



uOttawa

L'Université canadienne
Canada's university

FACULTÉ DES ÉTUDES SUPÉRIEURES
ET POSTDOCTORALES



FACULTY OF GRADUATE AND
POSTDOCTORAL STUDIES

Luc Jean-Guy Monette

AUTEUR DE LA THÈSE / AUTHOR OF THESIS

Ph.D. (Civil Engineering)

GRADE / DEGREE

Department of Civil Engineering

FACULTÉ, ÉCOLE, DÉPARTEMENT / FACULTY, SCHOOL, DEPARTMENT

Shore and Re-shore Sequences including Age of Concrete and Reshore Stiffnesses

TITRE DE LA THÈSE / TITLE OF THESIS

Noel Gardner

DIRECTEUR (DIRECTRICE) DE LA THÈSE / THESIS SUPERVISOR

CO-DIRECTEUR (CO-DIRECTRICE) DE LA THÈSE / THESIS CO-SUPERVISOR

EXAMINATEURS (EXAMINATRICES) DE LA THÈSE / THESIS EXAMINERS

J. Beaudoin

J. Salinas (absent)

D. Johnston (teleconference)

D. Palermo

Gary W. Slater

Le Doyen de la Faculté des études supérieures et postdoctorales / Dean of the Faculty of Graduate and Postdoctoral Studies

**Shore and Re-shore Sequences including Age of Concrete and Reshore
Stiffnesses**

by
Luc Jean-Guy Monette

A thesis
submitted under the supervision of
Dr. N.J. Gardner

in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy
in
Civil Engineering

Department of Civil Engineering
University of Ottawa
Ottawa, Ontario
K1N 6N5



Library and
Archives Canada

Bibliothèque et
Archives Canada

Published Heritage
Branch

Direction du
Patrimoine de l'édition

395 Wellington Street
Ottawa ON K1A 0N4
Canada

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence

ISBN: 978-0-494-32414-1

Our file Notre référence

ISBN: 978-0-494-32414-1

NOTICE:

The author has granted a non-exclusive license allowing Library and Archives Canada to reproduce, publish, archive, preserve, conserve, communicate to the public by telecommunication or on the Internet, loan, distribute and sell theses worldwide, for commercial or non-commercial purposes, in microform, paper, electronic and/or any other formats.

The author retains copyright ownership and moral rights in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

AVIS:

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque et Archives Canada de reproduire, publier, archiver, sauvegarder, conserver, transmettre au public par télécommunication ou par l'Internet, prêter, distribuer et vendre des thèses partout dans le monde, à des fins commerciales ou autres, sur support microforme, papier, électronique et/ou autres formats.

L'auteur conserve la propriété du droit d'auteur et des droits moraux qui protègent cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

In compliance with the Canadian Privacy Act some supporting forms may have been removed from this thesis.

Conformément à la loi canadienne sur la protection de la vie privée, quelques formulaires secondaires ont été enlevés de cette thèse.

While these forms may be included in the document page count, their removal does not represent any loss of content from the thesis.

Bien que ces formulaires aient inclus dans la pagination, il n'y aura aucun contenu manquant.


Canada

© Luc Jean-Guy Monette, Ottawa, Canada, 2007

To Elaine and Sophie, thanks for your support.
No more evening work and no more tuition fees!!

ABSTRACT

The research presented in this thesis endeavors to improve upon the Simplified (Extended) Method for the calculation of shoring/reshoring schedules, while maintaining its ease of use and practicality. The method developed assumes the parameters discussed below, most of which are contrary to those of the Simplified (Extended) Method.

- The loads applied to the underlying shores are not necessarily uniformly distributed.
- Shores are not infinitely stiff.
- The relative stiffness of different age slabs has a contributory effect on the distribution of loads between shores, reshores and slabs.
- The foundation (at the first level of shores) may not be completely rigid and the load distribution in the shores and slabs above may be affected by the foundation stiffness.

During construction of reinforced concrete flat slab buildings, a freshly cast slab relies on the slabs below it for support. The Simplified Method assumes that this weight is more or less equally shared by all supporting slabs. A methodology was developed to determine more realistic load ratios supported by the slabs in the shoring and reshoring system. A basic description of this methodology is presented below

- The stiffness characteristics of flat slabs for unit point loads applied at desired shoring and reshoring patterns were determined and stored in an array format in Microsoft Excel 2007.
- After the stiffnesses at each shore/reshore locations were determined, equations were developed which describe the relationship between slab

deflections (function of slab stiffness), shore loads and forces in reshores (unknown).

- Parameters such as reshore stiffnesses, age adjusted slab stiffnesses, foundation stiffness, determination of load ratios applied to shores from freshly cast slab (i.e. tributary area vs. detailed analysis) and concrete creep and shrinkage were examined.

The work in this thesis shows that neglecting reshore stiffness in calculating shoring/reshoring schedules is an erroneous assumption. Conclusions regarding the importance of taking into account reshore stiffnesses are provided below.

- Neglecting the elastic stiffness of reshores greatly overestimated the average load supported by reshores for all cases studied.
- Neglecting the elastic stiffness of reshores generally overestimates the load supported by individual reshores.
- Using infinite reshore stiffness provided a reasonable approximation of the maximum reshore loads.
- Neglecting reshore stiffness significantly underestimated the total load supported by the top slab in the reshored system.

ACKNOWLEDGEMENTS

Many thanks are extended to my supervisor, John Gardner. His patience and guidance was essential in the completion of this work. In addition, John's friend, Dinshaw Burjorjee, provided technical support for the solving of matrix equations using Microsoft Excel.

Although my wife's and daughter's assistance was not direct, their patience and understanding with a husband/father constantly glued to the computer was essential in the completion of this thesis. I also thank my wife for her financial support.

CONTENTS

SECTION	PAGE
CONTENTS	i
LIST OF TABLE	vi
LIST OF FIGURES	ix
CHAPTER 1: AN INTRODUCTION TO SHORING AND RESHORING OF FLAT SLAB BUILDINGS	1
1.1 INTRODUCTION	1
1.2 TERMINOLOGY	3
1.3 CONSTRUCTION SAFETY	4
1.4 BASIC CONCEPT OF RESHORING	7
1.5 SHORING/RESHORING DESIGN	8
1.6 SERVICEABILITY ISSUES	12
1.7 PREVIOUS RESEARCH	15
1.8 THE SIMPLIFIED METHOD	16
1.9 DISSAGREEMENTS WITH THE SIMPLIFIED (EXTENDED) METHOD	20
1.10 RESEARCH OBJECTIVES	21
CHAPTER 2: LITERATURE REVIEW	23
2.1 INTRODUCTION	23
2.2 ANALYSIS OF SHORING/RESHORING LOADS	23
2.2.1 Agarwal 1972, Agarwal and Gardner 1974	24
2.2.2 Gardner 1979	25
2.2.3 Lasisi and Ng 1979	26

2.2.4	Liu, Chen and Bowman 1985	27
2.2.5	Liu and Chen 1986	29
2.2.6	Liu, Chen and Bowman 1986	30
2.2.7	Aguinaga-Zapata and Bazant 1987	31
2.2.8	Gardner and Muscati 1989	32
2.2.9	Stivaros and Halvorsen 1990, 1991 and 1992	33
2.2.10	El-Shahhat and Chen 1992	35
2.2.11	Beeby 2000	36
2.2.12	De Almeida Prado, Silva Correa, and Ramalho 2002	39
2.3	OTHER ASPECTS OF SHORING/RESHORING	41
2.3.1	McKaig 1962	41
2.3.2	Gardner and Chan 1986	42
2.3.3	Grossman 1986	43
2.3.4	Hover 1988	44
2.3.5	Gardner 1990	45
2.3.6	Ambrose, Huston, Fuhr, Devino and Werner 1993	45
2.3.7	Gardner and Asamoah 1997	46
2.3.8	Rosowsky, Huston, Fuhr and Chen 1997	47
2.3.9	Kothekar 1998	47
2.3.10	Beeby 2001	47
2.3.11	King 2004	48
CHAPTER 3: DEVELOPMENT OF ANALYTICAL METHODOLOGY		49
3.1	INTRODUCTION	49
3.2	BASIC METHODOLOGY	49
3.3	DETERMINATION OF SLAB STIFFNESSES	50
3.4	DEVELOPMENT OF EQUATIONS	61
3.5	OTHER PARAMETERS	70
3.5.1	Determination of shoring loads	70
3.5.2	Stiffness of foundations	71
3.5.3	Creep and shrinkage	71

CHAPTER 4: RESULTS	79
4.1 INTRODUCTION	79
4.2 READING THE DETAILED RESULTS	79
4.2.1 Methodology	80
4.2.2 Generation of results	80
4.3 SUMMARY RESULTS	81
4.3.1 Effect of reshore stiffness for the 3 bays x 3 bays, 9.5m x 9.5m bays model	82
4.3.1.1 Results for 1 level of reshores (2 supporting slabs)	83
4.3.1.2 Results for 2 levels of reshores (3 supporting slabs)	84
4.3.1.3 Results for 3 levels of reshores (4 supporting slabs)	85
4.3.2 Effect of reshore stiffness for the 3 bays x 3 bays, 6.5m x 9.5m bays model	90
4.3.2.1 Results for 1 level of reshores (2 supporting slabs)	91
4.3.2.2 Results for 2 levels of reshores (3 supporting slabs)	92
4.3.2.3 Results for 3 levels of reshores (4 supporting slabs)	93
4.3.3 Effect of reshore Stiffness for the 3 bays x 3 bays, 9.5m x 9.5m (centre bay), 6.5m x 9.5m (edge bays), 6.5m x 6.5m (corner bays) model	98
4.3.3.1 Results for 1 level of reshores (2 supporting slabs)	99
4.3.3.2 Results for 2 levels of reshores (3 supporting slabs)	100
4.3.3.3 Results for 3 levels of reshores (4 supporting slabs)	101
4.3.4 Effect of reshore stiffness for the 2 bays x 2 bays, 9.5m x 9.5m bays model	106
4.3.4.1 Results for 1 level of reshores (2 supporting slabs)	107
4.3.4.2 Results for 2 levels of reshores (3 supporting slabs)	108
4.3.4.3 Results for 3 levels of reshores (4 supporting slabs)	109

4.3.5	Effect of bay sizes and aspect ratios for 1/3 x realistic reshore stiffness	114
4.3.5.1	Results for 1 level of reshores (2 supporting slabs)	115
4.3.5.2	Results for 2 levels of reshores (3 supporting slabs)	116
4.3.5.3	Results for 3 levels of reshores (4 supporting slabs)	117
4.3.6	Effect of bay sizes and aspect ratios for realistic reshare stiffness	119
4.3.6.1	Results for 1 level of reshores (2 supporting slabs)	119
4.3.6.2	Results for 2 levels of reshores (3 supporting slabs)	119
4.3.6.3	Results for 3 levels of reshores (4 supporting slabs)	120
4.3.7	Effect of bay sizes and aspect ratios for 3 x realistic reshare stiffness	124
4.3.7.1	Results for 1 level of reshores (2 supporting slabs)	124
4.3.7.2	Results for 2 levels of reshores (3 supporting slabs)	124
4.3.7.3	Results for 3 levels of reshores (4 supporting slabs)	125
4.3.8	Effect of bay sizes and aspect ratios for infinite reshare stiffness	129
4.3.8.1	Results for 1, 2 and 3 levels of reshores (2, 3 and 4 supporting slabs, respectively)	129
CHAPTER 5: PRACTICAL APPLICATION		132
5.1	INTRODUCTION	132
CHAPTER 6: DISCUSSION		137
6.1	INTRODUCTION	137
6.2	LOADS SUPPORTED BY RESHORES	137
6.3	LOADS SUPPORTED BY SLABS	141
6.4	EFFECTS OF CREEP AND SHRINKAGE	144
CHAPTER 7: CONCLUSIONS		145
7.1	INTRODUCTION	145
7.2	RESHORE STIFFNESS	145
7.3	SLAB SPANS/ASPECT RATIOS	147
7.4	EFFECT OF SLAB AGE	147
7.5	CREEP AND SHRINKAGE	147

7.6 ANALYSIS OF APPLIED LOAD	148
7.7 WORK TO BE PERFORMED	148
REFERENCES	149
ATTACHMENT 1 (ENCLOSED COMPACT DISK IN EXCEL 2007 FORMAT)	

LIST OF TABLES

TABLE	PAGE
Table 1.1: Comparison of minimum design load requirements for falsework for ACI 347R-03, CSA S269.1-1975 (R2003) and ASCE 37	11
Table 3.1: Simplified analysis to determine the effect of creep on the calculation of shoring and reshoring schedules	74
Table 4.1a: Results for 3 bays x 3 bays, 9.5m x 9.5m bays model, 1 level of reshores	89
Table 4.1b: Results for 3 bays x 3 bays, 9.5m x 9.5m bays model, 2 levels of reshores	89
Table 4.1c: Results for 3 bays x 3 bays, 9.5m x 9.5m bays model, 3 levels of reshores	90
Table 4.2a: Results for 3 bays x 3 bays, 6.5m x 9.5m bays model, 1 level of reshores	98
Table 4.2b: Results for 3 bays x 3 bays, 6.5m x 9.5m bays model, 2 levels of reshores	98
Table 4.2c: Results for 3 bays x 3 bays, 6.5m x 9.5m bays model, 3 levels of reshores	99
Table 4.3a: Results for 3 bays x 3 bays, 9.5m x 9.5m (centre bay), 6.5m x 9.5m (edge bays), 6.5m x 6.5m (corner bays) model, 1 level of reshores	107

Table 4.3b:	Results for 3 bays x 3 bays, 9.5m x 9.5m (centre bay), 6.5m x 9.5m (edge bays), 6.5m x 6.5m (corner bays) model, 2 levels of reshores	107
Table 4.3c:	Results for 3 bays x 3 bays, 9.5m x 9.5m (centre bay), 6.5m x 9.5m (edge bays), 6.5m x 6.5m (corner bays) model, 3 levels of reshore	108
Table 4.4a:	Results for 2 bays x 2 bays, 9.5m x 9.5m bays model, 1 level of reshores	116
Table 4.4b:	Results for 2 bays x 2 bays, 9.5m x 9.5m bays model, 2 levels of reshores	116
Table 4.4c:	Results for 2 bays x 2 bays, 9.5m x 9.5m bays model, 3 levels of reshores	117
Table 4.5a:	Results for different models, 1/3 x realistic reshore stiffness, 1 level of reshores	121
Table 4.5b:	Results for different models, 1/3 x realistic reshore stiffness, 2 levels of reshores	121
Table 4.5c:	Results for different models, 1/3 realistic reshore stiffness, 3 levels of reshores	122
Table 4.6a:	Results for different models, realistic reshore stiffness, -1 level of reshores	126
Table 4.6b:	Results for different models, realistic reshore stiffness, 2 levels of reshores	126
Table 4.6c:	Results for different models, realistic reshore stiffness, 3 levels of reshores	127
Table 4.7a:	Results for different models, 3 x realistic reshore stiffness, 1 level of reshores	131
Table 4.7b:	Results for different models, 3 x realistic reshore stiffness, 2 levels of reshores	131
Table 4.7c:	Results for different models, 3 x realistic reshore stiffness, 3 levels of reshores	132

Table 4.8a:	Results for different models, infinite reshore stiffness, 1 level of reshores	134
Table 4.8b:	Results for different models, infinite reshore stiffness, 2 levels of reshores	134
Table 4.8c:	Results for different models, infinite reshore stiffness, 3 levels of reshores	135
Table 6.1:	% Difference of load ratios for different reshore stiffnesses compared to infinitely stiff reshore load ratios, 1 level of reshores	142
Table 6.2:	% Difference of load ratios for different reshore stiffnesses compared to infinitely stiff reshore load ratios, 2 levels of reshores	143
Table 6.3:	% Difference of load ratios for different reshore stiffnesses compared to infinitely stiff reshore load ratios, 3 levels of reshores	143
Table 6.4:	% Difference of slab total load ratios for different reshore stiffnesses compared to infinitely stiff reshore slab load ratios, 1 level of reshores	146
Table 6.5:	% Difference of slab total load ratios for different reshore stiffnesses compared to infinitely stiff reshore slab load ratios, 2 levels of reshores	146
Table 6.6:	% Difference of slab total load ratios for different reshore stiffnesses compared to infinitely stiff reshore slab load ratios, 3 levels of reshores	147

LIST OF FIGURES

FIGURE	PAGE
Figure 1.1: Flat slab building under construction with 3 levels of scaffold shoring and 1 level of reshores (bottom level)	2
Figure 1.2: Flat slab building under construction with 1 level of scaffold shoring combined with flying forms	3
Figure 1.3: Construction failure, Bailey's Crossroads, Fairfax, Virginia, March 1973. Photo courtesy of the National Institute of Standards and Technology	6
Figure 1.4: Construction dead load ratios for 2 sets of shores and reshores (Gardner 1979)	19
Figure 3.1: Plan of 3 bays x 3 bays, 9.5m x 9.5m bays model	52
Figure 3.2: Plan of 3 bays x 3 bays, 6.5m x 9.5m bays model	53
Figure 3.3: Plan of 3 bays x 3 bays, 9.5m x 9.5m centre bay, 6.5m x 9.5m edge bays, 6.5m x 6.5m corner bays model	54
Figure 3.4: Plan of 2 bays x 2 bays, 9.5m x 9.5m bays model	55
Figure 3.5: Section through a typical model	56
Figure 3.6: Finite element model for 3 bays x 3 bays, 9.5m x 9.5m bays	57
Figure 3.7: Finite element model for 3 bays x 3 bays, 6.5m x 9.5m bays	57
Figure 3.8: Finite element model for 3 bays x 3 bays, 9.5m x 9.5m centre bay, 6.5m x 9.5m edge bays, 6.5m x 6.5m corner bays	58
Figure 3.9: Finite element model for 2 bays x 2 bays, 9.5m x 9.5m bays	58

Figure 3.10:	Finite element deflection contours with unit load near mid span of center bay for 3 bays x 3 bays, 9.5m x 9.5m bays model	59
Figure 3.11:	Finite element deflection contours with unit load near mid span of center bay, 3 bays x 3 bays, 6.5m x 9.5m bays model	59
Figure 3.12:	Finite element deflection contours with unit load at mid span of center bay, 3 bays x 3 bays, 9.5m x 9.5m centre bay, 6.5m x 9.5m edge bays, 6.5m x 6.5m corner bays model	60
Figure 3.13:	Finite element deflection contours with unit load near centre column, 2 bays x 2 bays, 9.5m x 9.5m bays model	60
Figure 3.14:	Simplified analysis model	62
Figure 3.15:	Isometric view showing shore locations for a single bay	63
Figure 3.16:	Isometric view showing reshore locations for a single bay	63
Figure 3.17a:	Development of elastic deflections in shoring and reshoring systems, assuming a single level of shores only	75
Figure 3.17b:	Development of elastic deflections in shoring and reshoring systems, assuming a single level of shores combined with a single level of reshores only	76
Figure 3.18a:	Development of elastic and inelastic deflections in shoring and reshoring systems, assuming a single level of shores only	77
Figure 3.18b:	Development of elastic and inelastic deflections in shoring and reshoring systems, assuming a single level of shores combined with a single level of reshores only	78
Figure 4.1:	3 bays x 3 bays, 9.5m x 9.5m bays model	82
Figure 4.2:	3 bays x 3 bays, 6.5m x 9.5m bays model	91
Figure 4.3:	3 bays x 3 bays, 9.5m x 9.5m (centre bay), 6.5m x 9.5m (edge bays), 6.5m x 6.5m (corner bays) model	100
Figure 4.4:	2 bays x 2 bays model, 9.5m x 9.5m bays	109
Figure 5.1:	Shoring and reshoring schedules for 1 level of reshores	137
Figure 5.2:	Shoring and reshoring schedules for 2 levels of reshores	138
Figure 5.3:	Shoring and reshoring schedules for 3 levels of reshores	139

CHAPTER 1

AN INTRODUCTION TO SHORING AND RESHORING OF FLAT SLAB BUILDINGS

1.1 INTRODUCTION

Safety during construction of reinforced concrete buildings is often a greater concern than safety during the service life of the finished structure. Great care goes into the design and quality control during construction of reinforced concrete buildings. This care has sometimes been lacking in the design and construction of the temporary structures (falsework) that support the fresh concrete until it attains sufficient strength. These temporary structures are important since flat plates/slabs (slabs with the absence of beams), which are architecturally and economically desirable, are susceptible to punching shear.

During construction, freshly cast reinforced concrete slabs are usually temporarily supported either from the ground (in the case of the first floor) or from the floors immediately below (in the case of floors above the first one). Support of the freshly cast floors is necessary until the floors have gained sufficient strength to support their own self weight and any superimposed construction loads. The weight of the freshly cast floor may cause an overload of the floors supporting it below. Possible modes of failure include punching shear (the governing structural failure mode of flat slabs is the shear resistance at the slab column interface, Feld 1966) or excessive deflections (long-term serviceability). Therefore, an ongoing concern for both engineers and contractors is determining the most efficient, yet safe, shoring and reshoring schedules.

To develop the optimum shoring and reshoring schedules (based on safety and cost efficiency), it is of prime importance to understand the distribution of loads during construction between the floors. Thus the importance of developing a realistic yet practical model for the determination of shoring/reshoring loads.

Figure 1.1 and 1.2 show a flat slab building under construction with scaffold type shoring / reshoring, flying forms (trusses) and single post reshores.



Figure 1.1: Flat slab building under construction with 3 levels of scaffold shoring and 1 level of reshores (bottom level)



Figure 1.2: Flat slab building under construction with 1 level of scaffold shoring combined with flying forms

1.2 TERMINOLOGY

The following terminology, will be used throughout this thesis. The terms presented may differ from country to country and synonyms for each (where applicable) are provided in brackets.

- **Casting Cycle:** The period of time between the casting of one level and casting the level immediately above it.
- **Construction Load:** All loads applied to a supporting slab during construction of a subsequent slab other than that supporting slab's self weight (including the weight of formwork, shoring, reshoring, wet concrete and construction live load).
- **Falsework:** The assembled structure that supports the formwork (usually comprised of beams/trusses, stringers and shores).
- **Formwork:** Formwork is the surface against which concrete is cast.

- **Preshore:** These are shores that are installed prior to the removal of formwork/shoring in order to reduce the supported span of the slab when the falsework is removed. Reshores are then installed between the preshores. This reduces the load supported by the freshly cast slab when compared to a reshored slab (greater load supported by the reshores).
- **Reshore (Reprop):** Vertical supports that transfer the loads imposed by the shores (freshly cast slab) on the top slab to the supporting slabs below. These are installed after the shoring has been removed and the slab is permitted to deflect and support its own weight. Reshores can be individual timber, steel or aluminum posts. Reshores should be installed “finger tight” so that the least amount of load due to tightening is applied to the reshores and the supporting slabs.
- **Shore (Prop):** The vertical supports that transfer the loads imposed on the falsework by the freshly cast slab to the supporting slab below. Shores can be individual timber, steel and aluminum posts or even easily movable systems such as flying table forms.
- **Stripping (Striking):** Removal of the formwork, thus requiring the removal of falsework supporting the formwork.
- **Realistic Shore/Reshore and Slab Stiffness:** Stiffness based on actual reshores and slabs. Realistic reshore stiffnesses are based on the Aluma Heavy Duty Post Shore. Realistic slab stiffnesses are based on slab age.
- **Load Ratio:** Proportion of the applied shore load supported by reshores or slabs

1.3 CONSTRUCTION SAFETY

It is usually in the contractor's and developer's best interest to strip formwork as early as possible to accelerate construction. Since formwork is a significant cost in concrete construction, the faster formwork can be reused, the fewer the number of forms are required. In addition, removal of shoring provides access to other trades so that other

stages of construction can proceed as early as possible (Beresford 1964). However, construction safety should never be compromised in the interest of financial benefits.

To ensure safety during construction, engineers usually impose an established criteria based on the developed compressive strength of concrete for determining the stripping time for formwork. Some researchers have reported an appropriate specified minimum strength of concrete for stripping formwork as 75% of the design strength (Fattal 1983). This requires the testing of concrete strength at early ages to ensure this criterion is attained.

Shoring/reshoring related failures account for the majority of failures in concrete construction (Lew 1976). In general, the primary causes of formwork disasters are excessive loads, premature removal of shores or inadequate lateral support for shoring members (Mossallam and Chen 1989). It has also been reported that construction failures of reinforced concrete structures are often not caused by a single cause, but often by multiple errors such as punching shear resulting in progressive collapse due to poor concrete strength or premature removal of shoring (Epaarachichi 2002).

Two failure modes are usually considered when shoring and reshoring are considered. One mode is the failure of a shore/reshore system leading to collapse of slabs. The second mode is collapse (punching shear) or excessive deflection of the supporting slabs due to the loads transmitted by shores/reshores. Construction loads can exceed the design load of slabs or the load capacity of the slabs based on strength at that time (Blakey and Beresford 1965).

The primary causes of shore/reshore failures are described as follows (Ambrose et al 1993):

- Excessive loads
- Premature removal of forms or shores
- Inadequate lateral support of shores

The fact that the majority of concrete building failures occur during construction, and that most of these are attributed to shoring/reshoring (regardless of all the research on the subject) indicates the need for further research and the development of standardized

methodology for shoring and reshoring schedules. This is of prime importance to ensure safety during construction.

Figure 1.3 shows a failure during the construction of a flat slab building at Bailey's Crossroads in Fairfax, Virginia, March 1973. The total building height was planned to be 26 storeys. The concrete was being placed on the 24th floor while shoring was prematurely removed from the 22nd, causing a progressive collapse down to the ground level. The failure killed 14 construction workers and injured 35. The supporting slab concrete had not attained sufficient strength to carry the imposed construction loads.



Figure 1.3: Construction failure, Bailey's Crossroads, Fairfax, Virginia, March 1973. Photo courtesy of the National Institute of Standards and Technology

1.4 BASIC CONCEPT OF RESHORING

The speed (and thus cost effectiveness) of construction of reinforced concrete buildings is governed by the rate of casting subsequent floors (usually expressed in days or weeks per floor). This rate can vary, usually between four to seven days, with two days in some extreme schedules.

Shoring is not removed until the concrete has attained sufficient strength to support its own self weight. In multi story construction, slabs are required to support not only their own self weight, but also part of the self weight of subsequent slabs as well as construction live loads through shoring, so that the construction can continue (Gardner 1990). Therefore, temporary support of slabs during construction is required to prevent collapse or undue deflection.

Basically, reshoring consists of distributing loads from the slabs under construction by strategically placing shores to transfer construction loads among the supporting slabs below. In reshored construction, a slab supports its self weight plus any construction live load while supporting a fraction, depending on the number of reshored slabs, of the construction load from the slabs above.

Reshoring the slabs, under those supporting shoring, is required to distribute the construction loads to more than one slab. Even with reshoring, a given slab may be required to support a construction load of a greater magnitude than its design service load. In addition, the speed of construction dictates that subsequent slabs be cast prior to the previous slabs having attained their 28 day design strength, thus further exacerbating the effect of construction loads.

The requirement for reshoring is solely a function of construction speed. Construction practice dictates that the stripping of forms will occur prior to slabs reaching their 28 day design strength, thus requiring reshoring to continue with the construction. The following factors usually govern the speed of construction:

- Speed of formwork removal from the last cast story and erection for the next floor
- Number of sets of formwork (shores)
- Number of sets of re-shores

- Slab strength/stiffness at time of formwork/shore removal

Another variant of reshoring is preshoring. Preshores are shores installed prior to the removal of falsework to limit slab deflection which increases the load in the preshores and the lower slab and reducing the load supported by the upper slab. Along the same idea, reshores could be installed with some precompression to reduce load on the upper slabs which also increases the load in the reshores and on lower slabs. These methods require great care and supervision at the construction site. It should be noted that it is very difficult to install any reshoring without a certain amount of precompression. So called “finger tightening” is not precise and may vary from worker to worker, which will have an effect on the initial load in reshores.

The design of shoring and reshoring for flat slab structures is similar to any other form of structural design. Loads must be predicted as accurately as possible and member resistances are determined at the age the members are required to resist the loads. The challenge lies in determining not only design loads, but also distribution of the loads through the shoring/reshoring/slab system.

1.5 SHORING/RESHORING DESIGN

The loads requiring temporary support from shoring and reshoring can be categorized as follows:

- Self weight of formwork and shoring
- Self weight of slabs
- Self weight of reshoring
- Self weight of stored construction materials
- Construction live loads
- Impact loading due to construction live load and concrete placement
- Lateral loads (extreme winds, hurricanes and earthquakes)

Dead loads can generally be calculated within a comfortable level of accuracy. However, live loads present a greater challenge due to their unpredictability. For this reason, most design codes specify a conservative construction live load and live load factor, which are intended to cover any foreseeable live loads during construction.

In addition to the above types of loads, the design of falsework/shoring should always take into account all possible load cases including special load cases such as unsymmetrical placement of concrete, uplift, concentrated loads of reinforcement and storage of construction materials. It has been reported that the storage of construction materials has frequently been the cause of formwork failure, where presumably the design had not taken these loads into account (Lew 1976).

There has been debate as to whether or not load factors should be applied to construction loads and, if so, should their magnitude be the same as those for the design of the building. Some researchers have postulated that since construction loads are generally short in nature and that consequences of failure are not as severe as they would be for a building in service, their magnitude should be less than for building design (Stivaros 1992). Others believe that since construction workers spend their entire lives on construction sites, their risk of injury should not be greater than those of the occupants of the finished buildings (Gardner 1990).

Since most concrete building failures occur during construction and given the difficulty in predicting the magnitude of construction live loads and the complexity of construction load distribution in the shoring/reshoring system, some form of load factors should be applied. Most design codes (except ASCE 37) do not discuss the use of load factors for construction loads. Therefore, the factors specified for design service loads are usually applied to construction loads. Further research is required to study this topic.

There is some variation in the magnitude of construction live loads specified by various codes. The scope of exact application for the construction loads specified in the codes is not always specified (i.e. applied to slab under construction only or to all upper and lower slabs (Gardner 1989)). The three main building code references in Canada for construction load specifications as well as their specified loads are summarized below. Table 1.1 provides a comparison of the minimum design load requirements of all three codes.

ACI 347R-03, Guide to Formwork for Concrete

- All dead loads, including, but not limited to, the weight of concrete, reinforcement, formwork/falsework.
- All live loads, including, but not limited to, workers, equipment, material storage, runways and impact.
- Formwork shall be designed for a live load of not less than 2.4 kPa
- When motorized carts are used, the minimum design live load shall not be less than 3.6 kPa.
- The design load for the combined dead and live load should not be less than 4.8kPa or 6.0 kPa if motorized carts are used.
- The formwork should be designed for any special conditions likely to occur during construction, such as the unsymmetrical placement of concrete, impact of machine delivered concrete, uplift, concentrated loads of reinforcement, form handling loads and storage of construction materials and any other special loading case.
- Post tensioning loads (loads transferred to the temporary structures by post tensioning).
- No load factors are specified specifically for construction loads.

CSA S269.1-1975 (R2003), Falsework for Construction Purposes

- The weight of concrete being supported, or 2.4 kPa on the horizontal projected area of the formwork, whichever is the greater.
- The weight of workmen, equipment and tools that will be supported during the concrete placing and finishing operations. In no case shall these loads be assumed to be less than 1.9 kPa of horizontal projected area of formwork.
- When motorized placing equipment is used, this minimum load shall be increased to 3.1 kPa.
- The actual weight of formwork supported by the falsework shall not be assumed to be less than 0.5 kPa.

- Loading due to any special conditions of construction likely to occur such as unsymmetrical placement of concrete, impact, uplift, concentrated loads and the additional pressure due to placing concrete pneumatically or by pump in confined locations.
- Loading due to stored construction materials, products of demolition or other similar loadings during construction, alterations or repair of buildings or other structures.

ASCE 37, Design Loads on Structures during Construction

- The weight of concrete being supported as well as all other dead loads.
- Combined material, personnel, equipment and other applicable construction loads.
- Depending on the type of construction site, the specified uniform load varies between 1 kPa to 3.6 kPa (from light duty to heavy duty construction sites).
- Concentrated loads of 1.1kN for each person, 2.2kN for each wheel of manually powered vehicles and 8.9kN for each wheel of powered equipment. Impact loads are included in the specified concentrated loads.
- Construction load factors are specified for various dead and live load cases.

Load Type	Minimum Specified Load (kPa)		
	ACI 347R-03	CSA S269.1-1975 (R2003)	ASCE 37
Formwork Self Weight	-	0.5	-
Live Load	2.4	1.9	1 to 3.6 (light duty to heavy duty)
Live Load with Motorized Cart	3.6	3.1	-
Combined Dead and Live Load	4.8	-	-
Combined Dead and Live Load with Motorized Cart	6.0	-	-
Concentrated Loads	-	-	1.1 kN (per person)
			2.2 kN per wheel of manual vehicles
			8.9kN per wheel of powered equipment

Table 1.1: Comparison of minimum design load requirements for falsework for ACI 347R-03, CSA S269.1-1975 (R2003) and ASCE 37

The design of formwork and falsework is usually the responsibility of the contractor. Given the importance of safety, and that falsework has historically been the greatest cause of failure in concrete construction, input by engineers and the need for better methods of shoring load evaluation is reinforced.

Some researchers have disputed the need for the complex design of shoring/reshoring systems. It has been reported that experiments by the BCA (British Cement Association) to investigate reshoring forces by monitoring them on site found that the results were so variable that they were not interpretable. This was partly due to construction operations on previously cast floors supporting reshores where, when particular reshores were in the way, they were removed temporarily and replaced. Therefore, it was concluded that it may not be worthwhile to expend effort to develop and apply sophisticated methods of calculating shore and reshore forces if reshores are to be removed in this way (Beeby 2000).

The design of reshoring requires an understanding of structural analysis to properly evaluate the load distribution in the shoring/reshoring system. The variables in the system are more complex than those usually assumed for building design since the younger age of the structures as well as the high load ratios introduce additional parameters to consider. However, as discussed above, sophisticated design would be fruitless unless the design method used could be simplified (while yielding the best and most realistic results possible) and appropriate quality control can be implemented on site. This would again reinforce the need for engineering design and field review of shoring/reshoring implementation.

1.6 SERVICEABILITY ISSUES

Although the structural capacity of the shoring/reshoring/slab system is usually the primary concern, other serviceability and materials issues should not be ignored. These issues include the effects of creep and shrinkage deflections on the load distribution in reshoring systems as well as the long term serviceability of reinforced concrete slabs.

It is well established that the strength of concrete at early ages is influenced by curing environment (Blakey and Beresford 1965). This must be taken into account when determining available slab capacity to support shoring and reshoring loads.

Some researchers have reported that with very early loading, creep deformations may influence the distribution of loads in reshoring systems. Nielson (1952), suggested that creep could be neglected since younger slabs (lower modulus of elasticity) support lower loads while the older slabs (higher modulus of elasticity) support higher loads (Blakey and Beresford 1965). Other researchers have concluded that the effect of creep should not be neglected in predicting reshoring loads (Aguinaga-Zapata and Bazant 1986).

Construction loads are usually applied to immature slabs, thus immediate elastic deflections are large. Upon removal of the construction loads, the elastic deflection recovery is less than the original elastic deflection since the modulus of elasticity increases with time. Creep deflections associated with the construction loads can be multiples of the immediate deflection. In addition, shrinkage deflections can occur.

Some research has concluded that creep effects due to early age loads are significant and cannot be ignored. It has also been concluded that construction schedule greatly affects the long term serviceability of slabs and that measured versus predicted slab deflections often do not correlate due to variations in material properties and the difficulty in assuming appropriate boundary condition (Gardner and Scanlon 1990).

The thickness of reinforced concrete floor systems is usually governed by the need to limit long term deflections under service loads. It has also been reported that slab deflection is more related to concrete strength than content of reinforcement (Vollum 2002). However, the deflection characteristics of reinforced concrete slabs varies during construction due the change in modulus of elasticity with time. Taylor (1967) reported that slab deflections were comprised of 3 components as follows:

- Initial or “elastic” deflection under slab dead load, construction loading and design live load.
- Warping of the slab caused by differential shrinkage

- Long term or “creep” deflection resulting mainly from slab dead load and permanent live load but also including the effects of construction loads and temporary live loads.

Due to the lower strength and modulus of elasticity of concrete at early ages, the negative consequences of removing formwork/shoring too early are excessive early age deflections (cracking) and an increase in long term creep deflections (Beresford 1964). In addition, cracking of slabs may very well first occur at the time of formwork and shore removal since the minimum cracking resistance may very well occur at that time (Hover 1988).

Although strength and deflection calculations of slabs are often performed based on uncracked sections, a factor for shrinkage restraint cracking may have to be applied. After concrete is cracked, the stiffness is more dependent on reinforcement and less on modulus of elasticity, while for uncracked sections the modulus of elasticity governs (Blakey and Beresford 1965).

Compared with concrete compressive strength, the increase of modulus of elasticity with time shows a much more rapid early rise and starts leveling off at approximately 3 days. The change in modulus of elasticity after 3 days is much more gradual and less significant than during the first 3 days (Blakey and Beresford 1965).

Some field research has indicated a reduction in the measured load carried by shores between the time of casting a new slab and the time shores were removed. The measured reduction was approximately 25%. The author attributed this to the concrete carrying more and more of the load as it cures. When the concrete is fully cured, the shoring only carries a fraction of the load and the rest is supported by the concrete structure (Ambrose et al 1993).

It has been established that early age construction loads can have a detrimental effect on the long term serviceability of flat slab structures. Therefore, it is important to understand the concrete properties when determining shoring/reshoring schedules and prior to allowing the removal of formwork. To determine material properties, in addition to compressive tests, split cylinder tests or tensile beam flexural tests should be

performed to determine concrete cracking strength (early age cracking). The determination of early age modulus of elasticity is also important (measure of deflection).

1.7 PREVIOUS RESEARCH

The bulk of the available work on this subject spans a period starting in 1952 to the present time. The first important paper on the shoring topic was produced by Neilson (1952), who performed analytical work on the calculation of construction load distribution in shores. However, his method proved to be complex and not practical for use by engineers and contractors.

The paper by Grundy and Kabaila in 1963 is considered the landmark paper on the calculation of construction loads in shoring systems. Their work was logically similar to that of Neilson's but with simplifying assumptions making their method easy and practical for use by engineers and contractors. Their method has since been known as the Simplified Method. Grundy and Kabaila presented examples of two and three levels of shores and showed that the load carried by the lowest supporting slab increased with the number of shored floors. Given its importance in the field of shoring and the fact that most analytical work since 1963 has been based on it, the Simplified Method will be discussed in more detail in the following section below.

Since the work by Grundy and Kabaila, several researchers have further advanced the topic. Agarwal and Gardner (1974) extended the Simplified Method to accommodate reshoring. The refinement by Agarwal and Gardner is referred to as the Extended Method in this thesis. Stivaros and Halvorsen (1990, 1991 and 1992) refined the Extended Method using the Equivalent Frame Analysis and refined assumptions to develop an application using microcomputers. Arafat (1996) extended the work by Stivaros and Halvorsen. He studied the significance of taking into account the development of concrete strength by applying the maturity method.

The Simplified Method was also refined by Liu, Chen and Bowman who developed a two dimensional computer model. Gardner developed a computer program (applying the Extended Method) for use by engineers and contractors to determine the most effective shoring/reshoring schemes, formwork stripping times and maximum forces

in shores and reshores due to construction loading for a given shoring/reshoring scheme. The most recent work, by Beeby, involved the use of finite element modeling and a more realistic modeling approach using shore stiffness.

Some research has concluded that the variation in load ratio with stiffness for timber shores is greater than with steel shores, with the stiffness of adjustable steel shores being sufficiently high to justify the assumption of infinite stiffness in the calculation shoring/reshoring load ratios (Beresford 1964). Major papers on the topic are discussed in detail in Chapter 2.

1.8 THE SIMPLIFIED METHOD

Since their landmark paper in 1963, most researchers and code authorities have recognized Grundy and Kabaila's Simplified Method, as extended by Agarwal and Gardner (1974), as the most practical method for the calculation of load ratios due to shoring during the construction of reinforced concrete buildings.

Because of its importance, the Simplified (Extended) Method is discussed in detail. The Simplified (Extended) Method uses simplifying assumptions to reduce the complexity of exact calculations of shoring/reshoring load ratios.

The simplifications made in the application of the Simplified (Extended) Method include, but are not limited to, the following:

- Shoring loads are applied as uniformly distributed loads to the supporting slab immediately below
- The axial stiffness of shores is considered to be infinitely rigid, thus all slabs interconnected by shores and reshores are assumed to deflect equally when a new load is added (the shores/reshores can be considered as continuous supports, with K being infinite)
- Foundations supporting shores at the first level are infinitely rigid
- All slabs are assumed to possess equal flexural stiffness without considering the concrete age (it has been reported that the effect of slab stiffness affects the results by approximately 5 to 10% of the maximum slab load). An increase of

slab stiffness with age can be incorporated, but this requires knowledge of the casting and stripping schedule.

- After removal of the shores, the forms are removed so that floor deflections occur before the installation of any reshore
- Calculated load ratio results can be increased by roughly 10% to include the self weight of forms and props
- Due to the weight of workers, equipment, materials, dumping and impacts produced by casting, complementary live loads must be added to the maximum construction load values of the floors and props
- The effect of shrinkage and creep of the concrete can be neglected
- Torsional moments and shearing forces in the formwork are neglected and hence the reaction produced by a support is assumed to be directly proportional to its compressive load

The Simplified (Extended) Method calculates the multiples of dead load (load ratios) supported by slabs and shores/reshores for each stage of shoring/reshoring and casting of slabs. Load ratios are calculated for each level as they occur so that the calculations take into account the entire construction history of a building. This method is best illustrated by example.

The following example (Figure 1.4) illustrates the application of the Simplified (Extended) Method for the calculation of shore, reshore and slab dead load ratios for flat slab construction using two sets of shores and two sets of reshores. Figure 1.4 below was taken from Gardner 1979.

Shore, reshore and slab dead load ratios are calculated step by step starting from the ground floor. Each level includes two steps. Step “a” is the erection of shoring while Step “b” is the casting of the next slab. The following discusses several of the steps illustrated below to demonstrate the Simplified (Extended) Method:

- Step 1a: Shoring is erected for the first level
- Step 1b: The first level slab is cast. The weight of the first level slab is supported by the shoring. The slab does not support any load.

- Step 2a: Shoring is erected for the second level
- Step 2b: The second level slab is cast. The weight of the second level slab is supported by the second level shoring and then transferred directly to the first level shoring. The first and second level slabs do not support any load.
- Step 3a: Shoring from the first level is removed and erected at the third level, thus allowing the first and second level slabs to deflect. The first level is then reshored. The first and second level slabs support their own self weight with no loads supported by the shoring/reshoring.
- Step 3b: The third level slab is cast and is supported by the shores and reshores below while the first and second level slabs support their respective self weight.
- Step 4a: Shoring from the second level is removed and erected at the fourth level, thus allowing the second and third level slabs to deflect and equally share the weight of the third level slab. The second level is then reshored.
- Step 4b: The fourth level slab is cast. The weight of this slab is transferred to the foundation by the shores/reshores below, thus the loads in the slabs below does not change.
- Step 5a: The shoring is removed from the third level and erected on the fifth level. This allows the third and fourth level slabs to deflect and each support half of the load in the shoring removed. The third level is then reshored.
- Step 5b: The fifth level slab is cast. The weight of the fifth level slab is shared equally among the four slabs below.

The steps are repeated for the number of levels being cast. It can be seen from Figure 1.4 below that the maximum load ratio (multiple of dead load) for two sets of shores and two levels of reshores is 1.75 for the last slab supported from the ground (slab two cycles old).

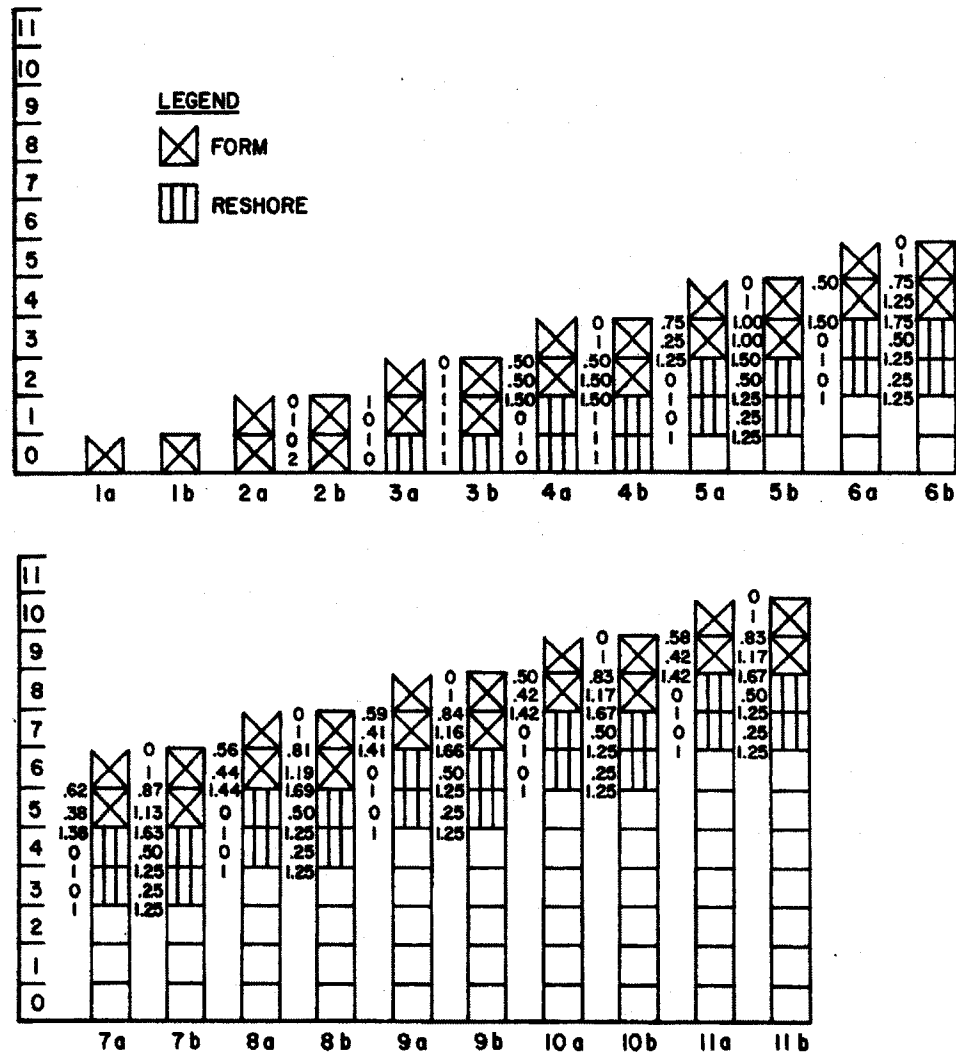


Figure 1.4: Construction dead load ratios for 2 sets of shores and reshores (Gardner 1979)

Previous researchers have compared the results of the Simplified (Extended) Method with measurements taken on flat slab concrete buildings under construction (Agarwal 1974). It was reported that the experimental results were generally in good agreement with the predicted values. However, Stivaros (1990) concluded that the agreement between the experimental and predicted values in the research by Agarwal was due to the measurements being taken near the center of the slabs, thus ignoring the influence of structural continuity. In addition, the measurements did not start from the ground level, thus the full loading-unloading construction cycle was not recorded.

Stivaros also concluded that the agreement between the measurements and predicted values were due to the use of steel shores, which justified the first assumption of the Simplified (Extended) Method.

1.9 DISAGREEMENTS WITH THE SIMPLIFIED (EXTENDED) METHOD

Assumptions made by the Simplified (Extended) Method have been shown by several authors to overestimate the loads supported by shores/reshores and consequently underestimate the supporting slab loads. This phenomenon is due in part to the following:

- Shores and reshores are not infinitely stiff. Load distributions are affected by the compressibility of shores and the magnitude of this effect is dependent the modulus of elasticity of the shores/reshores.
- The foundation supporting the base shores/reshores may not be infinitely stiff. This depends on soil types and whether or not support is provided by structural elements such as concrete slabs on grade.
- The loads applied by shoring may not be uniformly distributed
- Not all slabs have equal flexural stiffness
- The effects of shrinkage and creep could have an effect on calculated load ratios
- All reshores do not support an equal amount of load. A reshore member placed closer to a column will not support the same load as one near the center of a panel

Alone, any of the above factors may only have a small effect on the calculated load ratios using the Simplified (Extended) Method. However, in combination, these factors may have a significant effect.

1.10 RESEARCH OBJECTIVES

Most of the research to date on the subject of shoring and reshoring has been based on the Simplified (Extended) Method. Some of the more recent research has taken into account some of the variables neglected by the Simplified (Extended) Method. However, none of this research has performed a real life evaluation incorporating all of the factors which may affect the construction load distribution through shoring/reshoring and supporting slabs. Some research has endeavored to improve on the Simplified (Extended) Method. However, some of this research has been based on simplifying analysis using two dimensional simplified models (Liu et al. 1988, Stivaros and Halvorsen 1991). Beeby's (2000) research used finite element analysis to develop a simplified calculation of load ratios using a spreadsheet program. However, the scope of application and flexibility of Beeby's simplified calculation is not clear and, based on the examples he provides, equilibrium does not seem to be satisfied. Beeby's method also uses simplifications for the calculation of slab deflections used in the calculation of load ratios.

The research presented in this thesis endeavors to improve upon the Simplified (Extended) Method, while maintaining its ease of use and practicality, by taking into account most of the factors affecting the load distribution in shores/reshores and slabs during construction. The following will be developed:

- A simple and practical method for the calculation of shoring/reshoring load ratios for both engineers and contractors. The method will be based on real life parameters best representing the actual behaviour of the structure during construction. Deflection ratios will be determined by the use of advanced finite element analysis.
- A computer program capable of transforming simple input parameters into simple and practical output for the determination of the optimum shoring, reshoring and stripping schedules.

The method developed in this thesis assumes the following parameters. Most of these are contrary to those of the Simplified (Extended) Method. To our knowledge, no

research to date has developed such a comprehensive and realistic method for the calculation of load ratios due to construction loads in flat slab buildings.

- The loads applied to the underlying shores are not necessarily uniformly distributed. Modern construction procedures often utilize flying table forms or proprietary scaffold systems with wider leg spacing. This research assumes that the loads on each formwork support is based on the tributary area of the support. This may not always be true since the distribution of loads in flying table forms may depend on the design stiffness of main flexural members. This analysis would be left to the design engineer since the load distribution to shoring legs depends on the exact type of shoring system.
- Shores are not infinitely stiff. It is true that the axial stiffness of shores may be larger than the flexural stiffness of slabs. However, the fact that the shores undergo axial deflection cannot be discounted. The axial deflection of reshores and the associated increase in load supported by the slab will be compounded the greater the number of floors shored/reshored.
- The relative stiffness of different age slabs has a contributory effect on the distribution of loads between shores, reshores and slabs.
- The foundation (at the first level of shores) may not be completely rigid and the load distribution in the shores and slabs above may be affected by the foundation stiffness.

What is of importance is to develop a method for the evaluation of shoring, reshoring and slab loads during construction which will be as practical to use as the Simplified (Extended) Method for the design of shoring/reshoring schedules. However, to be feasible, this method must be simple to use. The computer program developed will facilitate use by engineers and contractors and yield an increased reliability of results, which would provide more cost effective and safe shoring/reshoring schedules. The ultimate goal is to standardize the analysis of shoring/reshoring schedules using realistic parameters and slab stiffnesses determined from three dimensional finite element analysis and to have this work adopted by building codes. To our knowledge, no similar standardized analysis currently exists.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Numerous publications detailing previous research on the topic of shoring/reshoring of flat slab concrete buildings were reviewed as part of the research presented in this thesis. This chapter summarizes the most pertinent of the publications reviewed. The intent is to provide the reader with previous research results while highlighting similarities and differences with the research presented in this thesis.

The papers discussed in this chapter are categorized in two sections. The first section, Analysis of Shoring/Reshoring Loads, presents previous work dealing with the calculation of shoring/reshoring/slab loads during construction. The second section, Other Aspects of Shoring/Reshoring, discusses work dealing with various other topics pertaining to the shoring and reshoring. The papers within each section are presented in chronological order. Because of its significance, the landmark paper by Grundy and Kabaila was discussed in Chapter 1.

2.2 ANALYSIS OF SHORING/RESHORING LOADS

After Grundy and Kabaila, several authors studied and developed methodologies for the calculation of construction loads in multi-story flat slab construction. The following section highlights such works which are deemed to be significant to the topic of shoring/reshoring and present an advancement in the field.

2.2.1 Agarwal 1972, Agarwal and Gardner 1974

Agarwal and Gardner conducted field measurements to determine the actual load ratios applied to slabs, shores and reshores during construction at two construction sites. The measured load ratios were compared with theoretical values calculated using the Extended Method (developed by Agarwal and Gardner based on the Simplified Method to account for reshoring). The goal of the research was to develop a methodology to determine a shoring and reshoring schedules for use in practice for different rates of construction, types of cement and ambient temperatures.

As part of this research, the importance of applicability of shore stiffness was examined. From the measured values observed for steel shores at both sites studied during construction, it was concluded that the assumption of completely rigid shores made by the Simplified and Extended Methods was justified.

Arrangements of various levels of shores and reshores were examined. It was determined that maximum load ratios increase with an increase in the number of shores and reduce with an increase in the number of levels of reshores.

The following assumptions were made in the calculation of load ratios using the Extended Method for comparison with the measured values:

- a) The weight and structural design of all slabs were substantially equal
- b) The weight of the freshly placed concrete and formwork was 110% that of the slab self weight
- c) The placing and curing temperature of the concrete in the early stages was 70 to 85 degrees Fahrenheit

It was reported that the experimental shore load measurements were in good agreement with those calculated using the Extended Method. It was also reported that the experimental values are likely varied by a margin of approximately 10% due to:

- a) The variation in atmospheric temperature between the dummy gauges and the active gauges used for the experimental measurements on shores
- b) Variation in cross sectional area of different shores
- c) Large length of electrical connection wires used for the measuring apparatus

- d) Plugging in and unplugging of the connecting wires to the measuring apparatus several times
- e) Differential effects of the wind on the strain gauges
- f) Bond between the steel shores and strain gauges

In addition to the good agreement between the calculated and experimental values, the following conclusions regarding the evaluation of shoring/reshoring load ratios were also presented:

- a) Construction loads on slabs can clearly exceed the design load by a considerable margin and thus should not be ignored during the design of slabs
- b) The analytical prediction of construction loads yielded an acceptable accuracy and the methodology is simple and easy to use.
- c) Increasing the number of levels of shores does not reduce the maximum construction load of a slab. Instead, the maximum construction load increases with the number of levels of shores. The age of the slab at which the maximum load occurs also increases, but the increase in concrete strength does not necessarily offset the increase in load. Therefore, it is suggested that no more than two or three (preferably one) levels of shores be used.
- d) It is suggested that the slab carrying the absolute maximum load be kept on props continuous to the ground for a longer period of time.

2.2.2 Gardner 1979

This paper is a summary of relevant information and presents a methodology for the control of construction loads in multistory concrete flat slab buildings taking into account member strength gain with time and temperature. The analysis of load ratios presented is based on the Extended Method. A solved example for the determination of shoring/reshoring and slab forces for an eleven storey building using two levels of shores and two levels of reshores (the example presented in Chapter 1) was presented.

The methodology for the calculation of construction loads developed assumes the following for the loads applied to each slab:

- a) Construction load factor (dead and live): 1.4
- b) Factor for error in theory (due to the use of a constant modulus of elasticity): 1.1
- c) Factor for the weight of shores/reshores/formwork: 1.1

The dead load ratios calculated from the Extended Method and the dead load of the slabs (tributary area per shore) are multiplied by the above factors, giving the dead load per slab shore. The factored construction live load per shore (also based on tributary area) is added to the dead load ratio, which results in the construction load ratio on each shore/reshore (U_{needed}).

After the loads have been calculated, the focus turns to the available resistance of the slabs. The method developed makes the following assumptions regarding the capacity of the slabs:

- a) Design Dead Load Factor: 1.4 (per CSA and ACI)
- b) Design Live Load Factor: 1.7 (per CSA and ACI)
- c) Development of tensile/bond strengths: $(f'_c)^{0.8}$ (Note: Gardner has since reported that the development of tensile/bond strength is a function of $(f'_c)^{1/3}$)

To determine the available slab strength ($U_{\text{available}}$), the design ultimate load capacity ratio for the slab ($U=D(1.4+(1.7)L/D)$) is multiplied by the reduction factor for the available developed concrete strength $((f'_c/f'_{c,28})^{0.8})$.

Thus U_{needed} is compared with $U_{\text{available}}$ and a determination is made as to whether or not the proposed construction schedule is adequate. If it is not, changes can be made such as an increase in cycle time or increase in concrete strength (early strength cement).

Based on the methodology developed, the use of a single level of shores and multiple levels of reshores as required for all multi storey flat slab construction (this combination yielded the lowest load ratios) was recommended.

2.2.3 Lasisi and Ng 1979

Lasisi and Ng developed a modified form of the Simplified (Extended) Method of analysis for the calculation of construction loads. Forces in shores and reshores during construction were measured and compared to the results of the analytical method. The

addition of a construction live load component to the analysis was also proposed since the Simplified (Extended) Method does not currently incorporate live load.

It was reported that a minimum load on reshores is required to engage them and ensure they don't fall when concrete is cast in adjacent bays (due to upward deflection). A minimum load of 4 kN is recommended to ensure the stability of reshores.

For the experimental measurements performed on reshores, the following assumptions were made:

- a) Each reshore carries a fraction of the construction load from above in proportion to the area of the floor slab that it supports
- b) The modulus of elasticity of the concrete slabs connected by shores and reshores is constant. Therefore, the construction load from a new slab is distributed equally among the supporting slabs.
- c) All shores have equal initial tightening forces

The results of the theoretical analysis (Simplified (Extended) Method taking into account construction live load) were compared with the measured values from an actual construction site. The maximum measured values corresponded well with the maximum predicted values. However, the average measured loads were found to be considerably less than the calculated values. It was also concluded that the recommended construction live load value specified by the ACI was justified

2.2.4 Liu, Chen and Bowman 1985

This work attempted to quantify the errors incurred when using the Simplified (Extended) Method to predict shore and slab loads during construction. Modification factors to account for the errors were suggested in an effort to develop a refined analysis method.

The Simplified (Extended) Method assumes shore stiffness to be infinite such that all slabs interconnected by shores deflect equally when a new load is added. All slabs are assumed to possess equal flexural stiffness and it is assumed that the difference between this assumption and reality is only 5 to 10%. In addition, the foundation at the ground level is assumed to be infinitely rigid, which may be true if a ground floor slab is in place

to support the shoring. However, if shores are supported on mud sills, this assumption may be totally erroneous.

Previous measurements of construction loads performed by other authors were discussed. Three factors regarding these previous measurements were highlighted as follows:

- a) Field measurements were not taken from ground level, so the actual slab and shore loads of the entire slab system during construction could not be determined.
- b) The shores and reshores typically chosen for instrumentation were located in the central portion of slabs. Therefore, the influence of the boundary conditions (beams, columns) were less pronounced.
- c) The values of shore stiffness and shore height were not reported in the work by one of the authors. Therefore, the measured values cannot be used for comparison with other work or analytical methods.

To account for the deficiencies in the assumptions of the Simplified (Extended) Method, a method using elementary matrix computer modeling was developed. A two dimensional model was developed employing the following assumptions:

- a) Reinforced concrete slabs are assumed to be linearly elastic and their stiffness time dependent
- b) The shores and reshores act as continuous uniform elastic supports with axial stiffnesses that are finite and time independent (The author states this assumption but the reshores shown in the sketches presented in the paper indicate discrete shores with pinned ends).
- c) The slab edges are either fixed or simply supported
- d) Joints between the shore and the slab are assumed to be pin-ended
- e) The foundation is assumed to be rigid and unyielding

From the comparison of the Simplified (Extended) Method, the refined method and field measurements, it was concluded that:

- a) The Simplified (Extended) Method is easy to use and apply and therefore is attractive.
- b) Comparison between the maximum loads calculated with the simplified and refined methods indicated a maximum relative difference in the two methods varies between

-5 and +9 percent. Because the effect of shore stiffness is not considered, the errors in the Simplified (Extended) Method are greater than those in the results predicted by the refined method.

- c) The Simplified (Extended) Method reliably predicted the construction step and location where the maximum slab and shore loads occur but generally underestimated the actual load ratios. Consequently, the maximum slab and shore loads predicted by the Simplified (Extended) Method can be corrected using a modification factor. Modification factors of 1.05 to 1.10 were suggested.

2.2.5 Liu and Chen 1986

Liu and Chen developed a three dimensional computer model capable of predicting the maximum construction loads in wooden shores in reinforced multi storey buildings. This model was used to examine the influence of random construction variables on construction loads.

The model developed (single bay model with two slab levels) assumed the following:

- a) Reinforced concrete slabs are linearly elastic and their stiffness is time dependent
- b) Reinforced concrete columns are assumed to be rigid and all four slab edges are free to rotate
- c) The weight and structural details of each floor are similar
- d) Wooden shores and reshores are linearly elastic supports
- e) Joints between the shore and the slab are pin-ended
- f) The foundation is rigid and unyielding

The out-of-straightness of shores and the loading eccentricity of the shores using a statistical distribution was taken into account. The variations of other parameters were also examined using statistical evaluation.

It was concluded that the influence of key random construction variables on the maximum wooden shore loads were as follows (in order of importance):

- a) modulus of elasticity for wooden shores
- b) live load, load eccentricity
- c) out-of-straightness of shores and dead load.

It was also concluded that the maximum shore loads occur on the two symmetrical axes of the slab.

2.2.6 Liu, Chen and Bowman 1986

Since it had previously been shown that the results of the Simplified (Extended) Method generally underestimates actual construction loads, a refined analysis method for the determination of shore slab interaction was developed. The basic assumptions of the refined method are as follows:

- a) Slabs behave elastically and their stiffness is time dependent
- b) The shores and reshores act as continuous uniform elastic supports with axial stiffnesses that are finite and time independent
- c) The foundation is rigid and unyielding
- d) The joints between the shores and slabs are pinned

A structural analysis program of an idealized single bay model with shores and fixed/pinned ends at the ends of the slab/beam element (two dimensional model) were used for the analysis to account for different rotational restraints at the ends of the slab. Since the stiffness of columns is much greater than that of the shores/reshores, the deflections at the columns was neglected. Flexural effects in the direction perpendicular to the slab/beam element in the model were also neglected, thus treating the analysis problem as a two dimensional one. This simplification is thought to be valid if the weight and structural detail of each floor are similar and the shores/reshores are evenly distributed on each floor.

It was concluded that the differences in slab moments and shore loads predicted by the refined and simplified (extended) methods are largely related to the variations in assumptions for shore and slab stiffness.

It was suggested that the error of the shore loads predicted by the Simplified (Extended) Method depends on the ground level shoring. Until the ground level of shores/reshores is removed, the Simplified (Extended) Method overestimates the shore loads. As the concrete slabs harden, the errors increase. After the ground level of shores is removed, the Simplified (Extended) Method underestimates the shore/reshore loads and the loads on the hardened slabs and overestimates the loads on the most recently cast slab.

Although the results of the refined analysis diverged from those of the Simplified (Extended) Method (mostly due to slab and shore stiffness), the Simplified (Extended) Method can still be used if the results for shore and slab loads are adjusted by a modification coefficient. It was also noted that, as the shore stiffness increases, the results of the refined analysis converge with those of the Simplified (Extended) Method.

2.2.7 Aguinaga-Zapata and Bazant 1987

Aguinaga-Zapata and Bazant developed a computerized method for analyzing the forces in shores and reshores during construction of concrete slab buildings. Of special interest were the long term deflections that account for creep of concrete, differences in age of concrete and the precise construction sequence.

The computer program developed assumed an infinitely rigid foundation. It was also assumed that the reshoring operation takes place in the middle of the casting cycle and a 0.2 day interval is allowed for the slab to reach its natural deflected shape after removal of shoring. The overall effect of creep is transfer of part of the load from the series of shored floors to the series of reshored floors.

It was reported that the differences between calculations based on the model developed and measurements taken by other authors may be due to the neglect of other influencing factors in their assumptions such as shrinkage warping (due to unsymmetrical drying and cracking) which would tend to increase loads on older slabs and decrease loads on younger slabs. In some cases, shrinkage warping was deemed responsible for the vanishing of forces in shores shortly after casting.

The following conclusions regarding the effects of creep on the load distribution in slabs and shoring/reshoring due to construction loads were presented:

- a) Taking creep into account is theoretically more justified than the existing methods which neglect creep.
- b) Creep does not appear to be significant in shores when no reshoring is present. The effect of creep is more significant but still not very large when reshoring is performed.
- c) The practical usefulness of the method developed in this paper taking into consideration the effects of creep makes possible calculating long term deflections as affected by early age loading history.

It was suggested that the solution developed in their work should not be construed as complete. To achieve a fully realistic model, it would be necessary to take into account shrinkage warping, the effects of simultaneous drying on creep, microcracking, the nonlinearity of creep. In addition, it would be necessary to formulate the solution in probabilistic terms to obtain standard deviations of the internal forces and deflections. It was also concluded that the internal forces determined by the model developed are not much different from the Simplified (Extended) Method (elastic solution) as well as the available experimental (measured) data.

2.2.8 Gardner and Muscati 1989

Gardner and Muscati developed a computer program to analyze the safety of construction schedules for multi story flat slab buildings. The program is versatile as an erection schedule can be input to determine its adequacy or the number of forms and reshores can be input to determine the stripping and casting schedule or the stripping and casting schedule can be input to determine the acceptable form and reshore schedule.

The program applies the Extended Method for determining load ratios on slabs and takes into account the maturity of individual slabs. The calculations are sensitive to the relationship between concrete shear strength and cylinder strength. It is recommended that designers apply conservative estimates of strength unless they are confident of the available shear strength of the concrete.

The program developed enables engineers to easily and accurately evaluate form and reshore schedules without the need for tedious manual calculations and is user defined for various code specified load factors and shear strength expressions.

2.2.9 Stivaros and Halvorsen 1990, 1991 and 1992

Stivaros and Halvorsen developed a computer based method for the analysis of construction loads using a two dimensional model based on the equivalent frame method. The equivalent frame method was applied using a computer to analyze a single and multi-bay models. Only the interior span of the multi-bay model was analyzed.

The multi-bay model always predicted higher maximum slab loads than the single bay model (with differences up to 14%). However, it was also shown that as the number of shored levels increase, the difference in results between both models was as small as 5%. Taking into account shoring stiffness, the multi-bay model predicted higher values than the single bay model, with the differences diminishing as the shore stiffness increases. The results of the equivalent frame method and the Simplified (Extended) Method converged as shore stiffness increased.

It was reported that a single bay model cannot adequately predict the shear load effects in interior columns due to both shear and unbalanced moments. Shear is critical as catastrophic collapses during construction are often the result of inadequate shear capacity, a function of the concrete strength developed.

When using two shored and one reshored levels, the simplified (extended) and the equivalent frame methods converge (approximately 5% difference) and as the number of reshored levels was increased, the difference between the two methods increases. This suggests that the previously proposed correction coefficients for the Simplified (Extended) Method of 5 to 10% may not be adequate for all shoring systems (i.e. Liu, Chen and Bowman 1985).

Concrete age yielded differences in calculated construction loads of up to 7% (between 3 and 7 day cycles). It was also shown that stiffer slabs (such as those with beams or drop panels) shared higher proportions of load than flat slabs. Thus it was

concluded that a change in slab stiffness affects load distribution (if shore stiffness is infinite, slab stiffness variation has a minimal effect).

The effect of shore stiffness can have a significant effect in construction load distribution. The stiffness of the shoring system is the most important factor in the mechanism of construction load distribution between the shoring system and the interconnected slabs. It was also concluded that the effect of shore stiffness can vary according to shore type, construction schedules and the individual structure itself. Therefore, it is not possible to establish standard patterns of load distribution valid for cases where compressible shores are used. Each individual construction case requires separate rigorous analysis to determine the construction load distribution.

The Simplified (Extended) Method's assumption that construction loads are applied as a UDL is not necessarily valid (i.e. very close spacing of shores). It was shown that the shore and reshore placement configuration as well as the exact number of shores/reshores can have a significant effect on the construction load distribution. The fewer the number of shores on a panel/slab, the smaller is the proportion of the construction loads shared by the slabs.

It was reported that an increase in the number of shored levels results in an increase in construction loads applied to older slabs. It was also shown that, unlike the Simplified (Extended) Method, where the construction live load is equally shared among interconnected slabs, the assumption of compressible shores and reshores tends to shift the slab loads to the uppermost floors.

Calculations as to the safety of the construction operations at the Harbour Cay Condominium structure using the Simplified (Extended) Method and the EFM single bay method was performed. These calculations concluded that the construction schedule was safe for punching shear of the slabs. A multi-bay analysis of the same structure showed that applied stresses exceeded available capacity at slab to column connections, suggesting that the single bay models were unconservative for this case.

2.2.10 El-Shahhat and Chen 1992

El-Shahhat and Chen developed a method for the analysis of reinforced concrete high-rise buildings during construction. The method is an improvement to the refined method (previous elaboration of the Simplified (Extended) Method developed by others) for the calculation of shore and slab loads during concrete placement. A comparison of both methods is presented below.

The refined method models the structure under construction as a structural computer model. Using matrix methods, the structure is analyzed to determine forces and displacements. Basic assumptions in the refined analysis are as follows:

- a) The slabs behave elastically and their stiffness are time dependent
- b) The shores and reshores behave as uniform and continuous elastic supports and their axial stiffness are time independent
- d) The foundation is rigid
- e) The joints between the shores and slabs are pinned together
- f) The slab edges are either fixed or simply supported

The refined analysis did not consider the history of the structure, as it did not take into account the effect of cumulative deformations with successive stages of construction.

The improved method utilizes the deflection approach by updating the deflection to the current stage of construction and establishes a system of equations for the unknown shore loads based on the deformed configuration of the structure. It was reported that the improved analysis provides a closer representation of the behaviour of the structure. The basic assumption of the improved analysis are:

- a) The slabs behave elastically and their stiffness is time dependent
- b) Shores and reshores are treated as continuous uniform elastic supports with finite and time independent axial stiffness
- c) The foundation is rigid
- d) The slab edges are either fixed or simply supported
- e) Joints between shores and slabs are pinned together and only compression forces are resisted by shores and reshores

- f) The principle of superposition was applied to determine the accumulated displacements due to successive loading steps and removing shores and reshores

The procedure developed for the calculation of construction load ratios for the improved analysis is divided in two. First, the refined method is used to analyze the structure under construction as a slab-beam element (two dimensional analysis). This is applied for the loading cases during the placement of concrete for slabs. Thus, the shore and slab loads and the displacements for the different points in the structure can be determined.

Secondly, removal of shores and reshores is examined following the displacement approach. This is achieved by considering the shore/reshore loads as unknown values and calculating the displacement as a function of the shore loads. By the application of compatibility of displacements, the unknown shore loads can be obtained.

It was concluded that the differences in the slab moments between the refined and improved methods were -8 and $+20$ percent respectively and maximum difference in the values of shore loads of -19 and $+3$ percent respectively.

2.2.11 Beeby 2000

Beeby's report describes the research performed at an experimental flat slab structure at Cardington, England. Beeby's work was part of the larger European Concrete Building Project which investigated various aspects of concrete building construction including shoring and reshoring, slab thickness, reinforcement arrangement and deflections. The investigation by Beeby focused on the early stripping of formwork and reshoring. The assessment of feasible formwork stripping time and loading applied to young slabs was established in a previous work by Beeby (2000).

The report concluded that the effectiveness of reshores in relieving loads on slabs during construction is significantly less than has been traditionally assumed. In addition, this study seemed to indicate little benefit in reshoring more than one floor.

The procedure employed for the installation of the reshores was consistent throughout the experiment, whereby they were placed into position but not tightened so that they were only loaded when additional loads are applied to the system. In practice,

reshores are often reported to be installed finger tight. Some experiments were performed on this topic, which indicated loads of up to 15 kN in the reshores by finger tightening.

The design loading for the experiment was determined using of the Simplified (Extended) Method. The instrumentation on the reshores was concentrated on two panels per floor on the 7 storey flat slab concrete building; an edge panel and an interior panel, which Beeby stated were not complicated by awkward boundary conditions.

The most immediately noticeable difference between the measured and calculated forces is that the measured forces are always lower than the predicted values. Therefore, a larger than predicted proportion of the load was supported by the uppermost reshored slab with less load being transferred to the slabs below. Thus, assuming the full design construction loads were actually applied, the slab supporting the shores would be significantly overloaded. This overloading was not observed during the experiment, which is attributed to the actual construction live loads likely being significantly lower than the assumed construction design load.

It was concluded that the differences between calculated and predicted values were due to the following factors:

- a) The backprops cannot be considered to be infinitely rigid.
- b) The assumption that shores and reshores apply uniformly distributed loads to underlying slabs is not valid

It was also reported that the forces in the reshores varied with time even though no major operations such as casting concrete and removal of formwork were occurring. This was attributed in part to variations in construction loading but more significantly to the variation in ambient temperatures (i.e. an increase in temperature creates an expansion of shores thus increasing the load in the shore). The forces induced in the reshores due to temperature increases were found to vary depending on placement of reshore (i.e. interior of panel, free edge).

The results discussed to date have dealt with average backprop loads for each panel. However, the forces in all reshores are not necessarily the same as the forces depend on the position of the reshores. It was also stated that an increase in the number

of reshores has the same effect as increasing the stiffness of reshores by the same proportion (i.e. doubling the number of reshores has the same effect as doubling the stiffness of the reshores).

Beeby stated that all previous analytical work assumed that reshores were placed directly below shores. This was not the case at Cardington and the Beeby does not believe that this is the case in practice. It was concluded that the location of the shores relative to the reshores has a significant effect on the loads in the reshores/slabs. This is due to the difference in form of the deflected shape when loaded by the shores compared with being loaded by the reshores (differences in deflection coefficients at the reshore locations).

Based on the experimental results of the Cardington building, a matrix (stiffness method) of equations to solve for the loads in shores/reshores was developed. A simplified method of calculating deflection coefficients was used. This method superimposes deflections based on strips in each direction of two way slabs. This is an approximation that underestimates deflections at column lines, therefore a modification factor was used to account for this.

The analytical method developed by for the calculation of reshore/slab forces made assumptions and yielded conclusions as follows:

- a) The slabs remained elastic with little flexural cracking.
- b) Preload in reshores due to initial tightening has some beneficial effect on the load transferred from the upper to the lower slabs by the reshores.
- c) The forces in reshores can be calculated with reasonable accuracy using the equations derived, if the preload in the reshores is known.
- d) The forces transmitted by reshores to lower floors are significantly smaller than has normally been assumed, thus meaning that the slabs supporting the shores carry a greater load than assumed.
- e) Both measured and calculated reshore forces show that there is little benefit for reshoring through two levels.

The reasonable agreement between the calculated and measured deflections indicated the validity of assuming the slabs as being uncracked when calculating

reshoring forces. Reinforcement was ignored in the calculation of deflections. It was suggested that ignoring the effect of reinforcement on deflection (reducing deflection) compensates for the presence of some limited cracking in the slabs.

A user friendly Microsoft Excel spreadsheet for the calculation of reshore forces was developed based on the more complex matrix method described above. The spreadsheet program seemed to underestimate backprop forces by approximately 6% on average. It was suggested that a correction factor to compensate for this difference should be applied. However the difference is so small that the application of the correction factor may not be necessary.

An anomaly due to the presence of shores near supports (beams, columns) was reported. If reshores lie closer to the supports than the shores, then from simple statics it can be seen that a negative reaction will be created at the support thus increasing the reshore load. The opposite happens when the shores are located closer to the support than the reshore. Furthermore, it was concluded that shores located close the supports simply transfer load directly to the supports and not the reshores. It was concluded that, because of these factors, no simple general equations could be developed for slabs supported on four sides.

2.2.12 De Almeida Prado, Silva Correa, and Ramalho 2002

De Almeida Prado, Silva Correa and Ramalho developed a methodology for the evaluation of construction loads based on sequential analysis using finite element modeling. The methodology takes into account the entire construction schedule (with the progressive addition of floors), thus simulating the shoring system with appropriate stiffness and predefined location of shores/reshores. All the different construction stages are considered, evaluating the strength and deformability properties of the slabs, beams and columns according to the concrete's maturing age.

The basic idea of the sequential method is the individual analysis of each construction stage. Each new event defines a new construction stage. Such events are the installation of shores and forms, casting, the removal of forms and shores and the placement/removal of reshores.

The structural analysis of each construction stage is performed with a three dimensional finite element model considering the material and geometric linearity. The foundation is considered to be rigid and shores are considered to be pinned to slabs. In addition to the results of internal forces, stresses, displacements and strains, the analysis developed allows for the evaluation of the loading history of each structural member, from the start to the conclusion of the construction work.

Computer based structural analysis of buildings usually considers that the entire structure exists when the loads are applied. Thus, the design process is developed after identifying the internal forces, displacements etc. through a global one step analysis, verifying the service and ultimate limit states. The global analysis is valid for vertical loads applied after the entire structure is completed. For loads such as the structure's self weight, which are imposed gradually during the progression of the construction phases, a global one step analysis is inaccurate. It is better to take into account the building's construction sequence and sequence of application of superimposed dead loads.

The distribution of construction loads changes continuously. At casting, a floor cannot support any load. However, as the concrete of the new floor and the entire structure matures, the concrete is capable of supporting some load.

Considering the construction of one floor per week, the load distribution should be calculated seven days after casting. Thus it is necessary to reanalyze the partial structure after that time, this time without the live loads. Modeling of the new floor stages is only necessary to evaluate transient construction safety and to establish the history of the structural elements' loads. To obtain the final results for the whole structure, the analysis may neglect these stages.

Based on the step by step analysis, an approximate method of analysis was developed, similar to the Simplified (Extended) Method but simpler and quicker to use to than the sequential analysis involving step by step work. The approximate method neglects the self weight of the shores and forms.

It was concluded that the Simplified (Extended) Method fails to consistently present the same results for different building structures. The approximate method corrects this problem, establishing the load distribution proportions with the primary structures.

The approximate method includes several other features. Firstly, the relative stiffness of floor and props are taken into account. Secondly, the columns do take some loads during the casting of new floors since they are finished and form the bearing system of the floor together with the props.

It was reported that the approximate method agrees well with the sequential analysis in some cases while in others the results diverge. It was also reported that the approximate method does present restrictions. The construction load ratios used expresses an average value for an entire floor, with some regions more and others less loaded by the props. This must be understood and taken into account in cases with heavy load concentrations.

2.3 OTHER ASPECTS OF SHORING/RESHORING

Several authors have studied other aspects of flat slabs under construction including construction failures, monitoring of shoring loads, deflections, criteria for the removal of shoring etc. The following section highlights such works which are deemed to be significant to the topic of shoring/reshoring and present an advancement in the field.

2.3.1 McKaig 1962

This book discusses various types of building failures encountered in modern times. Of note is Chapter 2 which discusses several failures due to formwork (shoring) and early removal of shores (punching shear), emphasizing the importance of proper shoring, reshoring and scheduling of concrete pours. The majority of the concrete failures discussed in this book are related to shoring.

2.3.2 Gardner and Chan 1986

Gardner and Chan examined the advantages and disadvantages of reshoring and preshoring in reinforced concrete flat slab construction. Both techniques can be summarized as follows:

- a) The reshoring technique consists of the removal of formwork and shores on an entire bay and the placement of reshores without any preload, such that the reshores only support loads superimposed on the reshored slab. The disadvantage of the reshoring technique is, while allowing the upper slab to deflect reduces the amount of load on the supporting slab, the upper slab deflection may be excessive as the concrete is too young to have developed sufficient stiffness. The effect of this can be large initial deflection along with associated creep deflection, which may affect on the long term serviceability behaviour of the slab.
- b) The preshoring technique attempts to reduce the excessive deflections associated with the reshoring technique. It is a refined version of the reshoring technique, whereby the unsupported slab span is reduced and controlled. Preshoring entails leaving specified shores in place during formwork/shore removal (to reduce slab deflection). Reshores are then placed in the locations of removed shores (with preshores left in place). The preshores are then removed and replaced with reshores. This reduces the span of the slab supporting its own self weight.

It was shown that the use of shores without any reshores gives the largest absolute load ratio, preshoring the next largest and reshoring the lowest load ratio on slabs. The desired reduced slab deflections, for which preshores are used, only occur for slabs reshored to the ground. Since preshoring requires a greater care with construction supervision, it was concluded that the small difference in slab load to developed strength ratio between preshored and reshored construction would not offset the additional increase in construction supervision.

2.3.3 Grossman 1986

Grossman discusses a shoring methodology using preshores for a two day construction cycle for high-rise structures which is widely used in New York City. An example of the sequence of shoring/casting activities during the construction of high rise concrete buildings using this methodology is described below. This methodology requires two and a quarter sets of forms.

- a) Monday: Concrete for a typical slab is placed beginning at one end of the floor. Several cylinders are taken at various pour locations and are to be tested at 24 hours. As soon as workers are able to walk on the concrete surface, they start erecting the shoring/formwork for the next level, starting from the same side that casting began.
- b) Tuesday Morning: Forms are removed from column and beam sides of the slab cast on Monday. Preshores are installed under each end of alternate sheets of plywood slab formwork. The preshores are wedged securely in place, but not tight enough to cause the lifting of the slab above. After the cylinders from Monday's early morning concrete placement indicate a compressive strength of 12MPa or more, the next step may proceed, but never earlier than noon.
- c) Tuesday Afternoon: A thinning out of shores begins at the end where the concrete pour began. Half the stringers and about 75 percent of the primary shores are removed. The preshores remain in place.
- d) Early Wednesday Morning: By this time, the falsework for the next slab is in place. Before placing concrete for the next level, the remaining primary shores and forms are removed, except for the plywood at the preshores. At the same time, reshores are placed and wedged against the bare concrete soffit at 2.4 meter intervals. Reshores are also placed within 0.9m from column faces on all four sides. As complete bays are stripped of all primary shores and completely reshored, and as the process proceeds into other bays, the preshores are removed.

As a safeguard, the stripping and reshoring work below the slab cast on Tuesday must be well advanced (at least two full bays ahead) before concrete placement of the next slab can begin. This is done to avoid any disturbance of the primary shores under the slab being cast and to keep workers away from the activities above.

The removal of reshores at the lowest supported level is only allowed at 21 days. Therefore, at any given time, at least 8 levels will participate in the support of a new slab and its construction live load. The division of the loads among reshores is in proportion the stiffness of each supporting slab (based on modulus of elasticity of the slabs at the time the construction load is applied).

Due to the removal of forms at such an early age, some cracking of the slabs can be anticipated. Therefore, additional reinforcement is added to help improve the effective stiffness of the slabs.

2.3.4 Hover 1988

Hover examined the effects of drying and form/shore removal on the flexural cracking in beams and slabs. It is reported that the minimum resistance to flexural cracking occurs while concrete surfaces are drying. This phenomenon is attributed to surface drying, which can decrease cracking resistance by approximately 50%. This minimum cracking strength may very well occur at the time of removal of formwork/falsework.

It was reported that the development of flexural cracking during the removal of formwork and shoring may be more sensitive to drying at the same time as loading than to the age of the concrete at the time of loading.

It was also reported that the cracking load increases very little with the increase of reinforcement. More heavily reinforced members will attain the cracking load well before their ultimate strength. Therefore, these slabs will crack at loads well below safe allowable loads. For lightly reinforced slabs, the cracking load may be similar or even greater than the allowable load based on strength. As the amount of reinforcing increases, the strength of the member increases at a greater rate than its ability to resist cracking.

Therefore, precautions to properly sequence the removal of formwork/falsework on the basis of structural capacity may not ensure that flexural cracking does not occur.

2.3.5 Gardner 1990

This work reviews the interdependence of the rate and method of construction and design code provisions on the safety and serviceability of flat slab type structures, since loads on supporting slabs during construction are determined by the construction schedule and may be large relative to the design loads.

The governing critical strength parameter for flat slab structures is punching shear. Most flat slab structures are designed with more punching shear capacity than required, which is also available during construction. In addition to loads, the contribution of creep and shrinkage to long term deflections due to construction loads are larger than the elastic deflections.

While few concrete structures collapse, these collapses usually occur during construction. Since construction workers spend their entire lives on construction sites, their risk of injury should not be greater than those of the occupants of the finished building. Therefore, it was concluded that load factors should be applied in the calculation of construction loads.

2.3.6 Ambrose, Huston, Fuhr, Devino and Werner 1993

Ambrose, Huston, Fuhr, Devino and Werner investigated sensing systems and techniques applicable to the monitoring of construction site shoring and scaffolding. It is surmised that there is an inherent limitation to computer models for the determination of the safety of formwork structures. These programs cannot predict extreme or unusual circumstances that may occur. These circumstances include the failure of structural components (without overloading) and construction crews not adhering to the shoring system design. Hence, a computer model may not correctly represent the actual loads present at the actual site.

Therefore a viable alternative to modeling the loads is the real time monitoring of the actual formwork/shoring loads. However, several limitations exist such as the feasibility of monitoring all shores and the cost of monitoring equipment.

It was also determined that by the time the instrumented shoring members were removed, the load had dropped to approximately 75% of the initial load. This was

attributed to the concrete carrying more and more of the load as it cures. When the concrete is fully cured, the shoring only carries a fraction of the load and the rest is supported by the concrete structure.

2.3.7 Gardner and Asamoah 1997

The loads occurring on the supporting slabs during construction can equal or exceed the design service load. The loads transferred to the supporting immature slabs by shores and reshores can cause extensive flexural cracking and large deflections. The high ratio of applied stress to available compressive strength and the lower modulus of elasticity of the immature concrete will cause significant creep resulting in significant long term deflections. Drying shrinkage can also contribute to the long term deflection and needs to be considered.

Excessive deflections can create serviceability problems such as cracked partitions, jamming of doors and windows and cracked and sagging floors. Therefore, the time of installation of non-structural elements is significant as damage may occur as a consequence of incremental deflection.

It was reported that most codes offer two methods for the control of deflections. The first is the calculation of deflections by the designer and comparing them with allowable limits. However, the calculation of flat slab deflections is difficult and the calculating incremental deflections due to creep and shrinkage are even more complex. The second method involves the application of code deemed-to-comply provisions based on span to thickness ratios for which serviceability is assumed to be satisfied and deflections need not be calculated.

A layered finite element program was used to study the effects of age of loading, span, panel aspect ratio, live load to dead load ratio and concrete strength on the deflection serviceability of flat slab systems. It was concluded that age of loading and span have a significant effect on the slab thickness required to satisfy serviceability requirements.

2.3.8 Rosowsky, Huston, Fuhr and Chen 1997

Rosowsky, Huston, Fuhr and Chen examined the forces in formwork shores during the actual construction of a reinforced concrete structure. It was reported that the tributary area method well predicted the average shore loads. The more conservative ACI specified construction loads approximated the maximum measured shore loads.

A great variability in the measured loads in shores, up to twice that expected from the tributary area contribution was observed. This was attributed to the variability in pre-compression of the shores during installation. In addition, a small decrease in shore loads was observed during the curing period. It is suggested that this may be the result of creep or a gain in slab strength and stiffness. It is also suggested that shore loads in steel shores can vary with daily temperature variations

2.3.9 Kothekar 1998

Kothekar compared the construction design loads mentioned in various standards (ANSI, ACI, OSHA, ASCE) with a goal of determining the adequacy of current provisions for vertical shore loads during construction. Load data from six different construction sites were used.

Based on the results of this study, it was concluded that the tributary area load provides a good estimate of the maximum average shore load. In addition, both ACI and ANSI provided reasonable estimates for maximum shore loads based on the instrumented projects considered in this study. The ACI load is lower than the ANSI which in turn is slightly lower than that obtained by the ASCE load standard. This is attributed to the ACI load being unfactored whereas the ANSI and ASCE loads are factored.

2.3.10 Beeby 2001

Beeby developed criteria for the determination of formwork stripping times. This criterion is based on two interconnected factors relating the early age of concrete to the speed of construction of multi storey reinforced concrete buildings. These are the time at

which formwork can be struck and the requirements for reshoring to ensure that slabs are not overloaded.

It was postulated that formwork stripping times are more dependent on serviceability criteria such as deflection and cracking (both related) than on strength factors such as shear and flexure (since flexural strength is influenced more by reinforcement than concrete strength and concrete strength has relatively small influence on shear strength, according to Beeby's interpretation of BS 8110).

Two criteria for the determination of formwork striking times were developed. The first is the cracking factor (F_{cr} , a function of load and modulus of elasticity and, thus deflection) and the second is the loading factor (F_w , ratio of applied load to design load). Formwork stripping times are determined by the calculation of these factors, allowing formwork stripping provided these factors are maintained below, or equal to, unity.

These theoretical criteria were compared to experimental data obtained from the Cardington Building Project and it was concluded that the criterion provided an acceptable and economical method for the determination of formwork stripping times during construction.

2.3.11 King 2004

A case study was performed on the collapse of the reinforced concrete building under construction at 2000 Commonwealth Avenue in Boston, Massachusetts in 1971. Four workers died in the collapse, however, the collapse occurred slowly enough to allow most of the workers to escape.

An investigation into the collapse concluded that the event occurred due to numerous concurrent factors, the major one being the lack of shoring under the top supporting slab during casting of the slab above. The top supporting slab had inadequate concrete strength and failed due to punching shear and created a chain reaction leading to the failure of the slabs below.

CHAPTER 3

DEVELOPMENT OF ANALYTICAL METHODOLOGY

3.1 INTRODUCTION

This chapter describes the development of the analytical methodology for the evaluation and development of shoring/reshoring cycles for flat slab buildings. The methodology was developed to be practical while reflecting the true structural behaviour (as much as is practically possible) of slab/shoring/reshoring systems. Aspects pertinent to the structural behaviour of these systems such as construction load distribution through shores and reshores, shore/reshore stiffness, slab age (stiffness), foundation stiffness and creep and shrinkage were considered.

3.2 BASIC METHODOLOGY

During the construction of reinforced concrete flat slab buildings, a freshly cast slab relies on the slabs below it for support. The Simplified Method assumes that this weight is equally shared by all supporting slabs. A methodology was developed to determine more realistic load ratios supported by the slabs in the shoring and reshoring system. A basic description of this methodology is presented below. A more detailed description is presented in the following sections.

1. The stiffness characteristics of flat slabs for unit point loads applied at desired shoring and reshoring patterns were determined. Slab stiffnesses at each shoring and reshoring location is a function of L/Δ . This was performed using a finite element analysis of selected flat slab models.

2. After the stiffnesses at each shore/reshore location had been determined, equations were developed to describe the relationship between slab deflections (function of slab stiffness), shore loads and forces in reshores (unknown). These equations were expressed in matrix form and solved for the reshore force ratios (proportion of applied load supported by each level of reshores). The total slab load ratios could be determined by calculating the differences between reshoring and shoring loads.
3. Parameters including reshore stiffnesses, age adjusted slab stiffnesses, foundation stiffness, determination of load ratios applied to shores from freshly cast slab (i.e. tributary area vs. detailed analysis) and concrete creep and shrinkage were examined.

3.3 DETERMINATION OF SLAB STIFFNESSES

Calculation of the distribution of loads from supporting slabs to reshores during the construction of flat slab buildings depends on individual slab stiffnesses. To determine the stiffness of flat slabs, a finite element analysis of selected models was performed using the LUSAS finite element software, Version 13.5-4. This software has linear and non-linear capabilities, although all slab models were analyzed assuming linear elastic behavior and uncracked slabs during construction. This assumption was supported in the work presented in Beeby 2000.

Single level flat slab models were constructed to examine different cases. It was determined that multi-storey models did not yield appreciable differences.

The models selected are described as follows:

- 3 bays x 3 bays, 9.5m x 9.5m bays
- 3 bays x 3 bays, 6.5m x 9.5m bays
- 3 bays x 3 bays, 9.5m x 9.5m centre bay, 6.5m x 9.5m edge bays, 6.5m x 6.5m corner bays
- 2 bays x 2 bays, 9.5m x 9.5m bays

Each of the models included the following characteristics:

- 300mm thick slabs (the slabs were assumed to be uncracked)
- 3.6m high column (clear storey) height
- 500mm x 500mm columns
- 500mm x 500mm solid elements (modeling of slabs)
- 250mm x 250mm solid elements (modeling of columns)

The model bay sizes, aspect ratios and individual member dimensions were chosen to provide a sample of realistic models when compared to common practice. The slab span to thickness ratios were based on current CSA-A.23.3-2004 requirements for the design of flat slabs. The optimum mesh size for the models was determined by performing a convergence analysis. The mesh size chosen proved to provide acceptable results (when compared to denser meshes) while being practical with respect to computer processing time. The finite element analysis was verified on simple slab models and compared to classical results from Timoshenko 1959 in order to verify the mesh size chosen.

The models were chosen to examine the effect of bay arrangement, size and aspect ratio of bays and number of bays. The 3 bays x 3 bays models were chosen since this was the largest size of model that could be practically analyzed. These models provided a center bay, edge bays and corner bays while being large enough to be relevant to actual buildings. Larger models became unwieldy and the extraction of deflection results became cumbersome (160000 total deflection points for a 5 bays x 5 bays model compared to 20736 total deflection points for a 3 bays x 3 bays model).

Different bay arrangements for each of the 3 bays x 3 bays models were chosen to provide a range of cases for comparison. The 2 bays x 2 bays model was chosen to determine the effect of model size (as this model can be directly compared to the 3 bays x 3 bays, 9.5m x 9.5m bays model) and since this model provides the worst case for punching shear (at center column).

The evaluations assumed the use of flying form trusses with 4 supports per truss. Three to 4 trusses per bay were used, depending on the bay dimensions. This resulted in 16 (9.5m x 9.5m bays), 12 (6.5m x 9.5m bays) and 9 (6.5m x 6.5m bays)

loading/deflection points per bay. Figures 3.1 to 3.5 describe the slab models as well as shoring and reshoring arrangements and provide the shore/reshore point numbering order described in the following section.

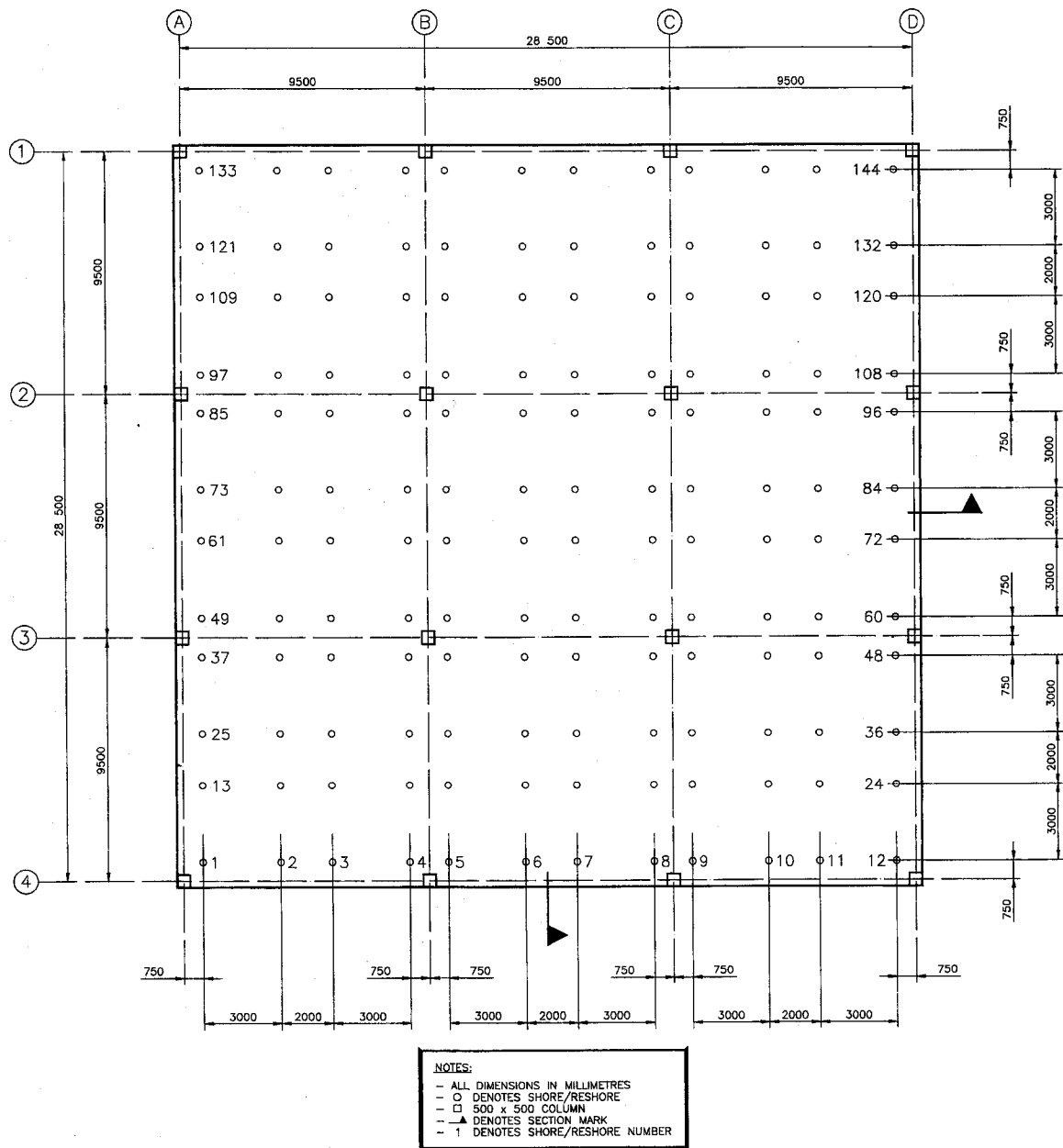


Figure 3.1: Plan of 3 bays x 3 bays, 9.5m x 9.5m bays model

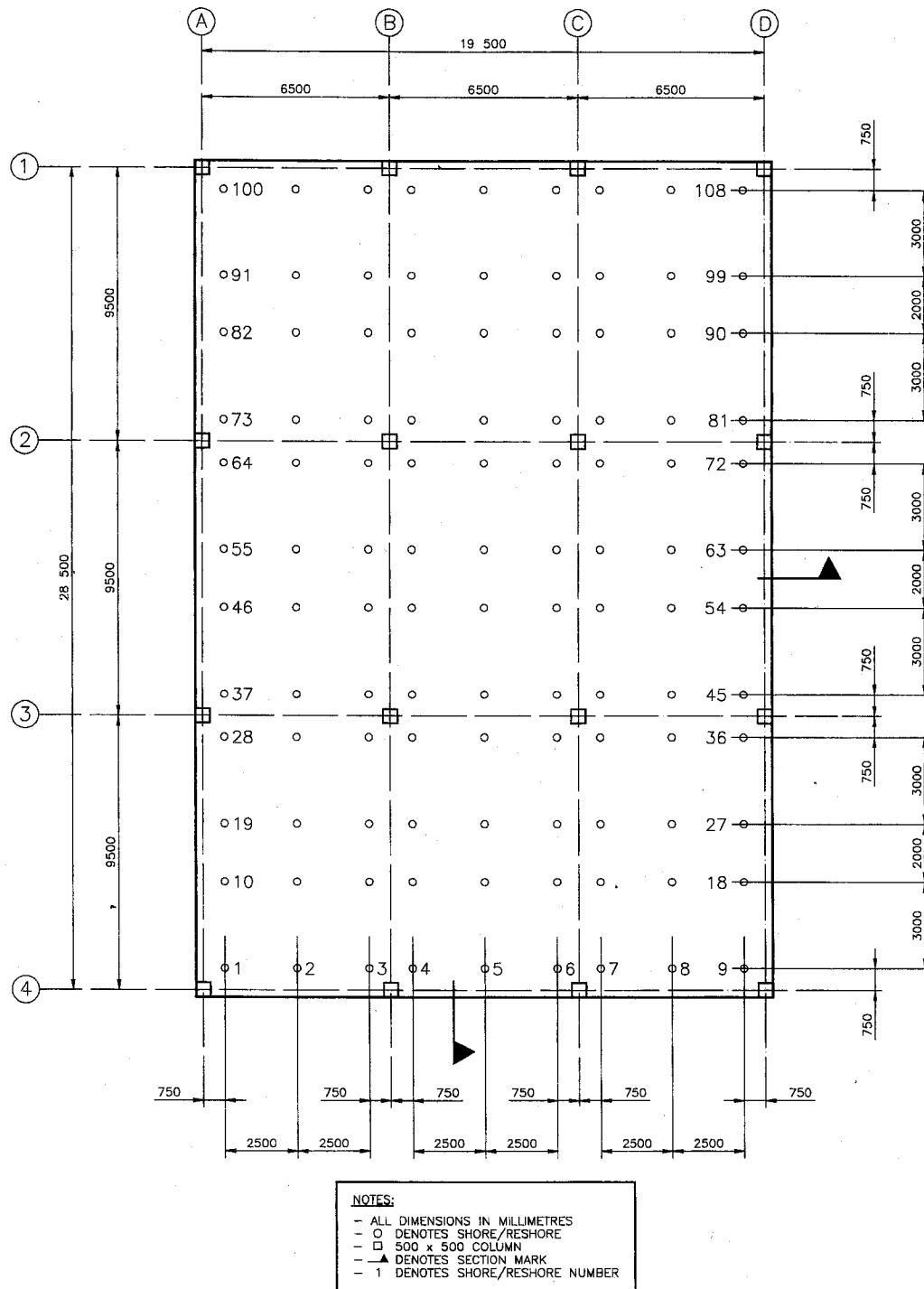


Figure 3.2: Plan of 3 bays x 3 bays, 6.5m x 9.5m bays model

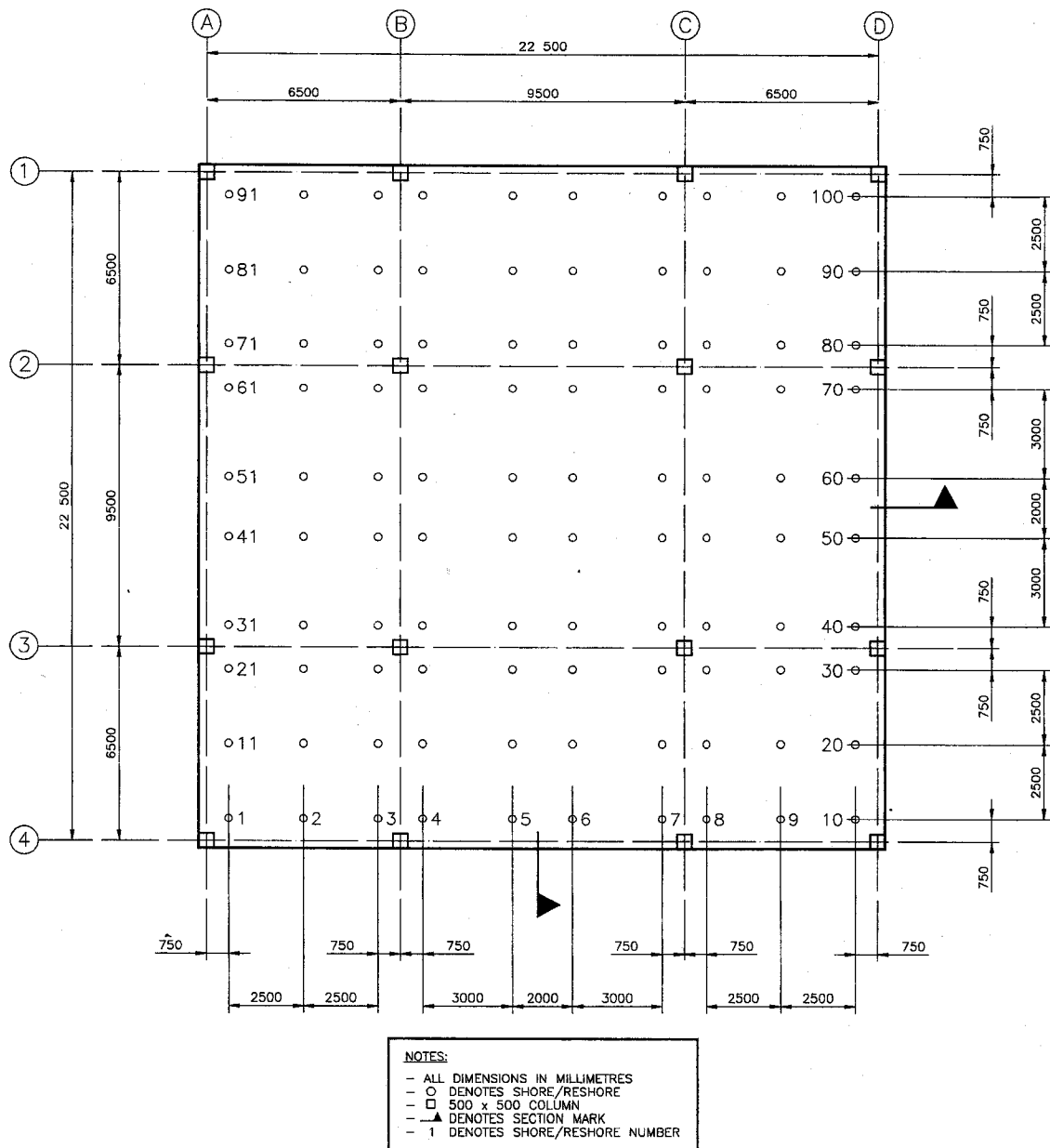


Figure 3.3: Plan of 3 bays x 3 bays, 9.5m x 9.5m centre bay, 6.5m x 9.5m edge bays, 6.5m x 6.5m corner bays model

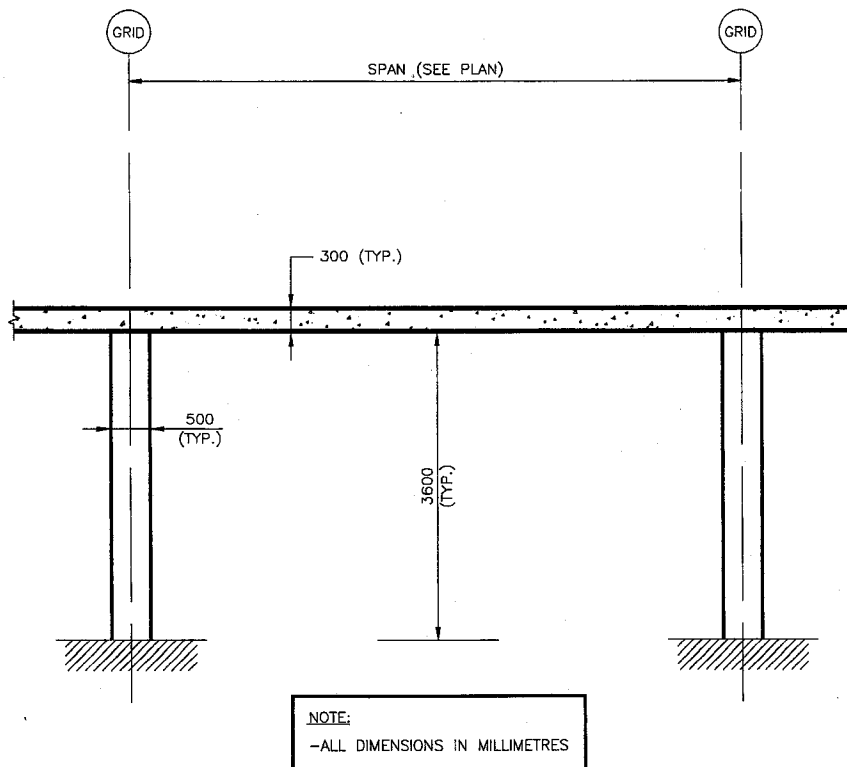


Figure 3.5: Section through a typical model

The technique for each single level model was to apply a point load at a given shore location and then calculate deflections at all designated shore locations due to this load (the slabs are un-shored and free to deflect). This was repeated for all loading points. A total number of 144 (3 bays x 3 bays, 9.5m x 9.5m bays), 108 (3 bays x 3 bays, 6.5m x 9.5m bays), 100 (3 bays x 3 bays, 9.5m x 9.5m centre bay, 6.5m x 9.5m edge bays, 6.5m x 6.5m corner bays) and 64 (2 bays x 2 bays, 9.5m x 9.5m bays) deflection calculations were generated per model. This provided the unit deflection data for all the slab models, which is the inverse function of unit stiffness. These unit deflections were stored in an array in a Microsoft Excel 2007 spreadsheet for each slab model.

Based on the unit deflection data for the finite element models, it was intended to develop a formula for the calculation of slab deflections. However, a convenient and practical formula to accurately summarize the slab deflections at any point due to a unit point load at a given location could not be developed based on the analysis of the data.

Therefore, evaluations were limited to the 4 models analyzed with typical shore and reshore layouts.

Figures 3.6 to 3.9 show the finite element meshes for each case. Figures 3.10 to 3.13 show a sample of the deflection contours plots for the different models.

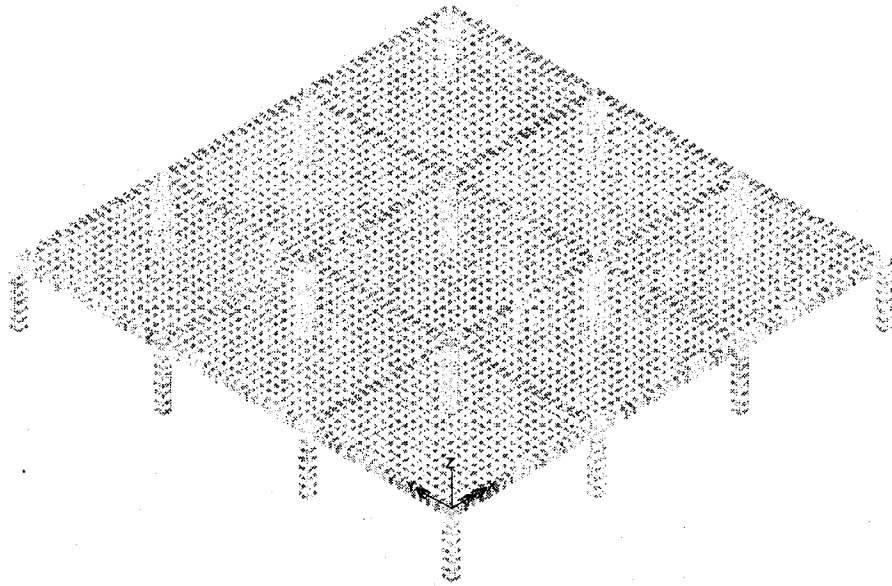


Figure 3.6: Finite element model for 3 bays x 3 bays, 9.5m x 9.5m bays

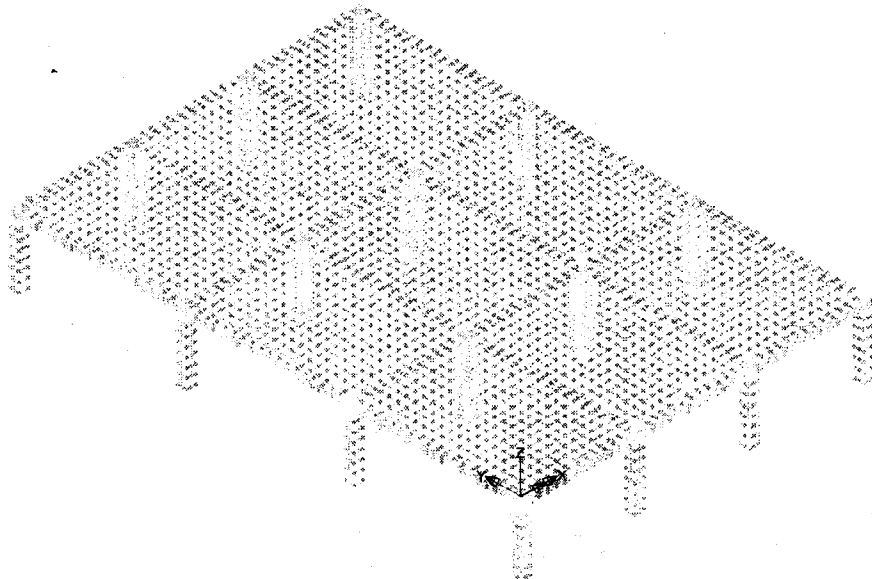


Figure 3.7: Finite element model for 3 bays x 3 bays, 6.5m x 9.5m bays

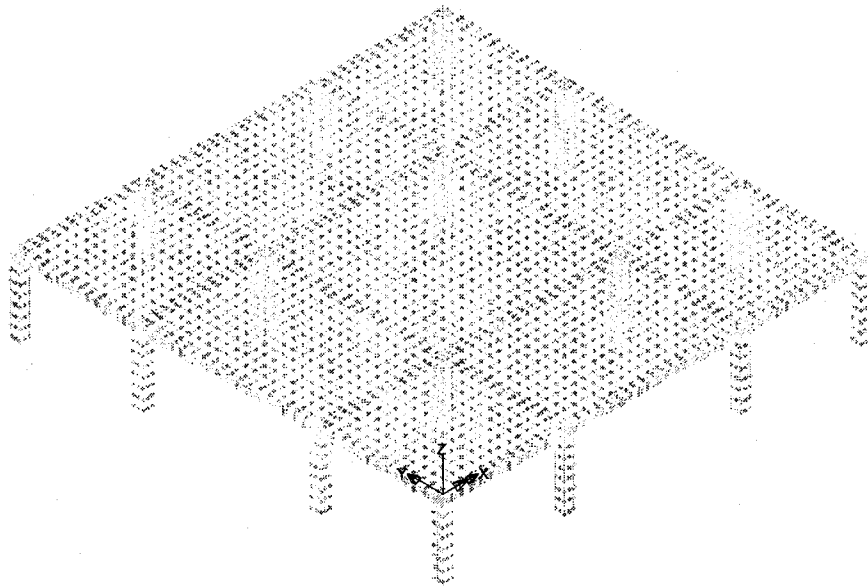


Figure 3.8: Finite element model for 3 bays x 3 bays, 9.5m x 9.5m centre bay, 6.5m x 9.5m edge bays, 6.5m x 6.5m corner bays

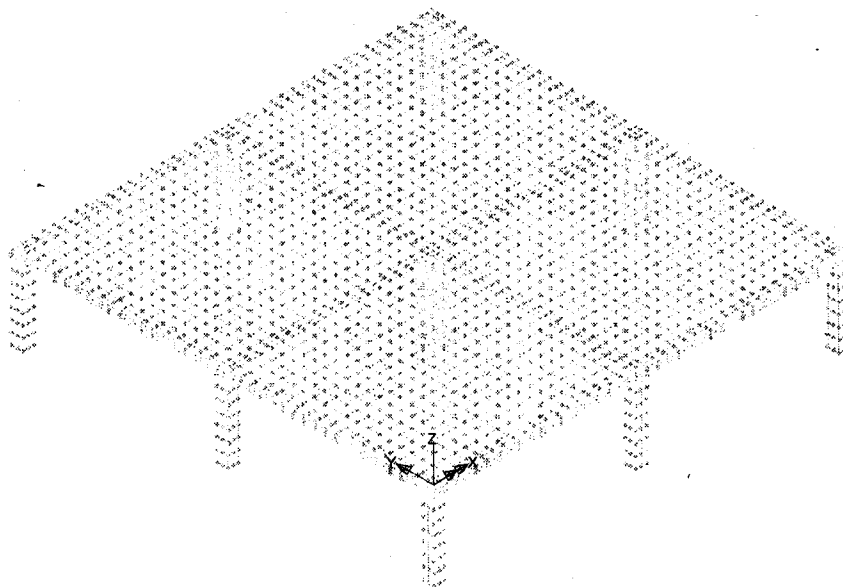


Figure 3.9: Finite element model for 2 bays x 2 bays, 9.5m x 9.5m bays

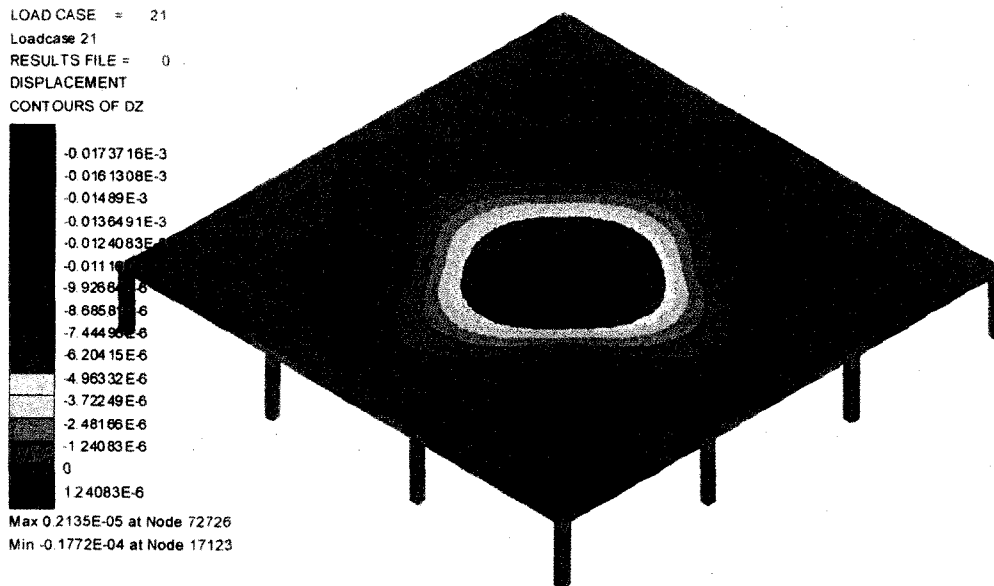


Figure 3.10: Finite element deflection contours with unit load near mid span of center bay for 3 bays x 3 bays, 9.5m x 9.5m bays model

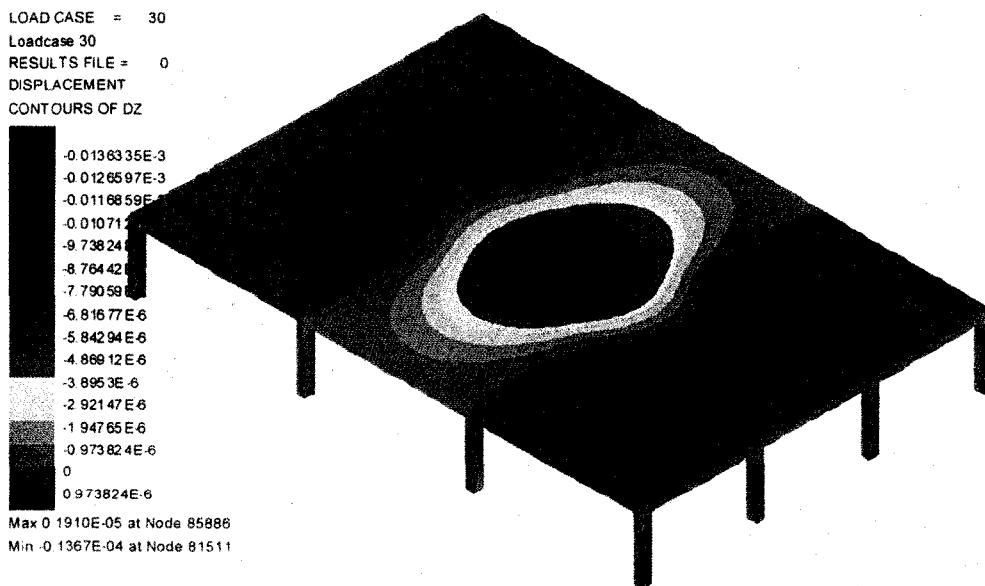


Figure 3.11: Finite element deflection contours with unit load near mid span of center bay, 3 bays x 3 bays, 6.5m x 9.5m bays model

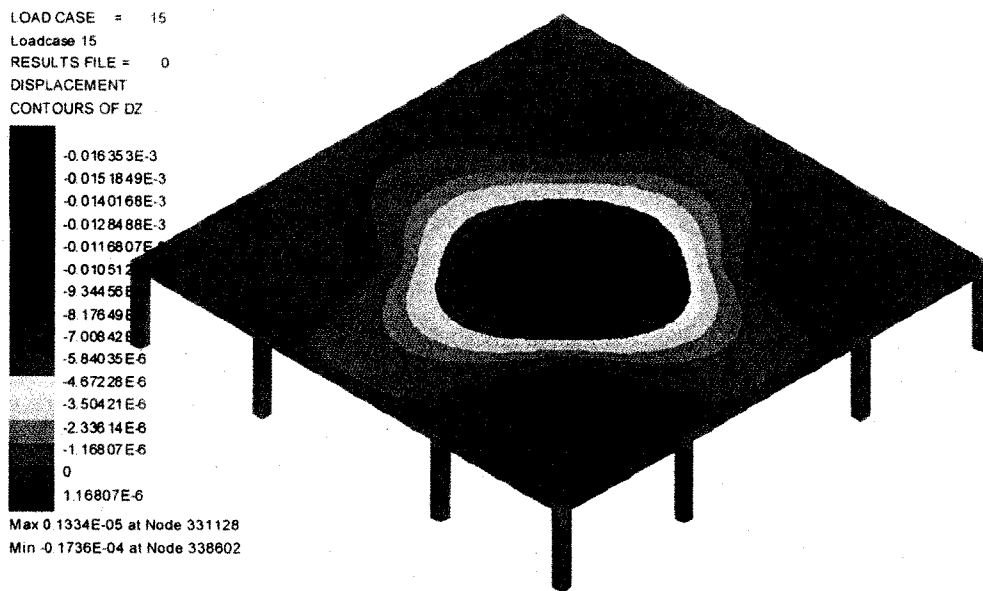


Figure 3.12: Finite element deflection contours with unit load at mid span of center bay, 3 bays x 3 bays, 9.5m x 9.5m centre bay, 6.5m x 9.5m edge bays, 6.5m x 6.5m corner bays model

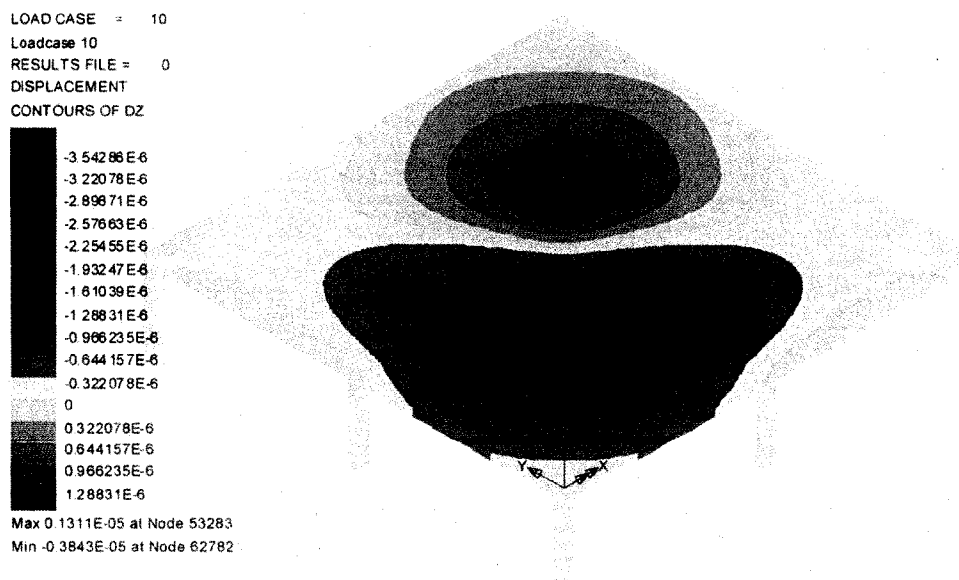


Figure 3.13: Finite element deflection contours with unit load near centre column, 2 bays x 2 bays, 9.5m x 9.5m bays model

3.4 DEVELOPMENT OF EQUATIONS

After slab stiffnesses had been determined from the finite element analysis for each model, sets of equations were developed to describe the relationship between the applied shore loads, the supporting slabs and the loads supported by the reshores (taking into account slab and reshore stiffnesses). Multiple levels of reshores were taken into account using superposition.

The reshore stiffness used was that of the Aluma Heavy Duty Post Shore with a calculated stiffness of 17,816 KN/m (referred to herein as a realistic reshore stiffness). The analysis was also performed using reshore stiffnesses of $1/3$ x realistic and 3 x realistic to examine the effect of different reshore stiffnesses. The reshore load ratio results using elastic shores were compared to results calculated using infinitely stiff reshores (Simplified Method) for comparison.

The slab stiffnesses used were those obtained from the finite element analysis. In addition, the effect of age adjusted slab stiffness was examined. Slab stiffnesses are a function of developed concrete strength which in turn is a function of age with lower slabs being stiffer than newer, upper slabs. The relationship between concrete strength and age is complicated since curing conditions will influence strength development. Concrete strength is usually measured on cylinders which likely have not undergone the exact same curing conditions as the slabs. Nonetheless, since current measurements on concrete strength are based on cylinder strength (i.e. to determine strength prior to stripping formwork), so are the concrete slab stiffness estimates. The effects of reinforcement on slab stiffness are ignored since it is presumed that all slabs within a multi slab building would have an equal amount of reinforcement and that the methodology developed utilizes relative stiffnesses between different slabs, which will be governed by concrete properties.

For comparison, reshore and slab force ratios were determined using equal slab stiffnesses as well as realistic relative slab stiffnesses based on a casting cycle of 3.5 and 7 days to determine the importance of relative slab stiffness on the reshoring process. The relationship used for the determination of the increase in concrete stiffness with age is described with the following equations.

- $f'/f_{c, 28 \text{ days}} = t^{3/4} / (2.8 + 0.77t^{3/4})$ (Gardner), where $f'/f_{c, 28 \text{ days}}$ is the ratio of the 28 day design strength achieved at time t in days
- The modulus of elasticity, E , is proportional to $(f')^{-1/2}$, therefore, the ratio of modulus of elasticity at time T versus that of 28 days was taken to be $(f'/f_{c, 28 \text{ days}})^{-1/2}$

The equations that describe the relationships between the shore loads, slabs and reshores are described and developed in the following figures. For demonstration purposes and clarity, the development of the equations is based on a single bay with 12 shore/reshore points with 1 level of reshores only. The process is similar for the complete models with 1, 2 and 3 levels of reshores. Figure 3.14 is a 2 dimensional section model demonstrating schematically the placement of shores and reshores (directly below the shoring points) and typical notation used in the equations. Figures 3.15 and 3.16 show a 3 dimensional view of the single bay demonstration model with 12 shore and reshore points (1 level of reshores).

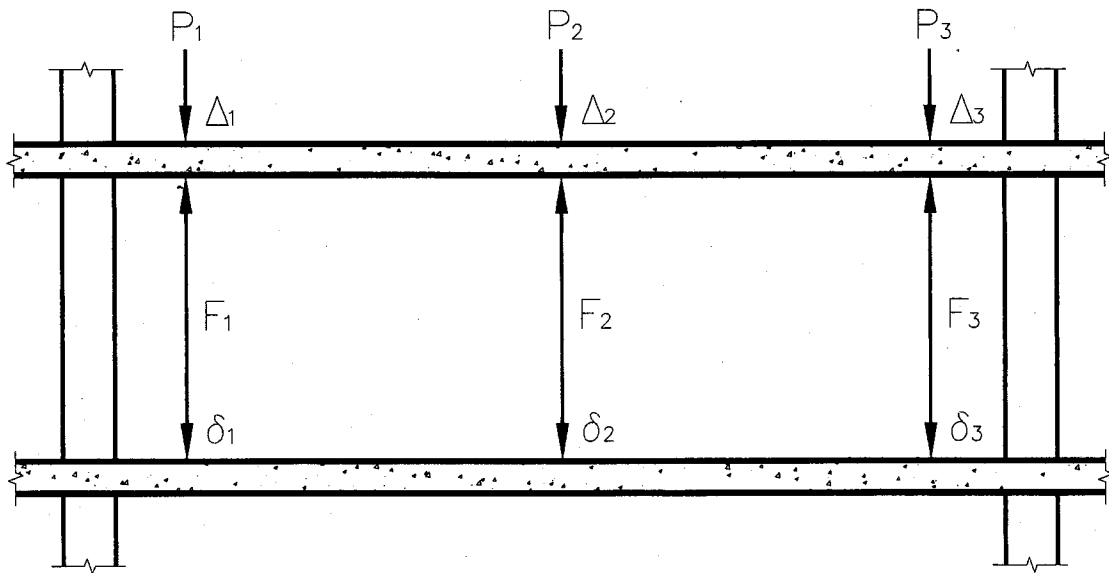


Figure 3.14: Simplified analysis model

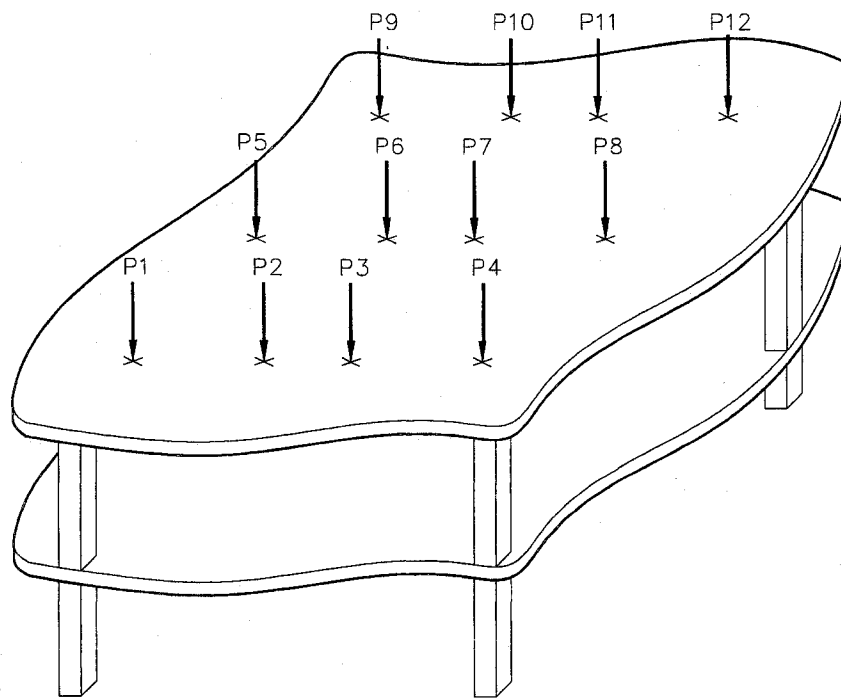


Figure 3.15: Isometric view showing shore locations for a single bay

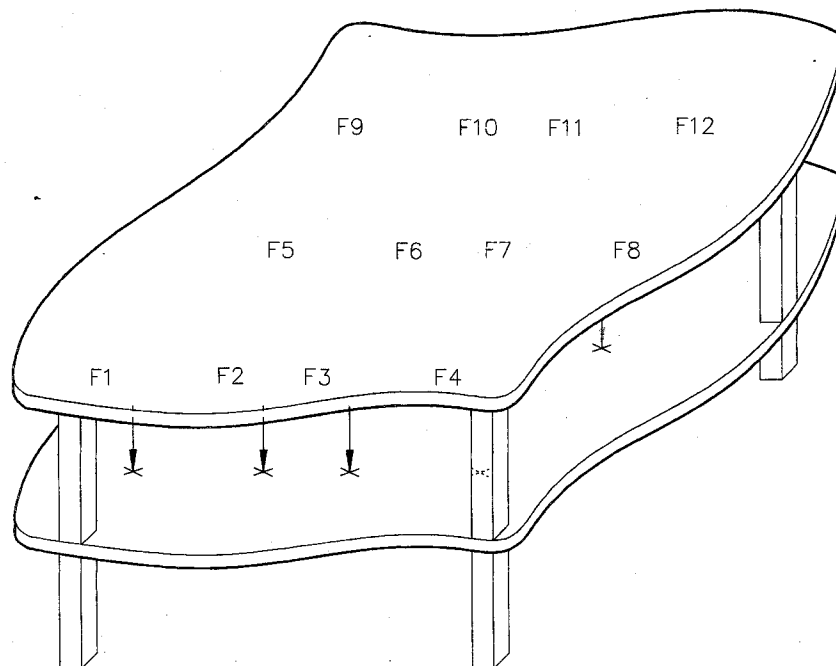


Figure 3.16: Isometric view showing reshore locations for a single bay

The following is the notation from the above figures used in the equations below. From Figures 3.14 to 3.16, we take:

P_i = Shore load at position i

F_i = Reshore load at position i

Δ_i = Top slab deflection at position i

δ_i = Bottom deflection at position i

K_{ij} = Top slab stiffness at position i due to the shore load at position j

k_{ij} = Bottom slab stiffness at position i due to the reshore load at position j

R = Reshore stiffness

Based on the above figures, the following set of equations (**equation 1**) describes the relationship between the top slab deflections, the shore loads and the reshore loads.

$$\begin{aligned}\Delta_1 &= (P_1-F_1)/K_{1-1} + (P_2-F_2)/K_{1-2} + (P_3-F_3)/K_{1-3} + \dots + (P_{12}-F_{12})/K_{1-12} \\ \Delta_2 &= (P_1-F_1)/K_{2-1} + (P_2-F_2)/K_{2-2} + (P_3-F_3)/K_{2-3} + \dots + (P_{12}-F_{12})/K_{2-12} \\ \Delta_3 &= (P_1-F_1)/K_{3-1} + (P_2-F_2)/K_{3-2} + (P_3-F_3)/K_{3-3} + \dots + (P_{12}-F_{12})/K_{3-12} \\ &\vdots \\ \Delta_{12} &= (P_1-F_1)/K_{12-1} + (P_2-F_2)/K_{12-2} + (P_3-F_3)/K_{12-3} + \dots + (P_{12}-F_{12})/K_{12-12}\end{aligned}$$

Similarly, the following set of equations describes the relationship between the top slab deflections, the bottom slab deflections and the reshore loads.

Given $\Delta_1 = F_1/R + \delta_1$ (**equation 2**), where δ_1 in equation 2 is substituted by equation 3, which describes the relationship between the bottom slab deflections and the reshore loads,

$$\delta_1 = (F_1)/k_{1-1} + (F_2)/k_{1-2} + (F_3)/k_{1-3} + \dots + (F_{12})/k_{1-12} \text{ (equation 3)}$$

the following equations (**equation 4**) are developed:

$$\begin{aligned}
\Delta_1 &= F_1/R + F_1/k_{1-1} + F_2/k_{1-2} + F_3/k_{1-3} \dots\dots\dots + F_{12}/k_{1-12} \\
\Delta_2 &= F_2/R + F_1/k_{2-1} + F_2/k_{2-2} + F_3/k_{2-3} \dots\dots\dots + F_{12}/k_{2-12} \\
\Delta_3 &= F_3/R + F_1/k_{3-1} + F_2/k_{3-2} + F_3/k_{3-3} \dots\dots\dots + F_{12}/k_{3-12} \\
&\vdots \\
\Delta_{12} &= F_{12}/R + F_1/k_{12-1} + F_2/k_{12-2} + F_3/k_{12-3} \dots\dots\dots + F_{12}/k_{12-12}
\end{aligned}$$

To simplify the notation, the subscripts **i** and **j**, which describe the shore and reshore and slab deflection positions, were substitute by a counter, subscript **n**, that describes both **i** and **j**. The counter **n** is described by the following equation.

$$\mathbf{n = (i-1)*12 + j \text{ (equation 5)}}$$

$$\begin{aligned}
\text{Therefore, from equation 5: } K_{1-1}/k_{1-1} &= K_1/k_1 \\
K_{1-2}/k_{1-2} &= K_2/k_2 \\
K_{1-3}/k_{1-3} &= K_3/k_3 \\
&\vdots \\
K_{12-2}/k_{12-2} &= K_{144}/k_{144}
\end{aligned}$$

Since the sets of equations 1 and equations 4 are expressed in terms of Δ (top slab deflection), these can be equated and arranged to equate the reshore load terms (**F**) and the shore load terms (**P**), so that the system of equations can be solved for the unknown, **F**. For example, taking $\Delta_1=\Delta_1$ from equation sets 1 and 4 and applying the counter **n**, the following equation is developed:

$$(P_1-F_1)/K_{1-1} + (P_2-F_2)/K_{1-2} + (P_3-F_3)/K_{1-3} + \dots\dots + (P_{12}-F_{12})/K_{1-12} = F_1/R + F_1/k_{1-1} + F_2/k_{1-2} + F_3/k_{1-3} \dots\dots + F_{12}/k_{1-12} \text{ (equation 6)}$$

Rearranging equation 6 results in:

$$F_1/R + F_1/k_1 + F_2/k_2 + F_3/k_3 \dots\dots + F_{12}/k_{12} + F_1/K_1 + F_2/K_2 + F_3/K_3 + \dots\dots + F_{12}/K_{12} = P_1/K_1 + P_2/K_2 + P_3/K_3 + \dots\dots + P_{12}/K_{12} \text{ (equation 7)}$$

From applying equation 7 for Δ_1 through Δ_{12} , the sets of equations can be assembled to writing the matrix equations (**equation 8**) for all 12 load and reshore points:

$$\begin{array}{c|c|c}
 \begin{array}{c} F_1 \\ F_2 \\ F_3 \\ F_4 \\ F_5 \\ F_6 \\ F_7 \\ F_8 \\ F_{10} \\ F_{11} \\ F_{12} \\ F_{13} \end{array} & * & \begin{array}{cccccccccccc}
 1/R + 1/K_1 + 1/k_1 & 1/K_2 + 1/k_2 & . & . & . & . & . & . & 1/K_{12} + 1/k_{12} & . & . & . \\
 1/K_{13} + 1/k_{13} & 1/R + 1/K_{14} + 1/k_{14} & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 1/K_{133} + 1/k_{133} & . & . & . & . & . & . & . & . & . & 1/R + 1/K_{144} + 1/k_{144} & .
 \end{array}
 \end{array} =$$

$$\begin{array}{c|c|c}
 \begin{array}{cccccccccccc}
 1/k_1 & 1/k_2 & 1/k_3 & 1/k_4 & 1/k_5 & 1/k_6 & 1/k_7 & 1/k_8 & 1/k_9 & 1/k_{10} & 1/k_{11} & 1/k_{12} \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 1/k_{133} & . & . & . & . & . & . & . & . & . & . & 1/k_{144}
 \end{array} & * & \begin{array}{c} P_1 \\ P_2 \\ P_3 \\ P_4 \\ P_5 \\ P_6 \\ P_7 \\ P_8 \\ P_{10} \\ P_{11} \\ P_{12} \\ P_{13} \end{array}
 \end{array}$$

By rearranging the matrices from equation 8, the reshore forces can be resolved as follows (equation 9):

$$\begin{array}{c}
 \begin{array}{c} F_1 \\ F_2 \\ F_3 \\ F_4 \\ F_5 \\ F_6 \\ F_7 \\ F_8 \\ F_{10} \\ F_{11} \\ F_{12} \\ F_{13} \end{array} \\
 =
 \end{array}
 \begin{array}{c}
 \begin{array}{cccccccccccc}
 1/R + 1/K_1 + 1/k_1 & 1/K_2 + 1/k_2 & . & . & . & . & . & . & . & . & 1/K_{12} + 1/k_{12} & . \\
 1/K_{13} + 1/k_{13} & 1/R + 1/K_{14} + 1/k_{14} & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 1/K_{133} + 1/k_{133} & . & . & . & . & . & . & . & . & . & . & 1/R + 1/K_{144} + 1/k_{144}
 \end{array}
 \end{array}
 \begin{array}{c}
 -1 \\
 \\
 \\
 \\
 \\
 \\
 \\
 \\
 \\
 \\
 \\
 \\
 *
 \end{array}$$

$$\begin{array}{c}
 \begin{array}{cccccccccccc}
 1/k_1 & 1/k_2 & 1/k_3 & 1/k_4 & 1/k_5 & 1/k_6 & 1/k_7 & 1/k_8 & 1/k_9 & 1/k_{10} & 1/k_{11} & 1/k_{12} \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 . & . & . & . & . & . & . & . & . & . & . & . \\
 1/k_{133} & . & . & . & . & . & . & . & . & . & . & 1/k_{144}
 \end{array}
 \end{array}
 \begin{array}{c}
 \\
 \\
 \\
 \\
 \\
 \\
 \\
 \\
 \\
 \\
 \\
 *
 \end{array}
 \begin{array}{c}
 P_1 \\
 P_2 \\
 P_3 \\
 P_4 \\
 P_5 \\
 P_6 \\
 P_7 \\
 P_8 \\
 P_{10} \\
 P_{11} \\
 P_{12} \\
 P_{13}
 \end{array}$$

For the 4 models analyzed, $[F] = [S2]^{-1} [S1] [P]$ (equation 9 above) results in the following sizes of matrices $[S1]$ and $[S2]$:

- 3 bays x 3 bays, 9.5m x 9.5m bays: 144 x 144 for 1 level, 288 x 288 for 2 levels and 432 x 432 for 3 levels of reshores.
- 3 bays x 3 bays, 6.5m x 9.5m bays: 108 x 108 for 1 level, 216 x 216 for 2 levels and 324 x 324 for 3 levels of reshores.
- 3 bays x 3 bays, 9.5m x 9.5m centre bay, 6.5m x 9.5m edge bays, 6.5m x 6.5m corner bays: 100 x 100 for 1 level, 200 x 200 for 2 levels and 300 x 300 for 3 levels of reshores.
- 2 bays x 2 bays, 9.5m x 9.5m bays: 64 x 64 for 1 level, 128 x 128 for 2 levels and 192 x 192 for 3 levels of reshores.

The output of equation 9 above, F , provides the reshore force ratio for each reshore location. The reshore force ratio is the proportion of the applied shoring load transferred to each level of reshores. The load ratios applied to the supporting slabs result from the differences between the applied or reshore load ratios above and below the supporting slab.

The application of the above discussed equations is presented in its entirety in Microsoft Excel 2007 (Beta Version) spreadsheets in Attachment 1 (attached compact disk). Previous versions of Microsoft Excel did not provide the capabilities required for the presentation, manipulation and the performance of the required matrix operations for these large data sets.

To understand the spreadsheets, the reader is directed to the file entitled “3x3 Bays, 9.5m x 9.5m, 1 Level of Reshores” in Attachment 1. Summary results and discussions are presented in Chapter 4. The following bullets provide a step by step description of the generation of the results, which is typical for all models and reshore cases.

- The first Tab at the lowest left hand corner of this spreadsheet presents the results for 1 level of reshores.
- The data set starting at Row 3 presents the unit deflection results from the finite element analysis (FEA) for the 144 separate shore positions for this case

(Column A provides the shore/reshore point numbering shown in Figures 3.1 to 3.4). Columns B and C present the x and y coordinates for each of the 144 shore positions.

- The unit deflection data (starting on Row 3) is then assembled into [S1], a 144 x 144 matrix (Row 152). These unit deflections represent 1/unit stiffness for each of the shore positions. [S1] is assembled by transposing the unit deflection data, due to the order in which the data was generated and extracted from the models.
- [S2] starts at Row 299 and is assembled from the unit deflection data and reshore stiffnesses.
- $[S2]^{-1}$ starts at Row 446.
- The product $[S2]^{-1} [S1]$ starts at Row 594.
- Row 750, Column B shows the load input, [P], for each shore based on the tributary area. The shore location numbers are shown in column A.
- Row 750, Column D displays the forces in each reshore, [F], obtained from the following matrix equation: $[F] = [S2]^{-1} [S1] [P]$
- Row 750, Column F displays the ratio of the reshore load over the shore load for each level of reshores
- Row 740, Columns D, E and F present the different reshore stiffnesses used. The Realistic reshore stiffness of 17816 N/mm is denoted by 'R'. A reshore stiffness of 1/3 x Realistic is denoted by 'R/3' and a reshore stiffness of 3 x Realistic is denoted by '3*R'. The infinite reshore stiffness case is denoted by 'Infinite'.
- Row 741, Column A is the location for the input of reshore stiffness values for the generation of results for reshore forces (input cell shaded yellow). To change the reshore stiffness in the highlighted cell, simply copy one of the stiffnesses provided in the table and paste (paste value only) into the cell.
- Row 740, Columns K,L,M and O,P,Q present the different slab relative stiffnesses used for a casting cycle of 3.5 days and 7 days.

- Row 743, Column I is the location for the input of slab stiffness values for the generation of results for reshore forces (input cell shaded yellow). To change the slab relative stiffness in the highlighted cell, simply copy one of the stiffnesses provided in the table and paste (paste value only) into the cell.

The spreadsheets are partially interactive as the reader can modify the reshore and slab relative stiffnesses to examine the effect of these parameters. It should also be mentioned that, for an infinite reshore stiffness, a very small value (1×10^{-15}) was used for the inverse of reshore stiffness ($1/R$) instead of zero.

Once the reshore ratios are determined for the different reshore stiffnesses, the logic of the Simplified Method could be applied to calculate shoring and reshoring schedules. Some sample shoring and reshoring schedule calculations for a single level of shores, 1, 2 and 3 levels of reshores and a casting cycle of 7 days are presented and discussed in Chapter 5. The results for realistic conditions are presented with those of the Simplified Method (infinitely stiff reshores) for comparison.

It should be noted that a single level of shores was used since it is believed that 1 level of shores is both economically and structurally the most efficient system (reshores are less expensive than shoring and formwork systems).

3.5 OTHER PARAMETERS

The major parameters thought to affect the distribution of applied shoring loads to a reshored slab system are reshore stiffness, slab stiffness and relative slab stiffness. The following sections describe other parameters which should also be considered.

3.5.1 Determination of shoring loads

Shores support the load of the formwork, fresh concrete and live load due to construction operations. It has been traditionally assumed that the load supported by the shores is proportional to the tributary area of formwork and freshly cast slab supported by each shore. This may be correct if a series of independent post shores are used to support formwork. Given the frequent use of more complex shoring structures, such as flying or table forms, the load in each shore would depend on the behaviour of the main structural

members of the system (i.e. the reactions at the supports of a continuous truss, such as flying table form trusses, are a function of the truss span and stiffness). In this thesis, calculations of reshoring loads were performed using input loads from shoring using the tributary area of the system (for simplicity). However, a cursory analysis was performed to examine the magnitude of the effect of taking into account the continuity of the flying form trusses. This cursory analysis determined that the difference in load supported by the shores varied by less than 6% from the values calculated using the tributary areas. This difference would have an effect on individual reshore load ratio values but would not change the average reshore load ratios and total slab load ratios.

3.5.2 Stiffness of foundations

Foundations for the bottom level of reshores have been assumed to be infinitely rigid. This is not completely correct as all material, including soils have a stiffness and will deflect under applied load. This was not directly taken into account into the developed methodology. However, this stiffness can be taken into account by taking the relative stiffness of the soil and the first level slab (as if the soil was a supporting slab in the system) and applying the relative stiffness into the equations developed in Section 3.2. The knowledge of the soil stiffness parameters would have to be provided by a geotechnical engineer.

3.5.3 Creep and shrinkage

All concrete under load experiences shrinkage and creep. Both are long term phenomena and are dependent upon many of the same parameters

Concrete shrinkage in reinforced concrete slabs is a very difficult problem. Concrete shrinkage includes plastic shrinkage, autogenous shrinkage for low water cement ratio (<0.4) concrete, drying shrinkage and carbonation shrinkage. Carbonation shrinkage is a long term phenomena and not relevant to the reshoring problem. Autogenous shrinkage is only of relevance to low water/cement ratio concretes which are inappropriate for flat slab systems. Plastic shrinkage occurs before the concrete has set and can be minimized by appropriate curing.

Presuming that reinforcement is placed to resist the tensile forces due to the applied loads, drying shrinkage will cause deflections in the same direction as the load induced deflections. There is very little information available describing the early age development of shrinkage under the curing conditions of suspended slab construction. Fortunately drying shrinkage predicted by code type equations is relatively small during the construction phase (approximately 60 microstrain at 7 days). Consequently shrinkage is neglected in these analyses.

All concrete under load creeps which has a significant effect on the deflections of early loaded concrete members. For the shoring and reshoring cases considered, using one level of shores and multiple levels of reshores, creep does not appear to affect the maximum slab loads which occur immediately after the new upper slab is cast.

As an example consider constructing a series of flat slabs using one level of stiff shores, no reshores and casting a new slab every 7 days. The first slab above the ground is cast and at the morning of the 7th day, the shores are removed and placed on top of the slab readying for the new slab. The slab deflects under its own self weight and the shores/formwork. In the afternoon of the 7th day, the new slab is placed and the supporting slab deflects. The supporting slab is now carrying the weight of two slabs plus the shores and deflects accordingly. By day 8 the older lower slab will have creep deflected due to creep under the action of its own self weight and the weight of the newly cast upper slab, which now has some strength and stiffness. However as the lower slab deflects, and the upper slab follows suit, some of the self weight of the upper slab is picked-up by the upper slab and the load on the lower slab decreases. By day 9, the deflections of the lower slab have increased due to creep from its self weight and the residual support of the upper slab. The upper slab deflection has increased due to early age creep for the part of its self weight it is carrying. With the assumption of infinitely stiff shores, the increases in deflection of the two slabs will be identical. As time progresses towards the 14th day, when the stripping and moving the shores/formwork operation will be repeated, the upper slab picks up an increasing fraction of its own self weight and the lower slab load decreases. Table 3.1 shows an trial analysis for this logic.

This example assumes 200 mm thick slabs cured 1 day and exposed to a relative humidity of 65%. The creep method chosen is GL2000 (Gardner 2004). The creep values are expressed as compliance, load induced strain per unit stress (i.e. microstrain/MPa). The inverse of the compliance is the reduced modulus of elasticity and directly proportional to deflection if the slab is not cracked. Please note that for this concrete loaded at 7 days, the compliance approximately doubles (effective modulus halves) by 14 days.

The load ratio for the lower, supporting, slab decreases from 2 at day 7 to 1.6 at day 14. A reduction in the load ratio of the supporting slabs with time has been reported by Ambrose et al 1993. There are many uncertainties inherent in this demonstration analysis:

- a) predicting early age creep by a method devised for long duration behaviour may be unwise.
- b) the pick-up of load by the upper slab is an aging creep phenomena which was not considered in the example
- c) the one day strength/stiffness gain of the upper slab concrete is unknown

Creep will have a significant effect on the long term deflections of slabs loaded at early ages. The research presented originally intended to further study this phenomena. However, given the complexity creep exacerbated by the variety and superposition of loading conditions, it was decided to abandon further evaluation. Figures 3.17 and 3.18 provide some schematic examples which demonstrate the complexity of predicting creep deflections in flat slabs.

As with shrinkage, it is our opinion that creep would require much more study specific to short term construction loads, and therefore it is neglected in our analyses.

						Age of casting (days, top slab)		0	1	2	3	4	5	6	7
Age of casting (days, bottom slab)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Age of loading (days, top slab)	Age of loading (days, bottom slab)														
	1	57	94	106	114	119	124	127	130	133	135	137	139	140	142
	2		49	76	85	91	95	98	101	103	105	107	108	109	111
	3			45	68	76	80	84	87	89	91	93	94	95	96
	4				43	63	70	74	77	80	82	84	85	86	88
	5					41	60	66	70	73	75	77	79	80	81
	6						40	58	63	67	70	72	74	75	76
0	7							39	56	61	64	67	69	70	71
1	8								38	54	59	62	65	67	69
2	9									37	53	58	61	63	65
3	10										37	52	56	59	62
4	11											37	51	55	58
5	12												36	50	54
6	13													36	49
7	14														36
							Load Ratio	2.00	1.92	1.92	1.88	1.85	1.82	1.82	1.81

Note: Creep compliances provided for ages of loading and casting. Resulting load ratios calculated and provided on bottom row.

Table 3.1: Simplified analysis to determine the effect of creep on the calculation of shoring and reshoring schedules.

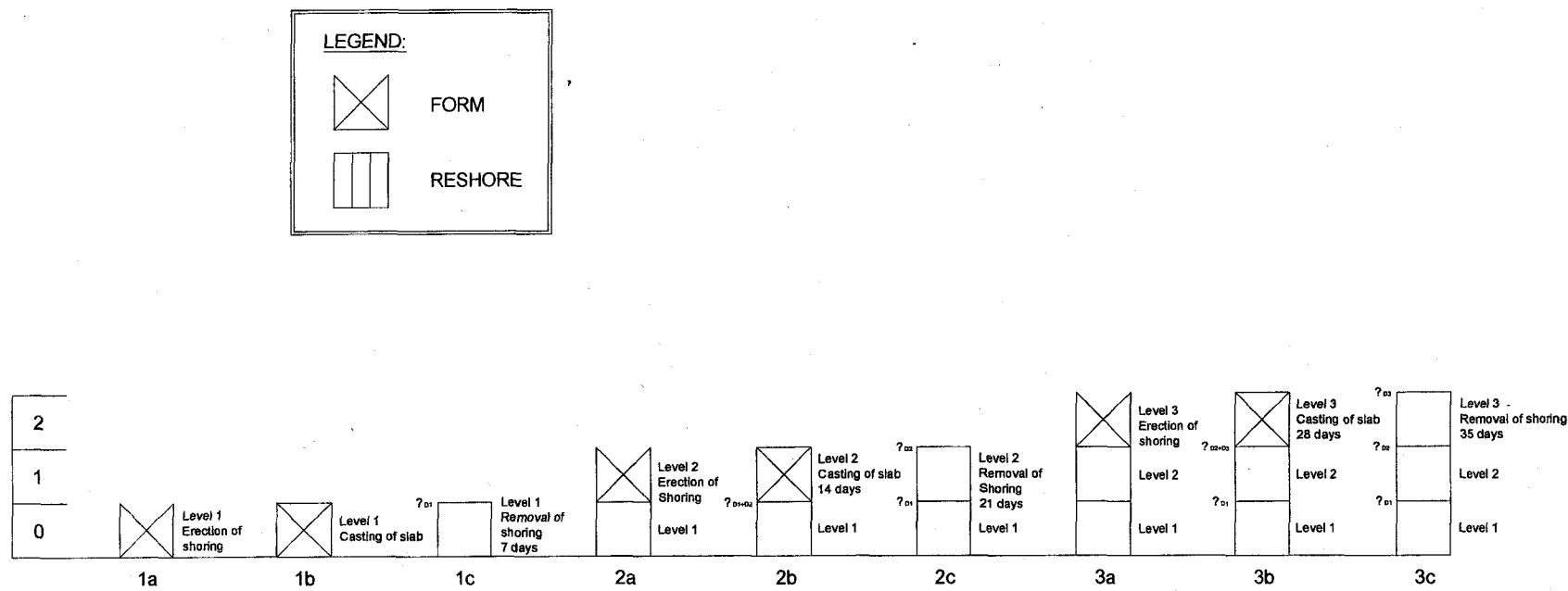


Figure 3.17a: Development of elastic deflections in shoring and reshoring systems, assuming a single level of shores only

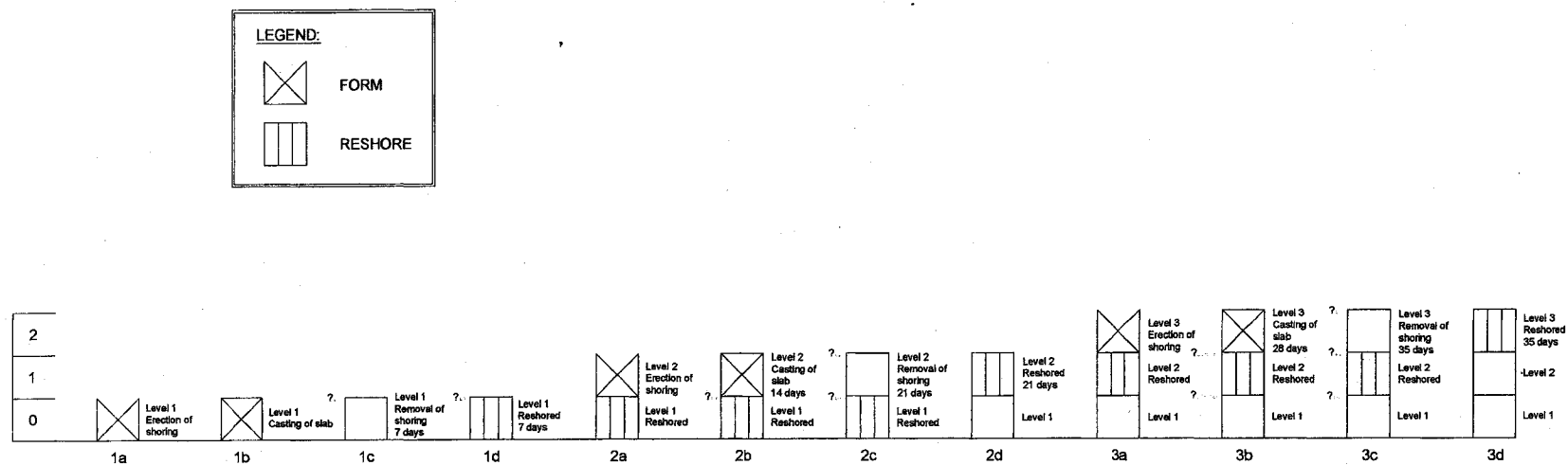


Figure 3.17b: Development of elastic deflections in shoring and reshoring systems, assuming a single level of shores combined with a single level of reshores only

77

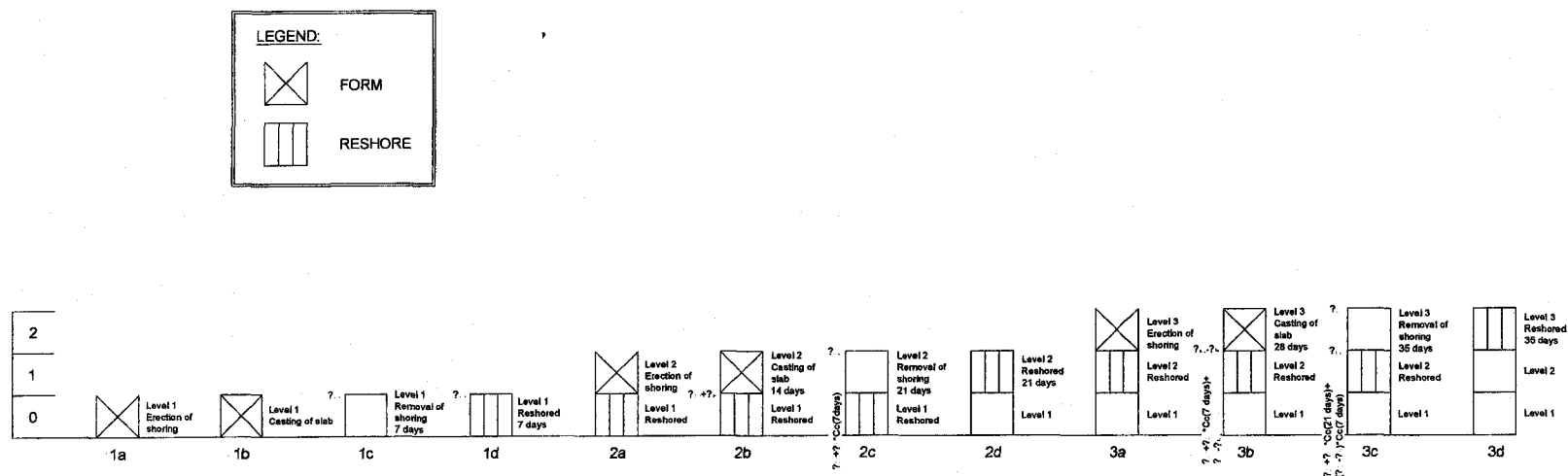


Figure 3.18b: Development of elastic and inelastic deflections in shoring and reshoring systems, assuming a single level of shores only and a single level of shores combined with a single level of reshores

CHAPTER 4

RESULTS

4.1 INTRODUCTION

This chapter presents the results from the analysis of the four models for 1, 2 and 3 levels of reshores. The results are presented in summary tables. This has been done due to the size of the results data files which are impractical to present in printed format. For the entirety of the results and the step by step calculations for each model and the different levels of reshores, the reader is directed to the enclosed compact disk (Attachment 1). Section 4.2 below provides a glossary of abbreviations and terms as well as a step by step description on how to read the results presented in electronic format.

The results of the above discussed development of equations are presented in their entirety in Microsoft Excel 2007 (Beta Version) spreadsheets in Attachment 1 (attached compact disk). Previous versions of Microsoft Excel did not provide the capabilities required for the presentation, manipulation and the performance of the required matrix operations for these large data sets.

4.2 READING THE DETAILED RESULTS

To demonstrate how to read the detailed results provided in attachment 1, the reader is directed to the file entitled "3x3 Bays, 9.5m x 9.5m, 1 Level of Reshores" on the attached CD. The following bullets provide a step by step description on reading the results for this model and reshore case, which is typical for all models and reshore cases.

4.2.1 Methodology

The following describes the portion of each spreadsheet that is assembled to generate the results. For a more detailed description of the development of the analytical methodology, the reader is directed to Chapter 3.

- The first Tab at the lowest left hand corner of this spreadsheet presents the results for 1 level of reshores.
- The data set starting at Row 3 presents the unit deflection results from the finite element analysis (FEA) for the 144 separate shore positions for this case (Column A). Columns B and C present the x and y coordinates for each of the 144 shore positions.
- The unit deflection data (starting on Row 3) is then assembled into [S1], a 144 x 144 matrix (Row 152). These unit deflections represent 1/unit stiffness for each of the shore positions. [S1] is assembled by transposing the unit deflection data, due to the order in which the data was generated and extracted from the models.
- [S2] starts at Row 299 and is assembled from the unit deflection data and reshore stiffnesses.
- $[S2]^{-1}$ starts at Row 446.
- The product $[S2]^{-1} [S1]$ starts at Row 594.
- Row 750, Columns B shows the load input, [P], for each shore based on the tributary area. The shore location numbers are shown in column A.
- Row 750, Column D displays the forces in each reshore, [F], obtained from the following matrix equation: $[F] = [S2]^{-1} [S1] [P]$
- Row 750, Column F displays the ratio of the reshore load over the shore load for each level of reshores

4.2.2 Generation of results

- Row 740, Columns D, E and F present the different reshore stiffnesses used. The Realistic reshore stiffness of 17816 N/mm is denoted by 'R'. A reshore stiffness of 1/3 x Realistic is denoted by 'R/3' and a reshore stiffness of 3 x Realistic is denoted by '3*R'. The infinite reshore stiffness is denoted by 'Infinite'.
- Row 741, Column A is the location for the input of reshore stiffness values for the generation of results for reshore forces (input cell shaded yellow). To change

the reshore stiffness in the highlighted cell, simply copy one of the stiffnesses provided in the table and paste (paste value only) into the cell.

- Row 740, Columns K,L,M and O,P,Q present the different slab relative stiffnesses used for a casting cycle of 3.5 days and 7 days.
- Row 743, Column I is the location for the input of slab stiffness values for the generation of results for reshore forces (input cell shaded yellow). To change the slab relative stiffness in the highlighted cell, simply copy one of the stiffnesses provided in the table and paste (paste value only) into the cell.
- Tables providing calculated reshore forces for the different reshore stiffnesses and relative slab stiffnesses of 1.0 and for realistic cases at casting cycles of 3.5 and 7 days start at Row 749 between Columns H and BK.
- The table summarizing the minimum, maximum and average reshore loads as well as the minimum, maximum and total loads supported by the slabs in the reshored system for each reshore stiffness and casting cycles are provided starting at Row 902. This is the table imported into the text for review and discussion. For example, the table on Row 902 is Table 4.1a presented in Section 4.3, Summary Results.

4.3 SUMMARY RESULTS

The following tables present the summary of results for each of the models and stiffnesses. The results are presented in two sets of comparisons. The first (Sections 4.3.1. to 4.3.4) compares the effect of the different reshore stiffnesses for each model, number and sizes of bays, with the results obtained for infinitely stiff reshores for 1, 2 and 3 levels of reshores. The second of comparisons (Sections 4.3.5 to 4.3.8) compares the effect of the arrangement of bays, bay sizes and aspect ratios between the different models for each reshore stiffness for 1, 2 and 3 levels of reshores.

4.3.1 Effect of reshore stiffness for the 3 bays x 3 bays, 9.5m x 9.5m bays model

The summary results for this model (Figure 4.1) are presented in Tables 4.1a to 4.1c shown following the text in this section. The effect of the different reshore stiffnesses when compared with infinitely rigid reshores for this model are summarized below.

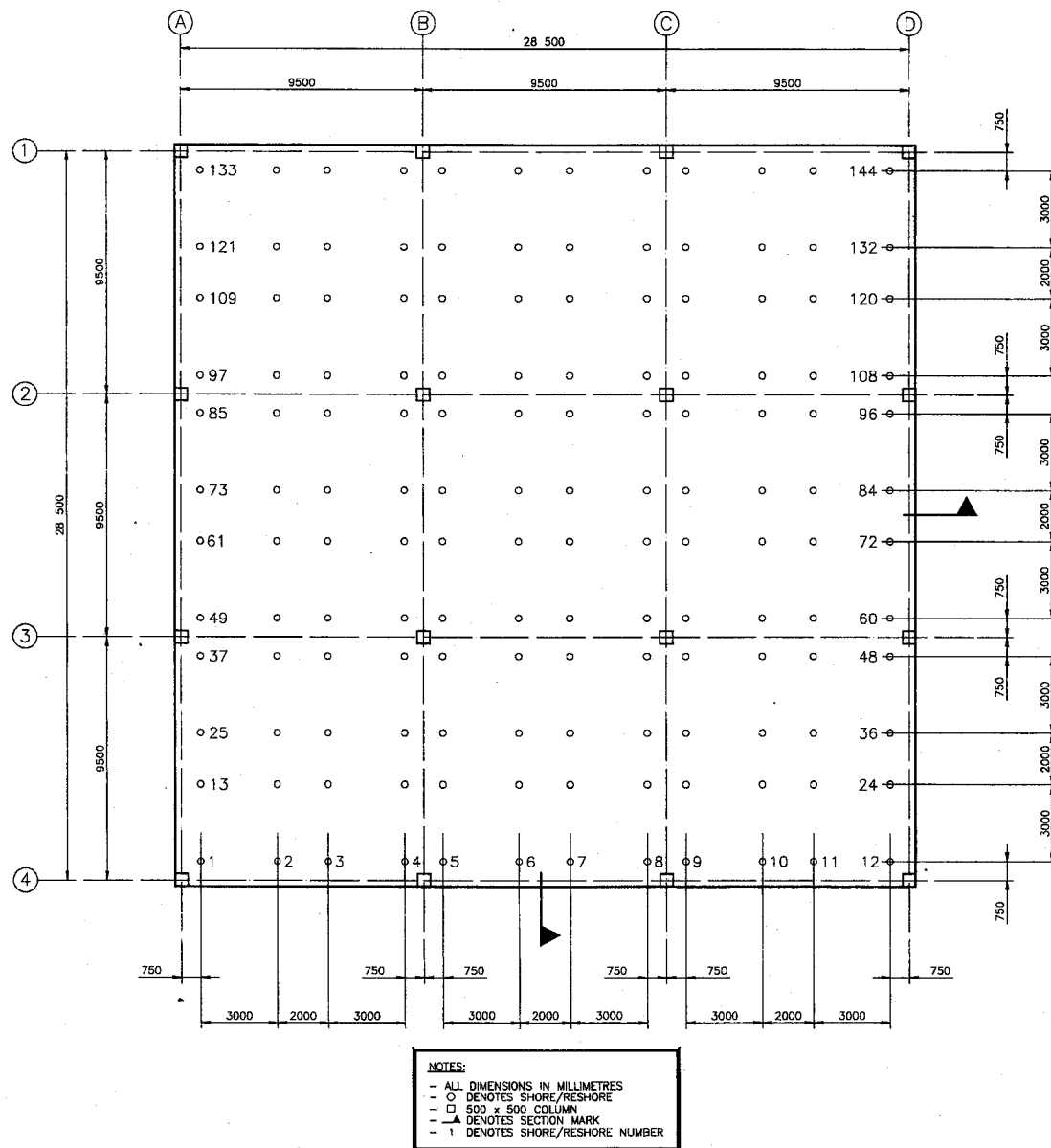


Figure 4.1: 3 bays x 3 bays, 9.5m x 9.5m bays model

4.3.1.1 Results for 1 level of reshores (2 supporting slabs, Table 4.1a)

1. The average reshore force ratio has a difference of -51% (1/3 realistic reshore stiffness), -30% (realistic stiffness) and -17% (3 x realistic reshore stiffness) when compared with the force ratio of 0.5 calculated using reshores with an infinite stiffness.

2. The total load ratio supported by the top slab has a difference of +51% (1/3 realistic reshore stiffness), +30% (realistic stiffness) and +17% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.5 calculated using reshores with an infinite stiffness.
3. The total load ratio supported by the lowest slab has a difference of -51% (1/3 realistic reshore stiffness), -30% (realistic stiffness) and -17% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.5 calculated using reshores with an infinite stiffness.
4. The maximum reshore force ratio has a difference of -26% (1/3 realistic reshore stiffness), -2% (realistic stiffness) and +6% (3 x realistic reshore stiffness) when compared with the force ratio of 0.5 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near to the mid-span of the corner bays (reshore locations 14, 23, 122, 131).
5. The minimum reshore force ratio has a difference of -85% (1/3 realistic reshore stiffness), -75% (realistic stiffness) and -62% (3 x realistic reshore stiffness) compared with the force ratio of 0.5 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns (reshore locations 52, 53, 56, 57, 88, 89, 92, 93).
6. The change in load carried by the reshores due to the different stiffnesses of the slabs (age of slabs) is between +3% (1/3 realistic reshore stiffness) to +7% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.

4.3.1.2 Results for 2 levels of reshores (3 supporting slabs, Table 4.1b)

1. The average force ratio for the top level of reshores has a difference of -60% (1/3 realistic reshore stiffness), -38% (realistic stiffness) and -22% (3 x realistic reshore stiffness) when compared with the force ratio of 0.67 calculated using reshores with an infinite stiffness.
2. The average force ratio for the lowest level of reshores has a difference of -71% (1/3 realistic reshore stiffness), -51% (realistic stiffness) and -30% (3 x realistic reshore stiffness) when compared with the force ratio of 0.34 calculated using reshores with an infinite stiffness.

3. The total load ratio supported by the top slab has a difference of +119% (1/3 realistic reshore stiffness), +76% (realistic stiffness) and +44% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.34 calculated using reshores with an infinite stiffness.
4. The total load ratio supported by the middle slab has a difference of -42% (1/3 realistic reshore stiffness), -25% (realistic stiffness) and -14% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.34 calculated using reshores with an infinite stiffness.
5. The total load ratio supported by the lowest slab has a difference of -77% (1/3 realistic reshore stiffness), -51% (realistic stiffness) and -30% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.34 calculated using reshores with an infinite stiffness.
6. The maximum force ratio for the top level of reshores has a difference of -39% (1/3 realistic reshore stiffness), -11% (realistic stiffness) and +3% (3 x realistic reshore stiffness) when compared with the force ratio of 0.67 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near to the mid-span of the corner bays (reshore locations 14, 23, 122, 131).
7. The maximum force ratio for the lowest level of reshores has a difference of -62% (1/3 realistic reshore stiffness), -24% (realistic stiffness) and 0% (3 x realistic reshore stiffness) when compared with the force ratio of 0.34 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near to the mid-span of the corner bays.
8. The minimum force ratio for the top level of reshores has a difference of -89% (1/3 realistic reshore stiffness), -79% (realistic stiffness) and -67% (3 x realistic reshore stiffness) compared with the force ratio of 0.67 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns (reshore locations 52, 53, 56, 57, 88, 89, 92, 93).
9. The minimum force ratio for the lowest level of reshores has a difference of -96% (1/3 realistic reshore stiffness), -87% (realistic stiffness) and -78% (3 x realistic reshore stiffness) compared with the force ratio of 0.34 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns (reshore locations 52, 53, 56, 57, 88, 89, 92, 93).

10. The change in load carried by the top level of reshores due to the different stiffnesses of the slabs (age of slabs) is between +2% (1/3 realistic reshore stiffness) to +6% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.
11. The change in load carried by the lowest level of reshores due to the different stiffnesses of the slabs (age of slabs) is between -2% (1/3 realistic reshore stiffness) to +9% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.

4.3.1.3 Results for 3 levels of reshores (4 supporting slabs, Table 4.1c)

1. The average force ratio for the top level of reshores has a difference of -64% (1/3 realistic reshore stiffness), -43% (realistic stiffness) and -35% (3 x realistic reshore stiffness) when compared with the force ratio of 0.75 calculated using reshores with an infinite stiffness.
2. The average force ratio for the middle level of reshores has a difference of -83% (1/3 realistic reshore stiffness), -60% (realistic stiffness) and -36% (3 x realistic reshore stiffness) when compared with the force ratio of 0.50 calculated using reshores with an infinite stiffness.
3. The average force ratio for the lowest level of reshores has a difference of -90% (1/3 realistic reshore stiffness), -68% (realistic stiffness) and -41% (3 x realistic reshore stiffness) when compared with the force ratio of 0.25 calculated using reshores with an infinite stiffness.
4. The total load ratio supported by the top slab has a difference of +191% (1/3 realistic reshore stiffness), +128% (realistic stiffness) and +76% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.25 calculated using reshores with an infinite stiffness.
5. The total load ratio supported by the middle-top slab has a difference of -25% (1/3 realistic reshore stiffness), -9% (realistic stiffness) and -4% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.25 calculated using reshores with an infinite stiffness.
6. The total load ratio supported by the middle-lower slab has a difference of -76% (1/3 realistic reshore stiffness), -52% (realistic stiffness) and -31% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.25 calculated using reshores with an infinite stiffness.

realistic reshore stiffness) when compared with the total load ratio of 0.25 calculated using reshores with an infinite stiffness.

7. The total load ratio supported by the lowest slab has a difference of -90% (1/3 realistic reshore stiffness), -68% (realistic stiffness) and -41% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.25 calculated using reshores with an infinite stiffness.
8. The maximum force ratio for the top level of reshores has a difference of -45% (1/3 realistic reshore stiffness), -18% (realistic stiffness) and 0% (3 x realistic reshore stiffness) when compared with the force ratio of 0.75 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near to the mid-span of the corner bays (reshore locations 14, 23, 122, 131).
9. The maximum force ratio for the middle level of reshores has a difference of -71% (1/3 realistic reshore stiffness), -36% (realistic stiffness) and -7% (3 x realistic reshore stiffness) when compared with the force ratio of 0.5 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near to the mid-span of the corner bays.
10. The maximum force ratio for the lowest level of reshores has a difference of -82% (1/3 realistic reshore stiffness), -47% (realistic stiffness) and -11% (3 x realistic reshore stiffness) when compared with the force ratio of 0.25 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near to the mid-span of the corner bays.
11. The minimum force ratio for the top level of reshores has a difference of -90% (1/3 realistic reshore stiffness), -81% (realistic stiffness) and -61% (3 x realistic reshore stiffness) compared with the force ratio of 0.75 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns (reshore locations 52, 53, 56, 57, 88, 89, 92, 93).
12. The minimum force ratio for the middle level of reshores has a difference of -97% (1/3 realistic reshore stiffness), -90% (realistic stiffness) and -81% (3 x realistic reshore stiffness) compared with the force ratio of 0.50 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns.
13. The minimum force ratio for the lowest level of reshores has a difference of -99% (1/3 realistic reshore stiffness), -93% (realistic stiffness) and -84% (3 x realistic reshore stiffness) compared with the force ratio of 0.25 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns.

realistic reshore stiffness) compared with the force ratio of 0.25 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns.

14. The change in load carried by the top level of reshores due to the different stiffnesses of the slabs (age of slabs) is between +2% (1/3 realistic reshore stiffness) to +5% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.
15. The change in load carried by the middle level of reshores due to the different stiffnesses of the slabs (age of slabs) is between +3% (1/3 realistic reshore stiffness) to +7% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.
16. The change in load carried by the lowest level of reshores due to the different stiffnesses of the slabs (age of slabs) is between -11% (1/3 realistic reshore stiffness) to +10% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.

3x3 Bays, 9.5m x 9.5m, 1 Level of Reshores																								
Reshore Stiffness		1/3 x Realistic						Realistic						3 x Realistic						Infinite				
Slab Relative Stiffness		1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00
Reshore Load Ratio	Max.	0.37	-26	0.39	4	0.38	3	0.49	-2	0.52	6	0.51	4	0.53	6	0.57	7	0.56	5	0.50	0.53	7	0.53	5
	Min.	0.07	-85	0.07	3	0.07	2	0.12	-75	0.13	4	0.13	3	0.19	-62	0.20	4	0.20	3					
	Avg.	0.25	-51	0.26	4	0.25	3	0.35	-30	0.37	5	0.36	4	0.41	-17	0.44	6	0.43	5					
Top Slab Load Ratio	Max.	0.93	85	0.93	0	0.93	0	0.88	75	0.87	-1	0.87	0	0.81	62	0.80	-1	0.80	-1	0.50	0.47	-7	0.47	-5
	Min.	0.63	26	0.61	-2	0.62	-2	0.51	2	0.48	-6	0.49	-4	0.47	-6	0.43	-8	0.44	-6					
	Total	0.75	51	0.74	-1	0.75	-1	0.65	30	0.63	-3	0.64	-2	0.59	17	0.56	-4	0.57	-3					
Bottom Slab Load Ratio	Max.	0.37	-26	0.39	4	0.38	3	0.49	-2	0.52	6	0.51	4	0.53	6	0.57	7	0.56	5	0.50	0.53	7	0.53	5
	Min.	0.07	-85	0.07	3	0.07	2	0.12	-75	0.13	4	0.13	3	0.19	-62	0.20	4	0.20	3					
	Total	0.25	-51	0.26	4	0.25	3	0.35	-30	0.37	5	0.36	4	0.41	-17	0.44	6	0.43	5					

Table 4.1a: Results for 3 bays x 3 bays, 9.5m x 9.5m bays model, 1 level of reshores

3x3 Bays, 9.5m x 9.5m, 2 Levels of Reshores																								
Reshore Stiffness		1/3 x Realistic						Realistic						3 x Realistic						Infinite				
Slab Relative Stiffness		1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00
Top Reshore Load Ratio	Max.	0.41	-39	0.42	3	0.42	2	0.60	-11	0.62	4	0.61	3	0.69	3	0.73	5	0.72	4	0.67	0.71	5	0.70	4
	Min.	0.08	-89	0.08	2	0.08	1	0.14	-79	0.15	3	0.14	2	0.22	-67	0.23	3	0.22	2					
	Avg.	0.27	-60	0.28	3	0.27	2	0.41	-38	0.43	4	0.43	3	0.52	-22	0.54	5	0.54	3					
Bottom Reshore Load Ratio	Max.	0.13	-62	0.13	-1	0.13	-1	0.25	-24	0.26	4	0.26	2	0.34	0	0.36	7	0.35	5	0.34	0.37	9	0.36	6
	Min.	0.01	-96	0.01	-6	0.01	-5	0.04	-87	0.04	0	0.04	0	0.07	-78	0.07	4	0.07	3					
	Avg.	0.08	-77	0.08	-2	0.08	-2	0.16	-51	0.17	3	0.17	2	0.23	-30	0.25	6	0.24	4					
Top Slab Load Ratio	Max.	0.92	172	0.92	0	0.92	0	0.86	153	0.85	0	0.86	0	0.78	130	0.77	-1	0.78	-1	0.34	0.30	-11	0.31	-8
	Min.	0.59	79	0.58	-2	0.58	-1	0.40	23	0.38	-6	0.39	-4	0.31	-6	0.27	-11	0.28	-8					
	Total	0.73	119	0.72	-1	0.73	-1	0.59	76	0.57	-3	0.57	-2	0.48	44	0.46	-5	0.46	-4					
Middle Slab Load Ratio	Max.	0.28	-16	0.30	5	0.29	4	0.34	2	0.36	4	0.35	3	0.35	6	0.36	3	0.36	3	0.34	0.34	2	0.34	2
	Min.	0.06	-81	0.06	4	0.06	3	0.10	-71	0.10	3	0.10	3	0.15	-56	0.15	3	0.15	2					
	Total	0.19	-42	0.20	4	0.20	3	0.25	-25	0.26	4	0.26	3	0.29	-14	0.30	3	0.29	3					
Bottom Slab Load Ratio	Max.	0.13	-62	0.13	-1	0.13	-1	0.25	-24	0.26	4	0.26	2	0.34	0	0.36	7	0.35	5	0.34	0.37	9	0.36	6
	Min.	0.01	-96	0.01	-6	0.01	-5	0.04	-87	0.04	0	0.04	0	0.07	-78	0.07	4	0.07	3					
	Total	0.08	-77	0.08	-2	0.08	-2	0.16	-51	0.17	3	0.17	2	0.23	-30	0.25	6	0.24	4					

Table 4.1b: Results for 3 bays x 3 bays, 9.5m x 9.5m bays model, 2 Levels of reshores

3x3 Bays, 9.5m x 9.5m, 3 Levels of Reshores																								
Reshore Stiffness		1/3 x Realistic						Realistic						3 x Realistic						Infinite				
Slab Relative Stiffness		1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00
Top Reshore Load Ratio	Max.	0.42	-45	0.43	3	0.43	2	0.62	-18	0.64	3	0.64	2	0.75	0	0.78	4	0.78	3	0.76	0.79	5	0.78	3
	Min.	0.08	-90	0.08	2	0.08	1	0.14	-80	0.15	2	0.15	2	0.23	-69	0.24	3	0.23	2					
	Avg.	0.27	-64	0.28	2	0.28	2	0.43	-43	0.44	3	0.44	2	0.56	-25	0.58	4	0.57	3					
Middle Reshore Load Ratio	Max.	0.14	-71	0.14	-3	0.14	-2	0.32	-36	0.32	1	0.32	1	0.47	-7	0.49	5	0.49	3	0.50	0.54	7	0.53	5
	Min.	0.01	-97	0.01	-7	0.01	-6	0.05	-90	0.05	-2	0.05	-2	0.09	-81	0.10	3	0.10	2					
	Avg.	0.08	-83	0.08	-4	0.08	-3	0.20	-60	0.20	1	0.20	0	0.32	-36	0.33	4	0.33	3					
Bottom Reshore Load Ratio	Max.	0.04	-82	0.04	-9	0.04	-7	0.13	-47	0.13	-1	0.13	0	0.22	-11	0.23	5	0.23	4	0.25	0.28	9	0.27	7
	Min.	0.00	-99	0.00	-24	0.00	-17	0.02	-93	0.02	-7	0.02	-5	0.04	-84	0.04	1	0.04	1					
	Avg.	0.02	-90	0.02	-11	0.02	-8	0.08	-68	0.08	-2	0.08	-1	0.15	-41	0.15	4	0.15	3					
Top Slab Load Ratio	Max.	0.92	260	0.92	0	0.92	0	0.85	233	0.85	0	0.85	0	0.77	200	0.76	-1	0.77	-1	0.26	0.22	-13	0.23	-10
	Min.	0.58	140	0.57	-2	0.57	-1	0.58	55	0.56	-5	0.56	-4	0.25	1	0.22	-12	0.22	-9					
	Total	0.73	191	0.72	-1	0.72	-1	0.57	128	0.56	-2	0.56	-2	0.44	76	0.42	-5	0.43	-3					
Middle-Top Slab Load Ratio	Max.	0.27	8	0.29	5	0.28	4	0.30	21	0.32	5	0.32	4	0.29	16	0.30	4	0.30	3	0.25	0.25	-1	0.25	0
	Min.	0.06	-75	0.06	4	0.06	3	0.09	-64	0.09	3	0.09	3	0.13	-46	0.14	2	0.14	2					
	Total	0.19	-25	0.20	5	0.19	4	0.23	-9	0.24	5	0.24	4	0.24	-4	0.25	3	0.25	3					
Middle-Bottom Slab Load Ratio	Max.	0.10	-80	0.10	0	0.10	0	0.19	-26	0.19	3	0.19	2	0.25	-2	0.26	4	0.26	3	0.25	0.27	5	0.26	3
	Min.	0.01	-95	0.01	-4	0.01	-3	0.03	-87	0.03	1	0.03	0	0.05	-78	0.06	2	0.06	1					
	Total	0.06	-76	0.06	-1	0.06	-1	0.12	-52	0.12	2	0.12	1	0.17	-31	0.18	4	0.18	2					
Bottom Slab Load Ratio	Max.	0.04	-82	0.04	-9	0.04	-7	0.13	-47	0.13	-1	0.13	0	0.22	-11	0.23	5	0.23	4	0.25	0.26	9	0.27	7
	Min.	0.00	-99	0.00	-24	0.00	-17	0.02	-93	0.02	-7	0.02	-5	0.04	-84	0.04	1	0.04	1					
	Total	0.02	-90	0.02	-11	0.02	-8	0.08	-68	0.08	-2	0.08	-1	0.15	-41	0.15	4	0.15	3					

Table 4.1c: Results for 3 bays x 3 bays, 9.5m x 9.5m bays model, 3 Levels of Reshores

4.3.2 Effect of reshore stiffness for the 3 bays x 3 bays, 6.5m x 9.5m bays model

The summary results for this model (Figure 4.2) are presented in Tables 4.2a to 4.2c shown following the text in this section. The effect of the different reshore stiffnesses when compared with the infinitely rigid reshores for this model are summarized below.

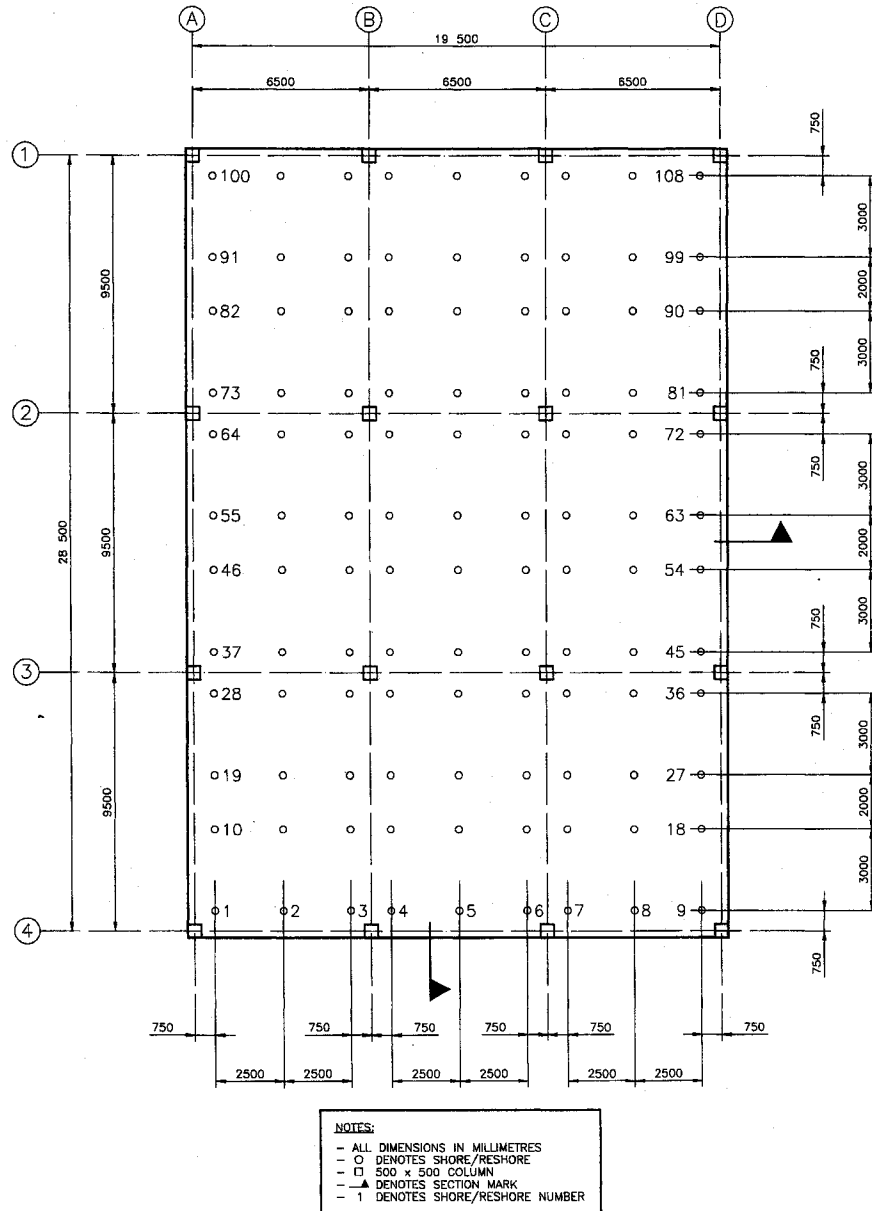


Figure 4.2: 3 bays x 3 bays, 6.5m x 9.5m bays model

4.3.2.1 Results for 1 level of reshores (2 supporting slabs. Table 4.2a)

1. The average reshore force ratio has a difference of -62% (1/3 realistic reshore stiffness), -40% (realistic stiffness) and -23% (3 x realistic reshore stiffness) when compared with the force ratio of 0.5 calculated using reshores with an infinite stiffness.
2. The total load ratio supported by the top slab has a difference of +62% (1/3 realistic reshore stiffness), +40% (realistic stiffness) and +23% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.5 calculated using reshores with an infinite stiffness.
3. The total load ratio supported by the lowest slab has a difference of -62% (1/3 realistic reshore stiffness), -40% (realistic stiffness) and -23% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.5 calculated using reshores with an infinite stiffness.
4. The maximum reshore force ratio has a difference of -35% (1/3 realistic reshore stiffness), -7% (realistic stiffness) and +5% (3 x realistic reshore stiffness) when compared with the force ratio of 0.5 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near the interior edge (short dimension) and near the mid-span (long dimension) of the corner bays (reshore locations 12, 16, 93, 97).
5. The minimum reshore force ratio has a difference of -87% (1/3 realistic reshore stiffness), -76% (realistic stiffness) and -61% (3 x realistic reshore stiffness) compared with the force ratio of 0.5 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns (reshore locations 40, 42, 67, 69).
6. The change in load carried by the reshores due to the different stiffnesses of the slabs (age of slabs) is between +2% (1/3 realistic reshore stiffness) to +7% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.

4.3.2.2 Results for 2 levels of reshores (3 supporting slabs, Table 4.2b)

1. The average force ratio for the top level of reshores has a difference of -70% (1/3 realistic reshore stiffness), -48% (realistic stiffness) and -29% (3 x realistic reshore stiffness) when compared with the force ratio of 0.67 calculated using reshores with an infinite stiffness.
2. The average force ratio for the lowest level of reshores has a difference of -86% (1/3 realistic reshore stiffness), -64% (realistic stiffness) and -40% (3 x realistic reshore stiffness) when compared with the force ratio of 0.34 calculated using reshores with an infinite stiffness.
3. The total load ratio supported by the top slab has a difference of +139% (1/3 realistic reshore stiffness), +97% (realistic stiffness) and +59% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.34 calculated using reshores with an infinite stiffness.
4. The total load ratio supported by the middle slab has a difference of -53% (1/3 realistic reshore stiffness), -33% (realistic stiffness) and -19% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.34 calculated using reshores with an infinite stiffness.
5. The total load ratio supported by the lowest slab has a difference of -86% (1/3 realistic reshore stiffness), -64% (realistic stiffness) and -40% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.34 calculated using reshores with an infinite stiffness.
6. The maximum force ratio for the top level of reshores has a difference of -47% (1/3 realistic reshore stiffness), -17% (realistic stiffness) and +1% (3 x realistic reshore stiffness) when compared with the force ratio of 0.67 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near to the mid-span of the corner bays (reshore locations 12, 16, 93, 97).
7. The maximum force ratio for the lowest level of reshores has a difference of -72% (1/3 realistic reshore stiffness), -34% (realistic stiffness) and -4% (3 x realistic reshore stiffness) when compared with the force ratio of 0.34 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near to the mid-span of the corner bays.

8. The minimum force ratio for the top level of reshores has a difference of -90% (1/3 realistic reshore stiffness), -80% (realistic stiffness) and -66% (3 x realistic reshore stiffness) compared with the force ratio of 0.67 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns (reshore locations 40, 42, 67, 69).
9. The minimum force ratio for the lowest level of reshores has a difference of -97% (1/3 realistic reshore stiffness), -90% (realistic stiffness) and -79% (3 x realistic reshore stiffness) compared with the force ratio of 0.34 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns.
10. The change in load carried by the top level of reshores due to the different stiffnesses of the slabs (age of slabs) is between +2% (1/3 realistic reshore stiffness) to +5% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.
11. The change in load carried by the lowest level of reshores due to the different stiffnesses of the slabs (age of slabs) is between -4% (1/3 realistic reshore stiffness) to +9% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.

4.3.2.3 Results for 3 levels of reshores (4 supporting slabs, Table 4.2c)

1. The average force ratio for the top level of reshores has a difference of -73% (1/3 realistic reshore stiffness), -53% (realistic stiffness) and -33% (3 x realistic reshore stiffness) when compared with the force ratio of 0.75 calculated using reshores with an infinite stiffness.
2. The average force ratio for the middle level of reshores has a difference of -90% (1/3 realistic reshore stiffness), -72% (realistic stiffness) and -47% (3 x realistic reshore stiffness) when compared with the force ratio of 0.50 calculated using reshores with an infinite stiffness.
3. The average force ratio for the lowest level of reshores has a difference of -95% (1/3 realistic reshore stiffness), -79% (realistic stiffness) and -54% (3 x realistic reshore stiffness) when compared with the force ratio of 0.25 calculated using reshores with an infinite stiffness.

4. The total load ratio supported by the top slab has a difference of +219% (1/3 realistic reshore stiffness), +159% (realistic stiffness) and +100% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.25 calculated using reshores with an infinite stiffness.
5. The total load ratio supported by the middle-top slab has a difference of -39% (1/3 realistic reshore stiffness), -16% (realistic stiffness) and -6% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.25 calculated using reshores with an infinite stiffness.
6. The total load ratio supported by the middle-lowest slab has a difference of -85% (1/3 realistic reshore stiffness), -64% (realistic stiffness) and -41% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.25 calculated using reshores with an infinite stiffness.
7. The total load ratio supported by the lowest slab has a difference of -95% (1/3 realistic reshore stiffness), -79% (realistic stiffness) and -54% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.25 calculated using reshores with an infinite stiffness.
8. The maximum force ratio for the top level of reshores has a difference of -53% (1/3 realistic reshore stiffness), -24% (realistic stiffness) and -3% (3 x realistic reshore stiffness) when compared with the force ratio of 0.75 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near to the mid-span of the corner bays (reshore locations 12, 16, 93, 97).
9. The maximum force ratio for the middle level of reshores has a difference of -80% (1/3 realistic reshore stiffness), -47% (realistic stiffness) and -12% (3 x realistic reshore stiffness) when compared with the force ratio of 0.5 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near to the mid-span of the corner bays.
10. The maximum force ratio for the lowest level of reshores has a difference of -89% (1/3 realistic reshore stiffness), -59% (realistic stiffness) and -19% (3 x realistic reshore stiffness) when compared with the force ratio of 0.25 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near to the mid-span of the corner bays.
11. The minimum force ratio for the top level of reshores has a difference of -91% (1/3 realistic reshore stiffness), -82% (realistic stiffness) and -69% (3 x realistic reshore stiffness).

reshore stiffness) compared with the force ratio of 0.75 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns (reshore locations 40, 42, 67, 69).

12. The minimum force ratio for the middle level of reshores has a difference of -98% (1/3 realistic reshore stiffness), -93% (realistic stiffness) and -82% (3 x realistic reshore stiffness) compared with the force ratio of 0.50 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns.
13. The minimum force ratio for the lowest level of reshores has a difference of -100% (1/3 realistic reshore stiffness), -96% (realistic stiffness) and -86% (3 x realistic reshore stiffness) compared with the force ratio of 0.25 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns.
14. The change in load carried by the top level of reshores due to the different stiffnesses of the slabs (age of slabs) is between +2% (1/3 realistic reshore stiffness) to +5% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.
15. The change in load carried by the middle level of reshores due to the different stiffnesses of the slabs (age of slabs) is between -4% (1/3 realistic reshore stiffness) to +7% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.
16. The change in load carried by the lowest level of reshores due to the different stiffnesses of the slabs (age of slabs) is between -12% (1/3 realistic reshore stiffness) to +10% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.

3x3 Bays, 6.5m x 9.5m, 1 Level of Reshores																									
Reshore Stiffness		1/3 x Realistic						Realistic						3 x Realistic						Infinite					
Slab Relative Stiffness		1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	
Reshore Load Ratio	Max.	0.33	-35	0.34	4	0.34	3	0.47	-7	0.49	5	0.49	4	0.53	5	0.56	6	0.55	5	0.50	0.53	7	0.53	5	
	Min.	0.06	-87	0.07	2	0.06	1	0.12	-76	0.13	4	0.13	3	0.20	-61	0.21	4	0.20	3						
	Avg.	0.19	-62	0.20	3	0.20	2	0.30	-40	0.31	5	0.31	4	0.38	-23	0.41	6	0.40	4						
Top Slab Load Ratio	Max.	0.94	87	0.93	0	0.34	-64	0.88	76	0.87	0	0.87	0	0.80	61	0.79	-1	0.80	-1	0.50	0.47	-7	0.47	-5	
	Min.	0.67	35	0.66	-2	0.06	-90	0.53	7	0.51	-5	0.51	-4	0.47	-5	0.44	-7	0.45	-5						
	Total	0.81	62	0.80	-1	0.20	-76	0.70	40	0.69	-2	0.69	-2	0.62	23	0.59	-4	0.60	-3						
Bottom Slab Load Ratio	Max.	0.33	-35	0.34	4	0.34	3	0.47	-7	0.49	5	0.49	4	0.53	5	0.56	6	0.55	5	0.50	0.53	7	0.53	5	
	Min.	0.06	-87	0.07	2	0.06	1	0.12	-76	0.13	4	0.13	3	0.20	-61	0.21	4	0.20	3						
	Total	0.19	-62	0.20	3	0.20	2	0.30	-40	0.31	5	0.31	4	0.38	-23	0.41	6	0.40	4						

Table 4.2a: Results for 3 bays x 3 bays, 6.5m x 9.5m bays model, 1 level of reshores

3x3 Bays, 6.5m x 9.5m, 2 Levels of Reshores																								
Reshore Stiffness		1/3 x Realistic						Realistic						3 x Realistic						Infinite				
Slab Relative Stiffness		1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00
Top Reshore Load Ratio	Max.	0.35	-47	0.36	2	0.36	2	0.55	-17	0.57	4	0.57	3	0.68	1	0.71	5	0.70	3	0.67	0.70	5	0.69	4
	Min.	0.07	-90	0.07	1	0.07	1	0.14	-80	0.14	2	0.14	2	0.22	-66	0.23	3	0.23	2					
	Avg.	0.20	-70	0.21	2	0.21	2	0.34	-48	0.36	3	0.35	2	0.47	-29	0.49	4	0.49	3					
Bottom Reshore Load Ratio	Max.	0.09	-72	0.09	-3	0.09	-2	0.22	-34	0.22	3	0.22	2	0.32	-4	0.34	7	0.34	4	0.33	0.36	9	0.35	6
	Min.	0.01	-97	0.01	-8	0.01	-6	0.03	-90	0.03	-1	0.03	-1	0.07	-79	0.07	3	0.07	2					
	Avg.	0.05	-86	0.05	-4	0.05	-3	0.12	-64	0.12	1	0.12	1	0.20	-40	0.21	5	0.21	3					
Top Slab Load Ratio	Max.	0.93	180	0.93	0	0.93	0	0.86	159	0.86	0	0.86	0	0.78	133	0.77	-1	0.77	-1	0.33	0.30	-11	0.31	-8
	Min.	0.65	95	0.64	-1	0.64	-1	0.45	34	0.43	-4	0.43	-3	0.32	-3	0.29	-10	0.30	-7					
	Total	0.80	139	0.79	-1	0.79	0	0.66	97	0.64	-2	0.65	-1	0.53	59	0.51	-4	0.51	-3					
Middle Slab Load Ratio	Max.	0.26	-23	0.27	4	0.27	3	0.33	0	0.35	4	0.34	3	0.35	6	0.37	3	0.36	3	0.33	0.34	2	0.34	2
	Min.	0.06	-83	0.06	3	0.06	2	0.10	-71	0.10	3	0.10	2	0.15	-54	0.16	3	0.16	3					
	Total	0.16	-53	0.16	4	0.16	3	0.22	-33	0.23	4	0.23	3	0.27	-19	0.28	3	0.28	3					
Bottom Slab Load Ratio	Max.	0.09	-72	0.09	-3	0.09	-2	0.22	-34	0.22	3	0.22	2	0.32	-4	0.34	7	0.34	4	0.33	0.36	9	0.35	6
	Min.	0.01	-97	0.01	-8	0.01	-6	0.03	-90	0.03	-1	0.03	-1	0.07	-79	0.07	3	0.07	2					
	Total	0.05	-86	0.05	-4	0.05	-3	0.12	-64	0.12	1	0.12	1	0.20	-40	0.21	5	0.21	3					

Table 4.2b: Results for 3 bays x 3 bays, 6.5m x 9.5m bays model, 2 levels of reshores

3x3 Bays, 6.5m x 9.5m, 3 Levels of Reshores																								
Reshore Stiffness		1/3 x Realistic						Realistic						3 x Realistic						Infinite				
Slab Relative Stiffness		1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00
Top Reshore Load Ratio	Max.	0.35	-53	0.36	2	0.36	2	0.57	-24	0.59	3	0.58	2	0.73	-3	0.76	4	0.75	3	0.75	0.78	5	0.78	3
	Min.	0.07	-91	0.07	1	0.07	1	0.14	-82	0.14	2	0.14	1	0.23	-69	0.24	3	0.24	2					
	Avg.	0.20	-73	0.21	2	0.21	2	0.35	-53	0.36	3	0.36	2	0.50	-33	0.52	3	0.51	2					
Middle Reshore Load Ratio	Max.	0.10	-80	0.10	-4	0.10	-3	0.27	-47	0.27	0	0.27	0	0.44	-12	0.46	4	0.45	3	0.50	0.54	7	0.53	5
	Min.	0.01	-98	0.01	-9	0.01	-7	0.04	-93	0.04	-4	0.04	-3	0.09	-82	0.09	1	0.09	1					
	Avg.	0.05	-90	0.05	-5	0.05	-4	0.14	-71	0.14	-1	0.14	-1	0.26	-47	0.27	3	0.27	2					
Bottom Reshore Load Ratio	Max.	0.03	-89	0.02	-12	0.02	-9	0.10	-59	0.10	-4	0.10	-2	0.20	-19	0.21	4	0.21	3	0.25	0.27	10	0.27	7
	Min.	0.00	-100	0.00	-31	0.00	-23	0.01	-96	0.01	-11	0.01	-8	0.03	-86	0.03	-2	0.03	-1					
	Avg.	0.01	-95	0.01	-14	0.01	-10	0.05	-79	0.05	-5	0.05	-3	0.11	-54	0.12	2	0.12	2					
Top Slab Load Ratio	Max.	0.93	274	0.93	0	0.93	0	0.86	245	0.86	0	0.86	0	0.77	207	0.76	-1	0.76	-1	0.25	0.22	-14	0.22	-10
	Min.	0.65	159	0.64	-1	0.64	-1	0.43	72	0.41	-4	0.42	-3	0.27	8	0.24	-10	0.25	-7					
	Total	0.80	219	0.79	-1	0.79	0	0.65	159	0.64	-1	0.64	-1	0.50	100	0.48	-3	0.49	-2					
Middle-Top Slab Load Ratio	Max.	0.25	1	0.26	5	0.26	4	0.30	22	0.32	5	0.32	4	0.29	16	0.30	3	0.30	3	0.25	0.25	-1	0.25	0
	Min.	0.06	-78	0.06	3	0.06	2	0.09	-63	0.10	3	0.10	3	0.14	-42	0.15	3	0.15	3					
	Total	0.15	-39	0.16	4	0.16	3	0.21	-16	0.22	5	0.22	4	0.24	-6	0.25	4	0.24	3					
Middle-Bottom Slab Load Ratio	Max.	0.08	-70	0.07	-1	0.07	-1	0.16	-35	0.17	2	0.17	1	0.24	-6	0.25	4	0.24	3	0.25	0.26	5	0.26	3
	Min.	0.01	-97	0.01	-6	0.01	-4	0.03	-90	0.03	-1	0.03	-1	0.05	-79	0.05	2	0.05	1					
	Total	0.04	-85	0.04	-2	0.04	-2	0.09	-64	0.09	2	0.09	1	0.15	-41	0.15	3	0.15	2					
Bottom Slab Load Ratio	Max.	0.03	-89	0.02	-12	0.02	-9	0.10	-59	0.10	-4	0.10	-2	0.20	-19	0.21	4	0.21	3	0.25	0.27	10	0.27	7
	Min.	0.00	-100	0.00	-31	0.00	-23	0.01	-96	0.01	-11	0.01	-8	0.03	-86	0.03	-2	0.03	-1					
	Total	0.01	-95	0.01	-14	0.01	-10	0.05	-79	0.05	-5	0.05	-3	0.11	-54	0.12	2	0.12	2					

Table 4.2c: Results for 3 bays x 3 bays, 6.5m x 9.5m bays model, 3 levels of reshores

4.3.3 Effect of reshore stiffness for the 3 bays x 3 bays, 9.5m x 9.5m (centre bay), 6.5m x 9.5m (edge bays), 6.5m x 6.5m (corner bays) model

The summary results for this model (Figure 4.3) are presented in Tables 4.3a to 4.3c shown following the text in this section. The effect of the different reshore stiffnesses when compared with the infinitely rigid reshores for this model are summarized below.

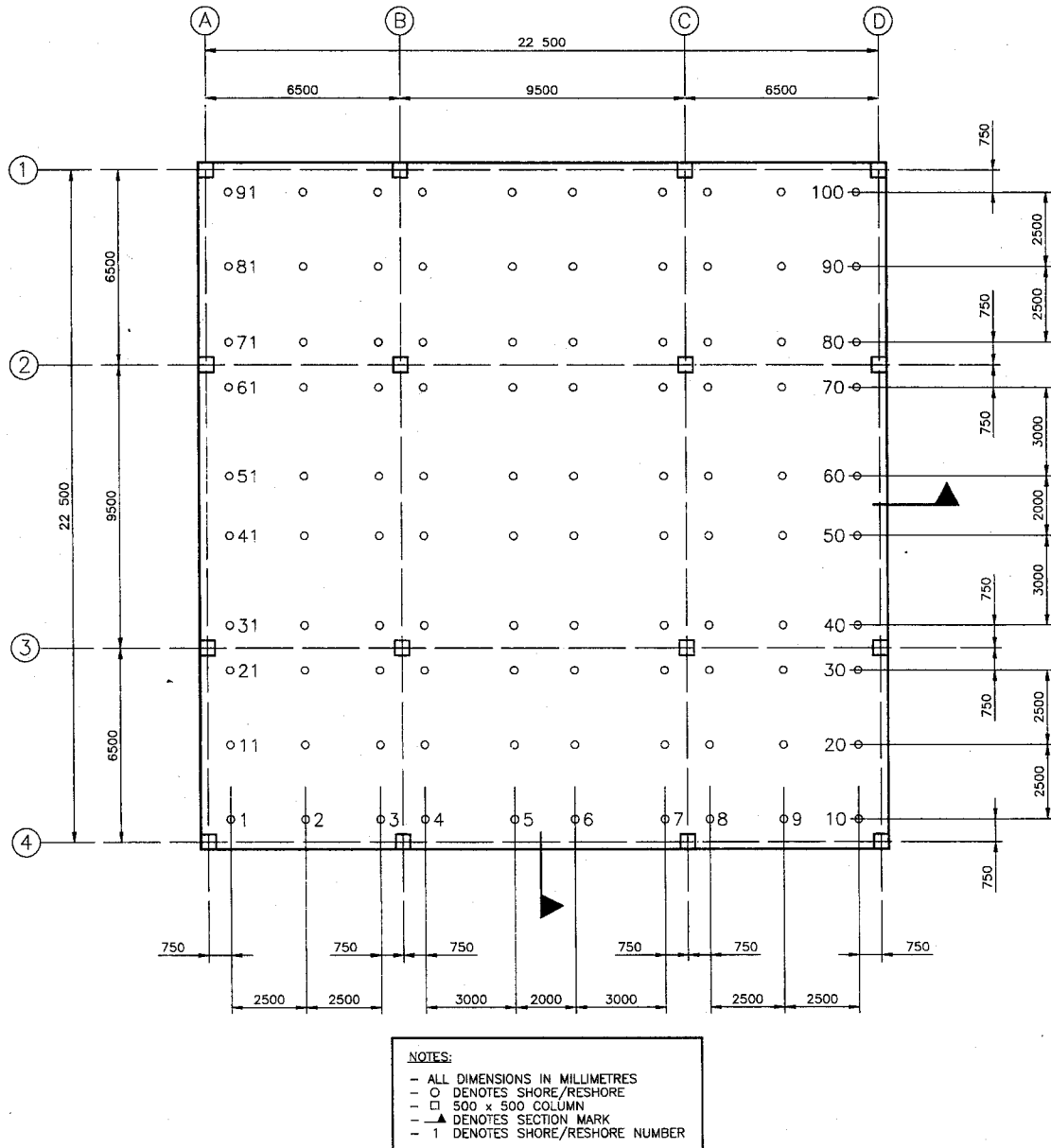


Figure 4.3: 3 bays x 3 bays, 9.5m x 9.5m (centre bay), 6.5m x 9.5m (edge bays), 6.5m x 6.5m (corner bays) model

4.3.3.1 Results for 1 level of reshores (2 supporting slabs, Table 4.3a)

1. The average reshore force ratio has a difference of -69% (1/3 realistic reshore stiffness), -47% (realistic stiffness) and -28% (3 x realistic reshore stiffness) when compared with the force ratio of 0.5 calculated using reshores with an infinite stiffness.
2. The total load ratio supported by the top slab has a difference of +69% (1/3 realistic reshore stiffness), +47% (realistic stiffness) and +28% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.5 calculated using reshores with an infinite stiffness.
3. The total load ratio supported by the lowest slab has a difference of -69% (1/3 realistic reshore stiffness), -47% (realistic stiffness) and -28% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.5 calculated using reshores with an infinite stiffness.
4. The maximum reshore force ratio has a difference of -35% (1/3 realistic reshore stiffness), -13% (realistic stiffness) and +2% (3 x realistic reshore stiffness) when compared with the force ratio of 0.5 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near the mid-span of the center bay (reshore locations 45, 46, 55, 56).
5. The minimum reshore force ratio has a difference of -89% (1/3 realistic reshore stiffness), -75% (realistic stiffness) and -60% (3 x realistic reshore stiffness) compared with the force ratio of 0.5 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns (reshore locations 23, 28, 73, 78).
6. The change in load carried by the reshores due to the different stiffnesses of the slabs (age of slabs) is between +3% (1/3 realistic reshore stiffness) to +7% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.

4.3.3.2 Results for 2 levels of reshores (3 supporting slabs, Table 4.3b)

1. The average force ratio for the top level of reshores has a difference of -76% (1/3 realistic reshore stiffness), -56% (realistic stiffness) and -35% (3 x realistic reshore stiffness) when compared with the force ratio of 0.67 calculated using reshores with an infinite stiffness.
2. The average force ratio for the lowest level of reshores has a difference of -90% (1/3 realistic reshore stiffness), -72% (realistic stiffness) and -48% (3 x realistic reshore stiffness) when compared with the force ratio of 0.34 calculated using reshores with an infinite stiffness.
3. The total load ratio supported by the top slab has a difference of +151% (1/3 realistic reshore stiffness), +111% (realistic stiffness) and +70% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.34 calculated using reshores with an infinite stiffness.
4. The total load ratio supported by the middle slab has a difference of -61% (1/3 realistic reshore stiffness), -39% (realistic stiffness) and -22% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.34 calculated using reshores with an infinite stiffness.
5. The total load ratio supported by the lowest slab has a difference of -90% (1/3 realistic reshore stiffness), -72% (realistic stiffness) and -48% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.34 calculated using reshores with an infinite stiffness.
6. The maximum force ratio for the top level of reshores has a difference of -47% (1/3 realistic reshore stiffness), -21% (realistic stiffness) and -6% (3 x realistic reshore stiffness) when compared with the force ratio of 0.67 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near to the mid-span of the corner bays (reshore locations 45, 46, 55, 56).
7. The maximum force ratio for the lowest level of reshores has a difference of -68% (1/3 realistic reshore stiffness), -34% (realistic stiffness) and -11% (3 x realistic reshore stiffness) when compared with the force ratio of 0.34 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near to the mid-span of the corner bays.

8. The minimum force ratio for the top level of reshores has a difference of -92% (1/3 realistic reshore stiffness), -81% (realistic stiffness) and -66% (3 x realistic reshore stiffness) compared with the force ratio of 0.67 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns (reshore locations 23, 28, 73, 78).
9. The minimum force ratio for the lowest level of reshores has a difference of -100% (1/3 realistic reshore stiffness), -94% (realistic stiffness) and -77% (3 x realistic reshore stiffness) compared with the force ratio of 0.34 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns.
10. The change in load carried by the top level of reshores due to the different stiffnesses of the slabs (age of slabs) is between +2% (1/3 realistic reshore stiffness) to +6% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.
11. The change in load carried by the lowest level of reshores due to the different stiffnesses of the slabs (age of slabs) is between -2% (1/3 realistic reshore stiffness) to +9% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.

4.3.3.3 Results for 3 levels of reshores (4 supporting slabs, Table 4.3c)

1. The average force ratio for the top level of reshores has a difference of -78% (1/3 realistic reshore stiffness), -60% (realistic stiffness) and -39% (3 x realistic reshore stiffness) when compared with the force ratio of 0.75 calculated using reshores with an infinite stiffness.
2. The average force ratio for the middle level of reshores has a difference of -98% (1/3 realistic reshore stiffness), -73% (realistic stiffness) and -56% (3 x realistic reshore stiffness) when compared with the force ratio of 0.50 calculated using reshores with an infinite stiffness.
3. The average force ratio for the lowest level of reshores has a difference of -97% (1/3 realistic reshore stiffness), -85% (realistic stiffness) and -63% (3 x realistic reshore stiffness) when compared with the force ratio of 0.25 calculated using reshores with an infinite stiffness.

4. The total load ratio supported by the top slab has a difference of +234% (1/3 realistic reshore stiffness), +179% (realistic stiffness) and +118% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.25 calculated using reshores with an infinite stiffness.
5. The total load ratio supported by the middle-top slab has a difference of -49% (1/3 realistic reshore stiffness), -23% (realistic stiffness) and -7% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.25 calculated using reshores with an infinite stiffness.
6. The total load ratio supported by the middle-lowest slab has a difference of -89% (1/3 realistic reshore stiffness), -71% (realistic stiffness) and -48% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.25 calculated using reshores with an infinite stiffness.
7. The total load ratio supported by the lowest slab has a difference of -97% (1/3 realistic reshore stiffness), -85% (realistic stiffness) and -63% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.25 calculated using reshores with an infinite stiffness.
8. The maximum force ratio for the top level of reshores has a difference of -52% (1/3 realistic reshore stiffness), -27% (realistic stiffness) and -9% (3 x realistic reshore stiffness) when compared with the force ratio of 0.75 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near to the mid-span of the corner bays (reshore locations 45, 46, 55, 56).
9. The maximum force ratio for the middle level of reshores has a difference of -76% (1/3 realistic reshore stiffness), -45% (realistic stiffness) and -18% (3 x realistic reshore stiffness) when compared with the force ratio of 0.5 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near to the mid-span of the corner bays.
10. The maximum force ratio for the lowest level of reshores has a difference of -86% (1/3 realistic reshore stiffness), -55% (realistic stiffness) and -23% (3 x realistic reshore stiffness) when compared with the force ratio of 0.25 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near to the mid-span of the corner bays.
11. The minimum force ratio for the top level of reshores has a difference of -93% (1/3 realistic reshore stiffness), -83% (realistic stiffness) and -68% (3 x realistic reshore stiffness).

stiffness) compared with the force ratio of 0.75 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns (reshore locations 23, 28, 73, 78).

12. The minimum force ratio for the middle level of reshores has a difference of -100% (1/3 realistic reshore stiffness), -96% (realistic stiffness) and -83% (3 x realistic reshore stiffness) compared with the force ratio of 0.50 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns.
13. The minimum force ratio for the lowest level of reshores has a difference of -101% (1/3 realistic reshore stiffness), -100% (realistic stiffness) and -89% (3 x realistic reshore stiffness) compared with the force ratio of 0.25 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns.
14. The change in load carried by the top level of reshores due to the different stiffnesses of the slabs (age of slabs) is between +2% (1/3 realistic reshore stiffness) to +5% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.
15. The change in load carried by the middle level of reshores due to the different stiffnesses of the slabs (age of slabs) is between -5% (1/3 realistic reshore stiffness) to +7% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.
16. The change in load carried by the lowest level of reshores due to the different stiffnesses of the slabs (age of slabs) is between -13% (1/3 realistic reshore stiffness) to +10% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.

3x3 Bays, 9.5m x 9.5m (centre bay), 6.5m x 9.5m (edge bays), 6.5m x 6.5m (corner bays), 1 Level of Reshores																									
Reshore Stiffness		1/3 x Realistic						Realistic						3 x Realistic						Infinite					
Slab Relative Stiffness		1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	
Reshore Load Ratio	Max.	0.32	-35	0.34	4	0.33	3	0.44	-13	0.46	6	0.45	4	0.51	2	0.54	5	0.53	4	0.50	0.53	7	0.53	5	
	Min.	0.05	-89	0.05	0	0.05	0	0.13	-75	0.13	3	0.13	2	0.20	-60	0.21	5	0.20	3						
	Avg.	0.16	-69	0.16	3	0.16	2	0.26	-47	0.28	4	0.27	3	0.36	-27	0.38	5	0.38	4						
Top Slab Load Ratio	Max.	0.95	89	0.95	0	0.95	0	0.87	75	0.87	0	0.87	0	0.80	60	0.79	-1	0.80	-1	0.50	0.47	-7	0.47	-5	
	Min.	0.68	35	0.66	-2	0.67	-1	0.56	13	0.54	-4	0.55	-3	0.49	-2	0.46	-6	0.47	-4						
	Total	0.84	69	0.84	-1	0.84	0	0.74	47	0.72	-2	0.73	-1	0.64	27	0.62	-3	0.62	-2						
Bottom Slab Load Ratio	Max.	0.32	-35	0.34	4	0.33	3	0.44	-13	0.46	6	0.45	4	0.51	2	0.54	5	0.53	4	0.50	0.53	7	0.53	5	
	Min.	0.05	-89	0.05	0	0.05	0	0.13	-75	0.13	3	0.13	2	0.20	-60	0.21	5	0.20	3						
	Total	0.16	-69	0.16	3	0.16	2	0.26	-47	0.28	4	0.27	3	0.36	-27	0.38	5	0.38	4						

Table 4.3a: Results for 3 bays x 3 bays, 9.5m x 9.5m (centre bay), 6.5m x 9.5m (edge bays), 6.5m x 6.5m (corner bays) model, 1 level of Reshores

3x3 Bays, 9.5m x 9.5m (centre bay), 6.5m x 9.5m (edge bays), 6.5m x 6.5m (corner bays), 2 Levels of Reshores																								
Reshore Stiffness		1/3 x Realistic						Realistic						3 x Realistic						Infinite				
Slab Relative Stiffness		1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00
Top Reshore Load Ratio	Max.	0.36	-47	0.37	3	0.36	2	0.53	-21	0.55	4	0.54	3	0.63	-6	0.66	5	0.65	4	0.67	0.70	5	0.69	4
	Min.	0.05	-92	0.05	1	0.05	0	0.13	-81	0.13	2	0.13	1	0.23	-66	0.24	3	0.24	2					
	Avg.	0.16	-75	0.17	2	0.17	1	0.30	-56	0.30	3	0.30	2	0.43	-35	0.45	4	0.45	3					
Bottom Reshore Load Ratio	Max.	0.11	-68	0.11	-2	0.11	-1	0.22	-34	0.23	4	0.22	2	0.30	-11	0.32	7	0.31	4	0.33	0.36	9	0.35	6
	Min.	0.00	-100	0.00	85	0.00	63	0.02	-94	0.02	-13	0.02	-9	0.08	-77	0.08	2	0.08	2					
	Avg.	0.03	-90	0.03	-4	0.03	-3	0.09	-72	0.09	0	0.09	0	0.17	-48	0.18	4	0.18	2					
Top Slab Load Ratio	Max.	0.95	184	0.95	0	0.95	0	0.87	161	0.87	0	0.87	0	0.77	131	0.76	-1	0.76	-1	0.33	0.30	-11	0.31	-8
	Min.	0.64	93	0.63	-2	0.64	-1	0.47	42	0.45	-4	0.46	-3	0.37	12	0.34	-8	0.00	-100					
	Total	0.84	151	0.83	0	0.83	0	0.70	111	0.70	-1	0.70	-1	0.57	70	0.55	-3	0.55	-2					
Middle Slab Load Ratio	Max.	0.25	-26	0.26	5	0.26	4	0.31	-8	0.32	4	0.32	3	0.36	9	0.38	5	0.38	4	0.33	0.34	2	0.34	2
	Min.	0.05	-85	0.05	2	0.05	1	0.10	-69	0.11	4	0.10	3	0.15	-54	0.16	3	0.16	2					
	Total	0.13	-61	0.13	4	0.13	3	0.20	-39	0.21	4	0.21	3	0.26	-22	0.27	4	0.27	3					
Bottom Slab Load Ratio	Max.	0.11	-68	0.11	-2	0.11	-1	0.22	-34	0.23	4	0.22	2	0.30	-11	0.32	7	0.31	4	0.33	0.36	9	0.35	6
	Min.	0.00	-100	0.00	85	0.00	63	0.02	-94	0.02	-13	0.02	-9	0.08	-77	0.08	2	0.08	2					
	Total	0.03	-90	0.03	-4	0.03	-3	0.09	-72	0.09	0	0.09	0	0.17	-48	0.18	4	0.18	2					

Table 4.3b: Results for 3 bays x 3 bays, 9.5m x 9.5m (centre bay), 6.5m x 9.5m (edge bays), 6.5m x 6.5m (corner bays) model, 2 Levels of Reshores

3x3 Bays, 9.5m x 9.5m (centre bay), 6.5m x 9.5m (edge bays), 6.5m x 6.5m (corner bays), 3 Levels of Reshores																								
Reshore Stiffness		1/3 x Realistic						Realistic						3 x Realistic						Infinite				
Slab Relative Stiffness		1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00
Top Reshore Load Ratio	Max.	0.36	-52	0.37	2	0.37	2	0.55	-27	0.57	3	0.56	2	0.68	-9	0.71	4	0.70	3	0.75	0.78	5	0.76	3
	Min.	0.05	-93	0.05	1	0.05	1	0.13	-83	0.13	2	0.13	1	0.24	-68	0.24	3	0.24	2					
	Avg.	0.16	-78	0.17	2	0.17	1	0.30	-60	0.31	3	0.31	2	0.45	-39	0.47	3	0.47	2					
Middle Reshore Load Ratio	Max.	0.12	-76	0.11	-3	0.12	-3	0.27	-45	0.28	1	0.28	1	0.41	-18	0.43	4	0.42	3	0.50	0.54	7	0.53	5
	Min.	0.00	-100	0.00	29	0.00	22	0.02	-96	0.02	-15	0.02	-11	0.09	-82	0.09	-2	0.09	-2					
	Avg.	0.04	-93	0.03	-5	0.03	-4	0.11	-78	0.11	-2	0.11	-1	0.22	-56	0.22	2	0.22	1					
Bottom Reshore Load Ratio	Max.	0.04	-86	0.03	-11	0.03	-8	0.11	-55	0.11	-1	0.11	-1	0.19	-23	0.20	5	0.20	4	0.25	0.27	9	0.27	7
	Min.	0.00	-101	0.00	-3	0.00	-3	0.00	-100	0.00	180	0.00	135	0.03	-89	0.02	-14	0.02	-10					
	Avg.	0.01	-97	0.01	-13	0.01	-9	0.04	-85	0.03	-6	0.04	-4	0.09	-63	0.09	0	0.09	0					
Top Slab Load Ratio	Max.	0.95	279	0.95	0	0.95	0	0.87	249	0.87	0	0.87	0	0.76	205	0.76	-1	0.76	-1	0.25	0.22	-14	0.22	-10
	Min.	0.64	156	0.63	-1	0.63	-1	0.45	80	0.43	-4	0.44	-3	0.32	28	0.29	-8	0.30	-6					
	Total	0.84	234	0.83	0	0.83	0	0.70	179	0.69	-1	0.69	-1	0.55	118	0.53	-3	0.53	-2					
Middle-Top Slab Load Ratio	Max.	0.24	-4	0.25	5	0.25	4	0.28	10	0.29	5	0.29	4	0.34	35	0.36	7	0.35	5	0.25	0.25	-1	0.25	0
	Min.	0.05	-79	0.05	2	0.05	1	0.10	-61	0.10	4	0.10	3	0.14	-45	0.14	2	0.14	2					
	Total	0.13	-49	0.13	4	0.13	3	0.19	-23	0.20	5	0.20	4	0.23	-7	0.24	5	0.24	3					
Middle-Bottom Slab Load Ratio	Max.	0.08	-67	0.08	0	0.08	-1	0.16	-35	0.17	3	0.16	2	0.22	-12	0.23	4	0.22	3	0.25	0.26	5	0.26	3
	Min.	0.00	-100	0.00	-107	0.00	-78	0.02	-92	0.02	-8	0.02	-6	0.06	-77	0.06	2	0.06	1					
	Total	0.03	-89	0.03	-3	0.03	-2	0.07	-71	0.07	0	0.07	0	0.13	-48	0.13	3	0.13	2					
Bottom Slab Load Ratio	Max.	0.04	-86	0.03	-11	0.03	-8	0.11	-55	0.11	-1	0.11	-1	0.19	-23	0.20	5	0.20	4	0.25	0.27	9	0.27	7
	Min.	0.00	-101	0.00	-3	0.00	-3	0.00	-100	0.00	180	0.00	135	0.03	-89	0.02	-14	0.02	-10					
	Total	0.01	-97	0.01	-13	0.01	-9	0.04	-85	0.03	-6	0.04	-4	0.09	-63	0.09	0	0.09	0					

Table 4.3c: Results for 3 bays x 3 bays, 9.5m x 9.5m (centre bay), 6.5m x 9.5m (edge bays), 6.5m x 6.5m (corner bays) model, 3 Levels of Reshore

4.3.4 Effect of reshore stiffness for the 2 bays x 2 bays, 9.5m x 9.5m bays model

The summary results for this model (Figure 4.4) are presented in Tables 4.4a to 4.4c shown following the text in this section. The effect of the different reshore stiffnesses when compared with the infinitely rigid reshores for this model are summarized below.

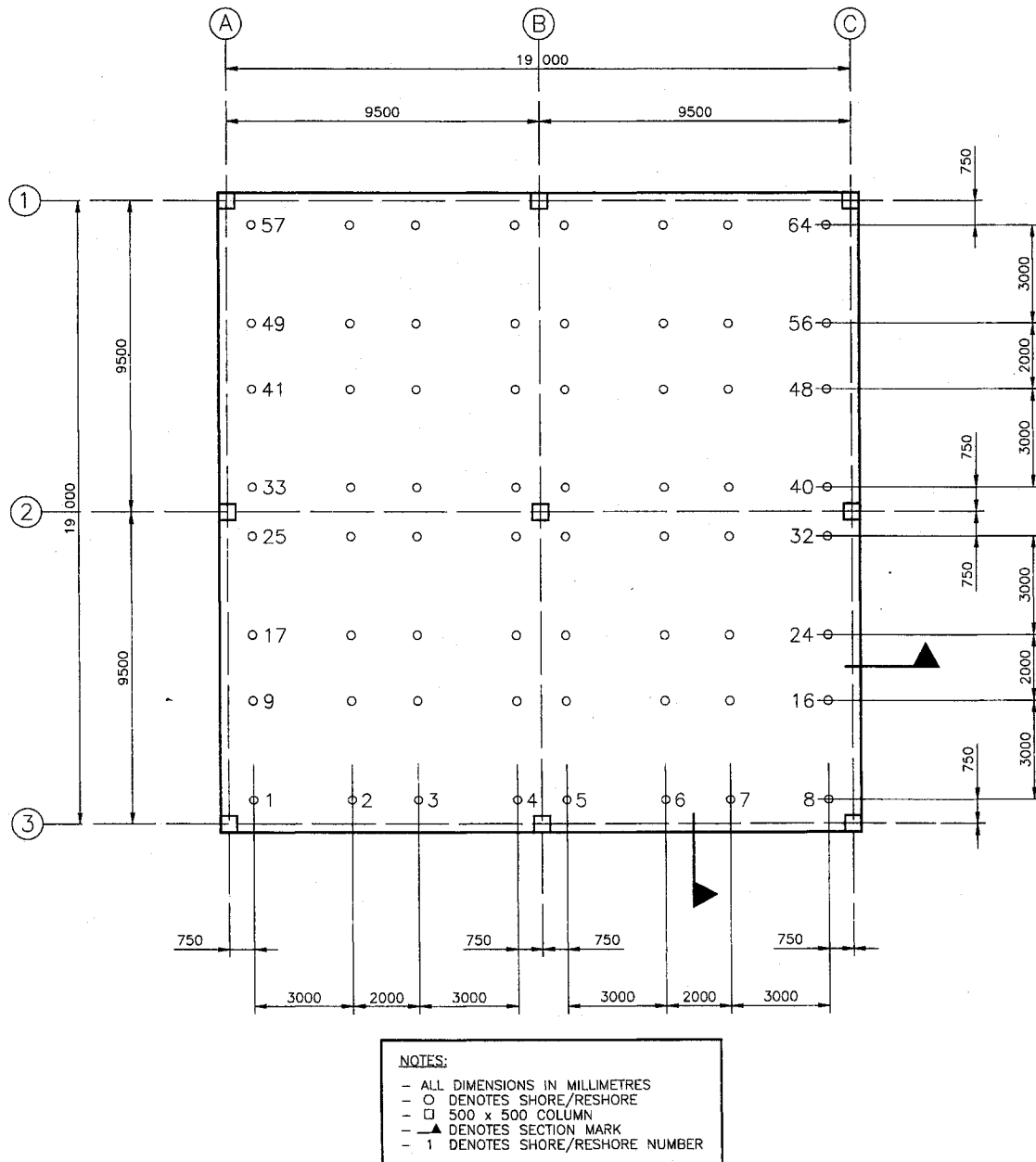


Figure 4.4: 2 bays x 2 bays, 9.5m x 9.5m bays model

4.3.4.1 Results for 1 level of reshores (2 supporting slabs, Table 4.4a)

1. The average reshore force ratio has a difference of -49% (1/3 realistic reshore stiffness), -29% (realistic stiffness) and -19% (3 x realistic reshore stiffness) when compared with the force ratio of 0.5 calculated using reshores with an infinite stiffness.
2. The total load ratio supported by the top slab has a difference of +49% (1/3 realistic reshore stiffness), +29% (realistic stiffness) and +19% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.5 calculated using reshores with an infinite stiffness.
3. The total load ratio supported by the lowest slab has a difference of -49% (1/3 realistic reshore stiffness), -29% (realistic stiffness) and -19% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.5 calculated using reshores with an infinite stiffness.
4. The maximum reshore force ratio has a difference of -27% (1/3 realistic reshore stiffness), -2% (realistic stiffness) and +6% (3 x realistic reshore stiffness) when compared with the force ratio of 0.5 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near the interior edge (short dimension) and near the mid-span (long dimension) of the corner bays (reshore locations 10, 15, 50, 55).
5. The minimum reshore force ratio has a difference of -84% (1/3 realistic reshore stiffness), -75% (realistic stiffness) and -62% (3 x realistic reshore stiffness) compared with the force ratio of 0.5 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns (reshore locations 28, 29, 36, 37).
6. The change in load carried by the reshores due to the different stiffnesses of the slabs (age of slabs) is between +3% (1/3 realistic reshore stiffness) to +7% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.

4.3.4.2 Results for 2 levels of reshores (3 supporting slabs, Table 4.4b)

1. The average force ratio for the top level of reshores has a difference of -58% (1/3 realistic reshore stiffness), -36% (realistic stiffness) and -21% (3 x realistic reshore stiffness) when compared with the force ratio of 0.67 calculated using reshores with an infinite stiffness.
2. The average force ratio for the lowest level of reshores has a difference of -75% (1/3 realistic reshore stiffness), -49% (realistic stiffness) and -29% (3 x realistic reshore stiffness) when compared with the force ratio of 0.34 calculated using reshores with an infinite stiffness.
3. The total load ratio supported by the top slab has a difference of +115% (1/3 realistic reshore stiffness), +73% (realistic stiffness) and +42% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.34 calculated using reshores with an infinite stiffness.
4. The total load ratio supported by the middle slab has a difference of -40% (1/3 realistic reshore stiffness), -24% (realistic stiffness) and -14% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.34 calculated using reshores with an infinite stiffness.
5. The total load ratio supported by the lowest slab has a difference of -75% (1/3 realistic reshore stiffness), -49% (realistic stiffness) and -29% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.34 calculated using reshores with an infinite stiffness.
6. The maximum force ratio for the top level of reshores has a difference of -39% (1/3 realistic reshore stiffness), -11% (realistic stiffness) and +4% (3 x realistic reshore stiffness) when compared with the force ratio of 0.67 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near to the mid-span of the corner bays (reshore locations 45, 46, 55, 56).
7. The maximum force ratio for the lowest level of reshores has a difference of -63% (1/3 realistic reshore stiffness), -25% (realistic stiffness) and +1% (3 x realistic reshore stiffness) when compared with the force ratio of 0.34 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near to the mid-span of the corner bays.

8. The minimum force ratio for the top level of reshores has a difference of -87% (1/3 realistic reshore stiffness), -78% (realistic stiffness) and -67% (3 x realistic reshore stiffness) compared with the force ratio of 0.67 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns (reshore locations 28, 29, 36, 37).
9. The minimum force ratio for the lowest level of reshores has a difference of -93% (1/3 realistic reshore stiffness), -86% (realistic stiffness) and -78% (3 x realistic reshore stiffness) compared with the force ratio of 0.34 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns.
10. The change in load carried by the top level of reshores due to the different stiffnesses of the slabs (age of slabs) is between +2% (1/3 realistic reshore stiffness) to +6% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.
11. The change in load carried by the lowest level of reshores due to the different stiffnesses of the slabs (age of slabs) is between -2% (1/3 realistic reshore stiffness) to +9% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.

4.3.4.3 Results for 3 levels of reshores (4 supporting slabs, Table 4.4c)

1. The average force ratio for the top level of reshores has a difference of -62% (1/3 realistic reshore stiffness), -41% (realistic stiffness) and -24% (3 x realistic reshore stiffness) when compared with the force ratio of 0.75 calculated using reshores with an infinite stiffness.
2. The average force ratio for the middle level of reshores has a difference of -82% (1/3 realistic reshore stiffness), -57% (realistic stiffness) and -35% (3 x realistic reshore stiffness) when compared with the force ratio of 0.50 calculated using reshores with an infinite stiffness.
3. The average force ratio for the lowest level of reshores has a difference of -89% (1/3 realistic reshore stiffness), -65% (realistic stiffness) and -40% (3 x realistic reshore stiffness) when compared with the force ratio of 0.25 calculated using reshores with an infinite stiffness.

4. The total load ratio supported by the top slab has a difference of +186% (1/3 realistic reshore stiffness), +123% (realistic stiffness) and +73% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.25 calculated using reshores with an infinite stiffness.
5. The total load ratio supported by the middle-top slab has a difference of -23% (1/3 realistic reshore stiffness), -8% (realistic stiffness) and -4% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.25 calculated using reshores with an infinite stiffness.
6. The total load ratio supported by the middle-lowest slab has a difference of -74% (1/3 realistic reshore stiffness), -50% (realistic stiffness) and -30% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.25 calculated using reshores with an infinite stiffness.
7. The total load ratio supported by the lowest slab has a difference of -89% (1/3 realistic reshore stiffness), -65% (realistic stiffness) and -40% (3 x realistic reshore stiffness) when compared with the total load ratio of 0.25 calculated using reshores with an infinite stiffness.
8. The maximum force ratio for the top level of reshores has a difference of -46% (1/3 realistic reshore stiffness), -18% (realistic stiffness) and -0% (3 x realistic reshore stiffness) when compared with the force ratio of 0.75 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near to the mid-span of the corner bays (reshore locations 45, 46, 55, 56).
9. The maximum force ratio for the middle level of reshores has a difference of -73% (1/3 realistic reshore stiffness), -37% (realistic stiffness) and -6% (3 x realistic reshore stiffness) when compared with the force ratio of 0.5 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near to the mid-span of the corner bays.
10. The maximum force ratio for the lowest level of reshores has a difference of -84% (1/3 realistic reshore stiffness), -49% (realistic stiffness) and -11% (3 x realistic reshore stiffness) when compared with the force ratio of 0.25 calculated using reshores with an infinite stiffness. The maximum reshore forces occur near to the mid-span of the corner bays.
11. The minimum force ratio for the top level of reshores has a difference of -95% (1/3 realistic reshore stiffness), -88% (realistic stiffness) and -80% (3 x realistic

reshore stiffness) compared with the force ratio of 0.75 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns (reshore locations 28, 29, 36, 37).

12. The minimum force ratio for the middle level of reshores has a difference of -97% (1/3 realistic reshore stiffness), -90% (realistic stiffness) and -81% (3 x realistic reshore stiffness) compared with the force ratio of 0.50 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns.
13. The minimum force ratio for the lowest level of reshores has a difference of -97% (1/3 realistic reshore stiffness), -90% (realistic stiffness) and -83% (3 x realistic reshore stiffness) compared with the force ratio of 0.25 calculated using reshores with an infinite stiffness. The minimum reshore forces occur near the interior columns.
14. The change in load carried by the top level of reshores due to the different stiffnesses of the slabs (age of slabs) is between +2% (1/3 realistic reshore stiffness) to +5% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.
15. The change in load carried by the middle level of reshores due to the different stiffnesses of the slabs (age of slabs) is between -3% (1/3 realistic reshore stiffness) to +5% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.
16. The change in load carried by the lowest level of reshores due to the different stiffnesses of the slabs (age of slabs) is between -10% (1/3 realistic reshore stiffness) to +7% (infinite reshore stiffness) when compared to the results calculated using a uniform stiffness for all slabs.

2x2 Bays, 9.5m x 9.5m, 1 Level of Reshores																								
Reshore Stiffness		1/3 x Realistic						Realistic						3 x Realistic						Infinite				
Slab Relative Stiffness		1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00
Reshore Load Ratio	Max.	0.37	-27	0.38	4	0.38	3	0.49	-2	0.52	6	0.51	4	0.53	6	0.57	7	0.56	5	0.50	0.53	7	0.53	5
	Min.	0.08	-84	0.08	4	0.08	3	0.13	-75	0.13	4	0.13	3	0.19	-62	0.20	4	0.20	3					
	Avg.	0.26	-49	0.27	4	0.26	3	0.36	-29	0.38	6	0.37	4	0.42	-17	0.44	6	0.44	5					
Top Slab Load Ratio	Max.	0.92	84	0.92	0	0.92	0	0.87	75	0.87	-1	0.87	0	0.81	62	0.80	-1	0.80	-1	0.50	0.47	-7	0.47	-5
	Min.	0.63	27	0.62	-2	0.62	-2	0.51	2	0.48	-6	0.49	-4	0.47	-6	0.43	-8	0.44	-6					
	Total	0.74	49	0.73	-1	0.74	-1	0.64	29	0.62	-3	0.63	-2	0.58	17	0.56	-4	0.56	-3					
Bottom Slab Load Ratio	Max.	0.37	-27	0.38	4	0.38	3	0.49	-2	0.52	6	0.51	4	0.53	6	0.57	7	0.56	5	0.50	0.53	7	0.53	5
	Min.	0.08	-84	0.08	4	0.08	3	0.13	-75	0.13	4	0.13	3	0.19	-62	0.20	4	0.20	3					
	Total	0.26	-49	0.27	4	0.26	3	0.36	-29	0.38	6	0.37	4	0.42	-17	0.44	6	0.44	5					

Table 4.4a: Results for 2 bays x 2 bays, 9.5m x 9.5m bays model, 1 level of reshores

2x2 Bays, 9.5m x 9.5m, 2 Levels of Reshores																								
Reshore Stiffness		1/3 x Realistic						Realistic						3 x Realistic						Infinite				
Slab Relative Stiffness		1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00
Top Reshore Load Ratio	Max.	0.40	-39	0.42	3	0.41	2	0.59	-11	0.62	4	0.61	3	0.69	4	0.72	5	0.72	4	0.67	0.70	5	0.69	4
	Min.	0.09	-87	0.09	2	0.09	2	0.15	-78	0.15	3	0.15	2	0.22	-67	0.23	3	0.23	3					
	Avg.	0.28	-58	0.29	3	0.29	2	0.42	-36	0.44	4	0.44	3	0.53	-21	0.55	5	0.54	3					
Bottom Reshore Load Ratio	Max.	0.12	-63	0.12	-2	0.12	-1	0.25	-25	0.26	4	0.26	2	0.34	1	0.36	7	0.35	5	0.35	0.36	9	0.35	6
	Min.	0.02	-93	0.02	-1	0.02	-1	0.05	-85	0.05	3	0.05	2	0.07	-78	0.08	5	0.08	3					
	Avg.	0.08	-75	0.08	-2	0.08	-1	0.17	-49	0.18	3	0.17	2	0.24	-29	0.25	6	0.25	4					
Top Slab Load Ratio	Max.	0.91	173	0.91	0	0.91	0	0.85	156	0.85	-1	0.85	0	0.78	134	0.77	-1	0.77	-1	0.33	0.30	-11	0.31	-8
	Min.	0.60	79	0.58	-2	0.59	-1	0.41	22	0.38	-6	0.39	-4	0.31	-7	0.28	-11	0.28	-8					
	Total	0.72	115	0.71	-1	0.71	-1	0.58	73	0.56	-3	0.56	-2	0.47	42	0.45	-5	0.46	-4					
Middle Slab Load Ratio	Max.	0.28	-16	0.29	5	0.29	4	0.34	3	0.36	4	0.35	3	0.35	6	0.36	3	0.36	3	0.33	0.34	2	0.34	2
	Min.	0.07	-80	0.07	4	0.07	3	0.10	-71	0.10	3	0.10	2	0.15	-56	0.15	3	0.15	2					
	Total	0.20	-40	0.21	4	0.21	3	0.25	-24	0.26	4	0.26	3	0.29	-14	0.30	3	0.30	3					
Bottom Slab Load Ratio	Max.	0.12	-63	0.12	-2	0.12	-1	0.25	-25	0.26	4	0.26	2	0.34	1	0.36	7	0.35	5	0.33	0.36	9	0.35	6
	Min.	0.02	-93	0.02	-1	0.02	-1	0.05	-85	0.05	3	0.05	2	0.07	-78	0.08	5	0.08	3					
	Total	0.08	-75	0.08	-2	0.08	-1	0.17	-49	0.18	3	0.17	2	0.24	-29	0.25	6	0.25	4					

Table 4.4b: Results for 2 bays x 2 bays, 9.5m x 9.5m bays model, 2 levels of reshores

2x2 Bays, 9.5m x 9.5m, 3 Levels of Reshores																								
Reshore Stiffness		1/3 x Realistic						Realistic						3 x Realistic						Infinite				
Slab Relative Stiffness		1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. Infinite	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00
Top Reshore Load Ratio	Max.	0.41	-46	0.42	2	0.42	2	0.62	-18	0.64	3	0.63	2	0.75	0	0.78	4	0.77	3	0.75	0.78	1	0.78	3
	Min.	0.09	-88	0.09	2	0.09	2	0.15	-80	0.16	3	0.15	2	0.23	-69	0.24	3	0.24	2					
	Avg.	0.28	-62	0.29	2	0.29	2	0.44	-41	0.46	3	0.45	2	0.57	-24	0.59	4	0.58	3					
Middle Reshore Load Ratio	Max.	0.14	-73	0.13	-3	0.13	-3	0.31	-37	0.32	1	0.32	1	0.47	-6	0.49	5	0.48	3	0.50	0.54	1	0.53	5
	Min.	0.03	-95	0.03	-3	0.03	-2	0.06	-88	0.06	1	0.06	1	0.10	-80	0.10	3	0.10	2					
	Avg.	0.09	-82	0.09	-3	0.09	-3	0.21	-57	0.21	1	0.21	1	0.33	-35	0.34	4	0.34	3					
Bottom Reshore Load Ratio	Max.	0.04	-84	0.04	-10	0.04	-7	0.13	-49	0.13	-1	0.13	-1	0.22	-11	0.23	5	0.23	4	0.25	0.27	1	0.27	7
	Min.	0.01	-97	0.01	-10	0.01	-7	0.02	-90	0.02	-1	0.02	0	0.04	-83	0.04	4	0.04	3					
	Avg.	0.03	-89	0.02	-10	0.03	-7	0.09	-65	0.09	-1	0.09	-1	0.15	-40	0.16	5	0.16	3					
Top Slab Load Ratio	Max.	0.91	264	0.91	0	0.91	0	0.85	239	0.84	0	0.85	0	0.77	207	0.76	-1	0.76	-1	0.25	0.22	5	0.22	10
	Min.	0.59	137	0.58	-2	0.58	-1	0.36	53	0.36	-5	0.37	-4	0.25	-1	0.22	-12	0.23	-9					
	Total	0.72	186	0.71	-1	0.71	-1	0.56	123	0.54	-2	0.55	-2	0.43	73	0.41	-5	0.42	-4					
Middle-Top Slab Load Ratio	Max.	0.27	9	0.29	5	0.28	4	0.31	22	0.32	5	0.32	4	0.28	13	0.29	3	0.29	2	0.25	0.25	0	0.25	0
	Min.	0.06	-75	0.07	4	0.07	3	0.09	-64	0.09	4	0.09	3	0.13	-46	0.14	3	0.14	2					
	Total	0.19	-23	0.20	5	0.20	4	0.23	-8	0.24	5	0.24	4	0.24	-4	0.25	3	0.25	2					
Middle-Bottom Slab Load Ratio	Max.	0.10	-62	0.10	0	0.10	-1	0.18	-26	0.19	3	0.19	2	0.25	-1	0.26	4	0.25	3	0.25	0.26	0	0.26	3
	Min.	0.02	-93	0.02	0	0.02	0	0.04	-86	0.04	2	0.04	1	0.06	-78	0.06	2	0.06	1					
	Total	0.06	-74	0.06	0	0.06	-1	0.13	-50	0.13	3	0.13	1	0.18	-30	0.18	4	0.18	2					
Bottom Slab Load Ratio	Max.	0.04	-84	0.04	-10	0.04	-7	0.13	-49	0.13	-1	0.13	-1	0.22	-11	0.23	5	0.23	4	0.25	0.27	1	0.27	7
	Min.	0.01	-97	0.01	-10	0.01	-7	0.02	-90	0.02	-1	0.02	0	0.04	-83	0.04	4	0.04	3					
	Total	0.03	-89	0.02	-10	0.03	-7	0.09	-65	0.09	-1	0.09	-1	0.15	-40	0.16	5	0.16	3					

Table 4.4c: Results for 2 bays x 2 bays, 9.5m x 9.5m bays model, 3 levels of reshores

4.3.5 Effect of bay sizes and aspect ratios for 1/3 x realistic reshore stiffness

The summary results for this reshore stiffness for the different models are presented in Tables 4.5a to 4.5c below. The effect of the different bay sizes and aspect ratios of models when compared with the 3 bays x 3 bays, 9.5m x 9.5m bays model are summarized below.

4.3.5.1 Results for 1 level of reshores (2 supporting slabs, Table 4.5a)

1. The average reshore force ratio has a difference of -23% (3 x 3 bays, 6.5m x 9.5m bays), -37% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +4% (2 x 2 bays, 9.5m x 9.5m) when compared with the force ratio of 0.25 for the 3 x 3 bays, 9.5m x 9.5m model.
2. The total load ratio supported by the top slab has a difference of +8% (3 x 3 bays, 6.5m x 9.5m bays), +12% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and -1% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.75 for the 3 x 3 bays, 9.5m x 9.5m model.
3. The total load ratio supported by the lowest slab has a difference of -23% (3 x 3 bays, 6.5m x 9.5m bays), -37% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +4% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.25 for the 3 x 3 bays, 9.5m x 9.5m model.

4.3.5.2 Results for 2 levels of reshores (3 supporting slabs, Table 4.5b)

1. The average force ratio for the top level of reshores has a difference of -25% (3 x 3 bays, 6.5m x 9.5m bays), -39% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +5% (2 x 2 bays, 9.5m x 9.5m) when compared with the force ratio of 0.27 for the 3 x 3 bays, 9.5m x 9.5m model.
2. The average force ratio for the lowest level of reshores has a difference of -39% (3 x 3 bays, 6.5m x 9.5m bays), -56% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +8% (2 x 2 bays, 9.5m x 9.5m) when compared with the force ratio of 0.08 for the 3 x 3 bays, 9.5m x 9.5m model.
3. The total load ratio supported by the top slab has a difference of +9% (3 x 3 bays, 6.5m x 9.5m bays), +15% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +15% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) when compared with the force ratio of 0.27 for the 3 x 3 bays, 9.5m x 9.5m model.

bays) and -2% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.73 for the 3 x 3 bays, 9.5m x 9.5m model.

4. The total load ratio supported by the middle slab has a difference of -19% (3 x 3 bays, 6.5m x 9.5m bays), -33% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +3% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.19 for the 3 x 3 bays, 9.5m x 9.5m model.
5. The total load ratio supported by the lowest slab has a difference of -39% (3 x 3 bays, 6.5m x 9.5m bays), -56% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +8% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.08 for the 3 x 3 bays, 9.5m x 9.5m model.

Results for 3 levels of reshores (4 supporting slabs, Table 4.5c)

1. The average force ratio for the top level of reshores has a difference of -25% (3 x 3 bays, 6.5m x 9.5m bays), -40% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +5% (2 x 2 bays, 9.5m x 9.5m) when compared with the force ratio of 0.27 for the 3 x 3 bays, 9.5m x 9.5m model.
2. The average force ratio for the middle level of reshores has a difference of -41% (3 x 3 bays, 6.5m x 9.5m bays), -58% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +9% (2 x 2 bays, 9.5m x 9.5m) when compared with the force ratio of 0.08 for the 3 x 3 bays, 9.5m x 9.5m model.
3. The average force ratio for the lowest level of reshores has a difference of -51% (3 x 3 bays, 6.5m x 9.5m bays), -66% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and -12% (2 x 2 bays, 9.5m x 9.5m) when compared with the force ratio of 0.02 for the 3 x 3 bays, 9.5m x 9.5m model.
4. The total load ratio supported by the top slab has a difference of +10% (3 x 3 bays, 6.5m x 9.5m bays), +15% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and -2% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.73 for the 3 x 3 bays, 9.5m x 9.5m model.
5. The total load ratio supported by the middle-top slab has a difference of -18% (3 x 3 bays, 6.5m x 9.5m bays), -32% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +3% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.19 for the 3 x 3 bays, 9.5m x 9.5m model.

6. The total load ratio supported by the middle-lowest slab has a difference of -37% (3 x 3 bays, 6.5m x 9.5m bays), -54% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +8% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.06 for the 3 x 3 bays, 9.5m x 9.5m model.
7. The total load ratio supported by the lowest slab has a difference of -51% (3 x 3 bays, 6.5m x 9.5m bays), -65% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +12% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.02 for the 3 x 3 bays, 9.5m x 9.5m model.

1/3 x Realistic Reshore Stiffness, 1 Level of Reshores																								
Reshore Stiffness		3x3 Bays, 9.5m x 9.5m (1)					3x3 Bays, 6.5m x 9.5m					3x3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m					2x2 Bays, 9.5m x 9.5m							
Slab Relative Stiffness		1.00	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)
Reshore Load Ratio	Max.	0.37	0.39	4	0.38	3	0.33	-12	0.34	-13	0.34	-12	0.32	-13	0.34	-13	0.33	-13	0.37	-1	0.38	-1	0.38	-1
	Min.	0.07	0.07	3	0.07	2	0.06	-12	0.07	-13	0.06	-13	0.05	-26	0.05	-28	0.05	-28	0.08	12	0.08	13	0.08	13
	Avg.	0.25	0.26	4	0.25	3	0.19	-23	0.20	-23	0.20	-23	0.16	-37	0.16	-38	0.16	-38	0.26	4	0.27	4	0.26	4
Top Slab Load Ratio	Max.	0.93	0.93	0	0.93	0	0.94	1	0.93	1	0.94	0	0.95	2	0.95	2	0.95	2	0.92	-1	0.92	-1	0.92	-1
	Min.	0.63	0.61	-2	0.62	-2	0.67	7	0.66	8	0.66	-1	0.68	8	0.66	8	0.67	8	0.63	1	0.62	1	0.62	1
	Total	0.75	0.74	-1	0.75	-1	0.81	8	0.80	8	0.80	-1	0.84	12	0.84	13	0.84	13	0.74	-1	0.73	-1	0.74	-1
Bottom Slab Load Ratio	Max.	0.37	0.39	4	0.38	3	0.33	-12	0.34	-13	0.34	-12	0.32	-13	0.34	-13	0.33	-13	0.37	-1	0.38	-1	0.38	-1
	Min.	0.07	0.07	3	0.07	2	0.06	-12	0.07	-13	0.06	-13	0.05	-26	0.05	-28	0.05	-28	0.08	12	0.08	13	0.08	13
	Total	0.25	0.26	4	0.25	3	0.19	-23	0.20	-23	0.20	-23	0.16	-37	0.16	-38	0.16	-38	0.26	4	0.27	4	0.26	4

Table 4.5a: Results for different models, 1/3 x realistic reshore stiffness, 1 level of reshores

1/3 x Realistic Reshore Stiffness, 2 Level of Reshores																								
Reshore Stiffness		3x3 Bays, 9.5m x 9.5m (1)					3x3 Bays, 6.5m x 9.5m					3x3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m					2x2 Bays, 9.5m x 9.5m							
Slab Relative Stiffness		1.00	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)
Top Reshore Load Ratio	Max.	0.41	0.42	3	0.42	2	0.35	-15	0.36	-15	0.36	-15	0.36	-14	0.37	-14	0.36	-14	0.40	-2	0.42	-2	0.41	-2
	Min.	0.08	0.08	2	0.08	1	0.07	-14	0.07	-14	0.07	-14	0.05	-30	0.05	-31	0.05	-31	0.09	18	0.09	19	0.09	18
	Avg.	0.27	0.28	3	0.27	2	0.20	-25	0.21	-25	0.21	-25	0.16	-39	0.17	-40	0.17	-40	0.28	5	0.29	5	0.29	5
Bottom Reshore Load Ratio	Max.	0.13	0.13	-1	0.13	-1	0.09	-27	0.09	-28	0.09	-28	0.11	-17	0.11	-17	0.11	-17	0.12	-5	0.12	-5	0.12	-5
	Min.	0.01	0.01	-6	0.01	-5	0.01	-35	0.01	-37	0.01	-36	0.00	-105	0.00	-110	0.00	-108	0.02	71	0.02	80	0.02	77
	Avg.	0.08	0.08	-2	0.08	-2	0.05	-39	0.05	-40	0.05	-40	0.03	-56	0.03	-57	0.03	-57	0.08	8	0.08	9	0.08	9
Top Slab Load Ratio	Max.	0.92	0.92	0	0.92	0	0.93	1	0.93	1	0.93	1	0.95	2	0.95	3	0.95	3	0.91	-1	0.91	-2	0.91	-2
	Min.	0.59	0.58	-2	0.58	-1	0.65	10	0.64	11	0.64	11	0.64	10	0.63	10	0.64	10	0.60	1	0.58	2	0.59	2
	Total	0.73	0.72	-1	0.73	-1	0.80	9	0.79	10	0.79	10	0.84	15	0.83	15	0.83	15	0.72	-2	0.71	-2	0.71	-2
Middle Slab Load Ratio	Max.	0.28	0.30	5	0.29	4	0.26	-9	0.27	-10	0.27	-10	0.25	-12	0.26	-12	0.26	-12	0.28	-1	0.29	-1	0.29	-1
	Min.	0.06	0.06	4	0.06	3	0.06	-9	0.06	-9	0.06	-9	0.05	-17	0.05	-18	0.05	-18	0.07	6	0.07	6	0.07	6
	Total	0.19	0.20	4	0.20	3	0.16	-19	0.16	-20	0.16	-20	0.13	-33	0.13	-33	0.13	-33	0.20	3	0.21	3	0.21	3
Bottom Slab Load Ratio	Max.	0.13	0.13	-1	0.13	-1	0.09	-27	0.09	-28	0.09	-28	0.11	-17	0.11	-17	0.11	-17	0.12	-5	0.12	-5	0.12	-5
	Min.	0.01	0.01	-6	0.01	-5	0.01	-35	0.01	-37	0.01	-36	0.00	-105	0.00	-110	0.00	-108	0.02	71	0.02	80	0.02	77
	Total	0.08	0.08	-2	0.08	-2	0.05	-39	0.05	-40	0.05	-40	0.03	-56	0.03	-57	0.03	-57	0.08	8	0.08	9	0.08	9

Table 4.5b: Results for different models, 1/3 x realistic reshore stiffness, 2 levels of reshores

Reshore Stiffness		1/3 x Realistic Reshore Stiffness, 3 Level of Reshores																							
Slab Relative Stiffness		3x3 Bays, 9.5m x 9.5m (1)					3x3 Bays, 6.5m x 9.5m					3x3 Bays, 9.5m x 9.5m, 6.6m x 9.6m, 6.6m x 6.6m					2x2 Bays, 9.5m x 9.5m								
		1.00	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)	
Top Reshore Load Ratio	Max.	0.42	0.43	3	0.43	2	0.35	-15	0.36	-16	0.36	-15	0.36	-14	0.37	-14	0.37	-14	0.41	-2	0.42	-2	0.42	-2	
	Min.	0.08	0.08	2	0.08	1	0.07	-14	0.07	-14	0.07	-14	0.05	-31	0.05	-31	0.05	-31	0.09	19	0.09	20	0.09	19	
	Avg.	0.27	0.28	2	0.28	2	0.20	-25	0.21	-26	0.21	-26	0.16	-40	0.17	-40	0.17	-40	0.28	5	0.29	5	0.29	5	
Middle Reshore Load Ratio	Max.	0.14	0.14	-3	0.14	-2	0.10	-29	0.10	-30	0.10	-30	0.12	-18	0.11	-18	0.12	-18	0.14	-5	0.13	-6	0.13	-6	
	Min.	0.01	0.01	-7	0.01	-6	0.01	-37	0.01	-38	0.01	-38	0.00	-110	0.00	-114	0.00	-113	0.03	88	0.03	96	0.03	94	
	Avg.	0.08	0.08	-4	0.08	-3	0.05	-41	0.05	-42	0.05	-42	0.04	-57	0.03	-58	0.03	-58	0.09	9	0.09	9	0.09	9	
Bottom Reshore Load Ratio	Max.	0.04	0.04	-9	0.04	-7	0.03	-39	0.02	-41	0.02	-41	0.04	-21	0.03	-22	0.03	-22	0.04	-9	0.04	-9	0.04	-9	
	Min.	0.00	0.00	-24	0.00	-17	0.00	-56	0.00	-61	0.00	-59	0.00	-179	0.00	-200	0.00	-192	0.01	223	0.01	282	0.01	263	
	Avg.	0.02	0.02	-11	0.02	-8	0.01	-51	0.01	-53	0.01	-53	0.01	-65	0.01	-66	0.01	-66	0.03	12	0.02	13	0.03	13	
Top Slab Load Ratio	Max.	0.92	0.92	0	0.92	0	0.93	1	0.93	1	0.93	1	0.95	3	0.95	3	0.95	3	0.91	-2	0.91	-2	0.91	-2	
	Min.	0.58	0.57	-2	0.57	-1	0.65	11	0.64	12	0.64	11	0.64	10	0.63	11	0.63	10	0.59	2	0.58	2	0.58	2	
	Total	0.73	0.72	-1	0.72	-1	0.80	10	0.79	10	0.79	10	0.84	15	0.83	15	0.83	15	0.72	-2	0.71	-2	0.71	-2	
Middle-Top Slab Load Ratio	Max.	0.27	0.29	5	0.28	4	0.25	-8	0.26	-8	0.26	-8	0.24	-12	0.25	-12	0.25	-12	0.27	-1	0.29	-1	0.28	-1	
	Min.	0.06	0.06	4	0.06	3	0.06	-8	0.06	-9	0.06	-8	0.05	-15	0.05	-17	0.05	-17	0.06	4	0.07	4	0.07	4	
	Total	0.19	0.20	5	0.19	4	0.15	-18	0.16	-19	0.16	-19	0.13	-32	0.13	-32	0.13	-32	0.19	3	0.20	3	0.20	3	
Middle-Bottom Slab Load Ratio	Max.	0.10	0.10	0	0.10	0	0.08	-25	0.07	-26	0.07	-26	0.08	-16	0.08	-17	0.08	-17	0.10	-4	0.10	-4	0.10	-4	
	Min.	0.01	0.01	-4	0.01	-3	0.01	-33	0.01	-34	0.01	-34	0.00	-96	0.00	-100	0.00	-99	0.02	59	0.02	64	0.02	63	
	Total	0.06	0.06	-1	0.06	-1	0.04	-37	0.04	-38	0.04	-38	0.03	-54	0.03	-55	0.03	-55	0.06	8	0.06	8	0.06	8	
Bottom Slab Load Ratio	Max.	0.04	0.04	-9	0.04	-7	0.03	-39	0.02	-41	0.02	-41	0.04	-21	0.03	-22	0.03	-22	0.04	-9	0.04	-9	0.04	-9	
	Min.	0.00	0.00	-24	0.00	-17	0.00	-56	0.00	-61	0.00	-59	0.00	-179	0.00	-200	0.00	-192	0.01	223	0.01	282	0.01	263	
	Total	0.02	0.02	-11	0.02	-8	0.01	-51	0.01	-53	0.01	-53	0.01	-65	0.01	-66	0.01	-66	0.03	12	0.02	13	0.03	13	

Table 4.5c: Results for different models, 1/3 x realistic reshore stiffness, 3 levels of reshores

4.3.6 Effect of bay Sizes and aspect ratios for realistic reshore stiffness

The summary results for this reshore stiffness for the different models are presented in Tables 4.6a to 4.6c below. The effect of the different bay sizes and aspect ratios of models when compared with the 3 bays x 3 bays, 9.5m x 9.5m bays model are summarized below.

4.3.6.1 Results for 1 level of reshores (2 supporting slabs, Table 4.6a)

1. The average reshore force ratio has a difference of -14% (3 x 3 bays, 6.5m x 9.5m bays), -24% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +2% (2 x 2 bays, 9.5m x 9.5m) when compared with the force ratio of 0.35 for the 3 x 3 bays, 9.5m x 9.5m model.
2. The total load ratio supported by the top slab has a difference of +7% (3 x 3 bays, 6.5m x 9.5m bays), +13% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and -1% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.65 for the 3 x 3 bays, 9.5m x 9.5m model.
3. The total load ratio supported by the lowest slab has a difference of -14% (3 x 3 bays, 6.5m x 9.5m bays), -24% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +2% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.35 for the 3 x 3 bays, 9.5m x 9.5m model.

4.3.6.2 Results for 2 levels of reshores (3 supporting slabs, Table 4.6b)

1. The average force ratio for the top level of reshores has a difference of -17% (3 x 3 bays, 6.5m x 9.5m bays), -29% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +3% (2 x 2 bays, 9.5m x 9.5m) when compared with the force ratio of 0.41 for the 3 x 3 bays, 9.5m x 9.5m model.
2. The average force ratio for the lowest level of reshores has a difference of -26% (3 x 3 bays, 6.5m x 9.5m bays), -43% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +4% (2 x 2 bays, 9.5m x 9.5m) when compared with the force ratio of 0.16 for the 3 x 3 bays, 9.5m x 9.5m model.
3. The total load ratio supported by the top slab has a difference of +12% (3 x 3 bays, 6.5m x 9.5m bays), +20% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +4% (2 x 2 bays, 9.5m x 9.5m) when compared with the force ratio of 0.41 for the 3 x 3 bays, 9.5m x 9.5m model.

6.5m bays) and -2% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.59 for the 3 x 3 bays, 9.5m x 9.5m model.

4. The total load ratio supported by the middle slab has a difference of -11% (3 x 3 bays, 6.5m x 9.5m bays), -19% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +1% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.25 for the 3 x 3 bays, 9.5m x 9.5m model.
5. The total load ratio supported by the lowest slab has a difference of -26% (3 x 3 bays, 6.5m x 9.5m bays), -43% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +4% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.16 for the 3 x 3 bays, 9.5m x 9.5m model.

4.3.6.3 Results for 3 levels of reshores (4 supporting slabs, Table 4.6c)

1. The average force ratio for the top level of reshores has a difference of -18% (3 x 3 bays, 6.5m x 9.5m bays), -30% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +3% (2 x 2 bays, 9.5m x 9.5m) when compared with the force ratio of 0.43 for the 3 x 3 bays, 9.5m x 9.5m model.
2. The average force ratio for the middle level of reshores has a difference of -30% (3 x 3 bays, 6.5m x 9.5m bays), -46% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +5% (2 x 2 bays, 9.5m x 9.5m) when compared with the force ratio of 0.20 for the 3 x 3 bays, 9.5m x 9.5m model.
3. The average force ratio for the lowest level of reshores has a difference of -36% (3 x 3 bays, 6.5m x 9.5m bays), -55% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and -7% (2 x 2 bays, 9.5m x 9.5m) when compared with the force ratio of 0.08 for the 3 x 3 bays, 9.5m x 9.5m model.
4. The total load ratio supported by the top slab has a difference of +14% (3 x 3 bays, 6.5m x 9.5m bays), +23% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and -2% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.57 for the 3 x 3 bays, 9.5m x 9.5m model.
5. The total load ratio supported by the middle-top slab has a difference of -8% (3 x 3 bays, 6.5m x 9.5m bays), -15% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +1% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.23 for the 3 x 3 bays, 9.5m x 9.5m model.

6. The total load ratio supported by the middle-lowest slab has a difference of -25% (3 x 3 bays, 6.5m x 9.5m bays), -41% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +4% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.12 for the 3 x 3 bays, 9.5m x 9.5m model.
7. The total load ratio supported by the lowest slab has a difference of -36% (3 x 3 bays, 6.5m x 9.5m bays), -55% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +7% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.08 for the 3 x 3 bays, 9.5m x 9.5m model.

Realistic Reshore Stiffness, 1 Level of Reshores																								
Reshore Stiffness		3x3 Bays, 9.5m x 9.5m (1)					3x3 Bays, 6.5m x 9.5m					3x3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.6m					2x2 Bays, 9.5m x 9.5m							
Slab Relative Stiffness		1.00	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)
Reshore Load Ratio	Max.	0.49	0.52	6	0.51	4	0.47	-5	0.49	-5	0.49	-5	0.44	-11	0.46	-11	0.45	-11	0.49	0	0.52	0	0.51	0
	Min.	0.12	0.13	4	0.13	3	0.12	-2	0.13	-3	0.13	-3	0.13	1	0.13	-1	0.13	0	0.13	2	0.13	2	0.13	2
	Avg.	0.35	0.37	5	0.36	4	0.30	-14	0.31	-14	0.31	-14	0.26	-24	0.28	-25	0.27	-25	0.36	2	0.38	2	0.37	2
Top Slab Load Ratio	Max.	0.88	0.87	-1	0.87	0	0.88	0	0.87	0	0.87	0	0.87	0	0.87	0	0.87	0	0.87	0	0.87	0	0.87	0
	Min.	0.51	0.48	-6	0.49	-4	0.53	5	0.51	6	0.51	5	0.56	11	0.54	12	0.55	12	0.51	0	0.48	0	0.49	0
	Total	0.65	0.63	-3	0.64	-2	0.70	7	0.69	8	0.69	8	0.74	13	0.72	15	0.73	14	0.64	-1	0.62	-1	0.63	-1
Bottom Slab Load Ratio	Max.	0.49	0.52	6	0.51	4	0.47	-5	0.49	-5	0.49	-5	0.44	-11	0.46	-11	0.45	-11	0.49	0	0.52	0	0.51	0
	Min.	0.12	0.13	4	0.13	3	0.12	-2	0.13	-3	0.13	-3	0.13	1	0.13	-1	0.13	0	0.13	2	0.13	2	0.13	2
	Total	0.35	0.37	5	0.36	4	0.30	-14	0.31	-14	0.31	-14	0.26	-24	0.28	-25	0.27	-25	0.36	2	0.38	2	0.37	2

Table 4.6a: Results for different models, realistic reshore stiffness, 1 level of reshores

Realistic Reshore Stiffness, 2 Levels of Reshores																								
Reshore Stiffness		3x3 Bays, 9.5m x 9.5m (1)					3x3 Bays, 6.5m x 9.5m					3x3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m					2x2 Bays, 9.5m x 9.5m							
Slab Relative Stiffness		1.00	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)
Top Reshore Load Ratio	Max.	0.60	0.62	4	0.61	3	0.55	-8	0.57	-8	0.57	-8	0.53	-12	0.55	-12	0.54	-12	0.59	-1	0.62	-1	0.61	-1
	Min.	0.14	0.15	3	0.14	2	0.14	-5	0.14	-5	0.14	-5	0.13	-9	0.13	-10	0.13	-10	0.15	4	0.15	4	0.15	4
	Avg.	0.41	0.43	4	0.43	3	0.34	-17	0.36	-17	0.35	-17	0.30	-29	0.30	-29	0.30	-29	0.42	3	0.44	3	0.44	3
Bottom Reshore Load Ratio	Max.	0.25	0.26	4	0.26	2	0.22	-14	0.22	-15	0.22	-14	0.22	-14	0.23	-14	0.22	-14	0.25	-1	0.26	-2	0.26	-2
	Min.	0.04	0.04	0	0.04	0	0.03	-20	0.03	-21	0.03	-21	0.02	-50	0.02	-57	0.02	-55	0.05	16	0.05	20	0.05	19
	Avg.	0.16	0.17	3	0.17	2	0.12	-26	0.12	-27	0.12	-27	0.09	-43	0.09	-44	0.09	-44	0.17	4	0.18	5	0.17	5
Top Slab Load Ratio	Max.	0.86	0.85	0	0.86	0	0.86	1	0.86	1	0.86	1	0.87	1	0.87	2	0.87	2	0.85	-1	0.85	-1	0.85	-1
	Min.	0.40	0.38	-6	0.39	-4	0.45	11	0.43	13	0.43	12	0.47	17	0.45	19	0.46	19	0.41	1	0.38	1	0.39	1
	Total	0.59	0.57	-3	0.57	-2	0.66	12	0.64	13	0.65	13	0.70	20	0.70	22	0.70	21	0.58	-2	0.56	-2	0.56	-2
Middle Slab Load Ratio	Max.	0.34	0.36	4	0.35	3	0.33	-3	0.35	-3	0.34	-3	0.31	-10	0.32	-10	0.32	-10	0.34	0	0.36	0	0.35	0
	Min.	0.10	0.10	3	0.10	3	0.10	1	0.10	1	0.10	1	0.10	5	0.11	6	0.10	6	0.10	2	0.10	2	0.10	2
	Total	0.25	0.26	4	0.26	3	0.22	-11	0.23	-11	0.23	-11	0.20	-19	0.21	-19	0.21	-19	0.25	1	0.26	1	0.26	1
Bottom Slab Load Ratio	Max.	0.25	0.26	4	0.26	2	0.22	-14	0.22	-15	0.22	-14	0.22	-14	0.23	-14	0.22	-14	0.25	-1	0.26	-2	0.26	-2
	Min.	0.04	0.04	0	0.04	0	0.03	-20	0.03	-21	0.03	-21	0.02	-50	0.02	-57	0.02	-55	0.05	16	0.05	20	0.05	19
	Total	0.16	0.17	3	0.17	2	0.12	-26	0.12	-27	0.12	-27	0.09	-43	0.09	-44	0.09	-44	0.17	4	0.18	5	0.17	5

Table 4.6b: Results for different models, realistic reshore stiffness, 2 levels of reshores

Realistic Reshore Stiffness, 3 Levels of Reshores																									
Reshore Stiffness		3x3 Bays, 9.5m x 9.5m (1)					3x3 Bays, 6.5m x 9.5m					3x3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m					2x2 Bays, 9.5m x 9.5m								
Slab Relative Stiffness		1.00	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)	
Top Reshore Load Ratio	Max.	0.62	0.64	3	0.64	2	0.57	-9	0.59	-9	0.58	-9	0.55	-12	0.57	-12	0.56	-12	0.62	-1	0.64	-1	0.63	-1	
	Min.	0.14	0.15	2	0.15	2	0.14	-6	0.14	-6	0.14	-6	0.13	-11	0.13	-12	0.13	-12	0.15	5	0.16	5	0.15	5	
	Avg.	0.43	0.44	3	0.44	2	0.35	-18	0.36	-18	0.36	-18	0.30	-30	0.31	-30	0.31	-30	0.44	3	0.46	3	0.45	3	
Middle Reshore Load Ratio	Max.	0.32	0.32	1	0.32	1	0.27	-17	0.27	-18	0.27	-18	0.27	-15	0.28	-15	0.28	-15	0.31	-2	0.32	-2	0.32	-2	
	Min.	0.05	0.05	-2	0.05	-2	0.04	-23	0.04	-25	0.04	-24	0.02	-62	0.02	-67	0.02	-66	0.06	27	0.06	30	0.06	29	
	Avg.	0.20	0.20	1	0.20	0	0.14	-29	0.14	-30	0.14	-30	0.11	-46	0.11	-48	0.11	-47	0.21	5	0.21	6	0.21	6	
Bottom Reshore Load Ratio	Max.	0.13	0.13	-1	0.13	0	0.10	-23	0.10	-25	0.10	-25	0.11	-15	0.11	-16	0.11	-16	0.13	-3	0.13	-4	0.13	-4	
	Min.	0.02	0.02	-7	0.02	-5	0.01	-35	0.01	-37	0.01	-36	0.00	-104	0.00	-112	0.00	-110	0.02	50	0.02	60	0.02	57	
	Avg.	0.08	0.08	-2	0.08	-1	0.05	-36	0.05	-38	0.05	-38	0.04	-55	0.03	-56	0.04	-56	0.09	7	0.09	8	0.09	8	
Top Slab Load Ratio	Max.	0.86	0.85	0	0.85	0	0.86	1	0.86	1	0.86	1	0.87	2	0.87	2	0.87	2	0.85	-1	0.84	-1	0.85	-1	
	Min.	0.38	0.36	-5	0.36	-4	0.43	15	0.41	16	0.42	16	0.45	20	0.43	22	0.44	21	0.38	2	0.36	2	0.37	2	
	Total	0.57	0.56	-2	0.56	-2	0.65	14	0.64	15	0.64	14	0.70	23	0.69	24	0.69	24	0.56	-2	0.54	-2	0.55	-2	
Middle-Top Slab Load Ratio	Max.	0.30	0.32	5	0.32	4	0.30	0	0.32	0	0.32	0	0.28	-9	0.29	-9	0.29	-9	0.31	0	0.32	0	0.32	0	
	Min.	0.09	0.09	3	0.09	3	0.09	4	0.10	4	0.10	4	0.10	8	0.10	8	0.10	8	0.09	2	0.09	2	0.09	2	
	Total	0.23	0.24	5	0.24	4	0.21	-8	0.22	-8	0.22	-8	0.19	-15	0.20	-15	0.20	-15	0.23	1	0.24	0	0.24	0	
Middle-Bottom Slab Load Ratio	Max.	0.19	0.19	3	0.19	2	0.16	-13	0.17	-13	0.17	-13	0.16	-14	0.17	-14	0.16	-14	0.18	-1	0.19	-2	0.19	-1	
	Min.	0.03	0.03	1	0.03	0	0.03	-18	0.03	-19	0.03	-18	0.02	-40	0.02	-46	0.02	-44	0.04	15	0.04	16	0.04	16	
	Total	0.12	0.12	2	0.12	1	0.09	-25	0.09	-25	0.09	-25	0.07	-41	0.07	-42	0.07	-42	0.13	4	0.13	4	0.13	4	
Bottom Slab Load Ratio	Max.	0.13	0.13	-1	0.13	0	0.10	-23	0.10	-25	0.10	-25	0.11	-15	0.11	-16	0.11	-16	0.13	-3	0.13	-4	0.13	-4	
	Min.	0.02	0.02	-7	0.02	-5	0.01	-35	0.01	-37	0.01	-36	0.00	-104	0.00	-112	0.00	-110	0.02	50	0.02	60	0.02	57	
	Total	0.08	0.08	-2	0.08	-1	0.05	-36	0.05	-38	0.05	-38	0.04	-55	0.03	-56	0.04	-56	0.09	7	0.09	8	0.09	8	

Table 4.6c: Results for different models, realistic reshore stiffness, 3 levels of reshores

4.3.7 Effect of bay sizes and aspect ratios for 3 x realistic reshore stiffness

The summary results for this reshore stiffness for the different models are presented in Tables 4.7a to 4.7c below. The effect of the different bay sizes and aspect ratios of models when compared with the 3 bays x 3 bays, 9.5m x 9.5m bays model are summarized below.

4.3.7.1 Results for 1 level of reshores (2 supporting slabs, Table 4.7a)

1. The average reshore force ratio has a difference of -7% (3 x 3 bays, 6.5m x 9.5m bays), -12% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +1% (2 x 2 bays, 9.5m x 9.5m) when compared with the force ratio of 0.41 for the 3 x 3 bays, 9.5m x 9.5m model.
2. The total load ratio supported by the top slab has a difference of +5% (3 x 3 bays, 6.5m x 9.5m bays), +9% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and 0% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.59 for the 3 x 3 bays, 9.5m x 9.5m model.
3. The total load ratio supported by the lowest slab has a difference of -7% (3 x 3 bays, 6.5m x 9.5m bays), -12% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +1% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.41 for the 3 x 3 bays, 9.5m x 9.5m model.

4.3.7.2 Results for 2 levels of reshores (3 supporting slabs, Table 4.7b)

1. The average force ratio for the top level of reshores has a difference of -9% (3 x 3 bays, 6.5m x 9.5m bays), -17% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +1% (2 x 2 bays, 9.5m x 9.5m) when compared with the force ratio of 0.52 for the 3 x 3 bays, 9.5m x 9.5m model.
2. The average force ratio for the lowest level of reshores has a difference of -15% (3 x 3 bays, 6.5m x 9.5m bays), -26% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +2% (2 x 2 bays, 9.5m x 9.5m) when compared with the force ratio of 0.23 for the 3 x 3 bays, 9.5m x 9.5m model.
3. The total load ratio supported by the top slab has a difference of +10% (3 x 3 bays, 6.5m x 9.5m bays), +18% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x

6.5m bays) and -1% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.48 for the 3 x 3 bays, 9.5m x 9.5m model.

4. The total load ratio supported by the middle slab has a difference of -5% (3 x 3 bays, 6.5m x 9.5m bays), -9% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +0% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.29 for the 3 x 3 bays, 9.5m x 9.5m model.
5. The total load ratio supported by the lowest slab has a difference of -15% (3 x 3 bays, 6.5m x 9.5m bays), -26% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +2% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.23 for the 3 x 3 bays, 9.5m x 9.5m model.

4.3.7.3 Results for 3 levels of reshores (4 supporting slabs, Table 4.7c)

1. The average force ratio for the top level of reshores has a difference of -11% (3 x 3 bays, 6.5m x 9.5m bays), -19% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +1% (2 x 2 bays, 9.5m x 9.5m) when compared with the force ratio of 0.56 for the 3 x 3 bays, 9.5m x 9.5m model.
2. The average force ratio for the middle level of reshores has a difference of -18% (3 x 3 bays, 6.5m x 9.5m bays), -31% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +2% (2 x 2 bays, 9.5m x 9.5m) when compared with the force ratio of 0.32 for the 3 x 3 bays, 9.5m x 9.5m model.
3. The average force ratio for the lowest level of reshores has a difference of -22% (3 x 3 bays, 6.5m x 9.5m bays), -37% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and -2% (2 x 2 bays, 9.5m x 9.5m) when compared with the force ratio of 0.15 for the 3 x 3 bays, 9.5m x 9.5m model.
4. The total load ratio supported by the top slab has a difference of +14% (3 x 3 bays, 6.5m x 9.5m bays), +24% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and -2% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.44 for the 3 x 3 bays, 9.5m x 9.5m model.
5. The total load ratio supported by the middle-top slab has a difference of -2% (3 x 3 bays, 6.5m x 9.5m bays), -3% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and 0% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.24 for the 3 x 3 bays, 9.5m x 9.5m model.

6. The total load ratio supported by the middle-lowest slab has a difference of -14% (3 x 3 bays, 6.5m x 9.5m bays), -25% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +2% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.17 for the 3 x 3 bays, 9.5m x 9.5m model.
7. The total load ratio supported by the lowest slab has a difference of -22% (3 x 3 bays, 6.5m x 9.5m bays), -37% (3 x 3 bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m bays) and +3% (2 x 2 bays, 9.5m x 9.5m) when compared with a total load ratio 0.15 for the 3 x 3 bays, 9.5m x 9.5m model.

3 x Realistic Reshore Stiffness, 1 Level of Reshores																								
Reshore Stiffness		3x3 Bays, 9.5m x 9.5m (1)					3x3 Bays, 6.5m x 9.5m					3x3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m					2x2 Bays, 9.5m x 9.5m							
Slab Relative Stiffness		1.00	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)
Reshore Load Ratio	Max.	0.53	0.57	7	0.56	5	0.53	-1	0.56	-1	0.55	-1	0.51	-3	0.54	-5	0.53	-4	0.53	0	0.57	0	0.56	0
	Min.	0.19	0.20	4	0.20	3	0.20	4	0.21	4	0.20	4	0.20	5	0.21	5	0.20	5	0.19	1	0.20	1	0.20	1
	Avg.	0.41	0.44	6	0.43	5	0.38	-7	0.41	-7	0.40	-7	0.36	-12	0.38	-13	0.38	-13	0.42	1	0.44	1	0.44	1
Top Slab Load Ratio	Max.	0.81	0.80	-1	0.80	-1	0.80	-1	0.79	-1	0.80	-1	0.80	-1	0.79	-1	0.80	-1	0.81	0	0.80	0	0.80	0
	Min.	0.47	0.43	-8	0.44	-6	0.47	1	0.44	1	0.45	1	0.49	4	0.46	6	0.47	6	0.47	0	0.43	0	0.44	0
	Total	0.59	0.56	-4	0.57	-3	0.62	5	0.59	6	0.60	6	0.64	9	0.62	10	0.62	10	0.58	0	0.56	-1	0.56	-1
Bottom Slab Load Ratio	Max.	0.53	0.57	7	0.56	5	0.53	-1	0.56	-1	0.55	-1	0.51	-3	0.54	-5	0.53	-4	0.53	0	0.57	0	0.56	0
	Min.	0.19	0.20	4	0.20	3	0.20	4	0.21	4	0.20	4	0.20	5	0.21	5	0.20	5	0.19	1	0.20	1	0.20	1
	Total	0.41	0.44	6	0.43	5	0.38	-7	0.41	-7	0.40	-7	0.36	-12	0.38	-13	0.38	-13	0.42	1	0.44	1	0.44	1

Table 4.7a: Results for different models, 3 x realistic reshore stiffness, 1 level of reshores

3 x Realistic Reshore Stiffness, 2 Levels of Reshores																								
Reshore Stiffness		3x3 Bays, 9.5m x 9.5m (1)					3x3 Bays, 6.5m x 9.5m					3x3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m					2x2 Bays, 9.5m x 9.5m							
Slab Relative Stiffness		1.00	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)
Top Reshore Load Ratio	Max.	0.69	0.73	5	0.72	4	0.68	-2	0.71	-2	0.70	-2	0.63	-9	0.66	-9	0.65	-9	0.69	0	0.72	0	0.72	0
	Min.	0.22	0.23	3	0.22	2	0.22	3	0.23	2	0.23	3	0.23	5	0.24	5	0.24	5	0.22	1	0.23	2	0.23	1
	Avg.	0.52	0.54	5	0.54	3	0.47	-9	0.49	-10	0.49	-10	0.43	-16	0.45	-17	0.45	-17	0.53	1	0.55	1	0.54	1
Bottom Reshore Load Ratio	Max.	0.34	0.36	7	0.35	5	0.32	-5	0.34	-5	0.34	-5	0.30	-12	0.32	-12	0.31	-12	0.34	0	0.36	0	0.35	0
	Min.	0.07	0.07	4	0.07	3	0.07	-3	0.07	-4	0.07	-4	0.08	6	0.08	4	0.08	5	0.07	2	0.08	3	0.08	3
	Avg.	0.23	0.25	6	0.24	4	0.20	-15	0.21	-15	0.21	-15	0.17	-26	0.18	-27	0.18	-27	0.24	2	0.25	2	0.25	2
Top Slab Load Ratio	Max.	0.78	0.77	-1	0.78	-1	0.78	-1	0.77	-1	0.77	-1	0.77	-2	0.76	-2	0.76	-2	0.78	0	0.77	0	0.77	0
	Min.	0.31	0.27	-11	0.28	-8	0.32	5	0.29	6	0.30	6	0.37	21	0.34	25	0.35	24	0.31	0	0.28	0	0.28	0
	Total	0.48	0.46	-5	0.46	-4	0.53	10	0.51	12	0.51	11	0.57	18	0.55	20	0.55	20	0.47	-1	0.45	-1	0.46	-1
Middle Slab Load Ratio	Max.	0.35	0.36	3	0.36	3	0.35	0	0.37	0	0.36	0	0.36	2	0.38	4	0.38	4	0.35	0	0.36	0	0.36	0
	Min.	0.15	0.15	3	0.15	2	0.15	5	0.16	6	0.16	6	0.15	4	0.16	4	0.16	4	0.15	1	0.15	1	0.15	1
	Total	0.29	0.30	3	0.29	3	0.27	-5	0.28	-5	0.28	-5	0.26	-9	0.27	-9	0.27	-9	0.29	0	0.30	0	0.30	0
Bottom Slab Load Ratio	Max.	0.34	0.36	7	0.35	5	0.32	-5	0.34	-5	0.34	-5	0.30	-12	0.32	-12	0.31	-12	0.34	0	0.36	0	0.35	0
	Min.	0.07	0.07	4	0.07	3	0.07	-3	0.07	-4	0.07	-4	0.08	6	0.08	4	0.08	5	0.07	2	0.08	3	0.08	3
	Total	0.23	0.25	6	0.24	4	0.20	-15	0.21	-15	0.21	-15	0.17	-26	0.18	-27	0.18	-27	0.24	2	0.25	2	0.25	2

Table 4.7b: Results for different models, 3 x realistic reshore stiffness, 2 levels of reshores

3 x Realistic Reshore Stiffness, 3 Levels of Reshores																								
Reshore Stiffness		3x3 Bays, 9.5m x 9.5m (1)					3x3 Bays, 6.5m x 9.5m					3x3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m					2x2 Bays, 9.5m x 9.5m							
Slab Relative Stiffness		1.00	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)
Top Reshore Load Ratio	Max.	0.75	0.78	4	0.78	3	0.73	-3	0.76	-3	0.75	-3	0.68	-10	0.71	-10	0.70	-10	0.75	0	0.78	0	0.77	0
	Min.	0.23	0.24	3	0.23	2	0.23	2	0.24	1	0.24	1	0.24	4	0.24	4	0.24	4	0.23	2	0.24	2	0.24	2
	Avg.	0.56	0.58	4	0.57	3	0.50	-11	0.52	-11	0.51	-11	0.45	-19	0.47	-19	0.47	-19	0.57	1	0.59	1	0.58	1
Middle Reshore Load Ratio	Max.	0.47	0.49	5	0.49	3	0.44	-7	0.46	-8	0.45	-8	0.41	-13	0.43	-13	0.42	-13	0.47	0	0.49	-1	0.48	-1
	Min.	0.09	0.10	3	0.10	2	0.09	-7	0.09	-8	0.09	-8	0.09	-7	0.09	-12	0.09	-11	0.10	4	0.10	4	0.10	4
	Avg.	0.32	0.33	4	0.33	3	0.26	-18	0.27	-19	0.27	-18	0.22	-31	0.22	-32	0.22	-32	0.33	2	0.34	3	0.34	3
Bottom Reshore Load Ratio	Max.	0.22	0.23	5	0.23	4	0.20	-9	0.21	-11	0.21	-10	0.19	-14	0.20	-14	0.20	-14	0.22	-1	0.23	-1	0.23	-1
	Min.	0.04	0.04	1	0.04	1	0.03	-15	0.03	-17	0.03	-17	0.03	-31	0.02	-41	0.02	-39	0.04	6	0.04	9	0.04	8
	Avg.	0.15	0.15	4	0.15	3	0.11	-22	0.12	-23	0.12	-23	0.09	-37	0.09	-40	0.09	-39	0.15	3	0.16	4	0.16	3
Top Slab Load Ratio	Max.	0.77	0.76	-1	0.77	-1	0.77	0	0.76	0	0.76	0	0.76	-1	0.76	-1	0.76	-1	0.77	-1	0.76	-1	0.76	-1
	Min.	0.25	0.22	-12	0.22	-9	0.27	10	0.24	13	0.25	12	0.32	30	0.29	35	0.30	34	0.25	1	0.22	1	0.23	1
	Total	0.44	0.42	-5	0.43	-3	0.50	14	0.48	15	0.49	15	0.55	24	0.53	26	0.53	26	0.43	-2	0.41	-2	0.42	-2
Middle-Top Slab Load Ratio	Max.	0.29	0.30	4	0.30	3	0.29	0	0.30	-1	0.30	-1	0.34	16	0.36	19	0.35	18	0.28	-3	0.29	-4	0.29	-4
	Min.	0.13	0.14	2	0.14	2	0.14	8	0.15	9	0.15	9	0.14	3	0.14	3	0.14	3	0.13	1	0.14	2	0.14	2
	Total	0.24	0.25	3	0.25	3	0.24	-2	0.25	-1	0.24	-1	0.23	-3	0.24	-2	0.24	-2	0.24	0	0.25	0	0.25	0
Middle-Bottom Slab Load Ratio	Max.	0.25	0.26	4	0.26	3	0.24	-5	0.25	-5	0.24	-5	0.22	-12	0.23	-12	0.22	-12	0.25	0	0.26	0	0.25	0
	Min.	0.05	0.06	2	0.06	1	0.05	-2	0.05	-2	0.05	-2	0.06	5	0.06	5	0.06	5	0.06	2	0.06	3	0.06	3
	Total	0.17	0.18	4	0.18	2	0.15	-14	0.15	-15	0.15	-15	0.13	-25	0.13	-26	0.13	-26	0.18	2	0.18	2	0.18	2
Bottom Slab Load Ratio	Max.	0.22	0.23	5	0.23	4	0.20	-9	0.21	-11	0.21	-10	0.19	-14	0.20	-14	0.20	-14	0.22	-1	0.23	-1	0.23	-1
	Min.	0.04	0.04	1	0.04	1	0.03	-15	0.03	-17	0.03	-17	0.03	-31	0.02	-41	0.02	-39	0.04	6	0.04	9	0.04	8
	Total	0.15	0.15	4	0.15	3	0.11	-22	0.12	-23	0.12	-23	0.09	-37	0.09	-40	0.09	-39	0.15	3	0.16	4	0.16	3

Table 4.7c: Results for different models, 3 x realistic reshore stiffness, 3 levels of reshores

4.3.8 Effect of bay sizes and aspect ratios for infinite reshore stiffness

The summary results for this reshore stiffness for the different models are presented in Tables 4.8a to 4.9c below. The effect of the different bay sizes and aspect ratios of models when compared with the 3 bays x 3 bays, 9.5m x 9.5m bays model are summarized below.

4.3.8.1 Results for 1, 2 and 3 levels of reshores (2, 3 and 4 supporting slabs, Tables 4.8a, 4.8b and 4.8c, respectively)

1. The average reshore force ratios are identical when comparing the results calculated using an infinite reshore stiffness for all models. Any differences shown in the table below are attributed to mathematical errors.
2. The total slab force ratios are identical when comparing the results calculated using an infinite reshore stiffness for all models. Any differences shown in the table below are attributed to arithmetic round off.

Table 4.8a: Results for different models, infinite reshore stiffness, 1 level of reshores

[illegible]

Table 4.8b: Results for different models, infinite reshore stiffness, 2 levels of reshores

Infinite Reshore Stiffness, 3 Levels of Reshores																								
Reshore Stiffness		3x3 Bays, 9.5m x 9.5m (1)					3x3 Bays, 6.5m x 9.5m						3x3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m						2x2 Bays, 9.5m x 9.5m					
Slab Relative Stiffness		1.00	Realistic (3.5 days)	% Diff. 1.00	Realistic (7 days)	% Diff. 1.00	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)	1.00	% Diff. (1)	Realistic (3.5 days)	% Diff. (1)	Realistic (7 days)	% Diff. (1)
Top Reshore Load Ratio	Max.	0.76	0.79	5	0.78	3	0.75	-1	0.78	-1	0.78	-1	0.75	-1	0.78	-1	0.78	-1	0.75	-1	0.78	-1	0.76	-1
	Min.																							
	Avg.																							
Middle Reshore Load Ratio	Max.	0.50	0.54	7	0.53	5	0.50	-1	0.54	-1	0.53	-1	0.50	-1	0.54	-1	0.53	-1	0.50	-1	0.54	-1	0.53	-1
	Min.																							
	Avg.																							
Bottom Reshore Load Ratio	Max.	0.25	0.28	9	0.27	7	0.25	-1	0.27	-1	0.27	1	0.25	-1	0.27	-1	0.27	-1	0.25	-1	0.27	-1	0.27	-1
	Min.																							
	Avg.																							
Top Slab Load Ratio	Max.	0.26	0.22	-13	0.23	-10	0.25	-3	0.22	-3	0.22	-3	0.25	-3	0.22	-3	0.22	-3	0.25	-3	0.22	-3	0.22	-3
	Min.																							
	Total																							
Middle-Top Slab Load Ratio	Max.	0.25	0.25	-1	0.25	0	0.25	-1	0.25	-1	0.25	-1	0.25	-1	0.25	-1	0.25	-1	0.25	-1	0.25	-1	0.25	-1
	Min.																							
	Total																							
Middle-Bottom Slab Load Ratio	Max.	0.25	0.27	5	0.26	3	0.25	-1	0.26	-1	0.26	-1	0.25	-1	0.26	-1	0.26	-1	0.25	-1	0.26	-1	0.26	-1
	Min.																							
	Total																							
Bottom Slab- Load Ratio	Max.	0.25	0.28	9	0.27	7	0.25	-1	0.27	-1	0.27	-1	0.25	-1	0.27	-1	0.27	-1	0.25	-1	0.27	-1	0.27	-1
	Min.																							
	Total																							

Table 4.8c: Results for different models, infinite reshore stiffness, 3 levels of reshores

CHAPTER 5

PRACTICAL APPLICATION

5.1 INTRODUCTION

The following section provides practical examples on the application of the analytical method developed in Chapter 3 and discussed in Chapter 4. The examples compare total dead load ratios supported by reshores and slabs for shore/reshore cycles using a single level of shores and 1, 2 and 3 levels of reshores. The examples use realistic slab (7 day casting cycle) and realistic reshore stiffnesses and are compared with the results generated using the Simplified Method (infinitely stiff shores) for the 3 bays x 3 bays, 9.5m x 9.5m bays model. Construction live loads and foundation stiffness are neglected for the simplicity of the demonstrations. Figures 5.1, 5.2 and 5.3 (1, 2 and 3 levels of reshores respectively) present the results of the calculations using the reshore load ratios presented in Chapter 4 and the logic of the Simplified Method. Stage a) for each scenario represents the erection of the formwork/shoring and reshoring. Stage b) represents the casting of slabs.

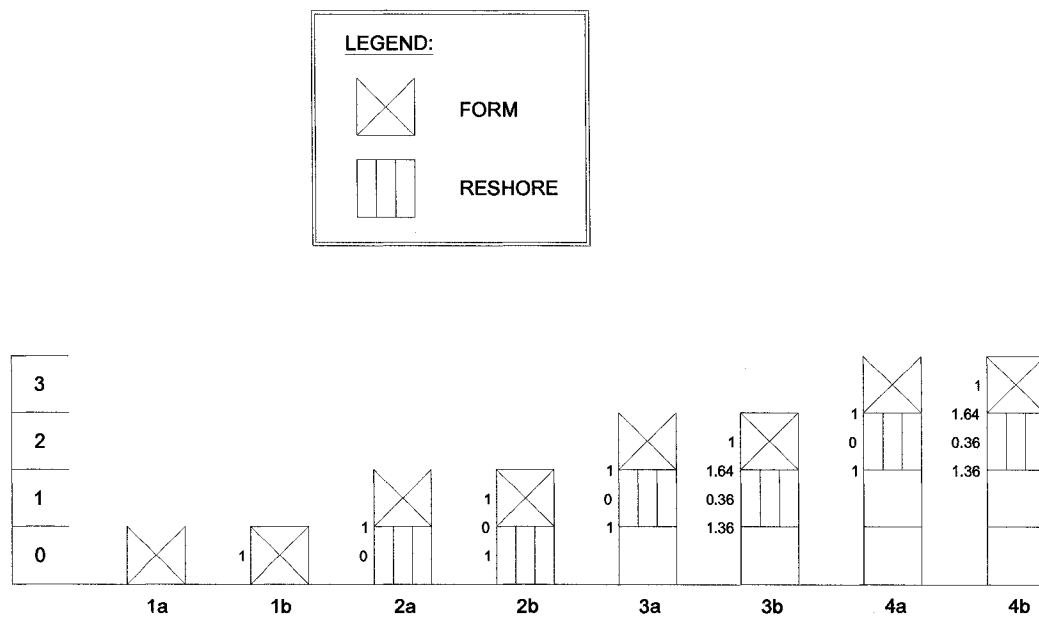
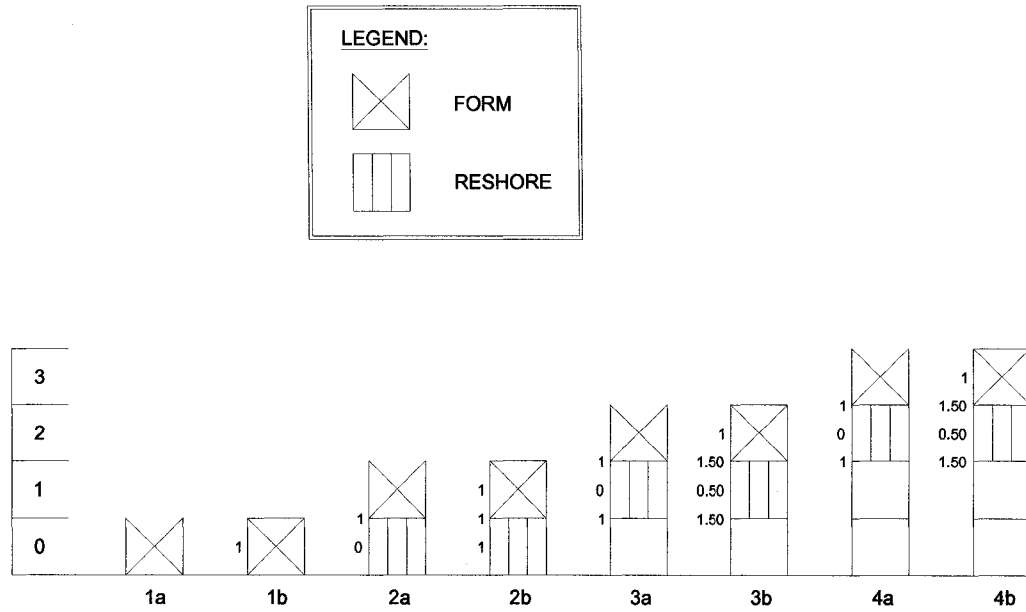


Figure 5.1: Shoring and reshoring schedules for 1 level of reshores. a) top figure using infinitely stiff shores, b) bottom figure using elastic shores.

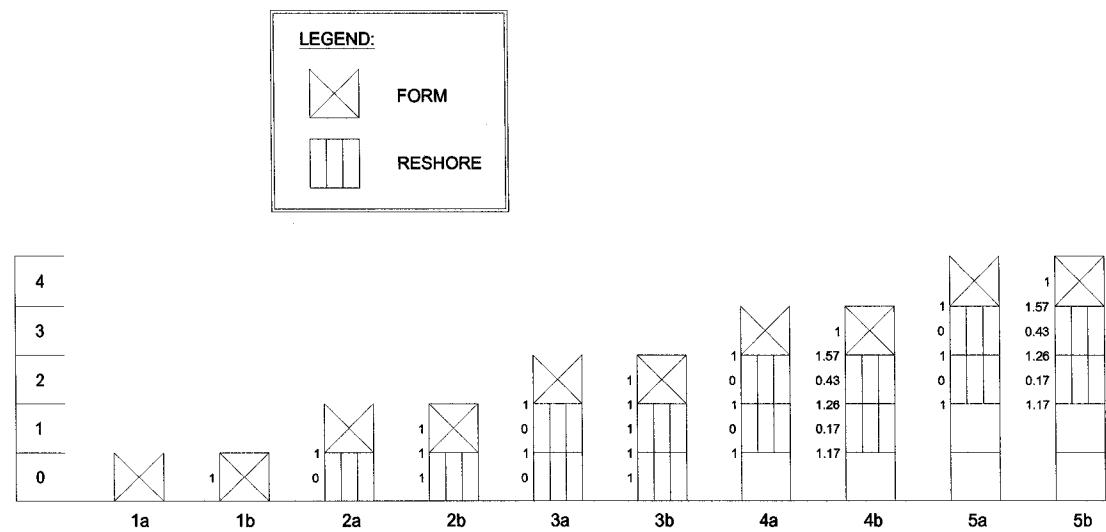
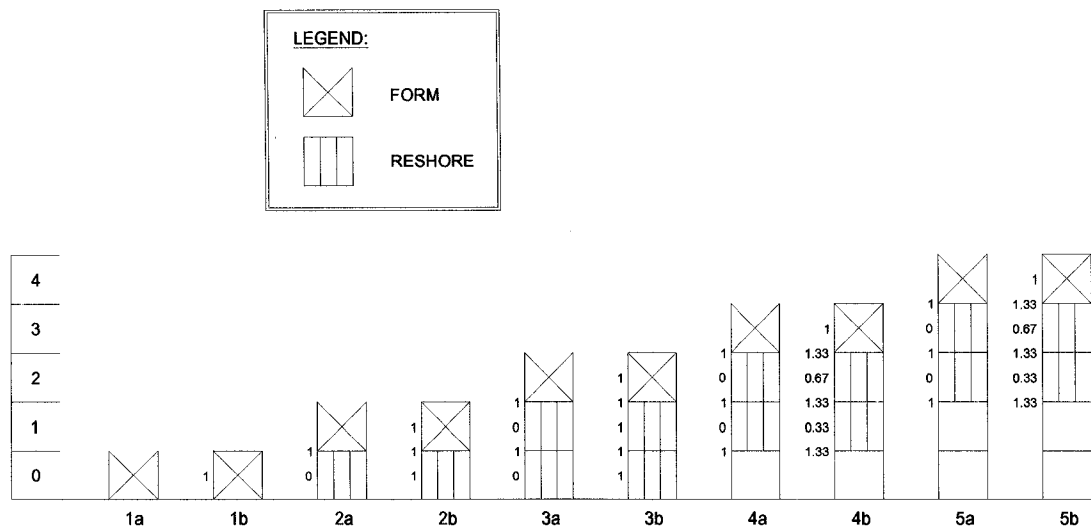


Figure 5.2: Shoring and reshoring schedules for 2 levels of reshores. a) top figure using infinitely stiff shores, b) bottom figure using elastic shores.

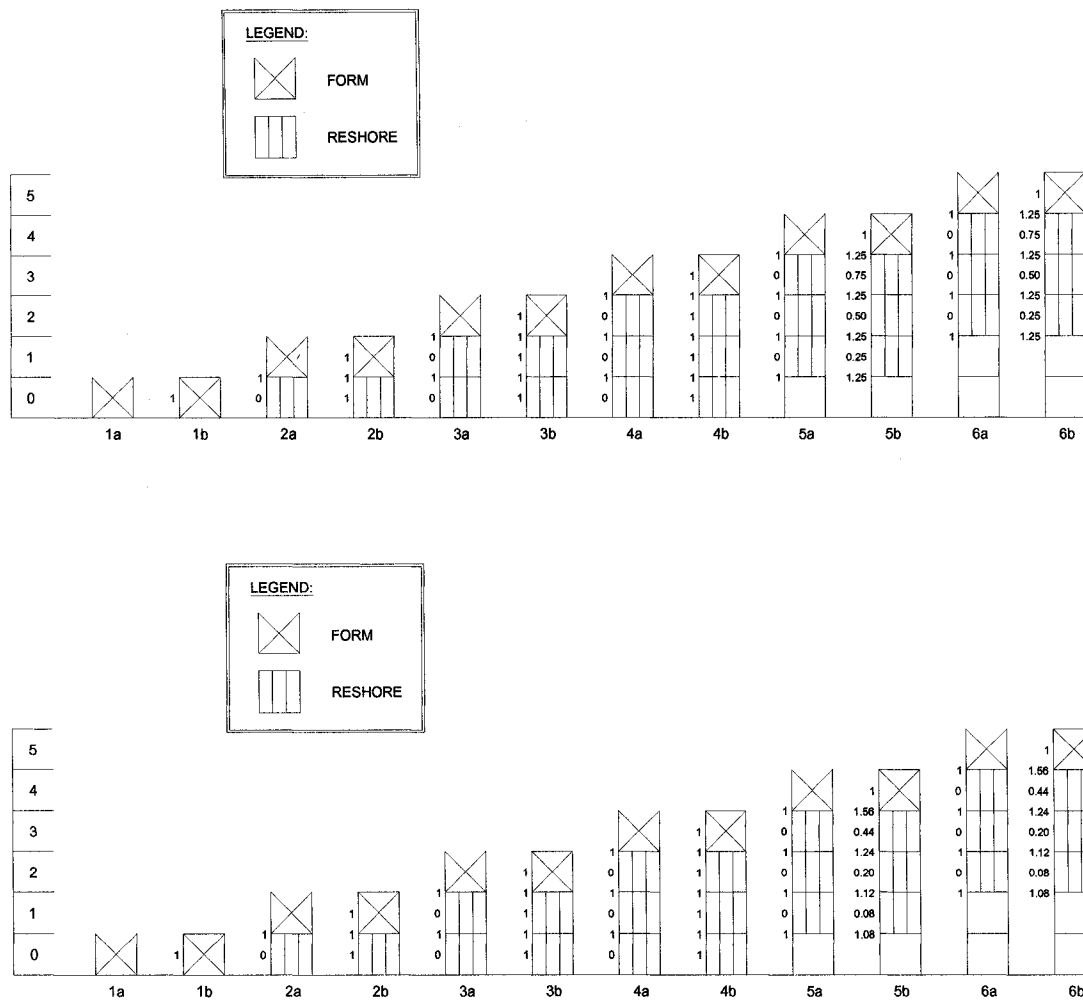


Figure 5.3: Shoring and reshoring schedules for 3 levels of reshores. a) top figure using infinitely stiff shores, b) bottom figure using elastic shores.

Examining Figures 5.1, 5.2 and 5.3, the following can be concluded with respect to the comparison of the realistic results and those of the Simplified Method.

1. The Simplified Method overestimates the average top reshore load ratio by 39% and underestimates the total top slab load ratio by 9% for 1 level of reshores.

2. The Simplified Method overestimates the average top reshore load ratio by 56% and underestimates the total top slab load ratio by 15% for 2 levels of reshores.
3. The Simplified Method overestimates the average top reshore load ratio by 70% and underestimates the total top slab load ratio by 20% for 3 levels of reshores.

CHAPTER 6

DISCUSSION

6.1 INTRODUCTION

The results presented in Chapters 4 and 5 from the analysis of the 4 models for 1, 2 and 3 levels of reshores (refined methodology) revealed significant differences compared with the reshore forces determined using the Simplified Method (infinitely stiff reshores). These differences and their significance are discussed in the following sections. The discussion is presented in 3 sections. Section 6.2 discusses the differences between the loads supported by the reshores for the Refined and Simplified methods and examines the effect of reshore stiffness, slab ages (construction schedule) and bay sizes/aspect ratios. Similarly, Section 6.3 focuses on the proportion of load transferred to supporting slabs. Section 6.4 discusses the effect of creep on the calculation of shoring/reshoring schedules.

6.2 LOADS SUPPORTED BY RESHORES

The following 3 tables summarize a portion of the results presented in Tables 4.1 to 4.4 of Chapter 4. Tables 6.1, 6.2 and 6.3 compare the reshore load ratios calculated assuming elastic reshores with those obtained assuming infinitely stiff reshores for 1, 2 and 3 levels respectively. Only the results for the cases assuming an equal stiffness (age) for all slabs are shown for comparison. The trends are similar for the results of the realistic casting schedule cases (3.5 days and 7 days).

The results presented in Tables 6.1 to 6.3 demonstrate that a decrease in the stiffness of reshores results in a decrease in the average load ratio supported by the reshores for all models when compared with the results for infinitely stiff reshores. This decrease is more significant as the number of levels of reshores increase. In addition, as reshore stiffnesses decrease, the middle and bottom levels of reshores become almost ineffectual with a reduction of 77% to nearly 100% (from stiffer to softer shores) from the values calculated using infinitely stiff reshores. In addition to the reshores, it is apparent that the slab spans/aspect ratios also have an effect on the loads supported by the reshores. This is directly related to the stiffness of the slabs.

The results for the 3 bays x 3 bays, 9.5m x 9.5m span model and the 2 bay x 2 bays, 9.5m x 9.5m span model demonstrate that the number of bays are relatively insignificant to the analysis. The slight differences can be attributed to the 2 x 2 Bays model being composed of 4 corner bays while the 3 x 3 Bays model is composed of 1 center bay, 4 edge bays and 4 corner bays, and therefore the slabs in this model are on average stiffer. Similarly, the other two 3 x 3 Bays models have shorter spans and therefore have an even higher average slab stiffness. From this, it can be concluded that an increase in slab stiffness (due to slab construction) has the effect of further reducing the proportion of load supported by the reshores. Therefore, not only does the stiffness of the reshores play a major role in shoring and reshoring schedules, the slab spans (stiffness) also have a significant influence.

Model	Reshore Stiffness		
	1/3 x Realistic	Realistic	3 x Realistic
3 x 3 Bays, 9.5m x 9.5m Bays	-51	-30	-17
3 x 3 Bays, 6.5m x 9.5m Bays	-62	-40	-23
3 x 3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m Bays	-69	-47	-28
2 x 2 Bays, 9.5m x 9.5m Bays	-49	-29	-19

Table 6.1: Difference (%) of load ratios for different reshore stiffnesses compared to infinitely stiff reshore load ratios, 1 level of reshores

Model	Reshore Stiffness		
	1/3 x Realistic	Realistic	3 x Realistic
Top Level of Reshores			
3 x 3 Bays, 9.5m x 9.5m Bays	-60	-38	-22
3 x 3 Bays, 6.5m x 9.5m Bays	-70	-48	-29
3 x 3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m Bays	-76	-56	-35
2 x 2 Bays, 9.5m x 9.5m Bays	-58	-36	-21
Bottom Level of Reshores			
3 x 3 Bays, 9.5m x 9.5m Bays	-71	-51	-30
3 x 3 Bays, 6.5m x 9.5m Bays	-86	-64	-40
3 x 3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m Bays	-90	-72	-48
2 x 2 Bays, 9.5m x 9.5m Bays	-75	-49	-29

Table 6.2: Difference (%) of load ratios for different reshore stiffnesses compared to infinitely stiff reshore load ratios, 2 levels of reshores

Model	Reshore Stiffness		
	1/3 x Realistic	Realistic	3 x Realistic
Top Level of Reshores			
3 x 3 Bays, 9.5m x 9.5m Bays	-64	-43	-35
3 x 3 Bays, 6.5m x 9.5m Bays	-73	-53	-33
3 x 3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m Bays	-78	-60	-39
2 x 2 Bays, 9.5m x 9.5m Bays	-62	-41	-24
Middle Level of Reshores			
3 x 3 Bays, 9.5m x 9.5m Bays	-83	-60	-36
3 x 3 Bays, 6.5m x 9.5m Bays	-90	-72	-46
3 x 3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m Bays	-98	-73	-56
2 x 2 Bays, 9.5m x 9.5m Bays	-82	-57	-35
Bottom Level of Reshores			
3 x 3 Bays, 9.5m x 9.5m Bays	-90	-68	-41
3 x 3 Bays, 6.5m x 9.5m Bays	-95	-79	-54
3 x 3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m Bays	-97	-85	-63
2 x 2 Bays, 9.5m x 9.5m Bays	-89	-65	-40

Table 6.3: Difference (%) of load ratios for different reshore stiffnesses compared to infinitely stiff reshore load ratios, 3 levels of reshores

The results calculated using infinitely stiff reshores indicate an equal sharing of load by all reshores for any given level. Tables 4.1 to 4.4 (Chapter 4) indicate a wide variation in the load ratios calculated assuming elastic reshores with minimum values occurring at reshores near columns and maximum values near the center of bays. This

indicates that reshores are significantly under stressed near columns, which questions the need for reshores so close to slab supports. An argument can be made that the presence of reshores near columns contributes to the punching shear resistance of the reshored slabs.

It should also be noted that for the elastic reshores, the calculated maximum (with the exception of a few cases as described below) and minimum reshore load ratios are significantly lower than those calculated using infinitely stiff reshores. Therefore, using the Simplified Method (infinitely stiff reshores) for the calculation of shoring/reshoring schedules would yield overly conservative reshore forces for the slab models studied. This would normally be acceptable from a safety perspective but may result in increased costs due to overdesign of the reshoring system.

The 3 x Realistic stiffness case saw an increase in the maximum shore load by up to 6% compared with the infinitely stiff shores. Therefore, the possibility exists that a few isolated reshores could be overstressed. Since this is isolated and only applies to a few reshores near the mid span, normal safety factors used in design may compensate sufficiently for this overstress. However, safety factors should not be used to account for errors in design.

From Tables 4.1 to 4.4, the differences in the average calculated reshore load ratios, comparing the results for a realistic reshoring schedules of 3.5 days and 7 days with those obtained assuming a uniform stiffness for each slab, vary between +2% to +7% for 1 level of reshores, +2% to +6% (top level) and -4 to +9% (bottom level) for 2 levels of reshores and +2% to +5% (top level), -5 to +7% (middle level) and -13% to +10% (bottom level) for 3 levels of reshores. These differences increased as the reshore stiffness increased. In addition, the differences increase from the top to bottom levels of reshores.

The differences observed with the realistic reshore schedules are all positive for the top level of reshores while they vary from positive to negative for the middle and bottom levels of reshores. All middle and bottom reshore load ratios decreased for the 1/3 x Realistic stiffness cases. Some of the middle and bottom reshore load ratios decreased for the 1/3 x realistic stiffness cases. All reshore load ratios saw an increase for the 3 x Realistic and Infinite stiffness cases.

Based on the reshore load ratios presented in Chapter 4, sample calculations to demonstrate the application of these ratios to the calculation of actual shoring/reshoring schedules (assuming 1 level of shores and 1, 2 and 3 levels of reshores) were presented in Chapter 5. These results are summarized as follows:

1. The Simplified Method overestimated the average top reshore load ratio by 39% for 1 level of reshores.
2. The Simplified Method overestimated the average top reshore load ratio by 56% for 2 levels of reshores.
3. The Simplified Method overestimated the average top reshore load ratio by 70% for 3 levels of reshores.

6.3 LOADS SUPPORTED BY SLABS

The following 3 tables summarize a portion of the results presented in Tables 4.1 to 4.4 of Chapter 4. Tables 6.4, 6.5 and 6.6 compare the total slab load ratios calculated assuming elastic reshores with those obtained assuming infinitely stiff reshores for 1, 2 and 3 levels respectively. Only the results for the cases assuming an equal stiffness (age) for all slabs are shown for comparison. The trends are similar for the results of the realistic casting schedule cases (3.5 days and 7 days).

The 3 tables below indicate that all cases of elastic reshores display a significant increase in the load ratio supported by the top slab, regardless of the number of reshored levels. This difference is greater as the stiffness of the reshores decreases. This results in a significant decrease in the load ratios for the supporting slabs below the top level of reshores.

Using the Simplified Method to calculate shoring/reshoring schedules would yield overly conservative results for lower slabs. More importantly, the Simplified Method would yield significantly un-conservative results for the top slab, the youngest in the supported system and the most critical with respect to punching failure.

Conversely to the reshore load ratios, taking into account the age adjusted stiffness of slabs reduces the total slab load ratios for the top slabs for all models and levels of reshores and is therefore beneficial.

Model	Reshore Stiffness		
	1/3 x Realistic	Realistic	3 x Realistic
Top Slab			
3 x 3 Bays, 9.5m x 9.5m Bays	+51	+30	+17
3 x 3 Bays, 6.5m x 9.5m Bays	+62	+40	+23
3 x 3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m Bays	+69	+47	+28
2 x 2 Bays, 9.5m x 9.5m Bays	+49	+29	+19
Bottom Slab			
3 x 3 Bays, 9.5m x 9.5m Bays	-51	-30	-17
3 x 3 Bays, 6.5m x 9.5m Bays	-62	-40	-23
3 x 3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m Bays	-69	-47	-28
2 x 2 Bays, 9.5m x 9.5m Bays	-49	-29	-19

Table 6.4: Difference (%) of slab total load ratios for different reshore stiffnesses compared to infinitely stiff reshore slab load ratios, 1 level of reshores

Model	Reshore Stiffness		
	1/3 x Realistic	Realistic	3 x Realistic
Top Slab			
3 x 3 Bays, 9.5m x 9.5m Bays	+119	+76	+44
3 x 3 Bays, 6.5m x 9.5m Bays	+139	+97	+59
3 x 3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m Bays	+151	+111	+70
2 x 2 Bays, 9.5m x 9.5m Bays	+115	+73	+42
Middle Slab			
3 x 3 Bays, 9.5m x 9.5m Bays	-42	-25	-14
3 x 3 Bays, 6.5m x 9.5m Bays	-53	-33	-19
3 x 3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m Bays	-61	-39	-22
2 x 2 Bays, 9.5m x 9.5m Bays	-40	-24	-14
Bottom Slab-51			
3 x 3 Bays, 9.5m x 9.5m Bays	-77	-51	-30
3 x 3 Bays, 6.5m x 9.5m Bays	-86	-64	-40
3 x 3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m Bays	-90	-72	-48
2 x 2 Bays, 9.5m x 9.5m Bays	-75	-49	-29

Table 6.5: Difference (%) of slab total load ratios for different reshore stiffnesses compared to infinitely stiff reshore slab load ratios, 2 levels of reshores

Model	Reshore Stiffness		
	1/3 x Realistic	Realistic	3 x Realistic
Top Slab			
3 x 3 Bays, 9.5m x 9.5m Bays	+191	+128	+76
3 x 3 Bays, 6.5m x 9.5m Bays	+219	+159	+100
3 x 3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m Bays	+234	+179	+118
2 x 2 Bays, 9.5m x 9.5m Bays	+186	+123	+73
Middle-Top Slab			
3 x 3 Bays, 9.5m x 9.5m Bays	-25	-9	-4
3 x 3 Bays, 6.5m x 9.5m Bays	-39	-16	-6
3 x 3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m Bays	-49	-23	-7
2 x 2 Bays, 9.5m x 9.5m Bays	-23	-8	-4
Middle-Bottom Slab			
3 x 3 Bays, 9.5m x 9.5m Bays	-76	-52	-31
3 x 3 Bays, 6.5m x 9.5m Bays	-85	-64	-41
3 x 3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m Bays	-89	-71	-48
2 x 2 Bays, 9.5m x 9.5m Bays	-23	-50	-30
Bottom Slab			
3 x 3 Bays, 9.5m x 9.5m Bays	-90	-68	-41
3 x 3 Bays, 6.5m x 9.5m Bays	-95	-79	-54
3 x 3 Bays, 9.5m x 9.5m, 6.5m x 9.5m, 6.5m x 6.5m Bays	-97	-85	-63
2 x 2 Bays, 9.5m x 9.5m Bays	-89	-65	-40

Table 6.6: Difference (%) of slab total load ratios for different reshore stiffnesses compared to infinitely stiff reshore slab load ratios, 3 levels of reshores

Based on the reshore load ratios presented in Chapter 4, sample calculations to demonstrate the application of these ratios to the calculation of actual shoring/reshoring schedules (assuming 1 level of shores and 1, 2 and 3 levels of reshores) were presented in Chapter 5. These results are summarized as follows:

1. The Simplified Method underestimated the total top slab load ratio by 9% for 1 level of reshores.
2. The Simplified underestimated the total top slab load ratio by 15% for 2 levels of reshores.
3. The Simplified Method underestimated the total top slab load ratio by 20% for 3 levels of reshores.

6.4 EFFECTS OF CREEP AND SHRINKAGE

As mentioned in Chapter 3, due to the complexity of the problems, our investigation into the effects of creep and shrinkage on reshored slabs during construction was not exhaustive. Our cursory investigation did determine that creep and shrinkage should not significantly affect the distribution of load between slabs and reshores. However, further research is required to understand these phenomena with respect to shoring/reshoring cycles and determine the magnitude of their effect. In addition, the effect of creep on the long term deflections of the slabs was not determined as this was found to be an even more complex problem.

CHAPTER 7

CONCLUSIONS

7.1 INTRODUCTION

Even though it has been, and is currently being, used to calculate shoring/reshoring schedules, the Simplified Method overestimates the proportion of load supported by all reshores and underestimates the proportion of load supported by the top slab in the reshored system. Therefore, it is concluded that the Simplified Method can be unsafe for the determination of shoring/reshoring loads. The following sections provide specific conclusions of this research. In addition, conclusions regarding the requirement for future work are provided.

7.2 RESHORE STIFFNESS

The work in this thesis has clearly shown that neglecting reshore stiffness in calculating shoring/reshoring schedules is a dubious assumption. Conclusions regarding the importance of taking into account reshore stiffnesses are provided below.

1. Neglecting the elastic stiffness of reshores greatly overestimated the average load supported by reshores for all cases studied. This overestimation increased as reshore stiffness and slab stiffness decreased (spans increased).
2. Neglecting the elastic stiffness of reshores generally overestimates the load supported by individual reshores. This overestimation is greatest near the slab supports (columns).

3. The overestimation of average and individual reshore loads does not present a concern for the safety of shoring/reshoring schedules. However, it may have cost implications which would be of interest to building owners. In addition, the duty of engineers is to design structural systems as accurately as possible. Additional safety may be desirable when dealing with structures during construction where the care of workers and quality control may be questionable. However, this additional safety would better serve everyone if consciously added to the entire system during design. Simply because the Simplified Method has been successfully applied in the past does not preclude the possibility of future disasters.
4. Using infinite reshore stiffness provided a reasonable approximation of the maximum reshore loads. However, calculations using elastic shores did indicate that the maximum reshore loads are sometimes exceeded by up to 6% for the cases studied. This level of overload may not be considered significant but as it can easily be calculated, should be taken into account during design.
5. Cases with stiffer reshores tended to converge towards the results of infinitely stiff shores. However, none of the elastic reshore cases examined were nearer than 17% of the infinitely stiff reshore results (for a reshore stiffness of 3 x realistic).
6. Assuming infinite reshore stiffness significantly underestimated the total load supported by the top slab in the reshored system. This presents a significant problem as the top slab in the system is the one with the lowest concrete strength (youngest slab) and therefore more susceptible to punching shear. This also presents a concern for early age and long term deflections.
7. Given that the Simplified Method continues to be successfully used by designers without frequent reported collapses, one may question the overall importance of taking into account reshore stiffnesses. Perhaps the lack of collapses can be

attributed to a significant overestimation of live loads during construction and underprediction of actual slab strength. However, such incidental safety factors should not preclude the need for a proper understanding of design loads by engineers.

7.3 SLAB SPANS/ASPECT RATIOS

The effect of slab aspect ratio/span is more related to the stiffness of the slabs than to shape. Shorter spans result in an increased stiffness of the slabs, which results in a reduction in load transferred from the top supported slab to the top level of reshores. The stiffer the slab system, the greater the overestimation of load ratios supported by the reshores and more importantly, the greater the underestimation of load supported by the top reshored slab. Therefore, stiff slabs with flexible reshores presents a worst case scenario for slab safety during construction when using the Simplified Method.

7.4 EFFECT OF SLAB AGE

Although not as important as the stiffness of reshores and slab spans (stiffness), the age of slabs does have an effect on the distribution of loads through the reshored system. Older (lower) slabs in the system are stiffer than the younger ones (upper) thus resulting in an increase in the ratio of load supported by the top level of reshores.

For middle and lower slabs in multi level reshoring systems, the effect of age adjusted slab stiffnesses was dependent on the stiffness of reshores. Weaker reshores resulted in a reduction of load supported by the middle and bottom levels of reshores. This resulted in an increase in slab load above these levels of reshores. For the cases with stiffer reshores, taking into account slab relative stiffnesses served to increase the reshore load ratios for all levels thus resulting in an increase in load on the lower slab and a decrease of load on the top slab.

7.5 CREEP AND SHRINKAGE

As previously mentioned, our work on the effect of creep and shrinkage was cursory. Our preliminary investigation did determine that creep and shrinkage should not

significantly affect the distribution of load between slabs and reshores. However, further research is required to properly understand these phenomena with respect to shoring/reshoring cycles and determine the magnitude of their effect.

In addition, the effect of creep on the long term deflections of the slabs was not determined as this was found to be an even more complex problem.

For shrinkage, exhaustive analytical and experimental work on reinforced concrete suspended slabs of different shapes and arrangement would be required to even obtain a cursory understanding. In addition, the range of reinforcement ratios and their termination locations as well as curing on shrinkage make the problem even more complex.

7.6 ANALYSIS OF APPLIED LOAD

The loads applied to the finite element models to obtain slab unit stiffnesses were determined using the tributary area of the shoring system. Since flying form trusses were assumed as the shoring system, this is not completely accurate. An analysis assuming the continuity of the trusses has determined that up to a 6% increase or decrease in some of the applied loads can be expected. However, this will depend on the type of shoring system used and would be up to the designer to assess the importance of proper determination of the input loads.

7.7 WORK TO BE PERFORMED

1. A convenient way to determine slab deflections is required. Based on the observation of deflections determined using the finite element models, no convenient pattern was determined.
2. The work presented in this thesis assumes a constant construction temperature. What has not been examined is the effect of temperature change (from day to night) on a reshored system due to the lack of information on the topic. Further research is required.
3. The full effects of shrinkage and creep on the safety of flat slabs during construction and on short and long term deflections of the slabs requires further examination.

REFERENCES

1. ACI Committee 318, ACI 318M-02, "Building Code Requirements for Structural Concrete and Commentary", American Concrete Institute, 2002, 443 pages.
2. ACI Committee 347, ACI 347R-03, "Guide to Formwork for Concrete", American Concrete Institute, 2003, 32 pages.
3. American Concrete Institute, "Avoiding Failures in Concrete Construction", Detroit, 1989.
4. ACI Committee 347, ACI 347.2R-05, "Guide for Shoring / Reshoring of Concrete Multistory Buildings", American Concrete Institute, 2005, 18 pages.
5. Abd El-Razek, M.E., "Effect of Temporary Bracing on the Construction Load Distributions in Multistory Buildings", Journal of Engineering and Applied Science, Vol. 45, No. 5, October 1998, pp. 661-676.
6. Agarwal, R.K., "An Experimental Investigation of Shoring Systems for High-Rise Flat-Slab Structures", Master's Thesis, University of Ottawa, Ottawa, May 1972.
7. Agarwal, R.K., Gardner, N.J., "Form and Shore Requirements for Multistorey Flat slab Type Buildings", Journal of the American Concrete Institute, Vol. 71, No. 11, November 1974, pp. 559-569
8. Aguinaga-Zapata, M., Bazant, Z.P., "Creep Deflections in Slab Buildings and Forces in Shores during Construction", ACI Journal, September – October 1986, pp.719-726.
9. Ambrose, T.P., Huston, D.R., Fuhr, P.L., Devino, E.A., Werner, M.P., "Shoring Systems for Construction Load Monitoring", Smart Materials and Structures, Vol. 3, No.1, March 1994, pp. 26-34.
10. Arafat, W.S., "Analysis of Loads and Schedule for Multistory Concrete Frame Construction Considering Maturity and Resources", Ph.D. Thesis, North Carolina State University, 1996.

11. Asamoah O. K., and Gardner, N. J., "Flat Slab Thickness Required to Satisfy Serviceability Including Early-Age Construction Loads," *ACI Structural Journal*, V.94, No.6, 1997, pp. 700-707.
12. ASCE Standard, ASCE 37, "Design Loads on Structures During Construction", Structural Engineering Institute of the American Society of Civil Engineers
13. Beeby, A.W., "Task 4: Early Striking of Formwork and Forces in Backprops", Building Research Establishment, 2000.
14. Beeby, A.W., "Criteria for the Loading of Slabs during Construction", ICE Proceedings – Structures and Buildings, Vol, 146, No. 2, May 2001, pp. 195 – 202.
15. Beeby, A.W., "The Forces in Backprops during Construction in Flat Slab Structures", ICE Proceedings – Structures and Buildings, Vol, 146, No. 3, August 2001, pp. 307-317.
16. Beresford, F.D., "An Analytical Examination of Propped Floors in Multi-Storey Flat Plate Construction", *Construction review*, Vol. 37, November 1964, pp. 16-20.
17. Beresford, F.D., "Shoring and Reshoring of Floors in Multi-story Buildings", Symposium on Formwork, Concrete Institute of Australia, North Sydney, April 1971.
18. Blakey, F.A., Beresford, F.D., "Stripping Formwork for Concrete in Buildings in Relation to Structural Design", *The Institution of Civil engineers, Civil Engineering Transactions*, C.E. T-4, Australia, October 1965, pp. 92-95.
19. Bordner, R. H., "Determining Shoring Loads for Post-Tensioned Concrete Construction," *Concrete Construction*, V. 82, No. 11, 1987, pp.945-948.
20. British Cement Association, "Early Striking of Formwork and Improved Backpropping", Best Practice Guide, British Cement Association, 2001.
21. Cantor, I.G., Rizzi, A.V., "Reshore and Preshore Procedures for Flat Plate Slabs", *Forming Economical Concrete Buildings, Proceeding of International Conference*, Portland Cement association, 1982, pp. 18.1-18.12.
22. Carino, N.J., "The Maturity Method – Theory and Application", *Cement, Concrete and Aggregates*, Vol. 6, No. 2, Winter 1984, pp. 61-73.
23. Carino, N. J., "The Maturity Method," *Handbook on Nondestructive Testing of Concrete*, 2nd Edition, CRC Press, 2004.

24. Carper, K.L., "Structural Failures during Construction", *Journal of Performance of Constructed Facilities*, Vol. 1, No. 3, 1987, pp. 132-144.
25. Chana, P., Moss M., "Re-engineering the Design and Construction Processes for In-situ Concrete Frames", *Structural Concrete*, Vol. 2, No. 2, June 2001.
26. Chen, W. F., "Study of Concrete Framed Structures during Construction", *Purdue University, School of Civil Engineering, Structural Engineering (Technical Report)*, CE-STR, No. 82-41, December 1982, p.23.
27. Chen, W.F., Mossallam, K.H., "Concrete Buildings: Analysis for Safe Construction", 1991.
28. Chen, W.F. et al., "Determining Shoring Loads for Reinforced Concrete Construction", *ACI Structural Journal*, Vol. 88, No.3, 1992, pp. 340-350.
29. Chen, W.F. et al., "Construction Load Distributions for Laterally Braced Framework", *ACI Structural Journal*, Vol. 89, No.4, 1992, pp. 415-424.
30. Choi, C.K, Kim, E., "Multistory Frames Under Sequential Gravity Loads", *Journal of Structural Engineering, ASCE*, Vol. 111, No. 11, 1985, pp. 2373-2384.
31. Concrete (London), "Strike Action", Vol. 30, No. 2, March-April, 1996, pp. 14.
32. Concrete International, "Vertical Loads and Pressures on Formwork", Vol. 20, No. 12, December 1998, pp. 63-64.
33. Canadian Standards Association, "CSA A23.3-04, Design of Concrete Structures".
34. Canadian Standards Association, "CSA S269.1-1975 (R2003), Falsework for Construction Purposes".
35. Canadian Standards Association, "CSA S269.3-M92, Concrete Formwork".
36. De Almeida Prado, J.F.M., Silva Correa, M. R., Ramalho, M.A., "A New Procedure for the Analysis of Construction Loads in Multistory Reinforced Concrete Structures", *Structural Design of Tall and Special Buildings*, Vol. 12, No. 4, December 2003, pp. 293-315.
37. Dusin, Robert C., "Forming the World's Tallest Concrete-Frame Building", *Concrete Construction*, Vol. 35, No. 1, January 1990, pp. 5.
38. Eldukair, Z.A., Ayyub, B.M, "Analysis of Recent U.S. Structural and Construction Failures", *Journal of Performance of Constructed Facilities*, Vol. 5, No. 1, 1991, pp. 57-73.

39. El-Shahhat, A.M., Chen, W., "Improved Analysis of Shore-Slab Interaction", ACI Structural Journal, Vol. 89, No. 5, Sep-Oct 1992, pp. 528-537.
40. El-Shahhat, A., Rosowsky, D. V., Chen, W.F., "Construction Safety of Multistory Concrete Buildings", ACI Structural Journal, American Concrete Institute, Vol. 90, No. 4, July-August, 1993, pp. 335-341.
41. Epaarachi, D.C., Stewart, M.G., Rosowsky, D.V., "Structural Reliability of Multistory Buildings during Construction", Journal of Structural Engineering, Vol. 128, No. 2, February 2002, pp. 205-213.
42. Epaarachi, D. C., Stewart, M. G., "Human Error and Reliability of Multistory Reinforced-Concrete Building Construction", Journal of Performance of Constructed Facilities, Vol. 18, No. 2, Feb. 2004, pp. 12-20.
43. Fang, D.P., Geng, C.D., Zhu, H.Y, Liu, X.L., "Floor Load Distribution in Reinforced Concrete Buildings during Construction", ACI Structural Journal, American Concrete Institute, Vol. 98, No. 2, March-April, 2001, pp. 149-156.
44. Fattal, S.G., "Effect of Construction Loads on Concrete Shoring System", Forming Economical Concrete Buildings, Portland Cement association, Skokie, 1982, pp. 10-1 – 10-21. National Institute of Standards and Technology, 1983, 139pp.
45. Fattal, S.G., "Evaluation of Construction Loads in Multi-story Concrete Buildings", NBS Building Science Series, No. 146, National Institute of Standards and Technology, 1983, 139 pages.
46. Feld, J., "Lessons from Failures of Concrete Structures", ACI Monograph No.1, American Concrete Institute, 1964, 179 pp. TA 681.F44L 1964
47. Feld, J., "Reshoring of Concrete Buildings", Engineering News Record, October 1966.
48. Feld, J., "Reshoring of Multistory Concrete Buildings", Concrete Construction, Vol. 19, No. 5, May 1974, pp. 243-246.
49. Feld, J., "Concrete Formwork Failures", ACI Journal, Vol. 72, No. 7, 1975, pp.351-355.
50. Feld, J., Carper, K.L., "Construction Failure", Second Edition, John Wiley & Sons, Inc., New York, 1997.
51. Gardner, N.J., Poon S.M., "Time and Temperature Effects on Tensile, Bond and Compressive Strengths", Journal of the American Concrete Institute, Vol 73, No. 7, 1976, pp. 405-409.

52. Gardner, N.J., "Control of Construction Loads on Multifloor Buildings", Canadian Journal of Civil Engineering, Vol. 6, No. 2, June 1979, pp. 253 – 259.
53. Gardner, N. J., "Shoring, Reshoring and Safety", Concrete International: Design and Construction, Vol. 7, No. 4, April 1985, pp. 28-34.
54. Gardner, N.J., Muscati, A., "Shore and Reshore Scheduling Using a Microcomputer", Concrete International: Design and Construction, Vol. 11, No. 8, August 1989, pp. 32-36.
55. Gardner, N.J., "Design and Construction Interdependence", Concrete International: Design and Construction, Vol. 12, No. 11, November 1990, pp. 32-38.
56. Gardner, N.J., Chan, C.S., "Comparison of Preshore and Reshore Procedures for Flat Slabs", American Concrete Institute, SP-90-11, 1986.
57. Gardner, N.J., Scanlon, A., "Long Term Deflections of Two-Way Slabs", Concrete International: Design and Construction, Vol. 12, No. 1, January 1990, pp. 63-67.
58. Gardner, N.J., "Comparison of Prediction Provisions for Drying Shrinkage and Creep of Normal Strength Concretes", Canadian Journal of Civil Engineering, Vol. 31, No. 5, September-October 2004, pp. 767-775.
59. Ghosh, S.K., "Deflections of Two-Way reinforced Concrete Shoring System", Forming Economical Concrete Buildings, Portland Cement association, Skokie, 1982, pp. 29-1 – 29-21. National Institute of Standards and Technology, 1983, 139pp.
60. Godfrey, K. A. Jr., "Building Failures: Problems and Solutions", Civil Engineering (New York), Vol. 54, No. 6, June 1984, pp. 62-66.
61. Gross, J.L., Lew, H.S., "Analysis of Shoring Loads and Slab Capacity for Multistory Concrete Construction", Forming Economical Concrete Buildings, Proceedings of the Second International Conference, SP-90, American Concrete Institute, 1986, pp. 106-130.
62. Grossman, J.S., "Two Day Construction Cycle for High-Rise Structures Based on Use of Preshores", Concrete Construction, March 1986, pp.307-312.
63. Grundy, P., Kabaila, A., "Construction Loads on Slabs with Shored Formwork in Multi – Storey Buildings", Journal of the American Concrete Institute, Vol. 60, No. 12, December 1963, pp. 1729 – 1738.

64. Hadipriono, F.C., Wang, H.K., "Analysis of Causes of Falsework Failures in Concrete Structures", *Journal of Construction engineering Management*, ASCE, Vol. 112, 1986, pp.112-121.
65. Harrison, T.A., "Formwork Striking Times – Criteria, Prediction and Methods of Assessment", CIRIA Report 136, Construction Industry Research and Information Association, 1995.
66. Hart, S., "Falsework Dangers", *Civil Engineering*, ASCE, May 1974.
67. Ho, Ka-Cheung, "Preliminary Investigation into Shoring System", University of Ottawa, Department of Civil Engineering, Ottawa, Canada, September 1970.
68. Hover, K.C., "The Influence of Form and Shore Removal on the Cracking of Beams and Slabs", *ACI Special Publication on Forming Economical Concrete Structures*, SP-107, American Concrete Institute, Detroit, 1988, pp. 169-184.
69. Hurd, M.K., "Formwork for Concrete, 6th Edition", American Concrete Institute, Special Publication SP4, 1995, pp. 486.
70. Hurd, M.K., Courtois, P.D., "Method of Analysis for Shoring and Reshoring in Multistory Buildings", *Proceedings of the Second International Conference on Forming Economical Concrete*, ACI SP-90, American Concrete institute, Detroit, pp. 91-108.
71. Institut Technique du Batiment et des Travaux Publics, "Les Délais de Décoffrage", Note Technique 75, Centre d'Assistance Technique et de Documentation du Batiment et des Travaux Publics, Paris, 1956.
72. Jensen, D. A., "Choosing a Forming System for Concrete Floors and Roof," *Concrete Construction*, V. 31, No.1, 1986, pp. 5-12.
73. Kamala, N., Dickens, J., Pallett, P., "Site Measurement of Loads in Shores and Reshores", *Concrete*, Vol. 30, No. 2, March / April 1996, pp.16-17.
74. Kaminetzky, D., "Design and Construction Failures", 1991, McGraw-Hill, New York.
75. Kaminetzky, D., Stivaros, P.C., "Early-Age Concrete: Construction Loads, Behavior and Failures", *Concrete International*, Vol. 16, No. 1, January 1994, pp. 58-63.
76. Karshenas, S., Ayoub, H., "Investigation of Live Loads on Concrete Structures during Construction", *Proceedings ICOSAR 89, 5th International Conference on Structural Safety and Reliability*, 1989, pp. 1807-1814.

77. Karshenas, S., Ayoub, H., "Analysis of Concrete Construction Live loads on Newly Poured Slabs", *Journal of Structural Engineering*, ASCE, Vol. 120, No. 5, 1994, pp.1525-1542.
78. King, S., Delatte, N. J. "Collapse of 2000 Commonwealth Avenue: Punching shear case Study", *Journal of Performance of Constructed Facilities*, Vol. 18, No. 1, February 2004, pp. 54-61.
79. Kothekar, D.V., Rosowsky, D.V., Huston, D.R., "Investigating the adequacy of Vertical Design Loads for Shoring", *Journal of Performance of Constructed Facilities*, Vol. 12, No. 1, 1998, pp. 41-47.
80. Lasisi, M.Y., Ng, S.F., "Construction Loads Imposed on Highrise Floor Slabs", *Concrete International: Design and Construction*, Vol. 1, No. 2, February 1979, pp. 24-29.
81. Lew, H. S., "Safety During Construction of Concrete Buildings – A Status Report", NBS Building Science Series 80, National Bureau of Standards, January 1976.
82. Lew, H. S., Carino, N.J., Fattal, S.G., "Cause of the Condominium Collapse in Cocoa Beach, Florida", *Concrete international: Design and Construction*, Vol. 4, No. 8, August 1982, pp. 64-73.
83. Lew, H. S., Gross, J.L., "Analysis of Shoring Loads and Capacity for Multistory Concrete Construction", *ACI Second International Conference on Forming Economical Concrete Buildings*, Chicago, Illinois, November 1984, 109-130.
84. Lew, H. S., "Construction Loads and Load Effects in Concrete Building Construction", *Concrete International: Design and Construction*, Vol. 7, No. 4, April 1985, pp. 20-23.
85. Liu, X. L., Chen, W.F., Bowman, M.D., "Load Distribution in Concrete Framed Structures during Construction", *Purdue University, School of Civil Engineering, Structural Engineering (Technical Report)*, CE-STR, No. 83-38, January 1984.
86. Liu, X. L., Chen, W.F., Bowman, M.D., "Construction Loads analysis for Concrete Structures", *Journal of Structural Engineering*, ASCE, Vol. 111, No. 5, May 1985, pp. 1019-1036.
87. Liu, X. L., Chen, W.F., Bowman, M.D., "Construction Loads on Supporting Floors", *Concrete International*, Vol. 7, No. 12, December 1985, pp. 21-26.

88. Liu, X. L., Chen, W.F., Bowman, M.D., "Shore Slab Interaction in Concrete Buildings", *Journal of Construction Engineering and Management*, ASCE, Vol. 112, No. 2, June 1986, pp. 227-244.
89. Liu, X. L., Chen, W.F., "Effect of Creep on Load Distribution in Multistory Reinforced Concrete Buildings during Construction", *ACI Structural Journal*, Vol. 84, 1987, pp192-200.
90. Liu, X. L., Chen, W.F., "Probability Distribution of Maximum Wooden shore Loads in Multistory R/C Buildings", *Structural Safety*, Elsevier Science Publishers, Vol. 4, No. 3, 1986, pp. 197-215.
91. Liu, X. L., Lee, H.M., Chen, W.F., "Analysis of Construction Loads on Slabs and Shores by Personal Computer", *Concrete International: Design and Construction*, Vol. 10, No. 6, June 1988, pp. 21-30.
92. Liu, X. L., Lee, H., Chen, W.F., "Shoring and Reshoring of High-rise Buildings, *Concrete International: Design and Construction*, Vol. 11, No. 1, January 1989, pp. 64-68.
93. Marosszeky, M., "Construction Loads Imposed in Multistory Structures", *Civil Engineering Transactions (Barton)*, Vol. CE14, No. 1, April 1972, pp. 91-93.
94. McKaig, T. H., "Building Failures, Case Studies in Construction and Design", McGraw-Hill Book Co., New York, 1962.
95. Mossallam, K.H., Chen, W.F., "Design consideration for Formwork in Multistory Concrete Buildings", *Engineering Structures*, Vol. 12, July, 1990, pp. 163-172.
96. Mossallam, K.H., Chen, W.F., "Determining Shoring Loads for Reinforced Concrete Construction", *ACI Structural Journal*, Vol. 88, No. 3, May – June 1991, pp. 340-350.
97. Mosallam, K., Chen, W.F., "Construction Load Distributions for Laterally Braced Formwork", *ACI Structural Journal*, Vol. 89, No. 4, July-August, 1992, pp. 415-424.
98. Nielsen, K.E.C., "Loads on Reinforced Concrete Floor Slabs and their Deflections During Construction", Swedish Cement and concrete Research Institute at the Royal Institute of Technology, Stockholm, 1952, 116 pp. NRC TP 875 S68 M4 No. 25
99. Noble, J., "Stop Guessing at Reshore Loads: Measure Them", *Concrete Construction*, July 1975, pp. 277-280.

100. Ofosu-Asamoah, K., Gardner, N.J., "Flat Slab Thickness Required to Satisfy Serviceability including Early Age Construction Loads", *ACI Structural Journal*, Vol. 94, No. 6, Nov-Dec, 1997, pp. 700-707.
101. Pallett, P., "Striking of Flat Slabs", *Concrete (London)*, Vol. 37, No. 5, May 2003, pp 30-32.
102. Peng, J.L., Rosowsky, D.V., Pan, A.D., Chen, W.F., Yen, T., "Analysis of Concrete Placement Load Effects Using Influence Surfaces", *ACI Structural Journal*, Vol. 93, No. 2, 1996.
103. Rosowsky, D., Huston, D., Fuhr, P., Chen, W.F., "Measuring Formwork Loads during Construction", *Concrete International*, Vol. 16, No. 11, November 1994, pp. 21-25.
104. Rosowsky, D., Huang, Y.L., Chen, W.F., Yen, T., "Modeling Concrete Placement Loads During Construction", *Structural Engineering Review*, Vol. 6, No. 2, 1994, pp. 71-84.
105. Rosowsky, D.V., Philbrick, T.W. Jr., Huston, D.R., "Observations from Shore Load Measurements during Concrete Construction", *Journal of Performance of Constructed Facilities*, Vol. 11, No. 1, February 1997, pp. 18-23.
106. Schousboe, I., "Bailey's Crossroads Collapse Reviewed", *American Society of Civil Engineers, Journal of the Construction Division*, Vol. 102, No. 2, June, 1976, pp. 365-378.
107. Scribner, C. F., Culver, C.G., "Investigation of the Collapse of l'Ambiance Plaza", *Journal of Performance of Constructed Facilities*, Vol. 2, No. 2, May 1988, pp. 58-79.
108. Staynes, B.W., "Pressures on Formwork and Striking Times", *Concrete (London)*, Vol. 32, No. 3, March 1998, pp. 11-13.
109. Stewart, M.G., "Effect of Construction and Service Loads on Reliability of Existing RC Buildings", *Journal of Structural Engineering*, Vol. 127, No. 10, October 2001, pp. 1232-1235.
110. Stivaros, P.C., Halvorsen, G.T., "Shoring / Reshoring Operations for Multistory Buildings", *ACI Structural Journal*, Vol. 87, No. 5, Sep-Oct, 1990, pp. 589-596.
111. Stivaros, P.C., Halvorsen, G.T., "Equivalent Frame Analysis of Concrete Buildings during Construction", *Concrete International: Design and Construction*, Vol. 13, No. 8, August 1991, pp. 57-62.

112. Stivaros, P.C., Halvorsen, G.T., "Construction Load Analysis of Slabs and Shores Using Microcomputers", *Concrete International: Design and Construction*, Vol. 14, No. 8, August 1992, pp. 27-32.
113. Taylor, R. S., "Pressure on Formwork Under Site Conditions", *Structural Concrete*, Vol. 1, No. 10, July-August 1963.
114. Taylor, P.J., "Effects of Formwork Stripping Time on Deflections of Flat Slabs and Plates", *Australian Civil Engineering and Construction*, Vol. 8, No. 2, February 1967, pp. 31-35.
115. Timoshenko, S., Woinowsky – Krieger, S., "Theory of Plates and Shells", McGraw – Hill, 1959.
116. Vollum, R.L., Moss, R.M., Hossain, T.R. "Slab Deflections in the Cardington In-situ Concrete Frame Building", *Magazine of Concrete Research*, Vol. 54, No. 1, February 2002, pp. 23 – 34.
117. Webster, F.A., "Reliability of Multistory Slab Structures Against Progressive Collapse during Construction", *ACI Journal*, Proceedings Volume 77, No. 6, November – December 1980, pp. 449-457.