a2a	Tipo Documento: Relazione Tecnica		
	Codice documento: SFP-RTC-100037-CCGT	Rev. 1	Pagina 1 di 58

Centrale di San Filippo del Mela
Progetto definitivo per l'installazione di un nuovo ciclo combinato a gas
Note di calcolo - Turbina a vapore

APPLICA

A2A/DGE/BGT/GEN/ING

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EMISSIONE					
1	10/12/2019	FU = Per Uso	C. Bettoni	D. Morgera	P. Coletti
0	26/11/2019	FA = Per Approvazione	L. Agostino	C. Bettoni	G. Ricci
REV	DATA	DESCRIZIONE	REDAZIONE	VERIFICA	APPROVAZIONE

- Il documento approvato e firmato in originale è depositato presso l'archivio tecnico della S.O.-

INDICE

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1 SCOPO DEL DOCUMENTO

Nel seguente documento vengono riportate le analisi strutturali e il progetto della fondazione della turbina a vapore. In Figura 1 è riportata la posizione planimetrica dell'elemento in esame.

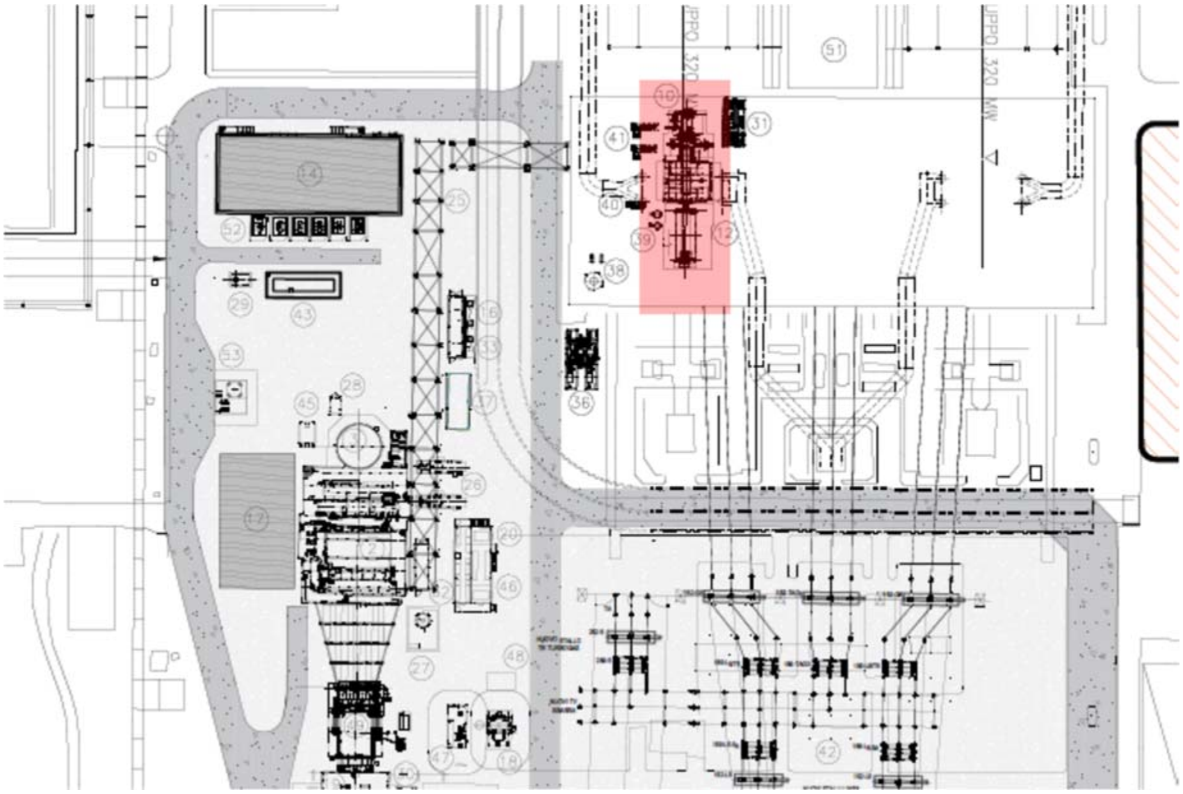


Figura 1 – Planimetria d'impianto – Ubicazione turbina a vapore

2 DOCUMENTI DI RIFERIMENTO

2.1 DOCUMENTI DI RIFERIMENTO

NORMATIVE

1 Decreto ministeriale 17 gennaio 2018 - AGGIORNAMENTO "Norme tecniche per le costruzioni".

2 Circolare 21 gennaio 2019, nr. 7 - "Istruzioni per l'applicazione dell'aggiornamento delle Norme tecniche per le costruzioni".

3 UNI EN 1992-1: Eurocodice 2 – Progettazione delle strutture di calcestruzzo - Parte 1-1: Regole generali e regole per gli edifici

RELAZIONI E SPECIFICHE TECNICHE

4	SFP-RTC-10004-CCGT-00	Relazione Sismica
5	SFP-RTC-10005-CCGT-00	Relazione Geotecnica

2.2 SOFTWARES

→ STAAD Pro

3 CARATTERISTICHE DEI MATERIALI

3.1 CALCESTRUZZO

Calcestruzzo gettato in opera per fondazione – C35/45

• resistenza caratteristica cilindrica	f_{ck} =	35	MPa
• resistenza caratteristica cubica	R_{ck} =	45	MPa
• resistenza media a compressione	f_{cm} =	43	MPa
• resistenza media a trazione	f_{ctm} =	3.20	MPa
• modulo di elasticità secante	E_{cm} =	34077	MPa

3.2 ACCIAIO

Acciaio per armatura strutture in c.a.

Barre ad aderenza migliorata, saldabile, tipo B450C dotato delle seguenti caratteristiche meccaniche:

• modulo elastico	E_s = 210000 MPa
• Tensione caratteristica di snervamento	f_{yk} = 450 MPa
• Tensione caratteristica di rottura	f_{tk} = 540 MPa

3.3 AZIONE DELLA NEVE

L'azione della neve sarà in accordo al D.M. 17/01/2018 - "Norme tecniche per le Costruzioni".

Per l'area di intervento si ha:

- q_{sk} = 0.6KN/m^2 (si veda Fig. 3.4.1 di [1])
- $C_e = 1$
- $C_t = 1$
- $\mu_1 = 0.8$
- q_s = 0.48 = KN/m^2

3.4 AZIONE DEL VENTO

L'azione del vento è in accordo al D.M. 17/01/2018 - "Norme tecniche per le Costruzioni". Per l'area di intervento si ha:

Considerando zona 4 (si veda Tab. 3.3.I di [1]):

- $v_{b,0}$ = 28 m/s
- a_0 = 500 m
- ks = 0.36

Essendo il sito situato a circa 89 m slm, la velocità base di riferimento sarà pari a:
$v_b = c_a\, v_{b,0}$ = 1 * 28 m/s= 28m/s.
La velocità di riferimento sarà pari a: vr = $v_b\, c_r$ = 28 * 1= 28m/s.

Considerando una categoria di esposizione II (si veda Tab. 3.3.II di [1]):

- kr = 0.19
- z0 = 0.05 m
- zmin = 4 m

Per tanto, la pressione del vento sarà data dalla seguente espressione:

$$p = q_r\, c_e\, c_p\, c_d$$

dove:

- qr = 490 N/m2

- Cd = 1
- Ct = 1
- Ce (z): coefficiente di esposizione.
- Cp: coeff. di pressione (si veda [2])

3.5 AZIONE SISMICA

In accordo al documento **Error! Reference source not found.** i parametri per l'azione sismica agli stati limite risultano:

Tabella 1 – Parametri azione sismica

STATO LIMITE	T_R (anni)	ag (g)	F_0 (-)	Tc* (sec)
SLO	30	0.053	2.415	0.277
SLD	50	0.066	2.423	0.301
SLV	476	0.159	2.527	0.374
SLC	976	0.201	2.567	0.404

3.5.1 Categoria di sottosuolo e condizioni topografiche

In accordo a quanto indicato nel documento **Error! Reference source not found.**, il sito è caratterizzato:

- **Categoria di sottosuolo C**: Depositi di terreni a grana grossa mediamente addensati o terreni a grana fina mediamente consistenti, a cui corrisponde un coefficiente d'amplificazione stratigrafica (S_S) pari a 1.50
- **Categoria topografica T1:** superficie pianeggiante, a cui corrisponde un coefficiente di amplificazione topografica (S_T) pari a 1.00.

---

4 FONDAZIONE TURBINA A VAPORE

4.1 DESCRIZIONE DEL PROGETTO E DEL MODELLO DI CALCOLO

La scelta progettuale adottata per la fondazione in esame consiste in una platea su pali di diametro 800 mm con interasse minimo pari a 3 diametri.

Per la determinazione delle sollecitazioni agenti sulla struttura in esame e lo svolgimento delle relative verifiche di resistenza si è fatto ricorso all'ausilio del programma di calcolo ad elementi finiti (F.E.M.) STAAD.Pro Advanced.

La platea di fondazione e l'impalcato sono modellati come elementi plate, mentre le travi e le colonne sono definiti come Beam element. I pali sono modellati come elementi monodimensionali (molle) caratterizzati da costanti di rigidezza che si sono ricavate dal documento **Error! Reference source not found.**.

In questa fase progettuale non vengono forniti i disegni, i dettagli e i carichi delle macchine, quindi sono stati considerati come dati di input (geometria e carichi) quelle derivanti da una turbina a vapore simile a quella utilizzata per progetti precedenti. Tali informazioni sono riportate nell'allegato A della presente relazione.

Le analisi strutturali sono state condotte assicurando che la frequenza della struttura non rientri nell'intervallo compreso tra 0.80÷1.20 volte la frequenza della macchina in accordo a quanto indicato al Par. 5.3.2 del Doc. **Error! Reference source not found.**. Di conseguenza è stata effettuata solo l'analisi della frequenza, visto che in questa fase non sono disponibili ulteriori dettagli sulle masse rotanti, grado di equilibrio e ampiezza ammissibile della deformazione.

In accordo a quanto definito nel documento **Error! Reference source not found.**, per la scelta progettuale adottata (palo D=800 mm, L=20 m), si riporta il riepilogo delle seguenti informazioni:

- Resistenza di progetto del singolo palo a compressione ($R_{c,d}$)/trazione ($R_{t,d}$) agli SLU - Tabella 2
- Rigidezza assiale del singolo palo (K_v) - Tabella 3;
- Resistenza di progetto del palo singolo ad azioni orizzontali ($R_{tr,d}$) - Tabella 4;
- Rigidezza orizzontale del singolo palo (K_h).

Tabella 2 – Riepilogo Capacità portanti a compressione/trazione agli SLU

		Approccio 2 (A1+M1+R3)		**Approccio 2 (A1+M1+R3)**	
D	**L_{palo}**	**Rd,compr ($R_{d,c}$)**	**Rd,traz ($R_{d,t}$)**	**Rd,comp - (Wp - Ws)**	**Rd,traz+ Wp**
(m)	**(m)**	**(kN)**	**(kN)**	**(kN)**	**(kN)**
0,8	20,0	3049,64	1596,67	2977,76	1873,13

Tabella 3 – Rigidezza assiale e massimo carico verticale di esercizio

D	**L**	**N_{SLE}**	**Kv**
[m]	**[m]**	**[kN]**	**[kN/mm]**
0,8	20	1600	200

Tabella 4 – Resistenza del palo ad azioni orizzontali agli SLU

D	**L**	**$R_{tr,d}$**
[m]	**[m]**	**[kN]**
0,8	20	203

Tabella 5 – Rigidezza orizzontale del palo

D	**L**	**H_{SLE}**	**Kh**
[m]	**[m]**	**[kN]**	**[kN/mm]**
0,8	20	142,50	18

4.2 MODELLO DI CALCOLO STRUTTURALE

Le dimensioni in pianta degli elementi plate che simulano la platea di fondazione e l'impalcato sono pari a 0.5 m x 0.5 m. Lo spessore della platea di fondazione è pari a 3 m mentre quello dell'impalcato è pari a 2.50 m.

La sezione tipica considerata per le travi perimetrali è di 2 m x 1m; mentre si distinguono due sezioni tipiche per le colonne esterne (2 m x 1,5 m) e per le colonne intermedie (2 m x 3,0 m). In Figura 2 si riporta la schematizzazione della struttura in esame sul programma di calcolo.

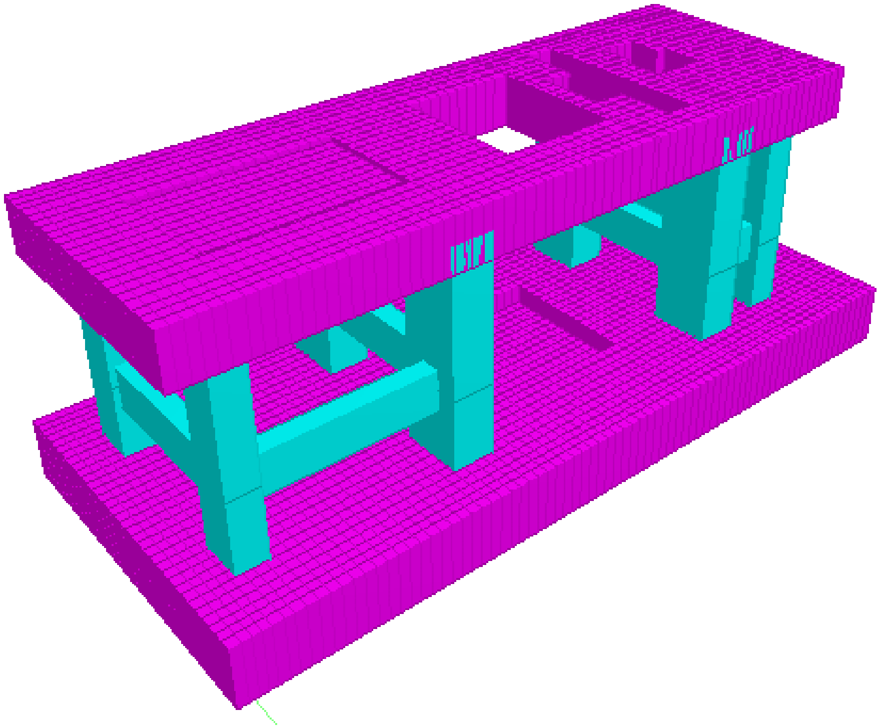


Figura 2 – Modello di calcolo 3D in STAAD

La fondazione in esame ospiterà, inoltre, i seguenti elementi d'impianto:

- Generatore turbina a vapore;
- HP turbine rotor (Turbina alta pressione);
- IP turbine rotor (Turbina pressione intermedia);
- LP turbine rotor (turbina bassa pressione).

Le caratteristiche geometriche della struttura di fondazione sono:

- Pali trivellati - Ø800mm – Lunghezza 20m;
- Platea di fondazione di dimensioni in pianta 18.40 m x 35.20 m e spessore di 3.0 m;
- Colonne e lastre per supporto dei vari componenti delle macchine.

4.3 VERIFICA DELL'ECCENTRICITÀ GEOMETRICA E DEL RAPPORTO DELLE MASSE

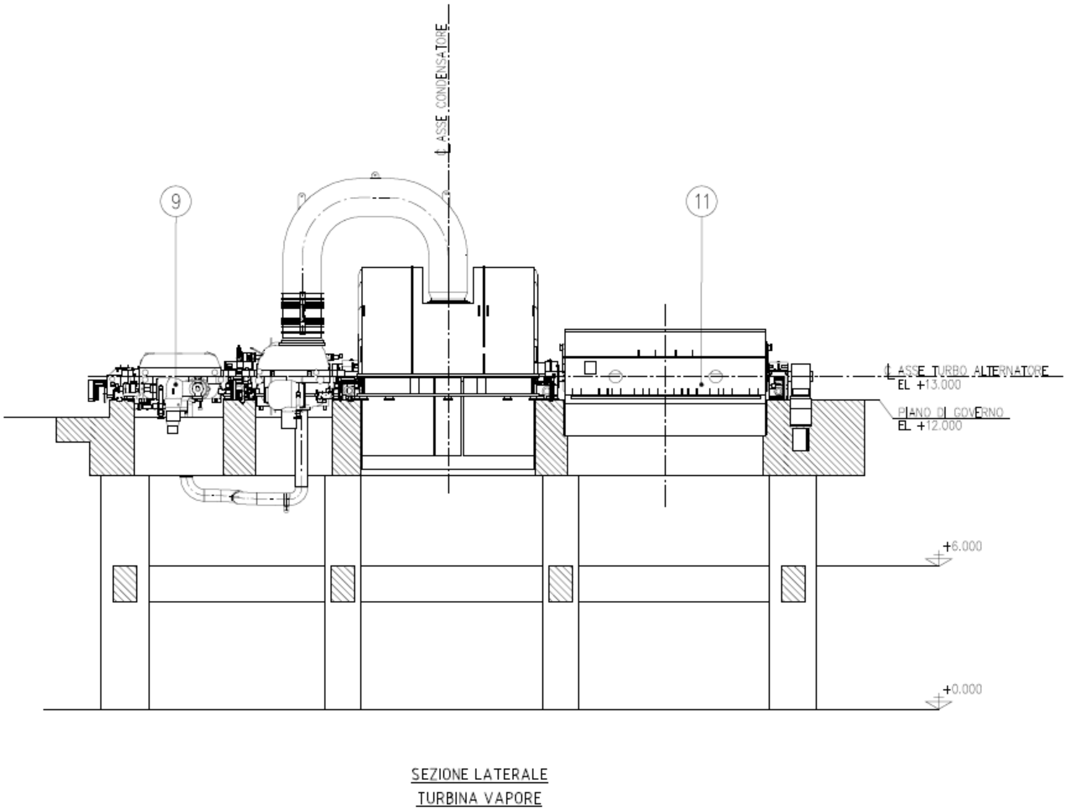


Figura 3 – Sezione laterale turbina a vapore

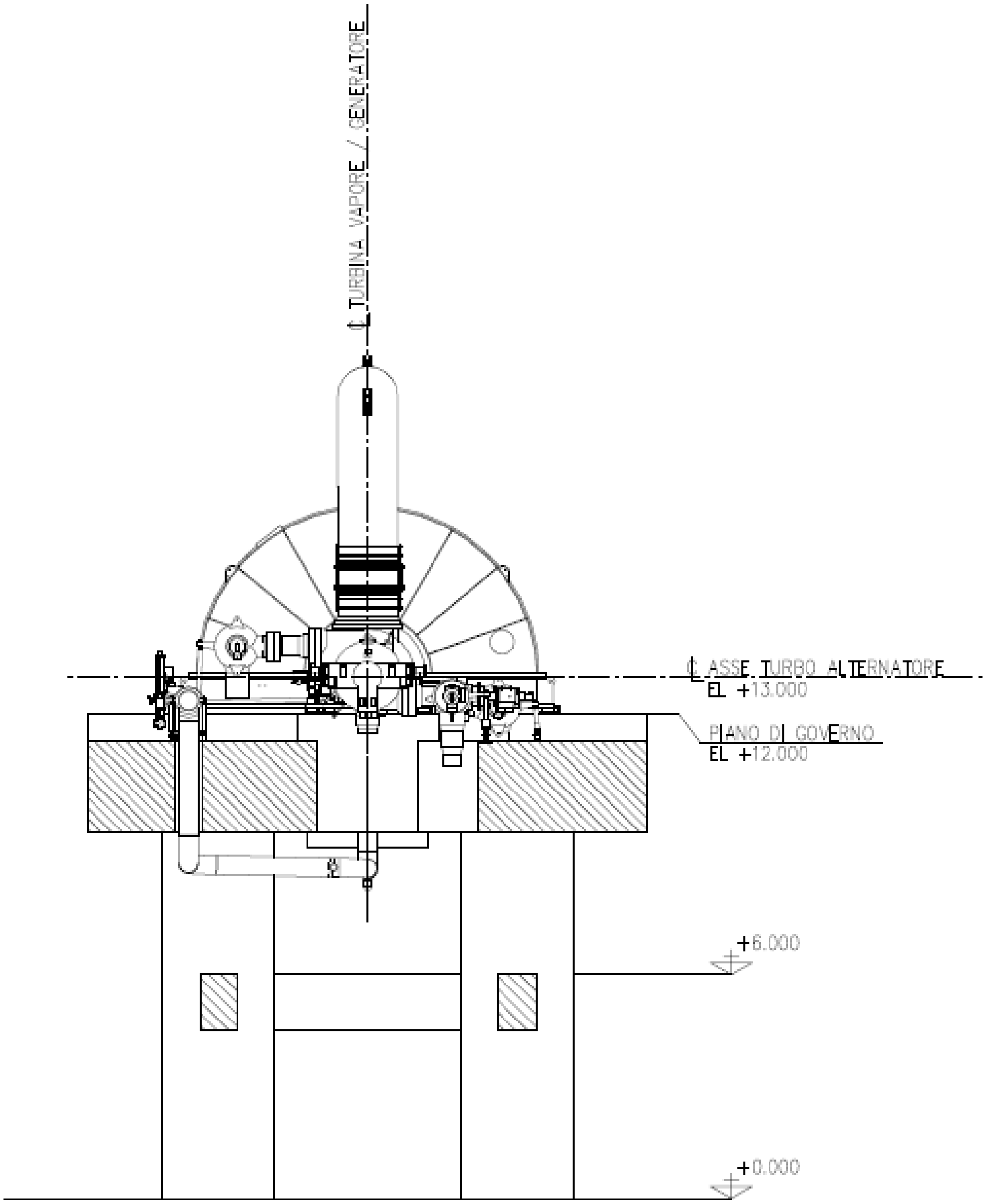


Figura 4 – Sezione frontale Turbina a vapore

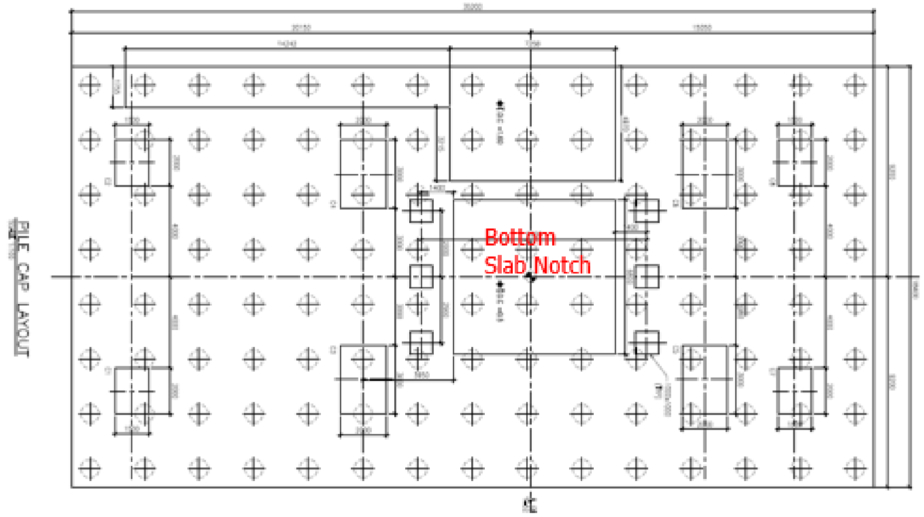


Figura 5 – Pianta pali fondazione Turbina a gas

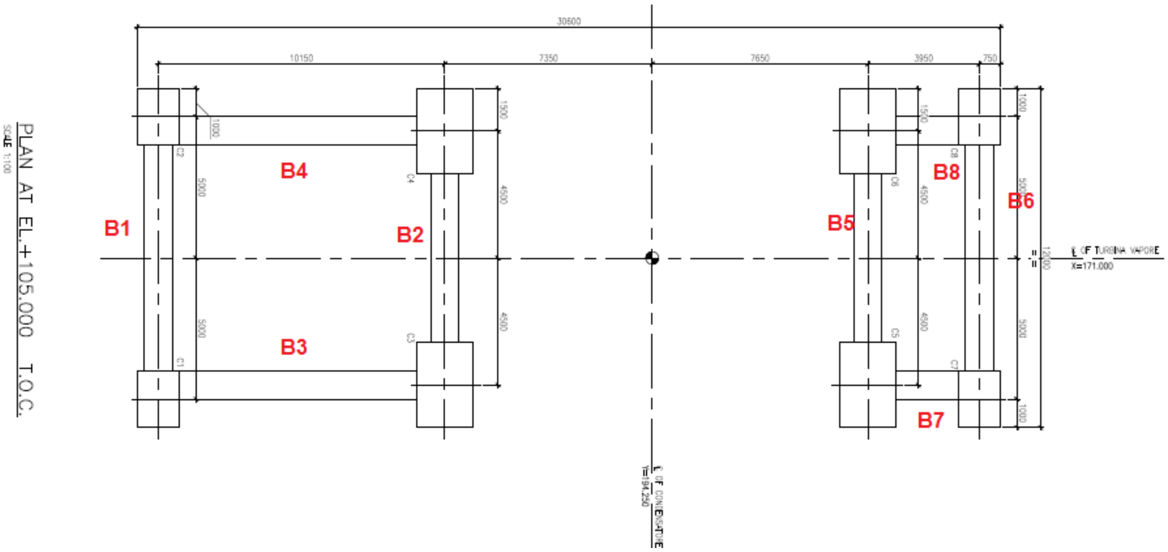


Figura 6 – Pianta elevazione +105.00 da T.O.C.

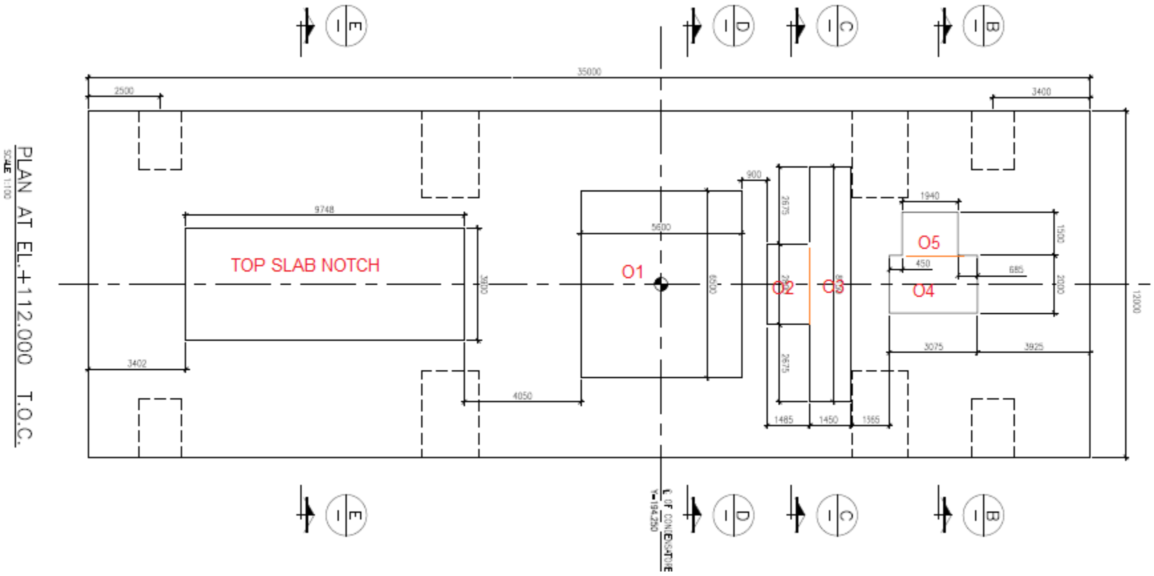


Figura 7 – Pianta elevazione +112 da T.O.C.

Tabella 6 – Riepilogo calcolo masse e momenti statici della struttura

Parameters :

Concrete Denstiy = 25 kN/m³
Origin = (0,0,0)

Evaluation :

Element	Element Name	Dimension			Weight	C. G. Co-			C. G. w.r.t to origin			Static Moment Of Mass		
No.		*Lx (m)*	*Ly*	*Lz*	*W (kN)*	*X*	*Y*	*Z*	*X (m)*	*Y (m)*	*Z (m)*	*kN-m*	*kN-m*	*kN-m*
1	Generator	-	-	-	3701.00	-	-	-	7.93	8.38	16.00	29330	30996	59216
2	LP Turbine	-	-	-	3352.00	-	-	-	19.65	8.38	16.00	65867	28073	53632
3	IP Turbine	-	-	-	951.00	-	-	-	24.85	8.38	16.00	23632	7965	15216
4	HP Turbine	-	-	-	715.00	-	-	-	29.19	8.38	16.00	20867	5988	11440
5	Foundation Slab	35.2	18.40	3.0	48576.00	-	-	-	17.60	9.20	1.50	854938	446899	72864
6	Foundation Slab Notch	7.1	6.80	1.9	-2293.30	-	-	-	20.15	8.38	2.05	-46210	-19206	-4701
7	C1	1.5	2.0	9.5	712.50	-	-	-	2.65	3.38	7.75	1888	2405	5522
8	C2	1.5	2.0	9.5	712.50	-	-	-	2.65	13.38	7.75	1888	9530	5522
9	C3	2.0	3.0	9.5	1425.00	-	-	-	12.80	3.88	7.75	18240	5522	11044
10	C4	2.0	3.0	9.5	1425.00	-	-	-	12.80	12.88	7.75	18240	18347	11044
11	C5	2.0	3.0	9.5	1425.00	-	-	-	27.80	3.88	7.75	39615	5522	11044
12	C6	2.0	3.0	9.5	1425.00	-	-	-	27.80	12.88	7.75	39615	18347	11044
13	C7	1.5	2.0	9.5	712.50	-	-	-	31.75	3.38	7.75	22622	2405	5522
14	C8	1.5	2.0	9.5	712.50	-	-	-	31.75	13.38	7.75	22622	9530	5522
15	B1	1.0	8.0	2.0	400.00	-	-	-	2.65	8.38	7.00	1060	3350	2800
16	B2	1.0	6.0	2.0	300.00	-	-	-	12.80	8.38	7.00	3840	2513	2100
17	B3	8.4	1.0	2.0	420.00	-	-	-	7.60	3.88	7.00	3192	1628	2940
18	B4	8.4	1.0	2.0	420.00	-	-	-	7.60	12.88	7.00	3192	5408	2940
19	B5	1.0	6.0	2.0	300.00	-	-	-	27.80	8.38	7.00	8340	2513	2100
20	B6	1.0	8.0	2.0	400.00	-	-	-	31.75	8.38	7.00	12700	3350	2800
21	B7	2.2	1.0	2.0	110.00	-	-	-	29.90	3.88	7.00	3289	426	770
22	B8	2.2	1.0	2.0	110.00	-	-	-	29.90	12.88	7.00	3289	1416	770
23	Top Slab	35.0	12.00	2.5	26250.00	-	-	-	17.65	8.38	13.75	463313	219844	360938
24	Top Slab Notch	9.75	3.90	1.0	-950.63	-	-	-	8.43	8.38	14.50	-8009	-7961	-13784
25	O1	5.6	6.50	2.5	-2275.00	-	-	-	20.15	8.38	13.75	-45841	-19053	-31281
26	O2	1.5	2.80	2.5	-262.50	-	-	-	24.60	8.38	13.75	-6458	-2198	-3609
27	O3	1.5	8.15	2.5	-764.06	-	-	-	26.10	8.38	13.75	-19942	-6399	-10506
28	O4	3.075	2.00	2.5	-384.38	-	-	-	29.70	8.38	13.75	-11416	-3219	-5285
29	O5	1.940	1.50	2.5	-181.88	-	-	-	29.57	10.13	13.75	-5378	-1842	-2501
	Summation				*87443.26*				-	-	-	*1518325.2*	*772093.3*	*585120.3*

Si riporta il calcolo dell'eccentricità lungo x, tramite la seguente espressione:

- Eccentricità in direzione X = 17.36 mm;
- Baricentro geometrico del palo in direzione X =17.60 mm

$$e_x := \frac{\Delta x}{\mathrm{Pilecap}_{\mathrm{length}}}$$

Eccentricity % = 0.67 %

La verifica risulta soddisfatta in quanto il limite dell'eccentricità in direzione X è del 3%, mentre quella in direzione Y è nulla.

Per il calcolo del rapporto delle masse si procede come segue:

$$\textbf{Rapporto delle masse} = \frac{\mathrm{W}_{\mathrm{fondazione}}}{\mathrm{W}_{\mathrm{macchina}}} = 9.03$$

La verifica del rapporto delle masse risulta soddisfatta in quanto deve essere garantita la seguente condizione:

$$\textbf{Rapporto delle masse} = \frac{\mathrm{W}_{\mathrm{fondazione}}}{\mathrm{W}_{\mathrm{macchina}}} = 9.03 > 3$$

4.4 PROPRIETÀ DINAMICHE DEL SUOLO E STIMA DEL MODULO DI TAGLIO DINAMICO (G')

I pali sono stati modellati come elementi monodimensionali (molle) dotati di costante di rigidezza, di seguito si riporta il calcolo di tali costanti.

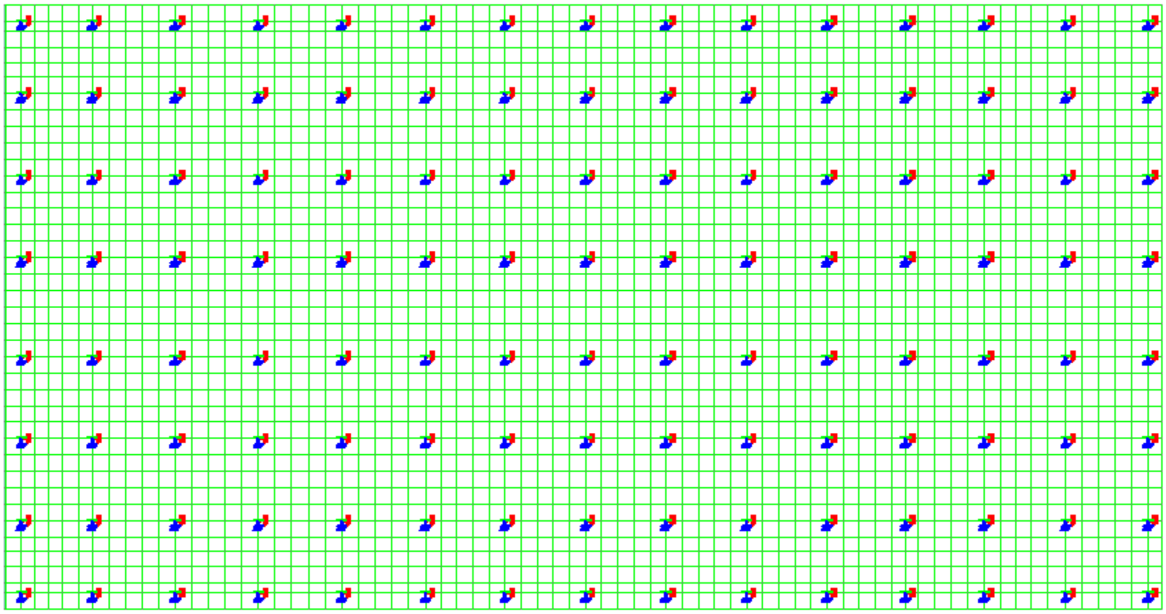


Figura 8 – Planimetria pali e platea di fondazione sul modello di calcolo STAAD

In Figura 9 è riportata la planimetria pianta fondazione, nella quale sono rappresentati il numero totale di pali (n=120) disposti secondo un interasse pari a 2.40 m.

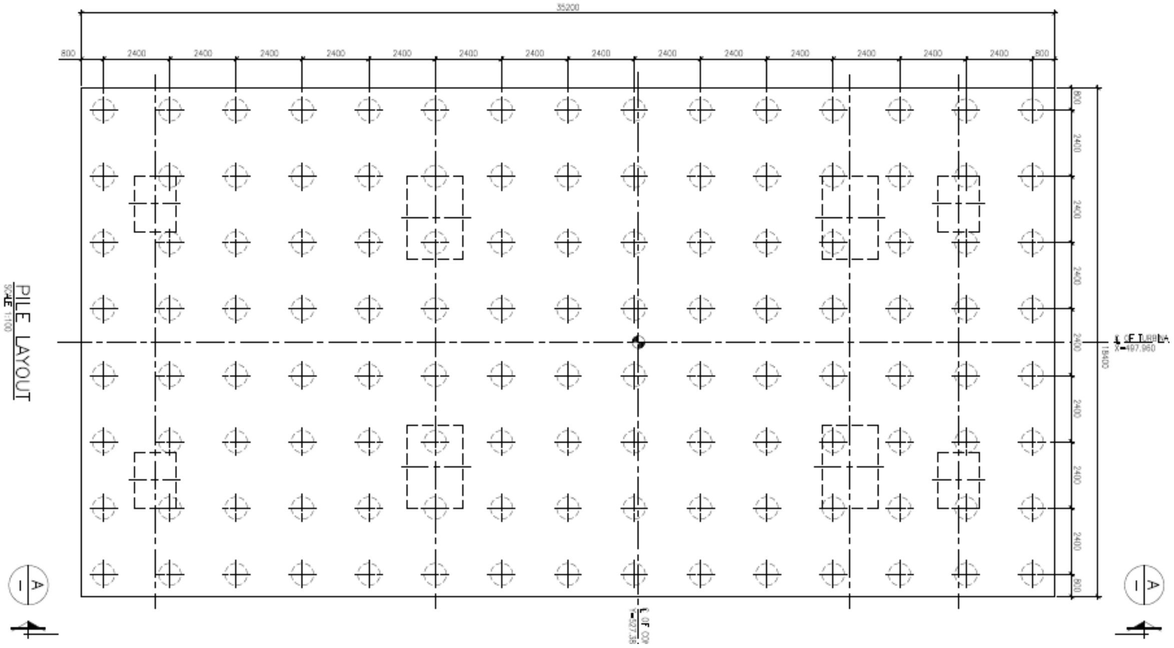
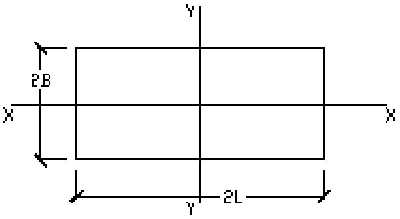


Figura 9 – Planimetria pianta pali

$\mathrm{Mpa} \equiv 10^{6}\mathrm{Pa}$ $\mathrm{kN} \equiv 10^{3}\mathrm{N}$ $\mathrm{rpm} \equiv \frac{\mathrm{Hz}}{60}$ $\mathrm{kNm} \equiv 10^{3}\mathrm{N}\cdot\mathrm{m}$ $\mathrm{Mg} := 10^{3}\cdot\mathrm{kgf}$

$\mathrm{Mg} = 9.807\cdot\mathrm{kN}$

Geometrical data:



Length of Pile cap $L := 17.6\mathrm{m}$ $2L = 35.2\,\mathrm{m}$

Width of Pile Cap $B := 9.2\mathrm{m}$ $2B = 18.4\,\mathrm{m}$ $\frac{L}{B} = 1.913$

Height of Foundation $h := 3\mathrm{m}$

Embedment into Soil $E := 3\mathrm{m}$ $E = 3\,\mathrm{m}$

Length of Pile $L_p := 20\mathrm{m}$ Bottom of Pile, $L_{p\_bot} := 18\mathrm{m}$

Size of Pile $D := 800\mathrm{mm}$

Density of Pile $\gamma_{Pile} := 25\frac{\mathrm{kN}}{\mathrm{m}^3}$ Poissons Ratio Pile $\mu_p := 0.15$

Soil properties:

Range of Depth:

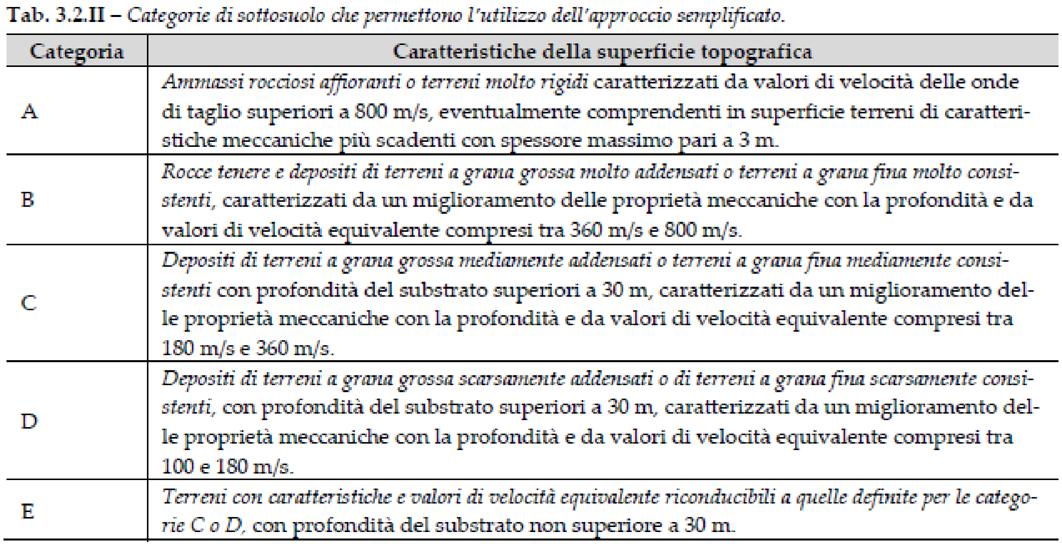
$z := 16\mathrm{m}$

Density of Soil along Depth:

$\gamma_{soil} := 1.8\cdot\frac{\mathrm{Mg}}{\mathrm{m}^3}$

In accordo a quanto indicato nel documento **Error! Reference source not found.**, la categoria di sottosuolo per il sito in esame è **C**, a cui corrisponde un valore di velocità equivalente di propagazione delle onde di taglio ($V_{S,eq}$) compreso tra 180m/s e 360 m/s, come indicato in Tabella 7. Per il case in esame si considera un valore di velocità equivalente $V_{S,eq}$=200 m/s.

Tabella 7 – Categoria di sottosuolo secondo la NTC18



Tab. 3.2.II – *Categorie di sottosuolo che permettono l'utilizzo dell'approccio semplificato.*

Categoria	Caratteristiche della superficie topografica
A	*Ammassi rocciosi affioranti o terreni molto rigidi* caratterizzati da valori di velocità delle onde di taglio superiori a 800 m/s, eventualmente comprendenti in superficie terreni di caratteristiche meccaniche più scadenti con spessore massimo pari a 3 m.
B	*Rocce tenere e depositi di terreni a grana grossa molto addensati o terreni a grana fina molto consistenti,* caratterizzati da un miglioramento delle proprietà meccaniche con la profondità e da valori di velocità equivalente compresi tra 360 m/s e 800 m/s.
C	*Depositi di terreni a grana grossa mediamente addensati o terreni a grana fina mediamente consistenti* con profondità del substrato superiori a 30 m, caratterizzati da un miglioramento delle proprietà meccaniche con la profondità e da valori di velocità equivalente compresi tra 180 m/s e 360 m/s.
D	*Depositi di terreni a grana grossa scarsamente addensati o di terreni a grana fina scarsamente consistenti,* con profondità del substrato superiori a 30 m, caratterizzati da un miglioramento delle proprietà meccaniche con la profondità e da valori di velocità equivalente compresi tra 100 e 180 m/s.
E	*Terreni con caratteristiche e valori di velocità equivalente riconducibili a quelle definite per le categorie C o D,* con profondità del substrato non superiore a 30 m.

Shear wave velocity of Soil: $v_s := 200 \cdot \frac{m}{s}$ For Soil type C

$G_z := \frac{\gamma_{soil}}{g} \cdot (v_s)^2$ $G_z = 72 \cdot MPa$

$G_d := G_z$ $G_d = 72 \cdot MPa$ Most expected value of Shear modulus of the soil in dynamic conditions

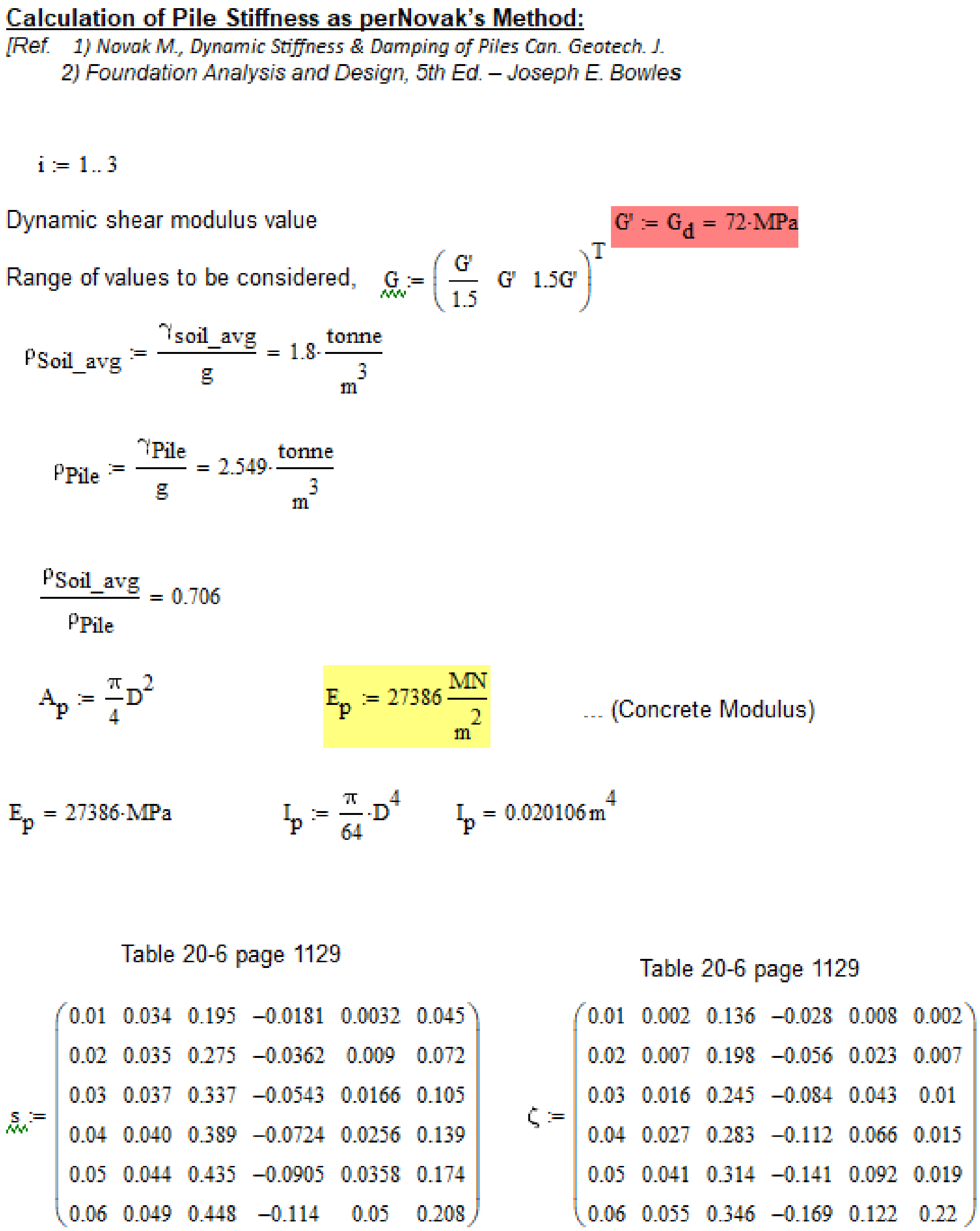
Average value of soil density and Poisson's Ratio over the study range considering depth of Pile at 20m:

$\mu_{soil} := 0.3$ ... assumed

$\gamma_{soil\_avg} := \gamma_{soil}$ $\gamma_{soil\_avg} = 17.7 \cdot \frac{kN}{m^3}$

$\mu_{soil\_avg} := \mu_{soil}$ $\mu_{soil\_avg} = 0.3$

Si riporta il calcolo della rigidezza del singolo palo secondo i metodi indicati nell'allegato D.



Calculation of Pile Stiffness as perNovak's Method:

[Ref. 1) Novak M., Dynamic Stiffness & Damping of Piles Can. Geotech. J.

2) Foundation Analysis and Design, 5th Ed. – Joseph E. Bowles

$i := 1..3$

Dynamic shear modulus value $G' := G_d = 72\cdot\text{MPa}$

Range of values to be considered, $G := \begin{pmatrix} \frac{G'}{1.5} & G' & 1.5G' \end{pmatrix}^T$

$$\rho_{Soil\_avg} := \frac{\gamma_{soil\_avg}}{g} = 1.8\cdot\frac{\text{tonne}}{m^3}$$

$$\rho_{Pile} := \frac{\gamma_{Pile}}{g} = 2.549\cdot\frac{\text{tonne}}{m^3}$$

$$\frac{\rho_{Soil\_avg}}{\rho_{Pile}} = 0.706$$

$A_p := \frac{\pi}{4}D^2$ $\qquad E_p := 27386\frac{MN}{m^2}$ ... (Concrete Modulus)

$E_p = 27386\cdot\text{MPa}$ $\qquad I_p := \frac{\pi}{64}\cdot D^4$ $\qquad I_p = 0.020106\,m^4$

Table 20-6 page 1129

$$s := \begin{pmatrix} 0.01 & 0.034 & 0.195 & -0.0181 & 0.0032 & 0.045 \\ 0.02 & 0.035 & 0.275 & -0.0362 & 0.009 & 0.072 \\ 0.03 & 0.037 & 0.337 & -0.0543 & 0.0166 & 0.105 \\ 0.04 & 0.040 & 0.389 & -0.0724 & 0.0256 & 0.139 \\ 0.05 & 0.044 & 0.435 & -0.0905 & 0.0358 & 0.174 \\ 0.06 & 0.049 & 0.448 & -0.114 & 0.05 & 0.208 \end{pmatrix}$$

Table 20-6 page 1129

$$\zeta := \begin{pmatrix} 0.01 & 0.002 & 0.136 & -0.028 & 0.008 & 0.002 \\ 0.02 & 0.007 & 0.198 & -0.056 & 0.023 & 0.007 \\ 0.03 & 0.016 & 0.245 & -0.084 & 0.043 & 0.01 \\ 0.04 & 0.027 & 0.283 & -0.112 & 0.066 & 0.015 \\ 0.05 & 0.041 & 0.314 & -0.141 & 0.092 & 0.019 \\ 0.06 & 0.055 & 0.346 & -0.169 & 0.122 & 0.22 \end{pmatrix}$$

Effective Radius of Pile

$r_0 := \sqrt{\frac{A_p}{\pi}} = 0.4\,m$

$\frac{L_p}{r_0} = 37.5$

$$Check_1 := \begin{cases} \text{"OK"} & \text{if } \frac{L_p}{r_0} > 30 \\ \text{"Revise"} & \text{otherwise} \end{cases}$$

$Check_1 = \text{"OK"}$

$V_{s_i} := \sqrt{\frac{G_i}{\rho_{Soil\_avg}}}$

$$V_s = \begin{pmatrix} 163.299 \\ 200 \\ 244.949 \end{pmatrix} \frac{m}{s}$$

$V_p := \sqrt{\frac{E_p}{\rho_{Pile}}}$

$V_p = 3277.59\,\frac{m}{s}$

$I_{xx} := I_p = 0.02011\,m^4$

$I_{yy} := I_p = 0.02\,m^4$

$Ra_i := \left(\frac{V_{s_i}}{V_p}\right)$

$$Ra = \begin{pmatrix} 0.049823 \\ 0.06102 \\ 0.074734 \end{pmatrix}$$

$J := I_{xx} + I_{xx} = 0.04\,m^4$

Machine Parameters:

Operating speed of the machine, $f_o := 3000\text{rpm}$ $\quad f_o = 50\cdot\text{Hz}$

Circular frequency, $\omega_o := f_o\cdot 2\cdot\pi = 314.159\cdot\frac{\text{rad}}{\text{sec}}$

The dimensionless frequency parameter for rectangular base, $a_{0_i} := \left(\frac{\omega_o\cdot r_0}{V_{s_i}}\right)$

$$a_0 = \begin{pmatrix} 0.77 \\ 0.628 \\ 0.513 \end{pmatrix}$$

Comment: a_0 should be ranged between 0 and 1.5. For a_0 to exceed 1.5, one would have a very high speed machine and /or a small ground shear wave velocity. In these cases, some kind of soil strengthening or the use of piles may be necessary if vibration control is critical.

Vertical Springs

$$K_{z_i} := \frac{E_p\cdot A_p}{r_0}\cdot\text{linterp}\left(s^{\langle 1\rangle}, s^{\langle 2\rangle}, Ra_i\right)$$

$$K_z = \begin{pmatrix} 1511.791 \\ 1703.858 \\ 1939.837 \end{pmatrix}\frac{1}{m}\cdot\text{MN}$$

$$c_{z_i} := \frac{E_p\cdot A_p}{V_{s_i}}\cdot\text{linterp}\left(\zeta^{\langle 1\rangle}, \zeta^{\langle 2\rangle}, Ra_i\right)$$

$$c_z = \begin{pmatrix} 3.435 \\ 3.884 \\ 4.25 \end{pmatrix} s\cdot\frac{\text{MN}}{m}$$

Horizontal Springs

$$K_{h_i} := \frac{E_p \cdot I_p}{\left(r_0\right)^3} \cdot \mathrm{linterp}\left(s^{\langle 1\rangle}, s^{\langle 5\rangle}, Ra_i\right)$$

$$K_h = \begin{pmatrix} 306.454 \\ 442.645 \\ 610.19 \end{pmatrix} \frac{1}{m} \cdot MN$$

$$c_{h_i} := \frac{E_p \cdot I_p}{V_{s_i} \cdot r_0^{\,2}} \cdot \mathrm{linterp}\left(\zeta^{\langle 1\rangle}, \zeta^{\langle 5\rangle}, Ra_i\right)$$

$$c_h = \begin{pmatrix} 1.929 \\ 2.152 \\ 2.335 \end{pmatrix} \frac{s}{m} \cdot MN$$

Rocking

$$K_{\theta_i} := \left(\frac{E_p \cdot I_p}{r_0} \cdot \frac{1}{rad}\right) \cdot \mathrm{linterp}\left(s^{\langle 1\rangle}, s^{\langle 3\rangle}, Ra_i\right)$$

$$K_\theta = \begin{pmatrix} 597.687 \\ 618.53 \\ 643.072 \end{pmatrix} \cdot MN \cdot \frac{m}{rad}$$

$$c_{\theta_i} := \frac{E_p \cdot I_{xx}}{V_{s_i}} \cdot \mathrm{linterp}\left(\zeta^{\langle 1\rangle}, \zeta^{\langle 3\rangle}, Ra_i\right)$$

$$c_\theta = \begin{pmatrix} 1.057 \\ 0.962 \\ 0.884 \end{pmatrix} s \cdot m \cdot MN$$

Torsion

$$G_p := \frac{E_p}{2\left(1+\mu_p\right)} = 1.191 \times 10^{4} \cdot \mathrm{MPa}$$

$$K_{t_i} := \left(\frac{G_p \cdot J}{r_0}\right) \cdot \mathrm{linterp}\left(s^{\langle 1 \rangle}, s^{\langle 6 \rangle}, Ra_i\right)$$

$$K_t = \begin{pmatrix} 207.539 \\ 253.133 \\ 308.947 \end{pmatrix} \mathrm{m} \cdot \mathrm{MN}$$

$$C_{t_i} := \left(\frac{G_p \cdot J}{V_{s_i}}\right) \cdot \mathrm{linterp}\left(\zeta^{\langle 1 \rangle}, \zeta^{\langle 6 \rangle}, Ra_i\right)$$

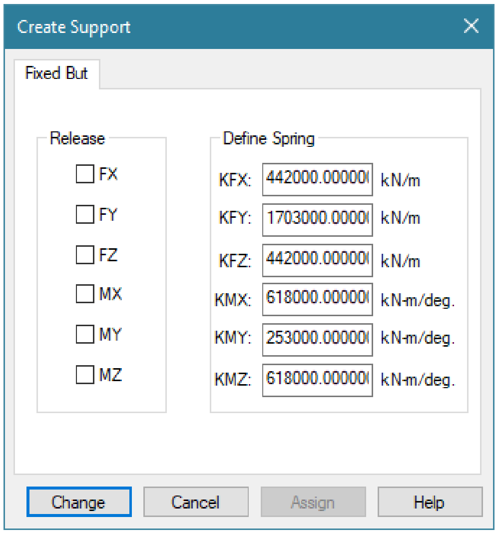
$$C_t = \begin{pmatrix} 0.0555 \\ 0.57579 \\ 1.00896 \end{pmatrix} \mathrm{s} \cdot \mathrm{m} \cdot \mathrm{MN}$$

Cross Stiffness

$$K_{x\theta_i} := \left(\frac{E_p \cdot I_p}{r_0^{\,2}}\right) \cdot \mathrm{linterp}\left(s^{\langle 1 \rangle}, s^{\langle 4 \rangle}, Ra_i\right)$$

$$K_{x\theta} = \begin{pmatrix} -310.346 \\ -400.575 \\ -511.485 \end{pmatrix} \cdot \mathrm{MN}$$

$$C_{x\theta_i} := \left[\frac{E_p \cdot I_p}{\left(r_0 \cdot V_s\right)_i}\right] \cdot \mathrm{linterp}\left(\zeta^{\langle 1 \rangle}, \zeta^{\langle 4 \rangle}, Ra_i\right)$$



Release

☐ FX
☐ FY
☐ FZ
☐ MX
☐ MY
☐ MZ

Define Spring

KFX: 442000.00000 kN/m
KFY: 1703000.0000 kN/m
KFZ: 442000.00000 kN/m
KMX: 618000.00000 kN-m/deg.
KMY: 253000.00000 kN-m/deg.
KMZ: 618000.00000 kN-m/deg.

4.5 ANALISI STATICA

Scopo dell'analisi è quello di verificare le reazioni sui pali e le sollecitazioni a cui è sottoposta la fondazione sotto diverse combinazioni di carico secondo gli stati limite ultimi (SLU) e le condizioni accidentali, in accordo a quanto indicato nel Doc. **Error! Reference source not found.**. Le deformazioni della fondazione sono verificate e controllate sotto diverse combinazioni di carico secondo gli stati limite di esercizio (SLE) in accordo al Doc. **Error! Reference source not found.**.

4.6 ANALISI DINAMICA

Scopo dell'analisi è quello di determinare la frequenza della struttura e confrontarla con la frequenza della macchina. L'analisi delle vibrazioni forzate e il controllo dell'ampiezza dovranno essere eseguiti nelle fasi di progettazione successive e quando saranno disponibili i dati del fornitore.

5 CARICHI CARATTERISTICI E COMBINAZIONI DI CARICO

5.1 CARICHI CARATTERISTICI

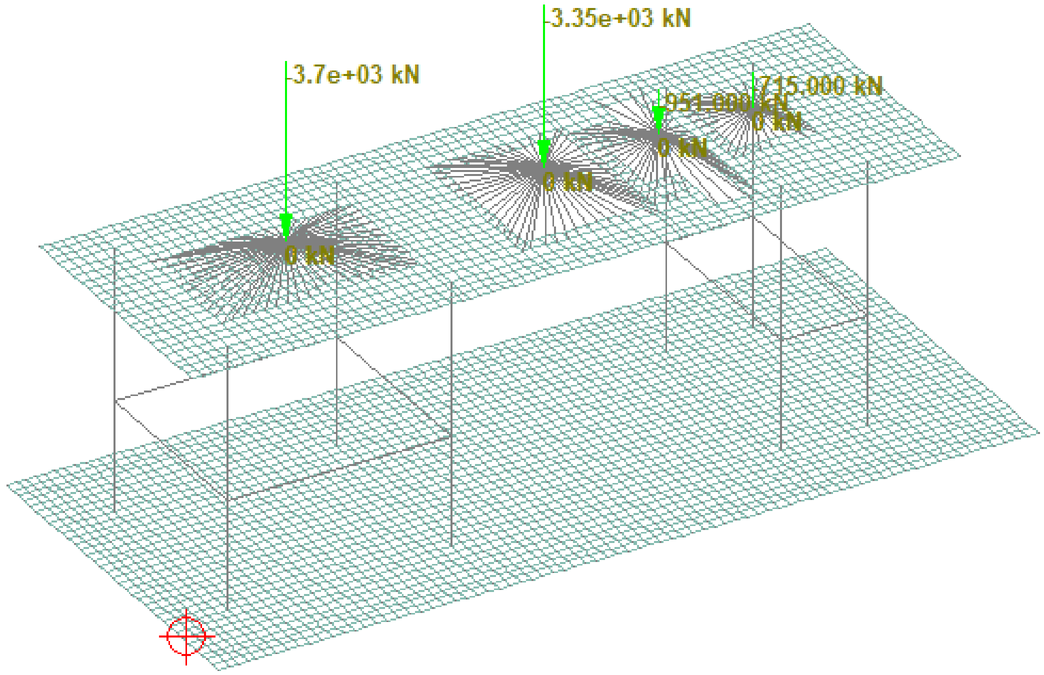
5.1.1 CARICHI PERMANENTI

Sono inclusi:

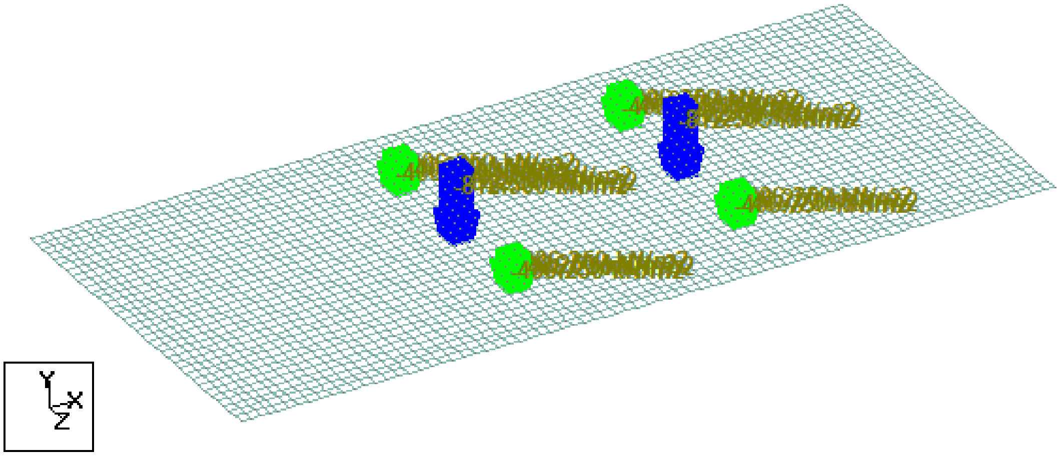
- Peso proprio Fondazione.

5.1.2 C ARICHI PERMANENTI DA VENDOR

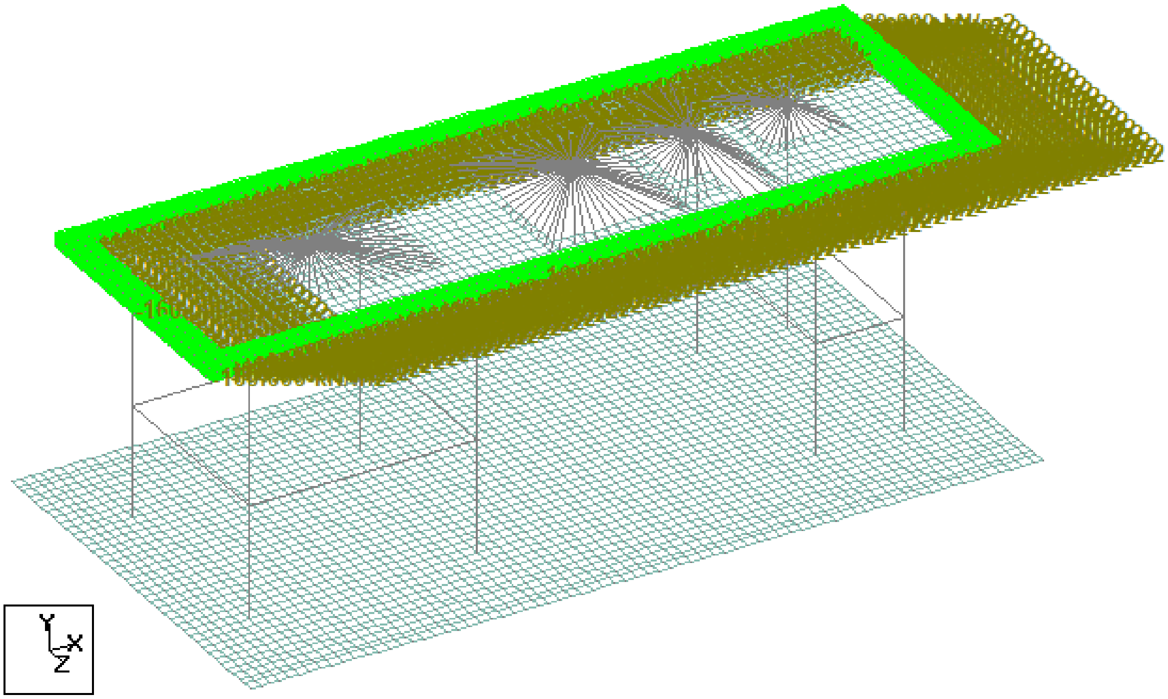
I carichi statici dati dal Vendor sono stati sommati e applicati nei CG dei diversi componenti della macchina.



Carichi macchina



Carichi Condensatore

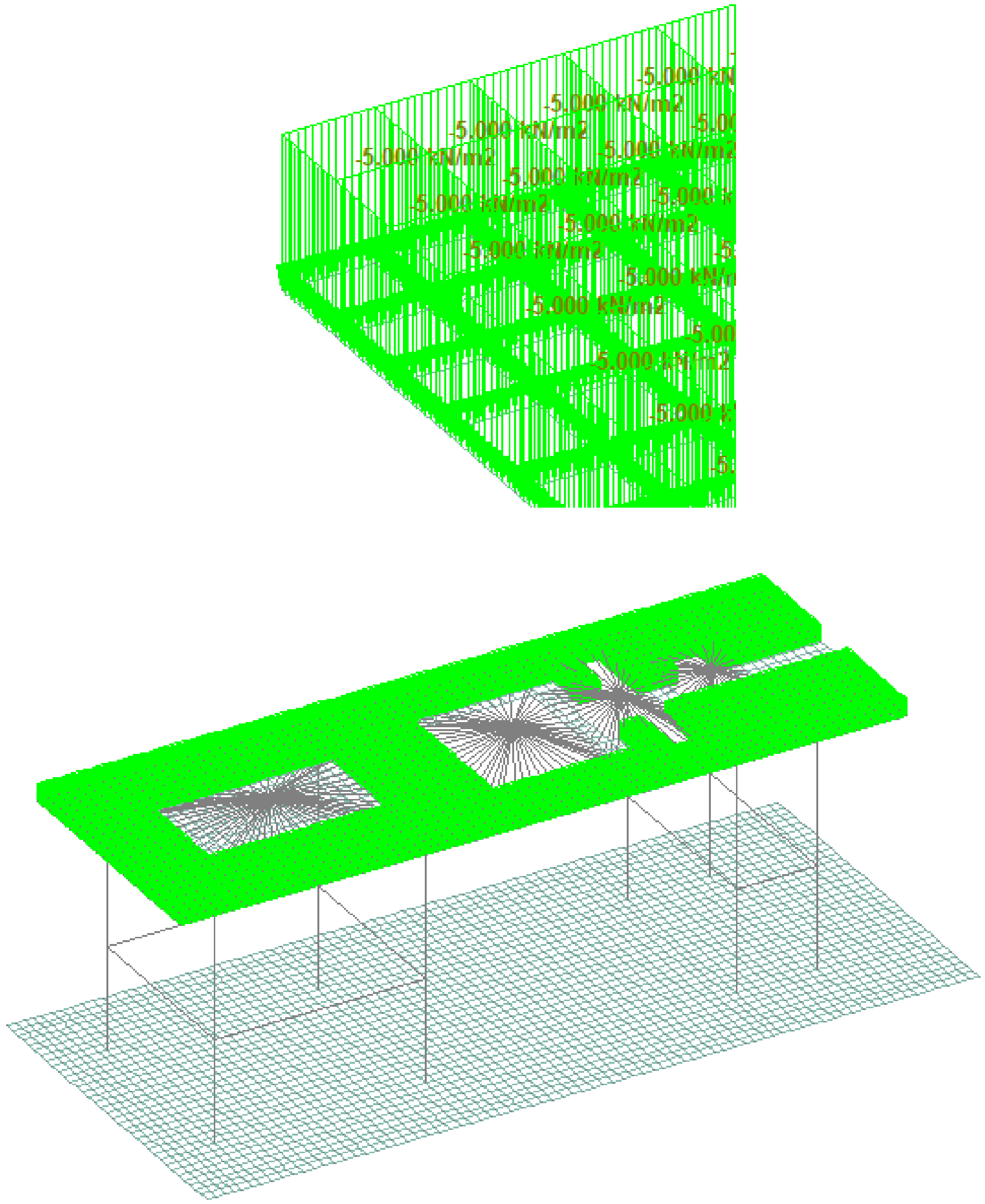


Peso proprio cabinato esterno

5.1.3 C ARICHI VARIABILI

Sono inclusi:

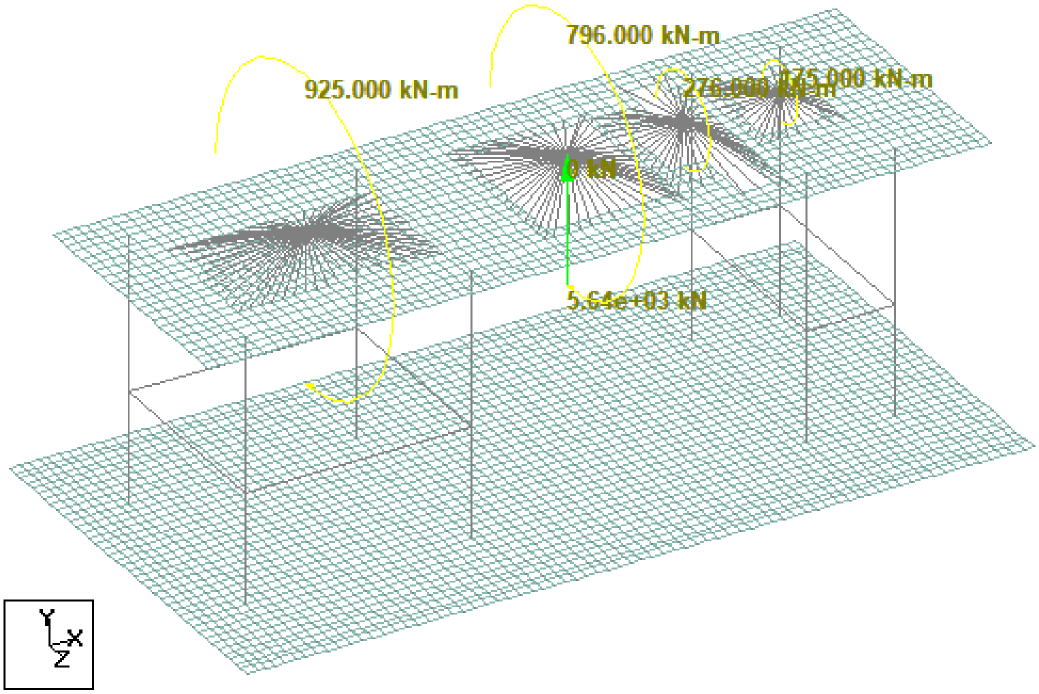
- Sovraccaricho di 5kN/m^2 applicato sull'estradosso della fondazione.



Carico variabile

5.1.4 CARICHI OPERATIVI

- Torque Load, come da dati del Vendor (si veda Allegato A).



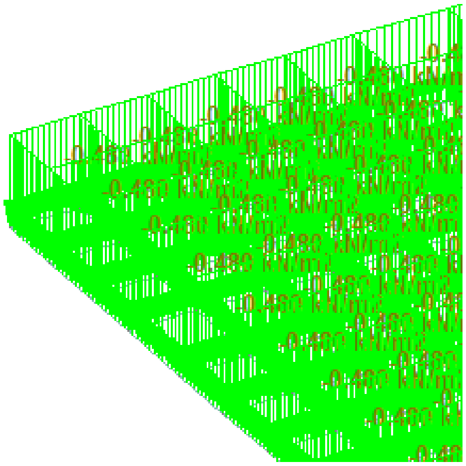
Torque Load

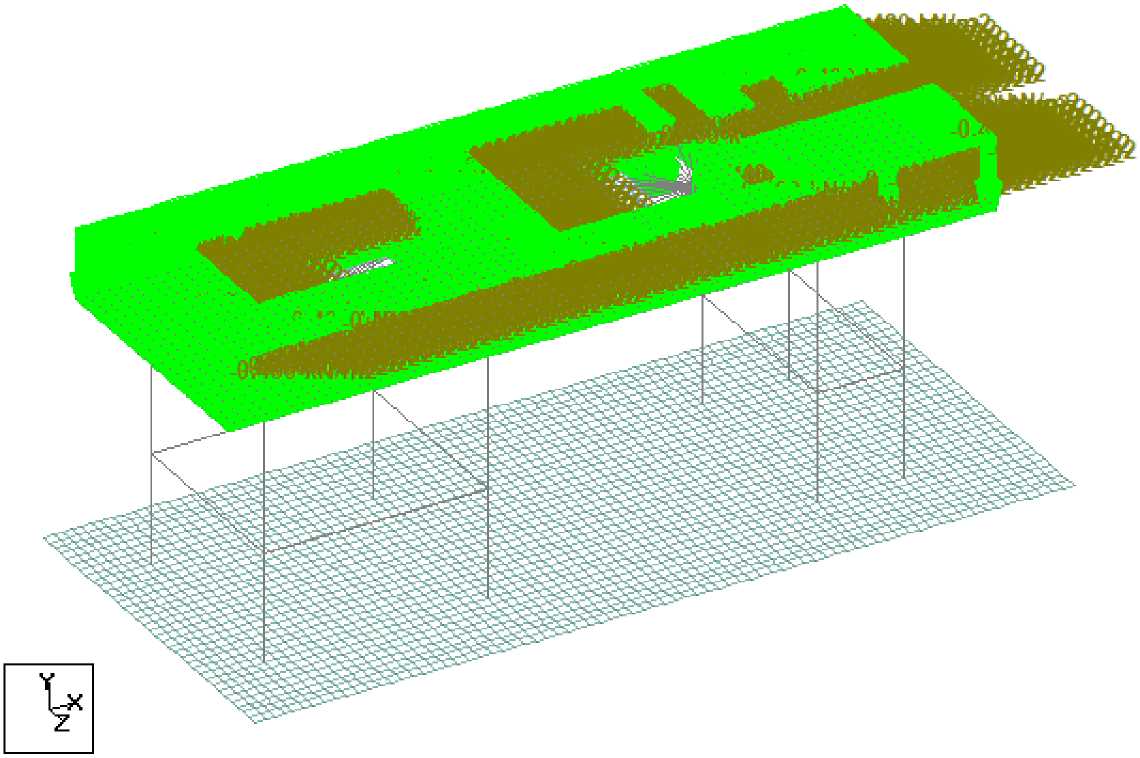
5.1.5 AZIONE DEL VENTO, X E Z

Dal momento che la massa della struttura è molto alta e che la sua altezza rimane esigua, tali forze non sono governanti al fine della progettazione.

5.1.6 AZIONE DA NEVE

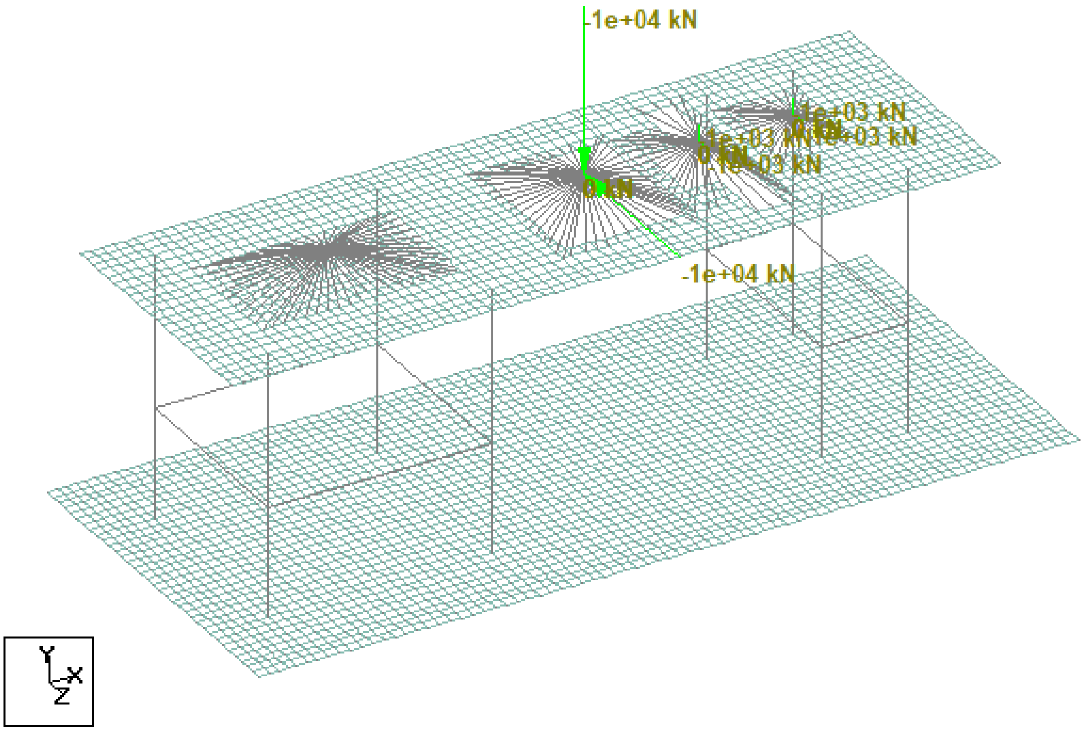
- Azione di 0.48kN/m2 applicato sull'estradosso della fondazione.





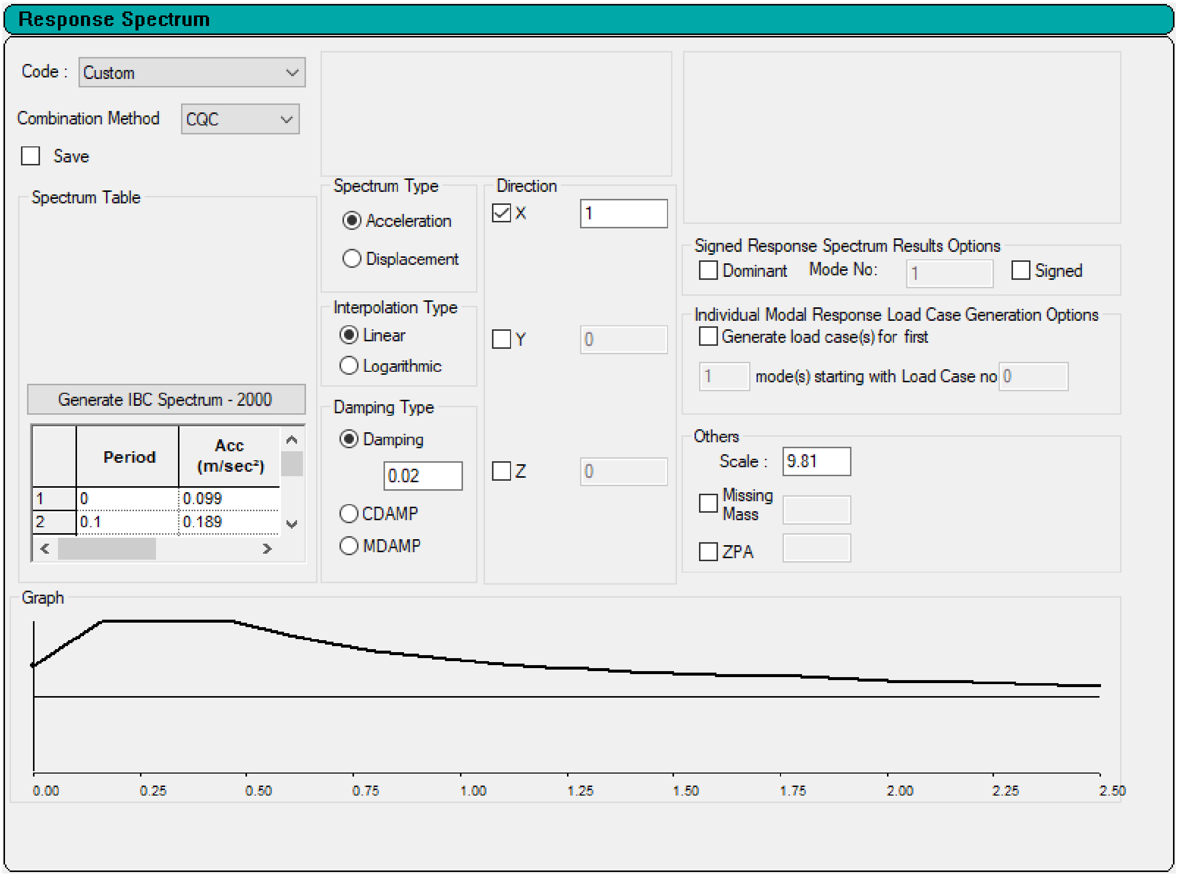
Azione da neve

5.1.7 BLADE RUPTURE



5.1.8 AZIONE SISMICA (E)

SLD



Response Spectrum

Code : Custom

Combination Method CQC

☐ Save

Spectrum Table

	Period	Acc (m/sec²)
1	0	0.099
2	0.1	0.189

Spectrum Type

● Acceleration
○ Displacement

Interpolation Type

● Linear
○ Logarithmic

Damping Type

● Damping 0.02
○ CDAMP
○ MDAMP

Direction

☑ X 1
☐ Y 0
☐ Z 0

Signed Response Spectrum Results Options

☐ Dominant Mode No: 1 ☐ Signed

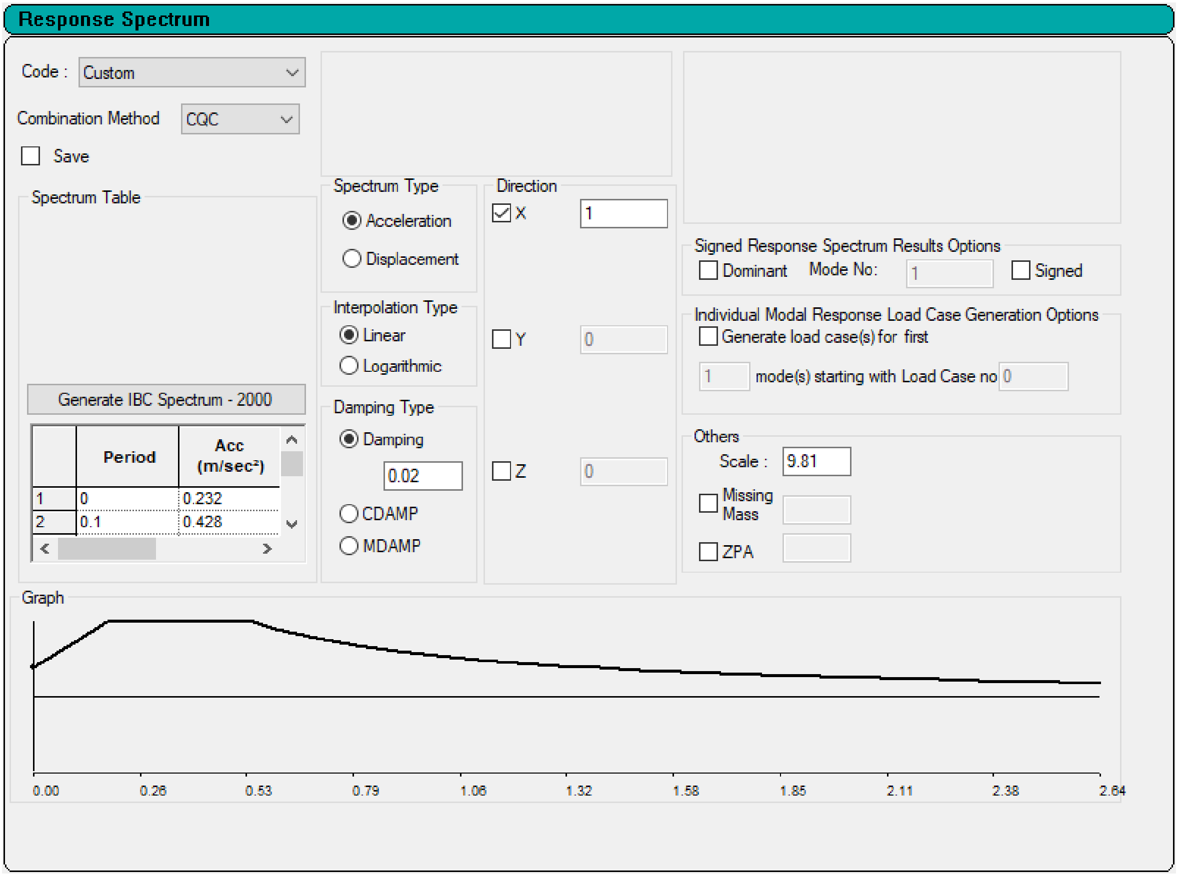
Individual Modal Response Load Case Generation Options

☐ Generate load case(s) for first 1 mode(s) starting with Load Case no 0

Others

Scale : 9.81
☐ Missing Mass
☐ ZPA

SLV



Response Spectrum

Code : Custom

Combination Method CQC

☐ Save

Spectrum Table

Generate IBC Spectrum - 2000

	Period	Acc (m/sec²)
1	0	0.232
2	0.1	0.428

Spectrum Type
- ● Acceleration
- ○ Displacement

Interpolation Type
- ● Linear
- ○ Logarithmic

Damping Type
- ● Damping 0.02
- ○ CDAMP
- ○ MDAMP

Direction
- ☑ X 1
- ☐ Y 0
- ☐ Z 0

Signed Response Spectrum Results Options
☐ Dominant Mode No: 1 ☐ Signed

Individual Modal Response Load Case Generation Options
☐ Generate load case(s) for first
1 mode(s) starting with Load Case no 0

Others
Scale : 9.81
☐ Missing Mass
☐ ZPA

Graph

5.2 CASI DI CARICO

LOAD 1 LOADTYPE Dead TITLE DEAD_STRUCTURE

LOAD 2 LOADTYPE Dead TITLE DEAD_VENDOR

LOAD 3 LOADTYPE Live TITLE LIVE_LOAD

LOAD 4 LOADTYPE None TITLE OPERATING_LOAD_GEN

LOAD 5 LOADTYPE Wind TITLE WIND_X

LOAD 6 LOADTYPE Wind TITLE WIND_Z

LOAD 7 LOADTYPE Temperature TITLE TEMPERATURE_+

LOAD 8 LOADTYPE Temperature TITLE TEMPERATURE_-

LOAD 9 LOADTYPE Snow TITLE SNOW_LOAD

LOAD 10 LOADTYPE None TITLE EMERGENCY_LOAD

LOAD 11 LOADTYPE None TITLE UNBALANCED_HP VER

LOAD 12 LOADTYPE None TITLE UNBALANCED_HP HOR

LOAD 13 LOADTYPE None TITLE UNBALANCED_GEN VER

LOAD 14 LOADTYPE None TITLE UNBALANCED_GEN HOR

LOAD 15 LOADTYPE Dead TITLE EARTHQUAKE_X VENDOR

LOAD 16 LOADTYPE Dead TITLE EARTHQUAKE_Z VENDOR

LOAD 17 LOADTYPE Dead TITLE EARTHQUAKE_Y VENDOR

LOAD 18 LOADTYPE None TITLE EARTHQUAKE_X SLD

LOAD 19 LOADTYPE None TITLE EARTHQUAKE_Z SLD

LOAD 20 LOADTYPE None TITLE EARTHQUAKE_X SLV

LOAD 21 LOADTYPE None TITLE EARTHQUAKE_Z SLV

LOAD 22 LOADTYPE None TITLE BLADE_RUPTURE

LOAD 23 LOADTYPE None TITLE SHORT_CIRCUIT

LOAD 24 LOADTYPE None TITLE UNBALANCED_IP VER

LOAD 25 LOADTYPE None TITLE UNBALANCED_IP HOR

LOAD 26 LOADTYPE None TITLE UNBALANCED_LP VER

LOAD 27 LOADTYPE None TITLE UNBALANCED_LP HOR

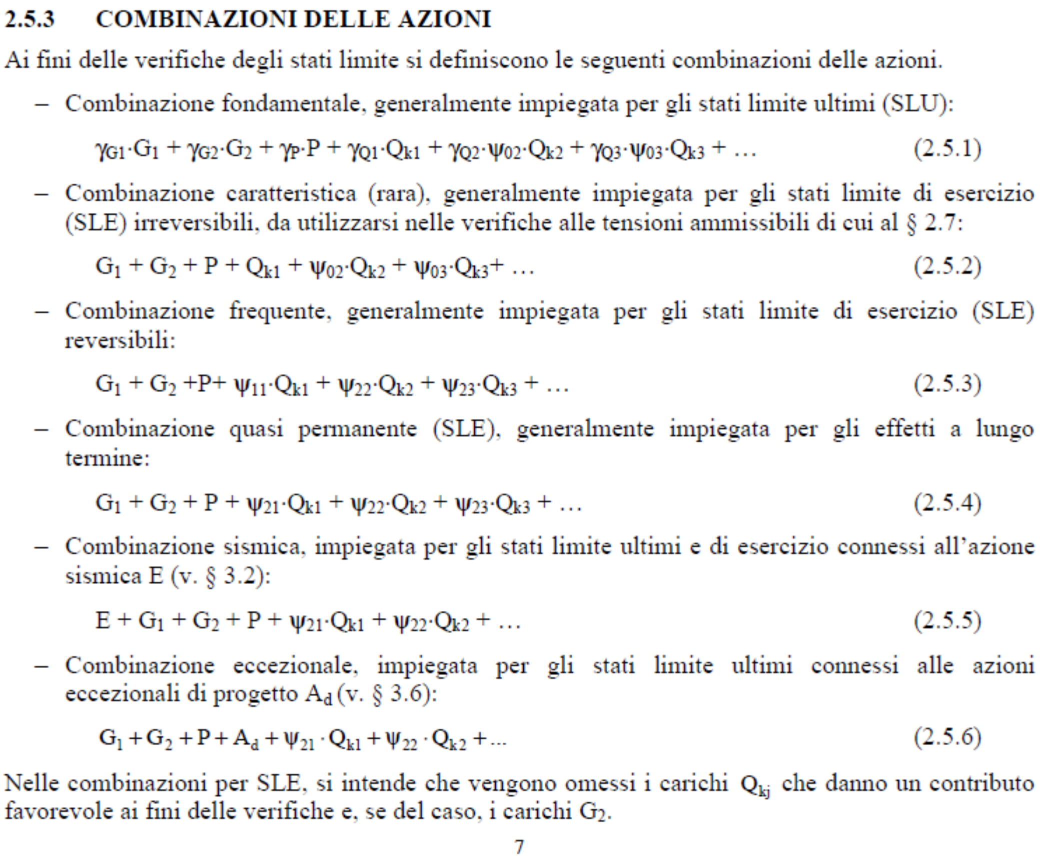
LOAD 28 LOADTYPE None TITLE OPERATING_LOAD_HP

LOAD 29 LOADTYPE None TITLE OPERATING_LOAD_IP

LOAD 30 LOADTYPE None TITLE OPERATING_LOAD_LP

5.3 COMBINAZIONI DI CARICO

Sono state considerate le seguenti combinazioni:



2.5.3 COMBINAZIONI DELLE AZIONI

Ai fini delle verifiche degli stati limite si definiscono le seguenti combinazioni delle azioni.

- Combinazione fondamentale, generalmente impiegata per gli stati limite ultimi (SLU):

$$\gamma_{G1} \cdot G_1 + \gamma_{G2} \cdot G_2 + \gamma_P \cdot P + \gamma_{Q1} \cdot Q_{k1} + \gamma_{Q2} \cdot \psi_{02} \cdot Q_{k2} + \gamma_{Q3} \cdot \psi_{03} \cdot Q_{k3} + \ldots \quad (2.5.1)$$

- Combinazione caratteristica (rara), generalmente impiegata per gli stati limite di esercizio (SLE) irreversibili, da utilizzarsi nelle verifiche alle tensioni ammissibili di cui al § 2.7:

$$G_1 + G_2 + P + Q_{k1} + \psi_{02} \cdot Q_{k2} + \psi_{03} \cdot Q_{k3} + \ldots \quad (2.5.2)$$

- Combinazione frequente, generalmente impiegata per gli stati limite di esercizio (SLE) reversibili:

$$G_1 + G_2 + P + \psi_{11} \cdot Q_{k1} + \psi_{22} \cdot Q_{k2} + \psi_{23} \cdot Q_{k3} + \ldots \quad (2.5.3)$$

- Combinazione quasi permanente (SLE), generalmente impiegata per gli effetti a lungo termine:

$$G_1 + G_2 + P + \psi_{21} \cdot Q_{k1} + \psi_{22} \cdot Q_{k2} + \psi_{23} \cdot Q_{k3} + \ldots \quad (2.5.4)$$

- Combinazione sismica, impiegata per gli stati limite ultimi e di esercizio connessi all'azione sismica E (v. § 3.2):

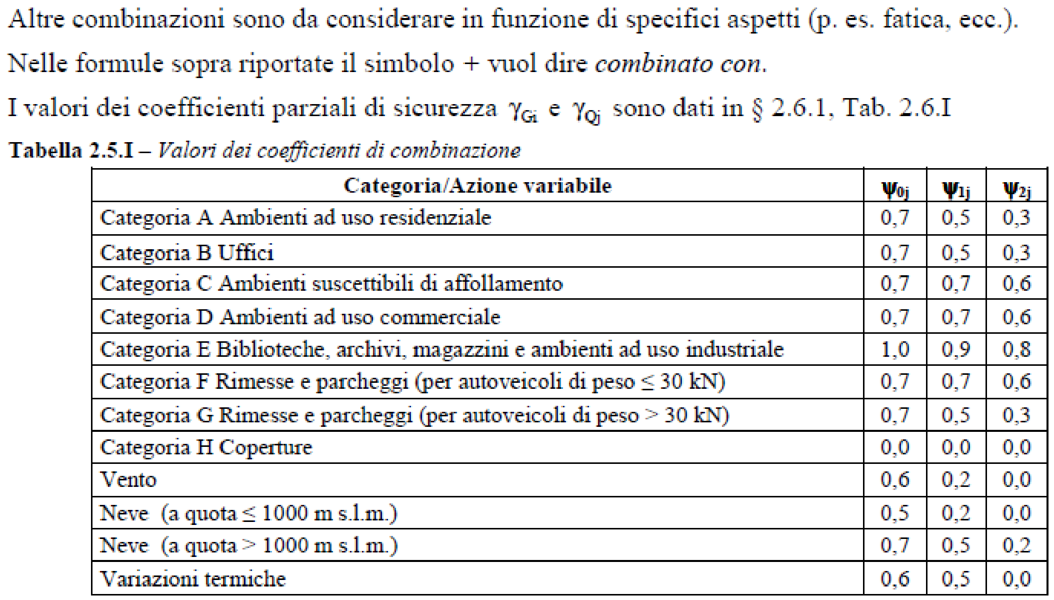
$$E + G_1 + G_2 + P + \psi_{21} \cdot Q_{k1} + \psi_{22} \cdot Q_{k2} + \ldots \quad (2.5.5)$$

- Combinazione eccezionale, impiegata per gli stati limite ultimi connessi alle azioni eccezionali di progetto A_d (v. § 3.6):

$$G_1 + G_2 + P + A_d + \psi_{21} \cdot Q_{k1} + \psi_{22} \cdot Q_{k2} + \ldots \quad (2.5.6)$$

Nelle combinazioni per SLE, si intende che vengono omessi i carichi Q_{kj} che danno un contributo favorevole ai fini delle verifiche e, se del caso, i carichi G_2.

7



Altre combinazioni sono da considerare in funzione di specifici aspetti (p. es. fatica, ecc.).

Nelle formule sopra riportate il simbolo + vuol dire *combinato con*.

I valori dei coefficienti parziali di sicurezza γ_{Gi} e γ_{Qj} sono dati in § 2.6.1, Tab. 2.6.I

Tabella 2.5.I – *Valori dei coefficienti di combinazione*

Categoria/Azione variabile	ψ_{0j}	ψ_{1j}	ψ_{2j}
Categoria A Ambienti ad uso residenziale	0,7	0,5	0,3
Categoria B Uffici	0,7	0,5	0,3
Categoria C Ambienti suscettibili di affollamento	0,7	0,7	0,6
Categoria D Ambienti ad uso commerciale	0,7	0,7	0,6
Categoria E Biblioteche, archivi, magazzini e ambienti ad uso industriale	1,0	0,9	0,8
Categoria F Rimesse e parcheggi (per autoveicoli di peso ≤ 30 kN)	0,7	0,7	0,6
Categoria G Rimesse e parcheggi (per autoveicoli di peso > 30 kN)	0,7	0,5	0,3
Categoria H Coperture	0,0	0,0	0,0
Vento	0,6	0,2	0,0
Neve (a quota ≤ 1000 m s.l.m.)	0,5	0,2	0,0
Neve (a quota > 1000 m s.l.m.)	0,7	0,5	0,2
Variazioni termiche	0,6	0,5	0,0

2.6.1 STATI LIMITE ULTIMI

Nelle verifiche agli stati limite ultimi si distinguono:

- lo stato limite di equilibrio come corpo rigido: **EQU**
- lo stato limite di resistenza della struttura compresi gli elementi di fondazione: **STR**
- lo stato limite di resistenza del terreno: **GEO**

Tabella 2.6.I – *Coefficienti parziali per le azioni o per l'effetto delle azioni nelle verifiche SLU*

		Coefficiente γ_F	EQU	A1 STR	A2 GEO
Carichi permanenti	favorevoli sfavorevoli	γ_{G1}	0,9 1,1	1,0 1,3	1,0 1,0
Carichi permanenti non strutturali(1)	favorevoli sfavorevoli	γ_{G2}	0,0 1,5	0,0 1,5	0,0 1,3
Carichi variabili	favorevoli sfavorevoli	γ_{Qi}	0,0 1,5	0,0 1,5	0,0 1,3

(1)Nel caso in cui i carichi permanenti non strutturali (ad es. carichi permanenti portati) siano compiutamente definiti si potranno adottare per essi gli stessi coefficienti validi per le azioni permanenti.

Nella Tab. 2.6.I il significato dei simboli è il seguente:

γ_{G1}	coefficiente parziale del peso proprio della struttura, nonché del peso proprio del terreno e dell'acqua, quando pertinenti;
γ_{G2}	coefficiente parziale dei pesi propri degli elementi non strutturali;
γ_{Qi}	coefficiente parziale delle azioni variabili.

6 ANALISI MODALE

6.1 DESCRIZIONE

Lo scopo della presente analisi è quella di valutare le frequenze naturali della macchina e del Sistema Fondazione. Il Modello strutturale è stato sviluppato con il programma di calcolo STAAD ed I seguenti carichi sono stati considerati per il calcolo dei modi di vibrare del Sistema:

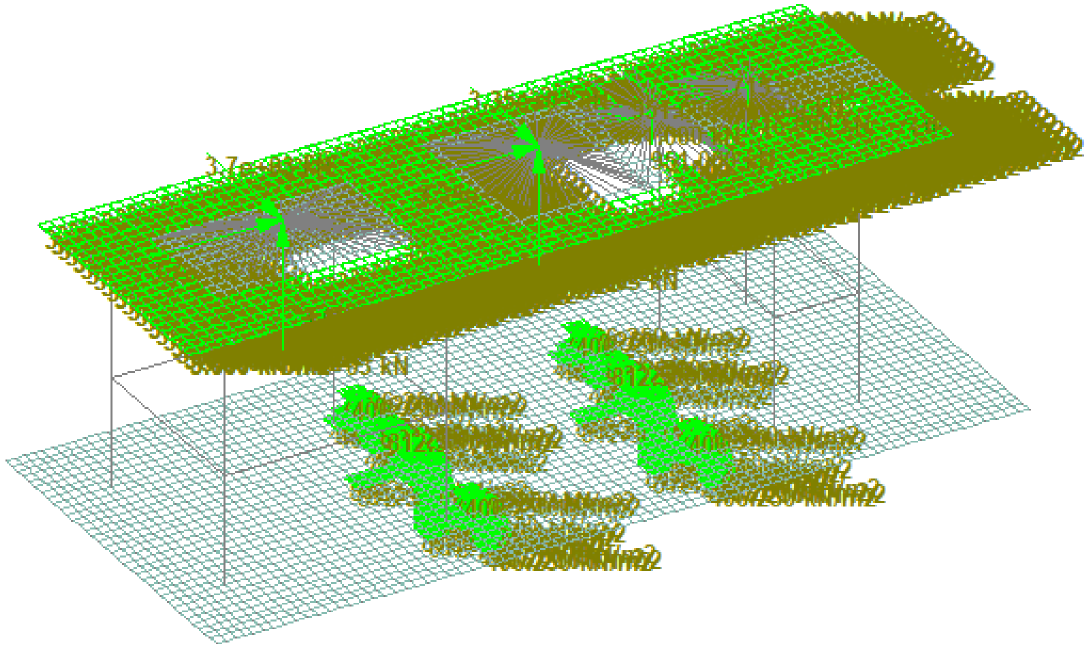
1) Peso proprio struttura

2) Pesi propri definiti dal Vendor.

3) 0.6 Carico variabile.

(Conservativamente, è stato considerato un 50% di carico variabile che agisce contemporaneamente durante le fasi operative della macchina).

In STAAD, le masse ed I modi sono definiti come di seguito:



6.2 FREQUENZE MODALI E MASSE PARTECIPANTI

Modo	Frequency Hz	Period seconds	Participation X %	Participation Y %	Participation Z %
1	3.33	0.30	87.82	0.00	0.00
2	3.53	0.28	0.00	0.00	68.17
3	4.39	0.23	0.00	0.00	19.85
4	12.69	0.08	0.07	53.63	0.00
5	15.11	0.07	0.05	14.10	0.00
6	18.14	0.06	0.71	22.21	0.00
7	19.39	0.05	0.00	0.00	1.04
8	21.00	0.05	6.36	0.23	0.00
9	21.21	0.05	0.00	0.00	2.18
10	22.04	0.05	0.00	0.00	0.05
11	22.18	0.05	0.00	0.00	0.13
12	22.57	0.04	1.14	0.59	0.00
13	24.07	0.04	0.00	0.00	0.39
14	24.77	0.04	0.00	0.00	2.27
15	24.94	0.04	0.37	0.10	0.00
16	27.05	0.04	0.00	0.00	0.16
17	28.53	0.04	0.00	0.00	1.89
18	31.29	0.03	0.00	0.00	0.98
19	32.02	0.03	0.00	0.00	0.01
20	32.82	0.03	0.00	0.73	0.00
21	36.06	0.03	0.01	0.60	0.00
22	40.99	0.02	0.00	0.00	0.00
23	42.63	0.02	0.00	0.00	0.00
24	43.52	0.02	0.00	4.70	0.00
25	49.94	0.02	0.03	0.00	0.00
26	50.10	0.02	0.00	0.00	0.00
27	51.67	0.02	0.00	0.14	0.00
28	52.52	0.02	0.00	0.01	0.00
29	52.60	0.02	0.00	0.01	0.00
30	53.76	0.02	0.00	0.01	0.00
31	55.24	0.02	0.00	0.48	0.00
32	57.14	0.02	0.00	0.07	0.00
33	57.87	0.02	0.00	0.15	0.00
34	60.85	0.02	0.00	0.00	0.00
35	63.09	0.02	0.00	0.01	0.00
36	63.41	0.02	0.00	0.00	0.01
37	64.72	0.02	0.01	0.20	0.00
38	69.05	0.01	0.00	0.60	0.00
39	70.58	0.01	0.01	0.14	0.00
40	72.08	0.01	0.10	0.04	0.00
41	72.40	0.01	0.01	0.00	0.00

Modo	Frequency Hz	Period seconds	Participation X %	Participation Y %	Participation Z %
42	74.19	0.01	0.00	0.00	0.00
43	78.02	0.01	0.00	0.00	0.02
44	78.80	0.01	0.02	0.35	0.00
45	81.39	0.01	2.07	0.01	0.00
46	81.99	0.01	0.00	0.00	1.04
47	82.25	0.01	0.35	0.11	0.00
48	82.48	0.01	0.01	0.00	0.75
49	83.84	0.01	0.82	0.12	0.00
50	86.39	0.01	0.02	0.00	0.00

Interpretazione

Dalla tabella riportata sopra, si evince che si ha circa il 100% della massa partecipata entro I primi 10 modi di vibrare. Per i modi di vibrare si rimanda all'Allegato B.

Inoltre, si evince che non ci sono anomalie nel comportamento strutturale della Fondazione.

Conclusioni

La frequenza naturale di vibrazione della Fondazione deve essere il 20% al di sotto del range operativo della macchina.

Frequenza della macchina = 3000 RPM = 50 Hz

La frequenza della Fondazione dovrà quindi stare al di fuori del range 40 Hz - 60 Hz.

Frequenza in Direzione X:

Modo 1 – Partecipante = 87.82%

Frequenza della fondazione = 3.33 Hz…………**OK**

Frequenza in Direzione Z:

Modo 2 – Partecipante = 68.17%

Frequenza della fondazione = 3.53 Hz………… **OK**

Modo 3 – Partecipante = 19.85%

Frequenza della fondazione = 4.39 Hz………… **OK**

7 CAPACITA' DEI PALI

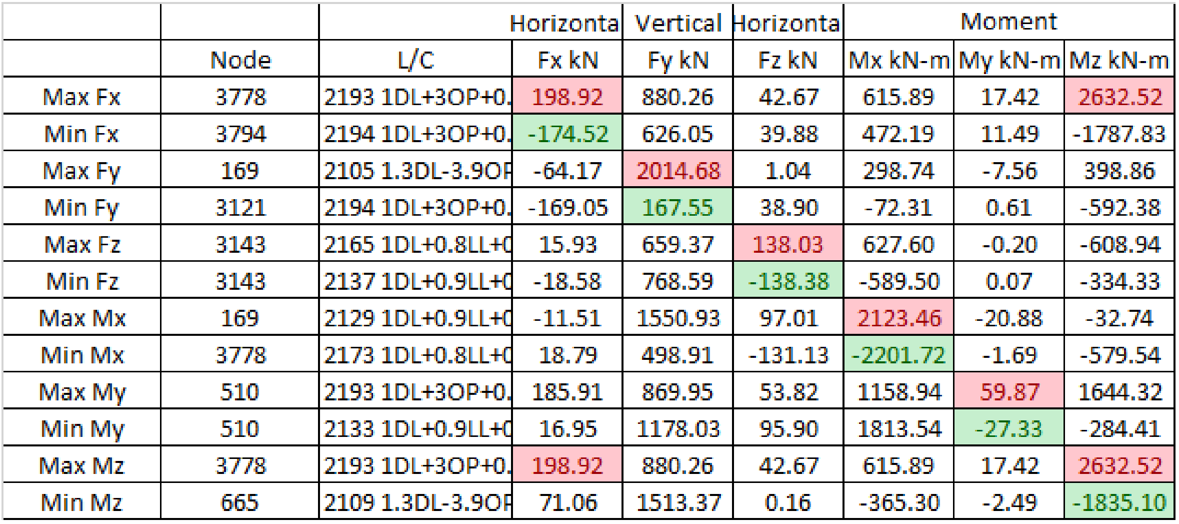
Il controllo statico dei pali è stato eseguito agli SLU.

Come da [5], per pali di diam. da 800mm, le capacità portanti agli SLU sono le seguenti:

1) Compressione = 2970 kN

2) Trazione = 1600 kN

3) Taglio = 203 kN



			Horizonta	Vertical	Horizonta		Moment	
	Node	L/C	Fx kN	Fy kN	Fz kN	Mx kN-m	My kN-m	Mz kN-m
Max Fx	3778	2193 1DL+3OP+0.	198.92	880.26	42.67	615.89	17.42	2632.52
Min Fx	3794	2194 1DL+3OP+0.	-174.52	626.05	39.88	472.19	11.49	-1787.83
Max Fy	169	2105 1.3DL-3.9OP	-64.17	2014.68	1.04	298.74	-7.56	398.86
Min Fy	3121	2194 1DL+3OP+0.	-169.05	167.55	38.90	-72.31	0.61	-592.38
Max Fz	3143	2165 1DL+0.8LL+	15.93	659.37	138.03	627.60	-0.20	-608.94
Min Fz	3143	2137 1DL+0.9LL+	-18.58	768.59	-138.38	-589.50	0.07	-334.33
Max Mx	169	2129 1DL+0.9LL+	-11.51	1550.93	97.01	2123.46	-20.88	-32.74
Min Mx	3778	2173 1DL+0.8LL+	18.79	498.91	-131.13	-2201.72	-1.69	-579.54
Max My	510	2193 1DL+3OP+0.	185.91	869.95	53.82	1158.94	59.87	1644.32
Min My	510	2133 1DL+0.9LL+	16.95	1178.03	95.90	1813.54	-27.33	-284.41
Max Mz	3778	2193 1DL+3OP+0.	198.92	880.26	42.67	615.89	17.42	2632.52
Min Mz	665	2109 1.3DL-3.9OP	71.06	1513.37	0.16	-365.30	-2.49	-1835.10

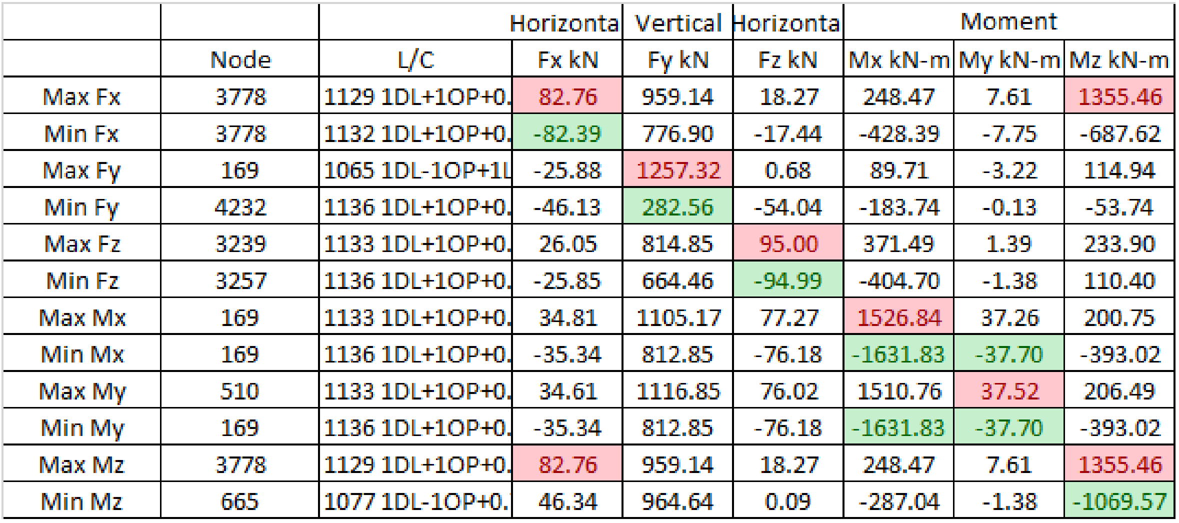
Max. reazione vertical al palo = 2014.7 kN < 2970 kN **OK**

La risultante a taglio = $\sqrt{198^2 + 42^2}$ = 202.4 kN < 203 kN **OK**

Come da [5], per pali di diam. da 800mm, le capacità portanti agli SLE sono le seguenti:

1) Compressione = 1600 kN

2) Taglio = 142.5 kN

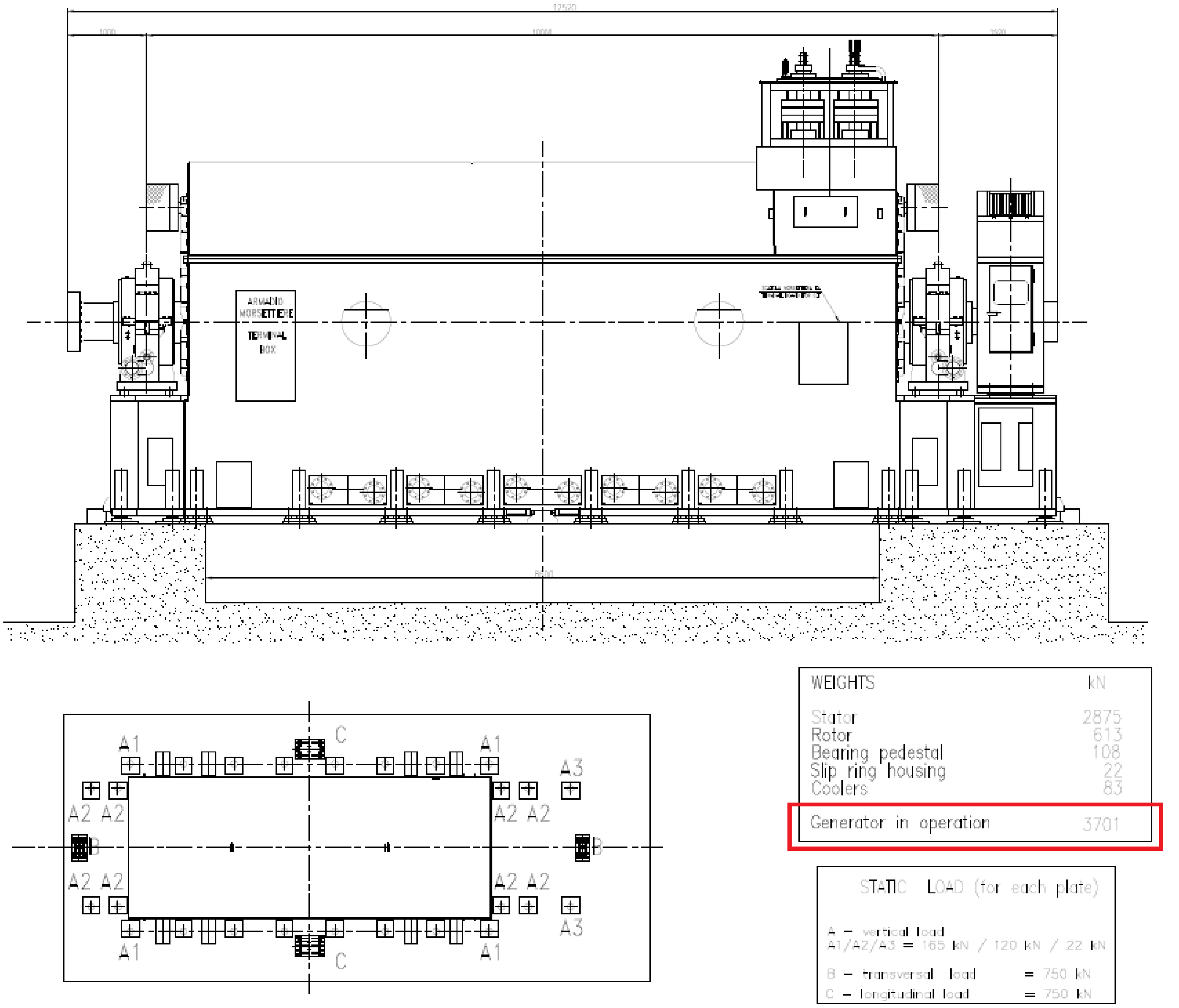


			Horizonta	Vertical	Horizonta	Moment		
	Node	L/C	Fx kN	Fy kN	Fz kN	Mx kN-m	My kN-m	Mz kN-m
Max Fx	3778	1129 1DL+1OP+0.	82.76	959.14	18.27	248.47	7.61	1355.46
Min Fx	3778	1132 1DL+1OP+0.	-82.39	776.90	-17.44	-428.39	-7.75	-687.62
Max Fy	169	1065 1DL-1OP+1L	-25.88	1257.32	0.68	89.71	-3.22	114.94
Min Fy	4232	1136 1DL+1OP+0.	-46.13	282.56	-54.04	-183.74	-0.13	-53.74
Max Fz	3239	1133 1DL+1OP+0.	26.05	814.85	95.00	371.49	1.39	233.90
Min Fz	3257	1136 1DL+1OP+0.	-25.85	664.46	-94.99	-404.70	-1.38	110.40
Max Mx	169	1133 1DL+1OP+0.	34.81	1105.17	77.27	1526.84	37.26	200.75
Min Mx	169	1136 1DL+1OP+0.	-35.34	812.85	-76.18	-1631.83	-37.70	-393.02
Max My	510	1133 1DL+1OP+0.	34.61	1116.85	76.02	1510.76	37.52	206.49
Min My	169	1136 1DL+1OP+0.	-35.34	812.85	-76.18	-1631.83	-37.70	-393.02
Max Mz	3778	1129 1DL+1OP+0.	82.76	959.14	18.27	248.47	7.61	1355.46
Min Mz	665	1077 1DL-1OP+0.	46.34	964.64	0.09	-287.04	-1.38	-1069.57

Max. reazione vertical al palo = 1257 kN < 1600 kN **OK**

La risultante a taglio = $\sqrt{26^2+95^2}$ = 98.5kN < 142 kN **OK**

8 ALLEGATO A – INPUT DA VENDOR



WEIGHTS	kN
Stator	2875
Rotor	613
Bearing pedestal	108
Slip ring housing	22
Coolers	83
Generator in operation	3701

STATIC LOAD (for each plate)

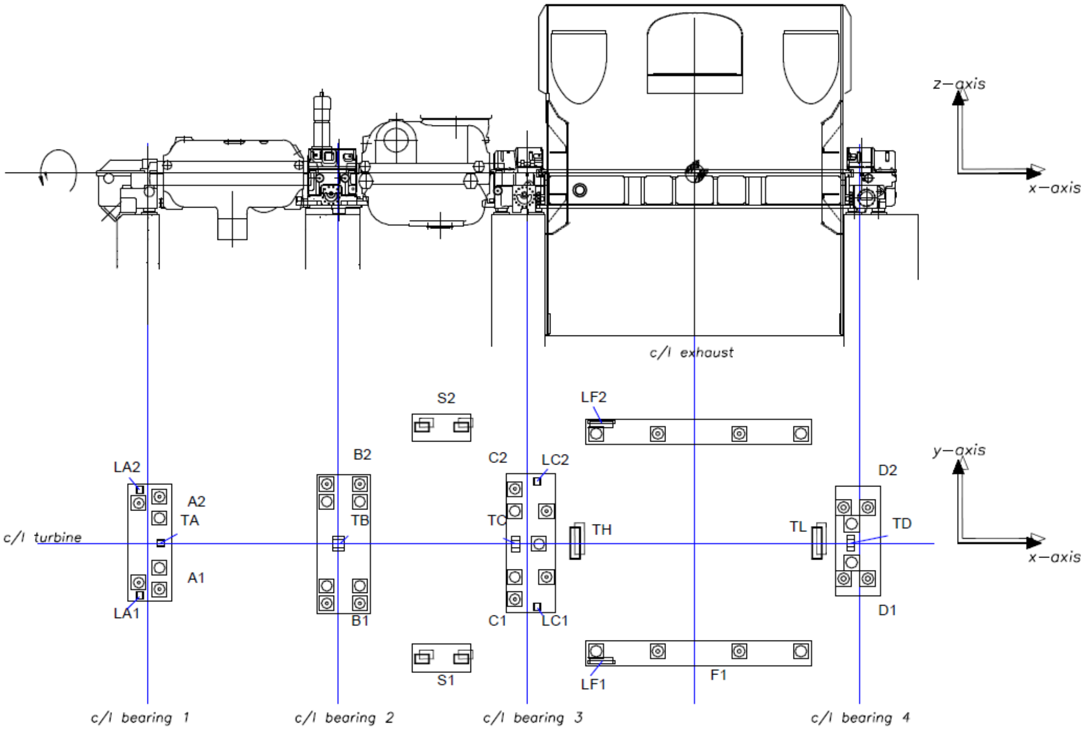
A – vertical load
A1/A2/A3 = 165 kN / 120 kN / 22 kN

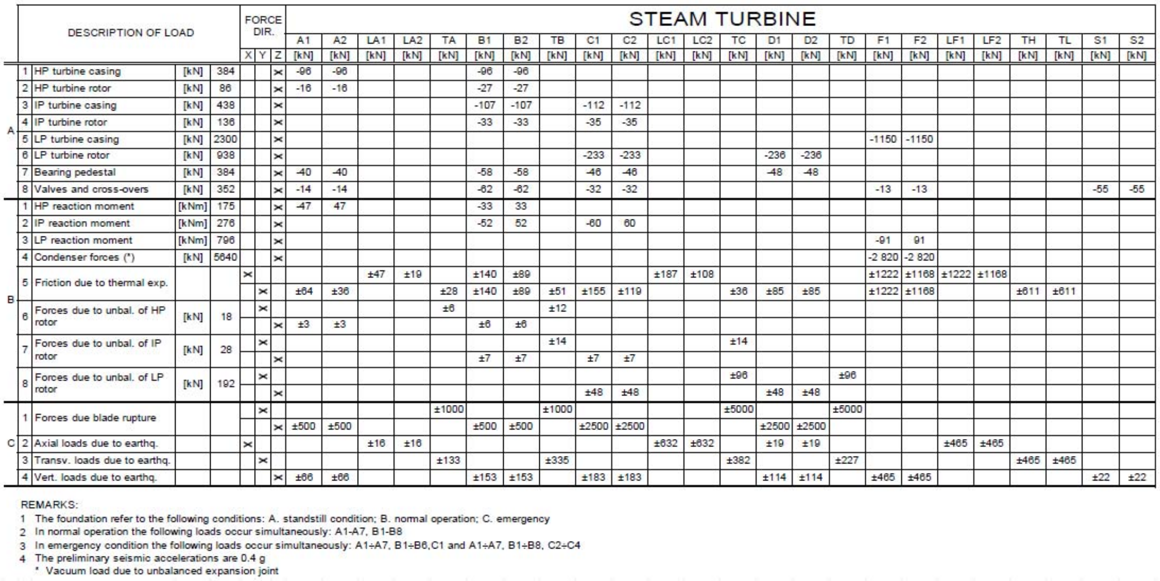
B – transversal load = 750 kN
C – longitudinal load = 750 kN

NOTE : THE LOCATION SIDE OF TERMINAL BOXES , INLET/OUTLET FLANGES OF COOLERS AND BEARING OIL TOGETHER WITH REMOVAL SIDE OF COOLERS ARE HOLD SIDES , TO BE DEFINED ACCORDING TO PLANT LAYOUT

Generator Load

1. STEAM TURBINE - LOCATION OF THE LOADS



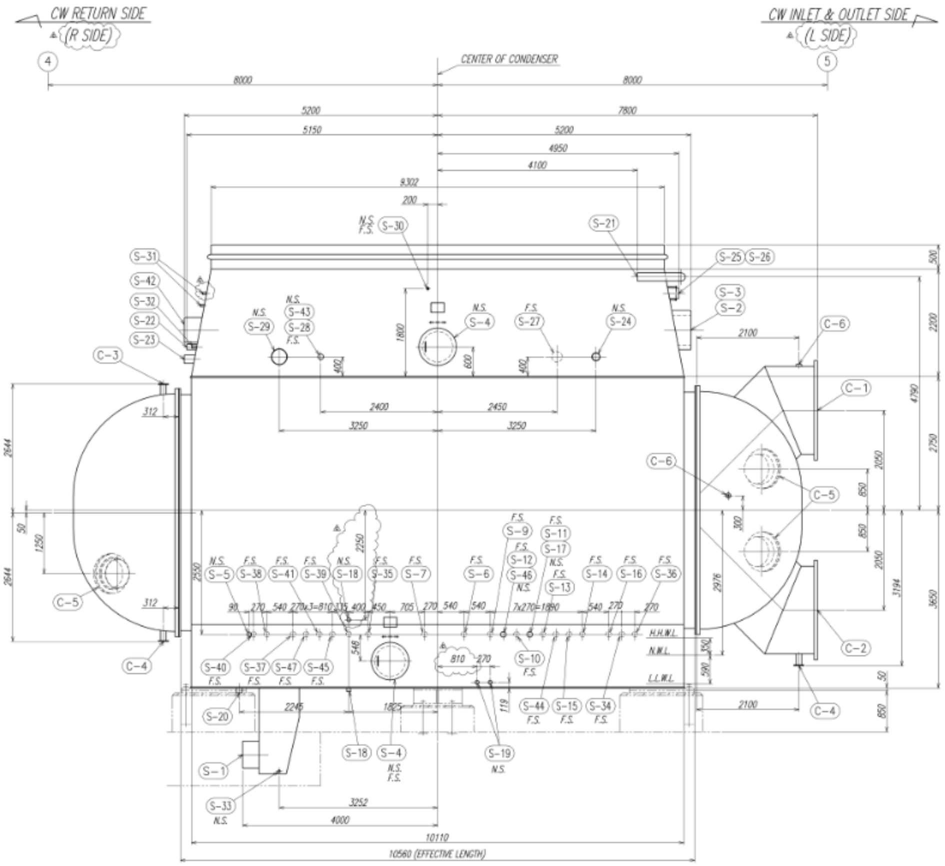


		DESCRIPTION OF LOAD			FORCE DIR.			STEAM TURBINE																							
								A1	A2	LA1	LA2	TA	B1	B2	TB	C1	C2	LC1	LC2	TC	D1	D2	TD	F1	F2	LF1	LF2	TH	TL	S1	S2
					X	Y	Z	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]	[kN]
A	1	HP turbine casing	[kN]	384			×	-96	-96				-96	-96																	
	2	HP turbine rotor	[kN]	86			×	-16	-16				-27	-27																	
	3	IP turbine casing	[kN]	438			×						-107	-107		-112	-112														
	4	IP turbine rotor	[kN]	136			×						-33	-33		-35	-35														
	5	LP turbine casing	[kN]	2300			×																	-1150	-1150						
	6	LP turbine rotor	[kN]	938			×									-233	-233				-236	-236									
	7	Bearing pedestal	[kN]	384			×	-40	-40				-58	-58		-46	-46				-48	-48									
	8	Valves and cross-overs	[kN]	352			×	-14	-14				-62	-62		-32	-32							-13	-13					-55	-55
B	1	HP reaction moment	[kNm]	175			×	-47	47				-33	33																	
	2	IP reaction moment	[kNm]	276			×						-52	52		-60	60														
	3	LP reaction moment	[kNm]	796			×																	-91	91						
	4	Condenser forces (*)	[kN]	5640			×																	-2 820	-2 820						
	5	Friction due to thermal exp.			×					±47	±19		±140	±89				±187	±108					±1222	±1168	±1222	±1168				
						×		±64	±36			±28	±140	±89	±51	±155	±119			±36	±85	±85		±1222	±1168			±611	±611		
	6	Forces due to unbal. of HP rotor	[kN]	18		×						±6			±12																
							×	±3	±3				±6	±6																	
	7	Forces due to unbal. of IP rotor	[kN]	28		×									±14					±14											
							×						±7	±7		±7	±7														
	8	Forces due to unbal. of LP rotor	[kN]	192		×														±96			±96								
							×									±48	±48				±48	±48									
C	1	Forces due blade rupture				×						±1000			±1000					±5000			±5000								
							×	±500	±500				±500	±500		±2500	±2500				±2500	±2500									
	2	Axial loads due to earthq.			×					±16	±16							±632	±632		±19	±19				±465	±465				
	3	Transv. loads due to earthq.				×						±133			±335					±382			±227					±465	±465		
	4	Vert. loads due to earthq.					×	±66	±66				±153	±153		±183	±183				±114	±114		±465	±465					±22	±22

REMARKS:

1 The foundation refer to the following conditions: A. standstill condition; B. normal operation; C. emergency
2 In normal operation the following loads occur simultaneously: A1-A7, B1-B8
3 In emergency condition the following loads occur simultaneously: A1÷A7, B1÷B6,C1 and A1÷A7, B1÷B8, C2÷C4
4 The preliminary seismic accelerations are 0.4 g
* Vacuum load due to unbalanced expansion joint

Turbina



DESIGN SPECIFICATION		
	STEAM SIDE	WATER SIDE
DESIGN PRESSURE	Full Vac. & 0.048 MPa(1.49 bar(a))	0.35 MPa
DESIGN TEMPERATURE	120℃	60℃
HYDROSTATIC TEST PRESSURE	FILLED WITH WATER	0.53 MPa
FLUID	STEAM&CONDENSATE	SEA WATER

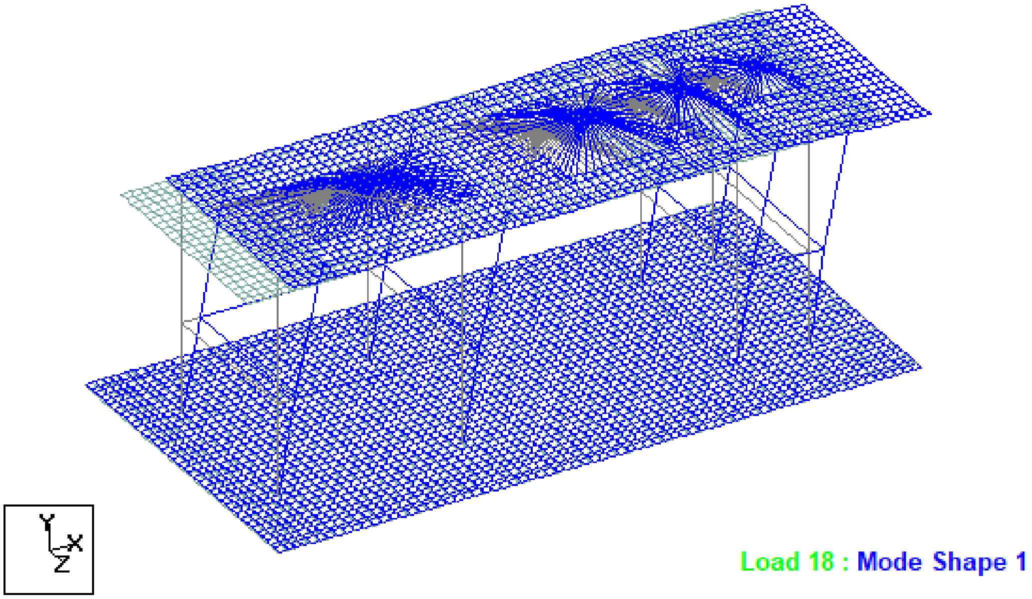
	TUBE SPECIFICATION	
	CONDENSING ZONE	AIR COOLING ZONE
MATERIAL	TITANIUM	
OUT.DIA.xTHICKNESS	ϕ25.4 x t0.7	ϕ25.4 x t0.7
NUMBER	29616	1560
TOTAL NUMBER	31176	
EFFECTIVE LENGTH	10560 mm	
HEAT TRANS. AREA	26266 m²	

WEIGHTS	
COMPLETE-DRY	325 ton
OPERATING	-270 ton
FLOODED	1300 ton

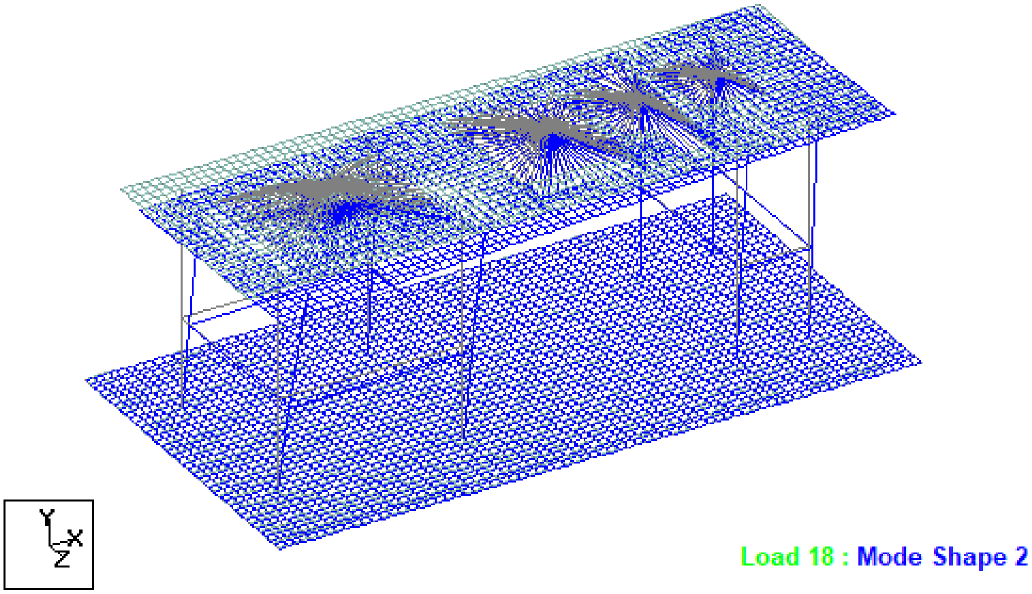
Condensatore

9 ALLEGATO B – MODI DI VIBRARE

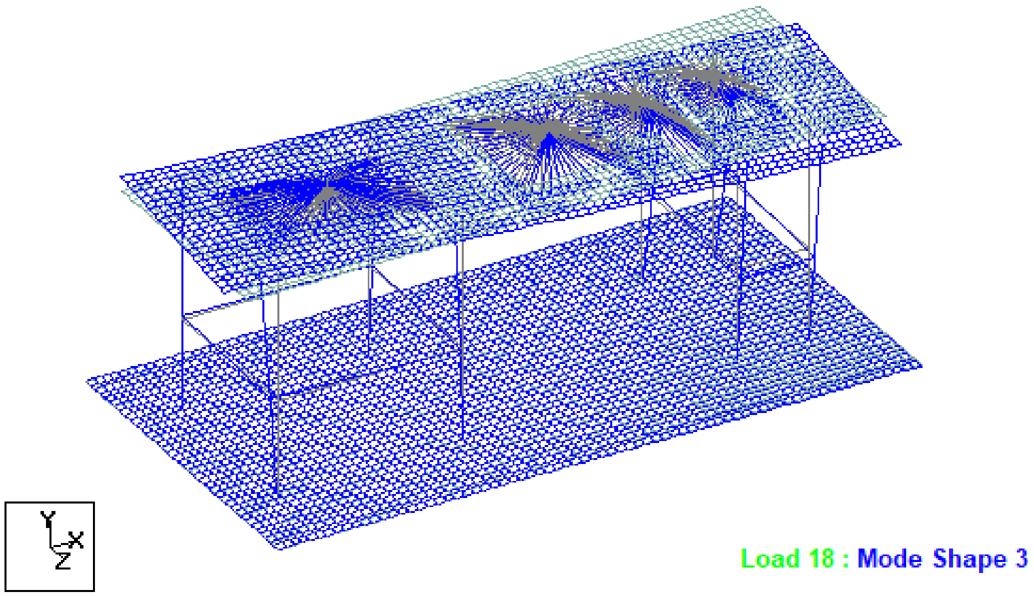
Vengono riportati di seguito i primi 10 modi di vibrare:



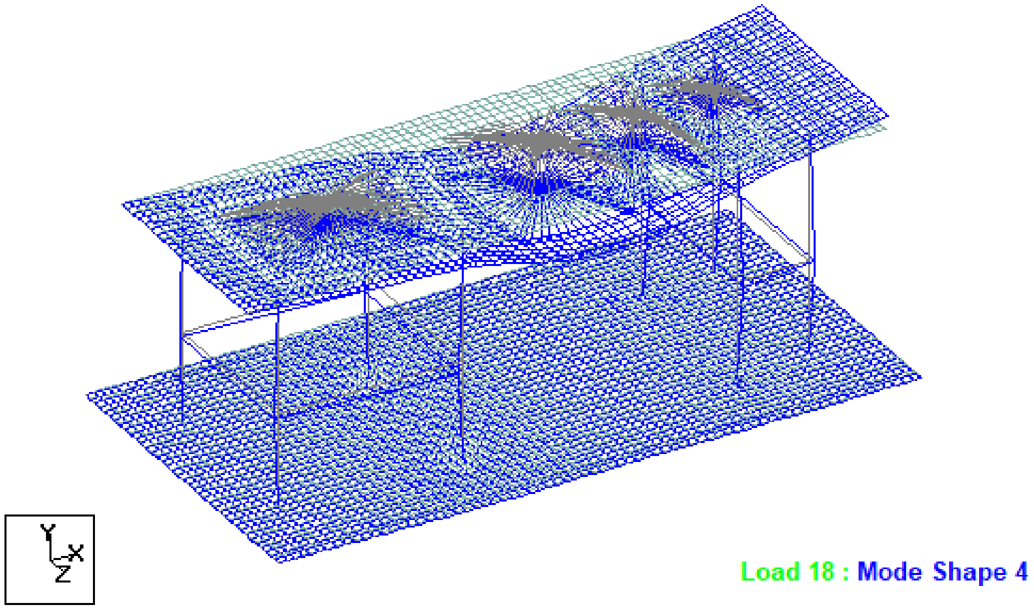
Mode 1



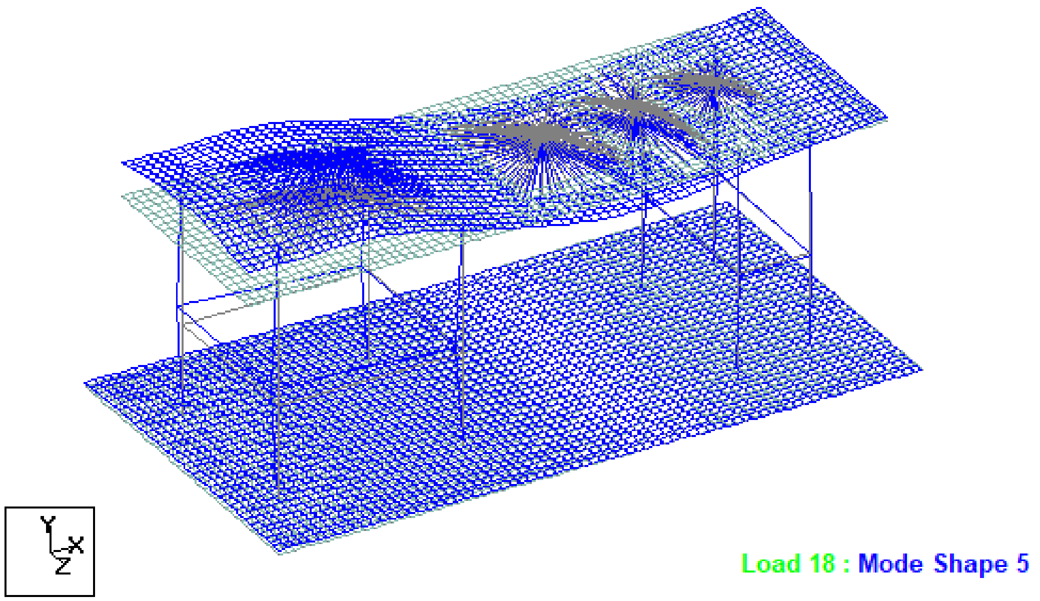
Mode 2



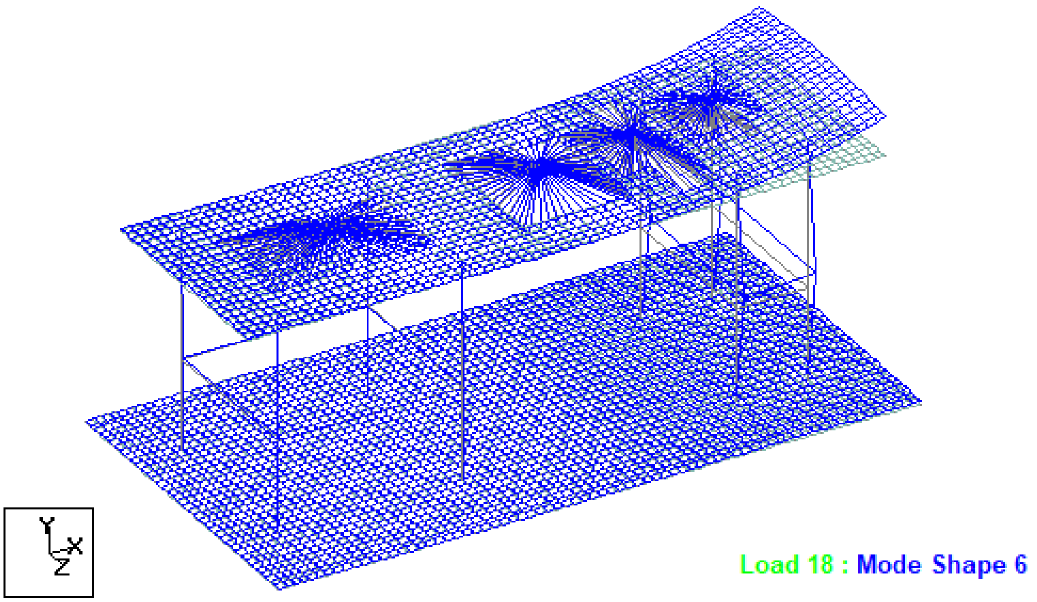
Mode 3



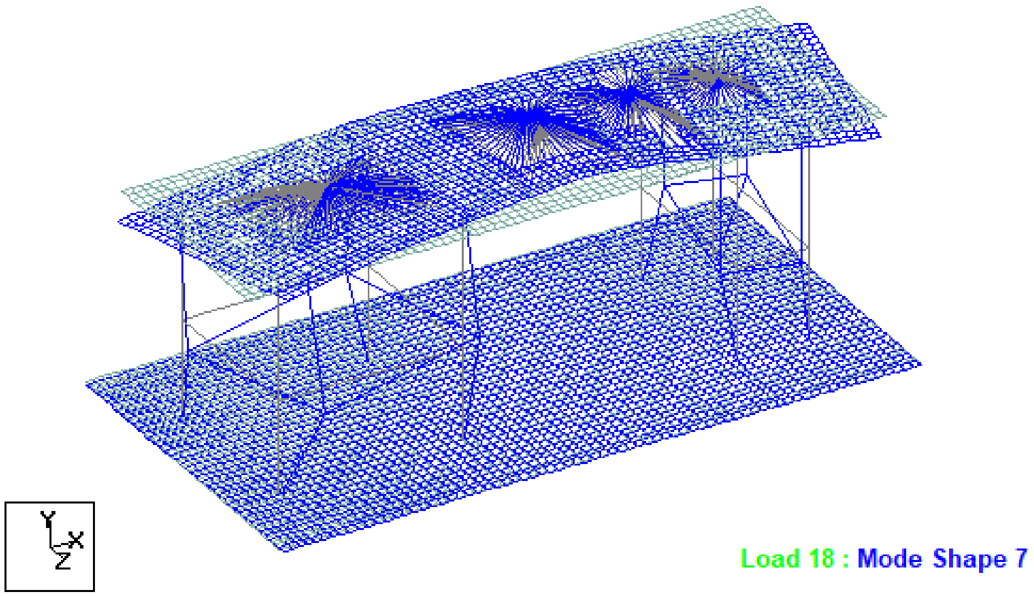
Mode 4



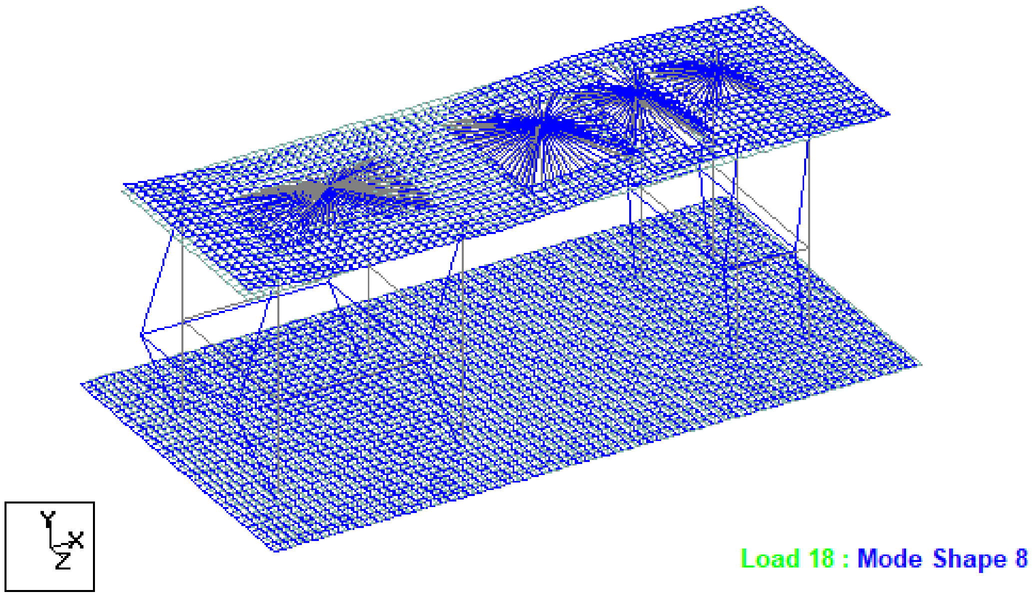
Mode 5



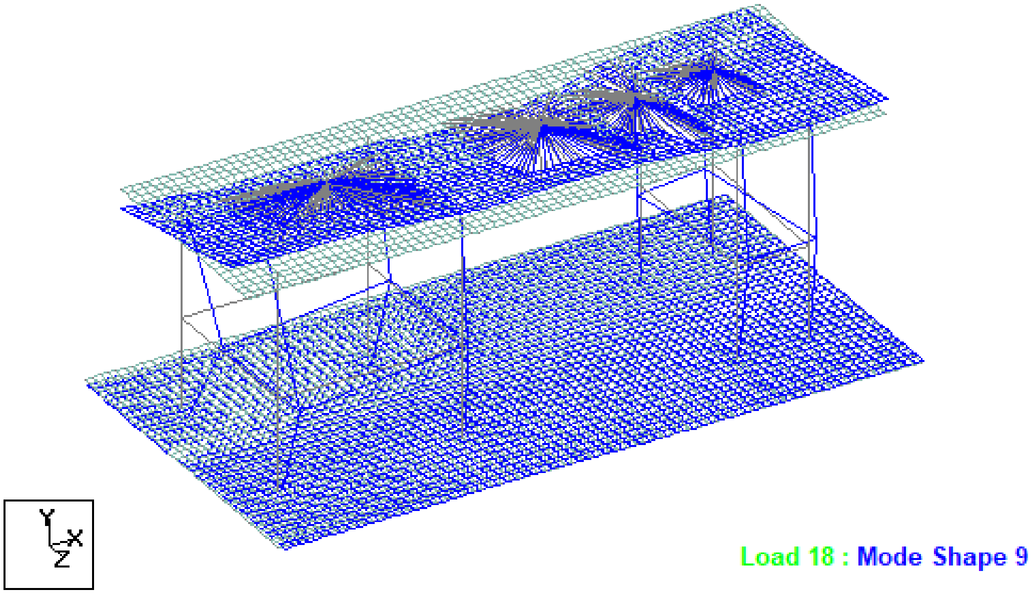
Mode 6



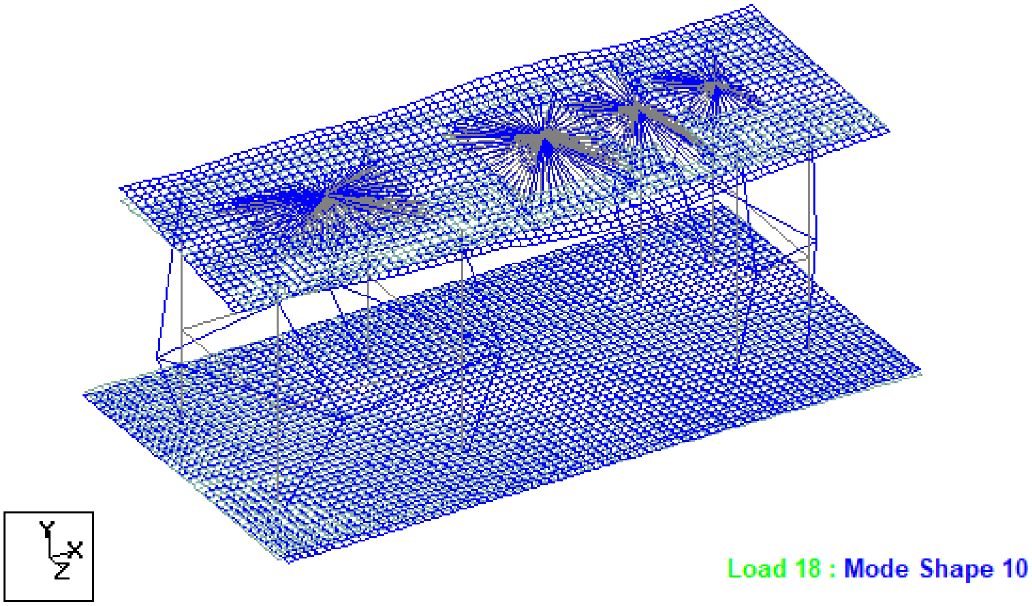
Mode 7



Mode 8



Mode 9



Mode 10

10 ALLEGATO C – COMBINAZIONI DI CARICO

LOAD COMB 1001 1DL+1OP+1LL+0.6TE+0.5SL+0.6WX

LOAD COMB 1002 1DL+1OP+1LL+0.6TE+0.5SL-0.6WX

LOAD COMB 1003 1DL+1OP+1LL+0.6TE+0.5SL+0.6WY

LOAD COMB 1004 1DL+1OP+1LL+0.6TE+0.5SL-0.6WY

LOAD COMB 1005 1DL+1OP+1LL+0.6TC+0.5SL+0.6WX

LOAD COMB 1006 1DL+1OP+1LL+0.6TC+0.5SL-0.6WX

LOAD COMB 1007 1DL+1OP+1LL+0.6TC+0.5SL+0.6WY

LOAD COMB 1008 1DL+1OP+1LL+0.6TC+0.5SL-0.6WY

LOAD COMB 1009 1DL+1OP+0.7LL+1TE+0.5SL+0.6WX

LOAD COMB 1010 1DL+1OP+0.7LL+1TE+0.5SL-0.6WX

LOAD COMB 1011 1DL+1OP+0.7LL+1TE+0.5SL+0.6WY

LOAD COMB 1012 1DL+1OP+0.7LL+1TE+0.5SL-0.6WY

LOAD COMB 1013 1DL+1OP+0.7LL+1TC+0.5SL+0.6WX

LOAD COMB 1014 1DL+1OP+0.7LL+1TC+0.5SL-0.6WX

LOAD COMB 1015 1DL+1OP+0.7LL+1TC+0.5SL+0.6WY

LOAD COMB 1016 1DL+1OP+0.7LL+1TC+0.5SL-0.6WY

LOAD COMB 1017 1DL+1OP+0.7LL+0.6TE+0.5SL+1WX

LOAD COMB 1018 1DL+1OP+0.7LL+0.6TE+0.5SL-1WX

LOAD COMB 1019 1DL+1OP+0.7LL+0.6TE+0.5SL+1WY

LOAD COMB 1020 1DL+1OP+0.7LL+0.6TE+0.5SL-1WY

LOAD COMB 1021 1DL+1OP+0.7LL+0.6TC+0.5SL+1WX

LOAD COMB 1022 1DL+1OP+0.7LL+0.6TC+0.5SL-1WX

LOAD COMB 1023 1DL+1OP+0.7LL+0.6TC+0.5SL+1WY

LOAD COMB 1024 1DL+1OP+0.7LL+0.6TC+0.5SL-1WY

LOAD COMB 1025 1DL+1OP+0.7LL+0.6TE+1SL+0.6WX

LOAD COMB 1026 1DL+1OP+0.7LL+0.6TE+1SL-0.6WX

LOAD COMB 1027 1DL+1OP+0.7LL+0.6TE+1SL+0.6WY

LOAD COMB 1028 1DL+1OP+0.7LL+0.6TE+1SL-0.6WY

LOAD COMB 1029 1DL+1OP+0.7LL+0.6TC+1SL+0.6WX

LOAD COMB 1030 1DL+1OP+0.7LL+0.6TC+1SL-0.6WX

LOAD COMB 1031 1DL+1OP+0.7LL+0.6TC+1SL+0.6WY

LOAD COMB 1032 1DL+1OP+0.7LL+0.6TC+1SL-0.6WY

LOAD COMB 1033 1DL+1OP+1LL+0.6TE+0.5SL+0.6WX

LOAD COMB 1034 1DL+1OP+1LL+0.6TE+0.5SL-0.6WX

LOAD COMB 1035 1DL+1OP+1LL+0.6TE+0.5SL+0.6WY

LOAD COMB 1036 1DL+1OP+1LL+0.6TE+0.5SL-0.6WY

LOAD COMB 1037 1DL+1OP+1LL+0.6TC+0.5SL+0.6WX

LOAD COMB 1038 1DL+1OP+1LL+0.6TC+0.5SL-0.6WX

LOAD COMB 1039 1DL+1OP+1LL+0.6TC+0.5SL+0.6WY

LOAD COMB 1040 1DL+1OP+1LL+0.6TC+0.5SL-0.6WY

LOAD COMB 1041 1DL+1OP+0.7LL+1TE+0.5SL+0.6WX

LOAD COMB 1042 1DL+1OP+0.7LL+1TE+0.5SL-0.6WX

LOAD COMB 1043 1DL+1OP+0.7LL+1TE+0.5SL+0.6WY

LOAD COMB 1044 1DL+1OP+0.7LL+1TE+0.5SL-0.6WY

LOAD COMB 1045 1DL+1OP+0.7LL+1TC+0.5SL+0.6WX

LOAD COMB 1046 1DL+1OP+0.7LL+1TC+0.5SL-0.6WX

LOAD COMB 1047 1DL+1OP+0.7LL+1TC+0.5SL+0.6WY

LOAD COMB 1048 1DL+1OP+0.7LL+1TC+0.5SL-0.6WY

LOAD COMB 1049 1DL+1OP+0.7LL+0.6TE+0.5SL+0.6WX

LOAD COMB 1050 1DL+1OP+0.7LL+0.6TE+0.5SL-0.6WX

LOAD COMB 1051 1DL+1OP+0.7LL+0.6TE+0.5SL+0.6WY

LOAD COMB 1052 1DL+1OP+0.7LL+0.6TE+0.5SL-0.6WY

LOAD COMB 1053 1DL+1OP+0.7LL+0.6TC+0.5SL+0.6WX

LOAD COMB 1054 1DL+1OP+0.7LL+0.6TC+0.5SL-0.6WX

LOAD COMB 1055 1DL+1OP+0.7LL+0.6TC+0.5SL+0.6WY

LOAD COMB 1056 1DL+1OP+0.7LL+0.6TC+0.5SL-0.6WY

LOAD COMB 1057 1DL+1OP+0.7LL+0.6TE+1SL+0.6WX

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LOAD COMB 1061 1DL+1OP+0.7LL+0.6TC+1SL+0.6WX

LOAD COMB 1062 1DL+1OP+0.7LL+0.6TC+1SL-0.6WX

LOAD COMB 1063 1DL+1OP+0.7LL+0.6TC+1SL+0.6WY

LOAD COMB 1064 1DL+1OP+0.7LL+0.6TC+1SL-0.6WY

LOAD COMB 1065 1DL-1OP+1LL+0.6TE+0.5SL+0.6WX

LOAD COMB 1066 1DL-1OP+1LL+0.6TE+0.5SL-0.6WX

LOAD COMB 1067 1DL-1OP+1LL+0.6TE+0.5SL+0.6WY

LOAD COMB 1068 1DL-1OP+1LL+0.6TE+0.5SL-0.6WY

LOAD COMB 1069 1DL-1OP+1LL+0.6TC+0.5SL+0.6WX

LOAD COMB 1070 1DL-1OP+1LL+0.6TC+0.5SL-0.6WX

LOAD COMB 1071 1DL-1OP+1LL+0.6TC+0.5SL+0.6WY

LOAD COMB 1072 1DL-1OP+1LL+0.6TC+0.5SL-0.6WY

LOAD COMB 1073 1DL-1OP+0.7LL+1TE+0.5SL+0.6WX

LOAD COMB 1074 1DL-1OP+0.7LL+1TE+0.5SL-0.6WX

LOAD COMB 1075 1DL-1OP+0.7LL+1TE+0.5SL+0.6WY

LOAD COMB 1076 1DL-1OP+0.7LL+1TE+0.5SL-0.6WY

LOAD COMB 1077 1DL-1OP+0.7LL+1TC+0.5SL+0.6WX

LOAD COMB 1078 1DL-1OP+0.7LL+1TC+0.5SL-0.6WX

LOAD COMB 1079 1DL-1OP+0.7LL+1TC+0.5SL+0.6WY

LOAD COMB 1080 1DL-1OP+0.7LL+1TC+0.5SL-0.6WY

LOAD COMB 1081 1DL-1OP+0.7LL+0.6TE+0.5SL+1WX

LOAD COMB 1082 1DL-1OP+0.7LL+0.6TE+0.5SL-1WX

LOAD COMB 1083 1DL-1OP+0.7LL+0.6TE+0.5SL+1WY

LOAD COMB 1084 1DL-1OP+0.7LL+0.6TE+0.5SL-1WY

LOAD COMB 1085 1DL-1OP+0.7LL+0.6TC+0.5SL+1WX

LOAD COMB 1086 1DL-1OP+0.7LL+0.6TC+0.5SL-1WX

LOAD COMB 1087 1DL-1OP+0.7LL+0.6TC+0.5SL+1WY

LOAD COMB 1088 1DL-1OP+0.7LL+0.6TC+0.5SL-1WY

LOAD COMB 1089 1DL-1OP+0.7LL+0.6TE+1SL+0.6WX

LOAD COMB 1090 1DL-1OP+0.7LL+0.6TE+1SL-0.6WX

LOAD COMB 1091 1DL-1OP+0.7LL+0.6TE+1SL+0.6WY

LOAD COMB 1092 1DL-1OP+0.7LL+0.6TE+1SL-0.6WY

LOAD COMB 1093 1DL-1OP+0.7LL+0.6TC+1SL+0.6WX

LOAD COMB 1094 1DL-1OP+0.7LL+0.6TC+1SL-0.6WX

LOAD COMB 1095 1DL-1OP+0.7LL+0.6TC+1SL+0.6WY

LOAD COMB 1096 1DL-1OP+0.7LL+0.6TC+1SL-0.6WY

LOAD COMB 1097 1DL-1OP+1LL+0.6TE+0.5SL+0.6WX

LOAD COMB 1098 1DL-1OP+1LL+0.6TE+0.5SL-0.6WX

LOAD COMB 1099 1DL-1OP+1LL+0.6TE+0.5SL+0.6WY

LOAD COMB 1100 1DL-1OP+1LL+0.6TE+0.5SL-0.6WY

LOAD COMB 1101 1DL-1OP+1LL+0.6TC+0.5SL+0.6WX

LOAD COMB 1102 1DL-1OP+1LL+0.6TC+0.5SL-0.6WX

LOAD COMB 1103 1DL-1OP+1LL+0.6TC+0.5SL+0.6WY

LOAD COMB 1104 1DL-1OP+1LL+0.6TC+0.5SL-0.6WY

LOAD COMB 1105 1DL-1OP+0.7LL+1TE+0.5SL+0.6WX

LOAD COMB 1106 1DL-1OP+0.7LL+1TE+0.5SL-0.6WX

LOAD COMB 1107 1DL-1OP+0.7LL+1TE+0.5SL+0.6WY

LOAD COMB 1108 1DL-1OP+0.7LL+1TE+0.5SL-0.6WY

LOAD COMB 1109 1DL-1OP+0.7LL+1TC+0.5SL+0.6WX

LOAD COMB 1110 1DL-1OP+0.7LL+1TC+0.5SL-0.6WX

LOAD COMB 1111 1DL-1OP+0.7LL+1TC+0.5SL+0.6WY

LOAD COMB 1112 1DL-1OP+0.7LL+1TC+0.5SL-0.6WY

LOAD COMB 1113 1DL-1OP+0.7LL+0.6TE+0.5SL+0.6WX

LOAD COMB 1114 1DL-1OP+0.7LL+0.6TE+0.5SL-0.6WX

LOAD COMB 1115 1DL-1OP+0.7LL+0.6TE+0.5SL+0.6WY

LOAD COMB 1116 1DL-1OP+0.7LL+0.6TE+0.5SL-0.6WY

LOAD COMB 1117 1DL-1OP+0.7LL+0.6TC+0.5SL+0.6WX

LOAD COMB 1118 1DL-1OP+0.7LL+0.6TC+0.5SL-0.6WX

LOAD COMB 1119 1DL-1OP+0.7LL+0.6TC+0.5SL+0.6WY

LOAD COMB 1120 1DL-1OP+0.7LL+0.6TC+0.5SL-0.6WY

LOAD COMB 1121 1DL-1OP+0.7LL+0.6TE+1SL+0.6WX

LOAD COMB 1122 1DL-1OP+0.7LL+0.6TE+1SL-0.6WX

LOAD COMB 1123 1DL-1OP+0.7LL+0.6TE+1SL+0.6WY

LOAD COMB 1124 1DL-1OP+0.7LL+0.6TE+1SL-0.6WY

LOAD COMB 1125 1DL-1OP+0.7LL+0.6TC+1SL+0.6WX

LOAD COMB 1126 1DL-1OP+0.7LL+0.6TC+1SL-0.6WX

LOAD COMB 1127 1DL-1OP+0.7LL+0.6TC+1SL+0.6WY

LOAD COMB 1128 1DL-1OP+0.7LL+0.6TC+1SL-0.6WY

LOAD COMB 1129 1DL+1OP+0.6LL+1EXE+0.3EZE

LOAD COMB 1130 1DL+1OP+0.6LL-1EXE+0.3EZE

LOAD COMB 1131 1DL+1OP+0.6LL+1EXE-0.3EZE

LOAD COMB 1132 1DL+1OP+0.6LL-1EXE-0.3EZE

LOAD COMB 1133 1DL+1OP+0.6LL+0.3EXE+1EZE

LOAD COMB 1134 1DL+1OP+0.6LL+0.3EXE-1EZE

LOAD COMB 1135 1DL+1OP+0.6LL-0.3EXE+1EZE

LOAD COMB 1136 1DL+1OP+0.6LL-0.3EXE-1EZE

LOAD COMB 1137 1DL+1OP+1LL

LOAD COMB 1138 1DL-1OP+1LL

LOAD COMB 2001 1DL+3.9OP+1.5LL+0.9TE+0.9SL+0.9WX

LOAD COMB 2002 1DL+3.9OP+1.5LL+0.9TE+0.9SL-0.9WX

LOAD COMB 2003 1DL+3.9OP+1.5LL+0.9TE+0.9SL+0.9WY

LOAD COMB 2004 1DL+3.9OP+1.5LL+0.9TE+0.9SL-0.9WY

LOAD COMB 2005 1DL+3.9OP+1.5LL+0.9TC+0.9SL+0.9WX

LOAD COMB 2006 1DL+3.9OP+1.5LL+0.9TC+0.9SL-0.9WX

LOAD COMB 2007 1DL+3.9OP+1.5LL+0.9TC+0.9SL+0.9WY

LOAD COMB 2008 1DL+3.9OP+1.5LL+0.9TC+0.9SL-0.9WY

LOAD COMB 2009 1DL-3.9OP+1.5LL+0.9TE+0.9SL+0.9WX

LOAD COMB 2010 1DL-3.9OP+1.5LL+0.9TE+0.9SL-0.9WX

LOAD COMB 2011 1DL-3.9OP+1.5LL+0.9TE+0.9SL+0.9WY

LOAD COMB 2012 1DL-3.9OP+1.5LL+0.9TE+0.9SL-0.9WY

LOAD COMB 2013 1DL-3.9OP+1.5LL+0.9TC+0.9SL+0.9WX

LOAD COMB 2014 1DL-3.9OP+1.5LL+0.9TC+0.9SL-0.9WX

LOAD COMB 2015 1DL-3.9OP+1.5LL+0.9TC+0.9SL+0.9WY

LOAD COMB 2016 1DL-3.9OP+1.5LL+0.9TC+0.9SL-0.9WY

LOAD COMB 2017 1DL+3.9OP+1.5LL+0.9TE+1.5SL+0.9WX

LOAD COMB 2018 1DL+3.9OP+1.5LL+0.9TE+1.5SL-0.9WX

LOAD COMB 2019 1DL+3.9OP+1.5LL+0.9TE+1.5SL+0.9WY

LOAD COMB 2020 1DL+3.9OP+1.5LL+0.9TE+1.5SL-0.9WY

LOAD COMB 2021 1DL+3.9OP+1.5LL+0.9TC+1.5SL+0.9WX

LOAD COMB 2022 1DL+3.9OP+1.5LL+0.9TC+1.5SL-0.9WX

LOAD COMB 2023 1DL+3.9OP+1.5LL+0.9TC+1.5SL+0.9WY

LOAD COMB 2024 1DL+3.9OP+1.5LL+0.9TC+1.5SL-0.9WY

LOAD COMB 2025 1DL-3.9OP+1.5LL+0.9TE+1.5SL+0.9WX

LOAD COMB 2026 1DL-3.9OP+1.5LL+0.9TE+1.5SL-0.9WX

LOAD COMB 2027 1DL-3.9OP+1.5LL+0.9TE+1.5SL+0.9WY

LOAD COMB 2028 1DL-3.9OP+1.5LL+0.9TE+1.5SL-0.9WY

LOAD COMB 2029 1DL-3.9OP+1.5LL+0.9TC+1.5SL+0.9WX

LOAD COMB 2030 1DL-3.9OP+1.5LL+0.9TC+1.5SL-0.9WX

LOAD COMB 2031 1DL-3.9OP+1.5LL+0.9TC+1.5SL+0.9WY

LOAD COMB 2032 1DL-3.9OP+1.5LL+0.9TC+1.5SL-0.9WY

LOAD COMB 2033 1DL+3.9OP+1.5LL+1.5TE+0.9SL+0.9WX

LOAD COMB 2034 1DL+3.9OP+1.5LL+1.5TE+0.9SL-0.9WX

LOAD COMB 2035 1DL+3.9OP+1.5LL+1.5TE+0.9SL+0.9WY

LOAD COMB 2036 1DL+3.9OP+1.5LL+1.5TE+0.9SL-0.9WY

LOAD COMB 2037 1DL+3.9OP+1.5LL+1.5TC+0.9SL+0.9WX

LOAD COMB 2038 1DL+3.9OP+1.5LL+1.5TC+0.9SL-0.9WX

LOAD COMB 2039 1DL+3.9OP+1.5LL+1.5TC+0.9SL+0.9WY

LOAD COMB 2040 1DL+3.9OP+1.5LL+1.5TC+0.9SL-0.9WY

LOAD COMB 2041 1DL-3.9OP+1.5LL+1.5TE+0.9SL+0.9WX

LOAD COMB 2042 1DL-3.9OP+1.5LL+1.5TE+0.9SL-0.9WX

LOAD COMB 2043 1DL-3.9OP+1.5LL+1.5TE+0.9SL+0.9WY

LOAD COMB 2044 1DL-3.9OP+1.5LL+1.5TE+0.9SL-0.9WY

LOAD COMB 2045 1DL-3.9OP+1.5LL+1.5TC+0.9SL+0.9WX

LOAD COMB 2046 1DL-3.9OP+1.5LL+1.5TC+0.9SL-0.9WX

LOAD COMB 2047 1DL-3.9OP+1.5LL+1.5TC+0.9SL+0.9WY

LOAD COMB 2048 1DL-3.9OP+1.5LL+1.5TC+0.9SL-0.9WY

LOAD COMB 2049 1DL+3.9OP+1.5LL+0.9TE+0.9SL+1.5WX

LOAD COMB 2050 1DL+3.9OP+1.5LL+0.9TE+0.9SL-1.5WX

LOAD COMB 2051 1DL+3.9OP+1.5LL+0.9TE+0.9SL+1.5WY

LOAD COMB 2052 1DL+3.9OP+1.5LL+0.9TE+0.9SL-1.5WY

LOAD COMB 2053 1DL+3.9OP+1.5LL+0.9TC+0.9SL+1.5WX

LOAD COMB 2054 1DL+3.9OP+1.5LL+0.9TC+0.9SL-1.5WX

LOAD COMB 2055 1DL+3.9OP+1.5LL+0.9TC+0.9SL+1.5WY

LOAD COMB 2056 1DL+3.9OP+1.5LL+0.9TC+0.9SL-1.5WY

LOAD COMB 2057 1DL-3.9OP+1.5LL+0.9TE+0.9SL+1.5WX

LOAD COMB 2058 1DL-3.9OP+1.5LL+0.9TE+0.9SL-1.5WX

LOAD COMB 2059 1DL-3.9OP+1.5LL+0.9TE+0.9SL+1.5WY

LOAD COMB 2060 1DL-3.9OP+1.5LL+0.9TE+0.9SL-1.5WY

LOAD COMB 2061 1DL-3.9OP+1.5LL+0.9TC+0.9SL+1.5WX

LOAD COMB 2062 1DL-3.9OP+1.5LL+0.9TC+0.9SL-1.5WX

LOAD COMB 2063 1DL-3.9OP+1.5LL+0.9TC+0.9SL+1.5WY

LOAD COMB 2064 1DL-3.9OP+1.5LL+0.9TC+0.9SL-1.5WY

LOAD COMB 2065 1.3DL+3.9OP+1.5LL+0.9TE+0.9SL+0.9WX

LOAD COMB 2066 1.3DL+3.9OP+1.5LL+0.9TE+0.9SL-0.9WX

LOAD COMB 2067 1.3DL+3.9OP+1.5LL+0.9TE+0.9SL+0.9WY

LOAD COMB 2068 1.3DL+3.9OP+1.5LL+0.9TE+0.9SL-0.9WY

LOAD COMB 2069 1.3DL+3.9OP+1.5LL+0.9TC+0.9SL+0.9WX

LOAD COMB 2070 1.3DL+3.9OP+1.5LL+0.9TC+0.9SL-0.9WX

LOAD COMB 2071 1.3DL+3.9OP+1.5LL+0.9TC+0.9SL+0.9WY

LOAD COMB 2072 1.3DL+3.9OP+1.5LL+0.9TC+0.9SL-0.9WY

LOAD COMB 2073 1.3DL-3.9OP+1.5LL+0.9TE+0.9SL+0.9WX

LOAD COMB 2074 1.3DL-3.9OP+1.5LL+0.9TE+0.9SL-0.9WX

LOAD COMB 2075 1.3DL-3.9OP+1.5LL+0.9TE+0.9SL+0.9WY

LOAD COMB 2076 1.3DL-3.9OP+1.5LL+0.9TE+0.9SL-0.9WY

LOAD COMB 2077 1.3DL-3.9OP+1.5LL+0.9TC+0.9SL+0.9WX

LOAD COMB 2078 1.3DL-3.9OP+1.5LL+0.9TC+0.9SL-0.9WX

LOAD COMB 2079 1.3DL-3.9OP+1.5LL+0.9TC+0.9SL+0.9WY

LOAD COMB 2080 1.3DL-3.9OP+1.5LL+0.9TC+0.9SL-0.9WY

LOAD COMB 2081 1.3DL+3.9OP+1.5LL+0.9TE+1.5SL+0.9WX

LOAD COMB 2082 1.3DL+3.9OP+1.5LL+0.9TE+1.5SL-0.9WX

LOAD COMB 2083 1.3DL+3.9OP+1.5LL+0.9TE+1.5SL+0.9WY

LOAD COMB 2084 1.3DL+3.9OP+1.5LL+0.9TE+1.5SL-0.9WY

LOAD COMB 2085 1.3DL+3.9OP+1.5LL+0.9TC+1.5SL+0.9WX

LOAD COMB 2086 1.3DL+3.9OP+1.5LL+0.9TC+1.5SL-0.9WX

LOAD COMB 2087 1.3DL+3.9OP+1.5LL+0.9TC+1.5SL+0.9WY

LOAD COMB 2088 1.3DL+3.9OP+1.5LL+0.9TC+1.5SL-0.9WY

LOAD COMB 2089 1.3DL-3.9OP+1.5LL+0.9TE+1.5SL+0.9WX

LOAD COMB 2090 1.3DL-3.9OP+1.5LL+0.9TE+1.5SL-0.9WX

LOAD COMB 2091 1.3DL-3.9OP+1.5LL+0.9TE+1.5SL+0.9WY

LOAD COMB 2092 1.3DL-3.9OP+1.5LL+0.9TE+1.5SL-0.9WY

LOAD COMB 2093 1.3DL-3.9OP+1.5LL+0.9TC+1.5SL+0.9WX

LOAD COMB 2094 1.3DL-3.9OP+1.5LL+0.9TC+1.5SL-0.9WX

LOAD COMB 2095 1.3DL-3.9OP+1.5LL+0.9TC+1.5SL+0.9WY

LOAD COMB 2096 1.3DL-3.9OP+1.5LL+0.9TC+1.5SL-0.9WY

LOAD COMB 2097 1.3DL+3.9OP+1.5LL+1.5TE+0.9SL+0.9WX

LOAD COMB 2098 1.3DL+3.9OP+1.5LL+1.5TE+0.9SL-0.9WX

LOAD COMB 2099 1.3DL+3.9OP+1.5LL+1.5TE+0.9SL+0.9WY

LOAD COMB 2100 1.3DL+3.9OP+1.5LL+1.5TE+0.9SL-0.9WY

LOAD COMB 2101 1.3DL+3.9OP+1.5LL+1.5TC+0.9SL+0.9WX

LOAD COMB 2102 1.3DL+3.9OP+1.5LL+1.5TC+0.9SL-0.9WX

LOAD COMB 2103 1.3DL+3.9OP+1.5LL+1.5TC+0.9SL+0.9WY

LOAD COMB 2104 1.3DL+3.9OP+1.5LL+1.5TC+0.9SL-0.9WY

LOAD COMB 2105 1.3DL-3.9OP+1.5LL+1.5TE+0.9SL+0.9WX

LOAD COMB 2106 1.3DL-3.9OP+1.5LL+1.5TE+0.9SL-0.9WX

LOAD COMB 2107 1.3DL-3.9OP+1.5LL+1.5TE+0.9SL+0.9WY

LOAD COMB 2108 1.3DL-3.9OP+1.5LL+1.5TE+0.9SL-0.9WY

LOAD COMB 2109 1.3DL-3.9OP+1.5LL+1.5TC+0.9SL+0.9WX

LOAD COMB 2110 1.3DL-3.9OP+1.5LL+1.5TC+0.9SL-0.9WX

LOAD COMB 2111 1.3DL-3.9OP+1.5LL+1.5TC+0.9SL+0.9WY

LOAD COMB 2112 1.3DL-3.9OP+1.5LL+1.5TC+0.9SL-0.9WY

LOAD COMB 2113 1.3DL+3.9OP+1.5LL+0.9TE+0.9SL+1.5WX

LOAD COMB 2114 1.3DL+3.9OP+1.5LL+0.9TE+0.9SL-1.5WX

LOAD COMB 2115 1.3DL+3.9OP+1.5LL+0.9TE+0.9SL+1.5WY

LOAD COMB 2116 1.3DL+3.9OP+1.5LL+0.9TE+0.9SL-1.5WY

LOAD COMB 2117 1.3DL+3.9OP+1.5LL+0.9TC+0.9SL+1.5WX

LOAD COMB 2118 1.3DL+3.9OP+1.5LL+0.9TC+0.9SL-1.5WX

LOAD COMB 2119 1.3DL+3.9OP+1.5LL+0.9TC+0.9SL+1.5WY

LOAD COMB 2120 1.3DL+3.9OP+1.5LL+0.9TC+0.9SL-1.5WY

LOAD COMB 2121 1.3DL-3.9OP+1.5LL+0.9TE+0.9SL+1.5WX

LOAD COMB 2122 1.3DL-3.9OP+1.5LL+0.9TE+0.9SL-1.5WX

LOAD COMB 2123 1.3DL-3.9OP+1.5LL+0.9TE+0.9SL+1.5WY

LOAD COMB 2124 1.3DL-3.9OP+1.5LL+0.9TE+0.9SL-1.5WY

LOAD COMB 2125 1.3DL-3.9OP+1.5LL+0.9TC+0.9SL+1.5WX

LOAD COMB 2126 1.3DL-3.9OP+1.5LL+0.9TC+0.9SL-1.5WX

LOAD COMB 2127 1.3DL-3.9OP+1.5LL+0.9TC+0.9SL+1.5WY

LOAD COMB 2128 1.3DL-3.9OP+1.5LL+0.9TC+0.9SL-1.5WY

LOAD COMB 2129 1DL+0.9LL+0.5TE+0.2SL+0.2WX+1E1

LOAD COMB 2130 1DL+0.9LL+0.5TE+0.2SL-0.2WX+1E1

LOAD COMB 2131 1DL+0.9LL+0.5TE+0.2SL+0.2WY+1E1

LOAD COMB 2132 1DL+0.9LL+0.5TE+0.2SL-0.2WY+1E1

LOAD COMB 2133 1DL+0.9LL+0.5TC+0.2SL+0.2WX+1E1

LOAD COMB 2134 1DL+0.9LL+0.5TC+0.2SL-0.2WX+1E1

LOAD COMB 2135 1DL+0.9LL+0.5TC+0.2SL+0.2WY+1E1

LOAD COMB 2136 1DL+0.9LL+0.5TC+0.2SL-0.2WY+1E1

LOAD COMB 2137 1DL+0.9LL+0.5TE+0.2SL+0.2WX-1E1

LOAD COMB 2138 1DL+0.9LL+0.5TE+0.2SL-0.2WX-1E1

LOAD COMB 2139 1DL+0.9LL+0.5TE+0.2SL+0.2WY-1E1

LOAD COMB 2140 1DL+0.9LL+0.5TE+0.2SL-0.2WY-1E1

LOAD COMB 2141 1DL+0.9LL+0.5TC+0.2SL+0.2WX-1E1

LOAD COMB 2142 1DL+0.9LL+0.5TC+0.2SL-0.2WX-1E1

LOAD COMB 2143 1DL+0.9LL+0.5TC+0.2SL+0.2WY-1E1

LOAD COMB 2144 1DL+0.9LL+0.5TC+0.2SL-0.2WY-1E1

LOAD COMB 2145 1DL+0.9LL+0.5TE+0.2SL+0.2WX+1E2

LOAD COMB 2146 1DL+0.9LL+0.5TE+0.2SL-0.2WX+1E2

LOAD COMB 2147 1DL+0.9LL+0.5TE+0.2SL+0.2WY+1E2

LOAD COMB 2148 1DL+0.9LL+0.5TE+0.2SL-0.2WY+1E2

LOAD COMB 2149 1DL+0.9LL+0.5TC+0.2SL+0.2WX+1E2

LOAD COMB 2150 1DL+0.9LL+0.5TC+0.2SL-0.2WX+1E2

LOAD COMB 2151 1DL+0.9LL+0.5TC+0.2SL+0.2WY+1E2

LOAD COMB 2152 1DL+0.9LL+0.5TC+0.2SL-0.2WY+1E2

LOAD COMB 2153 1DL+0.9LL+0.5TE+0.2SL+0.2WX-1E2

LOAD COMB 2154 1DL+0.9LL+0.5TE+0.2SL-0.2WX-1E2

LOAD COMB 2155 1DL+0.9LL+0.5TE+0.2SL+0.2WY-1E2

LOAD COMB 2156 1DL+0.9LL+0.5TE+0.2SL-0.2WY-1E2

LOAD COMB 2157 1DL+0.9LL+0.5TC+0.2SL+0.2WX-1E2

LOAD COMB 2158 1DL+0.9LL+0.5TC+0.2SL-0.2WX-1E2

LOAD COMB 2159 1DL+0.9LL+0.5TC+0.2SL+0.2WY-1E2

LOAD COMB 2160 1DL+0.9LL+0.5TC+0.2SL-0.2WY-1E2

LOAD COMB 2161 1DL+0.8LL+0.5TE+0.2SL+0.2WX+1E1

LOAD COMB 2162 1DL+0.8LL+0.5TE+0.2SL-0.2WX+1E1

LOAD COMB 2163 1DL+0.8LL+0.5TE+0.2SL+0.2WY+1E1

LOAD COMB 2164 1DL+0.8LL+0.5TE+0.2SL-0.2WY+1E1

LOAD COMB 2165 1DL+0.8LL+0.5TC+0.2SL+0.2WX+1E1

LOAD COMB 2166 1DL+0.8LL+0.5TC+0.2SL-0.2WX+1E1

LOAD COMB 2167 1DL+0.8LL+0.5TC+0.2SL+0.2WY+1E1

LOAD COMB 2168 1DL+0.8LL+0.5TC+0.2SL-0.2WY+1E1

LOAD COMB 2169 1DL+0.8LL+0.5TE+0.2SL+0.2WX-1E1

LOAD COMB 2170 1DL+0.8LL+0.5TE+0.2SL-0.2WX-1E1

LOAD COMB 2171 1DL+0.8LL+0.5TE+0.2SL+0.2WY-1E1

LOAD COMB 2172 1DL+0.8LL+0.5TE+0.2SL-0.2WY-1E1

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LOAD COMB 2192 1DL+0.8LL+0.5TC+0.2SL-0.2WY-1E2

LOAD COMB 2193 1DL+3OP+0.6LL+1EXD+0.3EZD

LOAD COMB 2194 1DL+3OP+0.6LL-1EXD+0.3EZD

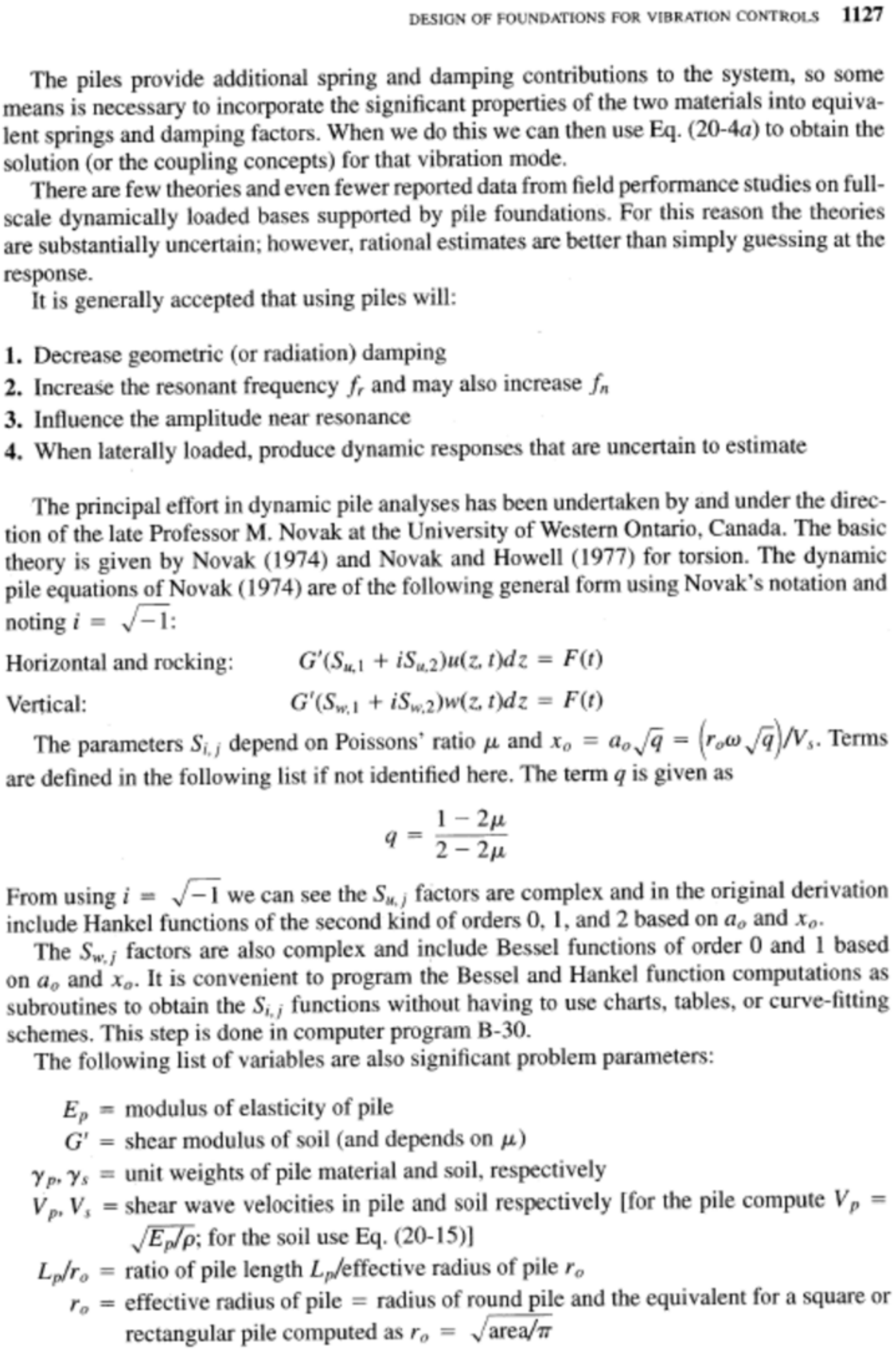
LOAD COMB 2195 1DL+3OP+0.6LL+1EXD-0.3EZD

LOAD COMB 2196 1DL+3OP+0.6LL-1EXD+0.3EZD

LOAD COMB 2197 1.3DL+3.9OP+1.5LL

LOAD COMB 2198 1.3DL-3.9OP+1.5LL

11 ALLEGATO D – ESTRATTI DA "Foundation Analysis and Design, 5th Ed. – Joseph E. Bowles"



The piles provide additional spring and damping contributions to the system, so some means is necessary to incorporate the significant properties of the two materials into equivalent springs and damping factors. When we do this we can then use Eq. (20-4*a*) to obtain the solution (or the coupling concepts) for that vibration mode.

There are few theories and even fewer reported data from field performance studies on full-scale dynamically loaded bases supported by pile foundations. For this reason the theories are substantially uncertain; however, rational estimates are better than simply guessing at the response.

It is generally accepted that using piles will:

1. Decrease geometric (or radiation) damping
2. Increase the resonant frequency f_r and may also increase f_n
3. Influence the amplitude near resonance
4. When laterally loaded, produce dynamic responses that are uncertain to estimate

The principal effort in dynamic pile analyses has been undertaken by and under the direction of the late Professor M. Novak at the University of Western Ontario, Canada. The basic theory is given by Novak (1974) and Novak and Howell (1977) for torsion. The dynamic pile equations of Novak (1974) are of the following general form using Novak's notation and noting $i = \sqrt{-1}$:

Horizontal and rocking: $G'(S_{u,1} + iS_{u,2})u(z,t)dz = F(t)$

Vertical: $G'(S_{w,1} + iS_{w,2})w(z,t)dz = F(t)$

The parameters $S_{i,j}$ depend on Poissons' ratio μ and $x_o = a_o\sqrt{q} = \left(r_o\omega\sqrt{q}\right)/V_s$. Terms are defined in the following list if not identified here. The term q is given as

$$q = \frac{1-2\mu}{2-2\mu}$$

From using $i = \sqrt{-1}$ we can see the $S_{u,j}$ factors are complex and in the original derivation include Hankel functions of the second kind of orders 0, 1, and 2 based on a_o and x_o.

The $S_{w,j}$ factors are also complex and include Bessel functions of order 0 and 1 based on a_o and x_o. It is convenient to program the Bessel and Hankel function computations as subroutines to obtain the $S_{i,j}$ functions without having to use charts, tables, or curve-fitting schemes. This step is done in computer program B-30.

The following list of variables are also significant problem parameters:

E_p = modulus of elasticity of pile

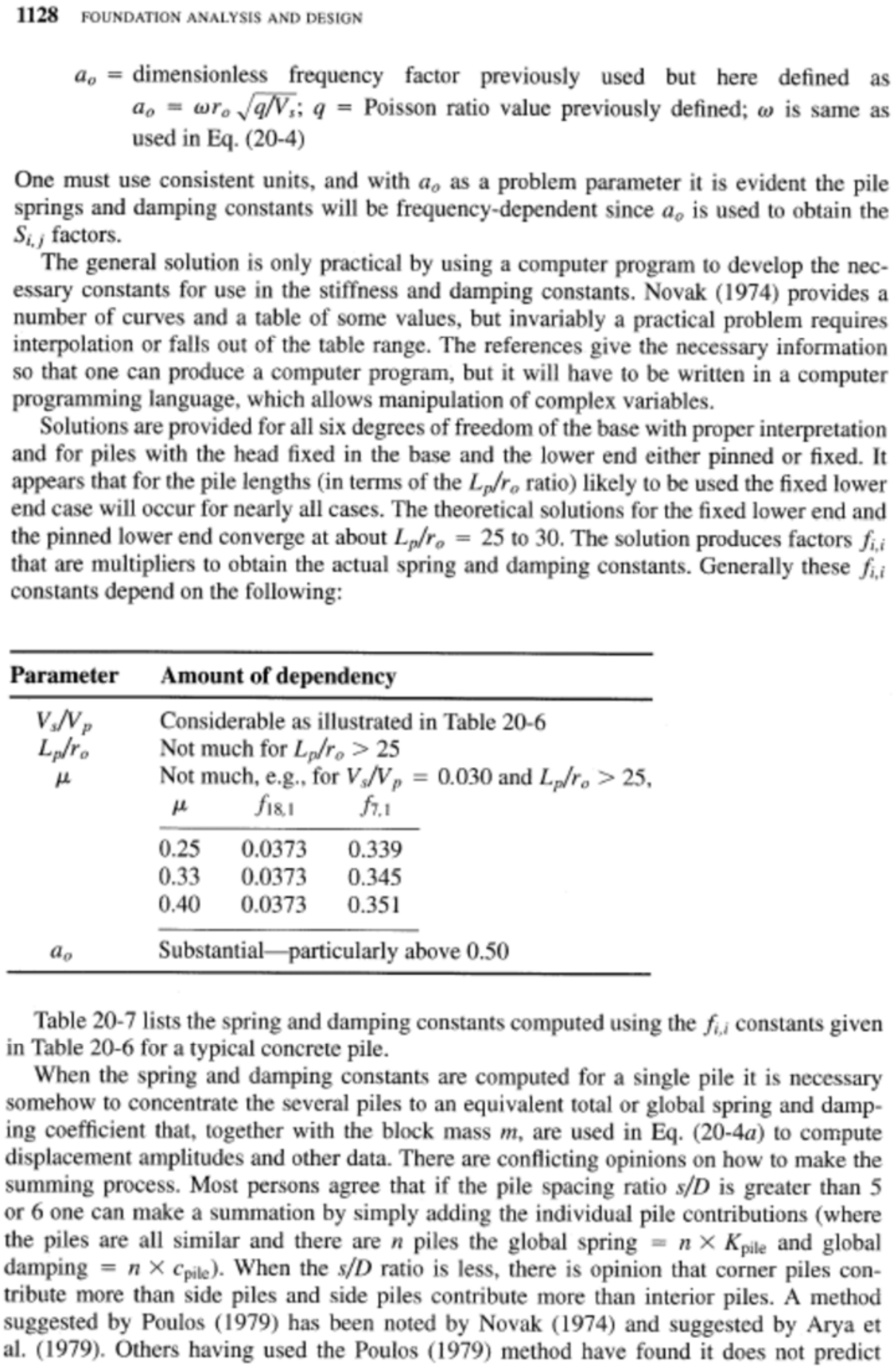
G' = shear modulus of soil (and depends on μ)

γ_p, γ_s = unit weights of pile material and soil, respectively

V_p, V_s = shear wave velocities in pile and soil respectively [for the pile compute $V_p = \sqrt{E_p/\rho}$; for the soil use Eq. (20-15)]

L_p/r_o = ratio of pile length L_p/effective radius of pile r_o

r_o = effective radius of pile = radius of round pile and the equivalent for a square or rectangular pile computed as $r_o = \sqrt{\text{area}/\pi}$



a_o = dimensionless frequency factor previously used but here defined as $a_o = \omega r_o \sqrt{q/V_s}$; q = Poisson ratio value previously defined; ω is same as used in Eq. (20-4)

One must use consistent units, and with a_o as a problem parameter it is evident the pile springs and damping constants will be frequency-dependent since a_o is used to obtain the $S_{i,j}$ factors.

The general solution is only practical by using a computer program to develop the necessary constants for use in the stiffness and damping constants. Novak (1974) provides a number of curves and a table of some values, but invariably a practical problem requires interpolation or falls out of the table range. The references give the necessary information so that one can produce a computer program, but it will have to be written in a computer programming language, which allows manipulation of complex variables.

Solutions are provided for all six degrees of freedom of the base with proper interpretation and for piles with the head fixed in the base and the lower end either pinned or fixed. It appears that for the pile lengths (in terms of the L_p/r_o ratio) likely to be used the fixed lower end case will occur for nearly all cases. The theoretical solutions for the fixed lower end and the pinned lower end converge at about $L_p/r_o = 25$ to 30. The solution produces factors $f_{i,i}$ that are multipliers to obtain the actual spring and damping constants. Generally these $f_{i,i}$ constants depend on the following:

Parameter	Amount of dependency		
V_s/V_p	Considerable as illustrated in Table 20-6		
L_p/r_o	Not much for $L_p/r_o > 25$		
μ	Not much, e.g., for $V_s/V_p = 0.030$ and $L_p/r_o > 25$,		
	μ	$f_{18,1}$	$f_{7,1}$
	0.25	0.0373	0.339
	0.33	0.0373	0.345
	0.40	0.0373	0.351
a_o	Substantial—particularly above 0.50		

Table 20-7 lists the spring and damping constants computed using the $f_{i,i}$ constants given in Table 20-6 for a typical concrete pile.

When the spring and damping constants are computed for a single pile it is necessary somehow to concentrate the several piles to an equivalent total or global spring and damping coefficient that, together with the block mass m, are used in Eq. (20-4a) to compute displacement amplitudes and other data. There are conflicting opinions on how to make the summing process. Most persons agree that if the pile spacing ratio s/D is greater than 5 or 6 one can make a summation by simply adding the individual pile contributions (where the piles are all similar and there are n piles the global spring $= n \times K_{\text{pile}}$ and global damping $= n \times c_{\text{pile}}$). When the s/D ratio is less, there is opinion that corner piles contribute more than side piles and side piles contribute more than interior piles. A method suggested by Poulos (1979) has been noted by Novak (1974) and suggested by Arya et al. (1979). Others having used the Poulos (1979) method have found it does not predict

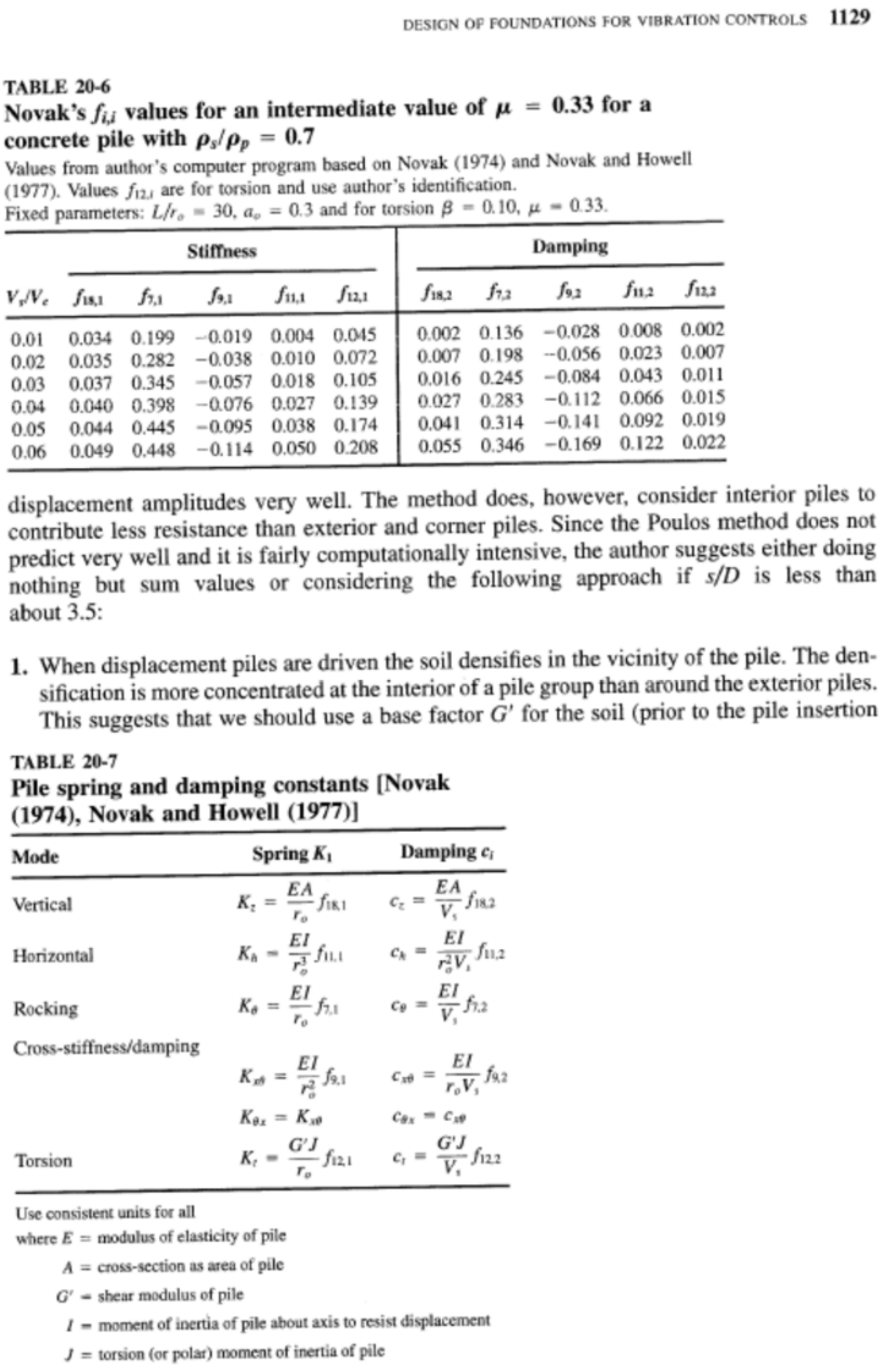


TABLE 20-6

Novak's $f_{i,j}$ values for an intermediate value of $\mu = 0.33$ for a concrete pile with $\rho_s/\rho_p = 0.7$

Values from author's computer program based on Novak (1974) and Novak and Howell (1977). Values $f_{12,i}$ are for torsion and use author's identification.
Fixed parameters: $L/r_o = 30$, $a_o = 0.3$ and for torsion $\beta = 0.10$, $\mu = 0.33$.

	Stiffness					Damping				
V_s/V_c	$f_{18,1}$	$f_{7,1}$	$f_{9,1}$	$f_{11,1}$	$f_{12,1}$	$f_{18,2}$	$f_{7,2}$	$f_{9,2}$	$f_{11,2}$	$f_{12,2}$
0.01	0.034	0.199	−0.019	0.004	0.045	0.002	0.136	−0.028	0.008	0.002
0.02	0.035	0.282	−0.038	0.010	0.072	0.007	0.198	−0.056	0.023	0.007
0.03	0.037	0.345	−0.057	0.018	0.105	0.016	0.245	−0.084	0.043	0.011
0.04	0.040	0.398	−0.076	0.027	0.139	0.027	0.283	−0.112	0.066	0.015
0.05	0.044	0.445	−0.095	0.038	0.174	0.041	0.314	−0.141	0.092	0.019
0.06	0.049	0.448	−0.114	0.050	0.208	0.055	0.346	−0.169	0.122	0.022

displacement amplitudes very well. The method does, however, consider interior piles to contribute less resistance than exterior and corner piles. Since the Poulos method does not predict very well and it is fairly computationally intensive, the author suggests either doing nothing but sum values or considering the following approach if *s/D* is less than about 3.5:

1. When displacement piles are driven the soil densifies in the vicinity of the pile. The densification is more concentrated at the interior of a pile group than around the exterior piles. This suggests that we should use a base factor *G'* for the soil (prior to the pile insertion

TABLE 20-7

Pile spring and damping constants [Novak (1974), Novak and Howell (1977)]

Mode	Spring K_1	Damping c_i
Vertical	$K_z = \frac{EA}{r_o} f_{18,1}$	$c_z = \frac{EA}{V_s} f_{18,2}$
Horizontal	$K_h = \frac{EI}{r_o^3} f_{11,1}$	$c_h = \frac{EI}{r_o^2 V_s} f_{11,2}$
Rocking	$K_\theta = \frac{EI}{r_o} f_{7,1}$	$c_\theta = \frac{EI}{V_s} f_{7,2}$
Cross-stiffness/damping		
	$K_{x\theta} = \frac{EI}{r_o^2} f_{9,1}$	$c_{x\theta} = \frac{EI}{r_o V_s} f_{9,2}$
	$K_{\theta x} = K_{x\theta}$	$c_{\theta x} = c_{x\theta}$
Torsion	$K_t = \frac{G'J}{r_o} f_{12,1}$	$c_t = \frac{G'J}{V_s} f_{12,2}$

Use consistent units for all
where E = modulus of elasticity of pile
A = cross-section as area of pile
G' = shear modulus of pile
I = moment of inertia of pile about axis to resist displacement
J = torsion (or polar) moment of inertia of pile