Referências Bibliográficas

[1] AALAMI, B.O.; BOMMER, A. **Design Fundamentals of Post-Tensioned Concrete Floors**. 1. ed. Post-Tensioning Institute, 1999. 178p.

[2] LIN, T. Y. **Design on Prestressed Concrete Structures**. 2 ed. New York: Wiley, 1963. 614p.

[3] THE CONCRETE CENTRE. ***Post-tensioned Concrete Floors*.** 2008. 21p.

[4] BENTO, J. **Fundamentos Do Concreto Protendido**. Universidade De São Paulo Escola De Engenharia De São Carlos, São Carlos, 2005. 110p.

[5] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 6118/2007. **Projeto de estruturas de concreto - Procedimento**. Rio de Janeiro, 2007.

[6] BUILDING CODE REQUIREMENTS FOR STRUCTURAL CONCRETE. **ACI 318M-05**. American Concrete Institute. Michigan: Farmington Hills, 2005.

[7] POST-TENSIONING INSTITUTE. **Post-Tensioning Manual.** 6. ed. U.S.A., 1995. 345p.

[8] LOUREIRO, G.J. **Projeto de Lajes Protendidas com Cordoalhas Engraxadas**. ANAIS DO VI SIMPÓSIO EPUSP SOBRE ESTRUTURAS DE CONCRETO. 2006.

[9] ANOZÉ, A. **Projeto e Execução de Lajes Protendidas**, Brasília 2002. 116p.

[10] RECOMMENDATIONS FOR CONCRETE MEMBERS PRESTRESSED WITH UNBOUNDED TENDONS. **ACI 423.3R-96**. Detroit, 1983.

[11] SOUZA, G.; LENZ, K. **Concreto Protendido Fundamentos Básicos**. 4. ed. Universidade Federal de Viçosa, 1998.

[12] ESTECHE P.; DAVID G. **Estudo de Modelos para Projeto de lajes Lisas Protendidas**. Florianópolis, 2008. Dissertação de Mestrado, Departamento de Engenharia Civil – Universidade Federal de Santa Catarina.

[13] KHAN, S.; WILLIAMS, M. **Post-Tensioned Concrete Floors**. Great Britain: Butterworth Heinemann. 1995. 312pg.

[14] SORIANO, L.; LIMA, S.; **Analise de Estruturas**. Volume I. 2. ed. Rio de Janeiro: Editora Ciência Moderna Ltda. 2006. 310pg.

[15] SANTOS, L. M. **Modelação de Lajes com Elementos de Grelha**. IST. Lisboa, 2001. Disponível em: http://www.civil.ist.utl.pt/~luis/textos/modelacao.pdf. Acesso em: 27 sep. 2011.

[16] FRIDMAN,P. **Análise Numérico-Experimental de Lajes Nervuradas Sujeitas a Cargas Estáticas de Serviço**. Porto Alegre, 2011. Tese de Doutorado, Departamento de Engenharia Civil – Universidade Federal do Rio Grande do Sul.

[17] HENNRICHS, C. **Estudos sobre a Modelagem de lajes planas de concreto Armado**. Florianópolis, 2003. Dissertação de Mestrado, Departamento de Engenharia Civil – Universidade Federal de Santa Catarina.

[18] Computers and Structures, Inc., **CSI Analysis Reference Manual For SAP2000, ETABS, and SAFE.** Berkeley, California, 2008.

Anexo A
Equações no Mathcad

Cálculos feitos no Mathcad para a obtenção de w, mx e my para o caso de placa com carregamento distribuído, sujeita a carga concentrada e com carga distribuída em um retângulo parcial.

A.1.
Placa com Carregamento Distribuído

$fck := 35$

$Ec := 4760\sqrt{fck}$

$Ec = 2.816\times 10^{4}$

$\nu := 0.2$

$G := \frac{Ec}{2\cdot(1+\nu)} \qquad G = 1.173\times 10^{4}$

$h := 0.2$

$D := 1000Ec\cdot\frac{h^{3}}{12\cdot(1-\nu^{2})} \qquad D = 1.956\times 10^{4}$

$p := 7.71$

$x := 5 \qquad y := 5$

$a := 10 \qquad b := 10$

$$w := \left(100\cdot 16\cdot\frac{p}{\pi^{6}\cdot D}\right)\cdot\sum_{m=1}^{19}\sum_{n=1}^{19}\frac{\left(\sin\left(m\cdot\pi\cdot\frac{x}{a}\right)\cdot\sin\left(n\cdot\pi\cdot\frac{y}{b}\right)\right)}{m\cdot n\cdot\left(\frac{n^{2}}{b^{2}}+\frac{m^{2}}{a^{2}}\right)^{2}} \qquad w = 1.602$$

$$mx := \left(16\cdot\frac{p}{\pi^{4}}\right)\cdot\sum_{m=1}^{19}\sum_{n=1}^{19}\frac{\left(\frac{\nu n^{2}}{b^{2}}+\frac{m^{2}}{a^{2}}\right)\cdot\left(\sin\left(m\cdot\pi\cdot\frac{x}{a}\right)\cdot\sin\left(n\cdot\pi\cdot\frac{y}{b}\right)\right)}{m\cdot n\left(\frac{n^{2}}{b^{2}}+\frac{m^{2}}{a^{2}}\right)^{2}} \qquad mx = 34.073$$

$$my := \left(16\cdot\frac{p}{\pi^{4}}\right)\cdot\sum_{m=1}^{19}\sum_{n=1}^{19}\frac{\left(\frac{n^{2}}{b^{2}}+\frac{\nu m^{2}}{a^{2}}\right)\cdot\left(\sin\left(m\cdot\pi\cdot\frac{x}{a}\right)\cdot\sin\left(n\cdot\pi\cdot\frac{y}{b}\right)\right)}{m\cdot n\left(\frac{n^{2}}{b^{2}}+\frac{m^{2}}{a^{2}}\right)^{2}} \qquad my = 34.073$$

A.2.
Placa Sujeita a Carga Concentrada

$fck := 35$

$Ec := 4760\sqrt{fck}$

$Ec = 2.816 \times 10^4$

$\nu := 0.2$

$G := \dfrac{Ec}{2\cdot(1+\nu)}$ $\qquad G = 1.173 \times 10^4$

$h := 0.2$

$D := 1000\,Ec\cdot\dfrac{h^3}{12\cdot(1-\nu^2)}$ $\qquad D = 1.956 \times 10^4$

$p := 276.535$

$x := 5 \qquad y := 5$

$a := 10 \qquad b := 10$

$\varepsilon := 5 \qquad \eta := 5$

$$w := \left(100\cdot 4\cdot\frac{p}{\pi^4\cdot a\cdot b\cdot D}\right)\cdot\sum_{m=1}^{19}\sum_{n=1}^{19}\frac{\left(\sin\left(m\cdot\pi\cdot\frac{\varepsilon}{a}\right)\cdot\sin\left(n\cdot\pi\cdot\frac{\eta}{b}\right)\right)\cdot\left(\sin\left(m\cdot\pi\cdot\frac{x}{a}\right)\cdot\sin\left(n\cdot\pi\cdot\frac{y}{b}\right)\right)}{\left(\frac{n^2}{b^2}+\frac{m^2}{a^2}\right)^2}$$

$w = 1.638$

$$mx := \left(4\cdot\frac{p}{\pi^2 a\cdot b}\right)\cdot\sum_{m=1}^{19}\sum_{n=1}^{19}\frac{\left(\frac{\nu n^2}{b^2}+\frac{m^2}{a^2}\right)\cdot\left(\sin\left(m\cdot\pi\cdot\frac{\varepsilon}{a}\right)\cdot\sin\left(n\cdot\pi\cdot\frac{\eta}{b}\right)\right)\cdot\left(\sin\left(m\cdot\pi\cdot\frac{x}{a}\right)\cdot\sin\left(n\cdot\pi\cdot\frac{y}{b}\right)\right)}{\left(\frac{n^2}{b^2}+\frac{m^2}{a^2}\right)^2}$$

$mx = 92.896$

$$my := \left(4\cdot\frac{p}{\pi^2 a\cdot b}\right)\cdot\sum_{m=1}^{19}\sum_{n=1}^{19}\frac{\left(\frac{n^2}{b^2}+\frac{\nu m^2}{a^2}\right)\cdot\left(\sin\left(m\cdot\pi\cdot\frac{\varepsilon}{a}\right)\cdot\sin\left(n\cdot\pi\cdot\frac{\eta}{b}\right)\right)\cdot\left(\sin\left(m\cdot\pi\cdot\frac{x}{a}\right)\cdot\sin\left(n\cdot\pi\cdot\frac{y}{b}\right)\right)}{\left(\frac{n^2}{b^2}+\frac{m^2}{a^2}\right)^2}$$

$my = 92.896$

A.3.
Placa com Carga Distribuída em um Retângulo Parcial

$fck := 35$

$Ec := \left(4760\sqrt{fck}\right)$

$Ec = 2.816\times 10^{4}$

$\nu := 0.2$

$G := \frac{Ec}{2\cdot(1+\nu)}$ $\qquad G = 1.173\times 10^{4}$

$h := 0.2$

$D := 1000 Ec\cdot\frac{h^{3}}{12\cdot\left(1-\nu^{2}\right)}$ $\qquad D = 1.956\times 10^{4}$

$p := 277.897$

$x := 5 \qquad y := 5$

$a := 10 \qquad b := 10$

$\varepsilon := 5 \qquad \eta := 5$

$u := 0.5 \qquad v := 0.5$

$$w := \left(100\cdot 16\cdot\frac{p}{\pi^{6}\cdot u\cdot v\cdot D}\right)\cdot\sum_{m=1}^{19}\sum_{n=1}^{19}\frac{\left(\sin\left(m\cdot\pi\cdot\frac{\varepsilon}{a}\right)\cdot\sin\left(n\cdot\pi\cdot\frac{\eta}{b}\right)\right)\cdot\left(\sin\left(m\cdot\pi\cdot\frac{u}{2\cdot a}\right)\cdot\sin\left(n\cdot\pi\cdot\frac{v}{2\cdot b}\right)\right)\cdot\left(\sin\left(m\cdot\pi\cdot\frac{x}{a}\right)\cdot\sin\left(n\cdot\pi\cdot\frac{y}{b}\right)\right)}{m\cdot n\cdot\left(\frac{n^{2}}{b^{2}}+\frac{m^{2}}{a^{2}}\right)^{2}}$$

$w = 1.638$

$$mx := \left(16\cdot\frac{p}{\pi^{4}\cdot u\cdot v}\right)\cdot\sum_{m=1}^{19}\sum_{n=1}^{19}\frac{\left(\frac{\nu n^{2}}{b^{2}}+\frac{m^{2}}{a^{2}}\right)\cdot\left(\sin\left(m\cdot\pi\cdot\frac{\varepsilon}{a}\right)\cdot\sin\left(n\cdot\pi\cdot\frac{\eta}{b}\right)\right)\cdot\left(\sin\left(m\cdot\pi\cdot\frac{u}{2\cdot a}\right)\cdot\sin\left(n\cdot\pi\cdot\frac{v}{2\cdot b}\right)\right)\cdot\left(\sin\left(m\cdot\pi\cdot\frac{x}{a}\right)\cdot\sin\left(n\cdot\pi\cdot\frac{y}{b}\right)\right)}{m\cdot n\cdot\left(\frac{n^{2}}{b^{2}}+\frac{m^{2}}{a^{2}}\right)^{2}}$$

$mx = 87.049$

$$my := \left(16\cdot\frac{p}{\pi^{4}\cdot u\cdot v}\right)\cdot\sum_{m=1}^{19}\sum_{n=1}^{19}\frac{\left(\frac{n^{2}}{b^{2}}+\frac{\nu m^{2}}{a^{2}}\right)\cdot\left(\sin\left(m\cdot\pi\cdot\frac{\varepsilon}{a}\right)\cdot\sin\left(n\cdot\pi\cdot\frac{\eta}{b}\right)\right)\cdot\left(\sin\left(m\cdot\pi\cdot\frac{u}{2\cdot a}\right)\cdot\sin\left(n\cdot\pi\cdot\frac{v}{2\cdot b}\right)\right)\cdot\left(\sin\left(m\cdot\pi\cdot\frac{x}{a}\right)\cdot\sin\left(n\cdot\pi\cdot\frac{y}{b}\right)\right)}{m\cdot n\cdot\left(\frac{n^{2}}{b^{2}}+\frac{m^{2}}{a^{2}}\right)^{2}}$$

$my = 87.049$

Anexo B
Tensões para Laje Nervurada

Tabela B.1 – Tensões da laje nervurada para os modelos considerando excentricidade (Offset), sem considerar excentricidade e modelo com sólidos.

Comp (m)	Sem offset			Com offset			Solidos		
	Top	Bott	Med	Top	Bott	Med	Top	Bott	Med
0.0	-0.83	-0.83	-0.83	-0.78	-0.88	-0.83	-0.76	-0.86	-0.81
0.3	-0.75	-0.75	-0.75	-0.69	-0.80	-0.75	-0.69	-0.78	-0.73
0.6	-0.66	-0.66	-0.66	-0.62	-0.72	-0.67	-0.61	-0.70	-0.65
0.9	-0.58	-0.58	-0.58	-0.53	-0.65	-0.59	-0.53	-0.64	-0.59
1.3	-0.50	-0.50	-0.50	-0.46	-0.53	-0.49	-0.46	-0.29	-0.37
1.7	-0.37	-0.37	-0.37	-0.33	-0.36	-0.35	-0.37	-0.21	-0.29
2.6	-0.18	-0.18	-0.18	-0.17	-0.18	-0.17	-0.18	-0.09	-0.14
3.4	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.05	-0.08
4.2	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.04	-0.05
5.0	-0.06	-0.06	-0.06	-0.07	-0.06	-0.06	-0.06	-0.03	-0.05
5.8	-0.08	-0.08	-0.08	-0.09	-0.07	-0.08	-0.08	-0.04	-0.06
6.6	-0.13	-0.13	-0.14	-0.13	-0.12	-0.13	-0.12	-0.06	-0.13
7.4	-0.23	-0.23	-0.24	-0.20	-0.21	-0.21	-0.21	-0.10	-0.21
8.3	-0.43	-0.43	-0.43	-0.36	-0.40	-0.38	-0.40	-0.22	-0.38
9.1	-0.58	-0.58	-0.58	-0.49	-0.72	-0.60	-0.49	-0.70	-0.59
9.4	-0.60	-0.60	-0.60	-0.51	-0.74	-0.62	-0.51	-0.70	-0.60
9.7	-0.62	-0.62	-0.62	-0.52	-0.75	-0.63	-0.51	-0.71	-0.61
10.0	-0.62	-0.62	-0.62	-0.52	-0.75	-0.64	-0.52	-0.72	-0.62
10.3	-0.62	-0.62	-0.62	-0.52	-0.75	-0.63	-0.51	-0.71	-0.61
10.6	-0.60	-0.60	-0.60	-0.51	-0.74	-0.62	-0.51	-0.70	-0.60
10.9	-0.58	-0.58	-0.58	-0.49	-0.72	-0.60	-0.49	-0.70	-0.59
11.3	-0.56	-0.56	-0.56	-0.48	-0.60	-0.54	-0.46	-0.39	-0.43
11.7	-0.43	-0.43	-0.43	-0.36	-0.40	-0.38	-0.40	-0.24	-0.32
12.6	-0.23	-0.23	-0.23	-0.20	-0.21	-0.20	-0.21	-0.12	-0.17
13.4	-0.13	-0.13	-0.14	-0.13	-0.12	-0.13	-0.12	-0.06	-0.13
14.2	-0.08	-0.08	-0.09	-0.09	-0.07	-0.09	-0.08	-0.04	-0.09
15.0	-0.06	-0.06	-0.07	-0.07	-0.06	-0.07	-0.06	-0.03	-0.07
15.8	-0.07	-0.07	-0.07	-0.07	-0.07	-0.08	-0.07	-0.04	-0.08
16.6	-0.10	-0.10	-0.11	-0.10	-0.10	-0.11	-0.10	-0.06	-0.11
17.4	-0.18	-0.18	-0.20	-0.17	-0.18	-0.19	-0.18	-0.10	-0.19
18.3	-0.37	-0.37	-0.37	-0.33	-0.36	-0.35	-0.37	-0.23	-0.30
18.8	-0.50	-0.50	-0.50	-0.46	-0.53	-0.49	-0.46	-0.15	-0.31
19.1	-0.58	-0.58	-0.58	-0.53	-0.65	-0.59	-0.53	-0.64	-0.59
19.4	-0.66	-0.66	-0.66	-0.62	-0.72	-0.67	-0.61	-0.70	-0.65
19.7	-0.75	-0.75	-0.75	-0.69	-0.80	-0.75	-0.69	-0.78	-0.73
20.0	-0.83	-0.83	-0.83	-0.78	-0.88	-0.83	-0.76	-0.86	-0.81

Anexo C
Coeficiente ϕ

Tabela C.1 – Quadro Resumo do coeficiente ϕ calculado para lajes maciças para diferentes larguras da faixa de protensão.

Faixas	Seção	MODELO 1		MODELO 2		MODELO 3			MODELO 4		
		ϕ_{max}	ϕ_{min}	ϕ_{max}	ϕ_{min}	$\phi_{max\ ext}$	$\phi_{max\ int}$	ϕ_{min}	$\phi_{max\ ext}$	$\phi_{max\ int}$	ϕ_{min}
L/4	A-A	1.03	0.10	1.00	0.13	1.01	0.83	0.14	1.01	0.84	0.14
	B-B	0.87	0.21	0.70	0.34	0.73	0.60	0.36	0.74	0.61	0.36
	C-C	1.04	-0.04	0.52	0.48	0.55	0.49	0.47	0.56	0.50	0.48
L/8	A-A	0.78	0.00	0.76	0.02	0.77	0.56	0.04	0.77	0.57	0.03
	B-B	0.54	0.03	0.41	0.13	0.44	0.32	0.15	0.44	0.33	0.14
	C-C	1.03	-0.04	0.26	0.24	0.29	0.24	0.23	0.30	0.25	0.23
L/20	A-A	0.38	-0.01	0.37	0.00	0.38	0.26	0.01	0.38	0.26	0.01
	B-B	0.24	0.00	0.18	0.04	0.19	0.13	0.05	0.19	0.13	0.06
	C-C	1.04	-0.05	0.10	0.09	0.12	0.10	0.09	0.13	0.10	0.09
L/40	A-A	0.20	-0.01	0.20	0.00	0.20	0.13	0.00	0.20	0.13	0.00
	B-B	0.12	0.00	0.09	0.02	0.10	0.06	0.03	0.10	0.07	0.03
	C-C	0.80	-0.05	0.05	0.05	0.06	0.05	0.04	0.06	0.05	0.05

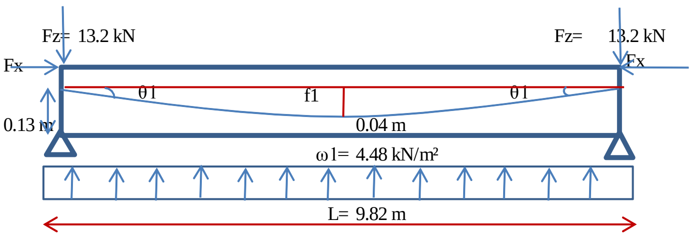
Anexo D
Memória de Cálculo

Neste anexo é apresentada a memória de cálculo do carregamento equivalente de protensão.

DIREÇÃO X

Zona 1

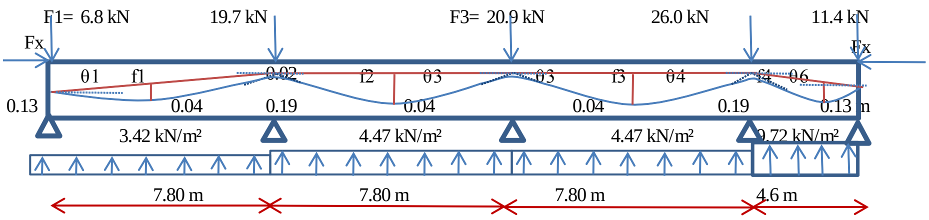
Espessura da laje:	0.23 m
Largura nervura:	0.6 m
Número de cabos:	3
Força de protensão:	P= 360 kN



f1= 0.13-0.04	f1= 0.09 m	
ω1= (8*0.09*360)/(9.82^2*0.6)	ω1= 4.48 kN/m²	**Σω= 26.40 kN**
θ1= (4*0.09)/(9.82)	θ1= 0.037	
Fv= P*θ1	Fz= 13.2 kN	**ΣFz= 26.40 kN**
Fx= P	Fx= 360 kN	Fx= 360 kN

Zona 2 y 4

Espessura da laje:	0.23 m
Largura nervura:	0.6 m
Número de cabos:	1
Força de protensão:	P= 120 kN



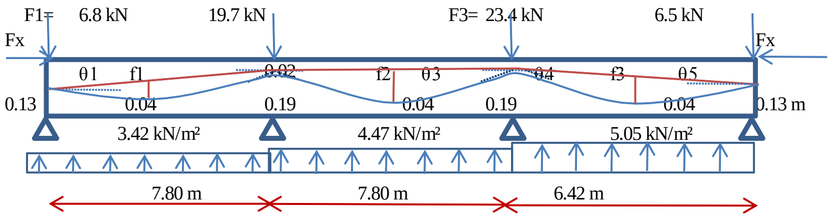
f1=f4= (0.19+0.02+0.13)/2)-0.04	f1=f4= 0.13 m
f2=f3= 0.19+0.02-0.04	f2=f3= 0.17 m

ω1= (8*0.13*120)/(7.8^2*0.6)	ω1= 3.42 kN/m²	ω1= 16.00 kN
ω2= (8*0.17*120)/(7.8^2*0.6)	ω2= 4.47 kN/m²	ω2= 20.92 kN
ω3= (8*0.17*120)/(7.8^2*0.6)	ω3= 4.47 kN/m²	ω3= 20.92 kN
ω4= (8*0.13*120)/(4.6^2*0.6)	ω4= 9.72 kN/m²	ω4= 26.98 kN
		Σω= 84.83 kN

θ1= (4*0.13-(0.19+0.02-0.13))/(7.8)=	0.0564	F1= P*θ1	F1= 6.8 kN
θ2= (4*0.13+(0.19+0.02-0.13))/(7.8)=	0.0769	F2= P*(θ2+θ3)	F2= 19.7 kN
θ3= (4*17)/7.8=	0.0872	F3= 2P*θ3	F3= 20.9 kN
θ4= (4*0.13+(0.19+0.02-0.13))/(4.6)=	0.1297	F4= P*(θ3+θ4)	F4= 26.0 kN
θ5= (4*0.13-(0.19+0.02-0.13))/(4.6)=	0.0951	F5= P*θ5	F5= 11.4 kN
			ΣFz= 84.83 kN
		Fx= P	Fx= 120 kN

Zona 3

Espessura da laje:	0.23 m
Largura nervura:	0.6 m
Número de cabos:	1
Força de protensão:	P= 120 kN



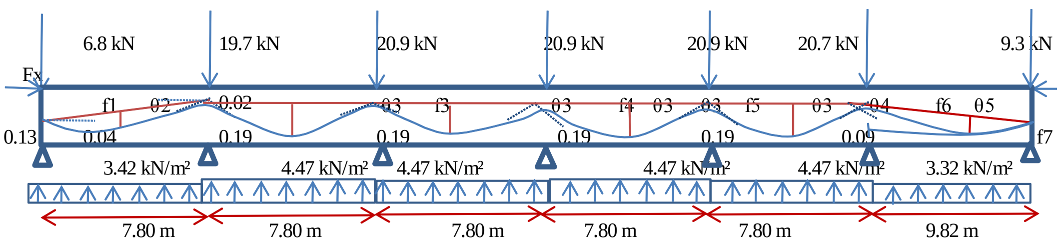
f1=f3= (0.19+0.02+0.13)/2)-0.04	f1=f3= 0.13 m
f2 0.19+0.02-0.04	f2 0.17 m

ω1= (8*0.13*120)/(7.8^2*0.6)	ω1=	3.42 kN/m²	ω1= 16.00 kN
ω2= (8*0.17*120)/(7.8^2*0.6)	ω2=	4.47 kN/m²	ω2= 20.92 kN
ω3= (8*0.13*120)/(6.42^2*0.6)	ω3=	5.05 kN/m²	ω3= 19.44 kN
			Σω= 56.36 kN

θ1= (4*0.13-(0.19+0.02-0.13))/(7.8)=	0.0564	F1= P*θ1	F1= 6.8 kN
θ2= (4*0.13+(0.19+0.02-0.13))/(7.8)=	0.0769	F2= P*(θ2+θ3)	F2= 19.7 kN
θ3= (4*0.17)/7.8=	0.0872	F3= P*(θ3+θ4)	F3= 23.4 kN
θ4= (4*0.13+(0.19+0.02-0.13))/(6.4)=	0.1075	F4= P*θ5	F4= 6.5 kN
θ5= (4*0.13-(0.19+0.02-0.13))/(6.4)=	0.0545		**ΣFz= 56.36 kN**
		Fx= P	Fx= 120 kN

Zona 5

Espessura da laje:	0.23 m
Largura nervura:	0.6 m
Número de cabos:	1
Força de protensão:	P= 120 kN

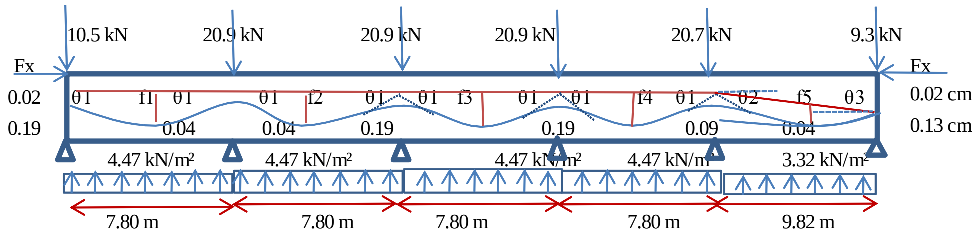


f1=f6=	(0.19+0.02+0.13)/2)-0.04	f1=f6=	0.13 m		
f2=f3=f4=f5=	0.19+0.02-0.04	f2=f3=f4=f5=	0.17 m		
f7=	(0.13+0.09)/2)-0.04	f7=	0.07 m		
ω1=	(8*0.13*120)/(7.8^2*0.6)	ω1=	3.42 kN/m²	ω1=	16.00 kN
ω2=	(8*0.17*120)/(7.8^2*0.6)	ω2=	4.47 kN/m²	ω2=	20.92 kN
ω3=	(8*0.17*120)/(7.8^2*0.6)	ω3=	4.47 kN/m²	ω3=	20.92 kN
ω4=	(8*0.17*120)/(7.8^2*0.6)	ω4=	4.47 kN/m²	ω4=	20.92 kN
ω5=	(8*0.17*120)/(7.8^2*0.6)	ω5=	4.47 kN/m²	ω5=	20.92 kN
ω6=	(8*(0.13+0.07)*120)/(9.8^2*0.6)	ω6=	3.32 kN/m²	ω6=	19.55 kN
				Σω=	**119.24 kN**

θ1= (4*0.13-(0.19+0.02-0.13))/(7.8)=	0.0564	F1=	P*θ1	F1=	6.77 kN
θ2= (4*0.13+(0.19+0.02-0.13))/(7.8)=	0.0769	F2=	P*(θ2+θ3)	F2=	19.69 kN
θ3= (4*0.17)/7.8=	0.0872	F3=	2P*θ3	F3=	20.92 kN
θ4= (4*0.13+(0.19+0.02-0.13))/(9.8)=	0.0611	F4=	2P*θ3	F4=	20.92 kN
θ5= (4*0.13-(0.19+0.02-0.13))/(9.8)=	0.0448	F5=	2P*θ3	F5=	20.92 kN
θ6= (4*0.07-(0.13-0.09))/(9.8)=	0.0244	F6=	P*(θ3+θ4+θ6)	F6=	20.73 kN
θ7= (4*0.07+(0.13-0.09-0.02))/(9.8)=	0.0326	F7=	P*(θ5+θ7)	F7=	9.29 kN
				ΣFz=	**119.24 kN**
		Fh=	P	Fh=	120 kN

Zona 6

Espessura da laje:	0.23 m
Largura nervura:	0.6 m
Número de cabos:	1
Força de protensão:	P= 120 kN



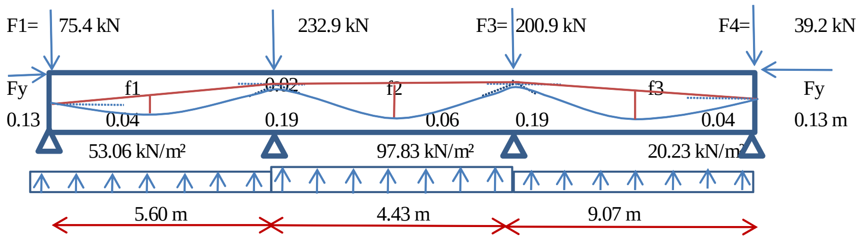
f1=f2=f3=f4=	0.19+0.02-0.04	f1=f2=f3=f4=	0.17 m		
f5=	(0.19+0.02+0.13)/2)-0.04	f5=	0.13 m		
f6=	((0.09+0.13)/2)-0.04	f6=	0.07 m		
ω1=	(8*0.17*120)/(7.8^2*0.6)	ω1=	4.47 kN/m²	ω1=	20.92 kN
ω2=	(8*0.17*120)/(7.8^2*0.6)	ω2=	4.47 kN/m²	ω2=	20.92 kN
ω3=	(8*0.17*120)/(7.8^2*0.6)	ω3=	4.47 kN/m²	ω3=	20.92 kN
ω4=	(8*0.17*120)/(7.8^2*0.6)	ω4=	4.47 kN/m²	ω4=	20.92 kN
ω5=	(8*(0.13+0.07)*120)/(9.82^2*0.6)	ω5=	3.32 kN/m²	ω5=	19.55 kN
				Σω=	**103.24 kN**

		F1=	P*θ1	F1=	10.46 kN
θ1= (4*0.17)/7.8=	0.0872	F2=	2P*θ1	F2=	20.92 kN
θ2= (4*0.13+(0.19+0.02-0.13))/(9.8)=	0.0611	F3=	2P*θ1	F3=	20.92 kN
θ3= (4*0.13-(0.19+0.02-0.13))/(9.8)=	0.0448	F4=	2P*θ1	F4=	20.92 kN
θ4= (4*0.07-(0.13-0.09))/(9.8)=	0.0244	F5=	P*(θ1+θ2+θ4)	F5=	20.73 kN
θ5= (4*0.07+(0.13-0.09))/(9.8)=	0.0326	F6=	P*(θ3+θ5)	F6=	9.29 kN
				ΣFz=	**103.24 kN**
	9.287169043	Fx=	P	Fx=	120 kN

DIREÇÃO Y

Faixa 1

Espessura da laje:	0.23 m
Largura faixa	0.6 cm
Número de cabos:	8
Força de protensão:	P= 960 kN

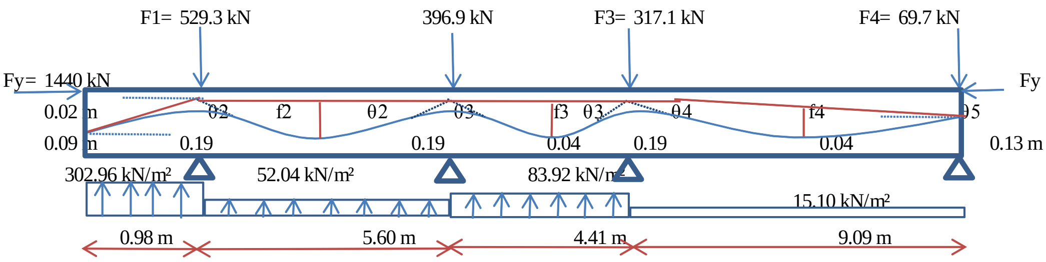


f1=f3=	(0.19+0.02+0.13)/2)-0.04	f1=f3=	0.13 m		
f2	0.19+0.02-0.06	f2	0.15 m		
ω1=	(8*0.13*960)/(5.6^2*0.6)	ω1=	53.06 kN/m²	ω1=	178.29 kN
ω2=	(8*0.15*960)/(4.43^2*0.6)	ω2=	97.83 kN/m²	ω2=	260.05 kN
ω3=	(8*0.13*960)/(9.07^2*0.6)	ω3=	20.23 kN/m²	ω3=	110.08 kN
				Σω=	**548.41 kN**

θ1= (4*0.13-(0.19+0.02-0.13))/(5.6)=	0.0786	F1=	P*θ1	F1=	75.4 kN
θ2= (4*0.13+(0.19+0.02-0.13))/(5.6)=	0.1071	F2=	P*(θ2+θ3)	F2=	232.9 kN
θ3= (4*0.15)/0.06=	0.1354	F3=	P*(θ3+θ4)	F3=	200.9 kN
θ4= (4*0.13+(0.19+0.02-0.13))/(9.07)=	0.0739	F4=	P*θ5	F4=	39.2 kN
θ5= (4*0.13-(0.19+0.02-0.13))/(9.07)=	0.0408			**ΣFz=**	**548.41 kN**
		Fy=	P	Fy=	960 kN

Faixa 2

Espessura da laje:	0.23 m
Largura faixa	1.20 m
Número de cabos:	12
Força de protensão:	P= 1440 kN

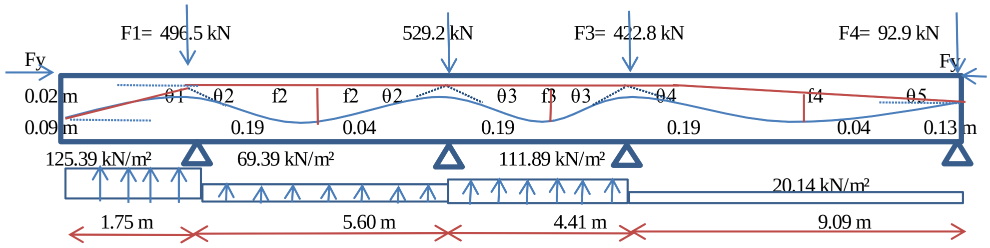


f1=	(0.19+0.02-0.09)	f1=	0.12 m		
f2=f3=	0.19+0.02-0.04	f2=f3=	0.17		
f4=	(0.19+0.02+0.13)/2)-0.04	f4=	0.13 m		
ω1=	(2*0.12*1440)/(0.975^2*1.2)	ω1=	302.96 kN/m²	ω1=	354.46 kN
ω2=	(8*0.17*1440)/(5.6^2*1.2)	ω2=	52.04 kN/m²	ω2=	349.71 kN
ω3=	(8*0.17*1440)/(4.41^2*1.2)	ω3=	83.92 kN/m²	ω3=	444.08 kN
ω4=	(8*0.13*1440)/(9.09^2*1.2)	ω4=	15.10 kN/m²	ω4=	164.75 kN
				Σω=	**1313.01 kN**

θ1= (0.12+(0.19+0.02-0.09))/(0.975)=	0.2462	F1=	P*(θ1+θ2)	F1=	529.3 kN
θ2= (4*0.17)/5.6=	0.1214	F2=	P*(θ2+θ3)	F2=	396.9 kN
θ3= (4*0.17)/4.41=	0.1542	F3=	P*(θ3+θ4)	F3=	317.1 kN
θ4= (4*0.13+(0.19+0.02-0.13))/(9.09)=	0.0660	F4=	P*θ5	F4=	69.7 kN
θ5= (4*0.13-(0.19+0.02-0.13))/(9.09)=	0.0484			**ΣFz=**	**1313.01 kN**
		Fy=	P	Fy=	1440 kN

Faixa 3

Espessura da laje:	0.23 m
Largura faixa	1.20 m
Número de cabos:	16
Força de protensão:	P= 1920 kN



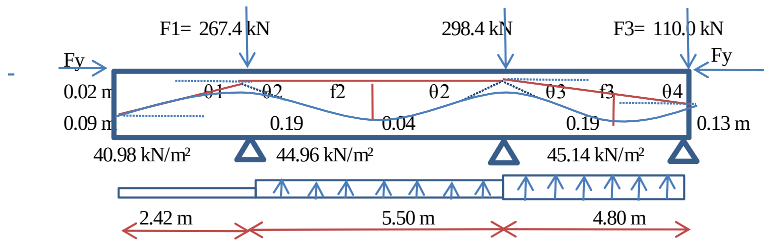
f1=	(0.19+0.02-0.09)	f1=	0.12 m
f2=f3=	0.19+0.02-0.04	f2=f3=	0.17
f4=	(0.19+0.02+0.13)/2)-0.04	f4=	0.13 m

ω1= (2*0.12*1920)/(1.75^2*1.2)	ω1= 125.39 kN/m²	ω1= 263.31 kN
ω2= (8*0.17*1920)/(5.6^2*1.2)	ω2= 69.39 kN/m²	ω2= 466.29 kN
ω3= (8*0.17*1920)/(4.41^2*1.2)	ω3= 111.89 kN/m²	ω3= 592.11 kN
ω4= (8*0.13*1920)/(9.09^2*1.2)	ω4= 20.14 kN/m²	ω4= 219.67 kN
		Σω= 1541.38 kN

θ1= (0.12+(0.19+0.02-0.09))/(1.75)=	0.1371	F1= P*(θ1+θ2)	F1= 496.5 kN
θ2= (4*0.17)/5.6=	0.1214	F2= P*(θ2+θ3)	F2= 529.2 kN
θ3= (4*0.17)/4.41=	0.1542	F3= P*(θ3+θ4)	F3= 422.8 kN
θ4= (4*0.13+(0.19+0.02-0.13))/(9.09)=	0.0660	F4= P*θ5	F4= 92.9 kN
θ5= (4*0.13-(0.19+0.02-0.13))/(9.09)=	0.0484		**ΣFz= 1541.38 kN**
		Fy= P	Fy= kN

Faixa 4

Espessura da laje:	0.23 m
Largura faixa	1.20 m
Número de cabos:	10
Força de protensão:	P= 1200 kN



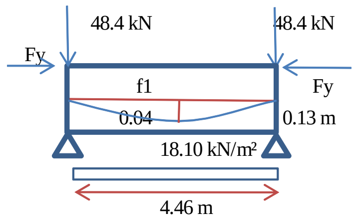
f1=	(0.19+0.02-0.09)	f1=	0.12 m
f2=	0.19+0.02-0.04	f2=	0.17 m
f3=	(0.13+0.02+0.19)/2)-0.04	f3=	0.13 m

ω1= (2*0.12*1200)/(2.42^2*1.2)	ω1= 40.98 kN/m²	ω1= 119.01 kN
ω2= (8*0.17*1200)/(5.5^2*1.2)	ω2= 44.96 kN/m²	ω2= 296.73 kN
ω3= (8*0.13*1200)/(4.8^2*1.2)	ω3= 45.14 kN/m²	ω3= 260.00 kN
		Σω= 675.74 kN

θ1= (0.12+(0.19+0.02-0.09))/(2.42)=	0.0992	F1= P*(θ1+θ2)	F1= 267.4 kN
θ2= (4*0.17)/5.5=	0.1236	F2= P*(θ2+θ3)	F2= 298.4 kN
θ3= (4*0.13+(0.19+0.02-0.13))/(4.8)=	0.1250	F3= P*θ4	F3= 110.0 kN
θ4= (4*0.13-(0.19+0.02-0.13))/(4.8)=	0.0917		**ΣFz= 675.74 kN**
		Fy= P	Fy= 1200 kN

Faixa 9

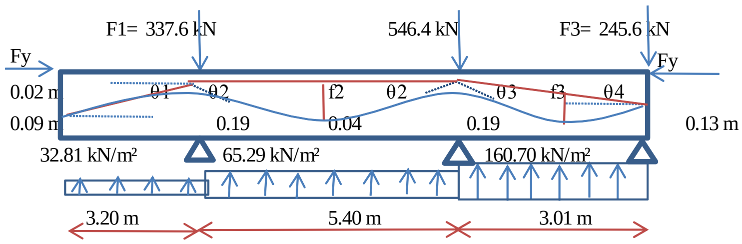
Espessura da laje:	0.23 m
Largura faixa	1.2 cm
Número de cabos:	5
Força de protensão:	P= 600 kN



		f4= 0.13-0.04	f4= 0.09 m
		Fy= P	Fy= 600 kN
ω1= (8*0.09*600)/(4.46^2*1.2)		ω1= 18.10 kN/m²	**ω1= 96.86 kN**
θ1= (4*0.09)/4.46=	0.0807	F1= P*θ1	F1= 48.4 kN
		F2= P*θ1	F2= 48.4 kN
			ΣFz= 96.86 kN

Faixa 5

Espessura da laje:	0.23 m
Largura faixa	1.20 m
Número de cabos:	14
Força de protensão:	P= 1680 kN

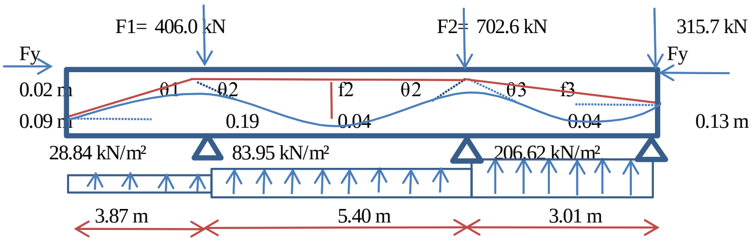


f1= (0.19+0.02-0.09)	f1= 0.12 m	
f2= 0.19+0.02-0.04	f2= 0.17 m	
f3= (0.13+0.02+0.19)/2)-0.04	f3= 0.13 m	
ω1= (2*0.12*1680)/(3.2^2*1.2)	ω1= 32.81 kN/m²	ω1= 126.00 kN
ω2= (8*0.17*1680)/(5.4^2*1.2)	ω2= 65.29 kN/m²	ω2= 423.11 kN
ω3= (8*0.13*1680)/(3.01^2*1.2)	ω3= 160.70 kN/m²	ω3= 580.47 kN
		Σω= 1129.58 kN

θ1= (0.12+(0.19+0.02-0.09))/(3.2)=	0.0750	F1= P*(θ1+θ2)	F1= 337.6 kN
θ2= (4*0.17)/5.4=	0.1259	F2= P*(θ2+θ3)	F2= 546.4 kN
θ3= (4*0.13+(0.19+0.02-0.13))/(3.01)=	0.1993	F3= P*θ4	F3= 245.6 kN
θ4= (4*0.13-(0.19+0.02-0.13))/(3.01)=	0.1462		**ΣFz= 1129.58 kN**
		Fy= P	Fy= 1680 kN

Faixa 6

Espessura da laje:	0.23 m
Largura faixa	1.20 m
Número de cabos:	18
Força de protensão:	P= 2160 kN

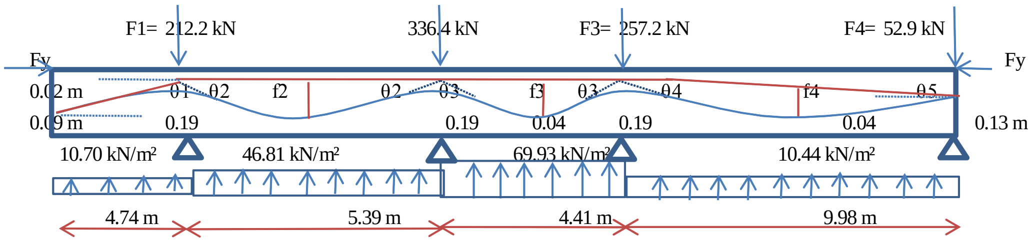


f1= (0.19+0.02-0.09)	f1= 0.12 m		
f2= 0.19+0.02-0.04	f2= 0.17 m		
f3= ((0.19+0.02+0.13)/2)-0.04	f3= 0.13 m		
ω1= (2*0.12*2160)/(3.87^2*1.2)	ω1=	28.84 kN/m²	ω1= 133.95 kN
ω2= (8*0.17*2160)/(5.4^2*1.2)	ω2=	83.95 kN/m²	ω2= 544.00 kN
ω3= (8*0.13*2160)/(3.01^2*1.2)	ω3=	206.62 kN/m²	ω3= 746.31 kN
			Σω= 1424.27 kN

θ1= (0.12+(0.19+0.02-0.09))/(3.87)=	0.0620	F1= P*(θ1+θ2)	F1= 406.0 kN
θ2= (4*0.17)/5.4=	0.1259	F2= P*(θ2+θ3)	F2= 702.6 kN
θ3= (4*0.13+(0.19+0.02-0.13))/(3.01)=	0.1993	F3= P*θ4	F3= 315.7 kN
θ4= (4*0.13-(0.19+0.02-0.13))/(3.01)=	0.1462		**ΣFz= 1424.27 kN**
		Fy= P	Fy= 2160 kN

Faixa 7

Espessura da laje:	0.23 m
Largura faixa	1.20 m
Número de cabos:	10
Força de protensão:	P= 1200 kN



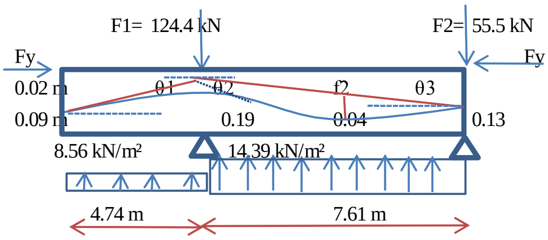
f1= (0.19+0.02-0.09)	f1= 0.12 m
f2=f3= 0.19+0.02-0.04	f2=f3= 0.17
f4= (0.19+0.02+0.13)/2)-0.04	f4= 0.13 m

ω1= (2*0.12*1200)/(4.735^2*1.2)	ω1=	10.70 kN/m²	ω1= 60.82 kN
ω2= (8*0.17*1200)/(5.39^2*1.2)	ω2=	46.81 kN/m²	ω2= 302.78 kN
ω3= (8*0.17*1200)/(4.41^2*1.2)	ω3=	69.93 kN/m²	ω3= 370.07 kN
ω4= (8*0.13*1200)/(9.98^2*1.2)	ω4=	10.44 kN/m²	ω4= 125.05 kN
			Σω= 858.72 kN

θ1= (0.12+(0.19+0.02-0.09))/(4.735)=	0.0507	F1= P*(θ1+θ2)	F1= 212.2 kN
θ2= (4*0.17)/5.39=	0.1262	F2= P*(θ2+θ3)	F2= 336.4 kN
θ3= (4*0.17)/4.41=	0.1542	F3= P*(θ3+θ4)	F3= 257.2 kN
θ4= (4*0.13+(0.19+0.02-0.13))/(9.98)=	0.0601	F4= P*θ5	F4= 52.9 kN
θ5= (4*0.13-(0.19+0.02-0.13))/(9.98)=	0.0441		**ΣFz= 858.72 kN**
		Fy= P	Fy= 1200 kN

Faixa 7A

Espessura da laje:		0.23 m
Largura faixa		1.20 m
Número de cabos:		8
Força de protensão:	P=	960 kN



f1= (0.19+0.02-0.09)	f1= 0.12 m	
f2= (0.19+0.02+0.13)/2)-0.04	f2= 0.13 m	
ω1= (2*0.12*960)/(4.735^2*1.2)	ω1= 8.56 kN/m²	ω1= 48.66 kN
ω2= (8*0.13*960)/(7.605^2*1.2)	ω2= 14.39 kN/m²	ω2= 131.28 kN
		Σω= 179.94 kN

θ1= (0.12+(0.19+0.02-0.09))/(4.735)=	0.0507	F1= P*(θ1+θ2)	F1= 124.4 kN
θ2= (4*0.13+(0.19+0.02-0.04))/(7.605)=	0.0789	F2= P*θ3	F2= 55.5 kN
θ3= (4*0.13-(0.19+0.02-0.04))/(7.605)=	0.0579		**ΣFz= 179.94 kN**
		Fy= P	Fy= 960 kN

Anexo E
Tensões para os Modelos de Viga e Casca

Tabela E.1 – Quadro resumo das tensões calculadas para a seção A e B para os modelos de viga e casca, no topo e base da laje.

TENSÕES (kN/cm²) NA SEÇÃO A					TENSÕES (kN/cm²) NA SEÇÃO B				
X (m)	Tipo Viga		Tipo Casca		X (m)	Tipo Viga		Tipo Casca	
	σ sup	σ inf	σ sup	σ inf		σ sup	σ inf	σ sup	σ inf
0.30	0.75	-1.43	0.75	-1.56	0.30	0.05	-1.16	0.03	-1.09
1.13	0.36	-1.90	0.58	-1.86	1.35	0.08	-0.89	0.03	-0.78
1.73	0.18	-2.12	0.44	-2.09	1.95	0.08	-0.64	0.04	-0.56
2.33	0.08	-2.26	0.34	-2.29	2.55	0.06	-0.44	0.04	-0.39
2.93	0.02	-2.36	0.27	-2.46	3.15	0.04	-0.30	0.03	-0.29
3.53	0.01	-2.43	0.23	-2.59	3.75	0.03	-0.23	0.02	-0.24
4.13	0.01	-2.49	0.21	-2.69	4.35	0.03	-0.22	0.02	-0.24
4.73	0.02	-2.53	0.19	-2.76	4.95	0.04	-0.26	0.01	-0.30
5.33	0.04	-2.57	0.18	-2.81	5.55	0.07	-0.37	0.02	-0.40
5.93	0.05	-2.60	0.18	-2.83	6.15	0.10	-0.56	0.03	-0.56
6.53	0.06	-2.61	0.18	-2.83	6.75	0.15	-0.79	0.05	-0.72
7.13	0.06	-2.61	0.17	-2.81	7.95	0.28	-1.00	0.10	-0.68
7.73	0.06	-2.60	0.16	-2.79	9.15	0.14	-0.80	0.03	-0.69
8.33	0.05	-2.58	0.16	-2.75	9.75	0.08	-0.57	0.00	-0.52
8.93	0.04	-2.54	0.14	-2.71	10.35	0.04	-0.38	-0.02	-0.35
9.53	0.04	-2.49	0.13	-2.64	10.95	0.02	-0.26	-0.04	-0.24
10.13	0.03	-2.43	0.11	-2.54	11.55	0.00	-0.20	-0.05	-0.20
10.73	0.03	-2.35	0.10	-2.41	12.15	0.00	-0.21	-0.05	-0.22
11.33	0.04	-2.25	0.09	-2.28	12.75	0.00	-0.27	-0.04	-0.30
11.93	0.05	-2.15	0.08	-2.16	13.35	0.02	-0.42	-0.02	-0.45
12.53	0.07	-2.05	0.07	-2.07	13.95	0.06	-0.67	0.02	-0.66
13.13	0.07	-1.96	0.04	-2.02	14.55	0.12	-0.96	0.07	-0.86
13.73	0.06	-1.88	0.01	-1.97	15.75	0.33	-1.19	0.17	-0.86
14.33	0.03	-1.79	-0.02	-1.92	16.95	0.13	-0.97	0.08	-0.85
14.93	0.00	-1.70	-0.04	-1.83	17.55	0.05	-0.67	0.02	-0.65
15.53	-0.04	-1.60	-0.06	-1.72	18.15	0.01	-0.42	-0.02	-0.44
16.13	-0.07	-1.52	-0.07	-1.59	18.75	-0.01	-0.26	-0.05	-0.29
16.73	-0.09	-1.45	-0.07	-1.49	19.35	-0.01	-0.18	-0.06	-0.21
17.33	-0.11	-1.41	-0.08	-1.44	19.95	-0.01	-0.16	-0.06	-0.20
17.93	-0.11	-1.41	-0.07	-1.45	20.55	0.00	-0.19	-0.06	-0.23
18.53	-0.11	-1.44	-0.07	-1.53	21.15	0.01	-0.29	-0.04	-0.32
19.13	-0.09	-1.47	-0.06	-1.65	21.75	0.04	-0.45	-0.02	-0.45

19.73	-0.08	-1.50	-0.04	-1.75	22.35	0.08	-0.64	0.01	-0.57
20.33	-0.06	-1.50	-0.02	-1.80	23.55	0.21	-0.79	0.07	-0.53
20.93	-0.05	-1.45	0.02	-1.77	24.75	0.09	-0.65	0.03	-0.56
21.53	-0.02	-1.33	0.08	-1.64	25.35	0.06	-0.47	0.00	-0.44
22.13	0.02	-1.17	0.15	-1.42	25.95	0.04	-0.32	-0.01	-0.33
22.73	0.09	-0.94	0.25	-1.13	26.55	0.03	-0.23	-0.02	-0.25
23.73	0.38	-0.46	0.48	-0.68	27.15	0.03	-0.20	-0.03	-0.22
					27.75	0.04	-0.21	-0.03	-0.25
					28.35	0.04	-0.27	-0.02	-0.32
					28.95	0.05	-0.41	0.00	-0.45
					29.55	0.08	-0.63	0.04	-0.63
					30.15	0.13	-0.89	0.09	-0.79
					31.35	0.29	-1.10	0.15	-0.78
					32.55	0.12	-0.86	0.06	-0.76
					33.15	0.06	-0.59	0.00	-0.57
					33.75	0.03	-0.36	-0.03	-0.47
					34.35	0.00	-0.23	-0.06	-0.26
					34.95	-0.01	-0.17	-0.08	-0.20
					35.55	-0.02	-0.18	-0.08	-0.21
					36.15	-0.02	-0.27	-0.06	-0.30
					36.75	0.00	-0.46	-0.03	-0.47
					37.35	0.05	-0.76	0.02	-0.71
					37.95	0.15	-1.11	0.10	-0.94
					39.15	0.47	-1.34	0.23	-0.95
					40.30	0.18	-1.13	0.05	-1.00
					40.90	0.07	-0.77	-0.04	-0.74
					41.50	-0.01	-0.44	-0.10	-0.45
					42.10	-0.05	-0.21	-0.15	-0.20
					42.70	-0.08	-0.07	-0.18	-0.04
					43.30	-0.09	0.00	-0.20	0.06
					43.90	-0.10	0.02	-0.21	0.08
					44.50	-0.12	0.00	-0.21	0.05
					45.10	-0.13	-0.07	-0.21	-0.05
					45.70	-0.14	-0.21	-0.20	-0.22
					46.30	-0.13	-0.43	-0.17	-0.47
					46.90	-0.11	-0.74	-0.13	-0.77
					47.50	-0.06	-1.07	-0.08	-1.03
					48.61	0.10	-1.31	0.06	-1.16