name								
	FS1	**FS2**	**FS3**	**FS4**	**FS5**	**FS6**	**FS7**	**FS8**	**FS9**
500	95.38	95.18	95.38	30.58	20.25	30.58	99.97	102.90	99.89
1000	95.81	96.69	95.81	31.09	20.86	31.09	98.05	100.05	100.33
1500	95.69	98.68	95.35	31.68	21.43	31.80	101.79	102.76	101.87

Results on Center of **Beam** Span

Beam Name	Span-A			Span-B			Span-C		
	Mesh Size (mm)			Mesh Size (mm)			Mesh Size (mm)		
	500	**1000**	**1500**	**500**	**1000**	**1500**	**500**	**1000**	**1500**
GB1	0.88	1.19	2.33	0.89	1.43	1.77	0.80	1.28	1.98
GB2	138.19	137.63	137.82	74.38	73.69	71.86	138.40	137.63	137.35
GB3	0.96	1.67	2.01	0.89	1.73	4.17	0.96	1.67	2.06
GB4	138.25	137.91	139.47	74.39	73.70	75.61	138.41	137.62	139.66
GB5	-23.94	-24.03	-22.45	-52.77	-52.33	-52.06	-23.97	-23.60	-22.88
GB6	-23.92	-23.76	-22.48	-52.76	-52.19	-50.55	-24.05	-23.63	-23.27
GB7	129.26	129.88	130.71	56.63	57.19	57.05	129.15	129.29	130.24
GB8	129.23	129.83	131.07	56.64	57.19	59.53	129.21	129.30	131.41

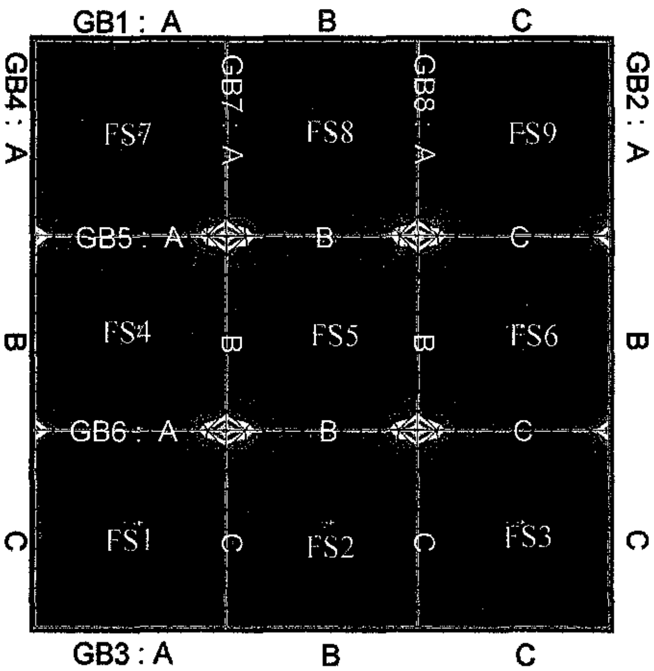


Fig. 10: Slab 10m x 10m with Regular Column Grid. Y-contour Displacement

4.ii.b *Irregular Column Grid Distribution*

4.ii.b.1 Maximum Positive **Nodal Deflection** Values in Millimeter (mm):

Refer Appendix Figure 11: (a), (b), and (c)

Results on Center of **Slab**

Mesh Size (mm)	Slab Name								
	FS1	**FS2**	**FS3**	**FS4**	**FS5**	**FS6**	**FS7**	**FS8**	**FS9**
500	19.90	3.84	32.24	12.97	10.19	18.94	14.89	17.04	21.60
1000	19.97	3.83	32.37	13.05	10.10	19.16	15.13	17.03	21.71
1500	18.93	4.91	32.18	13.37	10.28	18.70	15.05	17.48	21.65

Results on Center of **Beam** Span

Beam Name	Span-A			Span-B			Span-C		
	Mesh Size (mm)			Mesh Size (mm)			Mesh Size (mm)		
	500	**1000**	**1500**	**500**	**1000**	**1500**	**500**	**1000**	**1500**
GB1	13.09	13.28	13.19	0.80	0.85	0.97	23.20	23.32	23.40
GB2	11.75	12.11	11.87	11.72	11.84	11.83	7.92	7.42	7.82
GB3	12.09	12.15	12.16	-4.43	-4.41	4.48	31.49	31.60	31.67
GB4	5.63	6.28	5.96	2.27	2.32	2.60	23.28	23.66	23.48
GB5	14.19	14.38	14.33	10.69	10.78	10.81	2.64	2.61	2.57
GB6	16.82	17.53	16.99	10.37	10.48	10.49	21.12	20.63	21.27
GB7	6.97	6.51	6.90	13.74	13.97	13.91	10.92	11.01	11.64
GB8	17.57	17.65	17.72	0.02	0.08	0.16	26.59	26.72	26.79

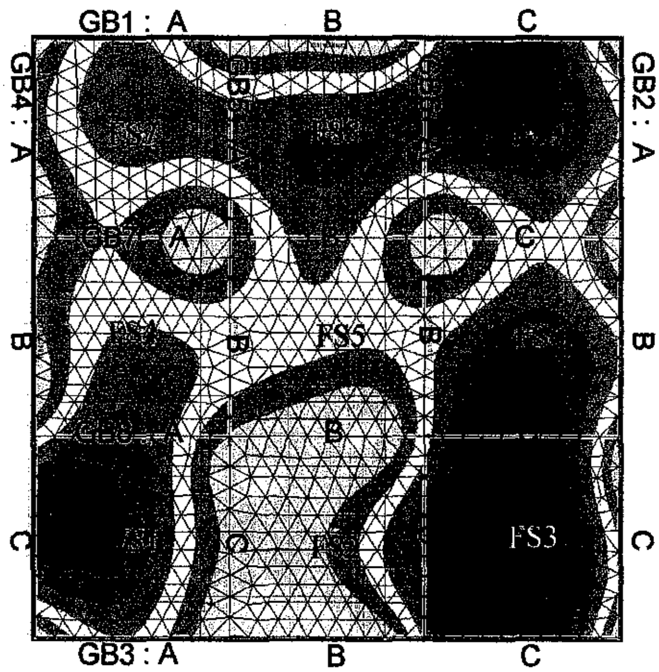


Fig. 11: Slab 10m x 10m with Irregular Column Grid. Maximum Nodal Deflection

4.ii.b.2 Maximum Positive Displacement Values of Moment for **X-direction** in kNm/m :

Refer Appendix Figure 12: (a), (b), and (c)

Results on Center of **Slab**

Mesh Size (mm)	Slab Name								
	FS1	**FS2**	**FS3**	**FS4**	**FS5**	**FS6**	**FS7**	**FS8**	**FS9**
500	93.65	-36.81	171.97	77.32	20.82	94.07	66.86	46.45	88.80
1000	98.93	-36.08	179.39	73.30	22.49	94.92	70.54	50.09	89.24
1500	98.23	-34.70	172.86	70.60	26.53	104.19	64.30	52.78	94.86

Results on Center of **Beam** Span

Beam Name	Span-A			Span-B			Span-C		
	Mesh Size (mm)			Mesh Size (mm)			Mesh Size (mm)		
	500	**1000**	**1500**	**500**	**1000**	**1500**	**500**	**1000**	**1500**
GB1	120.50	125.12	118.29	34.51	46.76	39.16	152.90	152.48	153.09
GB2	1.01	1.87	0.05	1.02	-0.29	-0.15	1.11	0.18	0.13
GB3	121.88	121.31	123.16	-24.49	-24.78	-20.89	204.37	203.72	204.34
GB4	0.72	1.45	2.53	0.85	0.43	2.67	0.73	-0.13	1.66
GB5	-9.14	-8.88	-7.03	-6.89	-14.71	-5.94	-100.67	-103.51	-100.74
GB6	-17.14	-16.50	-16.42	-42.96	-52.86	-42.42	31.31	32.32	32.66
GB7	69.60	76.96	68.16	96.22	98.63	99.42	102.53	103.27	116.15
GB8	112.86	113.29	113.16	-13.54	-13.28	-5.64	167.18	167.63	169.04

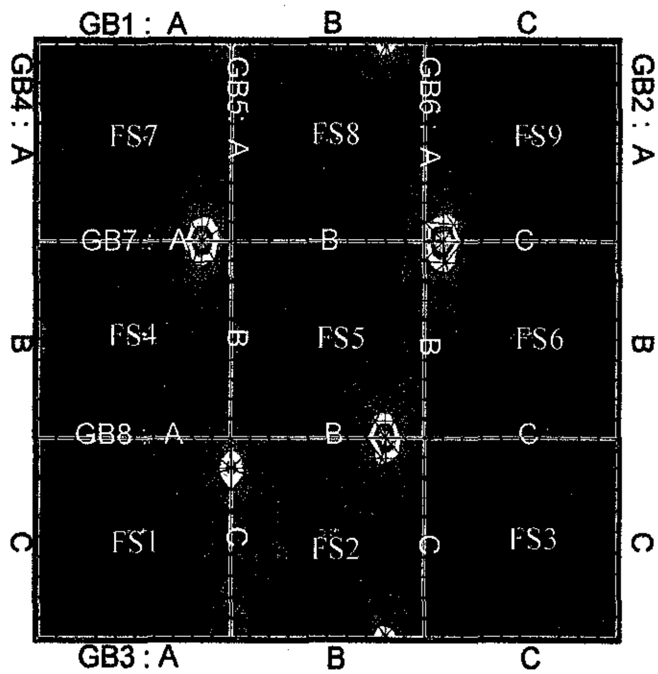


Fig. 12: Slab 10m x 10m with Irregular Column Grid, X-contour Displacement

4.ii.b.3 Maximum Positive Displacement Values of Moment for **Y-direction** in kNm/m :

Refer Appendix Figure 13: (a), (b), and (c)

Results on Center of **Slab**

Mesh Size (mm)	Slab Name								
	FS1	**FS2**	**FS3**	**FS4**	**FS5**	**FS6**	**FS7**	**FS8**	**FS9**
500	68.37	61.18	70.35	40.10	50.93	43.13	74.67	104.50	78.83
1000	68.76	59.85	70.77	40.58	51.46	44.24	78.83	106.71	79.19
1500	71.69	56.28	70.37	45.20	51.87	52.63	78.51	101.00	79.06

Results on Center of **Beam** Span

Beam Name	Span-A			Span-B			Span-C		
	Mesh Size (mm)			Mesh Size (mm)			Mesh Size (mm)		
	500	**1000**	**1500**	**500**	**1000**	**1500**	**500**	**1000**	**1500**
GB1	0.07	0.03	0.04	1.08	1.43	3.15	0.80	1.23	1.74
GB2	114.84	114.40	112.61	100.56	99.39	97.88	103.10	90.23	97.40
GB3	0.76	1.60	5.47	0.63	2.08	3.13	0.84	1.52	2.05
GB4	76.68	75.95	81.79	30.34	29.71	36.51	152.18	152.51	152.24
GB5	114.97	115.45	116.83	77.20	77.42	80.02	49.36	45.82	45.95
GB6	113.89	114.55	116.69	63.93	64.12	66.33	100.76	100.90	103.20
GB7	-79.39	-92.77	-82.17	-3.40	-3.13	-2.97	-92.42	-92.50	-79.92
GB8	18.36	19.12	20.14	-106.08	-105.78	-101.12	25.68	26.18	26.90

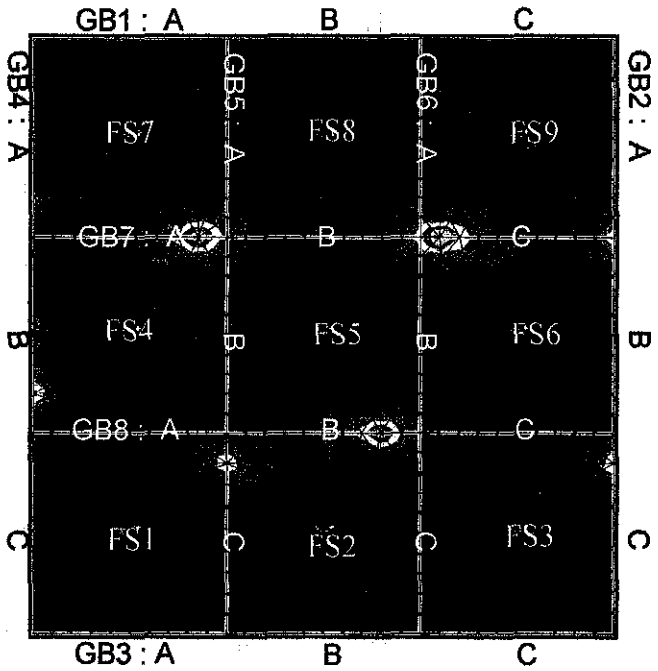


Fig. 13: Slab 10m x 10m with Irregular Column Grid. Y-contour Displacement

4.iii Slab 3m x 3m Size.

4.iii.a *Irregular Column Grid Distribution*

4.iii.a.1 Maximum Positive **Nodal Deflection** Values in Millimeter (mm):

Refer Appendix Figure 14: (a), (b), and (c)

Results on Center of **Slab**

Mesh Size (mm)	Slab Name								
	FS1	**FS2**	**FS3**	**FS4**	**FS5**	**FS6**	**FS7**	**FS8**	**FS9**
500	1.02	0.32	1.46	0.74	0.84	0.83	0.75	1.25	0.89
1000	1.09	0.30	1.43	0.74	0.94	0.81	0.76	1.16	0.97
1500	1.07	0.30	1.30	0.64	0.70	0.76	0.70	1.15	0.79

Results on Center of **Beam** Span

Beam Name	Span-A			Span-B			Span-C		
	Mesh Size (mm)			Mesh Size (mm)			Mesh Size (mm)		
	500	**1000**	**1500**	**500**	**1000**	**1500**	**500**	**1000**	**1500**
GB1	0.28	0.28	0.28	-0.10	-0.09	-0.13	0.54	0.54	0.54
GB2	0.17	0.17	0.17	0.33	0.28	0.23	0.03	0.00	0.02
GB3	0.34	0.34	0.34	-0.11	-0.11	-0.12	0.60	0.60	0.60
GB4	0.13	0.13	0.11	-0.07	-0.06	-0.08	0.55	0.55	0.55
GB5	-0.03	0.00	-0.08	1.03	1.04	1.04	0.00	0.04	-0.06
GB6	0.75	0.75	0.77	-0.10	-0.13	-0.15	1.05	1.05	1.06
GB7	0.59	0.61	0.62	0.60	0.60	0.62	-0.06	-0.04	-0.07
GB8	0.73	0.73	0.73	0.40	0.40	0.40	0.74	0.74	0.75

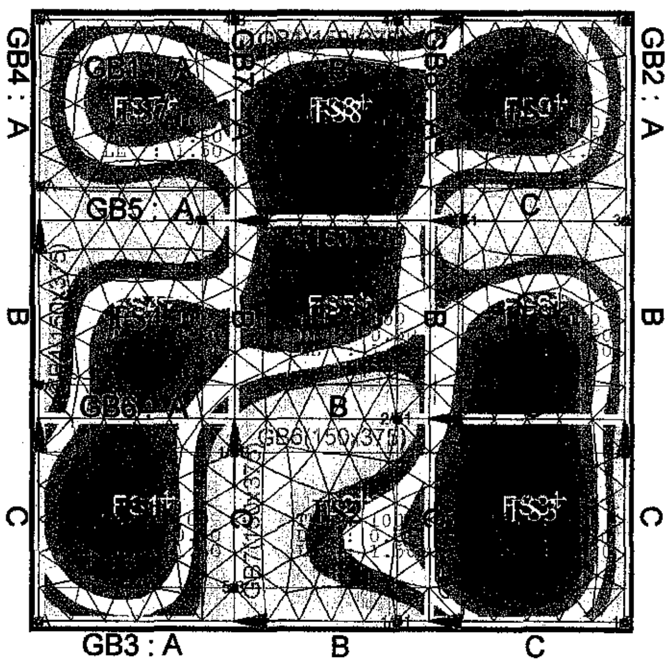


Fig. 14: Slab 3m x 3m with Irregular Column Grid. Maximum Nodal Deflection

4.iii.a.2 Maximum Positive Displacement Values of Moment for **X-direction** in kNm/m :

Refer Appendix Figure 15: (a), (b), and (c)

Results on Center of **Slab**

Mesh Size (mm)	Slab Name								
	FS1	**FS2**	**FS3**	**FS4**	**FS5**	**FS6**	**FS7**	**FS8**	**FS9**
500	2.43	0.66	2.85	1.45	1.30	1.53	1.43	1.97	1.40
1000	2.32	1.17	2.19	1.33	1.13	1.85	1.75	1.90	1.88
1500	2.05	0.65	3.53	1.50	1.49	1.58	1.70	2.48	1.58

Results on Center of **Beam** Span

Beam Name	Span-A			Span-B			Span-C		
	Mesh Size (mm)			Mesh Size (mm)			Mesh Size (mm)		
	500	**1000**	**1500**	**500**	**1000**	**1500**	**500**	**1000**	**1500**
GB1	0.59	0.67	0.92	0.32	-0.47	0.32	0.90	0.98	1.45
GB2	0.25	0.10	1.36	0.24	0.33	1.23	0.30	0.29	0.14
GB3	0.67	0.79	1.37	-0.41	-0.57	-0.42	1.01	1.07	1.74
GB4	0.25	0.82	-0.08	0.25	0.58	0.18	0.27	0.03	1.91
GB5	1.10	0.53	0.93	1.26	1.36	1.96	-1.05	-0.49	-0.91
GB6	0.88	1.03	1.41	-1.36	-1.80	-1.26	1.41	1.52	1.93
GB7	-2.51	-2.10	-1.42	-1.79	-1.21	-0.64	-4.17	-3.87	-3.43
GB8	-2.36	-1.90	-2.17	-2.66	-2.02	-2.49	-1.87	-1.59	-0.64

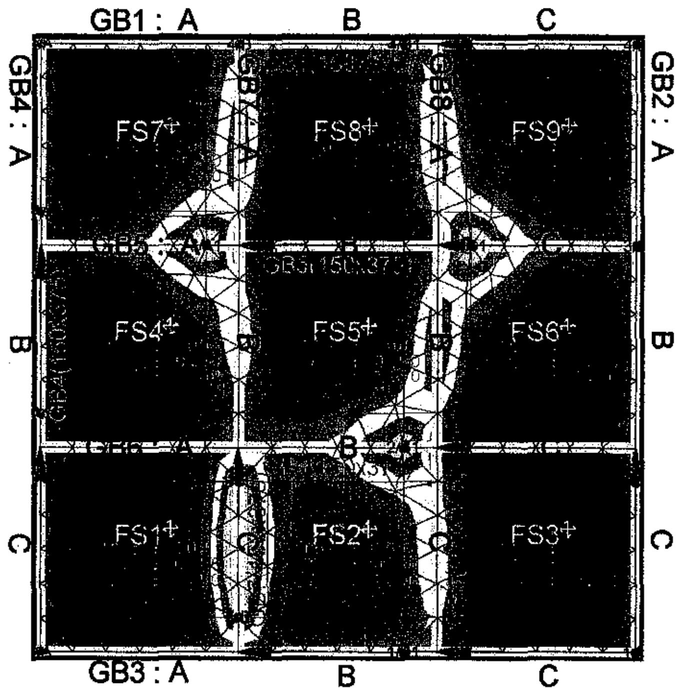


Fig. 15: Slab 3m x 3m with Irregular Column Grid. X-contour Displacement

4.iii.a.3 Maximum Positive Displacement Values of Moment for **Y-direction** in kNm/m :

Refer Appendix Figure 16: (a), (b), and (c)

Results on Center of **Slab**

Mesh Size (mm)	**Slab Name**								
	FS1	**FS2**	**FS3**	**FS4**	**FS5**	**FS6**	**FS7**	**FS8**	**FS9**
500	1.65	1.24	2.10	1.59	1.49	1.32	1.92	2.11	2.04
1000	1.78	2.31	2.08	1.61	1.61	1.47	2.23	2.20	2.24
1500	1.72	1.64	2.45	1.29	1.91	2.03	2.11	2.68	2.64

Results on Center of **Beam** Span

Beam Name	**Span-A**			**Span-B**			**Span-C**		
	Mesh Size (mm)			Mesh Size (mm)			Mesh Size (mm)		
	500	**1000**	**1500**	**500**	**1000**	**1500**	**500**	**1000**	**1500**
GB1	0.26	0.13	0.86	0.27	0.30	0.33	0.25	0.16	1.14
GB2	0.56	0.48	1.09	0.40	0.51	1.15	-0.06	-0.04	-0.03
GB3	0.25	0.39	1.08	0.25	0.35	0.16	0.26	0.20	0.15
GB4	0.47	0.86	0.21	-0.25	-0.21	-0.20	0.92	0.98	1.03
GB5	-4.48	-3.87	-3.31	-1.11	-0.80	-0.16	-4.61	-3.63	-3.45
GB6	-1.69	-1.24	-0.56	-3.98	-3.42	-2.56	-1.47	-1.22	-0.52
GB7	0.77	0.68	0.93	0.43	0.61	0.96	-1.02	-1.02	-1.07
GB8	0.84	0.77	0.86	-0.21	-0.11	-0.11	0.66	0.79	1.20

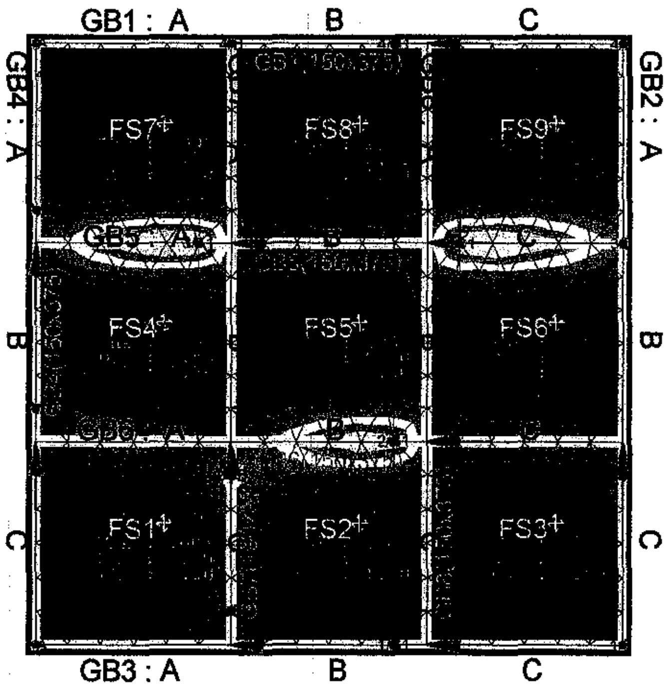


Fig. 16: Slab 3m x 3m with Irregular Column Grid. Y-contour Displacement

CHAPTER 5: DISCUSSIONS

5.i Discussions for *Result 4.i*

Different loading pattern will give different effects on the moment distribution contour. Previously, the author have selected 3 loading patterns as shown in Figure 1(a), (b), and (c) to be used during the analysis. The effects of the loading patterns are shown in Figure 2(a), (b), and (c). While Figure 3(a), (b), and (c) shows the effect of mesh sizes on the contour line. The finer the mesh size the smoother contour lines will be produced. This will give the effect on the moment distribution values in terms of deflection, and moment on X and Y axis. In the analysis, only slab FS 1, FS 2, and FS 5 was considered as these slabs have the different characteristic of the slab, but they are the same as the other slabs as the analysis was done on a square-shaped, equally sided slab. To understand the data, from the Figures in the appendices, the color codes represent the range of values. The lighter the color, less deflection occurs, while the darker the color gets on the contour lines, meaning there's higher value of deflection along the contour line.

5.i.1 ***Effects of mesh size on maximum deflection in the slab***

5.i.1.1 Slab with load pattern 1

In the corner slab FS 1 with as shown in Figure 4(a) in appendix, the maximum nodal deflection in the mid-slab was 1.12mm with 500mm mesh size. With 1000mm mesh size as in Figure 1(b), the value was 1.13mm and 1500mm as in Figure 1(c) the value was 1.00mm. This shows just a slight increase between 500mm and 1000mm mesh size but as it goes to the 1500mm mesh size, the value drops about 12%.

For slab FS 2, the coarse mesh of 1500mm size, gives the maximum deflection value at the mid slab of 0.30mm where as for the finer mesh of 500mm size, the maximum deflection value obtained was 0.38mm which increment is about 27%.

In the center slab FS 5, the fine mesh of 500mm gives the maximum deflection value at the mid slab of 0.34mm, and it slightly decreased when analyzed using mesh size 1000mm giving the value of 0.32mm. But when mesh size 1500mm was used, the maximum deflection value reduced about 44% giving the value 0.19mm. The result shows that there was an increment about 79% of deflection value from coarse meshing to fine meshing.

So for this case, it clearly shows that fine meshing will produce higher values of deflection while coarse meshing will produce lower values. This means that by using fine meshing, result will be more accurate, and structures design based on the analysis using coarse meshing may result to under-design structure integrity.

5.1.1.2 Slab with load pattern 2

For the corner slab FS 1, the maximum nodal deflection value was 0.57mm for the coarse mesh using mesh size 1500mm. The value increases in amount about 16% with the fine meshing of 500mm and the 1000mm size resulting to the maximum deflection value of 0.66mm.

For the FS 2 slab, when fine mesh was used in the analysis, the maximum deflection value at the mid slab is 0.79mm. This value was same for both mesh sizes of 500mm and 1000mm size. When coarse meshing of 1500mm size was used, the value was 0.69mm which is about 13% of reduction in values.

At the center slab FS 5, the lowest value obtained was -0.09mm when mesh 500mm size was used. The negative sign indicates that the deflection of the slab is in the hogging shape. The value was slightly increased to -0.10mm when 1000mm size of meshing was used. When coarse meshing of 1500mm size was used, the value increased about 67% resulting to the maximum deflection value to be -0.15mm.

For this case, it seems that mesh sizes between 500mm and 1000mm produced almost the same result. This means when mesh size range of 500mm and 1000mm is used, result produced will still be highly accurate, but when mesh size range increases from 1000mm to 1500mm, the result would start to reduce in value.

5.1.1.3 Slab with load pattern 3

In the corner slab FS 1, the maximum nodal deflection value at the mid slab was 1.08mm for both mesh sizes 500mm and 1000mm. But the deflection value reduced about 12% when coarse meshing of 1500mm size was used giving the result of 0.95mm.

For slab FS 2, when fine mesh size of 500mm was used, the maximum deflection value is 0.71mm. The value was slightly reduced when coarser mesh 1000mm size was used giving the value as 0.70mm. But the least value was produced when mesh 1500mm size was used. The maximum deflection value reduced about 15% compared to the fine mesh size used.

For the center slab FS 5, the fine mesh of 500mm gives the maximum deflection value at the mid slab which was 0.18mm, and it was slightly decreased when analyzed using mesh size 1000mm giving the value of 0.16mm. But when mesh size 1500mm was used, the maximum deflection value reduced about 78% giving the value 0.04mm. The result shows that there was an increment about 3.5 times of deflection value from coarse meshing to fine meshing.

So for this case, it also shows that mesh size range from 500mm to 1000mm will produce a reliable result to be used in structure design. But the coarser mesh size of 1500mm is absolutely not suitable to be used in design as it may cause under-design of structure.

5.i.2 Effects of mesh size on maximum displacement values of moment for X-direction in the slab.

As shown in Figure 5 and Figure 6 in the appendix.

5.i.2.1 Slab with load pattern 1

At the corner slab FS 1, the lowest moment displacement value was 1.59kNm which resulted from the coarse mesh of 1500mm size. But the value increased about 45% when the 1000mm mesh size was used giving the result of 2.31kNm. Awkwardly, the value slightly reduced to 2.29kNm when 500mm mesh size was used in the analysis.

For the case of slab FS 2, the maximum displacement values of moment increased from fine meshing to coarse meshing. The value of 0.52kNm was obtained from using the 500mm mesh size, the value increased to 0.55kNm when mesh 1000mm size was used. The highest value was 0.75kNm from the use of mesh 1500mm size which shows the increment 30%.

For the center slab FS 5, mesh 1000mm size produced the highest displacement value of moment which is 1.26kNm. The lowest value was produced when the coarse mesh size of 1500mm was used, giving the result of 0.50kNm which is about 60% in reduction. When 500mm mesh size was used, a slight reduction in value was produced compared to the 1000mm mesh size, which is 1.22kNm.

For this case, FS 1 and FS 5 both result shows that mesh with size 1000mm gives the highest value and FS 2 shows the decrease of value from coarse meshing to fine meshing. The result is quite unusual but may happen in certain cases.

5.i.2.2 Slab with load pattern 2

In the corner slab FS 1, the maximum displacement value of moment when coarse mesh of 1500mm was used, was 0.78kNm. The fine mesh of size 500mm produced the highest value of 1.43kNm which is about 83% of increment. The value obtained from using the 1000mm mesh size was 1.28kNm.

For slab FS 2, the fine mesh of size 500mm produced the maximum displacement value of moment of 1.69kNm. This value is the reduced to 1.50kNm when mesh 1000mm size was used. When the coarse mesh size of 1500mm was used, the value obtained was 1.48 which is about 12% in reduction compared to the fine mesh size used.

At the center slab FS 5, the fine mesh size of 500mm produced the maximum displacement of moment value of 0.34kNm. This value was then reduced to 0.24kNm when mesh 1000mm size was used to analyze. But then the value was reduced drastically to -0.27kNm when coarse mesh size of 1500mm was used which is about 179% lower compared to the finer mesh of 500mm. This contrasting result only has occurred in this particular condition of case.

5.i.2.3 Slab with load pattern 3

At the corner slab FS1, unusually the lowest value of maximum displacement value of moment was obtained from the mesh size of 1000mm which is 1.22kNm. The highest moment displacement value was 1.37kNm from the finer mesh of 500mm which is about 12% increment of value. The coarse mesh of 1500mm produced the maximum displacement value of 1.28kNm.

For slab FS 2, the result shows a normal behavior where the highest value was obtained from the fine meshing of 500mm which produced a result of 2.27kNm. The value then shows a reduction of 35% compare to the coarsest mesh size of 1500mm which is 1.47kNm. The average mesh size of 1000mm produced the moment displacement value of 2.08kNm.

At the middle slab FS 5, unusual result also occurs where the highest value of 0.44kNm occurs when the coarse mesh size of 1500mm was used and the lowest value of 0.31kNm was produced from using the finer mesh size of 500mm. This shows a reduction about 30% in value from coarse mesh to fine mesh. The mesh size of 1000mm also produced a high value of 0.42kNm moment displacement but lower than the mesh size of 1500mm.

5.i.3 Effects of mesh size on maximum displacement values of moment for Y-direction in the slab.

As shown in Figure 5 and Figure 6 in the appendix.

5.i.3.1 Slab with load pattern 1

In the corner slab FS 1, the results produced as normally it supposed to where the lowest maximum displacement value of moment was 2.01kNm with 1500mm mesh size and the value increased about 10% to the highest value which was 2.22kNm when smaller mesh size of 500mm was used. For the mesh size of 1000mm, the result for maximum displacement value of moment was 2.13kNm.

For slab FS 2, the maximum displacement value of moment was 0.74kNm with 1500mm mesh size, where as for 1500m mesh size, the value increased about 57% where the value was 1.16kNm. As for the 1000mm mesh size, the value was slightly reduced to 1.13kNm compared to the finer mesh size.

As for the center slab FS 5, the highest maximum displacement value for moment was obtained from the 1000mm mesh size, which produced the value 1.39kNm. The value reduced about 7% which is 1.29kNm with the 500mm mesh size. The lowest moment displacement value was obtained from the coarser mesh size of 1500mm which was 1.02kNm.

5.1.3.2 Slab with load pattern 2

In the corner slab FS 1, mesh size 1000mm produced the least maximum displacement value of moment which is 1.22kNm, where as for the finer mesh with size 500mm, the value was 1.37kNm which is about 12% higher than the coarser mesh size of 1000mm. As for the coarser mesh of 1500mm, the value increased slightly to 1.28kNm which rarely occurs for a coarser mesh size.

As for slab FS 2, the coarser mesh 1500mm size produced the lowest value of 1.47kNm but increased about 54% when finer mesh with size 500mm was applied resulting to the value of 2.27kNm. For coarser mesh with size 1000mm, the moment displacement value was 2.08kNm.

At the center slab FS 5, the finer mesh with size 500mm resulted the maximum displacement value of moment was 0.31mm but the coarser mesh with size 1500mm produced higher value of 0.44kNm. The reduction value about 30% from fine mesh to coarser mesh size seldom occurs since the coarser mesh size normally would result a less accurate value. From mesh size 1500mm to mesh size 1000mm, the value dropped

5.1.3.3 Slab with load pattern 3

In the corner slab FS 1, the highest maximum displacement value of moment was obtained from the mesh 1000mm size which was 2.04kNm, where as the lowest value was obtained from the finer mesh with size 500mm with value of 0.99kNm which was about 50% lower than the coarser mesh. Even the coarser mesh size of 1500mm produced a value about 100% higher compare to the finer mesh with size 500mm, which was 1.99kNm.

As for slab FS 2, the behavior of moment was normal, where the highest maximum displacement value for moment was obtained using the finer mesh with size 500mm which value was 1.98kNm. The value slightly dropped to 1.96kNm when coarser mesh with size 1000mm was used. The value for mesh with size 1500mm was about 32% lower compare to the finer mesh with size 500mm, which was 1.35kNm.

At the center slab FS 5, the coarser mesh with size 1500mm resulted to the lowest value of moment displacement which was 0.89kNm. The value increased to 2.11kNm which is about 137% higher compare to the coarser mesh of size 1500mm. The mesh with size 1000mm produced the maximum displacement value 1.12kNm of moment.

5.1.4 Effects of different meshing patterns, Triangular Mesh, Mixed Mesh, and Quadrilateral Mesh pattern on maximum nodal deflection values of the slab with different mesh sizes.

Analysis done based on Slab with load Pattern 3 as shown in Appendix-Figure 7

5.i.4.1 Mesh with size 500mm

At the corner slab FS 1, the highest maximum deflection value was 1.08mm using triangular mesh pattern, the value reduced about 0.01mm, resulting to the value of 1.07mm using mixed-mesh pattern, the value reduced more to 1.06mm when trial was done using quadrilateral mesh pattern. Increment between the lowest value and the highest value is about 2%.

The same result goes to slab FS 2. The increment of 2% from the lowest value, to the highest value, occurs when quadrilateral mesh pattern produced the deflection value of 0.69mm, where as the triangular mesh pattern produced the deflection value of 0.71mm. For the mixed-mesh pattern, the deflection value was 0.70mm.

At the center slab FS 5, triangular mesh pattern produced the highest value of deflection which was 0.18mm. Mixed-mesh pattern and quadrilateral mesh pattern produced the same value of deflection which was 0.17mm. The difference is very slight which was 0.01mm which was less than 1% compare to the triangular mesh pattern. For this case, it is shown that triangular gives the highest value thus will produce the most accurate value to be used in the structure design.

5.i.4.2 Mesh with size 1000mm

In the corner slab FS 1, triangular mesh pattern produced the highest deflection value which was 1.08mm. Then when analyzed using mixed-mesh pattern, the value drops slightly to 1.07mm. The lowest value was obtained from using the quadrilateral mesh pattern which was 1.02mm. The reduction from triangular mesh pattern to the quadrilateral mesh pattern was about 6%.

As for slab FS 2, mixed-mesh pattern produced the highest deflection value which was 0.71mm. The value slightly reduced to 0.70mm when analyzed using triangular mesh pattern. The lowest deflection value was 0.68mm, which was produced by using quadrilateral mesh pattern which reduction amount was about 4%.

At the center slab FS 5, mixed-mesh pattern produces a slightly higher deflection value compare to the triangular mesh pattern and the quadrilateral mesh pattern, which was 0.17mm, where as triangular mesh pattern and quadrilateral mesh pattern both values were 0.16mm. The deflection values difference between the patterns was about 6%.

For this case, the higher value was produced from the analysis using the mixed-mesh pattern. But the triangular mesh pattern also gives a high value although it is slightly lower compared to the mixed-mesh pattern's result.

5.1.4.3 Mesh with size 1500mm

In the corner slab FS 1, triangular mesh pattern shows the lowest deflection value which was 0.95mm but this is only 0.01mm difference compare to the mixed-mesh pattern which was 0.96mm. The value increased about 15% when it comes to the quadrilateral meshing pattern which deflection value was 1.09mm.

For slab FS 2, mixed-mesh pattern shows the lowest deflection value which was 0.59mm and the value increased slightly to 0.60mm when triangular mesh pattern was used in analyzing. But the highest deflection value was produced when the analysis was done using the quadrilateral mesh pattern which was 0.73mm, which was 24% in increment.

At the center slab FS 5, triangular mesh pattern shows the lowest deflection value which was 0.02mm, which was about 90% lower compared to the highest value obtained. Mixed-mesh pattern produced a deflection value of 0.04mm. The deflection value again shows the highest amount when quadrilateral mesh pattern was used in the analysis with 1500mm mesh size which the value was 0.20mm.

Overall, triangular mesh pattern produce the highest value which means triangular mesh pattern is the most accurate pattern to be used in the analysis of a flat plate slab. Although in the last case, quadrilateral mesh pattern shows the highest value, this pattern is still unsuitable as the high value resulted was because the coarser mesh pattern was used and this is unsuitable with other conditions of slab.

5.ii Discussions of ***Result 4.ii***

During the analysis, the author has chosen to use **Triangular** pattern meshing based previous result which Triangular mesh pattern produced the better results compare to other patterns. For this case, the analysis was done based on different condition of column distributions which are regular and irregular pattern. The analysis was done on different scale of slab size.

5.ii.1 ***Regular Columns Distribution on Slab of 10m x 10m***

5.ii.1.a Maximum Positive Nodal Deflection Values.

From overall overview, for the center of slab, almost all of the maximum deflection values were produced by the use of mesh size 1500mm. Maximum values were produced at the center of slab since this is a regular grid column, thus the load distribution became centralized to the center location of each slab. For the center of beam, the maximum value of deflection were also obtained when the analysis was done using larger mesh size of 1500mm. When compare to the results of using mesh size

1000mm, the values were not much difference to compare to the mesh of 1500mm size. The differences were about less than 1% reduction in values when mesh size was reduced.

For the center of slabs FS1, FS3, FS7 and FS9, the range of value was about the same, between 22mm to 23mm. This goes the same for the case of center of beam with same conditions such as beam Span A and Span C, with the range of value about 14.8mm to 15.2mm. Overall, every location of node on beam or slab with the same condition would produce a similar value. This is because the load distribution for a regular grid column are equal on every angle, so the result would be almost symmetry for the values on the left of the slab to the right of the slab, and vice versa for the top and bottom of the slab.

5.ii.1.b Maximum Positive Displacement Values of Moment for X-direction.

For moment on X-direction means the values are in terms of how the deflection occurs in the X-direction. Overall in the case of the node at the center of the slab, the highest values were produced among the mesh size 1000mm or 1500mm. The range of difference between the highest value and the lower value were more or less about 3%. For the case of the center of beam span, it was unconcluded because all three mesh size may produce the highest value.

The differences were only in terms of where the nodes are exactly located. It can be seen that when the node is located on the span near to the side of the slab, as on Span A and Span C, the higher value were produced when using the mesh size of 1500mm. But when the node is on the center of center span as Span B, then mesh 500mm would produce a higher value. But the range of difference in moment value produced by the mesh sizes was only about less than 1%.

5.ii.1.c Maximum Positive Displacement Values of Moment for Y-direction.

For moment on Y-direction means the values are in terms of how the deflection occurs in the Y-direction. From the figure it is seen that the top and bottom of the slab show the darker color meaning more deflection occurs on the sides of the slab compare to the middle of the slab. The value is about the same as the value produced by the moment of the X-direction. The value varies with the position of nodal and the higher value were produced by all three mesh sizes of 500mm to 1500mm. But it seems for both center of slab and center of beam span, the mesh size 1500mm produced slightly more of the higher value. But the value difference is very little about less than 1%.

5.ii.2 *Irregular Columns Distribution on Slab of 10m x 10m*

5.ii.2.a Maximum Positive Nodal Deflection Values.

Since the column distribution is irregular, the contour lines were also distributed in a scattered manner. Again here the lighter the color of the contour lines means that the value of deflection is smaller and where the color is darker, it means that the deflection is more. The scattered behaviors of the contour lines are effect of the irregularities of the column locations. It shows that the color gets lighter when it is nearer to the location of the column. That is the behavior of how the loads are distributed, where there are less supports, there would be more deflection and thus the contour color gets darker. The color gets very light when there more support near to the node location.

So in this case, it seems that for the center of slab, the mesh size of 1000mm and 1500mm produced the higher values of deflection. As for the center of beam span, GB 1, GB4, GB5, and GB6 of span A, mesh size 1000mm produce more higher values. But for span B of GB1, GB3, GB4, GB5, GB6 and GB8 mesh 1500mm produced the higher value. Span C, GB1, GB3,GB6, GB7, and GB8 produced more of higher deflection values when mesh size of 1500mm was used.

5.ii.2.b Maximum Positive Displacement Values of Moment for X-direction.

From the figure it shows that the left and right side of the slab occurs more moment deflection. Where there are columns positioned, the color gets very light since there is where the supports are. In this case, it is not clear which mesh size would give the higher value since all three mesh size did produce the higher values. The value just differ on which location of the nodes are. But it is clear for the center of beam span position on Span B which is the middle span of each beam, mesh size 1000mm produced the higher value. The inconsistency of result for example GB2 Span B and GB4 Span C where at the same node occurs both positive and negative value, might have occurred because of human error in collecting the data. But the slightly larger range of values as on center span of GB4, might have occur because of the mesh pattern might have change when the mesh size was changed causing the position of the node have varied.

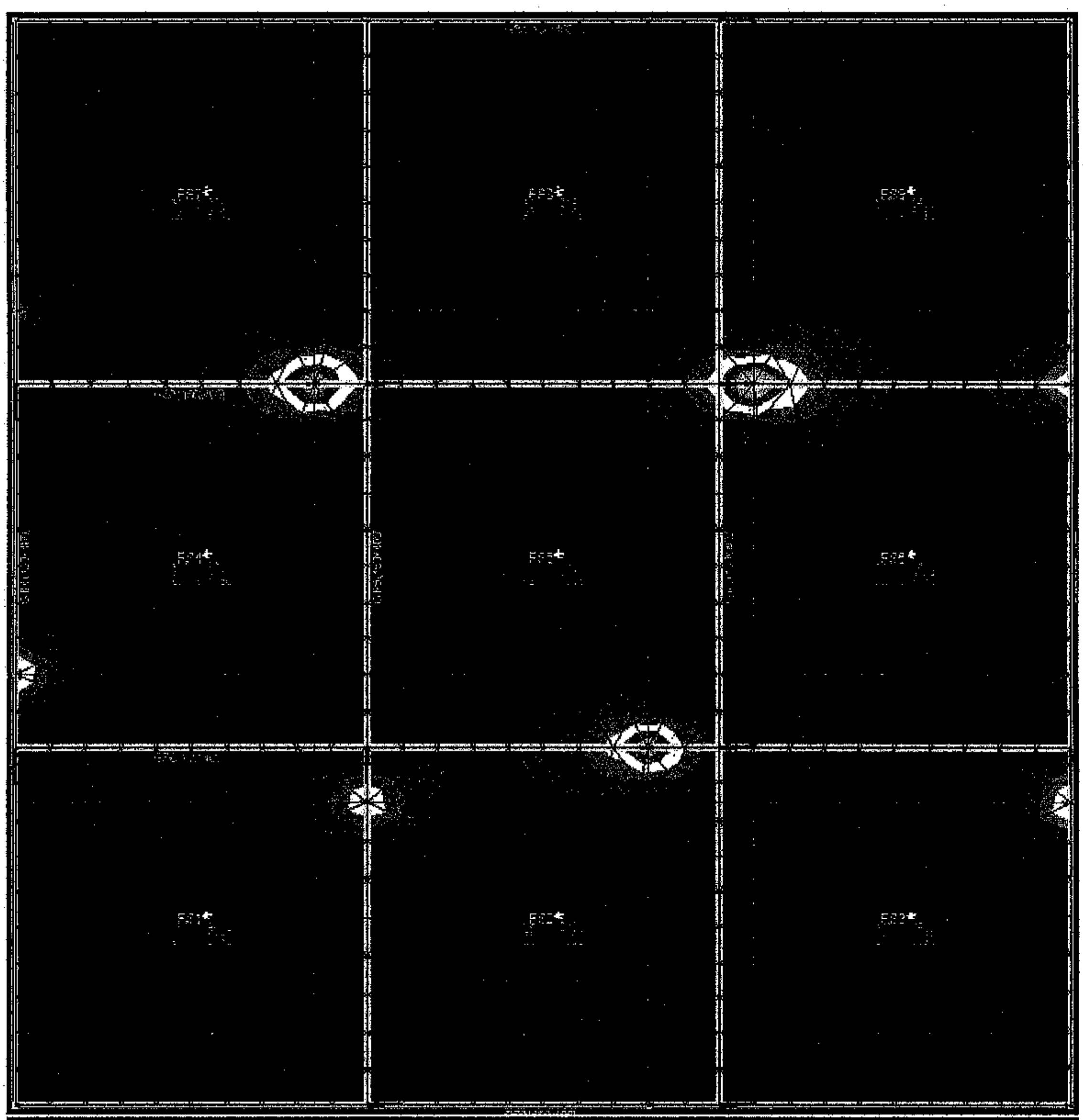
5.ii.2.c Maximum Positive Displacement Values of Moment for Y-direction.

For the center of slab, both 1000mm and 1500mm size produced the higher value. But the difference between the higher and the lower value of the node is quite large, which is about 10%. But for the center of beam span, the range of difference of values is not so big, which is about less than 3%. Overall, all the mesh size of 500mm, 1000mm, and 1500mm resulted in producing the higher value of moment. They just differ on where the locations of nodes are.

Figure 13

(b) Slab 10m x 10m with Irregular Grid Distribution and

Mesh Size = 1000mm, Y-direction Moment Contour



After several checks of regenerating the result, the value is still the same, meaning it can't be error from the software. So the variation of values may be resulted because of the different size of mesh used has effects on those particular nodes.

5.ii.3.c Maximum Positive Displacement Values of Moment for Y-direction.

Here for the case of center of slab, the mesh size that produced the higher values are the mesh size of 1000mm and 1500mm. For the case of the center of beam span, most of Span A and Span C obtained the higher values from using the larger mesh size of 1500mm. While for the middle span of the beam as Span B, the smaller mesh size of 500mm produced the higher values of moment. But it also seems that when the produced value is in negative form, meaning the deflection is concave, the smaller mesh size of 500mm is needed to produce the higher result.

CHAPTER 6: CONCLUSION

From the overall view, the finer mesh size will provide higher value of the central deflection, thus, a more accurate result. Finer meshing also produced higher value of displacement value of moment about axis. Hence, the coarse meshing will yield the relatively inaccurate displacement values but may be applicable to certain cases where mixed-meshing is needed. During analyzing, the finer meshing took up more memory spaces in the hard-disc and longer time to run the analysis. The coarser meshing was very fast to run and took less memory space.

For the meshing patterns, in a nutshell, Triangular meshing pattern resulted with the higher deflection values. Thus, triangular mesh pattern is more widely used to obtain the most accurate result to be used in the design process. Although triangular mesh patterns gave the higher result more frequently, in certain condition mixed-mesh pattern or quadrilateral mesh pattern need to be used to obtain the best result.

When Slab size is considered, overall, mesh size is proportional to the size of the slab. Meaning, the bigger the slab size, thus the mesh size used should be bigger. This is because when the mesh size is too small in ratio compare to the size of the slab, the result became more inaccurate as analyzed. Based on this project, it is proven that the optimal size of mesh most likely to be used for a large scale of slab, for example in this project size 10m x 10m slab, is between 1000mm to 1500mm, although in terms of majority of results, mesh size of 1500mm would be more appropriate.

When column distribution is considered, irregular column shows that the result would be more accurate if mesh size 1500mm is used. But for regular column grid distribution, the mesh size depends completely on the size of slab used.

This project is expected to serves as a benchmark towards understanding on the most effective method of structural design calculation which will help the consultants in producing the most reliable design that complies with the actual working condition which main requirements are cost effectiveness and on dateline basis.

CHAPTER 7: REFERENCES

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3. British Standards, Structural Use of Concrete – Part 1. Code of Practice For Design and Construction

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7. "http://en.wikipedia.org/wiki/Finite_element_analysis"

8. "http://en.wikipedia.org/wiki/Finite_element_method"

CHAPTER 8:

Appendices

Figure 1

Different loading patterns used for the analysis.

(a) ***Loading Pattern 1***

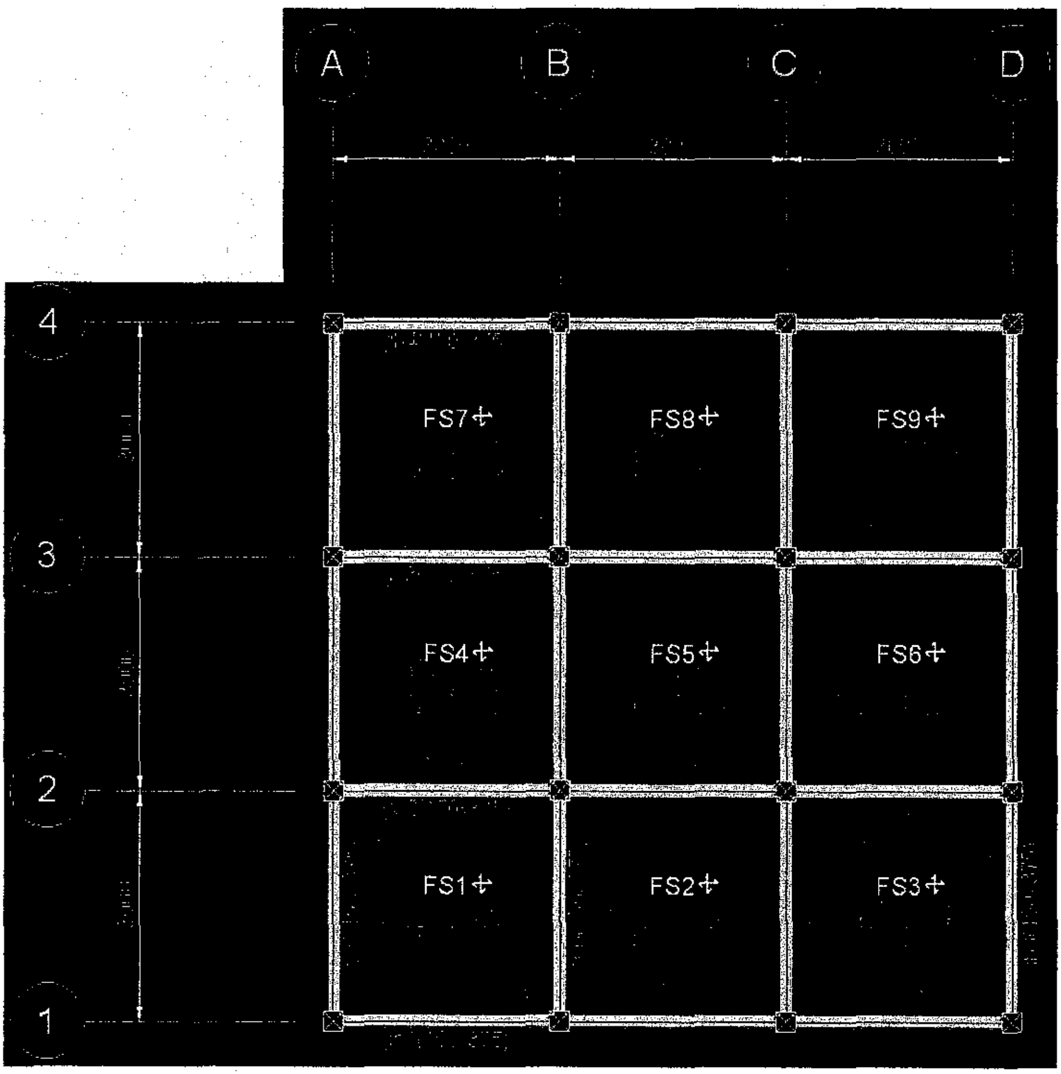


Figure 1

(b) ***Loading Pattern 2***

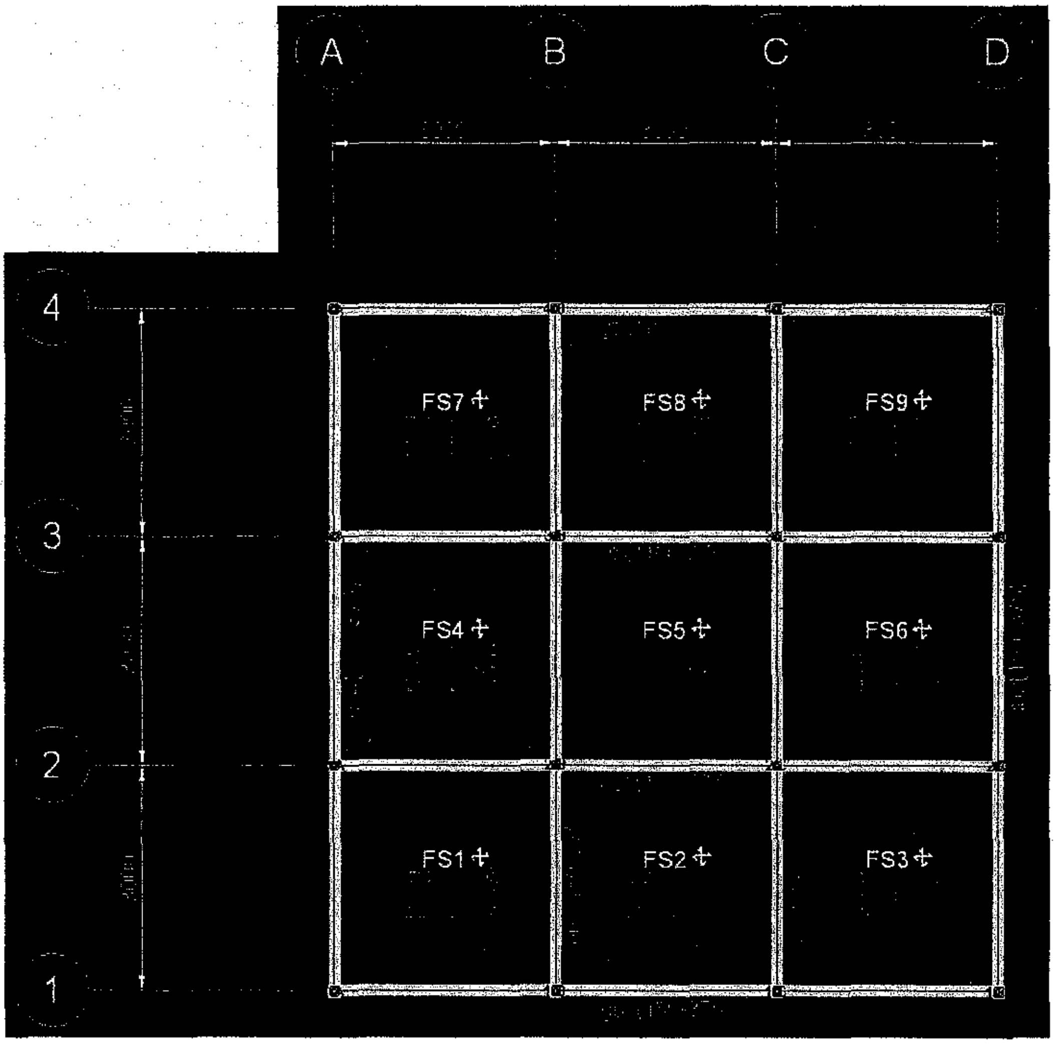


Figure 1

(c) ***Loading Pattern 3***

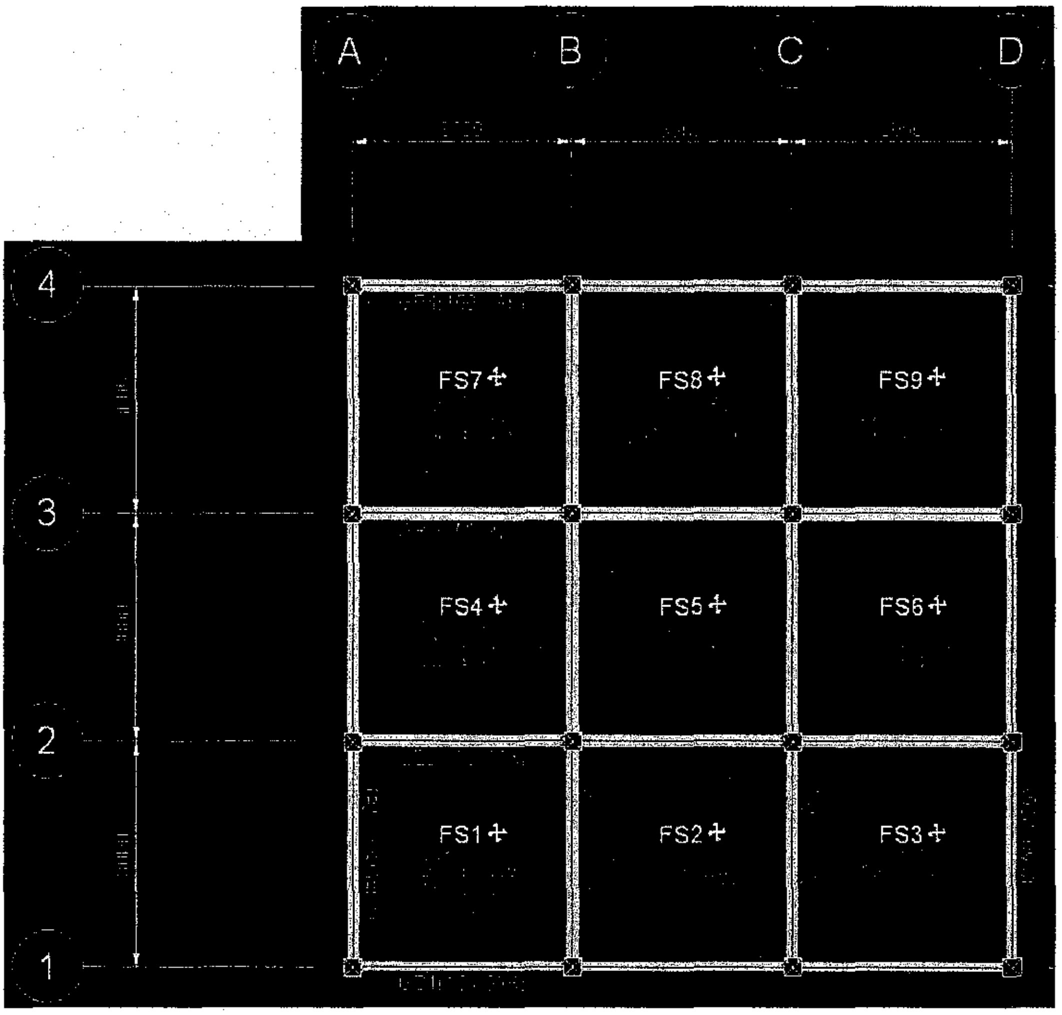


Figure 2

The different load distribution effects on each different slab load pattern.

(a) ***Pattern 1 load distributions.***

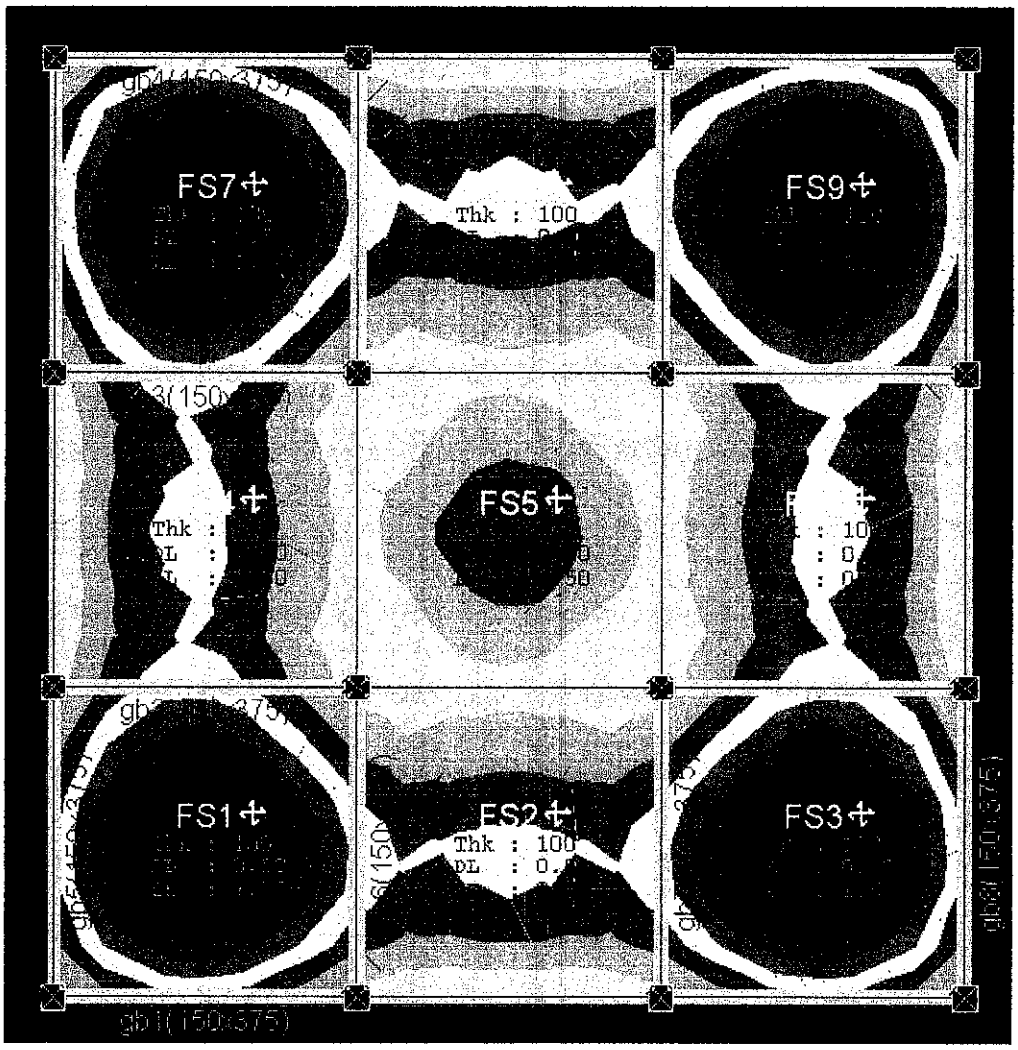


Figure 2

(b) ***Pattern 2 load distributions.***

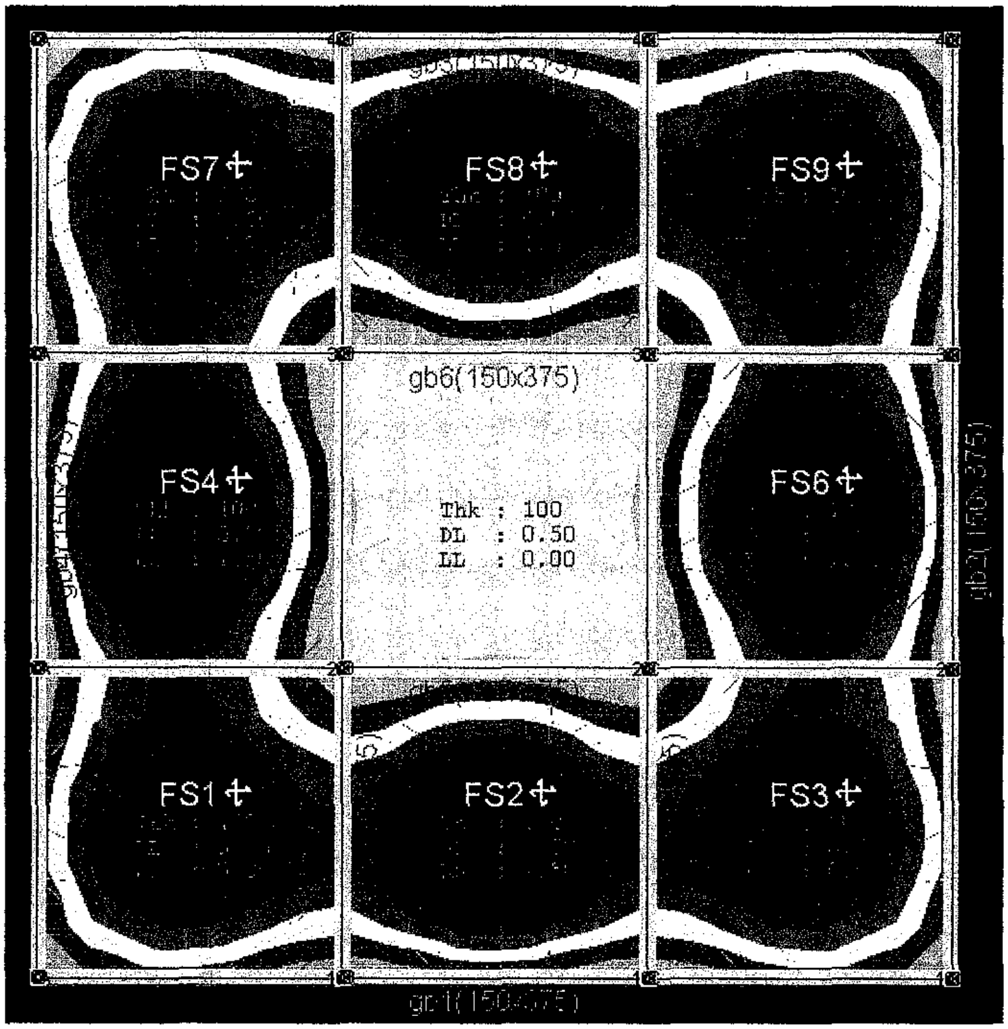


Figure 2

(c) ***Pattern 3 load distributions.***

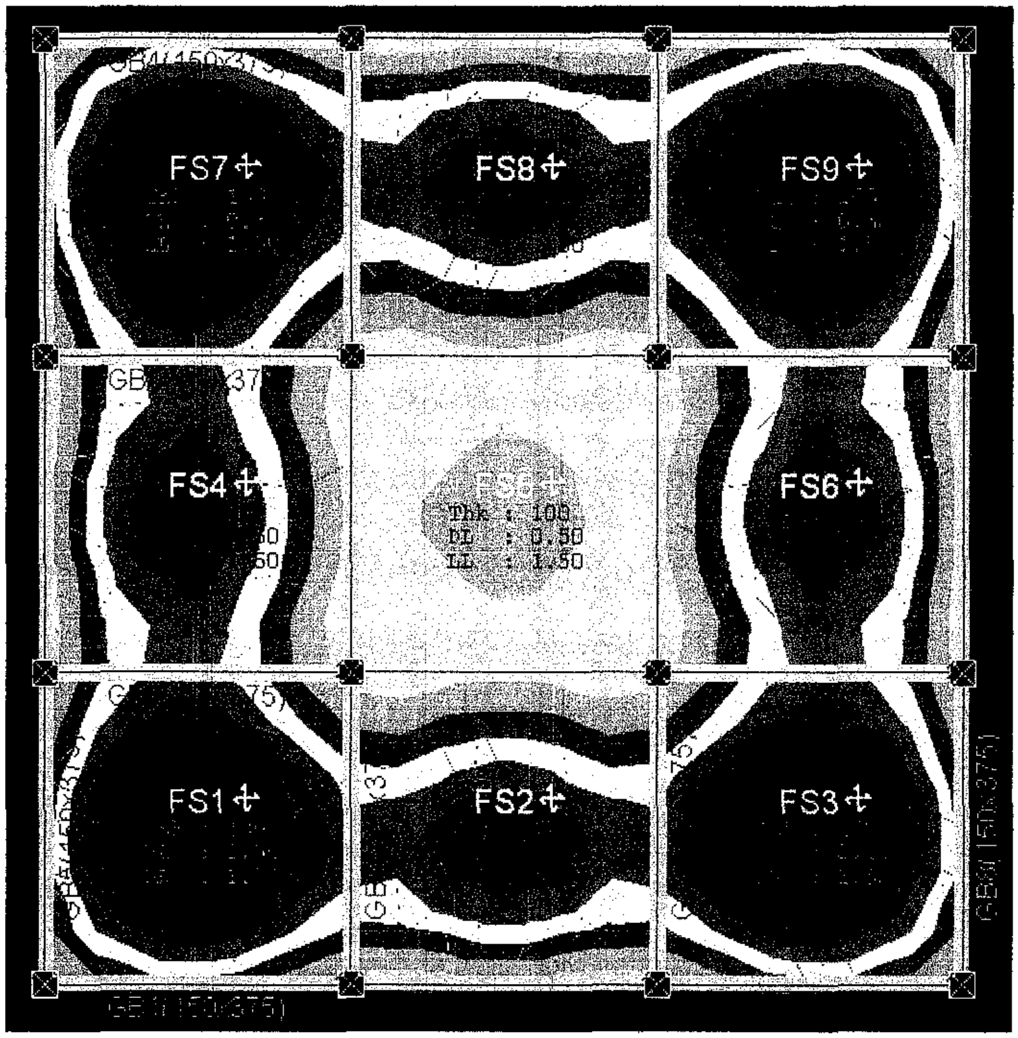


Figure 3

Different meshing sizes effects from fine to coarse meshing. When analysed using Triangular-Mesh.

Example from slab with Load Pattern 2.

(a) *Mesh Size = 500mm.*

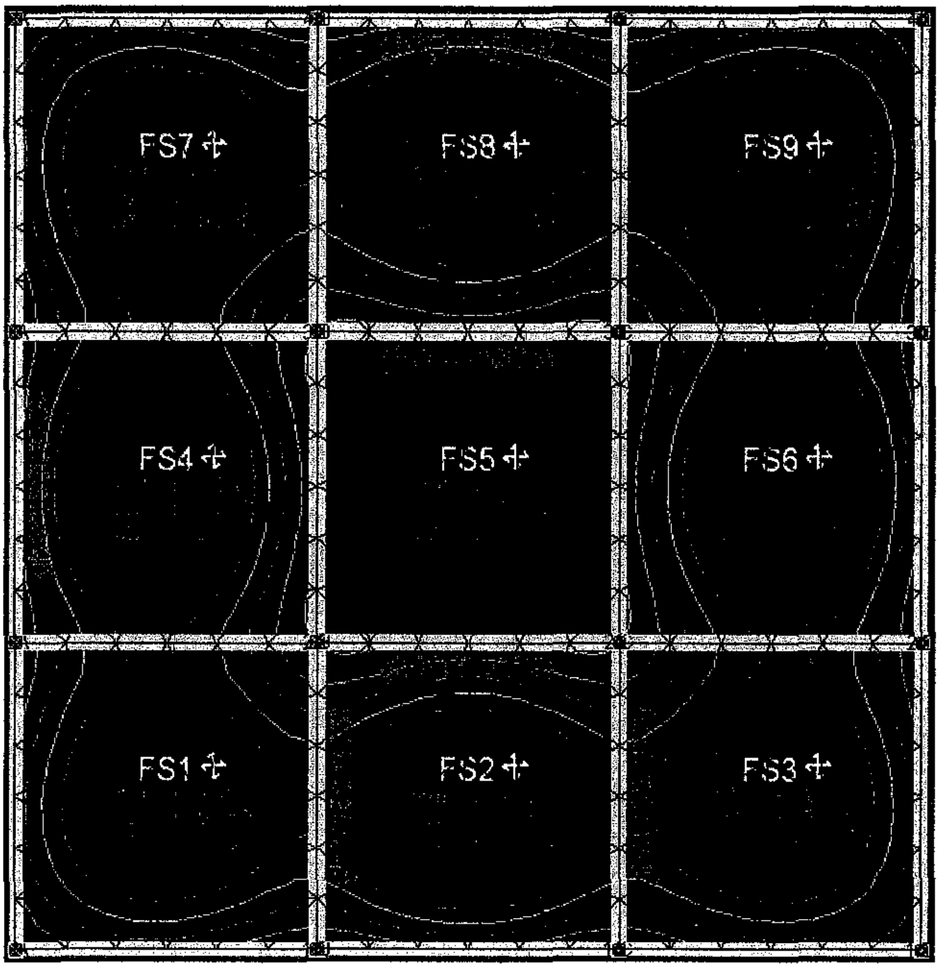


Figure 3

(b) Mesh Size = 1000mm

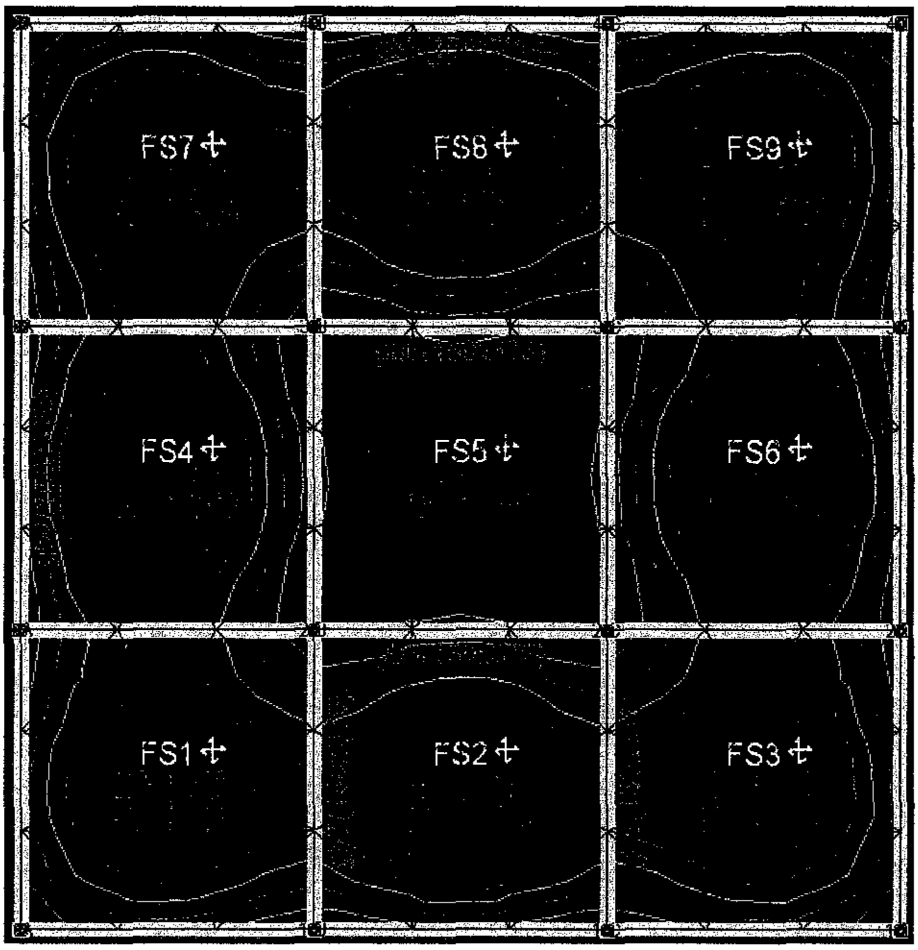


Figure 3

(c) Mesh Size = 1500mm

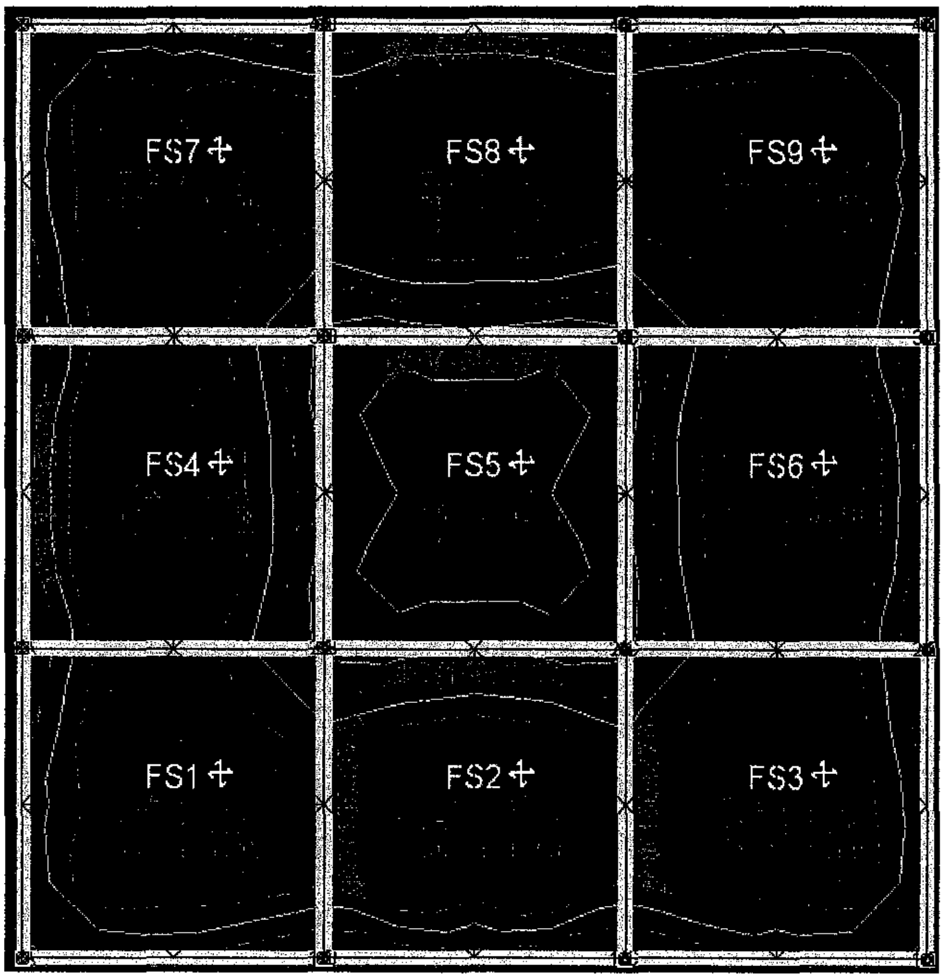


Figure 4

Maximum nodal deflections points value in **mm** on the same slab with same loading but different **meshing sizes.**

***Examples on slab with loading** pattern 1 of FS1.*

(a) Meshing size = 500mm

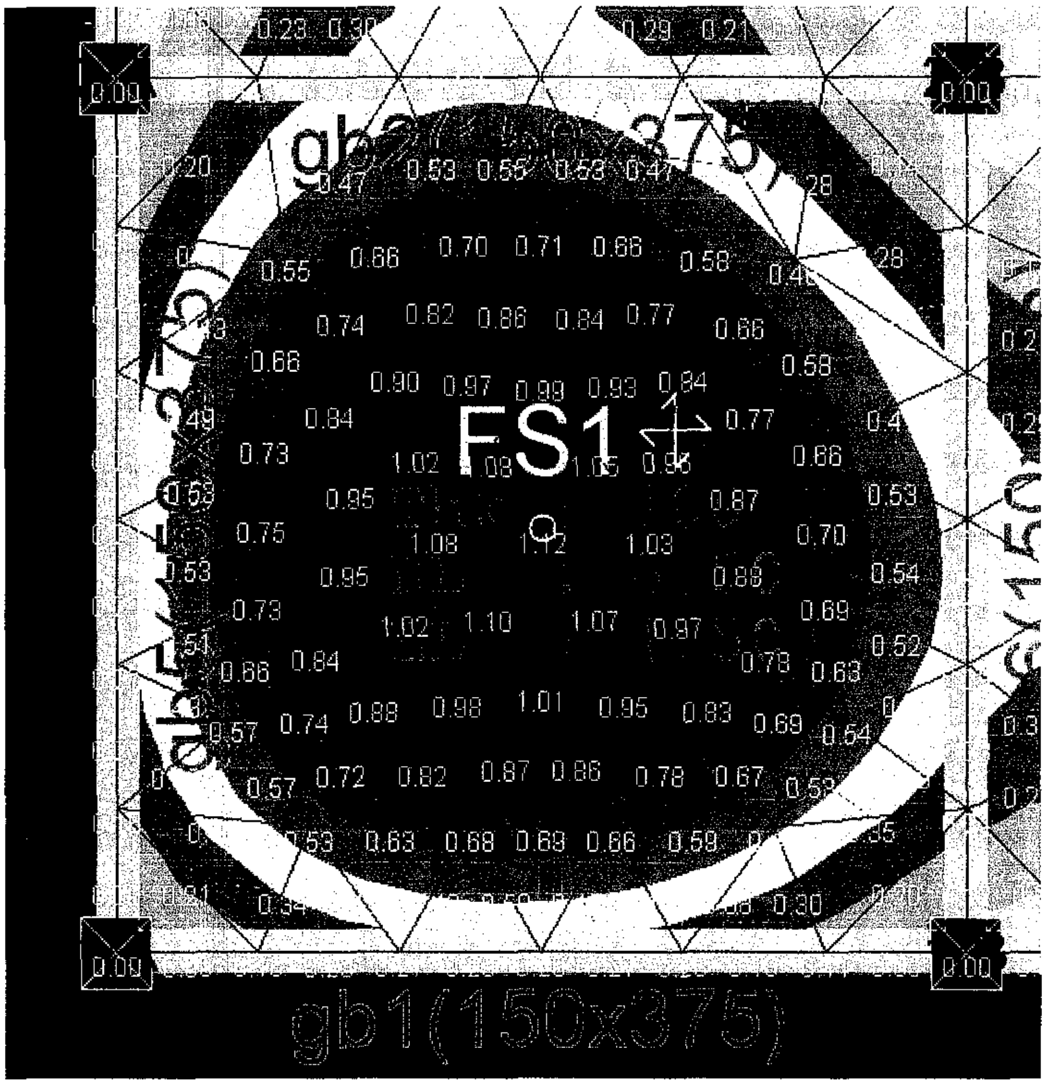


Figure 4

(b) Meshing size = 1000mm

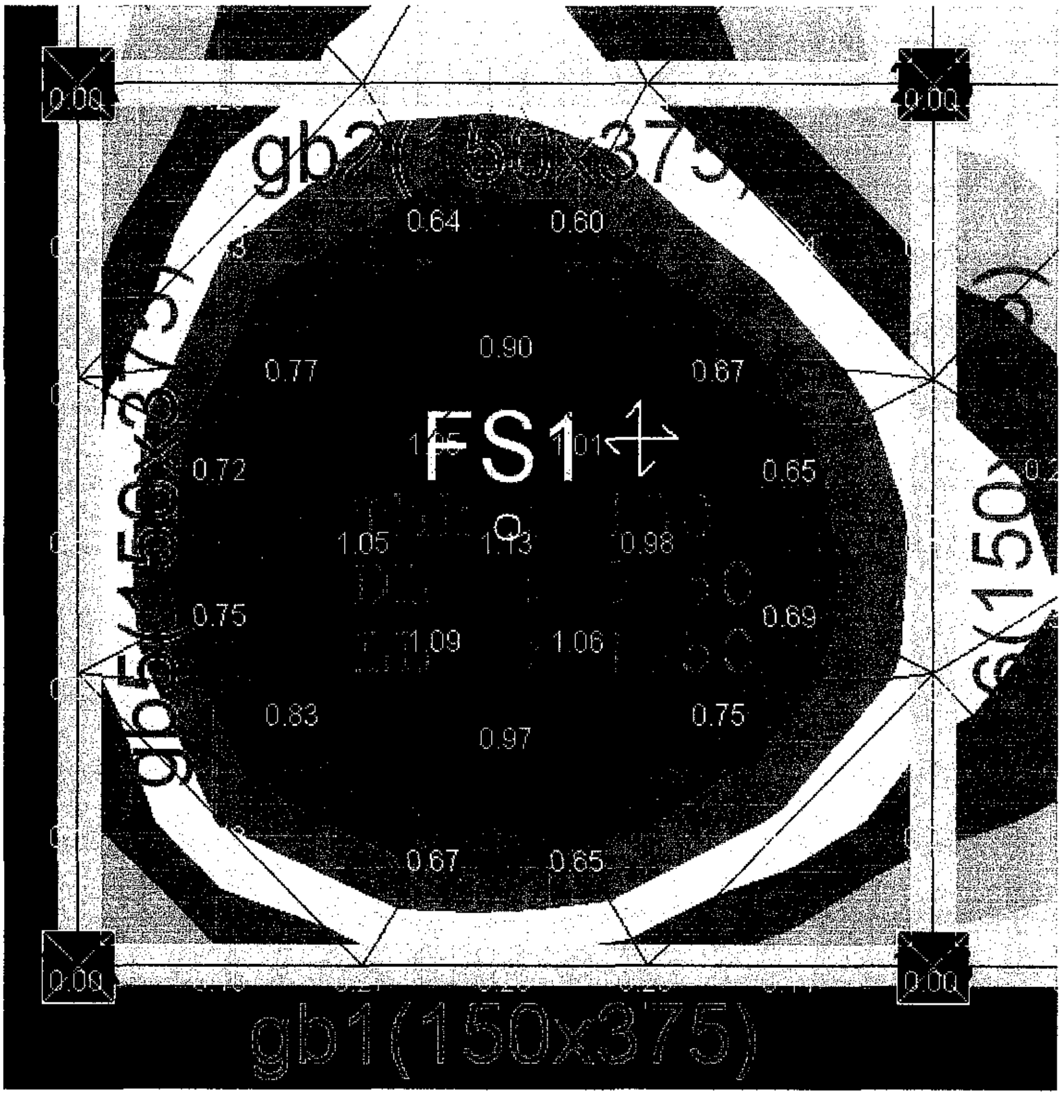


Figure 4

(c) Meshing size = 1500mm

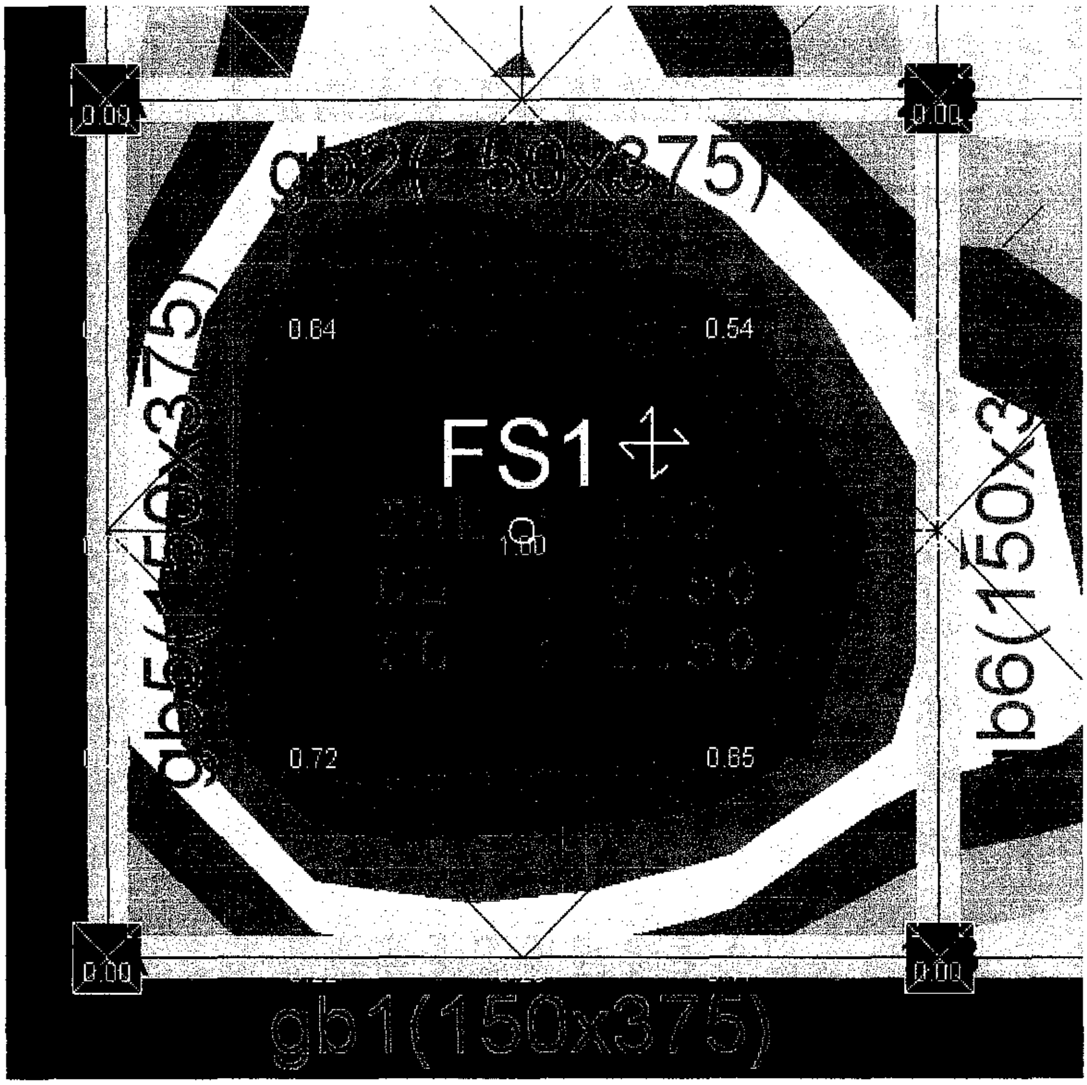
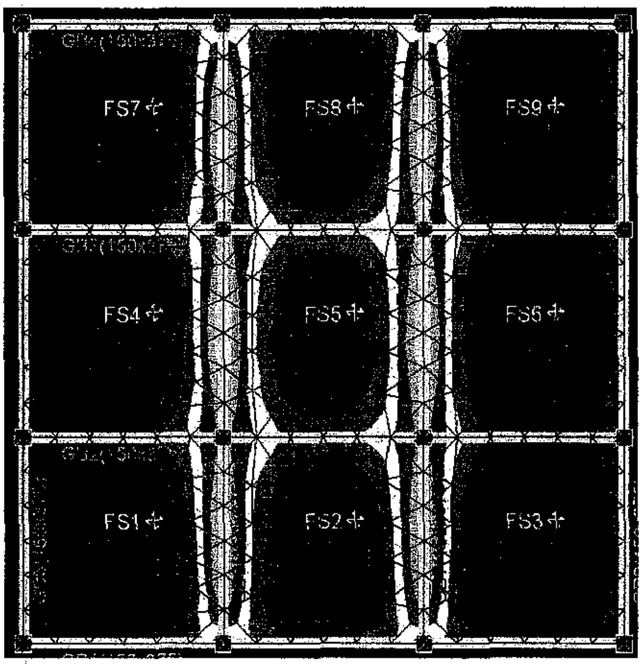


Figure 5

Effects of different meshing sizes on moment for X and Y direction contour.

(a) *Meshing size = 500mm.*



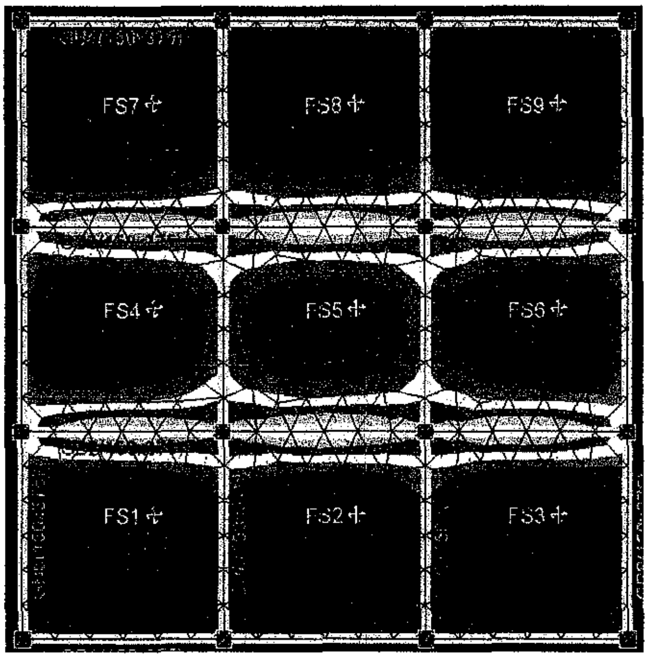
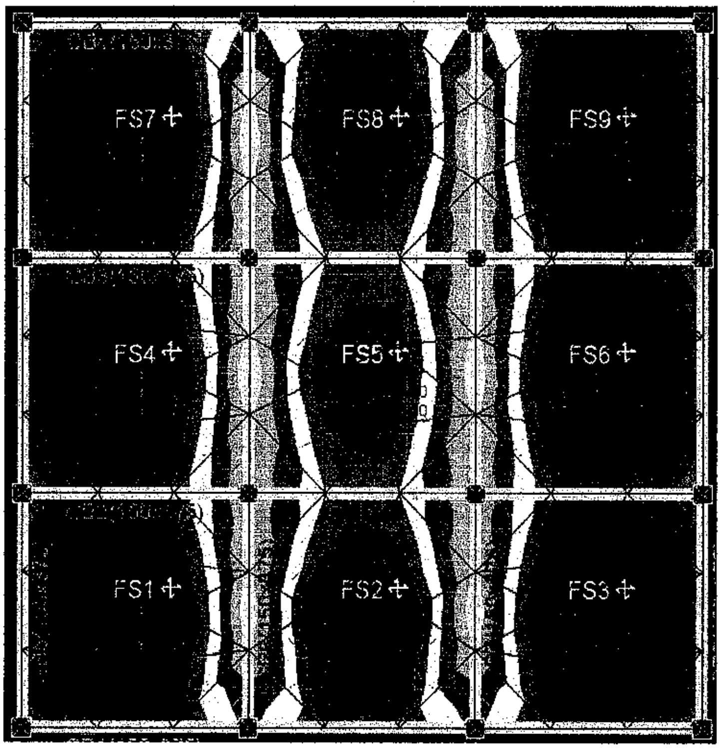


Figure 5

(b) Meshing size = 1000mm



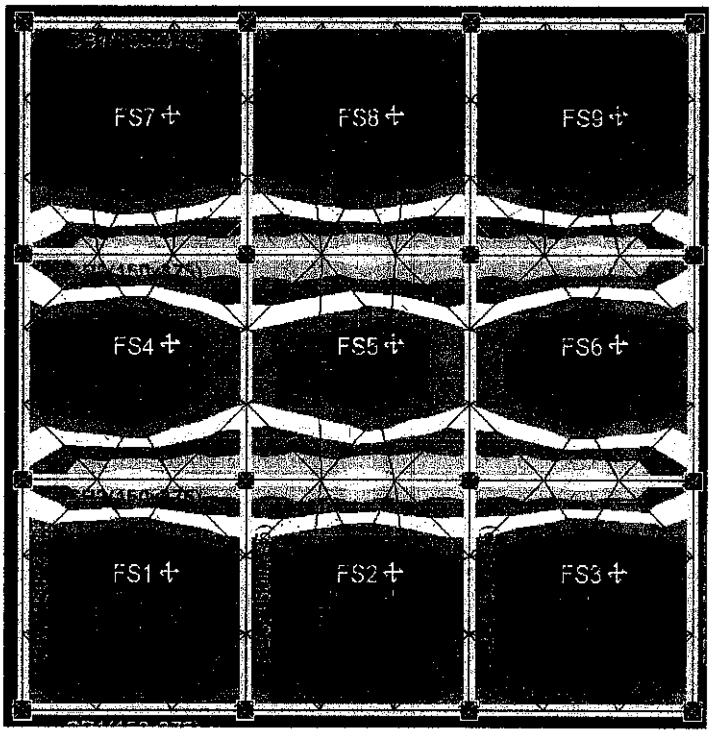
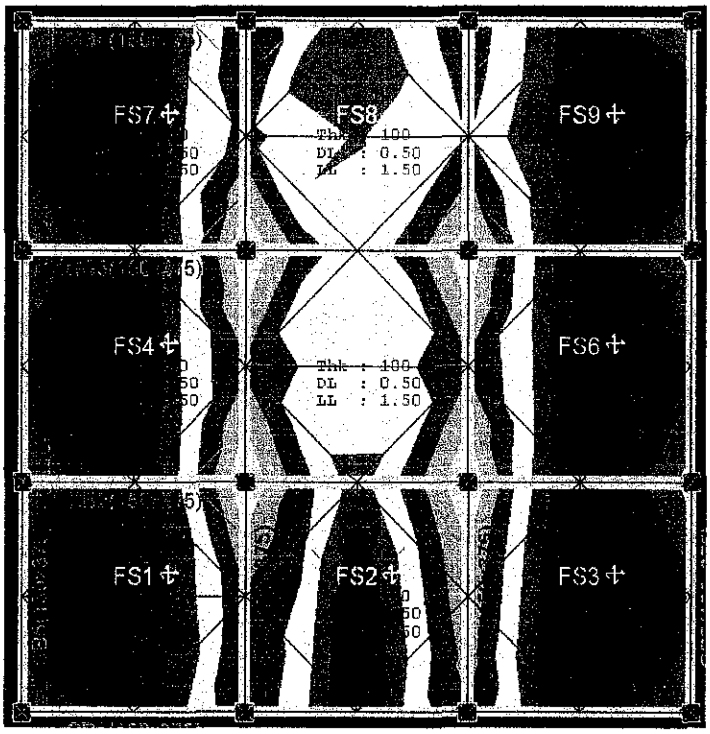


Figure 5

(c) Meshing size = 1500mm



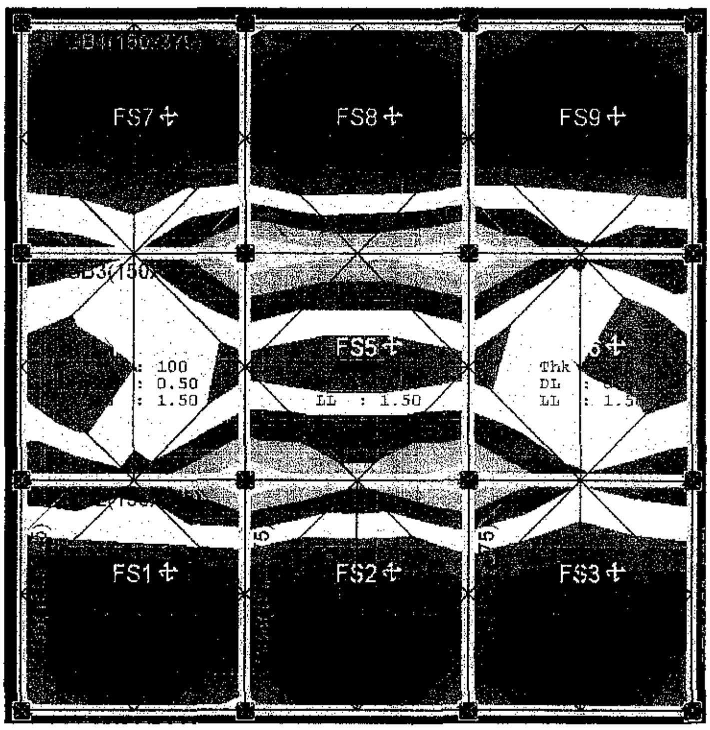
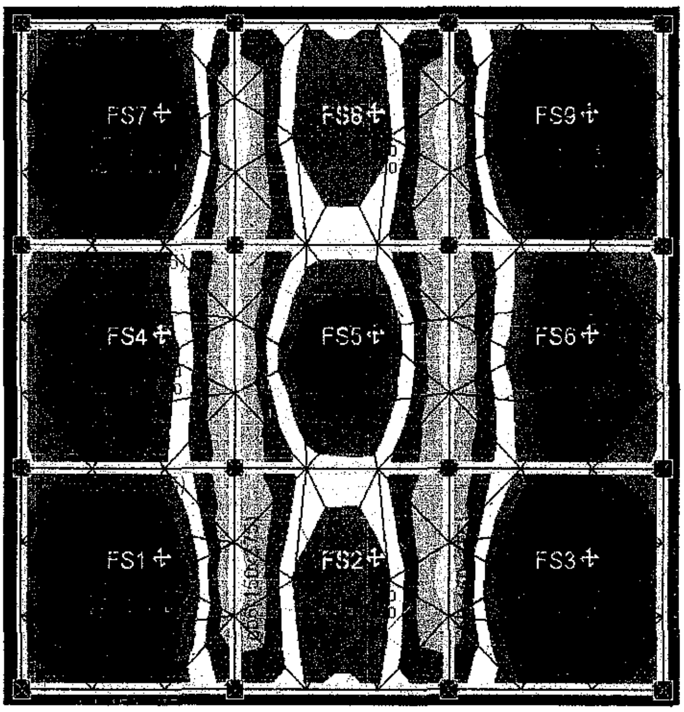


Figure 6

Effects on moment for X and Y direction contour on different load pattern.

Example using meshing size 1000mm.

(a) Load Pattern 1



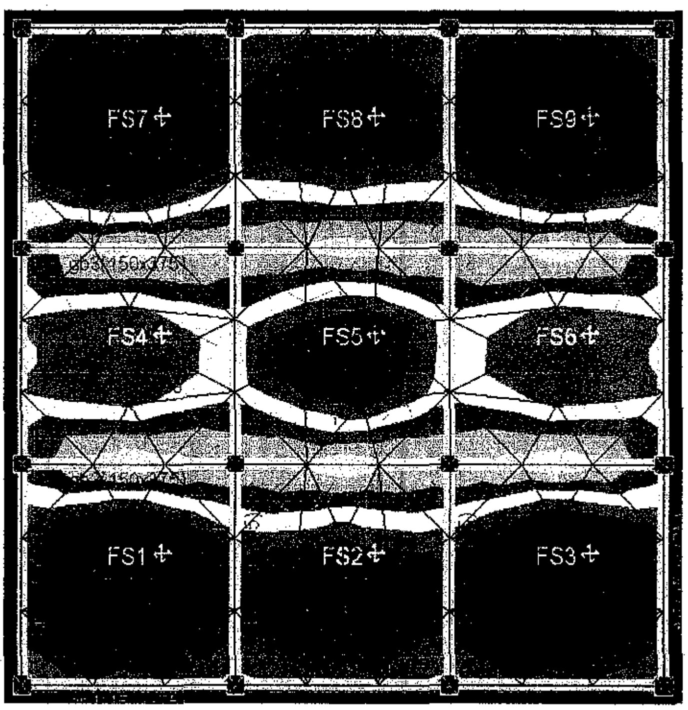
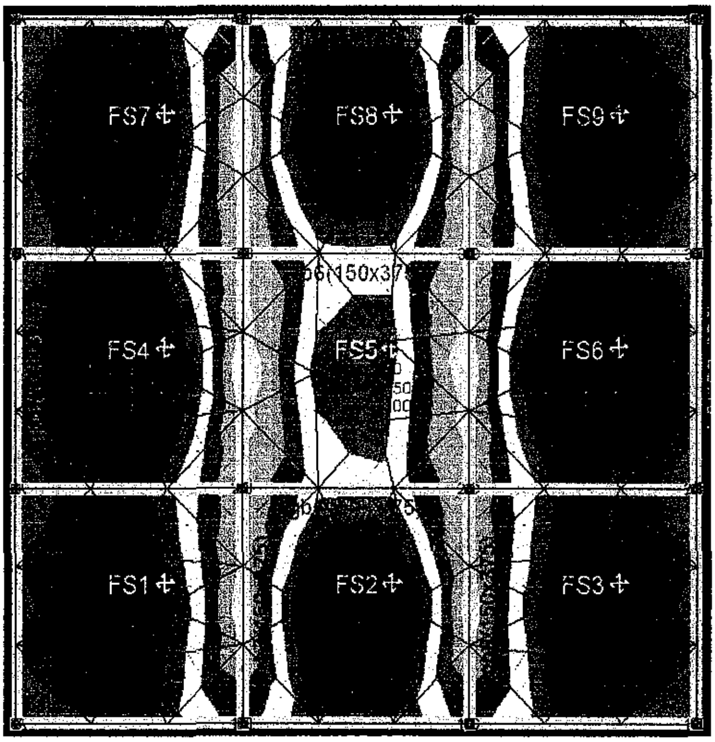


Figure 6

(b) Load Pattern 2



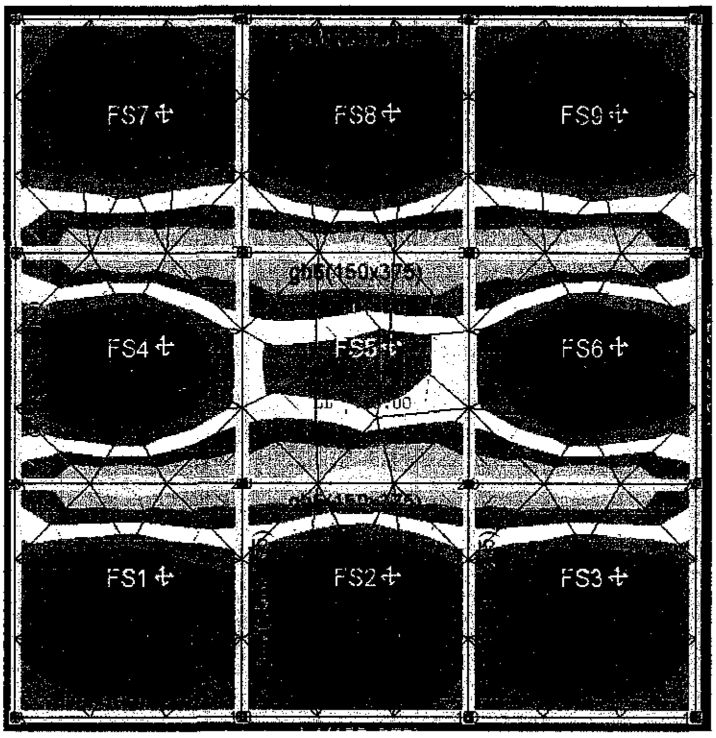
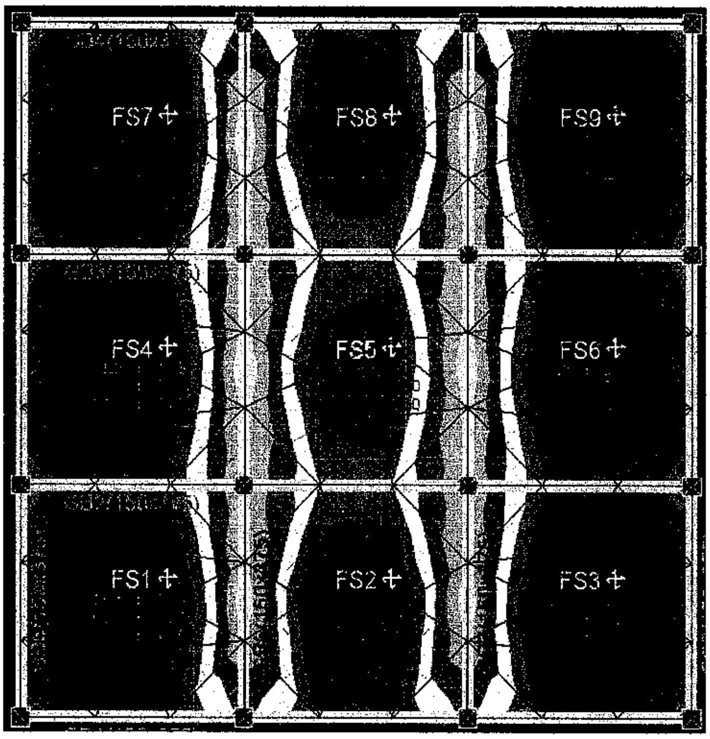


Figure 6

(c) Load Pattern 1



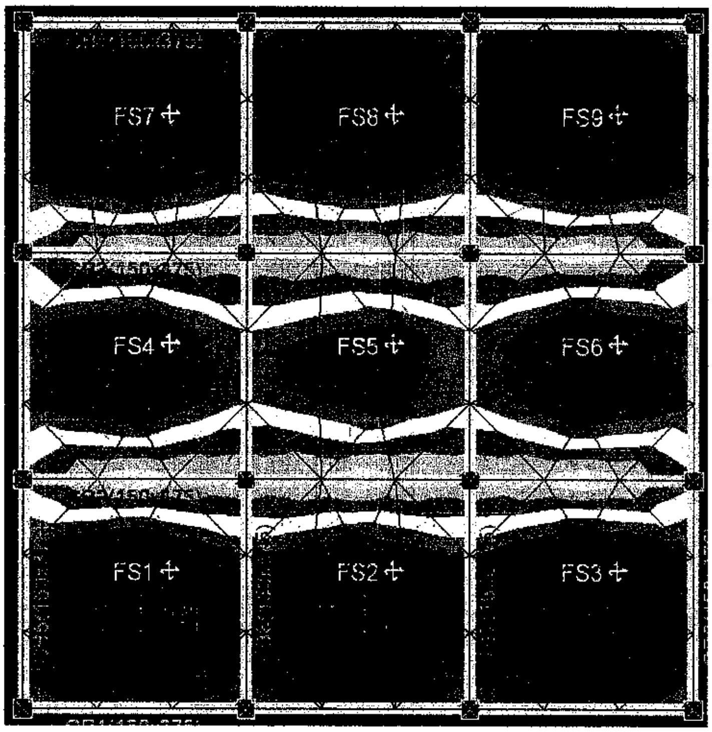


Figure 7

(a) Mixed-Mesh Pattern with 500mm meshing size

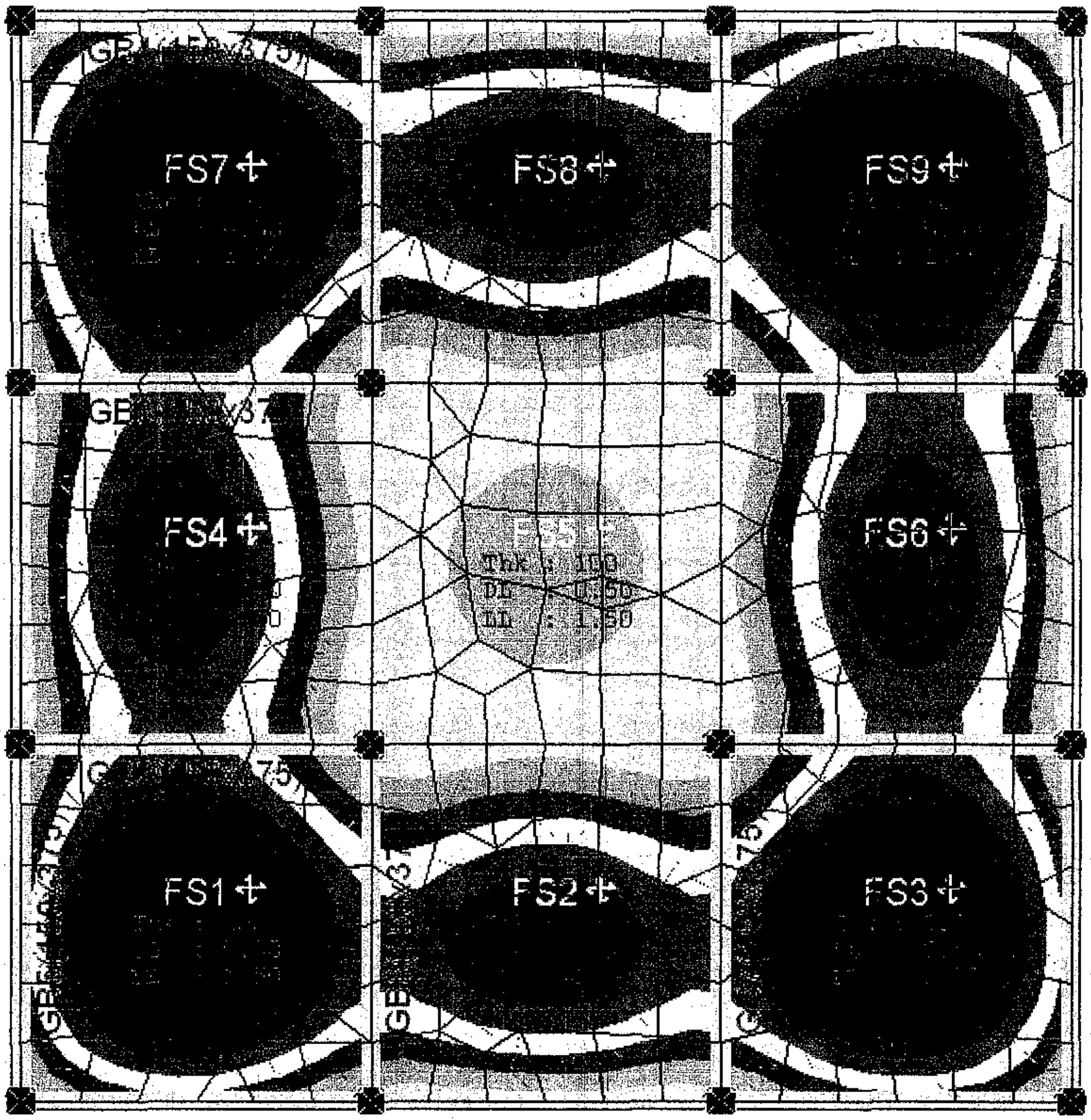


Figure 7

(b) Mixed-Mesh Pattern with 1000mm meshing size

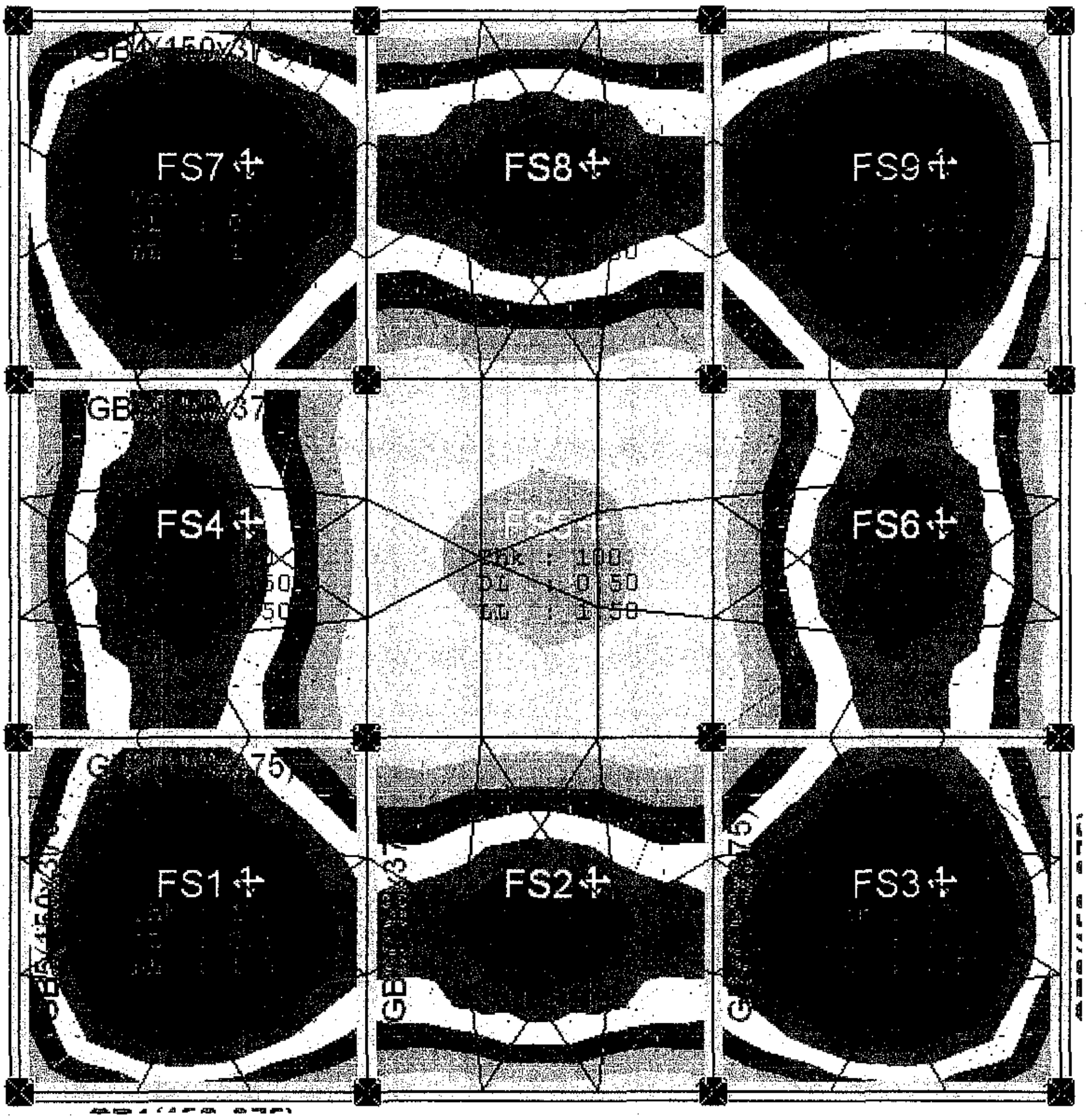


Figure 7

(c) Mixed-Mesh Pattern with 1500mm meshing size

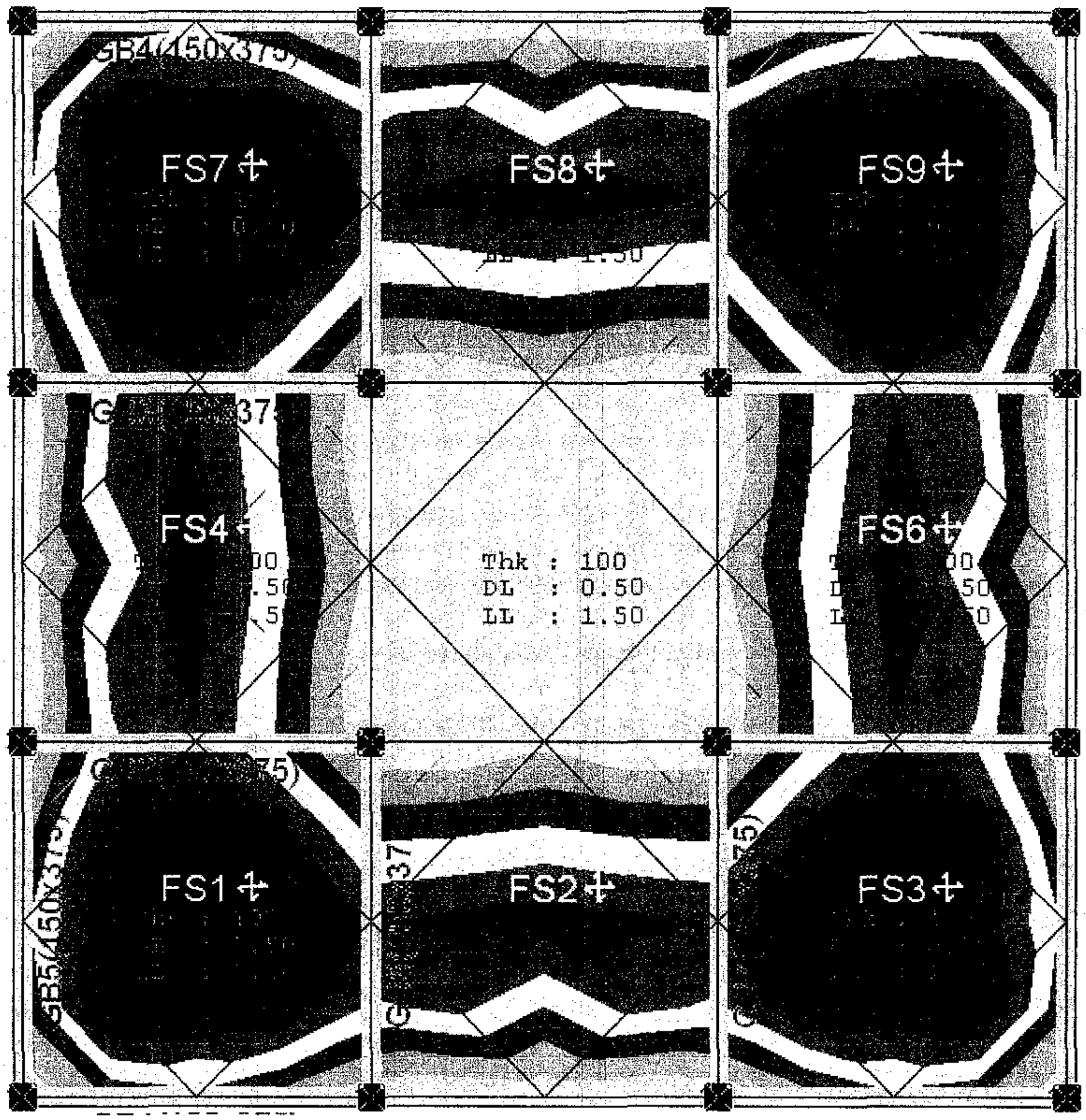


Figure 7

(d) Quadrilateral Mesh Pattern with 500mm meshing size

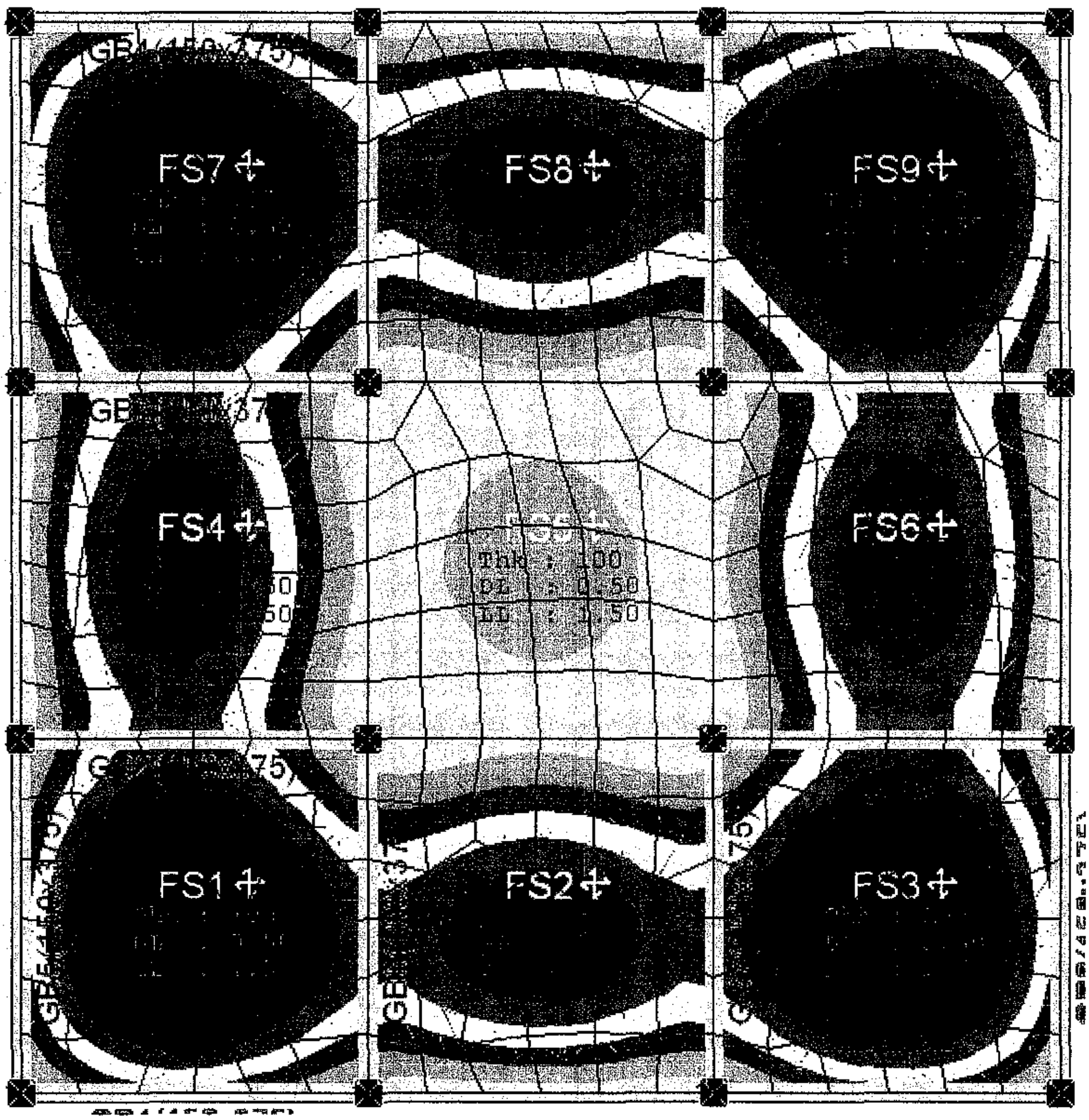


Figure 7

(e) Quadrilateral Mesh Pattern with 1000mm meshing size

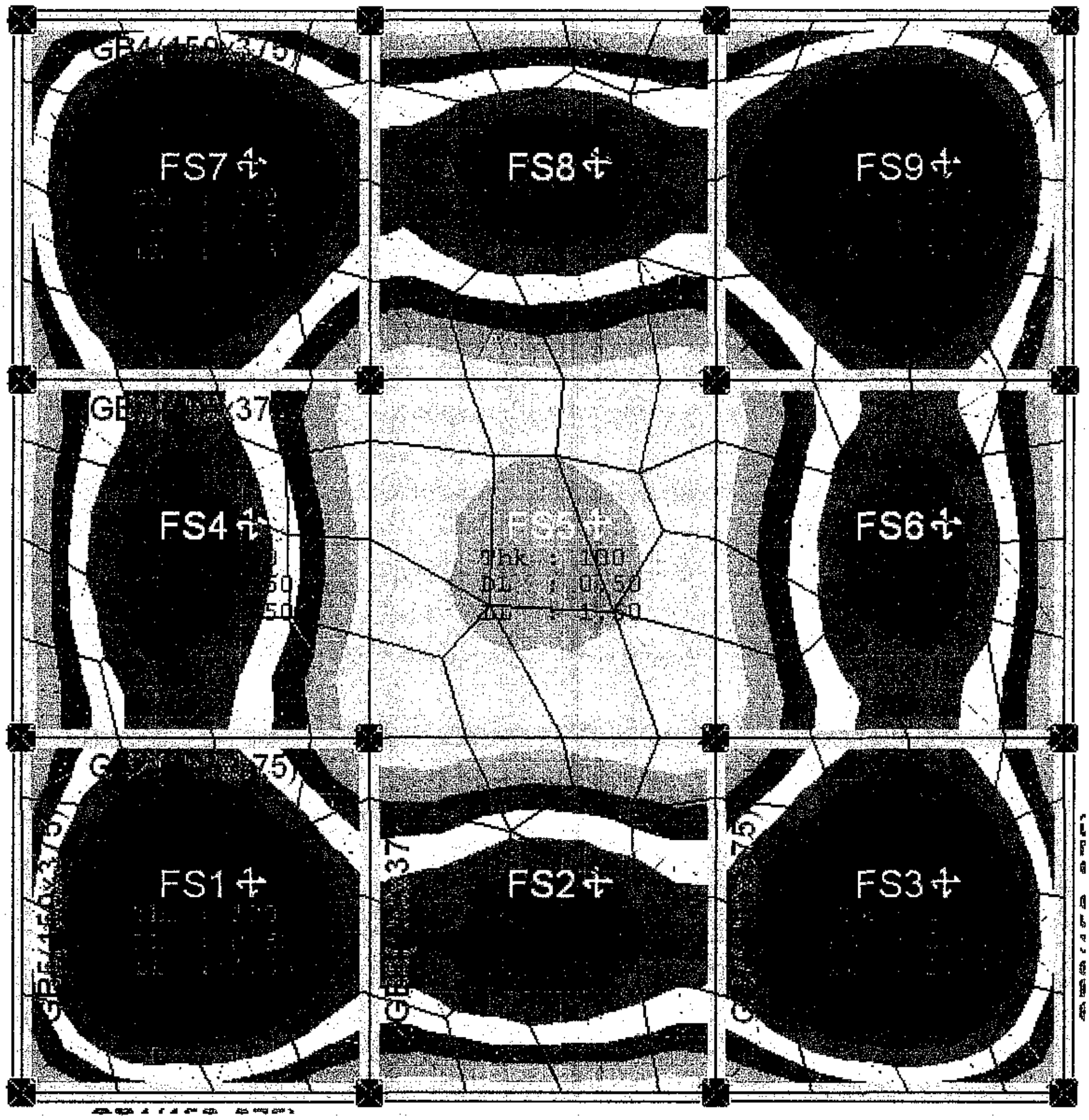


Figure 7

(f) Quadrilateral Mesh Pattern with 1500mm meshing size

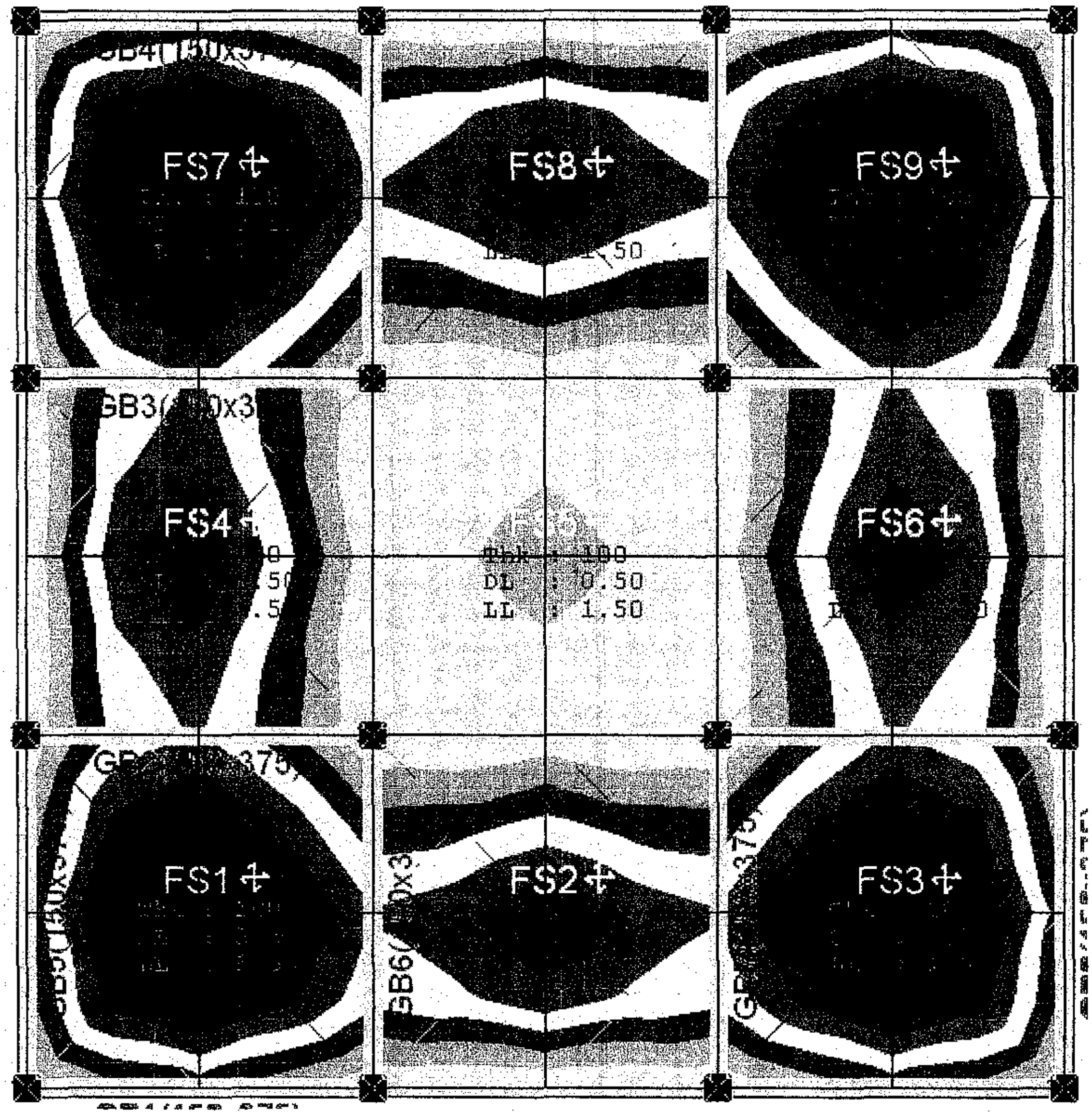


Figure 8

***(a)** Slab 10m x 10m with Regular Grid Distribution and*

Mesh Size = 500mm, Nodal Deflection

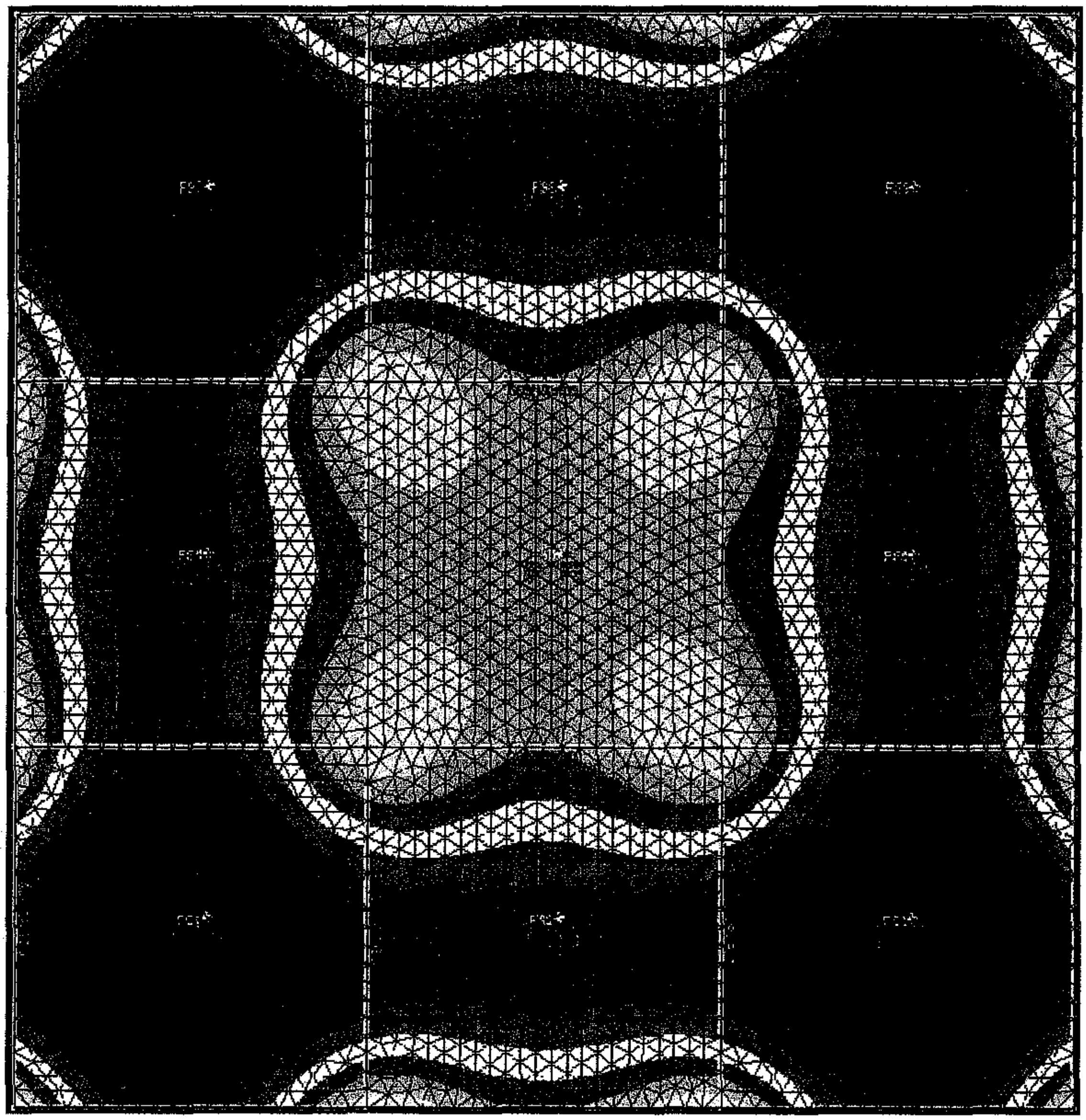


Figure 8

(b) Slab 10m x 10m with Regular Grid Distribution and

Mesh Size = 1000mm, Nodal Deflection

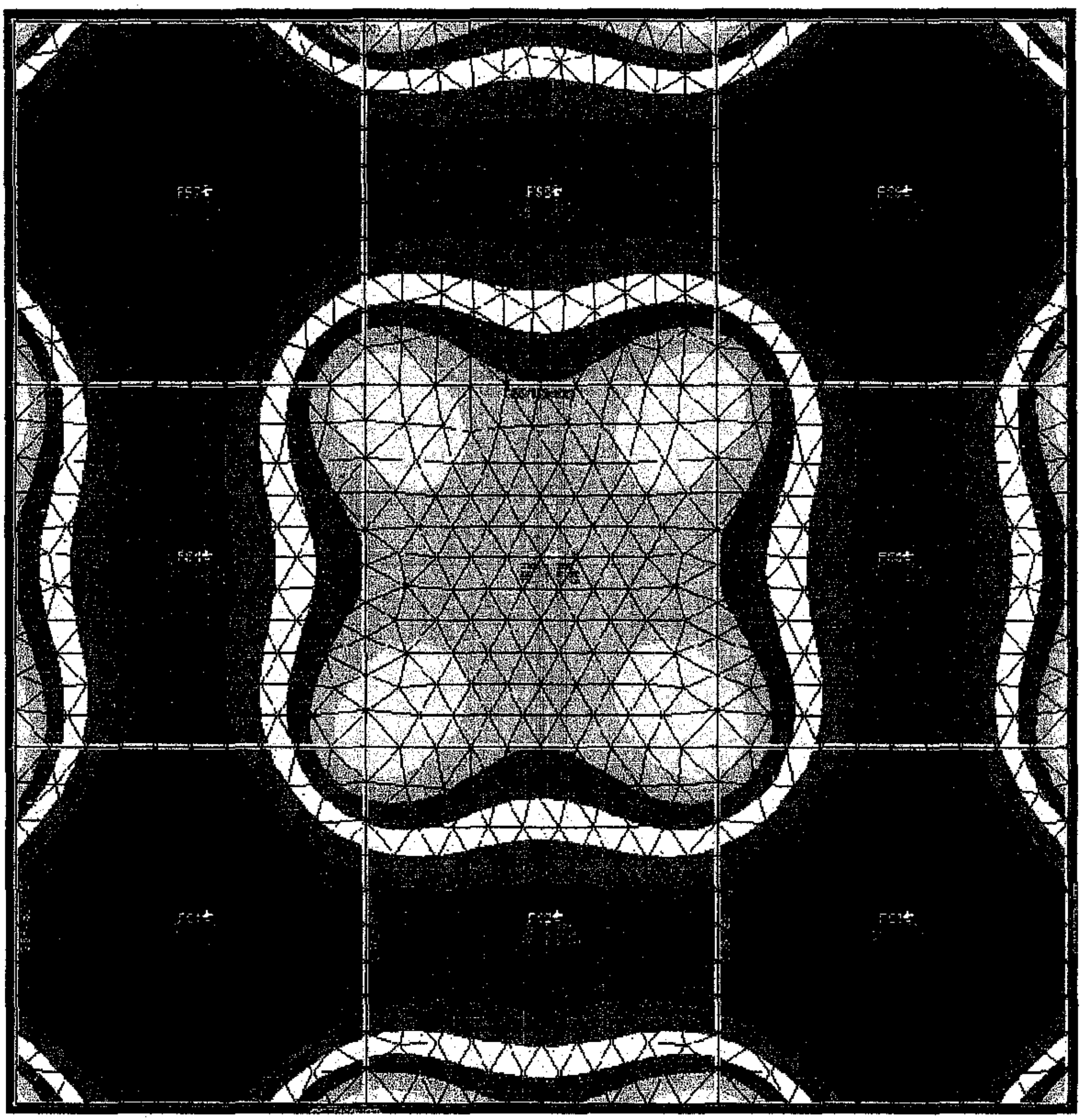


Figure 8

(c) Slab 10m x 10m with Regular Grid Distribution and

Mesh Size = 1500mm, Nodal Deflection

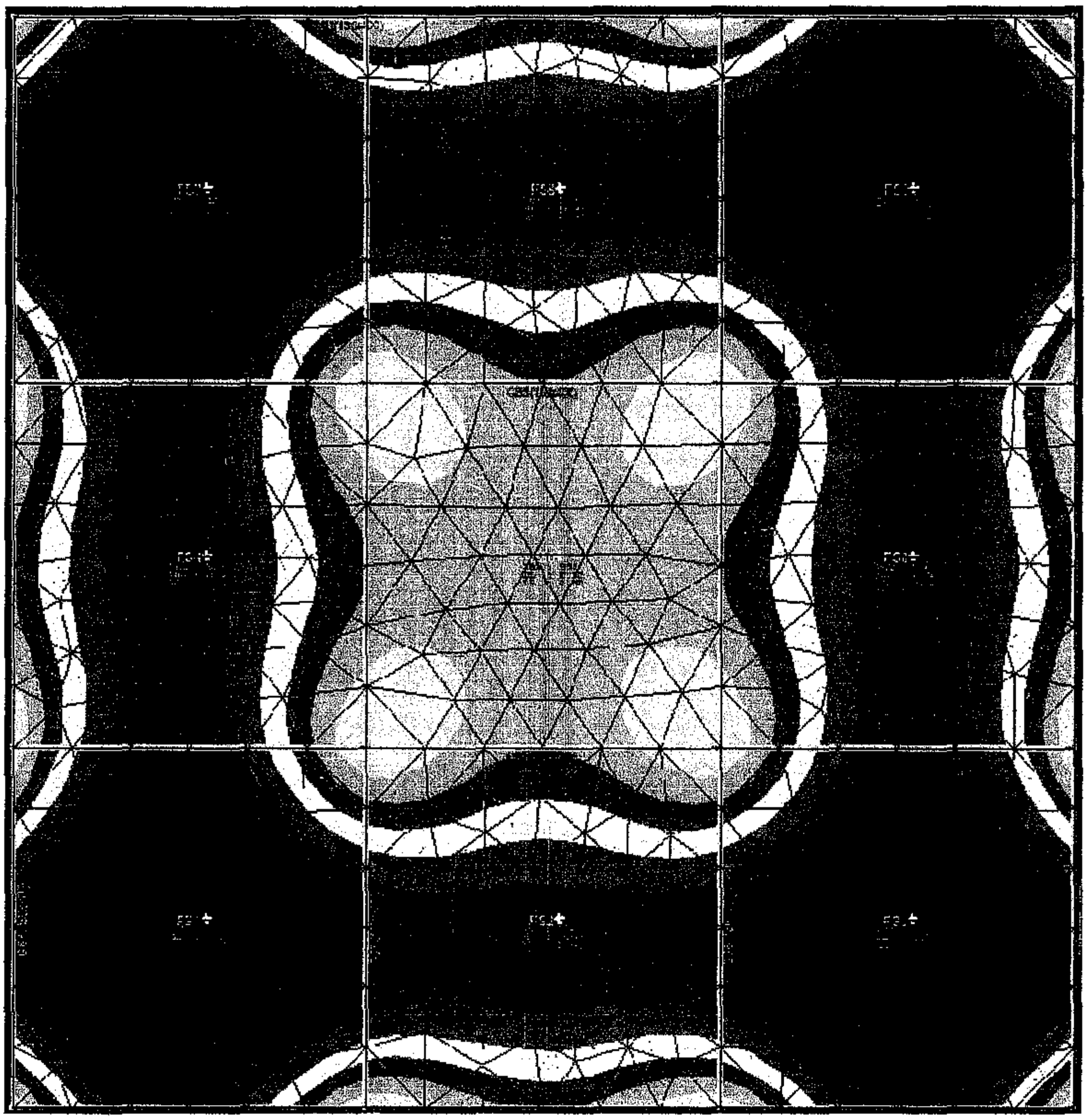


Figure 9

(a) Slab 10m x 10m with Regular Grid Distribution and

Mesh Size = 500mm, X-direction Moment Contour

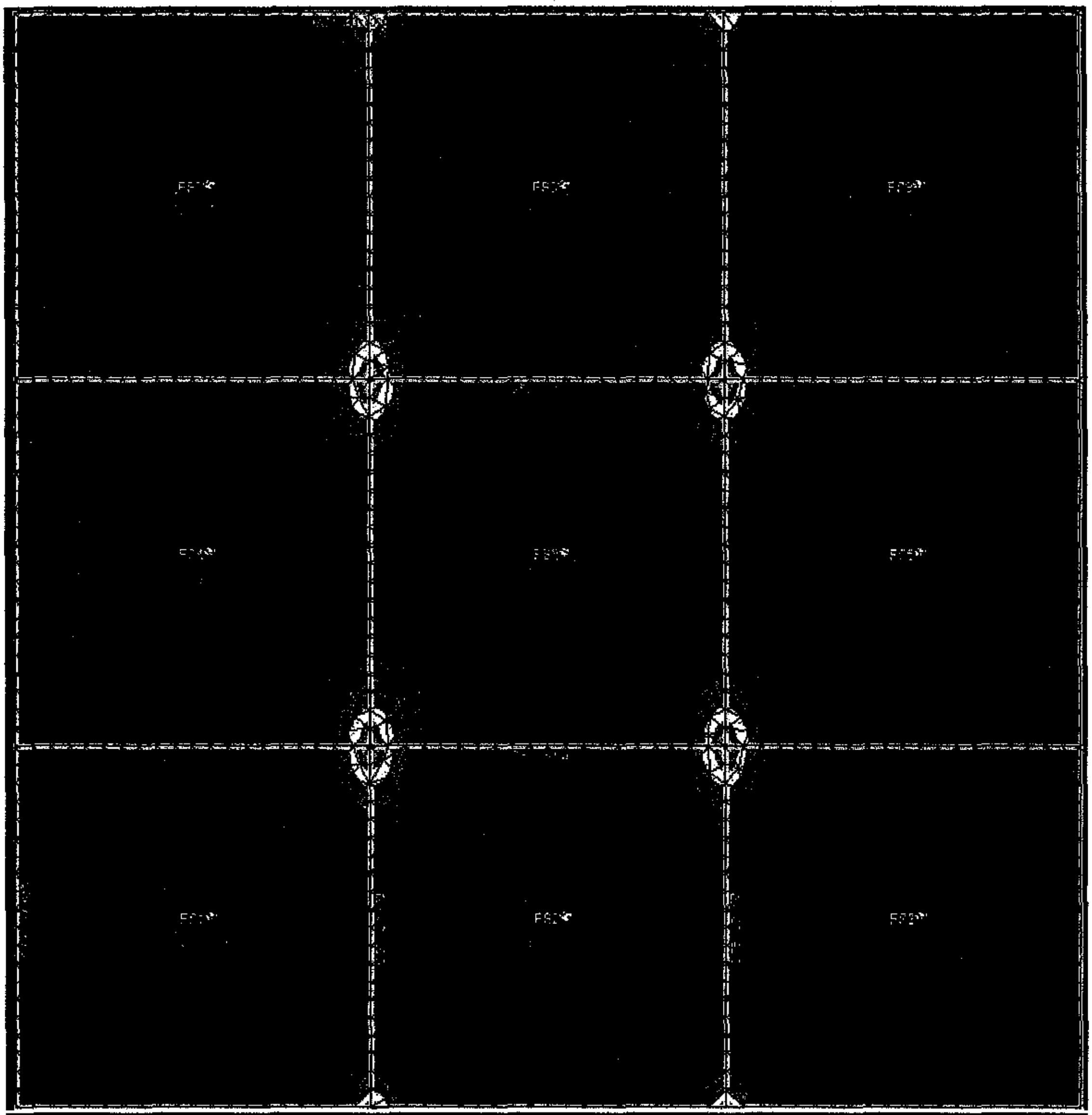


Figure 9

***(b)** Slab 10m x 10m with Regular Grid Distribution and*

Mesh Size = 1000mm, X-direction Moment Contour

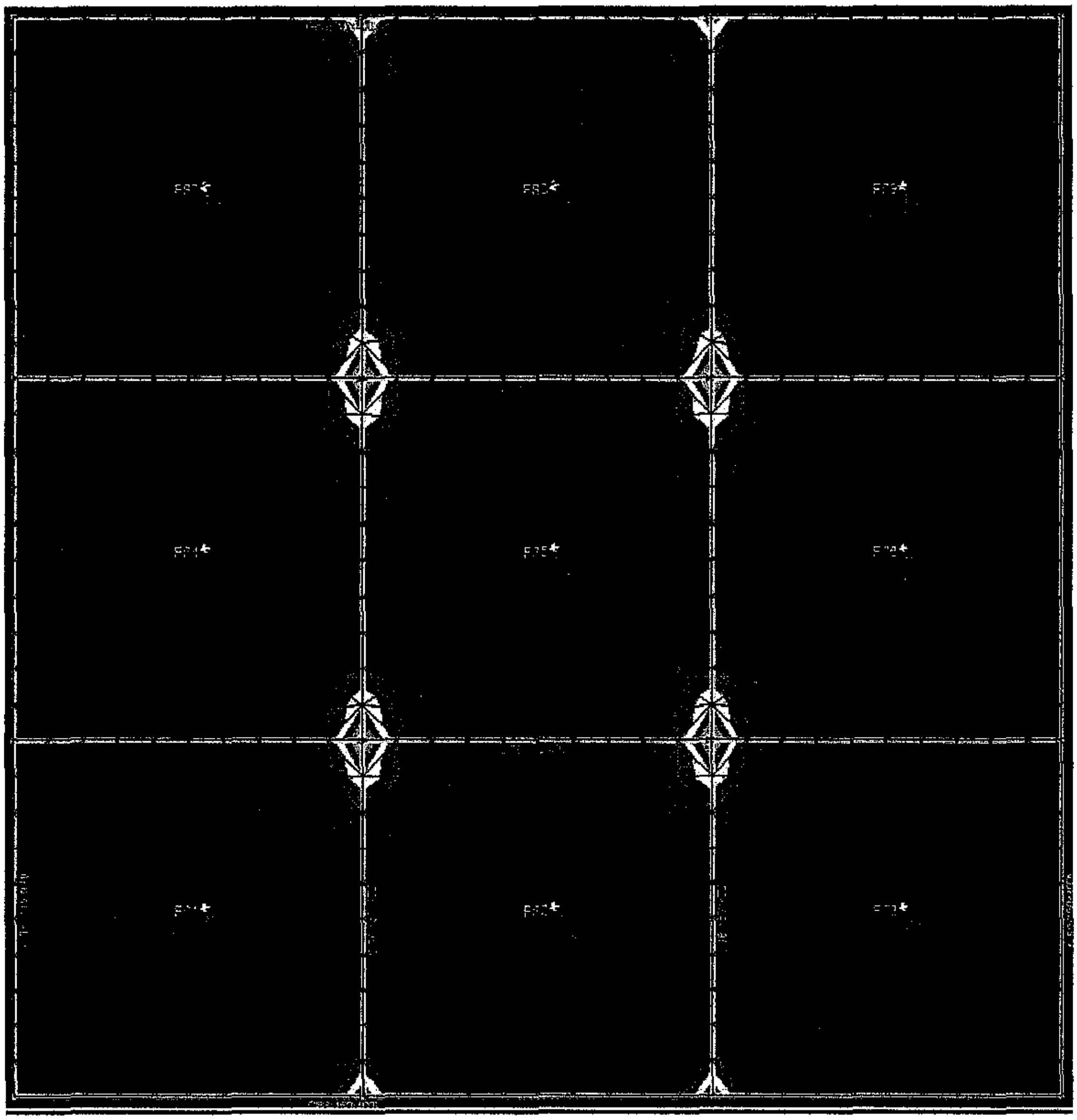


Figure 9

(c) Slab 10m x 10m with Regular Grid Distribution and

Mesh Size = 1500mm, X-direction Moment Contour

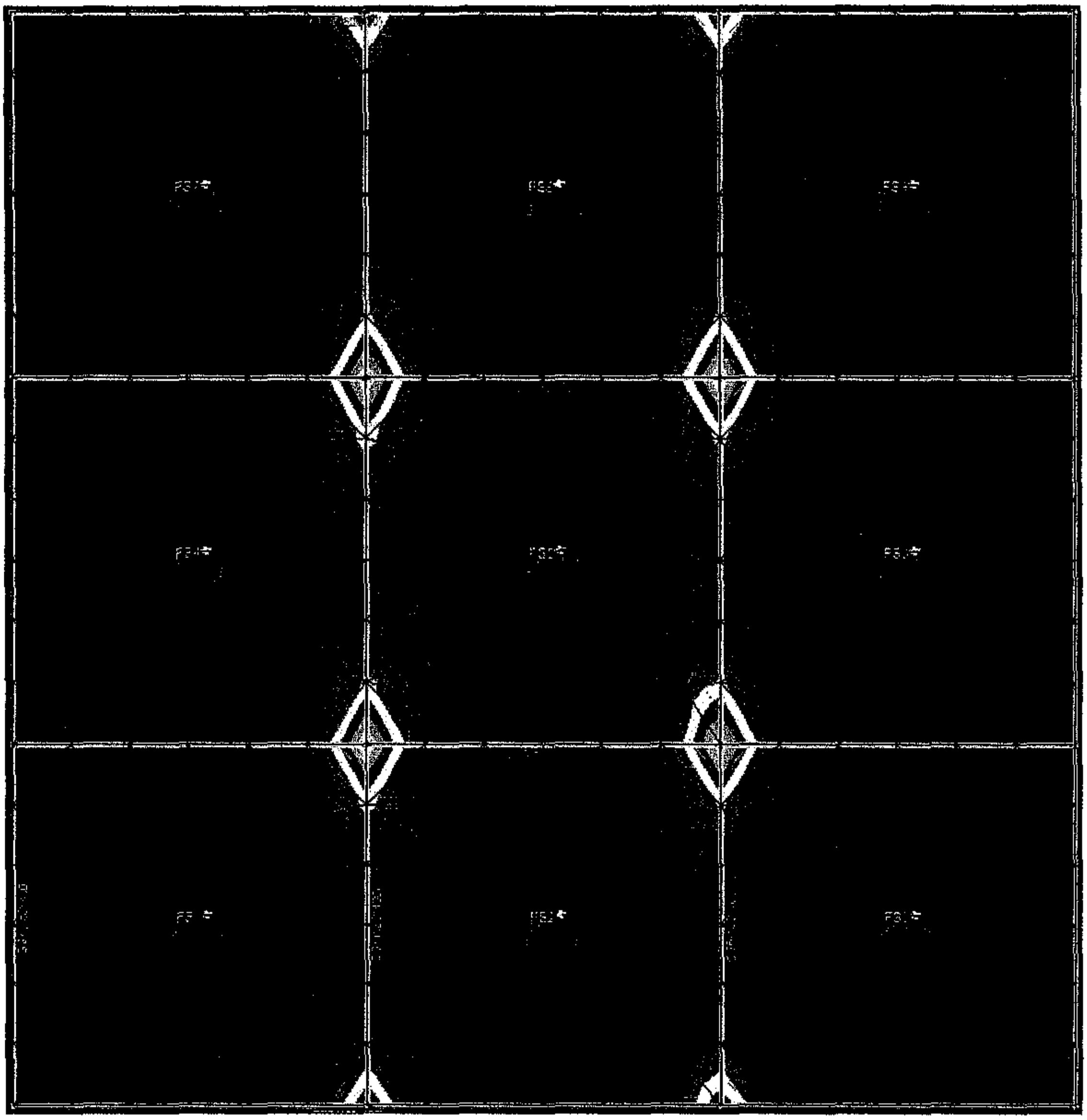


Figure 10

(a) *Slab 10m x 10m with Irregular Grid Distribution and*

Mesh Size = 500mm, Y-direction Moment Contour

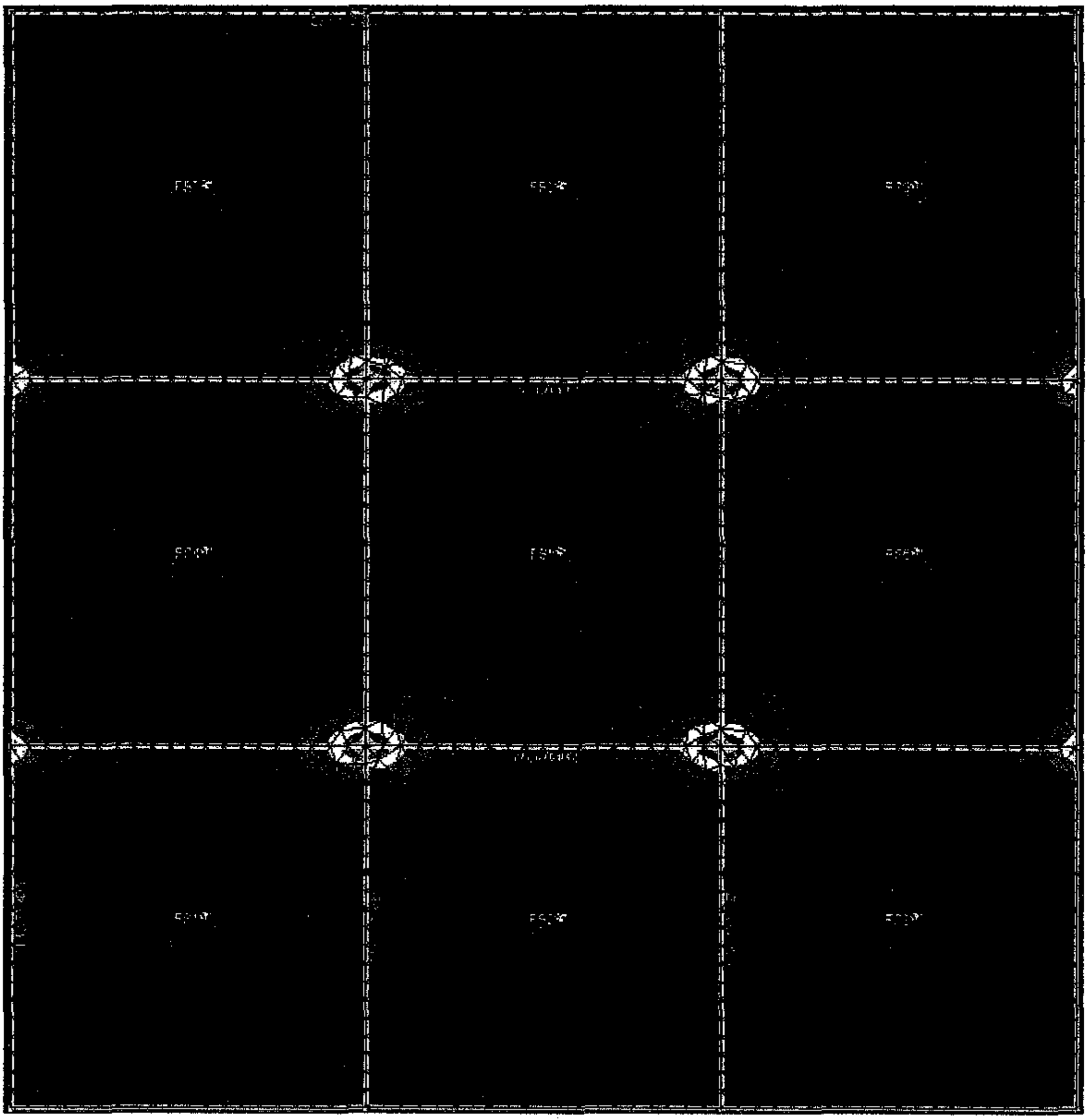


Figure 10

(b) Slab 10m x 10m with Irregular Grid Distribution and

Mesh Size = 1000mm, Y-direction Moment Contour

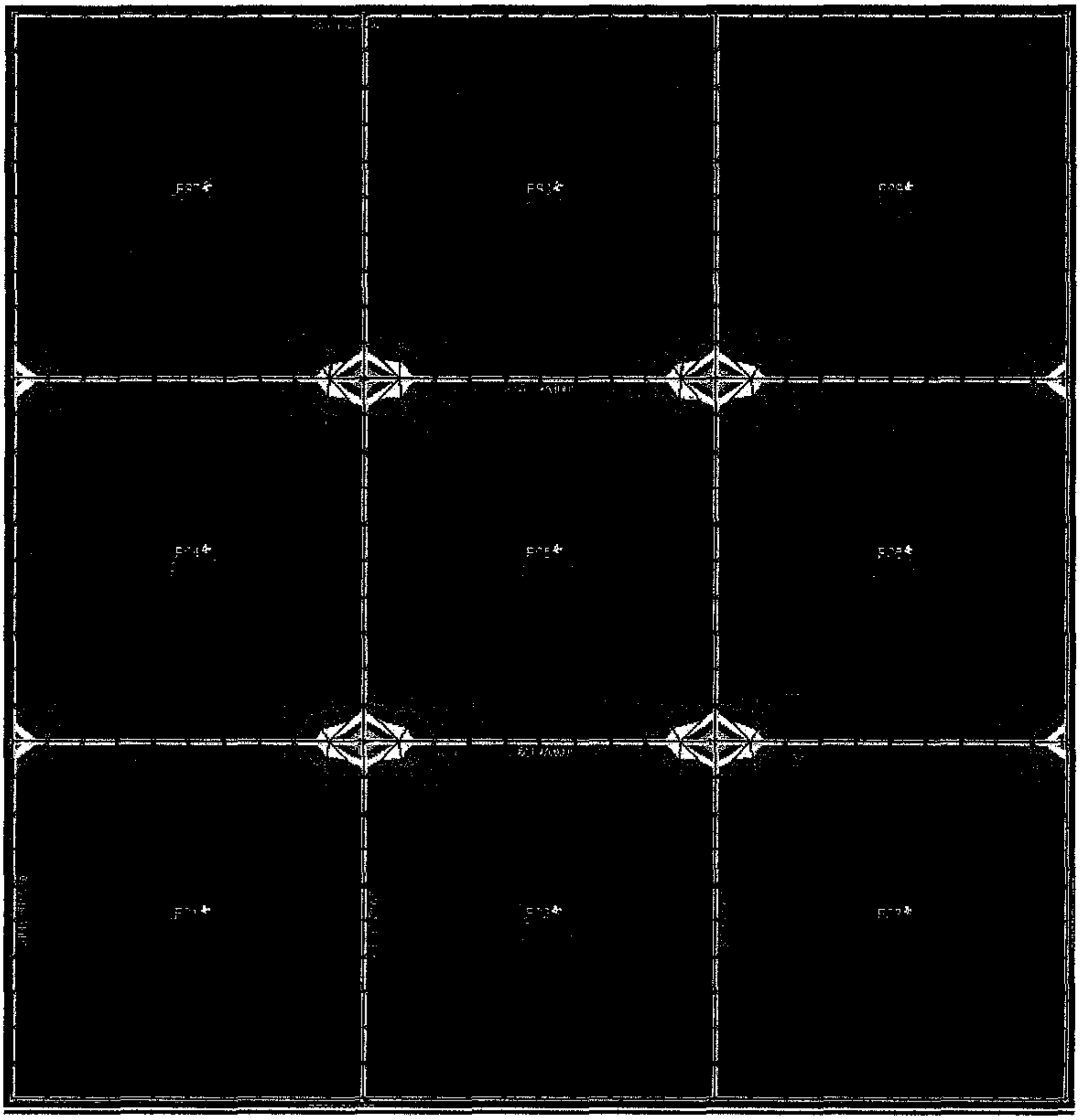


Figure 10

(c) Slab 10m x 10m with Irregular Grid Distribution and

Mesh Size = 1500mm, Y-direction Moment Contour

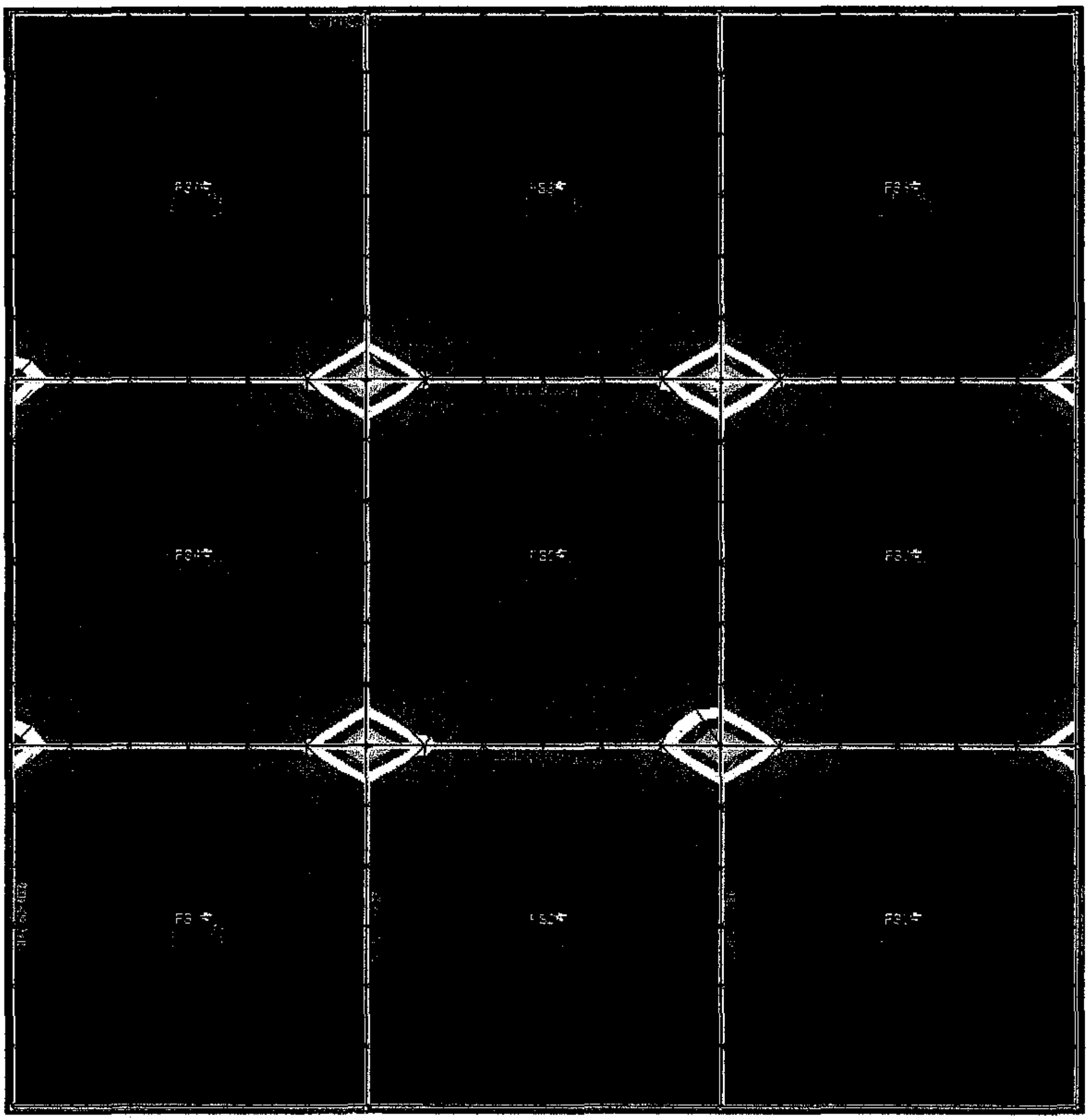


Figure 11

(a) Slab 10m x 10m with Irregular Grid Distribution and

Mesh Size = 500mm, Nodal Deflection

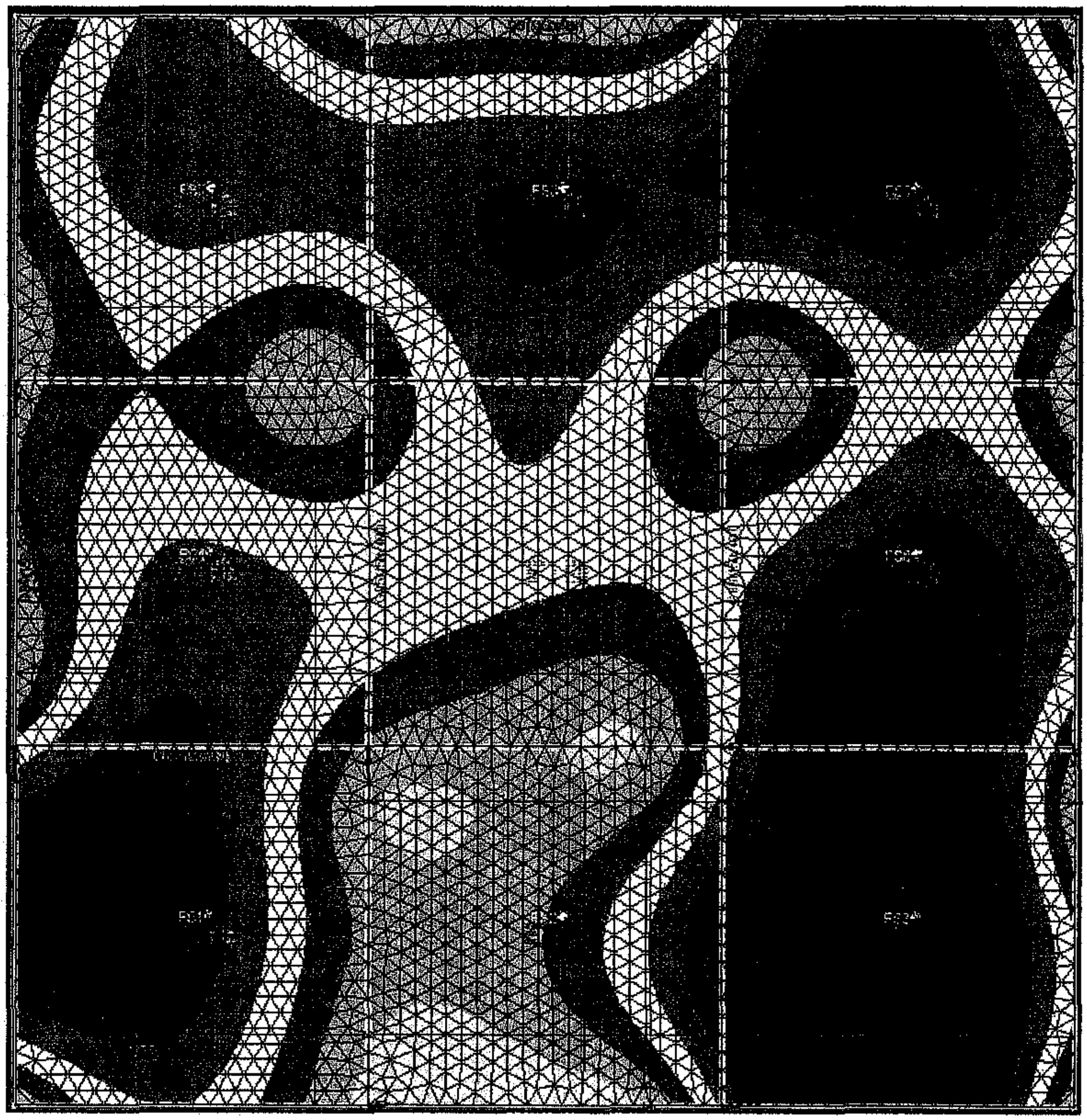


Figure 11

***(b)** Slab 10m x 10m with Irregular Grid Distribution and*

Mesh Size = 1000mm, Nodal Deflection

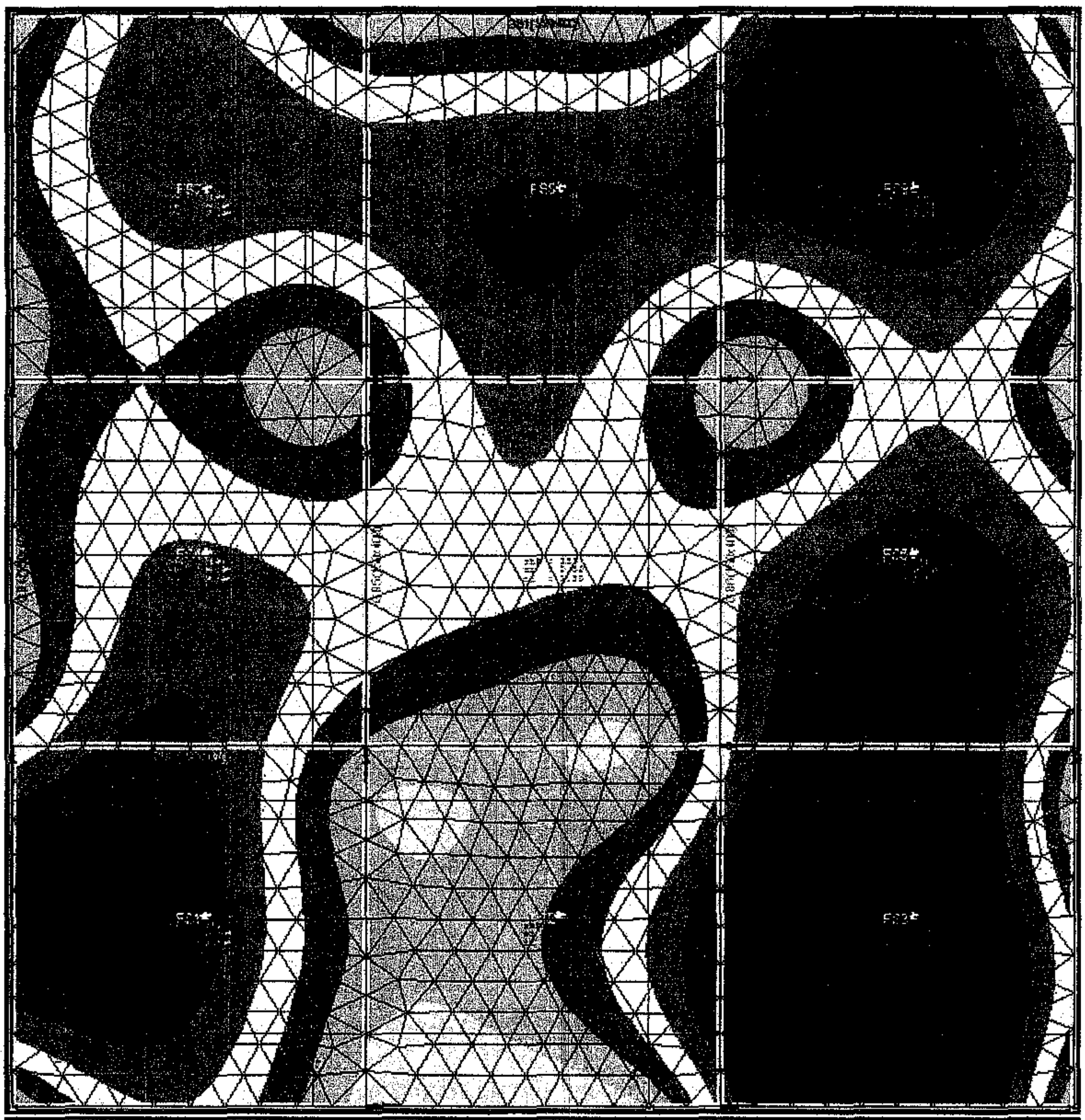


Figure 11

(c) Slab 10m x 10m with Irregular Grid Distribution and

Mesh Size = 1500mm, Nodal Deflection

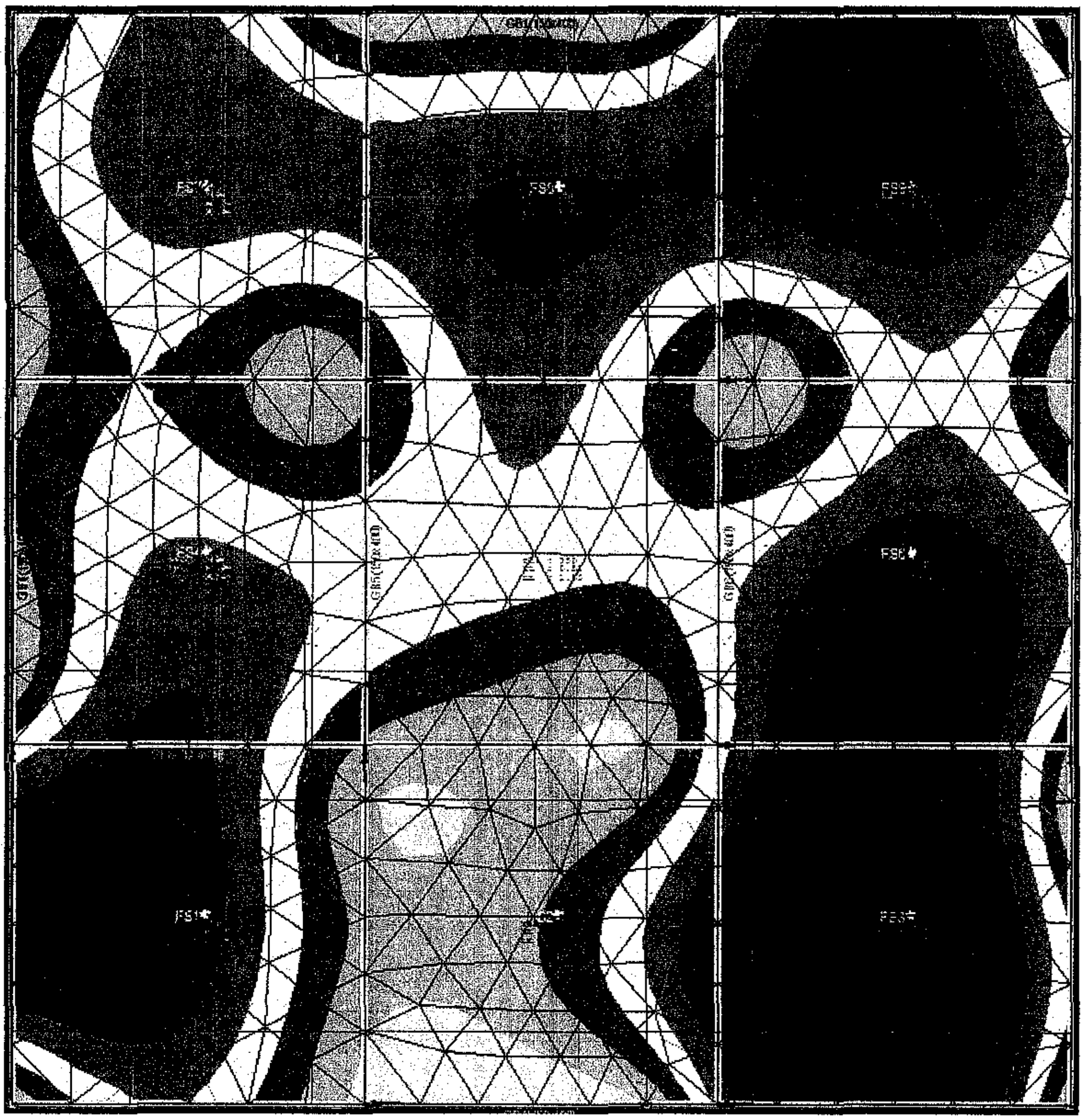


Figure 12

(a) Slab 10m x 10m with Irregular Grid Distribution and

Mesh Size = 500mm, X-direction Moment Contour

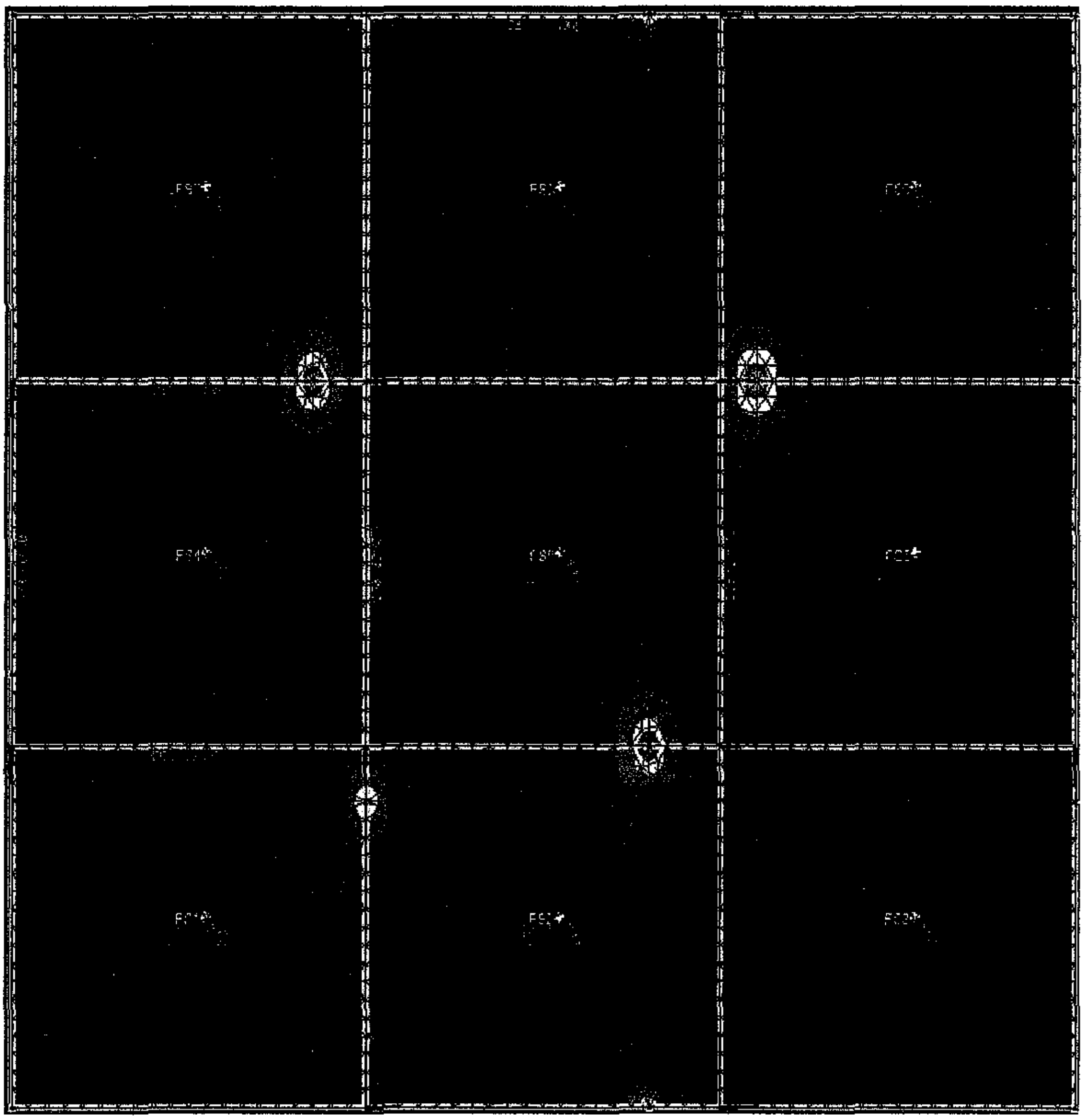


Figure 12

(b) Slab 10m x 10m with Irregular Grid Distribution and

Mesh Size = 1000mm, X-direction Moment Contour

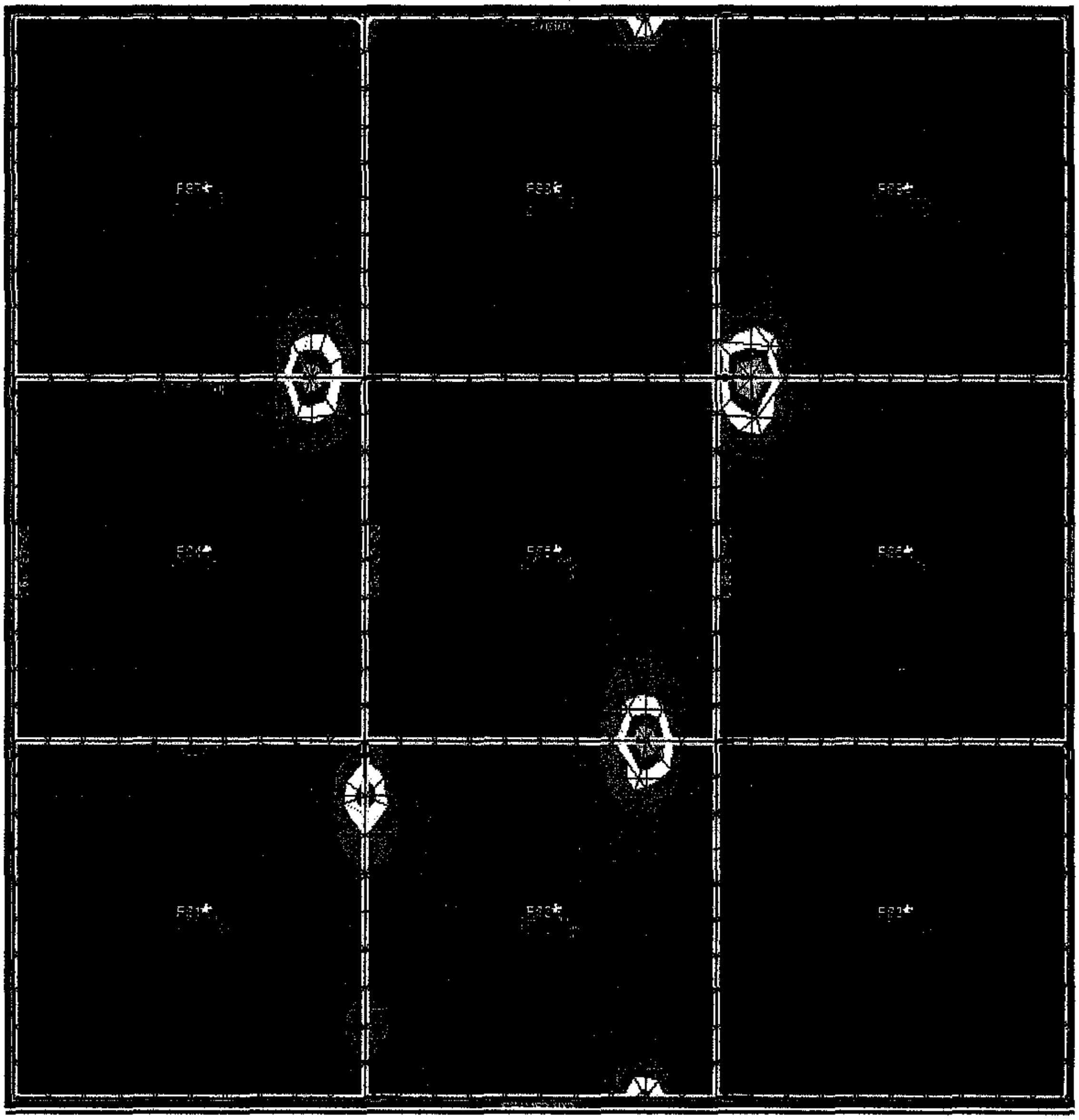


Figure 12

(c) Slab 10m x 10m with Irregular Grid Distribution and

Mesh Size = 1500mm, X-direction Moment Contour

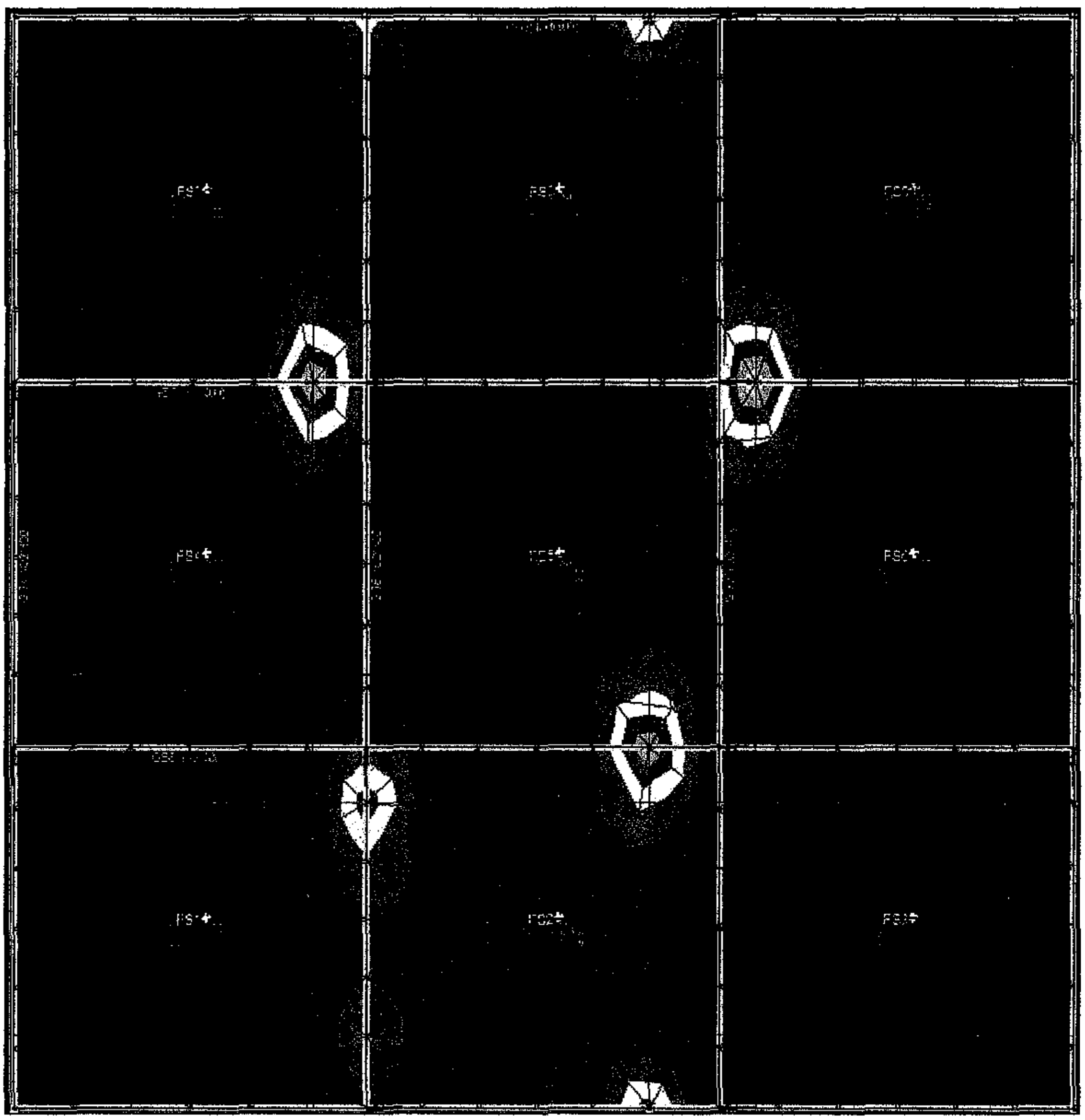


Figure 13

(a) *Slab 10m x 10m with Irregular Grid Distribution and*

Mesh Size = 500mm, Y-direction Moment Contour

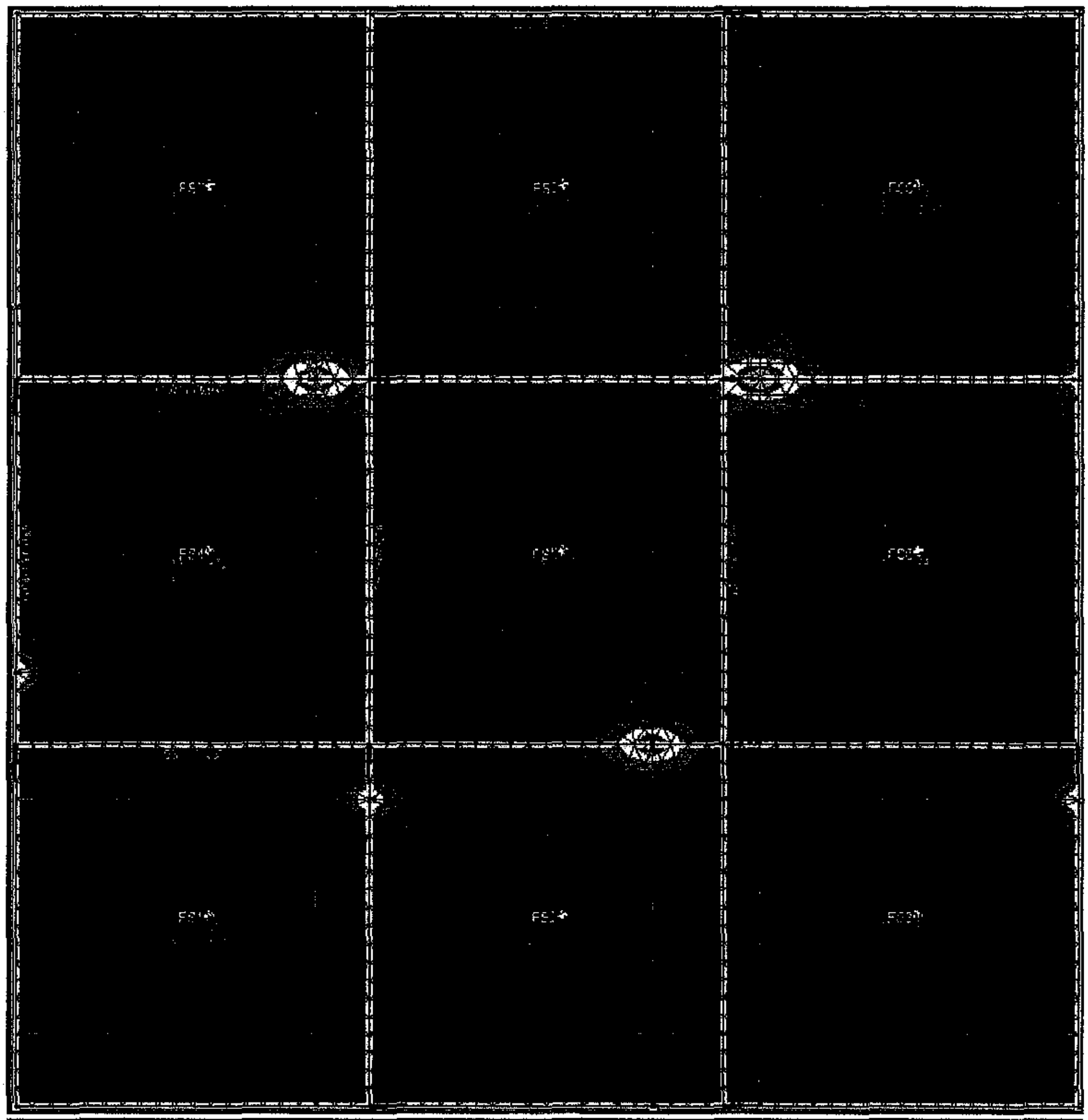


Figure 13

***(b)** Slab 10m x 10m with Irregular Grid Distribution and*

Mesh Size = 1000mm, Y-direction Moment Contour

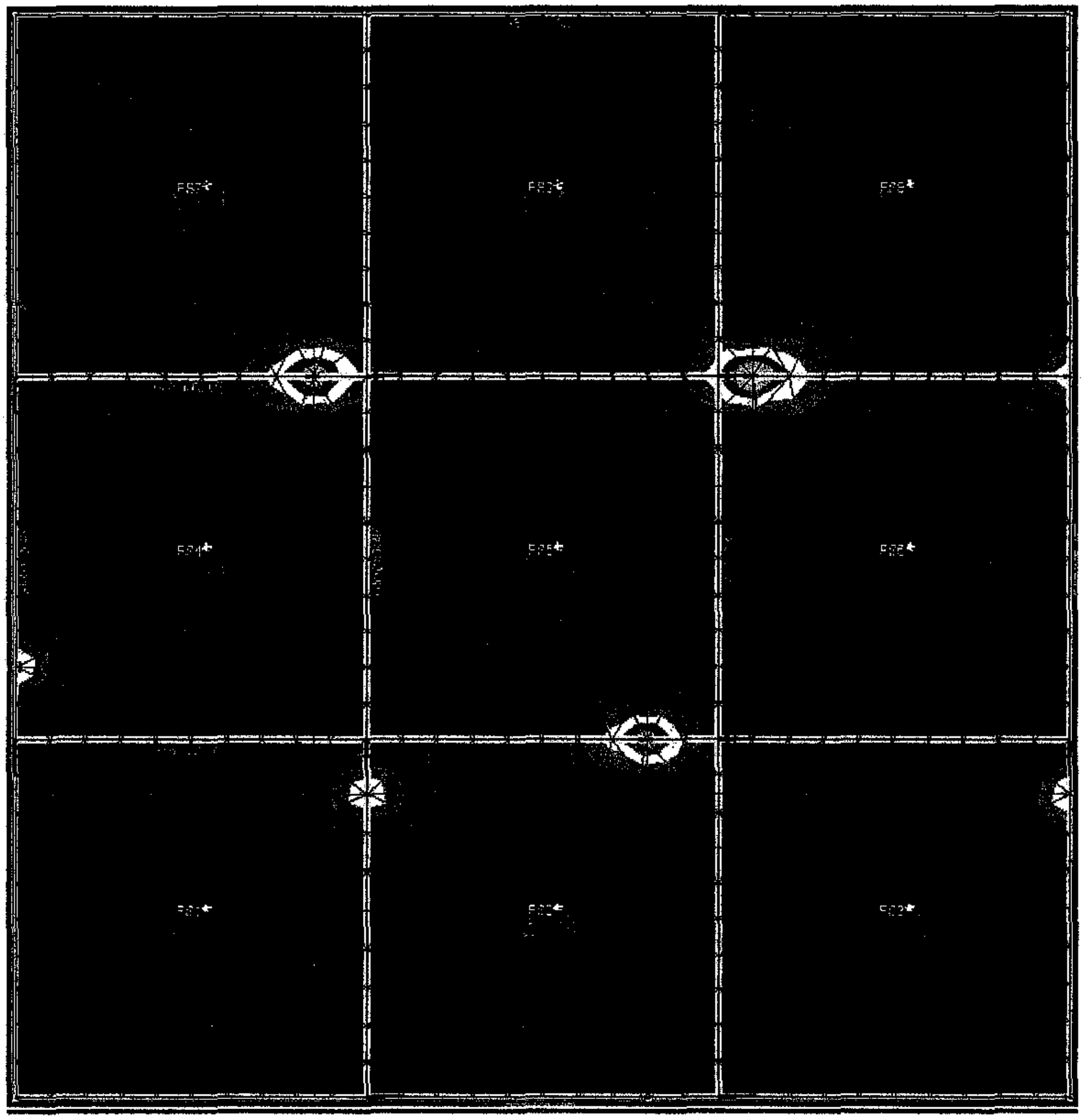


Figure 13

(c) Slab 10m x 10m with Irregular Grid Distribution and

Mesh Size = 1500mm, Y-direction Moment Contour

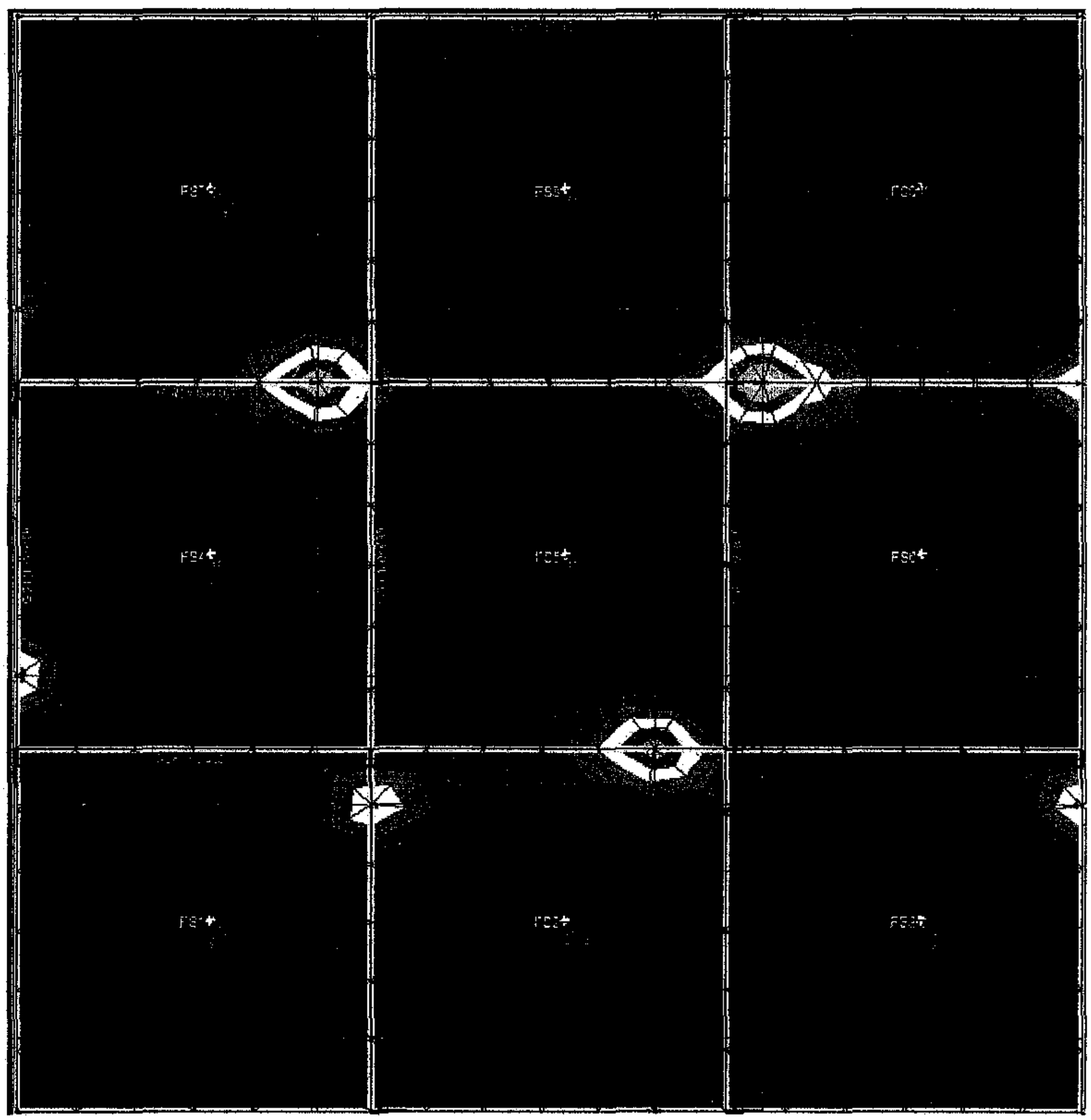


Figure 14

(a) Slab 3m x 3m with Irregular Grid Distribution and

Mesh Size = 500mm, Nodal Deflection

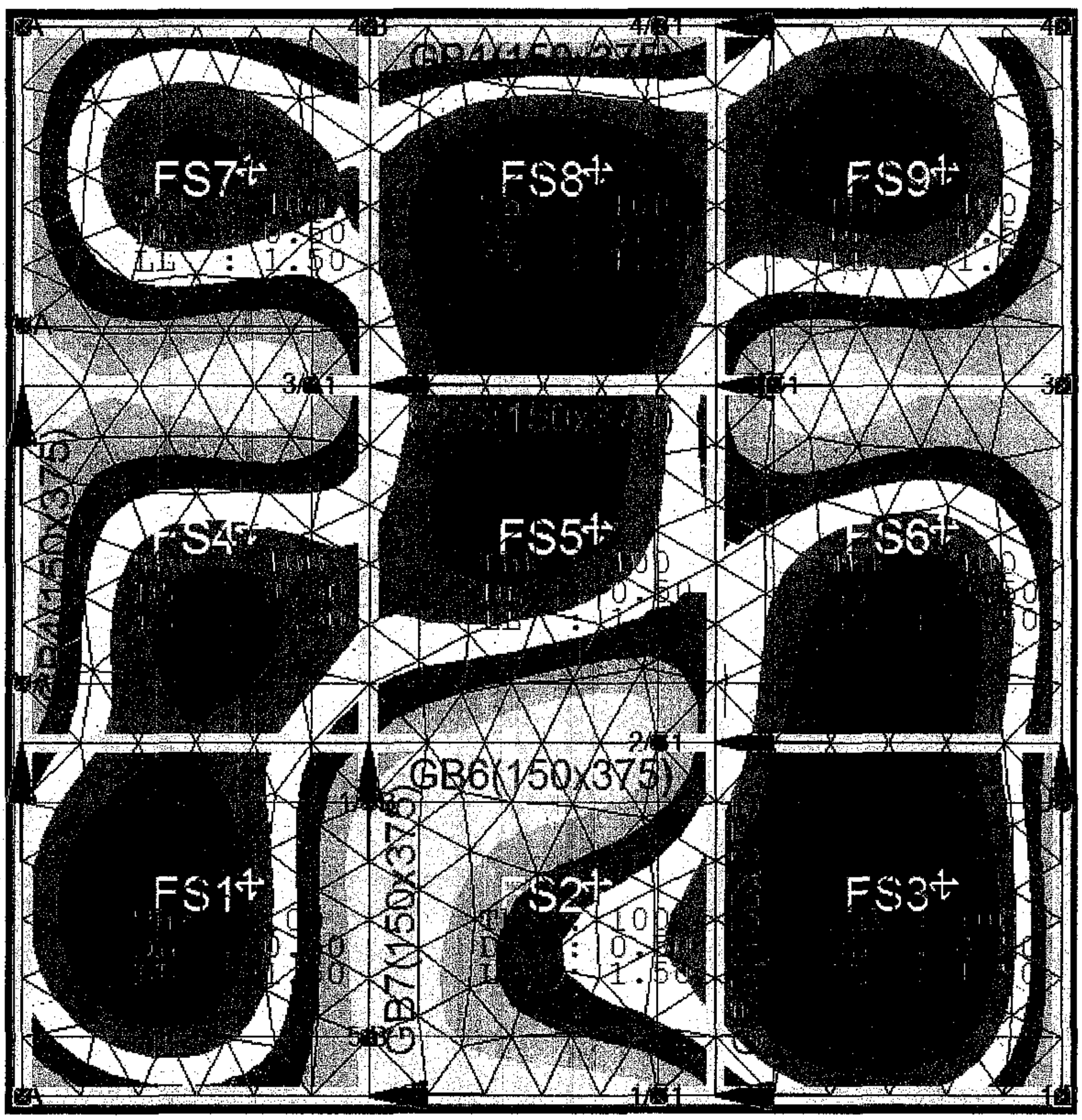


Figure 14

(b) Slab 3m x 3m with Irregular Grid Distribution and

Mesh Size = 1000mm, Nodal Deflection

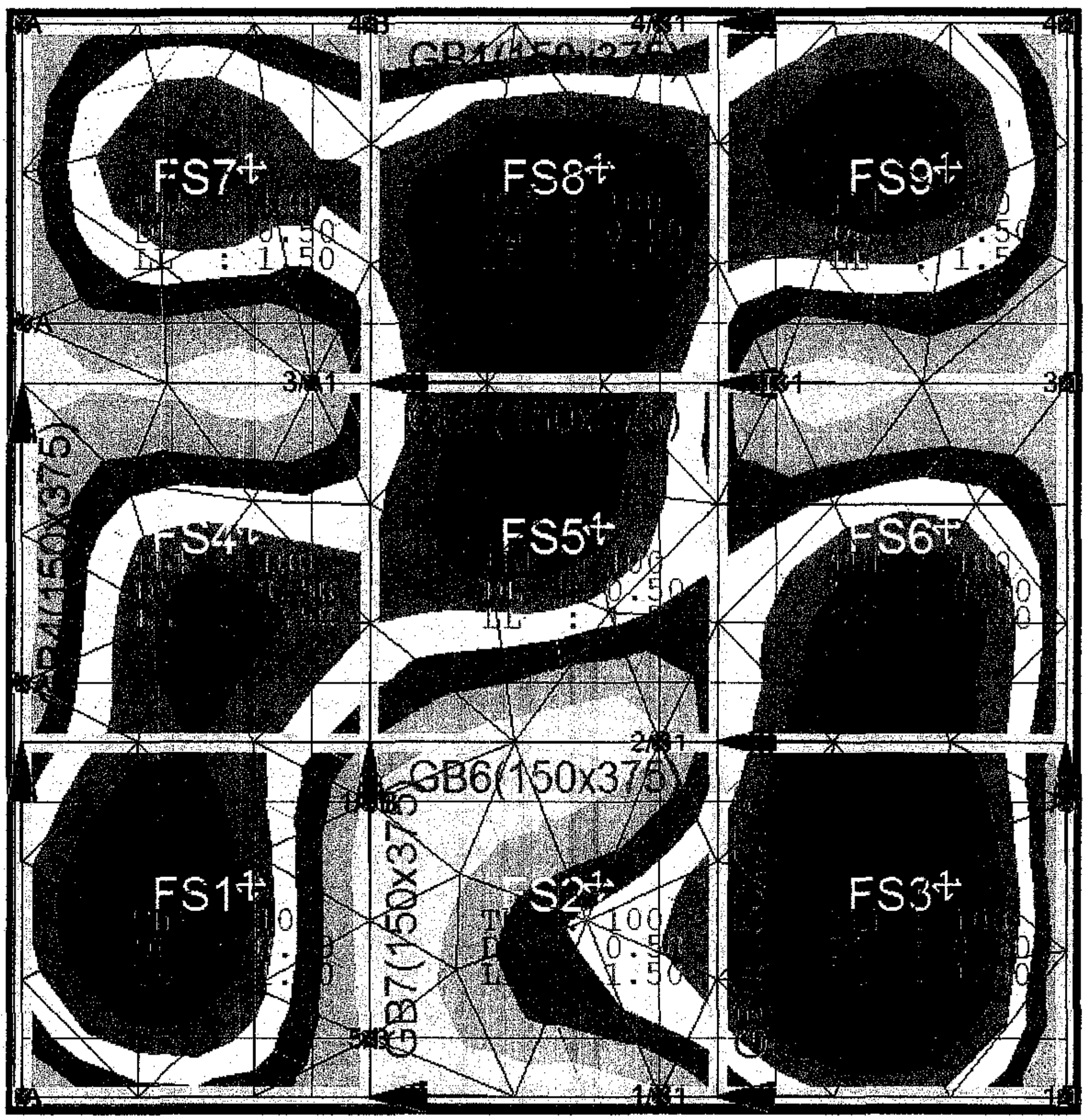


Figure 14

(c) Slab 3m x 3m with Irregular Grid Distribution

Mesh Size = 1500mm, Nodal Deflection

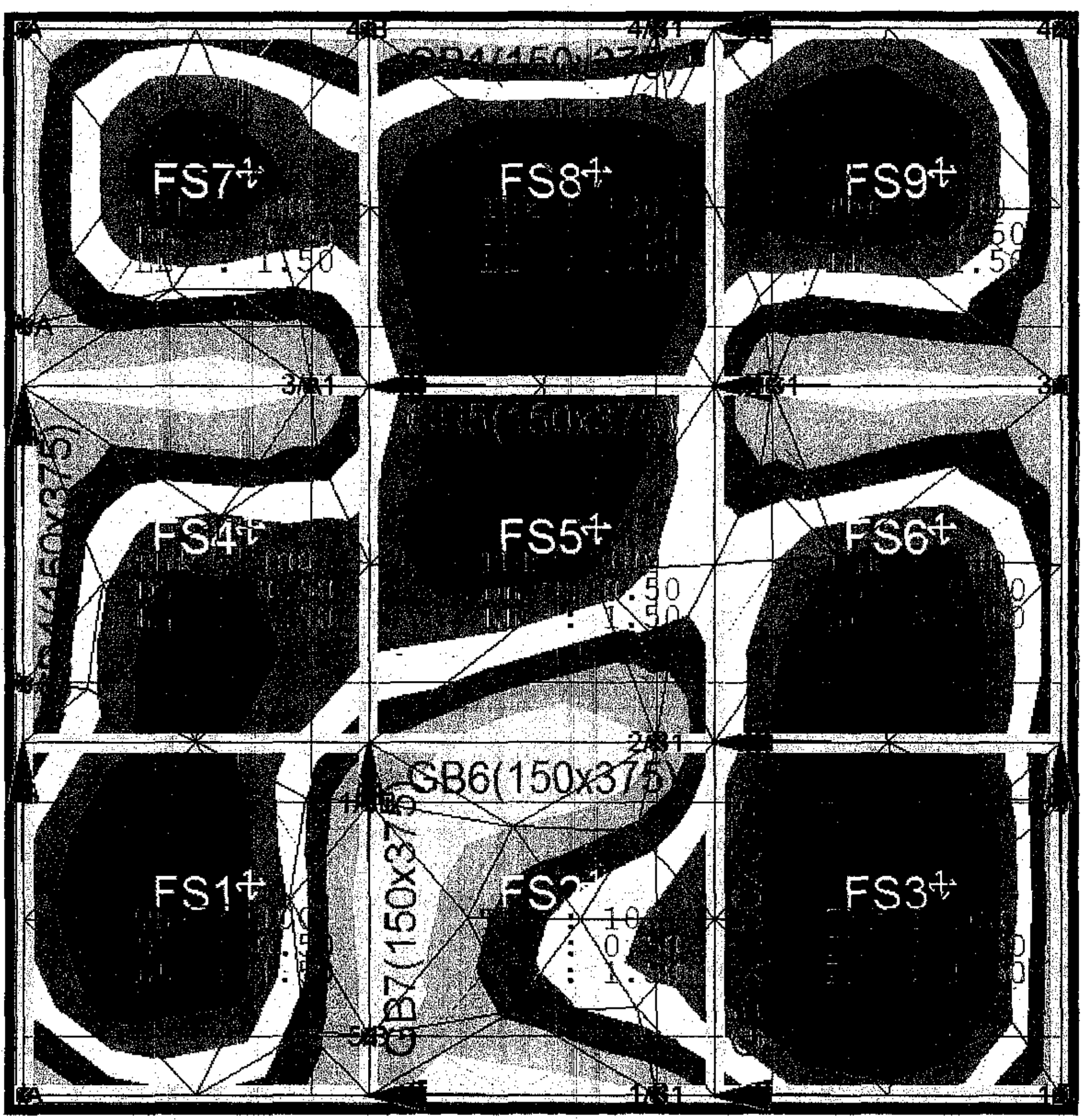


Figure 15

(a) Slab 3m x 3m with Irregular Grid Distribution

Mesh Size = 500mm, X-direction Moment Contour

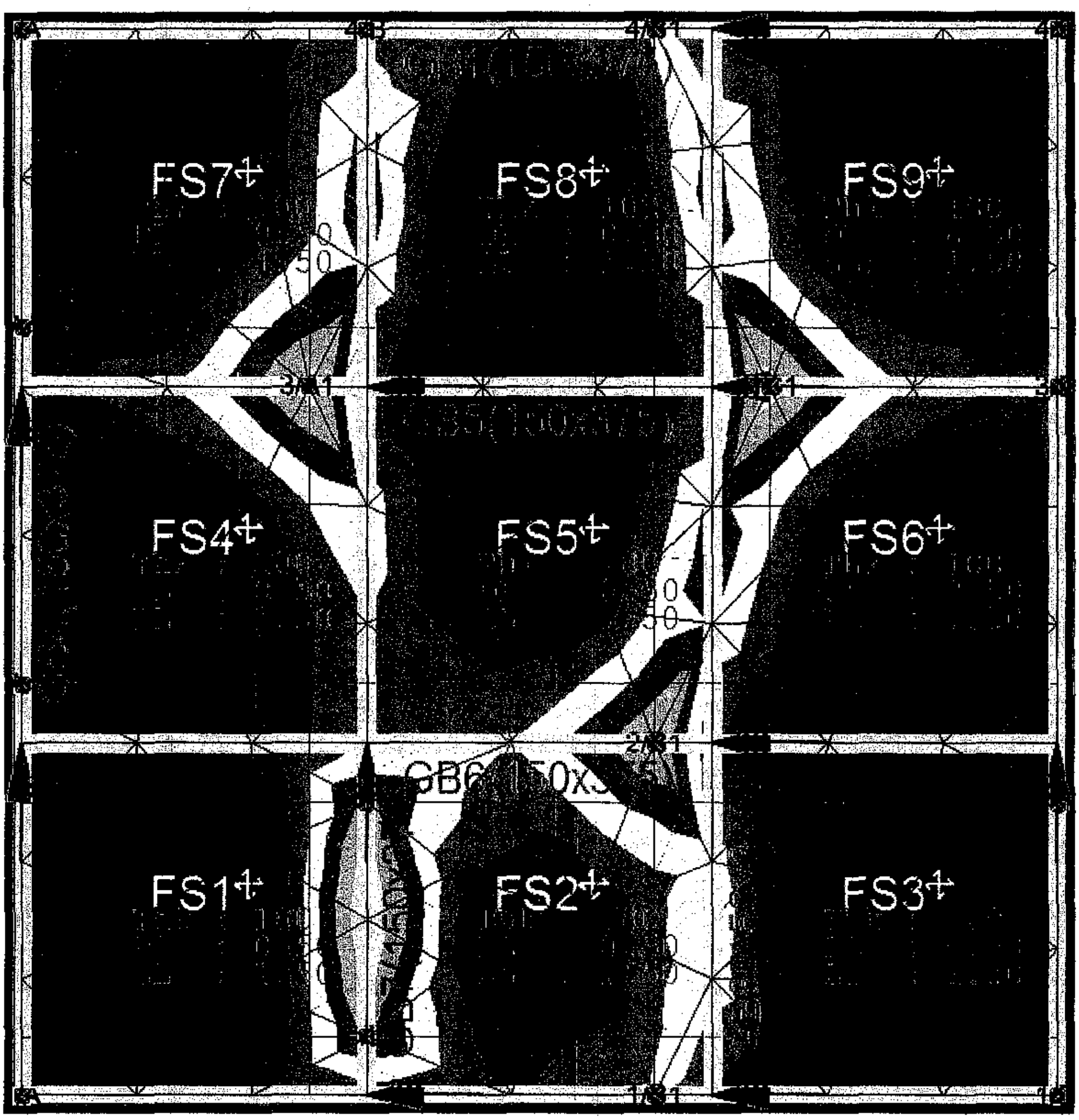


Figure 15

(b) *Slab 3m x 3m with Irregular Grid Distribution*

Mesh Size = 1000mm, X-direction Moment Contour

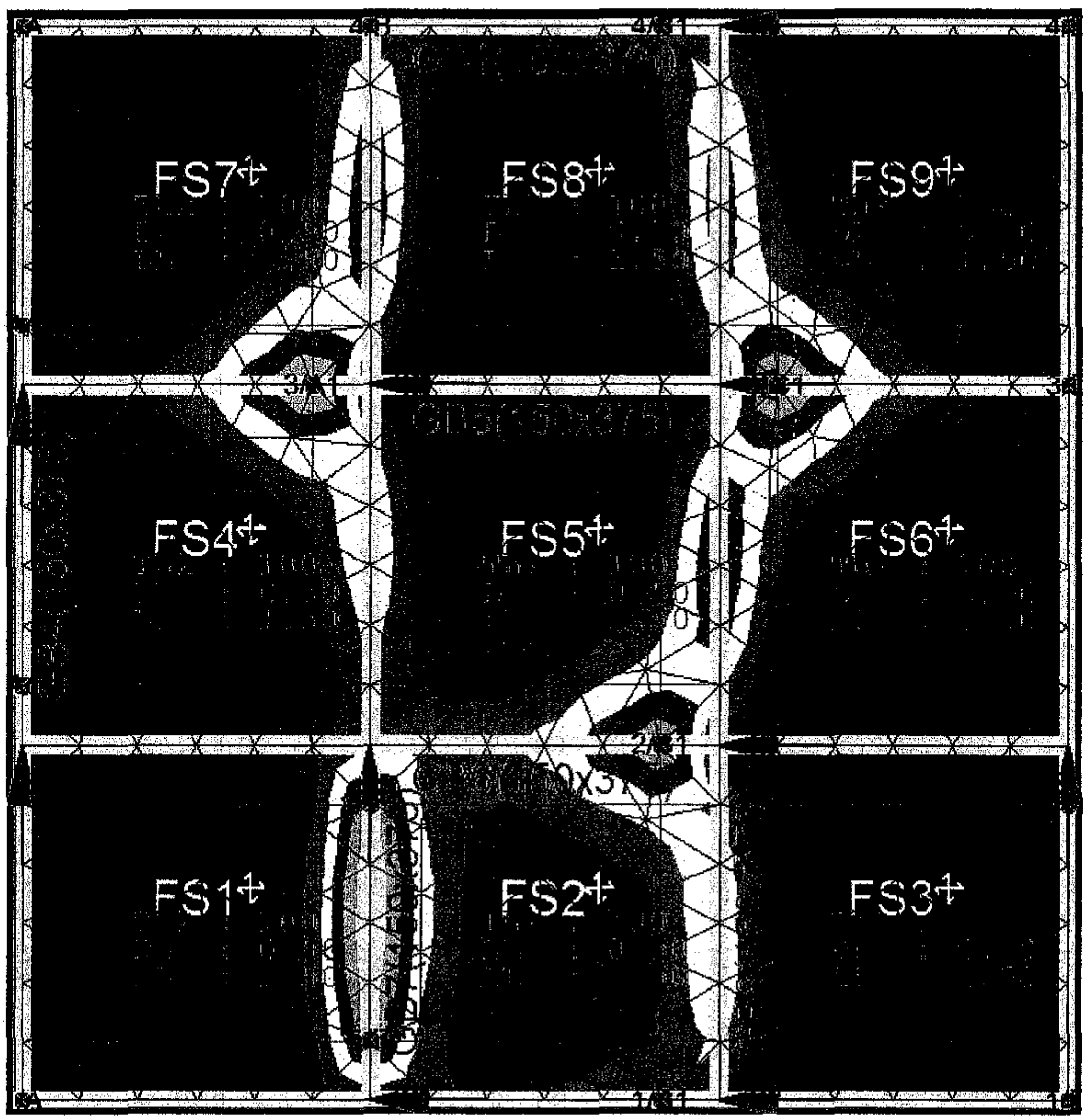


Figure 15

(c) Slab 3m x 3m with Irregular Grid Distribution

Mesh Size = 1500mm, X-direction Moment Contour

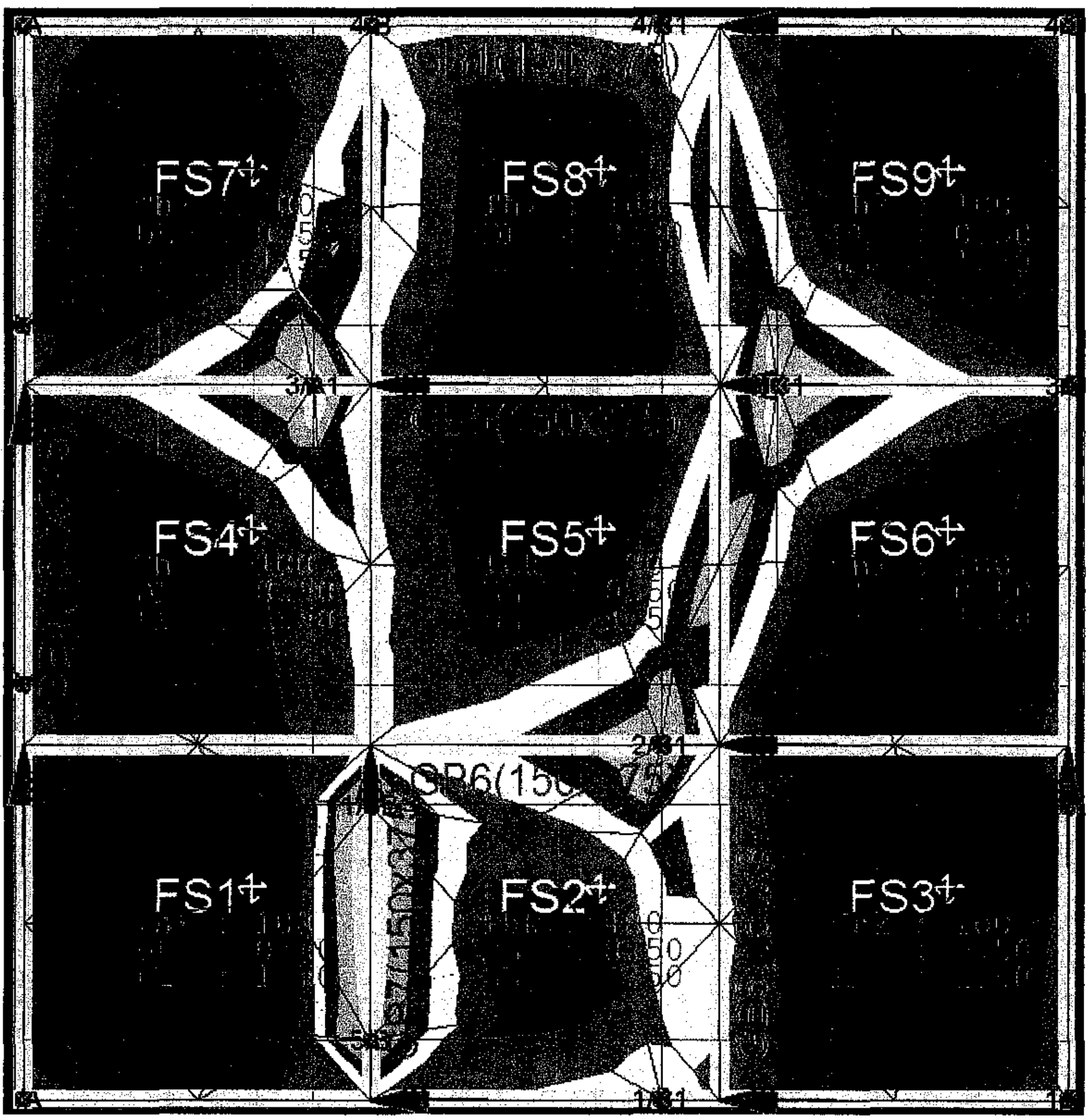


Figure 16

(a) *Slab 3m x 3m with Irregular Grid Distribution*

Mesh Size = 500mm, Y-direction Moment Contour

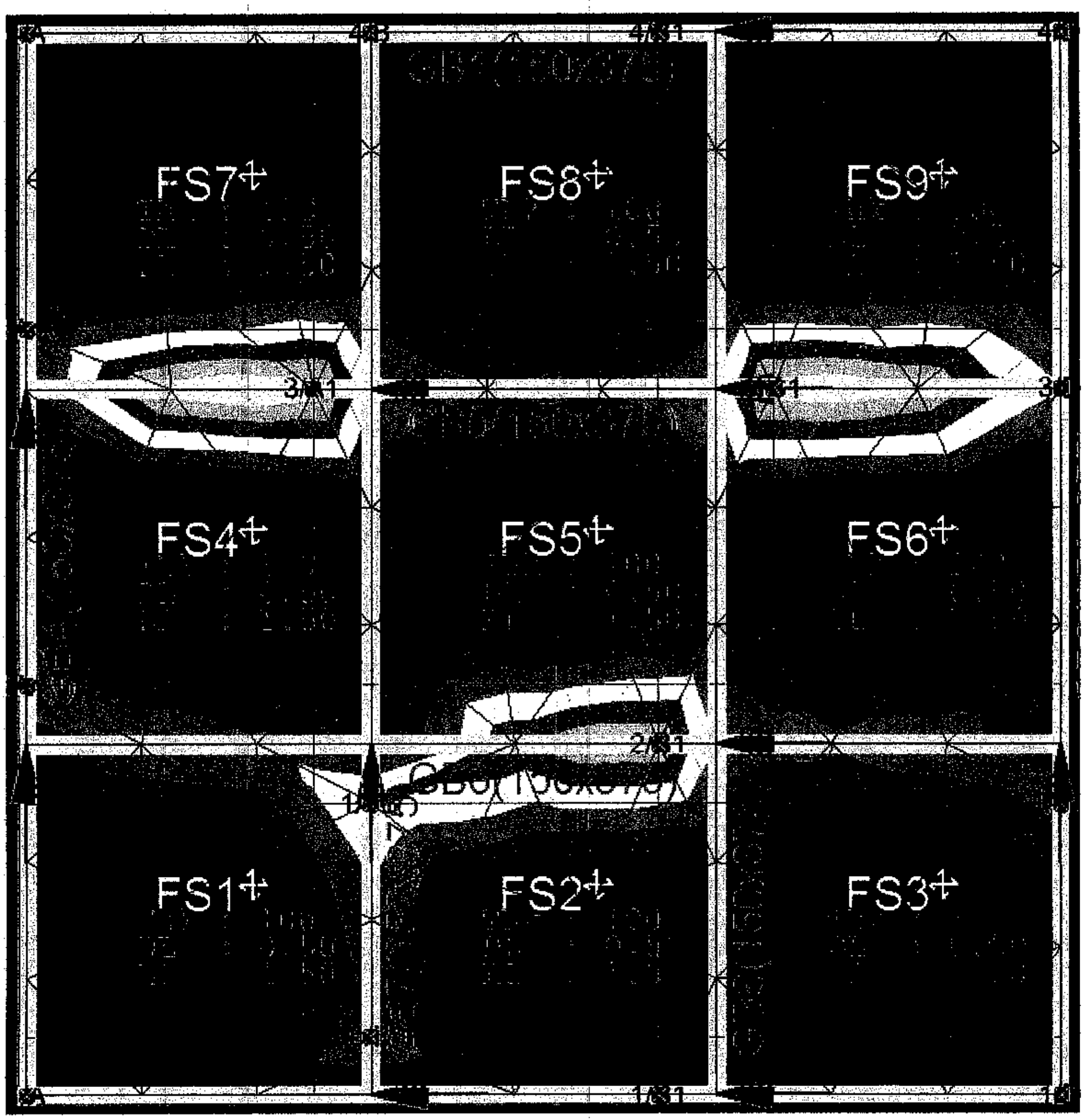


Figure 16

(b) *Slab 3m x 3m with Irregular Grid Distribution*

Mesh Size = 1000mm, Y-direction Moment Contour

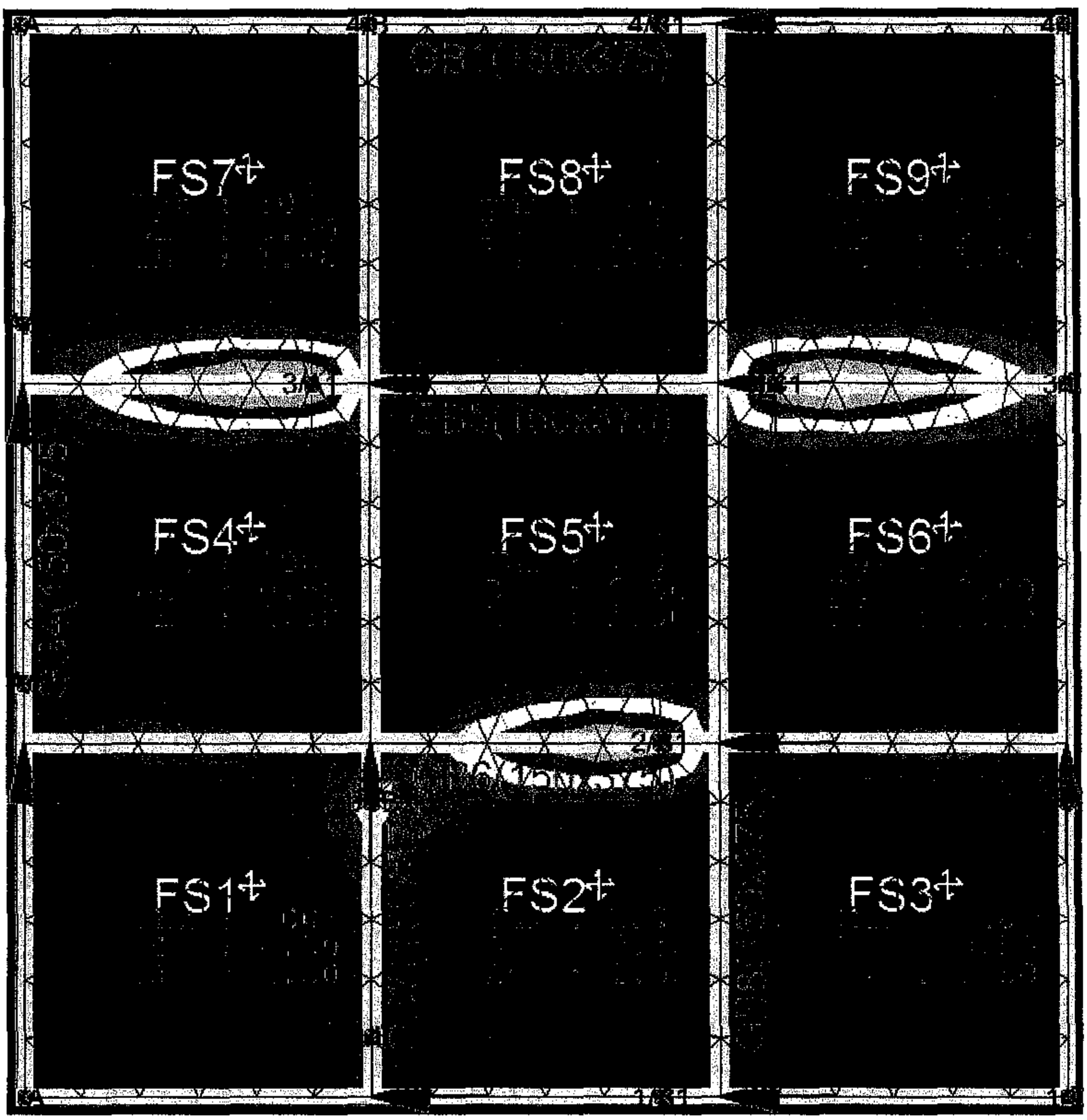


Figure 16

(c) Slab 3m x 3m with Irregular Grid Distribution

Mesh Size = 1500mm, Y-direction Moment Contour